

# Index

*Note:* Page numbers in *italic* type refer to figures; those in **bold** type relate to tables

- Abies*  
*alba* 306  
*Acacia* 201, 212  
*macarantha* 60  
*mearnsii* 213  
*nilotica* 30  
*Acer* 201, 302, 306  
*saccharum* 292  
 Acetate–malonate pathway 193  
 Acetic anhydride 298  
 Acetyl-CoA 259  
*Achillea*  
*millefolium* **40**  
*Achras*  
*zapota* 70–1  
 Acid butanol assay 210–11  
 Afalon (linuron) 100  
 Africa 55, 68–9, 71, 145  
   Eastern 153  
   Northern 152–3, 184  
   history of natural dyes in 27–36  
 Agaric 184  
*Ageratum* 140  
 Aglucones 50  
 Aglycon 153, 262  
 Aglycones 8, 17, 135, 163–4, 169–70  
*Agrimonia*  
*eupatoria* 46  
 Agrochemicals 241  
 Agronomy, of *Isatis* 77–92
- Ai 39, **40**  
   cultivation in Europe **42–3, 44**  
*Albugo*  
*candida* 85  
 Alkaloids 70  
*Alce*  
*alces* 207  
*Alcea*  
*rosea* var. *nigra* 145  
*Alchemilla*  
*vulgaris* **40**  
 Alder 289, **290**, 295, 302  
   bark **371, 379**  
   black 288–9, 293, 295, 297, 302, 306, **322**, 329  
   colour after steaming 296, 306–7  
   colour after thermal treatment 297  
   colour after UV radiation 306  
   extraction properties of 328  
   and hank dyeing 332  
 Alfalfa 208, 246, 250  
 Algae 244, 250, 269  
   brown 201  
   green 201  
   mass cultivation of 251  
 Aliphatic alcohols, in wood 279  
 Alizarin 6, 32, 151, 159–71  
   antioxidant properties 163  
   complex formation by 162  
   and hair dyeing 347  
   plant sources 159

- Alizarin (*Continued*)  
 structure of 160  
 use on wood 284
- Alizarin-2-methyl ether 170
- Alizarine-2- $\beta$ -primeveroside 164
- Alizarin lake 165
- Alkanet 22, 29, 286
- Alkanine 152
- Alkanna* 29  
*tinctoria* 22, 29, 286
- Alkyd resins 284
- Allium*  
*cepa* 16, **371, 379**
- Allura Red AC 144
- p*-allylphenol 71
- Alnus* 295  
*glutinosa* 288–9, 293, 295, 296, 297, 302,  
 306, **371, 379**
- Aloemodin 157  
 structure of 158
- Alternanthera*  
*sessilis* **239–40, 241**
- Alternaria* 169
- Alum 4, 22–3, 35, 67, 70, 154, 330, 361, 363, 371
- Aluminium 35, 268, 363  
 ions 4
- Amaranth 144
- Amaranthus*  
*retroflexus* 100
- Amberlite XAD16 124
- Amberlyst A-21 124
- America 71, 184  
 Central 53, 55, 59, 102  
 North 77, 152, 160  
 South 71, 102, 152, 160  
 dyes in 53–64  
 overview of major colorants **54**
- American cochineal 7
- Ames mutagenicity test 163, 167
- 4-aminocarminic acid 61  
 colour and pH 61
- Aminoindan-2-phosphonic acid 171
- 5-aminolevulinic acid (ALA) 248
- $\beta$ -aminoorceimine 191
- $\gamma$ -aminoorceimine 191
- $\alpha$ -aminoorcein 191
- $\beta$ -aminoorcein 191
- $\gamma$ -aminoorcein 191
- Amplified fragment length polymorphism  
 (AFLP) 77
- Ancient blues 10–13
- Ancient purple 13–15
- Ancient reds 6–10
- Ancient yellows 15–17
- Angelim vermelho 307
- Angiosperms 201
- Aniline 284, 286  
 black 25  
 derivatives 286  
 purple 15
- Annatto 53, **54**, 55, 224, 228, **229**  
 ADI of 53, 57  
 commercial preparations of 55  
 commercial production of 57  
 commercial uses of 56–7  
 in Eastern Asia 65–7  
 extraction procedure 56  
 powder 55  
 seeds **322**  
 HPLC chromatogram of extract 56
- Anthemis*  
*tinctoria* 16, **40, 48, 355, 371, 379**
- Antheraxanthin 223
- Anthocyanidin reductase 206
- Anthocyanidins 9, 135, 206  
 assay 210–11  
 found in nature **261**  
 structure of 136, **136, 259**
- Anthocyanins 9–10, 135–50, 257–9, **322**  
 acylation of 262  
 analysis 327  
 as antioxidants 141–2, 142  
 applications of 144–6  
 and ascorbic acid 264–5  
 blues 12–13  
 and blue supramolecular complex 13  
 colour and colour stability of 140–1, 261  
 commercial products and processing 146–7  
 and co-pigmentation 267–8, 267  
 diacylated 145  
 effects of external factors on 143  
 and enzymes 265–6  
 equilibria in solution 137–40  
 extraction of 146–7  
 as food colorants 144–5  
 and light 265  
 low stability of 144  
 and metal complexation 267–8  
 monoacylated 145  
 as natural colorants 261–8  
 natural sources for 142–4  
 and oxygen 264–5  
 purification of 147  
 reds 8–10

- self-association of 268, 268  
 stability and food matrix 263  
 structural transformation and  
   pH 263–4, 263  
 structure of 8, 136, 261–2  
 and sugars 265–6  
 and sulfur dioxide 266–7  
 and tannin 330  
 and temperature 264  
 uses of 9, 145–6
- Anthocyanin–sulfate complex** 266  
**Anthocyanoplasts** 258  
**Anthracene** 157  
 9,10-anthracenedione 161  
**Anthrachinon** 322  
 Anthrachinone, use on wood 284  
**Anthraglycosides** 157  
**Anthranilic acid** 113  
**Anthraquinones** 49, 161, 168  
   aglycones, protocol for isolation of 194  
   in ancient Egypt 3–4, 32  
   average values in *Rubia* 160  
   biosynthetic pathways for 168  
   colour-fastness of 195–6  
   dyes 157–71, 347  
     sources of 171  
   in fungi 192–6  
   glycosides 163  
   lakes 4  
   reds 6–7  
     structures of 7  
   resistance to fading 6  
   uses of 193
- Antimutagens** 247, 252  
**Antioxidants** 247, 252, 257–8, 270  
**Aphids** 34  
**Apigenin** 15, 32, 145  
**Apigeninidin** 145  
**Apples** 270  
*Apuleia*  
   *molaris* 307  
**Arabinosides** 265  
**Archil**, *see* **Orchil**  
**Argentina** 59–60  
**Arginine** 340  
**Armenian cochineal** 7  
**Aromatic aldehyde test** 211  
*Artocarpus*  
   *heterophyllus* 225  
**Ascochyta** 169  
**Ascorbic acid** 141–2  
   and anthocyanins 264–5
- Ash** 281, 289, 290, 302  
   bark 371, 379  
**Asia** 71, 92, 146, 160, 184  
*Asperula*  
   *tinctoria* 159  
**Astaxanthin** 224  
**Asteraceae**, *see* **Compositae**  
**Atranorin** 191  
   structure of 186  
**Atromentin** 192  
   structure of 187  
**Aurones** 257, 259, 268–9  
   structure of 259–60  
   yellows 17, 257  
**Auroxanthin** 223  
**Australia** 71, 153, 251  
**Austria** 101, 156, 315, 324, 353–65  
**Austrian Project Group on Natural  
   Dyes** 332  
**Auxiliaries** 319–20  
**Avocado** 234  
**Awobana paper** 145  
 2,2'-azino-bis-(3-ethylthiazoline-6-sulfonic acid)  
   (ABTS) 304  
**Azorubine** 144
- Babylon** 207  
**Bacteria** 244, 249, 292  
   pathogenic 159  
   role in indigo extraction 114–15  
   soil 92  
**Bacteriochlorophylls** 249  
**Badione A** 196  
*Banyuls* gene 206  
*Baphia*  
   *nitida* 25  
*Baphicacanthus* 69  
**Barbados pride** 66  
**Bark** 279, 325, 329, 371, 377, 380  
   alder 371, 379  
   ash 371, 379  
   extraction properties of 328  
   and hank dyeing 332  
   oak 36, 286  
**Barley** 212  
**Barwood** 25  
**Bathochromic shift** 261–2, 267–8  
**Bedstraw**  
   hedge 159  
   lady's 159  
**Beech** 162, 281, 288, 289, 290, 294–8, 302, 302,  
   306, 308

- Bees wax 285  
 Beetle  
   carpet 157, 163  
   flea 92  
     cabbage stem 85  
     striped 85  
 Bengal 102, 117  
 Benzene-1,2-diol 340  
 Benzopyrylium ring 141  
 1,2-benzoquinone 340  
 Benzoquinones 185  
   derivatives of 192  
   dyes 151–2  
 Berberine 325  
 Berry pomace **377, 380**  
 Betel **66, 71**  
*Betula* 201, 203, 209, 212, 293  
   *pendula* 203, 294, 302, 306  
   *pubescens* 203, 212  
 Bhutan 167  
 Bilberries **143, 145, 270**  
 Bilins 248  
 Birch 281, 289, **290**, 293–4, 302, 302, 306  
 bis-demethoxycurcumin 58  
 bisnorbadioquinone A 196  
 Bisulfite 267  
*Bixa*  
   *orellana* 53, **54, 55**, 65–7, **66**, 224, **229**  
 Bixaceae 55, 65–7  
 Bixin 55–7, 67, 224, **229**  
   ADI of 53  
   structure of 55  
 Blackberries **143, 322**  
 Blackcurrants 142, **143**, 144–5  
 Black dyes 68–9, 72, 184, 286, 346  
   in ancient Egypt 31  
   fast 23  
*Blatta* 22  
 Bleaching agents, for wood 301  
 Blister, white 85  
 Blueberries **143, 145**  
 Blue dyes 69, 185, 286, **322, 371**  
   ancient 10–13  
   anthocyanin 12–13  
   democratization of 23–4  
   indigo 10–12  
   Ottoman 34  
   from terphenylquinones 192  
 Blue firt 31  
*Boerhavia*  
   *diffusa* 232  
*Bogolan* cloth 21  
 Boletales **188–9**, 192, 196  
*Boletus* 184, **187, 190**  
   *erythropus* 196  
*Bolinus*  
   *brandaris* 14, 22  
 Bolivia 57, 61  
   production of dyes in 53  
 Boraginaceae 22  
 Botrytis elicitor 170  
*Bowdichia* 296  
 Brasil 8  
 Brasileto 25  
 Brasilin 346  
   structure of 345  
*Brassica*  
   *napus* 76–7  
 Brassicaceae, *see* Cruciferae  
 Brazil 55, 57, 59, 65, 238  
   production of dyes in 53  
   turmeric cultivation in 58  
 Brazilein 8, 8  
 Brazilin 8, 70, 286  
 Brazilwood 346  
   red 25  
 Broccoli **322**  
 6-bromoindigotin 15  
 6'-bromoindigotin 15  
 6-bromoindirubin 15  
 6'-bromoindirubin 15  
 Bronträger reaction 165  
 Broom, dyer's 24  
 Brown dyes 69–71, 192–3, 196, **322, 371**  
   in ancient Egypt 31  
   in Europe 46  
   from lichens 191–2  
 Brow-tuber **66**, 71–2  
 Brunette 23–4  
 Buckthorn 34  
   common, component used 39  
 Bugloss, dyer's 22  
 Butisan (metazachlor) 85  
 Butterfly, large white 85  
 Butternut **156**  
 By-products 355–6  
  
 Cabbage 237  
   red 144–5, 264, 271  
 Cactaceae, subfam. Opuntioideae 60  
*Caesalpinia* 346  
   *brasiliensis* 8  
   *echinata* 8, 25  
   *pulcherrima* **66, 71**

- sappan* 8, 25, **66**, 69–70, 346  
*spinos* 60  
*violacea* 8
- Calamus*  
*draco* 9
- Calcium 35
- Cambodia 65, 67–8, 70–1
- Camellia*  
*sinensis* **66**, 67, **371**, **379**
- Campeche wood 346
- Camwood 25
- Cantharellus*  
*cibarius* 185
- Canthaxanthin 224
- Caprifoliaceae **143**
- Capsanthin 223, **229**
- Capsicum*  
*annuum* **229**
- Capsorubin 223, **229**
- Carbinol pseudo-base, structure of 263
- Carbocation 207
- 2-carboxy-1,3-dihydroxyanthraquinone 161, 166  
*trans*-3-([1-carboxy-ethenyl]-oxy)-4-hydroxy-1,5-cyclohexadiene-1-carboxylic acid 171
- 3-carboxy-1,2,4-trihydroxyanthraquinone 161
- Caribbean 59
- Carmine 60–2  
 acid-stable 61  
 colour and pH 61
- Carminic acid 4, 6–7, 32, 61, 165  
 ADI of 53  
 colour and pH 61  
 structure of 61
- Carmoisine 144
- Carnauba wax 285
- $\alpha$ -carotene 223, **225**, 226–7, **229**, 231, **238**, **240**
- $\beta$ -carotene 223, **225**, 226–8, **229**, 231, 232, **238–40**, 243  
 all-*trans*- $\beta$ -carotene 226, 233, **240**, 241  
 9-*cis*- $\beta$ -carotene 226, 233  
 $\beta$ -carotene-5,6,5',6'-diepoxide 223, 232  
 $\beta$ -carotene-5,6-epoxide 223  
 $\gamma$ -carotene 223, 226  
 $\delta$ -carotene 223  
 $\zeta$ -carotene 222  
 $\chi$ -carotene **225**
- Carotenes 222, 250  
 acyclic, structure of 222  
 cyclic, structure of 223
- Carotenoids 17, 55, 59, 67, 244, 246, 251, **322**  
 as anticancer agents 228  
 as antioxidants 227
- chemistry of 221–5  
 concentrations in non-leafy vegetables **238**  
 dyes 221–36  
   production of 237–42  
   properties of 221–36  
 effect of freezing and blanching on **239**  
 epoxy, structure of 225  
 factors influencing composition in plant sources 237–41  
   climatic or geographic effects 238–9  
   cultivar or varietal differences 238  
   effect of agrochemicals 241  
   processing and cooking changes 239–41  
   stage of maturity 237  
   storage and packing 239  
 general procedure for analysis 228–33  
   chemical tests 231, **233**  
   chromatographic separation 230–1  
   detection and identification 231–3  
   extraction 230  
   problems and errors in 233–4  
   sampling 228–30  
   saponification 230  
 hydrocarbon 222  
 isomers of 224  
 as markers of dietary practice 227  
 as natural colorants 228, **229**  
 occurrence of 221  
 oxygen containing 222  
 photodiode array spectra of 232  
 plant sources of **225**  
 principal natural dyes, structure of 226  
 properties and functions of 225–8  
   in the retina 227–8  
   role as pro-vitamin A 225–6  
   RP-HPLC chromatogram of 232  
   yellows 17
- Carpinus*  
*betulus* 306
- Carrots 17, 40, 143, 237, **240**, **322**  
 black 144  
 extract of 228, **229**  
 purple 145–6, 262
- Carteria*  
*lacca* 6
- Carthamin 30, 151–2  
 extraction of 152  
 structure of 152  
 uses of 152
- Carthamon 152
- Carthamus* 269  
*tinctorius* 30, 33–34, **40**, 152

- Catalase 141  
 Catechins 144, 206, 270  
   structure of 204  
 Catechu 31, 346  
*Cedrela*  
   *toona* 224  
 Celandine, greater 40, 46  
 Cellulose 279  
   nitrate 284  
   triacetate 162  
 Cennini, Cennino 9  
*Centaurea*  
   *cyanus* 13  
   *jacea* 40  
*Centella*  
   *asiatica* 239–40, 241  
 Central America 53, 55, 59, 102  
 Chad 145  
 Chalcone isomerase 206  
 Chalcones 17, 205–6, 257, 259, 264, 268–9  
   structure of 259–60, 263  
   yellows 17, 257  
 Chalcone synthase (CHS) 143, 205  
 Chamomile  
   dyer's 16, 40, 322, 330, 355, 357  
   component used 39  
   and cotton fabric dyeing 333  
   cultivation in Europe 46, 48  
   and hank dyeing 332  
   and yarn dyeing 333  
 Chavibetol 71  
 Chavicol 71  
*Chelidonium*  
   *majus* 40, 46  
*Chenopodium*  
   *album* 100  
 Cherry 289, 290, 295, 299, 301, 302, 306  
   ammoniated 300  
   bird 301  
   maraschino 265  
   wood 281  
   yellow 237  
 Chestnut 203  
 Chile 61  
 Chilling haze 269  
 China 59, 67–8, 70–1, 91–2, 105, 152,  
   157, 207  
 Chitosan 171  
 5-chlorodermorubin 193  
*Chlorophora*  
   *tinctoria* 16  
 Chlorophyllides 244, 251  
 Chlorophyllins 163, 243–5  
   other applications of 247  
   sodium copper 243, 246, 249–50, 252  
   uses of 246  
 Chlorophylls 243–54, 322  
   analysis of 250  
   chemical structures of 247–50  
   chlorophyll *a* 244, 246–9, 251  
     absorbance spectra of 249  
   chlorophyll *b* 244, 246, 248–9, 251  
     absorbance spectra of 249  
   chlorophyll *c* 244, 248–9  
   chlorophyll *d* 244, 248–9  
   chlorophyll *e* 244  
   as colorants 244–6  
     of wood 289–90, 289, 290  
   and hair dyeing 347  
   molecular structure of 245  
   other applications of 247  
   physicochemical properties of 247–50  
   purity, standardization and quality  
     control 251–2  
   scheme of synthesis 248  
   sources of 250–1  
   stability of 250  
   storage and handling of 250–1  
   toxicological and safety aspects of 252  
 Chokeberries 145, 270  
 Chorismate 171  
 Chromatography 165, 231  
   thin layer (TLC) 153, 165  
 Chromium 363  
   salts 154  
 Chromogens 4  
 Chromophores 4, 246, 279  
   anthocyanin 13  
   anthraquinone-based 3, 6  
   cyanidin 13  
   flavylium 9  
   of indigo 12  
   oligomeric 306  
   red 9  
   separation and characterization of 5–6  
   in wood 291  
   yellow 15  
*Chrysanthemum* 16  
 Chrysophanol 157–9, 168  
   structure of 158  
 Cinnamic acids 262, 265  
 Civilizations, colours in 21–6  
 Cleavers 379  
   common 159

- Clothes, preparation in ancient  
Egypt 27–8
- Coatings, for wood 283–5
- Cobalt salts 346
- Coccoidea 22
- Cochineal 6, 7, 32, 34, **54**, 60–2, 193  
American 7  
Armenian 7, 24  
black 61  
commercial production of 60–1  
commercial uses of 61  
Persin 30  
Polish 7, 24  
red 4, 34  
silver 61
- Cochineal A Red 144
- Cocoa 269
- Cocus*  
*ilicis* 34
- Colombia 59
- Colophonium 285
- Colorants, *see* Natural colorants;  
Synthetic colorants
- Coloration, standardization of 331
- Colorifico 55
- Colour fastness 322–5, **325**  
compliance with 368  
examples of **324**
- Colours  
available range of **371**  
in civilizations 21–6  
conchylarian 22  
dark 382  
gamut and shade 321  
of plant material **322**  
range of 370–1  
reproducibility of 370  
of wood 279–82, 288–90  
measurement 282–3  
stability 283  
surface 278–9
- Colour shift, in mordanting 330
- Combretaceae 67
- Commelina*  
*communis* var. *hortensis* 145
- Commelinin 13
- Compositae 24, **48**
- Concentrates 326
- Cones, dyeing of yarn on 333
- Confidor (imidacloprid) 100
- Conifers 295
- Consumer expectations 371–5
- Copals 285
- Co-pigmentation 140–1, 144, 261  
and anthocyanins 267–8, 267  
intramolecular 145
- Copper 268, 363  
and hair dyeing 347  
ions 4  
salts 346
- Copper(II)chlorine  $e_4$  249, 252  
ethyl ester 252
- Copper(II)chlorine  $e_6$  249, 252
- Copper(II)phosphoride  $a$  249
- Copper(II)rhodin  $g_7$  249
- Coptic textiles, dyeing in 31–2, 32
- Coreopsis* 17
- Cori (coconut fibre) 162
- Cornflower, blue 13
- Cortinarius* 192, 198  
*sanguineus* **189**, 193–6  
biosynthetic relationship of  
pigments 193  
isolation of anthraquinone aglycones  
from 194
- Costs 369, 375–80, **377**  
acceptable 379–80  
aspects influencing 376–8  
categories of 375, **375**  
of colorants and dyeing process 369  
of drying process 376  
of industrial production 375–80, **377**, **380**  
of naturally dyed products 369  
of process engineering 368–9  
of quality control 376  
of raw materials 376
- Cotinus*  
*coggygria* 16
- Cotton 27, 162, **322**  
dyeing of fabric 333–4
- Couching 114–16
- 4-coumaroyl-CoA 205
- Cranberries **143**, 145, 212, 265
- Crassula*  
*argentea* 209
- Cress, garden 250
- Crocin 17, 223, **229**  
structure of 17
- Crocin 17, **229**  
structure of 17
- Crocus*  
*sativus* 17, 162, 223, **229**
- Crop rotation, and *Isatis* 77
- Crowberries **143**

- Cruciferae 22, 42, 77, 122  
 Crustaceans 224  
 Cryptoflavin 223  
 $\alpha$ -cryptoxanthin 232  
 $\beta$ -cryptoxanthin 223, 225, 226–7, 232, 238  
 $\beta$ -cryptoxanthin-5,6-epoxide 223  
*Cucurbita*  
   *maxima* 225  
   *moschata* 225  
 Cultivation  
   of dye plants 40–1, 354–5  
   of *Indigofera* 102  
   organic farming 354  
   sustainable farming 355  
*Curcuma*  
   *longa* 53, 54, 57, 66, 70  
 Curcumin 58, 70, 246  
   commercial uses of 58  
   extraction of 58  
   structure of 58  
 Curcuminoids 53, 58  
 Currants, black 322  
 Cutch, *see* Catechu  
 Cutworms 92  
 Cyanidin 141, 142, 144, 261, 266, 268–9  
 Cyanidin-3,5-diglucoside 140  
 Cyanidin-3-glucoside 141, 266  
 Cyanidin-3-glycosides 327  
 Cyanidin-3-OGl 141  
 Cyclitol 203  
 Cyclopentanone 248  
 Cycocel 156  
 Cystein 347  
 Cystine 340  
  
*Dactylopius* 60  
   *coccus* 6–7, 7, 24, 54, 60  
*Daemonorops*  
   *draco* 9, 136  
*Daphne*  
   *gnidium* 16, 24  
 Daphne, flax-leaved 16, 24  
 Dar al-Tiraz (textile factory) 33  
 Dates 237  
*Daucus*  
   *carota* 229  
 3-dehydroshikimic acid 205  
 Delphinidin 136, 141, 142, 261, 268–9  
 Demethoxycurcumin 58  
 Deoxyanthocyanidins 9, 135–6  
   structure of 136  
 3-deoxyanthocyanidins 145  
  
*Dermocybe* 188–9, 192  
   *sanguinea* 171, 194, 195–6  
   *semisanguinea* 185  
 Dermocybin 193, 195–6  
   structure of 189  
 Dermocybin-1- $\beta$ -d-glycopyranoside 193  
 Dermorubin 193  
 Diaion HP-20 210  
 6,6'-dibromoindigo 3  
 6,6'-dibromoindigotin, synthesis of 14, 15  
 6,6'-dibromoindirubin, synthesis of 14, 15  
 Diglycosides 8, 9  
 Dihydroflavonol 206  
 Dihydroflavonol 4-reductase 206  
 Dihydrokaempferol 156  
   structure of 260  
 Dihydroporphyrins 248  
 1,2-dihydroxy-9,10-anthracenedione 161  
 1,2-dihydroxyanthraquinone 4, 6, 160, 347  
 Dihydroxyanthraquinone-glycosids 160  
 1,3-dihydroxyanthraquinone 161  
 1,3-dihydroxy-2-carboxyanthraquinone  
   161–2  
 7,4'-dihydroxyflavylium 136  
 1,3-dihydroxy-2-formylanthraquinone 161  
 1,3-dihydroxy-2-hydroxymethyl-  
   anthraquinone 164, 166, 347  
 5,6-dihydroxyindole 347  
 7,4'-dihydroxy-5-methoxyflavylium 136  
 1,3-dihydroxy-2-methylanthraquinone 347  
 1,4-dihydroxy-2-naphthoic acid 168  
 3,4-dihydroxy-phenylalanine (DOPA) 347  
 $\alpha$ -diketone 264  
 1,2-dimethoxyanthraquinone 165  
 1,4-dimethoxyanthraquinone 165  
 4,8-dimethyl-tetradecaheptaene-acid mono methyl  
   ester 56  
 2,4-dinitrophenol 143  
*Dinizia*  
   *excelsa* 307  
*Dioscorea*  
   *cirrrosa* 66, 71–2  
 Dioscoreaceae 71–2  
*Diospyros*  
   *mollis* 66, 68  
 Dioxindole 109  
 15,15'-dioxygenase 226  
 Diseases  
   of *Isatis* crops 84–5  
   of *Persicaria* (*Polygonum*) crops 100  
 Disodium copper chlorine e<sub>4</sub> 246  
 Dispalmitate 59

- Dithionite 118, 124
- Dock  
 curled 159  
 tanner's 159
- Dracaena*  
*cinnabari* 9  
*draco* 9, 136
- Dracaenaceae 9
- Dracoflavylum 9, 9, 136  
 chemical reactions for 10
- Dracorhodin 9, 9
- Dracorubin 9, 9
- Dragon's blood resin 9, 136  
 chemical structures of 9
- Drosophila*  
*melanogaster* 163
- Drying oils, for wood 284
- Drying process  
 costs of 376  
 methods for wood 292–3
- Dunaliella* 251
- Dyehouses, requirements of 356
- Dyeing  
 after chroming 154  
 analysis of process 317–21, 318  
 dyestuffs and chemicals in 319–20  
 energy in 318–19  
 machinery in 321  
 water in 318  
 for analytical purposes 285–8  
 ancient Egyptian techniques for 28–9  
 application of colouring matter in 360, 360  
 complexity of 4  
 in Coptic textiles 31–2, 32  
 direct 29  
 double (over-dyeing) 29  
 energy consumption in 358–9, 359  
 environmental aspects of 353–65  
 industry requirements for 356  
 kataplasma 342  
 life-cycle considerations 361–4  
 dyeing procedure 363  
 dyestuff extraction 362–3  
 inputs and outputs 362  
 raw material 362  
 transport 363–4  
 machines for 333–4  
 one-bath 360, 360, 363  
 plant components used in 39  
 procedure 360, 361, 363  
 costs of, *see* Costs  
 design for sustainable approach 365  
 residual materials and by-products  
 in 355–6  
 substantive 29  
 and sustainability 353–65  
 technologies 329  
 comparison of 319  
 of textiles 162–4, 315–37  
 two-bath 363  
 water consumption in 359, 360
- Dye plants 28  
 blue 42–3  
 brown 46  
 cultivation of 40–1, 354–5, 361–2  
 agricultural criteria for 355  
 modern methods for 41–8  
 in Europe 39–52  
 promising for cultivation 40  
 native species 355  
 potential 39–40  
 raw material for 361–2  
 processing of 362  
 quality of 370  
 red 43–4  
 yellow 44–6
- Dyes  
 in ancient Egypt 28  
 anthraquinoid, *see* Anthraquinones, dyes  
 anthraquinone, *see* Anthraquinones, dyes  
 antimicrobial properties of 198  
 from antiquity 4–5  
 basic set of 321  
 benzoquinone, *see* Benzoquinones, dyes  
 black, *see* Black dyes  
 blue, *see* Blue dyes  
 brown, *see* Brown dyes  
 for calcium deposits 163  
 carotenoid, *see* Carotenoids, dyes  
 distinguished from pigments 4, 319–20  
 flavonoid, *see* Flavonoids, dyes  
 for food 40  
 for fur 184  
 green, *see* Green dyes  
 for hair 33, 69, 154, 157, 159, 208, 304, 339–50  
*see also* Hair  
 impregnation of wood with 286–90  
 Boucherie treatment 287  
 osmosis treatment 287  
 submerging and soaking 287  
 vacuum/pressure treatment 287  
 indigoid, *see* Indigoids, dyes  
 influence of preservation on content 41

Dyes (*Continued*)

- in Islamic textiles 33–4
  - lac, *see* Lac, dyes
  - from lichens 183–200
  - low fastness of 40
  - mauve, *see* Mauve dyes
  - metal reaction, *see* Metal reaction dyes
  - mordant 214
  - from mushrooms 183–200
  - for nails 154
  - naphthoquinone, *see* Naphthoquinones, dyes
  - natural, *see* Natural dyes
  - new approaches in lichens and fungi 198
  - plant, *see* Dye plants; Plant dyes
  - production of extracts 48–50
  - quinoid, *see* Quinoid dyes
  - reactive 284
  - red, *see* Red dyes
  - scientific analysis of ancient 5–6
  - for skin 11, 154
  - sources in ancient Egypt 29–31
  - in South America 53–64
  - synthetic, *see* Synthetic dyes
  - toxicity of 198
  - vat, *see* Vat dyes
  - for wood 285–90
  - for wool 184–5, 191
  - yellow, *see* Yellow dyes
- Dyestuffs 319–20
- and auxiliaries 319–20
  - binding principles for 341–2
  - and chemicals 319–20
  - classes of **320**
  - concentrates of 326
  - extraction of 362–3
  - handling of 326
  - and mordants 319–20
  - processing to 357–60
    - procedural steps **358**
  - requirements of 321
  - seasonability of 357
  - standardization of 326–7
- E-cinnamate 205
- Eastern Asia 65–72
- East Indian red wood 69
- Ebenaceae 68
- Echinonone 224
- Echinodontium*
- tinctorum* 184
- Ecological aspects 327–8
- of raw materials 361–2
- Economic aspects 367–84
- Economy, closed-loop 381–2
- Ecuador 57, 60–1, 65
- Egypt 69, 152
- history of natural dyes in 27–36
- Elderberries 40, **143**, 144–5
- Elder, black **325**
- Electromagnetic radiation 305
- $\alpha$ -eleostearic acid 285
- Ellagic acid 32, 203, 207, 296
- structure of 204
- Ellagitannins 203, 205
- structure of 204
- Elm 281
- El Salvador 102
- Emberella 238
- Emodin 157–9, 161, 168, 193, **195–6**, 198
- structure of 158, **189**
- Emodin-1- $\beta$ -d-glycopyranoside 193
- Empetraceae **143**
- Empetrum*
- nigrum* **143**
- Endive 237
- Endocrocin 193
- Energy
- consumption of 358–9
    - procedure-added **359**
  - in dyeing process 318–19
- E numbers 271
- E102 144
  - E122 144
  - E124 S 144
  - E163 N 144, 146, 271
- Environment 351–84
- and natural colorants 353–65
- Environmental Impact Assessment (EIA) 76
- Enzymes
- and anthocyanins 265–6
  - oxidative 303
  - pectolytic 265
- Epicatechin 206, 269
- structure of 204
- Epigallocatechin gallate 163
- Epoxy carotenoids 223
- Epoxy esters 284–5
- Ericaceae **143**, 145
- Erysiphe*
- cruciferarum* 85, 92
- Erythrosine 144
- Ethyl acetate 106–8
- Eucalyptus* **66**, 71
- globulus* 301

- grandis* 301  
*urophylla* 301
- Euclea*  
*schimperi* 212
- Eugenia*  
*uniflora* **225**
- Eumelanin 340, 347
- Europe 57, 71, 120, 146, 152, 157, 160, 184, 355  
 Central 92, 94, 100–1  
 Northern 183–4  
 Western 61, 170, 245–6
- European Union (EU) 57–8, 271, 347
- Evernia* **186**
- Extraction/dyeing process, temperature  
 profile of 329
- Fabaceae, *see* Leguminosae
- Fabric, dyeing of 333–4
- Fagaceae 25
- Fagus*  
*orientalis* 162  
*silvatica* 288, 294–8, 302, 306, 308
- Farming  
 organic 354  
 sustainable 355
- Fastness, *see* Colour fastness
- Fatty acids  
 naturally occurring 285  
 in wood 279, 285
- Ferns 201
- Fertilizers  
 for *Isatis* 86  
 for *Persicaria* (*Polygonum*) 101
- Ficus* 34
- Finland 75–6, 78, 85–6, 90, 92
- Fir 281  
 Douglas 289, **290**, 301–2  
 silver 306
- Fisetin 16
- Fisetinidin 145
- Fish 224
- Fixation, and molecule dimensions 197–8
- Fixed-bed reactor 127
- Flava-3,4-*cis*-diol 206
- Flava-3,4-*cis*-diol 4-reductase 206
- Flavan-3-ol 206–7
- Flavanols 270
- Flavanone 3-hydroxylase 206
- Flavanones 206, 269–70
- Flavans 270
- Flavones 13, *13*, 44, 49, 145, 258, 270  
 structure of *16*, **16**, 260
- Flavonoids 9, 16, 46, 136, 143, 203, **322**  
 absorption bands of 259  
 analysis of 327  
 biosynthesis of 259, 260  
 dyes 32  
 general chemical structure 258–9, 259  
 as natural colorants 268–9  
 as natural pigments 257–75  
 regulations on colorant use 271  
 role in plant 258  
 therapeutic effects on diet 270–1  
 in wood 279, 281  
 yellows 15–16, 268–9
- Flavonoles 44, 49
- Flavonols 16, 67, 257–9, 268–70, 296  
 structure of **16**, 259–60  
 yellows 257
- Flavylium 136  
 cations (AH<sup>+</sup>) 10, 137–40, 263, 266  
 structure of 263  
 reds 8–10  
 synthetic salts 10, 136–7  
 structure of *136*
- Flax 28, 162
- Fluaxifop-*P*-butyl (Fusilade) 100
- Fluorescein 144
- Fluroxypyr (Starane 180) 85
- Folin–Ciocalteu assay 210
- Folin–Dennis assay 210
- Fomes*  
*fomentarius* 184
- Food and Agriculture Organization (FAO) 252
- Food matrix 265  
 and anthocyanin stability 263
- 2-formyl-1,3-dihydroxyanthraquinone 166
- Fortuny, Mariano 21
- Foulard unit 326
- Fragaria* **143**
- France 92, 144
- Fraxinus*  
*excelsior* **371**, **379**
- Fruit  
 anthocyanin content of **143**  
 citrus 238  
 palm 234
- Fungi 292  
 brown-rot 303  
 drying of 195  
 dyes  
 colour-fastness of 197–8  
 new approaches to 198  
 as source of 184

- Fungi (*Continued*)  
 ectomycorrhizal and mycorrhizal 185  
 other colorants of 196  
 white-rot 303  
 and wood decay 303
- Furan 297–8
- Furfural 297–8
- Fusarium* 169  
*oxysporum* 171
- Fusilade (fluaxifop-*P*-butyl) 100
- Fustic  
 old 16, **16**  
 young 16
- Galactosidases 266
- Galactosides 265
- Galium* 43  
*aparine* **159, 379**  
*mollugo* **159, 162**  
*odoratum* **159**  
*tinctorum* **379**  
*verum* **159**
- Gallic acid 32, 203, 205, 207, 212,  
 279, 296  
 structure of 204
- Gallnuts 346
- Gallotannins 203, 205, 211, 346
- Galls 202
- Garapeira 307
- Garment dyeing machines 333–4
- Genista*  
*tinctoria* 16, 24, **40**
- Geobacillus*  
*pallidus* 115
- Germany 75, 78, 85–6, 89, 92, 100,  
 170, 355
- Gloeophyllum* 303
- Glucitol 203
- Glucose 203  
 $\beta$ -glucosidase 49, 115, 125  
 reaction with indican 117, 125
- 3-glucosides 141
- $\beta$ -glucosides 266
- C-glucosyl flavone 144
- Glutamine 207, 340
- Glutathione 141  
 oxidation of 157
- Glycerol 285
- Glycine 207, 248
- Glycosidases 266
- Glycosides 15, 17, 136, 156, 168, 193–4
- Glyphosate (Roundup) 100
- Golden rod  
 Canadian **40, 322, 325, 327–9, 355, 357, 371, 379**  
 extraction properties of 328
- Good Agricultural Practice (GAP) 76
- Gotrytis* 169
- Gotukola **239–40**
- Grana* 34
- Grapes 144, 213, **322**  
 pomace 145–6, **325, 327, 371**  
 red **143**  
 as source of anthocyanins 146, 271
- Grass **322**
- Greece 3
- Green dyes 34, 67, 71, 192, **322**  
 in ancient Egypt 31  
 emerald 23  
 gay 23  
 grass 23  
 Ottoman 34
- Green walnut shells 151, 157, 343
- Greenweed, dyer's 16, **40**
- Grevillines, yellow dyes from 192
- Grevillin, structure of **188**
- Grey dyes 184, 192, 286, **371**
- Guaiacyl 298
- Guajacol 303
- Guatemala 65
- Gum, blue 301
- Gurob 30
- Gymnosperms 201
- Gyrophoric acid 191  
 structure of **186**
- Haem 248
- Haematein 8, 8
- Haematococcus* 251
- Haematoxylin 8, 70, 345  
 combined with henna 346  
 structure of 345
- Haematoxylum*  
*brasiletto* 8, 25  
*campechianum* 8, 286, 345
- Hair  
 dyeing with henna 342–3  
 dyeing with indigo 343–5  
 dyeing with natural colorants 339–50  
 general requirement of dyeing concepts 340–1,  
**341**  
 human 340  
 regulations on dye products 347  
 relevant natural dyes for 342–7

- Haiti 59
- Hapalopilus*  
*nidulans* 187, 192
- Hardiness, of *Isatis* 77
- Harshingar 224
- Harvesting  
 of *Isatis* 86–90, 87  
 of *Persicaria* (*Polygonum*) 94, 100
- Heartwood 280–1
- Hellula*  
*undalis* 92
- Hematein 286
- Hematoxylin 284, 286
- Hemicelluloses 279, 298
- Hemicetal 10
- Hemiketal 137, 141
- Henna 30, 32–3, 66, 69, 151, 153  
 agricultural aspects of 155–6  
 combined with haematoxylin 346  
 and corrosion prevention 154  
 extraction of 153  
 and hair dyeing 342–3  
 uses of 154
- Henenosid  
 aglycone of 153  
 A, B and C 153, 342
- Herbicides  
 availability and use 85  
 Specific Off-Label Approvals (SOLA) 85
- Hexahydroxydiphenic acids (HHDP) 203, 207  
 structure of 204
- Hexamethyl-disilazane (HMDS) 165
- Hexaplex*  
*trunculus* 14, 22
- Hibiscus*  
*sabdariffa* 144
- High-performance liquid chromatography  
 (HPLC) 103, 153, 161  
 with diode array detection (HPLC-DAD) 6, 32,  
 170, 211, 250  
 with electrospray ionization (HPLC-ESI)  
 211–12  
 with mass spectrometric detection  
 (HPLC-MS) 6, 169–70, 211–12, 250  
 normal phase (NP-HPLC) 212  
 reverse phase (RP-HPLC) 212, 230–1,  
 232, 250
- High-performance thin layer chromatography  
 (HPTLC) 153
- High-pressure liquid chromatography  
 (HPLC) 165  
 mass spectrometry (HPLC-MS) 165
- Hollyhock 145
- Holocellulose 298  
 disintegration of 297–8
- Homoptera 22
- Hornbeam 306
- Hydnellum* 185, 192
- Hydnum* 188
- Hydrogen peroxide 141, 302–5  
 and hair dyeing 345
- Hydrojuglon 343  
 glucoside 296, 343
- Hydroperoxide 142
- Hydroquinone 68  
 8-hydroxy brazilein 8  
 3-hydroxy flavones 16
- Hydroxyanthraquinones 61, 165
- Hydroxyl benzotriazole (HOBT) 304
- 7-hydroxy-2-methylantraquinone 166
- 1-hydroxy-2-methylantraquinone 166
- 5-hydroxy-3-methyl-1,4-naphthoquinone 157
- 5-hydroxy-naphthohydroquinone-4- $\beta$ -d-  
 glycosid 343
- 5-hydroxy-naphthohydroquinone-4- $\beta$ -d-  
 glycoside 156
- 2-hydroxy-1,4-naphthoquinone 33–34, 152–6  
 structure of 153, 342
- 4-hydroxy-1,4-naphthoquinone, structure of 342
- 5-hydroxy-1,4-naphthoquinone 152, 156–7, 343  
 structure of 153
- $\alpha$ -hydroxyorcein 191
- $\beta$ -hydroxyorcein 191
- $\gamma$ -hydroxyorcein 191
- Hymenaea*  
*courbaril* var. *courbaril* 307
- Hyperchromic shift 262, 267–8
- Hypobranchial glands 22
- Imidacloprid (Confidor) 100
- Impurities, of indigo 48–9, 127–30, 128–9
- India 55, 59, 65, 67–8, 70–1, 102, 152–3, 155
- Indican 11, 49, 68, 93, 101–3, 108, 110–11,  
 115–16  
 reaction with  $\beta$ -glucosidase 117  
 structure of 109
- Indigo 3–4, 11, 15, 22, 29, 66, 68–9, 322  
 absorbance maxima for 107  
 aggregation of 106–8  
 agricultural aspects of 75–103  
 in ancient Egypt 30–2  
 blues 10–12  
 carmine 106  
 commercial producers of 119

**Indigo (Continued)**

- dye bath 12
- exotic 24
- extraction of 105–30
  - procedures for 114–26
- fluorescent intermediates during
  - formation 123
- formation of 108–14
  - from indoxyl 112
- and hair dyeing 343–5
- high-throughput production equipment 120–1
- impurities of 48–9, 127–30, 128–9
- Indian **102, 322**
- indigotin content of 49
- Java **102**
- leuco, see *Leuco indigo*
- market for 50
- methods of determining 106–8, **106**
- mixed with lawson (reng) 343, 345
- model of natural formation 128–30, 129
- Natal **102**
- Ottoman 33–4
- precursors of 108–14
  - capture using resins 124
- purity of 126–30
- reduction of 344–5, 344
- species cultivated for **102**
- sublimation and desublimation of 126–7, 126
- synthetic 11, 24, 126
- use in illumination 5
- yields of 118–20, 122, 124–6
  - effect of alkali on 118
- Indigofera* 11, 24, 29, **66**, 68–9, 75, 101–3, 105, 108
  - anil* 101
  - argentea* 29
  - arrecta* 101, **102**
  - coerulea* 101, **102**
  - cultivation of 102
  - galegioides* 69
  - indigo extraction by steeping leaves 117–19
  - micheliana* 101, **102**
  - species cultivated for indigo **102**
  - suffruticosa* 101, **102**
  - sumatrana* 101
  - tinctoria* 11, 22, 29, 33, 68–9, 101, **102**
  - yields of 102–3
- Indigofera **322**
- Indigoids, dyes 32
- Indigotier sauvage **102**
- Indigotin 11, 11, 32, **49**, 286
  - dye colour in wood 289–90, 289, **290**
- Indirubin 11–12, 15, 108
  - formation from indoxyl 113
- 1-*H*-indol-3-yl 6'-*O*-(carboxyacetyl)- $\beta$ -d-ribohex-3'-ulopyranoside 110
- 1-*H*-indol-3-yl  $\beta$ -d-ribohex-3-ulopyranoside 110
- Indole 123
- Indonesia 68, 70–1
- Indoxyl 11, 68, 105
  - acetate 108, 113, 122–3, 127–8
  - anion 12
  - capture using resins 124
  - fluorescence of 123, 127–8
  - formation of indigo from 112
  - formation of indirubin from 113, 114
  - glucoside 11, 30
  - instability and 'decay' of 118
  - and isatan in extraction 122
  - phosphate 122
  - released by steeping 117
- Indoxyl- $\beta$ -d-glucoside 108
- Indoxyl-5-ketogluconate 108, 110
- Inductively coupled plasma separation
  - with atomic emission spectrometric detection (ICP-AES) 6
  - with mass spectrometric detection (ICP-MS) 6
- International Organic Farming Organization (IFOAM) 354
- International Organization for Standardization (IOS) 197
- Ionone rings 222, 226
- Iran 69, 167
- Iron 248, 268, 330, 361, 363
  - buff 30, 35
  - chloride 361
  - hydrated oxide 28
  - ions 4
  - as mordant 361, 371
  - salts 35, 154, 346
  - sulfate 361
  - as mordant 67, 70
- Irrigation
  - of *Isatis* 86
  - of *Persicaria (Polygonum)* 101
- Isatans
  - and indoxyl in extraction 122
  - isatan A 110, 112
    - structure of **109**
  - isatan B 49, 108–10, 112, 115
    - structure of **109**
  - isatan C 109
- Isatin 11–12, 113–14
  - effect on fluorescence 123
  - hydrolase 114

- Isatis 322**  
*Isatis* 75–92, 110, 112  
 agronomy of 77–92  
 and crop rotation 77  
 developmental stages of 79–84  
 fertilizers for 86  
 hardness of 77  
 harvesting of 86–90, 87  
 indigo extraction  
   from crushed leaves 114–15  
   by steeping leaves 119–24  
*indigotica* 77, 91–2, **91**, 105, 110  
   indigo precursors in **111**  
 irrigation of 86  
 seed production in 90–1  
 seed sowing 78–9  
*tinctoria* 11, 22–3, 29, 39, **40**, 42–3, 76,  
   91–2, **91**, 105, 110  
   affect of sowing date on yield of **87**  
   indigo precursors in **111**  
   relationship between indigo precursor levels  
     and PAR 88  
   seed yield and quality of **90**  
   sowing and harvesting dates for **78**  
   weeds, pests and diseases of 84–5  
   yields of 86–90, 88–9  
 Islamic textiles, dyes in 33–4  
 Isoflavones 270  
 Isoindirubin 109  
 Israel 251  
 Italy 75–6, 78, 85–7, 90–3, 100–1, 120–2, 271  
  
 Jamaica 59  
 Japan 57, 61, 71, 92, 145  
 Jatobá 307  
 Jet dyeing machines 333  
 Jig dyeing machines 333  
 Jiquilite **102**  
 Juglanaceae 156  
*Juglans* 299  
   *cinerea* **156**  
   *mandshurica* 156  
   *nigra* **156**, 296, 301  
   *regia* **156**, 162, 296, 343, 346, **379**  
 Juglon 151–2, 162, 343  
   structure of 153, 342  
 Juglone 156–7, 168  
   cytotoxicity of 157  
   sources of **156**  
  
 Kaempferol 16, 156, 270  
 Kale 237–8, 241  
  
 Kataplasma dyeing 342  
 Katurumurunga **239–40**  
 Kenya 65  
 $\alpha$ -keratin 340  
*Kermes* 22  
   *vermilio* 6–7, 24, 32  
 Kermes 6, 7, 23, 33–4, 184, 193  
   in ancient Egypt 30, 32  
   dyer's 24  
 Kermesic acid 6  
*Kermococcus*  
   *vermilio* 34  
*Kerria* 24  
   *chinensis* 6  
   *lacca* 6, 7, 285  
 Khao youak 69  
*Khaya*  
   *senegalensis* **66**, 69  
 Khola 33  
 Kinetin 156  
*Klebsiella*  
   *pneumoniae* 159, 163  
 Knapweed, rayed **40**  
 Knotweed, dyer's 105, **322**, 355  
 Kok khan 69  
  
 L-phenylalanine 205  
*L\*a\*b\** colour space values 282–3, **322**  
 Labiatae **49**  
 Lac 6, 24, 285  
   common 6  
   crimson 33  
   dyes 6, 7, 32, 34  
   Indian 6, 34  
   stick 6  
 Laccacids 6, 32  
 Laccases 303–4  
   general oxidation reaction 304  
*Laccifer*  
   *lacca* 6  
*Lactarius* 184  
 Lady's mantle **40**  
*Lakshadia*  
   *lacca* 6  
 Lamiaceae, *see* Labiatae  
 Laos 65, 67–71  
 Lapis-lazuli 8  
   use in illumination 5  
*Laricifomes*  
   *officinalis* 184  
*Lasallia*  
   *pustulata* **186**, 191

- Lawson 151–6, 162, 168, 342  
 agricultural aspects of 155–6  
 complexes of 153  
 effects of mordants on 154  
 extraction of 153  
 mixed with indigo (reng) 343, 345  
 properties and use 153–4  
 quantitative analysis of 153  
 structure of 153, 342
- Lawsone 69
- Lawsonia*  
*inermis* 153, 155, 342  
*spinosa* 66, 69
- Leather production 207, 213
- Lecanora* 185  
 chemistry of purple dyeing procedure 191
- Lecanoric acid 191  
 structure of 186
- Leguminosae 22, 24–5, 68–71, 101, 168
- Lentagran WP (pyridate) 85
- Lepidoptera 100
- Lettuce 237
- Leucine 340
- Leucoanthocyanidin 206
- Leuco* indigo 106–8, 113–14, 117, 124, 343  
 fluorescence of 123  
 and hair dyeing 343–4  
 protonation of 344
- Leucopelargonidin, structure of 260
- Leuco species 11
- Lichen purple 23, 191
- Lichens 23, 39, 152  
 cultivation of 184–5  
 dyes from 183–200  
 colour-fastness of 197–8  
 new approaches to 198  
 dyestuffs in 185–96
- Light, and anthocyanins 265
- Light fastness 197, 324, 325
- Lignans, in wood 279, 281
- Lignin 279, 298  
 degradation of 296
- Liliaceae 9
- Linden 293
- Linder, Johan 184
- Linen 27–8, 322  
 dyeing of fabric 333–4
- Linoleic acid 285
- Linolenic acid 285
- Linseed 285
- Linuron (Afalon) 100
- Lipstick tree 66
- Lithospermum*  
*erythrorhizon* 22, 43
- Litmus 185–91
- Liverwort 46
- Lobaria* 188
- Locust, black 281, 295, 301, 306
- Logwood 286, 345
- Lucidin 159, 161, 164–5, 168–70  
 formation of covalent base  
 adducts 167  
 genotoxicity of 166–7  
 and hair dyeing 347  
 primeveroside 161, 164, 166, 170  
 structure of 166
- Lucidin- $\omega$ -ethylether 166, 170
- Lucidin- $\omega$ -methylether 166
- Lucidine 347
- Lutein 53, 59–60, 225, 226–8, 229, 231, 232, 238  
 ADI of 53  
 structure of 59  
 all-*trans*-lutein 59
- Luteochrome 223
- Luteolin 15, 32, 145, 153, 342  
 structure of 16
- Luteolinidin 141, 145
- Luteoxanthin 223
- Lycopene 222, 225, 226–8,  
 229, 238
- Lycopersicon*  
*esculentum* 229
- Lythraceae 69
- Machinery, in dyeing process 321
- Mackloeur 68
- Maclura*  
*tinctoria* 16, 25
- Madagascar 67
- Madder 22–3, 29, 151, 159, 160–71, 193, 322,  
 330, 355, 357  
 agricultural aspects 168–71  
 analysis of 165  
 in Ancient Egypt 30–2  
 cell cultures 170  
 component used 39  
 crop as factor of cultivation 169  
 diseases of 169  
 dormancy breakage of 170  
 dyer's 24  
 in Europe 39, 40, 160  
 cultivation of 43–4, 45, 45–6  
 extraction 50, 164  
 genetic transformation 170

- and hair dyeing 347
- Indian 159, 160, 163
- Japanese 159
- lake 165
- medical uses 163–4
- nutrient requirements of 168
- Ottoman 34
- propagation of 169
- properties of 160–2, 164
- purification 164
- red 4, 13
- root 162, 371, 377, 379–80
- safety aspects 166–8
- toxicity of 163, 166–8
- wild 159
- yields of 169
- Madder family, *see* Rubiaceae
- Magnesium 248, 268
- Mahogany 299
  - Indian 224
- Makua 66, 68
- Malaysia 67–8, 70–1
- Maleic anhydride 298
- Malonyl-CoA 205
- Malonylflavone 13
- Malvaceae 145
- Malvidin 142, 261, 262
- Malvidin 3,5-diglucoside 140
  - colouring power and pH 140
  - mole fraction distribution of species 137–40, 137
  - structural transformations of 139
- Malvidin-3-OG,1 141
- Mango 237–8
- Manihot*
  - esculenta* 239–40
- Manilkara*
  - zapota* 66, 70–1
- Manioc 239–40
- Maple 281, 289, 290, 302, 302, 306
  - hard 292
- Maqrisi 29
- Marein 17, 17
- Mare Nostrum*, *see* Mediterranean Sea, global markets of
- Marigold 16, 54, 59–60
  - Aztec 59
  - big 40
  - commercial forms of 59–60
  - commercial uses of 60
- Marjoram
  - wild 40, 46
  - cultivation of 49
- Market research 372–5
- Marupá 307
- Mauritia*
  - vinifera* 225
- Mauve dyes 15
- Mauveine 15
- Mauvein, the triumph of 22–3
- Mauve mania 15
- Mayweed 371, 379
- Medicago*
  - sativa* 246
- Mediterranean 183–4
  - ancient world of 3–4
  - history of natural dyes in 3–17
- Mediterranean Sea, global markets of 3
- Medium density fibreboards (MDFs) 290
- Melamine–urea–formaldehyde (MUF) resin 214
- Melanin 340
- Meliaceae 69
- Meloidogyne* 92
  - incognita* 156
- Metal complexation
  - and anthocyanins 267–8
  - and hair dyeing 345–6
- Metal ions 13, 268, 284
- Metallochlorophylls, stability of 250
- Metallochlorophyllins 250
- Metal reaction dyes 346
- Metals, toxicity of 363
- Metazachlor (Butisan) 85
- Methyl 3-carboxy-3-devinyl-pyrropeophorbide *a* 247
- Methyl jasmonate 170
- N*-methyl-2-pyrrolidone (NMP) 108
- Metobromuron (Patoran FL) 100
- Mexico 59–60, 71, 102
- Microalgae 251
- Microanalysis 5–6
- Microtus*
  - oeconomus* 207
- Mignonette 371, 377, 379–80
- Mildew 92
  - powdery 85
- Milfoil 40
- Milk 263
  - cap 184
- Millettia*
  - laurentii* 296
- Mimosa* 213
  - catechu* 31
- Miyake, Issey 21

- Mollugin 165–6  
 Molluscs 183  
 Monobromindigo 14  
 Monogalloylglucose 205  
 Monoglycosides 9  
 Moose 207  
 Moraceae 25  
 Mordanting 330–1  
   three stages of 330–1, 331  
 Mordants 4, 22–3, 29, 146  
   acid 35–6  
   and ageing process 34  
   alum, *see* Alum  
   analysis of 6  
   in ancient Egypt 35–6  
   basic 35–6  
   colour shift due to 330  
   in dyeing procedure 363  
   in dyeing process 319–20  
   effect on fastness and fading 162  
   effect on lawson 154  
   and hank dyeing 332  
   iron, *see* Iron  
   and metal complexes 345–6  
   and *Rheum* extracts 159  
   tannins, *see* Tannins  
   for textile dyeing 161  
   for wood 284  
   and yarn dyeing 333  
 Morin 16  
*Morinda* 168  
   *angustifolia* 159, 165  
   *citrifolia* 171  
 Morindone 159  
 Mould 266  
 Movingue 301  
 Mukunuwanna 239–40  
 Mulberry 301  
   dyer's 25  
 Mullein 40  
 Munjistin 160–2, 164, 166  
   ethyl ester 170  
*Murasaki* 22  
*Murex* 14  
   *brandaris* 14–15  
   *trunculus* 14–15  
 Murex  
   banded dye 22  
   spiny dye 22  
 Muricidae 12, 15, 22  
 Mushrooms 39, 152  
   colour-fastness of dyes 197–8  
   cultivation of 184–5  
   drying of 195  
   dyes  
     new approaches to 198  
     as source of 183–200  
   dyestuffs in 185–96  
 Mutachrome 223  
 Mutatoxanthin 223  
 Myanmar 67–8, 70–1  
 Myrecetin 16  
 Myricetin 270  
 Myristate-palmitate 59  
 Myrtaceae 71  
  
 Nacre 66, 69  
 Naphthoquinones 49, 162, 168  
   dyes 152–7, 342–3  
 Naringenin 135, 156  
   structure of 260  
 Narrawood 25  
 Natural Black 1 345  
 Natural Brown 1 346  
 Natural Brown 7 156, 343  
 Natural colorants  
   acceptable daily intake (ADI) 53  
   anthocyanins as 261–8  
   application in technical use and consumer  
     products 255–350  
   carotenoids as 228, 229  
     structure of 226  
   chlorophylls as 244–6  
   and colours in civilizations 21–6  
   costs of, *see* Costs  
   demand according to colour 379  
   economic aspects of 367–84  
   environmental aspects of 353–65  
   flavonoids as 268–9  
   for food 137, 144–6  
   in fungi 186–90  
   future for 25–6  
   for hair 154, 339–50  
   historical aspects of 1–36  
   industrial use of  
     basic requirements for 368–70  
     challenges for 370–1  
     and closed-loop economy 381–2  
     consumer expectations for 371–5, 374  
     market research for 372–5  
     production costs of 375–80, 377, 380  
   in lichens 186–90  
   market development for 382–3  
   production of 73–254

- properties of 73–254, 319  
 quinoids as 151–82  
 residual materials and by-products 355–6  
 security of supply 369–70  
 South American overview **54**  
 and sustainability 353–65  
 in textile dyeing 315–37  
 Vietnamese sources for **66**
- Natural coloration, reasons for 316–17
- Natural dyeing 321–32  
 aspects of application 328–9  
 costs of 325–6, 375–80  
 dye-ability of substrates 321–6  
 ecological aspects of 327–8  
 fastness criteria 322–5  
 requirements of dyestuff 321  
 technology 329  
 using ‘dye bags’ 331–2
- Natural dyes  
 in ancient Mediterranean 3–17  
 classical palette for 3–4  
 consumer associations with 374  
 in Eastern Asia 65–72  
 economic aspects of 367–84  
 extraction of 328–9  
 for hair dyeing 342–7  
 history in North Africa (Egypt) 27–36  
 on industrial scale 332–4  
 in Pharaonic textiles 28  
 reasons for 316–17, **317**  
 in Vietnam 65–72  
 and wood coloration 277–313  
 and wool fabric 33
- Natural lacquer systems, for wood 284
- Natural Orange 6 153, 342–3
- Natural Red 8 **159**, 160–71
- Natural Red 1 3 **159**
- Natural Red 14 **159**
- Natural Red 16 **159**
- Natural Red 24 346
- Natural Red 26 151
- Natural resins 285
- Natural Yellow 23 157
- Nematodes 92
- Neoxanthin 223, 232
- Nepal 71
- Nerium*  
*oleander* 162
- Netherlands 169
- Nettles 40, **322**
- Neurosporene 222
- New World 4, 7
- Nigeria 145
- Nitrogen packing 265
- No observed effect level (NOEL) 271
- Nopalea* 60
- Norbadiene 196  
 structure of **190**
- Norbixin 55–7, 67, 224, **229**  
 ADI of 53  
 structure of 55
- Nordamnacanthal **159**, 160–2, 164, 166, 170
- Nordracorhodin **9**
- North America, *see* America, North
- Norway 271
- Novarom G 125
- Novozym 199 125
- Nut 289, **290**, 302  
 green **322**  
 shells **325**, **377**, **379**
- Nyctanthes*  
*arbor-tristis* 224
- Oak 203, 213, 281, 286, 288, 289,  
**290**, 292, 294–5, 299, 301, 302, 306  
 ammoniated 299  
 balls 36  
 black 25  
 component used 39  
 dyer’s 34  
 Kermes 34
- Ocenebra*  
*erinaceus* 22
- Ocher 28
- Ochrolechia* **186**  
*tartarea* **186**, 191
- Okanin 4'-O-glucoside 17
- Okanin, glycosides of 17
- Oleander 162
- Oleic acid 285
- Oleoresins 56, 58, 60  
 commercial production of 59  
 commercial uses of 58
- Olives 237
- Onions 270, **322**  
 component used 39  
 peels, *see* Onions, skins of  
 red 329, 333–4  
 skins of 16, **322**, **325**, 329, 333–4, **371**, **377**,  
**379–80**  
 extraction properties of 328  
 and hank dyeing 332
- Onosma*  
*echioides* 152

- Opoppo 184  
*Opuntia* 60  
 Orange dyes 67, 184, 193,  
 196, **322**  
 Orceins 191  
 Orchil 23, 29, 185–91  
 Orcinol 191  
*Origanum*  
   *vulgare* **40**, 46  
 Orsellinic acid 191  
*Ostrinia*  
   *nubilaris* 100  
 Ottoman textile 34  
 Oxidation–reduction reactions 4  
 Oxidative stress 141  
 Oxonium cation 263  
   structure of 263  
 Oxonium ion, heat degradation of 264  
 Oxyfluorfen 85  
 Oxygen, and anthocyanins 264–5  
 Oyster drill 22  
  
 Pacific islands 67  
 Paddle dyeing machines 334  
 Pagoda tree **66**  
 Pakistan 68  
 Palmitic acid 285  
 Pandanus 238  
 Papayas 238  
 Papilionaceae, *see* Leguminosae  
 Paprika 55, 228, **229**  
*Parmelia* **186–7**, 191  
   *saxatilis* 191  
 Parsley 250, **322**  
 Patoran FL (metobromuron) 100  
*Paxillus*  
   *atrotomentosus* **187**, 192  
 Pear 306  
   prickly 60  
 Pelargonidin 136, 141, **142**, **261**, 265–6, 269  
   structure of 260  
 Pelargonidin-3-glucoside 266  
 Pendimethalin (Stomp) 85  
*Penicillioopsis*  
   *clavariaeformis* 198  
 $\beta$ -1,2,3,4,6-pentagalloyl-*O*-d-glucopyranoside  
   (PGG) 203  
 Pentagalloylglucose 203  
   structure of 204  
 3-pentagalloylglucose, structure of monomers  
   of 204  
 2',3',4',3'4-pentahydroxychalcone 17  
  
 3,4',5',7,8-pentahydroxy-2',3-methylen-neoflavan,  
   structure of 345  
 Peonidin **142**, **261**  
 Pepper, red 223  
 Perkin, William Henry 15, 22  
 Pernambuk wood 346  
 Peroxidases 266, 303–4  
 Peroxyl 141  
 Perse 23  
 Persian berries 16, **16**, 34  
 Persian nut, component used 39  
*Persicaria* 75, 92–101  
   agronomy of 93–101  
   developmental stages of 93–9  
   fertilizers for 101  
   harvesting of 94, 100  
   irrigation of 101  
   seed production of 101  
   seed sowing of 94, 100  
   *tinctoria* 75–6, 92  
     effect of sowing date on yields **99**  
     relationship between indican content and  
       PAR 93–4  
   weeds, pests and diseases of 100  
   yields of 94, 100  
 Peru 57, 59–61, 65  
 Pests  
   of *Isatis* crops 84–5  
   of *Persicaria* (*Polygonum*) crops 100  
 Petunidin **142**, **261**, 262, 268–9  
*Phanerochaete*  
   *chrysosporium* 303  
 PH, and anthocyanin structural  
   transformation 263  
*Phellodon* 185, 192  
 Phenolases 266  
 Phenolic rings 258  
 Phenolics 201  
   ontogenetic changes in Salicaceae 202  
   in wood 279  
 Phenol, total content (TPH) 327  
 Phenylalanine 259, 260  
 Phenylalanine ammonia-lyase (PAL) 205  
 2-phenylbenzopyrylium 135  
   as food colorants 137  
   thermodynamics and kinetics of  
     derivatives 137–40, 137  
 Phenyl isocyanate 298  
 Phenylpropanoid pathway 205, 259  
 Pheomelanins 340  
 Pheophorbides 244–5, 247,  
   250–1

- Pheophytins 244–5, 251  
   pheophytin *a* 250  
   pheophytin *b* 250
- Philippines 65, 68, 70–1
- Phloroglucinol 201
- Phlorotannins 201, 269
- Phoenicians 3, 14
- Phoma* 169
- Phosphoinositide 3-kinase 171
- Phospholipase C 171
- Photodegradation 305
- Photodiode array spectra, of carotenoids 232
- Photosynthesis 244
- Phototherapy 247
- Phycobilins 251
- Phyllotreta*  
   *undulata* 85
- Physcion 157, 193  
   structure of 158, **188**
- Phytium elicitor 170
- Phytoalexins, proanthocyanidin 258
- Phytoene 222
- Phytofluene 222
- Picea*  
   *abies* 192, 287, 302, 306  
   *excelsa* 306
- Pieris*  
   *brassicae* 85
- Pigments  
   distinguished from dyes 4, 319–20  
   lake 4
- Pine 213, 281, 289, **290**, 302, 302  
   black 281  
   needles 251  
   Scots 298, 301  
   Southern 296  
   stone 301  
   yellow 162
- Pinus* 296  
   *nigra* 281  
   *radiata* 213  
   *sylvestris* 162, 192, 298, 302
- Piper*  
   *betle* **66**, 71
- Piperaceae 71
- Pisolithus*  
   *arhizus* **190**, 196
- Pisoquinone 196
- Plant dyes 28  
   regional aspects of sources 37–72  
   see also *Dye plants*
- Plant material  
   colours of **322**  
   mixtures of 331–2  
   native species 355  
   supply of 354–7  
     selection for sustainability 356–7, 357
- Plant Protection Products Directive  
   (91/414/EEC) 85
- Plants, extraction properties of 328
- Platanillo **102**
- Pleurotus*  
   *ostreatus* 303
- Pliny 7, 22
- Plumbagin 157
- Plums 306
- Poaceae 145
- Pococco 184
- Polyamide 162, **322**  
   dyeing of tights 334  
   knitted 378
- Polyester 162, 196
- Polyethylenimine 213
- Polygonaceae 42, 92, 168
- Polygonum* 49, 75, 92–101, 108  
   agronomy of 93–101  
   *aviculare* 100  
   developmental stages of 93–9  
   fertilizers for 101  
   harvesting of 94, 100  
   indigo extraction  
     from crushed leaves 115–16  
     by steeping leaves 124–6  
   irrigation of 101  
   seed production of 101  
   seed sowing of 94, 100  
   *tinctorum* 39, **40**, 42–3, 75–6, 92, 105, 355  
     indigo precursors in **111**  
     relationship between indican content and  
       PAR 93–4  
   weeds, pests and diseases of 100  
   yields of 94, 100
- Polyketide pathway 168, 205
- Polyphenol-ammonia-lyase (PAL) 143
- Polyphenols 67, 141, 201
- Polyphoric acid, structure of **187**
- Polyporales 184
- Polyporic acid 192
- Polyporus* **187–8**  
   *mori* 184
- Pomace  
   berry **377**, **380**  
   grape 145–6, **325**, 327, **371**  
   tea **377**, **380**

- Pomegranate pericarp 346  
 Ponceau GR 144  
 Poplar 289, **290**, 293, 302, 302  
 Popo 184  
*Populus* 293, 302  
   *alba* 202, 203  
 Porphyrins 247–8  
*Porphyrophora* 7, 22, 24  
   *hamelii* 7  
   *polonica* 7  
 Potassium 268  
   hydroxide 56  
   iodate test 211  
 Potatoes, sweet 144, 146, 238, **240**  
 Privet  
   berries **322**  
   Egyptian 153  
 Proanthocyanidins 201, 269  
   hydrolysis of 269  
 Process engineering, costs of 368–9  
 Procyanidin 205  
 Prodelfinidin 205  
 Production costs, *see* Costs  
 Proline 171, 207  
 Prolycopene 224  
 Propelargonidin 205  
 Protoporphyrin IX 248  
 Protosappanins 70  
 Pro-vitamin A **240**  
   role of carotenoids as 225–6  
 Prunes 301  
*Prunus* 295  
   *avium* 299, 301, 306  
   *domestica* 306  
 Prussian blue assay 210  
 Pseudopurpurin 159–71  
   and hair dyeing 347  
   plant sources 159  
   structure of 160  
*Pseudotsuga*  
   *menziesii* 302  
*Psylliodes*  
   *chrysocephala* 85, 92  
*Pterocarpus*  
   *indicus* 25  
   *santalinus* 25  
   *soyauxii* 25  
*Pterolobium*  
   *stellatum* 212  
 Pulvinic acid 196  
   structure of **189**  
 Pumpkins 238, **240**, **322**  
  
*Punica*  
   *granatum* 346  
 Purple  
   aniline 15  
   ancient 13–15, 191  
   in Egypt 31  
   dyes 183  
   lichen 23  
   mania 15  
   synthetic fulfilment of 22–3  
   murex 34–5  
   symbolism of 13  
*Purpura* 14  
   *haemastoma* 14–15  
 Purpurin 6, 32, 159–71  
   antimutagenic effect of 145, 163–4  
   calcium salt of 164  
   plant sources 159  
   structure of 160  
 Purpuroxanthin 161, 167  
 Pyridate (Lentagran WP) 85  
 Pyrogallic acid 212  
 Pyrogallol 346  
 Pyrolysis-gas chromatography/mass spectrometry  
   (Py-GC/MS) 165  
*Pyrus* 306  
  
 Quality control, costs of 376  
 Quebracho wood 213  
 Quercetin 16, 144, 156, 270  
 Quercitol 203  
 Quercitron 25  
*Quercus* 201, 213, 286, 288,  
   290, 292, 295, 299,  
   301, 306  
   *coccifera* 34  
   *infectoria* 34  
   *lusitanica* 34  
   *velutina* 25  
 Quinic acid 203  
 Quinizarin 165  
 Quinoid dyes 151–82  
 Quinoid (quinoidal) base 137, 140  
   structure of 263  
 Quinone methide 207  
  
 Radish 144, 265, 271  
   red 145–6  
 Rajasthan 156  
*Ramalina*  
   *crassa* **187**  
 Rape, oilseed 76–7

- Raspberries 141, **143**, **379**  
 Rastik 346  
 Ratanjot 152  
 Raw materials, costs of 376  
 Reactive oxygen species (ROS), and  
   disease 141  
 Red 2 144  
 Red 3 144  
 Red 40 144  
 Red dyes 69–70, 192–3, 261, **322**, **371**  
   in ancient Egypt 30  
   from lichens 191–2  
   linguistic root of 7  
   Ottoman 34  
   scale of use 24–5  
 Red Ecarlate 144  
 Redox recycling 157  
 Redwoods 8  
 Regulations, on hair dye products 347  
 Relbún **159**  
*Relbunium*  
   *hypocarpium* **159**  
 Renewable resources, dawning era of 25–6  
 Reng 343, 345  
*Reseda* **322**  
   *luteola* 15, **16**, 24, 32, 39, **40**, **48**, 355,  
   **371**, **379**  
 Resedaceae 24, **48**  
 Residual materials 355–6  
   criteria for 356  
 Resin acids, in wood 279  
 Resins 292  
   potential use in indigo production 124  
 Retinol 226, 243  
 Rhamnaceae 168  
 Rhamnetin 16  
*Rhamnus* 16, **16**  
   *chlorophorus* 34  
   *infectorius* 34  
   *utilis* 34  
 Rhéin 157  
   structure of 158  
*Rheum* 157–9  
   *palmatum* 157  
   *rhabarberum* 157  
   *rhaponticum* 157  
 Rhodanine colour test 211–12  
 Rhubarb 157, 330  
*Ribes*  
   *nigrum* **143**  
 Ricinoleic acid 284, 285  
 RN orange 144  
*Robinia*  
   *pseudacacia* 281, 295, 301, 306  
*Roccella* 23, 185, **186**, 191  
   chemistry of purple dyeing procedure 191  
 Roccellaceae 23  
 Rock-shell, red-mouthed 22  
 Rosaceae **143**  
 Rose dyes **322**  
 Roselle 144  
 Roundup (glyphosate) 100  
 Royal purple 183  
 Rubens, Peter Paul 11  
 Ruberythric acid 161, 163–5, 170  
*Rubia* 22, 29, 165, 170  
   *akane* **159**, 171  
   *cordifolia* **159**, 160, 163  
   *iberika* **159**  
   *peregrina* **159**  
   *tinctorum* 6, 24, 29, 39, **40**, 43–4, **159**, 160,  
   162, 164–6, 168, 195, 347, 355, **371**, **379**  
   suspension cultures 170–1  
 Rubiaceae 6, 22, **45**, 159, 168  
 Rubiadin **159**, 166–7  
   and hair dyeing 347  
   structure of 166  
*Rubus*  
   *fruticosus* **143**  
   *idaeus* 141, **143**, **379**  
   *occidentalis* **143**  
*Rumex* 157–9  
   *acetosa* 159  
   *crispus* 159  
   *hymenosepalus* 159  
   *maritimus* 159  
 Rust 28  
 Rutin 70  
 Safflor carmin 152  
 Safflor yellow 152  
 Safflower 30, 33–4, **40**, 43, 151–2,  
   269, 285  
 Saffron 17, 34, 162, 223, 228, **229**, **322**  
 Salazinic acid 191  
   structure of **187**  
 Salicylates 203  
*Salix* 203, 209  
   *eriocephala* 203  
   *myrsinifolia* 203, 209  
   *pentandra* 202, 203  
   *sericea* 203  
*Salmonella* 163, 167  
   *typhimurium* 166

- Sambucus*  
*nigrum* **143**  
 Sandalwood 25  
 Sapodilla **66**, 70–1  
 Saponification 230, 249  
 Saponin 70  
 Sapotaceae 70–1  
 Sappan chalcone 70  
 Sappanwood 25, **66**, 69–70, 346  
*Sarcodon* 185, 192  
*imbricatus* 192  
*squamosus* **187–8**, 192, 197  
 Satin 34  
 Sawwort 16, 24, **40**, **379**  
 Saxifragaceae **143**  
 Scale insects 34, 60  
   crimson-dyeing 24  
 Scandinavia 183, 191  
*Schinopsis*  
*balansae* 213  
*Schinus*  
*molle* 60  
 Scotland 183, 191  
 Seed production  
   in *Isatis* 90–1  
   in *Persicaria* (*Polygonum*) 94, 100  
 Selective amplified microsatellite polymorphic  
   locus (SAMPL) 77  
 Self-association, of anthocyanins 268, 268  
 Sephadex LH20 210  
 Serine 340  
*Serratula*  
*tinctoria* 16, 24, **40**, **379**  
*Sesbania*  
*grandiflora* **239–40**  
 Shellac 34, 285  
   resin 6  
 Shells 162  
 Shikimate pathway 168  
 Shikimic acid 203  
   pathway 205  
 Shikonine 152  
 Siberia 157  
 Silk 34, 162, 299  
 Silver nitrate 346  
*Simarouba*  
*amara* 307  
 Singlet oxygen 141, 227, 305  
 Sodium  
   carbonate 50  
   copper chlorophyllin, *see* Chlorophyllins,  
     sodium copper  
   hydroxide 56  
   Solar cells 247  
*Solidago*  
*canadensis* **40**, 355, **371**, **379**  
*virgaurea* 16  
 Solvents 362  
   importance in extraction 49–50  
   influence on axial transport in wood 288  
*Sophora*  
*japonica* **66**, 70  
 Sorghum 145, 209, 212, 258  
*Sorghum*  
*bicolor* 145  
   var. *colorans* 145  
 Sorrel, common 159  
 South America, *see* America, South  
 Soybean 285  
 Soy isoflavones 258  
 Spain 65, 75–6, 78, 86, 91–2  
 Spectrophotometry  
   determination of indigo by **106**  
   ultraviolet–visible (UV–VIS) 5–6, 153, 164,  
     169, 231, 233  
 Spectroscopy, Fourier transform infrared  
   (FT-IR) 34, 153  
 Spinach 237, 250–1, **322**  
 Spindigo Project 75–6, 85–6, 92,  
   120, 127  
*Spirulina* 251  
*platensis* 251  
*Spondias*  
*lutea* **225**  
 Spruce 192, 281, **290**, 298, 302  
   European 306  
   Norway 287, 302, 306  
 Squashes **240**  
 Sri Lanka 68, 70–1, 238  
 Starane 180 (fluroxypr) 85  
 Stearates 284  
 Steroids 9  
 Sterols, in wood 279  
*Sticta* **187**  
*aurata* **189**, 196  
 Stilbenes, in wood 279  
 Stilbens, in wood 279, 281  
 Stomp (pendimethalin) 85  
*Stramonita*  
*haemastoma* 14, 22  
 Strawberries 142, **143**  
   red currant 237  
*Strobilanthes*  
*cusia* 69  
 Substrates, dye-ability of 321–6  
 Succinic anhydride 298

- Succinyl-CoA 248  
 Succinylcyanin 13  
 Sucupira, South American 296  
 Sudan 145  
 Sugars, and anthocyanins 265–6  
*Suillus* **188**  
 Sukumo 115–16  
 Sulfanilamide drugs 212  
 Sulfite 266–7, 298  
 Sulfur dioxide, and anthocyanins 266–7  
 Sunflower 285  
 Sunt berry 30  
 Superoxide 141  
   dismutase 141  
 Supramolecular complex, blue 12–13, 13  
 Sustainability  
   of natural colorants 353–65  
   selection process for plant material 356–7, 357  
*Swietenia* 299  
 Synthetic colorants 144, 315–16  
   bans on 144, 146  
 Synthetic dyes 22, 25, 39, 355  
   prices of 378–9  
 Syringic aldehyde 303  
 Syringyl 298
- Tachardia*  
   *lacca* 6  
*Tagetes* 59, 228, **229**  
   *erecta* **40, 54, 59, 229**  
*Tanacetum*  
   *vulgare* **40, 46, 379**  
 Tannic acids 46  
 Tannin agents 201–19  
 Tannin-binding protein (TBP) 207  
 Tanning, chromium-free 50  
 Tannins 68, 70–1, 159, 201–19, 269, 286, 299,  
   346, 363  
   analysis of 209–12  
   and anthocyanins 330  
   biosynthesis of 203–7  
   chemical activities of 208–9  
   chemical structure of 203–7  
   condensed (CT) 201–4, 269  
     biosynthesis of 206  
     structure of monomers of 204  
   degradation of 203–7, 297  
   extraction and purification 209–10  
   hydrolysable (HT) 201–3, 269  
     biosynthesis of 205  
     structure of monomers of 204  
   metal complexes of 208  
     as mordants 32, 36, 214  
     occurrence of 201–3  
     properties of 207–8  
     quantification of 210–12  
     sample preservation 209  
     toxicology and safety aspects of 212–14  
     uses of 212–14  
     in wood 279
- Tansy **379**  
   common **40, 46**  
 Tar, black 25  
 Tartaric acid 34  
 Tartrazine 144  
 Tea **66, 67, 212, 325**  
   black **371, 379**  
   green 141  
   and hair dyeing 346  
   pomace **377, 380**  
*Telephora* 185, 192  
   *palmata* 192  
 Telephoric acid 192  
   structure of **188**  
 Temperature, and anthocyanin  
   changes 264
- Terminalia*  
   *catappa* **66, 67**  
 Terphenylquinones 185  
   blue colours from 192  
 Tetrahydroporphyrins 248–9  
 Tetrahydroxychalcone 135  
 3',4',5,7-tetrahydroxy-flavone 342  
 3,4',5',7-tetrahydroxy-2',3-methylen-neoflavan,  
   structure of 345  
 Tetramethylammonium hydroxide 165  
 2,2,6,6-tetramethyl-1-piperidinyloxy radical  
   (TEMPO) 304  
 Tetrapyrroles 244, 247  
 Textile industry, requirements of **356**  
 Textiles  
   auxiliaries 325  
   dyeing of 162–4  
   Ottoman 35  
   test methods 323  
 Thailand 65, 67–8, 70–1  
 Thaisidae 12  
 Theaceae 67  
 Theophrastus 7  
 Thermogravimetric analysis 127  
 Thiourea 156  
 Thistle, torch 60  
 Thylakoids 250  
 Thymelaeaceae 24

- Tibet 157  
*Tilia* 293  
 Tin 268, 363  
   ions 4  
   salts 154  
 $\alpha$ -tocopherol 144, 227  
 Tomatoes 17, **229**, 238  
 Toxicity 363  
 Toyopearl HW-40 210  
*Trametes* **188**, 303  
   *hirsuta* 303  
   *versicolor* 303  
   *villosa* 303  
 Transcription factors 206–7  
 Transport 363–4  
 Tree rings 280–1  
 Triglycerides 285  
   in wood 279  
 1,2,4-trihydroxyanthraquinone 160–2  
 1,2,4-trihydroxy-9,10-anthraquinone 163  
 Trihydroxyanthraquinone-glycosids  
   160  
 1,2,4-trihydroxy-3-carboxy-  
   anthraquinone 347  
 3,4,5-trihydroxyl benzoic acid 205  
 1,3,8-trihydroxy-6-methyl-9,  
   10-anthracenedione 161  
 1,2,4-trihydroxy-naphthoquinone 153  
 Trisodium copper chlorine  
   e<sub>6</sub> 246  
   structure of 246  
 Tunaxanthin 224  
 Turkey 169–70  
 Turkey red 34  
 Turmeric 34, **54**, 55–9, **66**, 70  
   ADI of 53  
   Allepey type 59  
   commercial production of 59  
   commercial uses of 58  
   cultivation of 57  
 Tween 80 171  
 Tylosis 281  
 Tyrian purple 3–4, 13–15, 183  
   and Akrotiri frescos 14  
   in ancient Egypt 32  
 Tyrindoxyl sulfate 15  
 Tyrosine 340  
  
 Ultraviolet (UV) radiation 305  
 Umbrella tree **66**, 67  
 United Kingdom (UK) 75, 78,  
   85–6, 89, 92, 127, 144  
  
 United States of America (USA) 57–8, 61, 68,  
   146, 239, 246, 251, 269, 271  
   Food & Drug Administration (FDA) 144,  
     252, 271  
 Uralkyds 285  
*Ureibacillus*  
   *thermosphaericus* 115  
 Urine, maceration in 23  
 Uroporphyrinogen III 248  
*Usnea*  
   *dasyopoga* **187**  
  
*Vaccinium*  
   *corymbosum* **143**, 145  
   *macrocarpon* **143**, 145  
   *myrtillus* **143**, 145  
 Vacuum packing 265  
 Van Gogh, Vincent 4  
 Vanillic acid 303  
 Vanillin addition assay 210–11  
 Vat dyes 4, 11–12  
 Velvet 34  
 Venezuela 59–60, 65  
*Verbascum* **40**  
*Verzino* 8  
 Vietnam 92  
   natural dyes in 65–72  
   sources for natural colorants **66**  
 Vinegar 35  
 Violales 55  
 Violet dyes 70, 183, 192, **322**  
 Violuric acid (VIO) 304  
 Violxanthin 223, 232, 238  
 Vitaceae **143**, 145  
 Vitamins  
   antioxidant 141  
   vitamin A 226  
   vitamin B<sub>12</sub> 251  
   vitamin C 243  
   vitamin E 243  
*Vitis*  
   *vinifera* **143**, 213, **371**, **379**  
 Vitruvius 9, 30, 135  
 Vole, root 207  
  
 Wales 92  
 Walnut **156**, 162, 281, 296, 299  
   black **156**, 157, 296, 301  
   green shells 151, 157, 343  
   hybrid 296  
   leaves 343  
 Washing fastness 324

- Waste management  
 'cleaner production' processes 361  
 'zero emission' approach 361
- Water  
 consumption 359, **360**  
 in dyeing process 318  
 waste 361
- Wattle 213
- Waxes 285  
 in wood 279  
 for wood 284
- Webcap, blood-red 193–6
- Webworm, cabbage 92
- Weed control  
 in dye crops 41  
 in *Isatis* crops 84–5  
 in *Persicaria* (*Polygonum*)  
 crops 100
- Weld 15, **16**, 24, 32, 355, 357  
 component used 39  
 in Europe 39, **40**  
 cultivation of 46, 47, **48**  
 extraction 50
- Wengé, African 296
- Wet fastness 324, **325**
- Whortleberry 144
- Wine 212, **379**  
 aging 268  
 red 141
- Winkle, sting 22
- Woad 22–3, 29,  
 105, **322**  
 in ancient Egypt 29–31  
 balls 114–15, 122  
 Chinese 77, 105  
 component used 39  
 in Europe 39, **40**  
 cultivation of **42–3**, 44
- Wood  
 ammoniation of 298–301  
 impact on colour 299–301, 300  
 anatomical appearance  
 280–1, 280  
 bleaching of 301–2  
 impact on colour 301–2, 302  
 chemical composition of  
 279, 280  
 coatings for 283–5  
 coloration with natural dyes  
 277–313  
 colour of 279–82  
 description 282–3  
 modification 290–308, 293  
 stability 283  
 discoloration of 292  
 drying of 291–4  
 impact on colour 294, **294**  
 technology 292–3  
 dyeing of, with indigotin  
 and chlorophyll 289–90, 289, **290**  
 enzymatic treatment of 303–4  
 heartwood 281  
 physical properties of surface 282  
 products 290  
 radiation of 296, 305–8  
 impact on colour 305–7  
 technology 307–8  
 steaming of 295–6  
 impact on colour 295–6, 306–7  
 technology 295  
 thermal treatment of 297–8  
 impact on colour 297–8  
 technology 297  
 tree rings 280–1  
 veneers 290
- Woodruff  
 dyer's **159**, **379**  
 sweet **159**
- Wool 27, 162, **322**  
 fabric, and natural dyes 33  
 hair 340  
 yarn 378  
 hank dyeing of 332–3
- Woolen caps, dyed 332–3, 332
- World Health Organization (WHO) 252
- Xanthophylls 59, 221–3, 250–1  
 structure of 224
- Xanthopurpurin 166
- Xanthoria* **188**  
*parietina* **186**, 191
- Xerocomus* **187**
- Yarn, dyeing cones of 333
- Yarn dyeing machines 333
- Yellow dyes 67, 69–71, 184, 193, 196, 286,  
**322**, 325, **371**  
 ancient 15–17  
 in Egypt 30  
 aurone 17  
 carotenoid 17  
 chalcone 17  
 flavonoid 15–16  
 from grevillines 192

Yellow dyes (*Continued*)

from lichens 191–2

Ottoman 34

scale of use 24–5

Yellow pigments, flavonoid 268–9

Yellow wood 16

Yields

of *Indigofera* 102–3

of *Isatis* 86–90

of *Persicaria (Polygonum)* 94, 100

Yogurt 263

Zeatine 143

Zeaxanthin 223, **225**, 226–8, **229**

all-*trans*-zeaxanthin 59

Zingiberaceae 57, 70