

Contents

Chapter 1	Uses and Applications of Extracts from Natural Sources	1
<i>R. N. Cavalcanti, T. Forster-Carneiro, M. T. M. S. Gomes, M. A. Rostagno, J. M. Prado and M. A. A. Meireles</i>		
1.1	Introduction	1
1.2	Uses and Applications	3
1.2.1	Coloring Agents	4
1.2.2	Flavors and Fragrances: Essential Oils	19
1.2.3	Edible Fats and Oils	31
1.2.4	Functional Foods and Nutraceuticals	36
1.3	Conclusions	46
Acknowledgements		46
References		46
Chapter 2	Extraction of Natural Products: Principles and Fundamental Aspects	58
<i>M. Palma, G. F. Barbero, Z. Piñeiro, A. Liazid, C. G. Barroso, M. A. Rostagno, J. M. Prado and M. A. A. Meireles</i>		
2.1	Introduction	58
2.2	Principles and Fundamentals of Extraction	59
2.3	Exhaustive Versus Non-exhaustive Extraction Methods	66
2.4	Conventional Extraction Techniques	67
2.4.1	Soaking	67
2.4.2	Soxhlet	69
2.4.3	Distillation with Water and/or Steam	73

2.5	Main Extraction Variables	78
2.5.1	Preparation of the Solid	78
2.5.2	Solvent	79
2.5.3	Temperature	82
2.5.4	Time	82
2.5.5	Solvent to Feed Ratio	82
2.6	Case Study	83
2.7	Conclusions	85
	Acknowledgements	86
	References	86
Chapter 3	Ultrasound-assisted Extraction	89
	<i>Daniella Pingret, Anne-Sylvie Fabiano-Tixier and Farid Chemat</i>	
3.1	Introduction	89
3.2	Ultrasound-assisted Extraction	90
3.2.1	Ultrasound Principles	90
3.2.2	Instrumentation	93
3.2.3	Important Parameters	96
3.2.4	Ultrasound-assisted Extraction: Applications in Food	102
3.3	Examples of Solvent-free Ultrasound-assisted Extraction of Carotenoids	105
3.3.1	Carotenoids Uses and Conventional Extraction	105
3.3.2	Solvent-free Ultrasound-assisted Extraction of β -Carotene	106
3.3.3	Analysis and Evaluation of UAE Process	107
3.4	Costs and Investment in Industrial Ultrasound	108
3.5	Conclusion	108
	References	109
Chapter 4	Microwave-assisted Extraction	113
	<i>Emilie Destandau, Thomas Michel and Claire Elfakir</i>	
4.1	Introduction	113
4.2	Principles of Microwave-assisted Extraction	114
4.2.1	Microwave Heating Principle	114
4.2.2	Microwave Heating Applied to Plant Matrices	117
4.3	Microwave Instrumentation	118
4.3.1	Oven Design	119
4.3.2	Reactor Design	120

4.4	Parameter Influence on Microwave-assisted Extraction	121
4.4.1	Solvent	122
4.4.2	Temperature and Pressure	125
4.4.3	Extraction Time	126
4.4.4	Power	126
4.4.5	Nature of the Matrix	127
4.5	Trends in Microwave-assisted Extraction and Applications	128
4.5.1	Extraction of Sensitive Compounds	128
4.5.2	Extraction Methods Improved by Microwave Heating	130
4.5.3	Green Extraction without Solvent	135
4.6	Case Study	144
4.6.1	Optimization of the Pressurized Solvent-free Microwave Extraction (PSFME) Procedure	144
4.6.2	Influence of the Number of Cycles	145
4.6.3	Proposed Mechanism of PSFME	147
4.6.4	Comparison with other Extraction Methods	148
4.6.5	Advantages of PSFME	150
4.7	Conclusion	150
	List of Abbreviations	152
	References	152

Chapter 5 Accelerated Liquid Extraction 157

Feliciano Priego-Capote and María del Pilar Delgado de la Torre

5.1	Introduction	157
5.2	Static Accelerated Solvent Extraction (Static ASE)	158
5.2.1	Steps Involved in the Static ASE Process	158
5.2.2	Static ASE Commercial and Laboratory-designed Devices	161
5.3	Dynamic Accelerated Solvent Extraction (Dynamic ASE)	163
5.3.1	Steps Involved in the Dynamic ASE Process	163
5.3.2	Dynamic ASE Laboratory-designed Devices	164
5.4	Coupling ASE to Other Steps of the Analytical Process	165
5.5	Parameters Affecting Performance in ASE	167
5.5.1	Temperature	167
5.5.2	Pressure	169
5.5.3	Type of Solvent	169
5.5.4	Solvent to Feed Ratio	170
5.5.5	Sample Composition	171

5.5.6 Particle Size	171
5.5.7 Extraction Time	171
5.6 Comparison of ASE with other Extraction Techniques	172
5.7 Applications of ASE for the Isolation of Natural Products	176
5.7.1 Lipids	182
5.7.2 Volatile Compounds	183
5.7.3 Polar Compounds	184
5.8 Case Study	187
5.8.1 Optimisation of the Main Variables Involved in SHLE	187
5.8.2 Influence of Extraction pH	189
5.8.3 Comparison of SHLE with MAE and UAE for Extraction of Vine Shoots	189
5.9 Conclusions: Benefits and Limitations of ASE for Isolation of Natural Products	190
Acknowledgements	190
References	190

Chapter 6 Supercritical Fluid Extraction 196

Jose A. Mendiola, Miguel Herrero, María Castro-Puyana and Elena Ibáñez

6.1 Introduction	196
6.2 Fundamentals of Supercritical Fluid Extraction	197
6.2.1 Physical Properties of Supercritical Fluids	197
6.2.2 Supercritical Solvents	199
6.3 Instrumentation	201
6.4 Parameters Affecting the Extraction Process	203
6.4.1 Raw Material (Particle Size, Porosity, Location of the Solute, Moisture Content)	204
6.4.2 Solubility (Pressure and Temperature)	205
6.4.3 Use of Modifiers	208
6.4.4 Solvent Flow Rate (Solvent-to-Feed Ratio)	209
6.5 Applications	209
6.5.1 Plants	209
6.5.2 Marine Products	213
6.5.3 Agricultural and Food By-products	216
6.6 Case Study	220
6.6.1 Effect of Extraction Time	220
6.6.2 Effect of Pressure, Temperature and Modifier	221
6.6.3 Effect of Solvent	222
6.7 Future Trends and Conclusions	223
References	225

Chapter 7 Recent Trends and Perspectives for the Extraction of Natural Products	231
<i>M. E. M. Braga, I. J. Seabra, A. M. A. Dias and H. C. de Sousa</i>	
7.1 Introduction	231
7.2 Target Extracts/Compounds	236
7.3 Raw Materials	244
7.4 Extraction Methods	250
7.4.1 Microwave-assisted Extraction	253
7.4.2 Ultrasound-assisted Extraction	255
7.4.3 High-pressure Liquid Extraction	257
7.4.4 Supercritical Fluid Extraction	258
7.5 Extraction Solvents and Solvent Mixtures	261
7.5.1 Extraction Solvent Modification with Additives (Enzymes, H^+ / OH^- , Surfactants)	263
7.5.2 Solvent Mixtures and Non-conventional Highly Hydrophobic Organic Solvents	267
7.5.3 Ionic Liquids	268
7.5.4 Aqueous Biphasic Systems (ABS)	269
7.5.5 Tunable Solvents	271
7.6 Conclusions and Future Perspectives	274
References	275
Chapter 8 Post-extraction Processes: Improvement of Functional Characteristics of Extracts	285
<i>Ángel Martín, Soraya Rodríguez-Rojo, Alexander Navarrete, Esther de Paz, Joao Queiroz and María José Cocero</i>	
8.1 Introduction	285
8.2 Purification of Extracts and Elimination of Solvents	286
8.2.1 Evaporation of Solvents	287
8.2.2 Freeze-drying	287
8.2.3 Reverse Osmosis	287
8.3 Particle Size Reduction	289
8.3.1 Top-down Methods	290
8.3.2 Bottom-up Methods	291
8.4 Formulation	298
8.4.1 Solvent Evaporation Method	300
8.4.2 Spray-drying Technique	301
8.4.3 High-pressure Emulsion Techniques	301
8.4.4 Supercritical Fluid Processes	303
8.4.5 Overview	305

8.5 Case Study: Formulation of β -carotene as a Natural Colorant	305
8.5.1 Formulation of β -carotene by Precipitation from Pressurized Organic Solvent-on-water Emulsions	307
8.5.2 Formulation of β -carotene with Soybean Lecithin by PGSS-drying	309
8.5.3 Co-precipitation of β -carotene with Polyethylene Glycol by Supercritical Anti-solvent Process (SAS)	309
8.5.4 Formulation of β -carotene by Supercritical Extraction from an Emulsion (SEE)	310
8.6 Conclusions	311
References	311

Chapter 9 Isolation and Purification of Natural Products 314
Wang Xiao, Fang Lei, Zhao Hengqiang and Lin Xiaojing

9.1 Introduction	314
9.2 Pre-isolation or Enrichment	315
9.2.1 Solvent Partitioning	316
9.2.2 Adsorption Enrichment	318
9.2.3 Membrane Separation	318
9.2.4 Solid Phase Extraction (SPE)	321
9.3 Purification	323
9.3.1 Chromatographic Techniques	323
9.3.2 Crystallization	339
9.4 Case Studies	340
9.4.1 Isolation of Saponins from <i>Clematis chinensis</i>	340
9.4.2 Isolation of Tritoniopsins A-D from <i>Cladiella krempfi</i>	341
9.4.3 Isolation of <i>cis</i> -Clerodane-type Furanoditerpenoids from <i>Tinospora crispa</i>	341
9.4.4 Isolation of Flavonoids from <i>Paeonia suffruticosa</i>	344
9.4.5 Isolation of Alkaloids from <i>Stephania kwangsiensis</i>	347
9.4.6 Isolation of Psoralen and Isopsoralen from <i>Psoralea corylifolia</i>	348
9.4.7 Isolation of Six Isoflavones from <i>Semen sojae praeparatum</i> by Prep-HPLC	348

9.4.8	Isolation of Anthocyanins from Eggplant	352
9.4.9	Isolation and Purification of Flavonoid and Isoflavonoid from <i>Sophora japonica</i>	354
9.5	Conclusions	356
	References	357

Chapter 10 Scale-up of Extraction Processes **363**
Julian Martínez and Luiz Paulo Sales Silva

10.1	Introduction	363
10.2	Fundamental Aspects of Scale-up Operations	364
10.2.1	What is Scale-up?	364
10.2.2	Scale-up Criteria	366
10.3	Factors Involved	372
10.3.1	Solubility	373
10.3.2	Solvent Flow Rate	374
10.3.3	Substrate Properties	374
10.3.4	Extraction Bed Geometry	375
10.4	State of the Art	376
10.4.1	Models for Extraction Processes	376
10.4.2	Some Examples of Scale-up Criteria in Extraction Processes	380
10.4.3	Scale-up Correlations	387
10.4.4	Configurations of Industrial Units	388
10.4.5	Some Published Works on Scale-up of Extraction Processes	390
10.5	Case Study: Supercritical CO ₂ Extraction from Red Pepper	391
10.5.1	Experimental Procedures	391
10.5.2	Results and Discussion	393
10.6	Conclusion	396
	References	397

Chapter 11 Integration of Pressurized Fluid-based Technologies for Natural Product Processing **399**
Diego T. Santos, Maria T. M. S. Gomes, Renata Vardanega, Mauricio A. Rostagno and M. Angela A. Meireles

11.1	Introduction	399
11.2	Sequential Extraction using Different Process Conditions or Techniques	400
11.3	On-line Fractionation/Purification	404
11.3.1	On-line Separators: Fractionation by Changes in Temperature and Pressure	404

11.3.2	On-line Extraction and Adsorptive Purification Processes	406
11.3.3	On-line Coupling of Extraction and Membrane Processes for Purification	418
11.4	Integration of Pressurized Fluids to Different Technologies for Extract Stabilization	420
11.5	Case Study – Integrated Extraction and Encapsulation of Bixin from Annato Seeds	425
11.5.1	Materials and Methods	425
11.5.2	Results and Discussion	430
11.6	Conclusions	437
	Acknowledgements	438
	References	438
Chapter 12	Economic Evaluation of Natural Product Extraction Processes	442
	<i>Camila G. Pereira, Juliana M. Prado and M. Angela A. Meireles</i>	
12.1	Introduction	442
12.2	Cost Estimation of Industrial Processes	443
12.2.1	Costs Associated with the Raw Material	444
12.2.2	Costs Associated with the Operational Conditions	445
12.2.3	Costs Associated with the Industrial Requirements	445
12.3	Cost Estimation Procedures	446
12.3.1	Cost Estimate as a Function of Equipment Capacity	446
12.3.2	Lang Factor	448
12.3.3	Manufacturing Cost Estimation	448
12.4	Manufacturing Cost of Vegetable Extracts	450
12.4.1	Supercritical Extraction Process	450
12.4.2	Other Extraction Processes	464
12.5	Case Study	465
12.5.1	Introduction	465
12.5.2	Materials and Methods	465
12.5.3	Results and Discussion	466
12.6	Conclusion	469
	Acknowledgement	469
	References	469
Subject Index		472

Subject Index

References to figures are given in *italic* type. References to tables are given in **bold** type.

- ABE *see* agitated bed extraction
Abelmoschus moschatus, 25
ABS *see* aqueous biphasic systems
absorbed, distributed, metabolized and excreted (ADME), 237
accelerated liquid extraction, 157–90
accelerated solvent extraction (ASE), 157–8
applications for isolation of natural products, 176–7, 178–81, 182–7
lipids, 177, 181, 182–3
polar compounds, 177, 184–7
 antioxidants, 184–5
 essential oils, 184–6
 nutraceuticals and drugs, 184, 186–7
volatile compounds, 177, 183–4
benefits and limitations for isolation of natural products, 190
comparison with other extraction techniques, 172–6
coupling to other steps of the analytical process, 165–7, 166
dynamic accelerated solvent extraction (*see* dynamic accelerated solvent extraction)
integration of pressurized fluid-based technologies, 416
parameters affecting performance, 167–72
extraction time, 167, 171–2
particle size, 167, 171
pressure, 167, 169
sample composition, 167, 171
solvent-to-feed ratio, 170–1
solvent type, 167, 169–70
temperature, 167–9, 168
recent trends and perspectives, 257–8
acetic acid, 317
acetone, 80–1, 122, 169–70, 182, 255, 260, 262, 401
Class 3 solvents, 286
extracted with, 341, 430
acetonitrile, 80, 169–70, 268, 272, 326
acid/bases, 60, 261
acid salts, 263
acyclic lycopene, 6
ADA *see* American Dietetic Association
adlay seeds, 257
ADME *see* absorbed, distributed, metabolized and excreted
adsorption, 234
AEOE *see* aqueous enzymatic oil extraction
aerosol solvent extraction system (ASES), 295
agarwood, 26

- agitated bed extraction (ABE), 464, 464–5
aglycones, 13, 14
aglycone, 147–8, 356
Agrimonia eupatoria, 187
alcohols, 21, 23, 197, 272
 aromatic, 265
aldehydes, 21, 23
alfalfa, 6, 13
algae, 213, 216, 248–9, 256, 275
 green, 182
alginates, 264
alimentary oil, 271
alkaloids, 3, 21, 105, 212, 294, 317–18, 328, 332
 case study, isolation of, 347, 347–8
 recent trends and perspectives for the extraction of, 232, 239, 241, 244, 263–4, 266, 270–1, 275
alkyl carbonic acid, 258, 273
alkylresorcinols, 260
almond, 105, 256, 260
 oil, 256–7
aloin A, 130
alumina, 325
aluminum oxide, 325
Amaranthaceae plants, 17
Ambrosia artemisiifolia, 3
American Dietetic Association (ADA), 36
American ginseng, 187 (*see also* Asian ginseng; Brazilian ginseng; ginseng)
amides, 318
amidine, 274
amidocyanogen, 318
amino acids, 37, 186, 232, 239, 270
aminopropyl, 325
amplitude of wave, 97–8
amyris, 26
analgesics, 275
Andrews, Thomas, 197
anethole, 22, 23
Angelica, 183
Angelica sinensis, 187
Aniba rosaeodora, 26
anise, 25, 83, 84–5
 oil, 25
annatto, 6–8, 423
 seeds, 400, 425–37
Anthemis tinctoria, 3
antheraxanthin, 8
anthocyanidins, 13, 14
anthocyanins, 5, 6, 13–16, 37–8, 42, 173, 185
 case study, isolation of, 352, 353, 354
 chemical structure, 14
 recent trends and perspectives for the extraction of, 258–60, 263, 273
anthocyanins, 173
anthraquinones, 125, 256
anticarcinogenic agent, 425
antifungals, 244, 275
anti-inflammatories, 244, 275
antimicrobials, 244, 275, 465
antimutagenic agent, 425
antioxidant(s), 3, 103–4, 184–6, 244, 275, 425, 465
 compounds, 212, 216
 natural, 305
antiproliferatives, 244
Apiaceae, 26
apigenin, 175, 345
 -7-glucoside, 184
 turinoside, 175
apiole, 22
apocarotenic acid, 8
apocarotenoid, 7
apple peel, 185
Applied Separations, 391
apricot, 27, 105, 140, 256
aqueous biphasic systems (ABS), 269–71
aqueous enzymatic oil extraction (AEOE), 256
Arecaceae, 35
argon, 255
aristolochic acid, 187
aromas, 244 (*see also* fragrances)
aromatherapy, 20, 29

- aromatic salts, 265
Arthospyra platensis, 220, 273
 arthritis, 42
 ascorbic acid, 4, 14, 17, 128–30
ASE see accelerated solvent extraction
ASES see aerosol solvent extraction system
 Asian ginseng, 40 (*see also* American ginseng; Brazilian ginseng; ginseng)
 astaxanthin, 130, 182, 213, 216
 atherosclerosis, 20, 36, 39, 42
 azeotropic distillation, 136, 339
- babassu, 464
Bacillus cereus, 137
 bacteria, 248–9, 275
 barks
 essential oil sources, 26
 basic compounds, 263
Basidiomycota, 16
 basil, 27, 92, 93, 124, 137, 173
 beer, 259
 beets, 270
 red, 17
 sugar, 264
 benzene, 80, 286
 benzoic acid, 4
 benzopyran derivatives, 6
 benzyl acetate, 29
 berberine, 266
 acid, 187
 bergamot oil, 29–30
 betacyanins, 16, 17, 37
 betalains, 5, 5–6, 16–17, 37, 270
 betalamic acid, 16, 17
 betanidin, 16
Beta vulgaris, 17
 betaxanthins, 16, 17, 37
 betulin, 258
 birch, 26, 258
 bisabolene, 25
 α -bisabolol, 25
 bisdemethoxycurcumin, 18
Bixa orellana, 6, 423, 425–37
 bixin, 6–7, 400, 425–37, 430, 445
- blackcurrant, 16
 bleaching, 31
BMC see minimum bactericidal concentration
 borapetosides, 342, 345
 bornyl acetate, 31
 boswellic acid, 265
 brandy, 104
 Branson, 95
 Brazilian ginseng, 40, 423 (*see also* American ginseng; Asian ginseng; ginseng)
 Brazil wood, 3
Buchi, 163, 292
 buriti
 fruits, 35
 oil, 35, 463–4
 butane, 262, 286
 butter, 420
 butyldenephthalide, 187
- cabbage, red, 16
 cactus fruits, 17
 cade, 26
 caffeic acid, 42
 caffeine, 81, 205, 294
 Cagniard de la Tour, Charles, 197
Calamintha nepeta, 137
C. albifloris, 8
 β -calendic acid, 38
 calf brain, 182
 campestanol, 39
 camphene, 31
 camphor, 27
Cananga odorata, 30
 cancer, 3, 20, 42, 186
 chemoprevention, 216
Candida utilis, 17
 canola oil, 209
 canthaxanthin, 6, 216
 capillary supercritical fluid chromatography (cSFC), 339
 capsaicin, 8, 42, 104
 capsaicinoids, 8, 80
 capsaicinoids, 104
 capsanthin, 8

- Capsicum*, 80, 414
capsicuman, 264
Capsicum annuum, 8
Capsicum frutescens, 104
 case study, 391–6, 393–5
capsolutein, 8
capsorubin, 8
caraway seeds, 260
carbohydrates, 36–8, 65, 239–40, 275, 325
carbon-based compounds, 232
carbon bisulfide, 197
carbon dioxide, 199, 199–200, 202, 208, 222–3, 262, 271–3, 286, 293
carbon dioxide-expanded liquids (CXL), 220, 222, 224
carbon disulfide, 81
carbon disulphide, 169
carbonic acid, 258, 272–3
carbon nanotubes, 321
carbon powder, 138
carbon tetrachloride, 80
carbonyl iron powder, 254
carboxylic acids, 325
cardamom, 124, 127
cardiovascular disease, 3, 20, 186, 305
 prevention by soybeans, 45, 45
carnauba palm, 464
carnosic acid, 104, 123
carotenes, 6, 35, 37, 81, 123
 α -carotene, 6, 41
 β -carotene, 6, 8–10, 82, 130, 212, 216, 266, 303, 304
 case study: formulation as natural colorant, 305, 307–11, 309–10
 coloring agents, 9–10
 nutraceuticals, 41
 solvent-free ultrasound-assisted extraction, 106–8, 106–8
carotenoids, 3, 5, 5–11, 35, 37, 80–1, 182, 425, 463
 chemical structure, 7
 conventional extraction, 105–6
 natural colorants, 305
 nutraceuticals, 41–2
post-extraction processes, 303, 305
solvent-free ultrasound-assisted extraction, 105–8
supercritical fluid extraction, 205, 209, 212–13, 216–17, 223
ultrasound-assisted extraction, 89, 104
uses, 105–6
carrot, 6, 9–10, 105–6
 black, 16
carvacrol, 28, 260
carvone, 104
Caryophyllales, 16
caryophyllene, 25
 β -caryophyllene, 29
cascarilla, 26
cassia, 26
cataracts, 41–2, 305
(+)-catechin, 43, 82, 401
cavitation bubbles, 92, 92, 97–9, 101–2
cavity, 119
 monomode, 119, 119
 multimode, 119, 119
cayenne peppers, 80, 128
C. camphora, 27

- Chaenomeles sinensis*, 122, 127
 chalcones, 42
Chamaemelum nobile, 29
 chamomile, 3, 25, 29–30
 German, 29–30
 Roman, 29–30
 chavicol, 22, 23
Chemical Engineering Plant Cost Index (CEPCI), 446
 cherry, 16, 260
 Chinese herbal medicine, 182, 187, 341, 347–8
 Chinese herbs, 130, 254–5
Chlorella protothecoides, 270
Chlorella vulgaris, 216
 chlorinated solvents, 197
 chloroform, 80–1, 122, 317, 326, 401, 430
 chlorogenic acid (GCA), 266
 chlorophylls, 3, 5, 5–6, 11–13
 chemical structure, 11
 limitations of use as coloring agents, 12
 chlorophyllins, 12
 cholesterol, 20, 39, 294
 chromatographic techniques, vii, 66, 234, 323–39, 333–6, 338, 340
 chrysantenone, 137
 1,8-cineole, 27
 cinnamaldehyde, 22, 23, 26
 cinnamon, 26
 cinnamyl alcohol, 23
cis-clerodane-type furanoditerpenoids, 341–3, 344
 citral, 265
 citronella, 24
 citronellal, 186
 citronellol, 23–4, 24
 citrus
 oils, 24, 30
 peel, 6, 30, 140
Citrus sinensis, 124
Cladiella krempfi, 341, 343–4
Clematis chinensis, 340–1, 342–3
 cloud point concentration (CPC), 266
 clove, 20, 25, 29, 75, 260
 case study, 465–7, 466, 467, 468, 469
 clover, 187
C. lutens, 8
CMC *see* critical micellar concentrations
 cobalt, 232
 cocaine, 128
 cocoa
 beans, 32
 butter, 32, 267, 296
 seed, 420
 coffee, 81, 463 (*see also* green coffee beans)
COL *see* costs of operational labor
 cold expression, 30
 colorants, 104, 200, 244, 275
 inorganic, 4
 natural (*see* natural colorants)
 synthetic, 4 (*see also* synthetic dyes)
 coloring agents, 3–18 (*see also under* cosmetics; pharmaceutical)
 color production
 mechanism of, 4
 column liquid chromatography, 321
COM *see* cost of manufacturing
 compression phases, 91, 91–2
 coniferyl, 168
 constant extraction rate period (CER), 64, 65, 203, 445
 α -copaene, 186
 copaiba oil, 28
Copaifera, 28
Copernicia cerifera, 464
 coriander, 20
 oil, 20
Coriandrum sativum, 20
 corilagin, 255
 corn, 33, 267
 germ oil, 33–4
 cornmint, 24
 cosmetics
 accelerated liquid extraction, 163, 172, 174, 185

- applications of natural products, v, 12–13, 83, 357, 372
coloring agents, 3–4, 6, 9, 305, 425
flavors and fragrances, 19–20, 26, 28–30, 35–6
formulations, 298, 299, 300
extracts of natural products, 1, 2, 314, 356–7
recent trends and perspectives for extraction of natural products, 231–2, 234, 237, 241, 244, 250, 265, 275
ultrasound-assisted extraction, 90, 96, 103–5, 109
co-solvents, 208 (*see also* modifiers)
cost of manufacturing (COM), 444–5, 465–6, 466
cost of raw material (CRM), 444–5, 449
costs of operational labor (COL), 449
costs of utilities (CUT), 449
costs of waste treatment (CWT), 449
coumarins, 3, 123, 318, 332
counter-current chromatography (CCC), 315, 329–30
counter-current supercritical fluid extraction (CC-SFE), 201
CPC *see* centrifugal partition chromatography; cloud point concentration
cranberry, 16
(–)crebanine, 348
cress seed, 264
critical micellar concentrations (CMC), 265
CRM *see* cost of raw material
crocin, 8–9
Crocus sativus, 3, 8
crustaceans, 213
β-cryptoxanthin, 8, 41
crystallization, 234
from a solution, 291
cSFC *see* capillary supercritical fluid chromatography
C. speciosus, 266
Cuminum cyminum, 124, 138
cupuassu butter, 32
Curcuma longa, 17–18
curcumin, 18, 18, 173
purified, 18
curcuminoids, 5, 5–6, 17–18, 259, 265
Curie, Pierre, 198
CUT *see* costs of utilities
cuttlefish bag, 3
CWT *see* costs of waste treatment
CXL *see* carbon dioxide expanded liquids
cyanobacteria, 216, 220–3, 256
cyanopropyl silica, 182
Cymbopogon citratus, 186
Cymbopogon flexuosus, 265
cymyl compounds, 28
cyperene, 186
cyperone
α-cyperone, 186
β-cyperone, 186
Cyperus rotundus, 186
cystitis, 42
Dactylopius coccus, 2
Dactylopius coccus Costa, 5
DAG *see* diacyl glycerols
daidzein, 45
Daucus carota, 9
DC *see* diffusion-controlled period
DCR *see* diffusion-controlled rate period
demethoxycurcumin, 18
dextran, 269, 325
DHA *see* docosahexaenoic acid
diabetes, 3
diacyl glycerols (DAG), 104
dichloroethane
1,1-dichloroethane, 80, 286
1,2-dichloroethane, 80, 286
dichloromethane, 80–1, 169, 183, 186, 262, 326, 427–31
dietary supplements, 357
diethylamine, 212

- diethyl ether, 169
 differential scanning calorimetry (DSC), 429, 435
 diffusion
 scale-up of extraction processes, limited by, 384–7
 diffusion-controlled period (DC), 64, 65, 67, 445
 diffusion-controlled rate period (DCR), 203
 dihydrocapsaicin, 8, 104
 dillapiole, 22
 dimethylallyl pyrophosphate, 22
 dimethyl ether (DME), 224
 dimethyl sulfoxide (DMSO), 272, 286
 Dionex, 158, 162, 166
 dioscin, 265
 diosmetin, 175
 dioxane, 122
 1,4-dioxane, 169
 dipole rotation, 115, 115
 direct manufacturing cost (DMC), 448–50
 diseases
 prevention of, 3, 20
 diterpenoids, 341
 DMC *see* direct manufacturing cost
 DME *see* dimethyl ether
 DMSO *see* dimethyl sulfoxide
 docosahexaenoic acid (DHA), 213
 drugs, 1, 289
 natural products extracted by ASE, 184, 186–7
 DSC *see* differential scanning calorimetry
 dynamic accelerated solvent extraction (dynamic ASE), 160–1, 163–5 (*see also* accelerated solvent extraction)
 laboratory-designed devices, 161, 164–5
 steps in process, 160, 163–4
 dynamic ASE *see* dynamic accelerated solvent extraction
 dysmenorrhea, 344
 economic evaluation of natural product extraction processes, 80, 442–69
 case study, 465–7, 466, 467, 468, 469
 materials and methods, 465–6, 466
 results and discussion, 466–7, 467, 468, 469
 cost estimation of industrial processes, 443–4, 444
 costs associated with industrial requirements, 444, 445–6
 costs associated with operational conditions, 444, 445
 costs associated with raw material, 444, 444–5
 cost estimation
 procedures, 446–50
 cost estimate as a function of equipment capacity, 446–8
 Lang factor, 446, 448
 manufacturing cost
 estimation, 448–50
 direct manufacturing cost, 448–50
 fixed (indirect) manufacturing cost, 450, 458
 general expenses, 448, 450
 manufacturing cost of vegetable extracts, 450, 451–60, 461–5
 other extraction processes, 464, 464–5
 supercritical extraction process, 450, 451–2, 461, 462, 463–4
 edible fats, *see* fats, edible
 edible oils, *see* oils, edible
 effervescent atomization, 293
 eggplant, 352, 353, 354
 egg yolk, 182
 eicosadienoic acid, 38
 eicosapentaenoic acid (EPA), 213
Elaeis guineensis, 10, 35
 Elan Nanosystems, 290

- elderberry, 16, 258–9
elemicin, 22
ellagic acid, 42
Ellettaria cardamomum, 124
emitter, 93–4, 99–100
emodin, 130
encapsulation techniques, 421–3, 422,
 424, 432–5
enfleurage, 29
enocianina, 16
enocyanin, 16
enuresis, 348
enzymes, 261, 263
EPA *see* eicosapentaenoic acid;
 United States Environmental
 Protection Agency
($-$)-epicatechin, 43, 82, 401
 gallate, 82
($-$)-epigallocatechin, 82
 gallate, 82
Epimedium, 117, 118
ER *see* extract reservoir
Erigeron breviscapus, 124
erythrose-4-phosphate, 21
Escherichia coli, 137
essential oils, 19–31, 212, 217, 223,
 239–41, 244–5, 254, 275, 405
 natural products extracted by
 ASE, 184–6
 sources, 25–31
esters, 23, 76, 318
estradiol hormones, 43
estragole, 22, 23
ethane, 224, 271
ethanol, 68, 71, 80–1, 104, 122, 124,
 400–1, 416
 accelerated liquid extraction, 169,
 174, 182, 187
Class 3 solvents, 286
modifier, 208, 212–13, 216–17,
 221, 260, 420
recent trends and perspectives for
 extraction of natural
 products, 262–3, 267, 272–3
supercritical fluid extraction, 200,
 222–3
ether, 197
ethyl
 acetate, 80–1, 133, 217, 262,
 416
 isolation and purification of
 natural products, 317, 326,
 345
 post-extraction processes, 286,
 305, 307
ether, 81
 lactate, 81, 271
ethylene glycol, 265
Eucalyptus, 20
eucalyptus oil, 28
Eugenia caryophyllata, 29
Eugenia caryophyllus, 465
eugenol, 22, 23, 25–7, 465
Euterpe oleracea, 464
evaporation, 234
 of solvents, 287, 300–1
Evernia prunastri, 21
exhaustive extraction methods,
 66–7, 69
extraction bed geometry
 secondary scale-up criteria, 371–2,
 375–6
extraction of natural products,
 vi–vii, 46
 analytical, 59, 66, 85
 conventional techniques, 67–78,
 172
 soaking, 67–9, 85
 Soxhlet, 69–73, 70, 83, 85
 water and/or steam
 distillation, 73–8, 74,
 83–5, 85
exhaustive *vs.* non-exhaustive
 methods, 66–7
extraction efficiency, 67, 171,
 212
industrial production, 59,
 66, 85
isolation and purification of
 natural products (*see* isolation
 and purification of natural
 products)

- extraction of natural products
(continued)
- main variables, 78–82
 preparation of the solid, 78–9, 85
 solvent, 79–82, 85
 solvent to feed ratio, 82, 85
 temperature, 82, 85
 time, 82, 85
- preparative separations, 59–60, 85
- principles and
 fundamentals, 59–66
- recent trends and
 perspectives, 231–6, 274–5
- extraction methods, 250–61, 275
- extraction solvents and solvent mixtures, 261–75
 aqueous biphasic systems, 269–71
 extraction solvent modification with additives, 263–7
 ionic liquids, 268–9
 solvent mixtures and non-conventional highly hydrophobic organic solvents, 267
 tunable solvents, 271–4
- raw materials, 244–9
- target extracts/compounds, 236–7, **238**, 239–44
- semi-preparative separations, 59–60, 85
- extract reservoir (ER), 166
- Extrelut particles, 159
- falling extraction rate period (FER), 64, 65, 67, 203, 445
- farnesal, 25
- farnesol, 24, 25
- fats, 36
- fats, edible, 1, 31–6
 commercial applications, 32–6
 biodiesel feed stock, 36
 liquid oils, 33–6
 buriti oil, 35
 corn germ oil, 33–4
- grape seed oil, 34–5
 jojoba oil, 36
 olive husk oil, 34
 palm oil, 35
 rice bran oil, 35
 safflower oil, 33–4
 soybean oil, 33–4
 sunflower oil, 33
 wheat germ oil, 36
- shortening products, 32
- spread products, 32–3
 cocoa butter, 32
 cupuassu butter, 32
 margarine, 33
- processing, 31
- sources of, 31
- fatty acids, 31, 35, 71, 182, 186, 217, 232, 305
 free (FFA), 259
 ω -3 fatty acids, 38, 213
- FBE *see* fluidized-bed extraction
- FC *see* flash chromatography
- FDA *see* United States Food and Drug Administration
- fenchone, 23–4
- fennel, 24, 83, 84, 186
- FER *see* falling extraction rate period
- ferromagnetic materials, 197
- ferulic acid, 42, 187
- FFA *see* free fatty acids
- Fick's law, 64, 374
 second law, 68
- fish, 213, 248–9, 275
 oil, 420
- fixed (indirect) manufacturing cost (FMC), 448, 450
- flash-boiling atomization, 293
- flash chromatography (FC), 327
- flavones, 42–3, 123
- flavonoids, 3, 5, 13, 37, 42–3, 68, 80, 216, 401
- case studies
 isolation and purification of, 354, 354–6, 356
 isolation of, 344–6, 345

- isolation and purification of, 318, 320, 332
microwave-assisted extraction, 126–7, 140
recent trends and perspectives for extraction of, 256, 263, 266
flavonols, 42–3, 82, 173
flavors, 1, 3, 8, 19–31, 103–4, 200, 273, 357, 465
flaxseed, 105
oil, 256
Florisil, 159
flowers
 essential oil sources, 28–30
fluidized-bed extraction (FBE), 73
Fluid Management System (FMS), 163
FMAE *see* focused microwave-assisted extraction
FMASD *see* focused microwave-assisted steam distillation
FMASE *see* focused microwave-assisted Soxhlet extraction
FMC *see* fixed (indirect) manufacturing cost
FMS *see* Fluid Management System
focused microwave-assisted extraction (FMAE), 120
focused microwave-assisted Soxhlet extraction (FMASE), 71, 72, 130–2, 131
focused microwave-assisted steam distillation (FMASD), 77–8, 78
Foeniculum vulgare, 83, 186
Foeniculum vulgaris, 187
Folch extraction, 172
Folin–Ciocalteu test, 187
food (*see also* fruits and vegetables)
 additives, v, 112
 applications of natural products, v, viii, 6–9, 20, 83, 163
 agricultural and food by-products, 216–17, **218–19**, 220
 formulations, 298, **299**, 300
engineering, viii
extracts of natural products, 1, 2, 3–4, 163, 169, 236
functional, 1–3, 36–45
preservatives, 20, 184
processing, 89
recent trends and perspectives for extraction of natural products, 231, 241, 244, 250, 262, 264–5
science, viii
supplements, 3, 232, 237
formic acid, 352
formononetin, 126
Foundation for Innovation in Medicine, 186
fractionation/separation method, 259
fragrances, 1, 3, 19–31, 103–4, 163, 273 (*see also* aromas)
freeze-drying, 287, 288
frequency of wave, 97–9
friction
 secondary scale-up criteria, 370
fruits and vegetables, 103–4 (*see also* food)
fungi, 248–9, 256, 275
fungicides, 243–4, 465
galactomannans, 264
galactosidases, 263
galbanum, 23
gallic acid, 22, 42, 190, 266
(-)-gallocatechin gallate, 82
Ganoderma atrum, 124–6
Garcinia mangostana, 212
Gardenia jasminoides, 8
GAS *see* gas antisolvent
gas antisolvent (GAS), 224
gas chromatography (GC), 414
gas chromatography-mass spectrometry (GC-MS), 166
gas-expanded liquids (GXL), 222–4, 272–3
gas-liquid chromatography (GLC), 339
gas-to-product (GTP) ratio, 296
GBE *see* *Ginkgo biloba* extracts

- GC *see* gas chromatography
 GCA *see* chlorogenic acid
 GC-MS *see* gas chromatography-mass spectrometry
GCP *see* Good Clinical Practice
GE *see* general expenses
 gelucires, 270-1
 general expenses (GE), 448, 450
 generally recognized as safe (GRAS), 200, 208, 307, 449
 genistein, 45
 gensenoids, 170
 geraniin, 255
 geraniol, 23-4, 24, 186
 geranium, 24
Geranium sibiricum, 255
 germacrone, 25
 Gibbs free energy, 60
 ginger, 27, 245, 257
 gingerols, 27, 187
Ginkgo biloba extracts (GBE), 320
Ginkgo biloba, 263, 320, 401
 ginseng, 40-1 (*see also* American ginseng; Asian ginseng; Brazilian ginseng)
 ginsenosides, 40, 41, 187
 GIOTTI, 96
 glace fruits, 170
GLC *see* gas-liquid chromatography
GLP *see* Good Laboratory Practice
 glucose, 21, 60
 D-glucose, 42
 glucosidases, 263
 glucoside, 42
 esters, 267
 glucosinolates, 3
 glutaric acid, 289
 glycerol, 265, 271
 glyceryl esters, 31
 glycinein, 45
 glycosidases, 15
 glycosides, 28, 140, 317
Glycyrrhizae radix, 128
 glycyrrhizin, 187
 glycyrrhizic acid, 128
 G. Mariana and C. Spa (GMC), 96
GMC *see* G. Mariana and C. Spa
GMP *see* Good Manufacturing Practice
Good Clinical Practice (GCP), 234
Good Laboratory Practice (GLP), 234
Good Manufacturing Practice (GMP), 234, 262
 Goto model, 261
 grapefruit, 25, 30
 grape(s), 140, 185, 260
 canes, 68
 extracts, 16
 pomace, 174
 red, 173, 258
 seed oil, 34-5
 seeds, 259, 401, 461
 graphite, 131
 powder, 138
GRAS *see* generally recognized as safe
 grass, 22
 green algae, *see* algae: green
 green coffee beans, 205, 442 (*see also* coffee)
 green extraction, 128, 172
 without solvent, 135-40, 144
 green solvents, 224, 272-3
 green tea, 423 (*see also* tea)
 extracts, 297
 leaves, 257
GTP ratio *see* gas-to-product ratio
 guaiac, 26
 guar, 264
 guava, 128, 217, 254
 gums, 264
 gut flora, 38
GXL *see* gas-expanded liquids
Haematococcus pluvialis, 205
 hastelloid, 165
 hazelnut, 68, 217, 260
HBA *see* hydroxybenzoic acid
HCA *see* hydroxycinnamic acid

- heat transfer
secondary scale-up criteria, 367
- Helianthus annuus*, 33
- Hemerocallis disticha*, 212
- hemes, 5, 6
- hemicellulose, 263
- hemiterpenoids, 23, 24
- hemoglobin, 3
- heptane, 81
- herbs and spices, 104
- hexadecatrienoic acid, 38
- hexane, 70–1, 80–1, 105, 116, 167, 169, 262, 267, 274
Class 2 solvents, 286
n-hexane, 71, 132, 169, 175, 184, 267, 317, 326
- HF *see* hydrogen fluoride
- HHPE *see* high hydro-static pressure extraction
- Hielscher, 95
- high hydro-static pressure extraction (HHPE), 257
- high-performance liquid chromatography (HPLC), 325, 414, 416–17, 427
- high-pressure emulsion techniques, 301–3, 302, 307–8
- high-pressure homogenization, 290–1
- high-pressure liquid extraction, 257–8
- high-pressure solvent extraction (HPSE), 157
- high-speed counter-current chromatography (HSCCC), 329–30, 330, 332, 333–6, 337
- high-throughput screening (HTS), 237
- Hippophaë rhamnoides*, 114, 122, 144
- homocapsaicin, 104
- homodihydrocapsaicin, 104
- hop(s), 23, 258–9, 405
extracts, 29
- HPLC *see* high-performance liquid chromatography
- HPSE *see* high-pressure solvent extraction
- HSCCC *see* high-speed counter-current chromatography
- HTS *see* high-throughput screening
- humulene, 29
 α -humulene, 25, 29
- Humulus lupulus*, 405
- hydrocolloids, 264
- hydro-distillation, 74, 76, 253, 256
- hydrogen fluoride (HF), 320
- hydrosol, 74
- hydrotropes, 265
- hydroxybenzoic acid (HBA), 42
- hydroxy carboxylic acid, 42
- hydroxycinnamic acid (HCA), 37, 42, 43
- hydroxytyrosol, 184
- Hylocereus*, 17
- Hylocereus pyrhrizus*, 17
- hyoscyamine, 264
- IL *see* ionic liquids
- Illicium anisatum*, 137
- Illicium verum*, 25, 138
- ILMAE *see* ionic liquid microwave-assisted extraction
- imidazolium, 268
- Indigofera tinctoria*, 3
- indole, 29, 37
- industrial applications, vii–viii (*see also* scale-up of extraction processes)
- inflammation, 3
- Inonotus obliquus*, 133, 256
- insecticides, 465
- instantaneous controlled pressure-drop process, 259
- integration of pressurized fluid-based technologies, 399–438
case study: integrated extraction and encapsulation of bixin from annatto seeds, 425–37, 430
materials and methods, 425–30
extract and capsule characterization, 429–30

- integration of pressurized fluid-based technologies (*continued*)
- integrated system using PLE-SAS, 428, 428–9
 - off-line encapsulation by supercritical anti-solvent process, 426–8, 427
 - plant material, 425
 - pressurized liquid extraction, 425–6, 426
 - results and discussion, 430–7
 - dissolution profiles of capsules formed, 435–7, 437
 - DSC analysis, 435
 - encapsulation of PLE extracts by SAS, 432–5
 - influence of extraction solvent on PLE performance, 430, **430**
 - influence of temperature and static extraction time on PLE performance, 431, **431**
 - PLE kinetic extraction curve, 431–2, **431–2**
 - integration of pressurized fluids to different technologies for extract stabilization, 420–3, **422, 424**
 - on-line fractionation/purification, 404–6, **407–13**, 414–20
 - on-line coupling of extraction and membrane processes for purification, 418, 419, 420
 - on-line extraction and adsorptive purification processes, 406, **407–13**, 414–18
 - on-line separators: fractionation by changes in temperature and pressure, 404–6
 - sequential extraction using different process conditions or techniques, 400–1, **402–3**, 404
 - ionic conduction, 115
 - ionic liquid microwave-assisted extraction (ILMAE), 123
 - ionic liquids (IL), 123, 170, 224, 254
 - extraction solvents and solvent mixtures, 262, 268–9
 - β -ionone, 9
 - iron, 232
 - iron carbonyl powder, 124, 138
 - Isatis indigoitica*, 105
 - isoflavones, 38, 42–3, 65, 68, 186–7, 216, 256
 - case study, isolation of, 348, 351–2
 - isoflavonoids, 37, 45
 - case study: isolation and purification of, 354, 354–6, 356
 - isolation and purification of natural products, vii, 314–57, 316
 - case studies, 340–56
 - pre-isolation or enrichment, 315–22
 - adsorption enrichment, 318
 - membrane separation, 318–20, **321**
 - solid phase extraction, 321–2, **322, 322**
 - solvent partitioning, 316–18, **317**
 - purification, 323–39, **329, 333–6**, **338, 340**
 - chromatographic techniques, 323–39, **333–6**, **338, 340**
 - crystallization, 339, **340**
 - isomenthone, 137
 - isooctane, 81
 - isopentenyl pyrophosphate, 22–3
 - isoprene, 23, 24, 25
(2-methylbutadiene), 22
 - isoprenoid derivatives, 6
 - isopropanol, 71, 272
 - isopsoralen, 348, 351
 - isorhamnetin, 140, 146, 150
-3-*O*-glucoside, 147
-3-*O*-rutinoside, 147
-7-*O*-rhamnoside, 146, 150
 - isovaleric acid, 31

- jabuticaba, 258, **464**, 464–5
jambu, 246
jasmine, 28–9
Jatropha curcas, 256
jatropha seeds, 256
jatrorrhizine, 266
jojoba oil, 36
- kaempferol, 140, 217, 345
Kalamon fruit, 81
kaurenoic acid, 28
kavalactones, 182
kermes lice, 3
ketocarotenoids, 8
khusimol, 25
khusimone, 25
Klebsiella pneumoniae, 137
- labile compounds, 130
lactic acid
 L-lactic acid, 270
Lang factor, 446, 448
lanolin, 267
LAS *see* liquid anti-solvent
Lauraceae, 26
Lavandula stoechas, 75
Lavandula viridis, 75
lavender, 24–5, 29, 135
LCA *see* life-cycle analysis
LC-DAD *see* liquid chromatography coupled to diode array detection
LC-MD *see* liquid chromatography coupled to mass detection
LDL *see* low density lipoprotein leaching
 kinetics, 168, 170
 process, 167–71, 190
leaves
 essential oil sources, 27–8
lecithin, 294, 309
Leguminosae, 28
lemon, 30
lemongrass, 24, 186
lichens, 123
licorice, 128
life-cycle analysis (LCA), 223
- lignans, 3, 37, 42–3, 239
lignin, 168, 263, 272–3
lignocellulosic materials, 168, 189
ligustilide, 187
lime, 30
limonene, 23–4, 30, 104, 176, 186, 260, 271
 d-limonene, 71
limonin, 265
linalool, 27, 29–30
linalyl acetate, 29–30
linoleic acid, 36, 38
linolenic acid
 α -linolenic acid, 38
 γ -linolenic acid, 38, 222–3, 273
lipids, 21, 22, 65, 103, 213, 224, 317
 lipidic natural products extracted by ASE, 177, **181**, 182–3
 recent trends and perspectives for the extraction of, 239–41, 244, 260, 275
liposomes, 298
Lippia alba, 134
liquid anti-solvent (LAS), 291
liquid chromatography, vi, 167, 416
liquid chromatography coupled to diode array detection (LC-DAD), 167, 187
liquid chromatography coupled to mass detection (LC-MD), 167
liquid-liquid extraction (LLE), 66, 197, 234, 264, 321
LLE *see* liquid-liquid extraction
l-menthol, 24
longan fruit pericarp, 257
low density lipoprotein (LDL), 36, 39
low-pressure liquid column chromatography (LPLC), 323, 325–7
LPLC *see* low-pressure liquid column chromatography
lutein, 6, 41, 182, 212, 216, 270, 305
 esters, 257
luteolin, 175, 345
 -7-glucoside, 184
 glucoside, 175

- lycopene, 7, 10–11, 41–2, 133, 217, 256, 260, 305, 310
Lycopersicum esculentum, 10
- maceration, 29, 107, 107, 148, 149, 150, 172–3
- macroporous resins, 318, 319, 355
- macular degeneration, 42, 305
- MAE *see* microwave-assisted extraction
- MAG *see* monacyl glycerols
- magnetron tube, 119
- MAHD *see* microwave hydro-distillation
- maize, 33
- malagueta, 391
- malic acid
- L-malic acid, 270
- malto-oligosaccharides, 328
- MAM *see* microwave absorption medium
- mammalian cells, 248
- margarine, 33
- marigold, 257
- marine sources
- applications of SFE for extracts of natural products, 213, 214–15, 216
 - raw material for extracts of natural products, 248–9, 275
- MASD *see* microwave-accelerated steam distillation
- maslinic acid, 81
- massoia, 26
- Matricaria recutita*, 29, 187
- Mauritia flexuosa*, 35
- Medicago sativa*, 13
- medical devices
- applications of natural products, 3
- medicines
- applications of natural products (*see under* pharmaceutical)
- medium-pressure liquid column chromatography (MPLC), 325
- MEKC *see* micellar electrokinetic chromatography
- membrane separation, 234, 315, 318–20, 321, 418–20
- menstruation, irregular, 344
- Mentha arvensis*, 24
- Mentha crispa*, 124
- Mentha piperita*, 24, 138
- Mentha pulegium*, 140
- Mentha spicata*, 140
- menthol, 23
- mint, 138 (*see also* mint)
- menthone, 137
- metaphosphoric acid, 129
- methanol, 80–1, 104, 200, 326, 401
- accelerated liquid extraction, 167, 170, 174
 - Class 2 solvents, 286
 - microwave-assisted extraction, 122, 124
 - modifier, 208, 212, 216, 260
 - recent trends and perspectives for extraction of natural products, 262, 267–8, 273
- methoxy derivatives, 21
- methyl
- acetate, 262
 - chavicol, 22, 27
 - cinnamate, 22
 - ethyl ketone, 80
 - eugenols, 22
 - jasmonate, 21
 - tertiary butyl ether (MtBE), 337
 - zizanoate, 25
- methylene dioxy compounds, 21
- mevalonic acid, 22–3
- MHG *see* microwave hydro-diffusion and gravity
- micellar electrokinetic chromatography (MEKC), 266
- micelle-mediated separation (MMS), 265–6
- micelles, 265, 298, 299
- microalgae, 71, 205, 213, 216, 220, 248–9, 256, 266, 275
- microwave absorption medium (MAM), 137–8

- microwave-accelerated steam distillation (MASD), 134
microwave-assisted extraction (MAE), 75, 113–51, **121**
advantages of, 150–1
comparison with other extraction methods, 172, 174–5, 189–90
costs and limitations, 151
economic evaluation, 443
microwave heating applied to plant matrices, 117–18
microwave heating principle, 114–17, **116**
microwave instrumentation, 118–21
oven design, **119**, 119–20
reactor design, 120–1
closed systems, 120–1
open systems, 120
parameter influence on, 121–8, 151
extraction time, 121, 126, 128
microwave power, 121, 126–8
nature of matrix, 127–8
matrix moisture, 127
matrix size, 127–8
pressure, 125–6
solvent composition, 121–4, 128
solvent to feed ratio, 121, 124–5, 128
temperature, 121, 125–6, 128
recent trends and perspectives, 253–5
trends and applications, 128–40, **141–3**, 144
case study of pressurized solvent-free microwave extraction, 144–8, **145**, 149, 150
advantages of PSFME, 150
comparison with other extraction methods, 148, 149, 150
influence of the number of cycles, 145–7, **146**
proposed mechanism of PSFME, 147–8, **148**, 148
extraction methods improved by microwave heating, 130–5
focused microwave-assisted Soxhlet extraction, 130–2, **131**
microwave hydro-distillation, 133, 133–4
microwave steam distillation, 134–5, **135**
ultrasonic microwave-assisted extraction, 132, 132–3
extraction of sensitive compounds, 128–30
nitrogen-protected microwave-assisted extraction, 128–9
vacuum microwave-assisted extraction, 129, 129–30
green extraction without solvent, 135–40, 144
microwave hydro-diffusion and gravity, 139, 139–40, 144
solvent-free microwave extraction, 136, 136–8
vacuum microwave hydro-distillation, 138
microwave-assisted Soxhlet extraction, 255–6
microwave heating supercritical fluid extraction (MSFE), 260
microwave hydro-diffusion and gravity (MHG), 139, 139–40, 144, 254
microwave hydro-distillation (MWHD or MAHD), 133, 133–4
microwave-integrated Soxhlet (MIS), 131
microwave ovens for extraction, 119, 119–20
microwave(s), vii, 114–17
electromagnetic spectrum, 114, 114
power, 121, 126–8

- microwave steam diffusion (MSDf), 135
- microwave steam distillation (MSD), 134–5, 135
- milling, 290, 379
- minerals, 36, 186, 232
- minimum bactericidal concentration (BMC), 137
- mint, 24 (*see also* menthol: mint garden), 124
- MIS *see* microwave-integrated Soxhlet
M. laevigata, 266
- MMS *see* micelle-mediated separation modifiers, 208–9, 221–2 (*see also* co-solvents)
- molecular weight cut-off (MWCO), 418
- monacyl glycerols (MAG), 104
- Monarda fistulosa*, 24
- monoterpeneS, 23, 27, 37, 74, 137
- monoterpenoids, 23–4
- MPLC *see* medium-pressure liquid column chromatography
- MSD *see* microwave steam distillation
- MSDf *see* microwave steam diffusion
- MSFE *see* microwave heating supercritical fluid extraction
- MtBE *see* methyl tertiary butyl ether
- mulberry leaves, 267
- murex shellfish, 3
- MWCO *see* molecular weight cut-off
- MWHD *see* microwave hydro-distillation
- myrcene, 23, 29
- myricetin, 130, 140
- Myristicaceae, 25–6
- Myristica fragrans*, 20, 25
- myristicin, 22
- Myrtaceae, 29
- Myrtus communis*, 212
- Nannochloropsis oculata*, 216
- NanoCrystals, 290
- naphthalenes, 239
- natural colorants, 1, 3–4, 6–8, 270, 298
- natural product(s) applications, v, vii, 46 (*see also under* cosmetics; food; medical devices; medicines; pharmaceutical)
- definition, v
- extraction (*see* extraction of natural products)
- n*-butanol, 317, 337, 345
- neral, 186
- nerolidol, 25
- nettles, 13
- nicotine, 271
- Nigella sativa*, 183
- nitrogen, 255, 273
- nitrogen-based compounds, 232
- nitrogen-protected microwave-assisted extraction (NPMAE), 128–9
- nitrous oxide, 262, 286
- n*-octenyl succinate (OSA) starch, 307–8
- non-chromatographic techniques, vii
- non-exhaustive extraction methods, 66–7
- nootkatone, 25
- noridihydrocapsaicin, 104
- nor-patchoulenol, 25
- nor-tetrapatchoulol, 25
- NPMAE *see* nitrogen-protected microwave-assisted extraction
- nutmeg, 20, 25–6
- nutraceuticals, 1–3, 8, 36–45
- natural products extracted by ASE, 184, 186–7
- nutrition, viii
- Nyctasthes arbortristes*, 8
- OAHD *see* Ohmic-assisted hydro-distillation
- oakmoss, 21
- oak wood, 183
- Ocimum basilicum*, 124, 137, 173
- octacosanol, 36

- OEC *see* overall extraction curve
OEPO *see* organic solvent extraction and particle formation on-line
Ohmic-assisted hydro-distillation (OAHD), 76, 77
oil-in-water (O/W) emulsion, 300, 302, 304–5
oils, edible, 1, 3, 31–6
 commercial applications, 32–6
 biodiesel feed stock, 36
 liquid oils, 33–6
 buriti oil, 35
 corn germ oil, 33–4
 grape seed oil, 34–5
 jojoba oil, 36
 olive husk oil, 34
 palm oil, 35
 rice bran oil, 35
 safflower oil, 33–4
 soybean oil, 33–4
 sunflower oil, 33
 wheat germ oil, 36
shortening products, 32
spread products, 32–3
 cocoa butter, 32
 cupuassu butter, 32
 margarine, 33
processing, 31
sources of, 31
Olea europaea, 184
oleaginous seeds, 104–5, 256
oleanolic acid, 81, 122
oleic acid, 34, 71
oleoresin, 28, 246
oleuropein, 175, 184
oligoethylene glycol monoalkyl ether, 266
oligopeptides, 239
olive, 81
 leaves, 126, 171
 oil, 34, 132, 164, 184, 205
 pomace, 164, 171
 Tunisian leaves, 175
onion, 140, 255
Opuntia, 17
Opuntia ficus-indica cv. *Gialla*, 17
Opuntia ficus-indica cv. *Rossa*, 17
orange, 30
 peels, 124, 135, 138, 257, 271
Orbignya speciosa, 464
oregano, 27–8, 124, 137, 260
organic acids, 4, 37
organic solvent extraction and particle formation on-line (OEPO), 423, 438
organic solvents, 262, 267, 286, 400, 416
organosulfides, 37
Origanum onites, 20, 75
Origanum vulgare, 124, 137
Orthosiphon stamineus, 258
OSA *see* n-octenyl succinate starch
osteoporosis, 4, 186, 348
overall extraction curve (OEC), 203
O/W emulsion *see* oil-in-water emulsion
ox liver, 182
packed-column supercritical fluid chromatography (pSFC), 339
Paeonia suffruticosa, 344–6, 345–6
palm, 464
 leaves, 222
 oil, 6, 10, 35, 266
palmatine, 266
palmitic acid, 71, 132
Panax, 40
Panax ginseng, 40, 187
Panax quinquefolius, 40
paprika, 6, 8, 42, 122–3
 oleoresin, 8
particles from gas-saturated solutions (PGSS), 294, 296, 303, 305, 422
 drying process, 297, 297, 309
particle size distribution (PSD), 289
passiflora seed oil, 207
patchouli, 25
 alcohol, 25
 oil, 25
P. brasiliensis, 423
PC *see* principal components

- PCA *see* precipitation from a compressed anti-solvent; principal component analysis
- p*-cymene, 28, 71
- peach almond oil, 381, 385
- peanuts, 256
- pectin, 257, 263–4
- pectinases, 263
- PEG *see* polyethylene glycol
- Penicillium decumbens*, 263
- pepper, 27, 104, 123
- green, 128, 254
 - red, 8
 - case study, 391–6, **393–5**
 - sweet, 264
 - yellow, 128
- peppermint, 24, 138
- oil, 28
- peptides, 37, 325
- perfluoroalkoxy (PFA), 120
- perfumery
- extracts of natural products, 1, 2, 3
 - perfumes, 1, 19–20, 25–6, 28–30
- period of wave cycle, 97
- peroxidases, 15
- Pertusaria pseudocorallina*, 123
- pervaporation, 234
- pesticides, 243–4, 275
- petroleum, 420
- ether, 81, 123, 317, 341
- PFA *see* perfluoroalkoxy
- Pfaffia, 40
- Pfaffia glomerata*, 40
 - Pfaffia iresinoides*, 40
 - Pfaffia paniculata*, 40
- pfaffic acid, 41
- PGSS *see* particles from gas-saturated solutions
- pH, extraction, 189
- pharmaceutical
- applications of natural products, v, viii, 38, 80, 185, 318, 357, 372, 465
 - coloring agents, 4, 6, 8–9, 12, 305, 425
- flavors and fragrances, 19–20, 26–7
- formulations, 298, **299**, 300
- extracts of natural products, 1, 2, 34, 83, 169, 200, 234, 235
- isolation and purification of natural products, 314, 318, 356–7
- post-extraction processes, 286–9, 291, 295, 300
- recent trends and perspectives for extraction of natural products, 241, 244, 250, 262, 264–5, 275
- ultrasound-assisted extraction, 90, 96, 104–5, 109
- phenolases, 15
- phenolic acids, 3, 37–8, 42–3, 185
- phenolic compounds, 37, 42–3, 44, 81, 145, 216–17, 223
- accelerated liquid extraction, 171, 173, 184, 186, 189–90
- recent trends and perspectives for extraction of, 232, 241, 254–5, 257, 260
- phenolics, 37–8, 42–3, 45, 68, 80, 318, 332
- recent trends and perspectives for extraction of, 239–40, 244, 275
- phenolic terpenes, 20
- phenols, 21, 42, 184–5, 189, 268
- phenylalanine, 22, 42
- phenylpropane, 21, 27
- phenylpropanoids, 22, 23, 43
- pheophorbides, 12
- pheophytins, 11–12
- phosphatidylcholine, 37
- phosphoenolpyruvate, 21
- phospholipids, 182–3, 294, 298
- phosphorus, 232
- photosynthesis, 11, 21
- PHSE *see* pressurized hot solvent extraction
- phthalides, 187
- phytic acid, 43

- phytochemical(s), 3, 38, 43, 46, 58, 103
composition, viii
profile, 79
- phytoestrogens, 37, 43
- phytol, 11–12
- phytostanols, 39
- phytosterols, 3, 37, 39, 43
- pH-zone-refining counter-current chromatography, 332, 337, **338**
- picrocrocin, 8–9
- Pimpinella anisum*, 25, 83
- pinene
α-pinene, 30–1, 71
β-pinene, 30–1
- pinolenic acid, 37–8
- Pinus densiflora*, 257
- Pinus pinaster*, 258–9
- Piperaceae, 26
- piperine, 123, 265
- piperitone, 137
- Piper nigrum*, 123
- β-pirene, 176
- pistachio, 258
- plankton, 248
- plants
applications of SFE for extracts of natural products, 209, **210–11**, 212–13
raw material for extracts of natural products, 245–8, 275
- PLE *see* pressurized liquid extraction
- plums, 140
- PMAE *see* pressurized microwave-assisted extraction
- podocarpic acid, 38
- polar compounds, 373, 400
natural products extracted by ASE, 177, 184–7
- polyacrylamide, 325
- Polyethylene glycol (PEG), 123, 269, 271–2, 291, 296, 309–10, 427–8
- polyglycolized glycerides, 270–1
- polyketides, 21, 239
- polylactic acid, 300
- polylactic-*co*-glycolic acid, 300
- polyphenoloxidase (PPO), 17
- polyphenols, 3, 42–3, 81, 212, 216–17, 267, 401, 420
- polypropylene glycol (PPG), 271
- polypyrrroles, 239
- polysaccharides, 133, 256, 264–5, 325
- polystyrene, 318, 325
- polytetrafluoroethylene, 131
- polyunsaturated fatty acids (PUFA), 37–8, 213
ω-3, 213, 223
- polyvinylidene fluoride (PVDF), 320
- polyvinyl pyrrolidone (PVP), 320
- pomegranate, 208
- post-extraction processes, 285–311
case study: formulation of β-carotene as natural colorant, 305, 307–11, 309–10
- formulations, 298–305, **299, 306**
high-pressure emulsion techniques, 301–3, 302
- solvent evaporation method, 300–1
- spray-drying technique, 301
- supercritical fluid processes, 303–5
- particle size reduction, 289–97, **306**
- bottom-up methods, 291–7
crystallization from a solution, 291
- drying processes with enhanced atomization, 293
- micronization processes with supercritical fluids, 293–7
- spray-drying, 291–2, 292
- top-down methods, 290–1
high-pressure homogenization, 290–1
- milling, 290
- purification of extracts and elimination of solvents, 286–8
evaporation of solvents, 287
freeze-drying, 287, 288
reverse osmosis, 287–8, 288

- potassium, 232
 potato, purple sweet, 16
P. paulensis, 423
 PPG *see* polypropylene glycol
 PPO *see* polyphenoloxidase
 precipitation from a compressed anti-solvent (PCA), 295
 preferential pathways, 375
 prenylflavonoids, 258
 preparation of solid
 main variable in extraction, 78–9, 85
 preparative high-performance liquid chromatography (prep-HPLC), 315, 323, 327–9, 329, 348, 351–2
 prep-HPLC *see* preparative high-performance liquid chromatography
 pressing, 148, 149, 150
 pressure
 parameter affecting performance in ASE, 167, 169
 parameter affecting solubility in SFE, 205–8
 parameter effect in SFE case study, 222–2
 parameter influence on MAE, 125–6
 primary scale-up criteria, 367
 pressurized hot solvent extraction (PHSE), 157
 pressurized liquid extraction (PLE), 75, 148, 149, 157, 177, 223, 373
 economic evaluation, 443, 464, 464–5
 integration of pressurized fluid-based technologies, 416–17, 425–6, 428–33, 437–8
 recent trends and perspectives, 253, 257–8, 266
 pressurized liquids, vii
 pressurized microwave-assisted extraction (PMAE), 120
 pressurized solvent extraction (PSE), 416
 pressurized solvent-free microwave extraction (PSFME), 144–8, 145, 149, 150
 principal component analysis (PCA), 207–8
 principal components (PC), 207
 proanthocyanidins, 82, 167
 procyanidin, 43, 258, 401
 propagation velocity, 98
 propane, 262, 272, 286
 propanol
 1-propanol, 80
 2-propanol, 80, 169
 propyl acetate, 80, 262
 propylene glycol, 265
 prostaglandins, 21
 protease inhibitors, 43
 protein-based compounds, 232
 protein inhibitors, 37
 protein-polyphenol complexes, 65
 proteins, 37, 65, 186, 245, 263
 PSD *see* particle size distribution
 PSE *see* pressurized solvent extraction
 pSFC *see* packed-column supercritical fluid chromatography
 PSFME *see* pressurized solvent-free microwave extraction
Psidium guajava, 123
Psoralea corylitolia, 348, 352
 psoralen, 348, 351
 PUFA *see* polyunsaturated fatty acids
 purification and isolation of natural products *see* isolation and purification of natural products
 purity, vi, 59–60
 PVDF *see* polyvinylidene fluoride
 PVP *see* polyvinyl pyrrolidone
 pyridine, 286
 Queen Elisabeth of Hungary, 19
 quercetin, 130, 140, 146, 150, 266
 quercitrin, 266
 quinones, 239
 quintessential oil, 19

- radish, 16
Radix astragali, 126
Radix glycyrrhizae, 187
ragweed, 3
Raoult's law equation, 373
rape seeds, 105
rapid expansion of supercritical solution into aqueous solution (RESSAS), 295
rapid expansion of supercritical solutions (RESS), 293–5, 294, 422
rarefaction phases, 91, 91, 98
raspberry, 16
refractive index (RI), 328
resins
 essential oil sources, 28
response surface methodology (RSM), 207, 220
RESS see rapid expansion of supercritical solutions
RESSAS see rapid expansion of supercritical solution into aqueous solution
RESS non-solvent (RESS-NS), 295
RESS-NS see RESS non-solvent
resveratrol, 68, 130, 217
REUS, 95, 106
reverse osmosis, 287–8, 288
reversible ionic liquids (RevIL), 273
RevIL see reversible ionic liquids
rhizomes, 17–18
 essential oil sources, 27
rhubarb, 256
RI see refractive index
rice bran, 105
 oil, 35
roots
 essential oil sources, 31
rose, 24, 28
 hips, 82
rosemary, 19, 25, 27–8, 104, 174, 185, 267, 423
 leaves, 140, 296
rosewood, 26
rosmarinic acid, 104, 123
Rosmarinus officinalis, 28, 123, 137, 185, 187, 423
RSM see response surface methodology
rumenic acid, 38
rutin, 266
Saccocalyx satureioides, 75
saffloomin A, 130
safflower
 oil, 33–4
saffron, 6, 8–9
 flower, 3
safranal, 8–9
safrole, 23
sage, 173, 267
 garden, 138
Saint John's wort, 166
Salvia officinalis, 138, 173
Salvia triloba, 266
sandalwood, 26
Santalum, 26
saponins, 37, 40, 43, 124–6, 182, 208, 318
 case study, isolation of, 340–1, 342–3
SAS see supercritical anti solvent process
scale-up of extraction processes, 363–97
 case study: supercritical CO₂ extraction from red pepper, 391–6, 393–5
 experimental procedures, 391–3
 extractions, 391–2, 393
 materials, 391
 mathematical model, 392–3
 results and discussion, 393–6, 394–5
factors involved, 372–6
 extraction bed geometry, 375–6
 solubility, 373–4
 solvent flow rate, 374
 substrate properties, 374–5

- scale-up of extraction processes
(continued)
 fundamental aspects of scale-up operations, 354–72
 definition of scale-up, 364–5
 in extraction processes, 365–6
 scale-up criteria, 366, 366–72
 primary, 367
 secondary, 367–72
 state of the art, 376–91
 configurations of industrial units, 388–90
 operation modes, 388–9, 389
 working principles, 389–90, 390
 examples of scale-up criteria in extraction processes, 380–7
 processes limited by diffusion, 384–7
 processes limited by solubility, 381–4
 models of the extraction process, 376–80
 empirical models, 377
 models with theoretical basis, 377–80
 scale-up correlations, 387–8, 388
 some published works, 390–1, 391
 scanning electron micrograph (SEM), 134
 SC-CO₂ *see* supercritical carbon dioxide
 SCD *see* simplex centroid design
 SCF *see* supercritical fluids
Schefflera heptaphylla, 134
Schisandra chinensis, 123
Schizochytrium limacinum, 216
 scopolamine, 264
 scutellarin, 124
 SD *see* steam distillation
 SDf *see* steam diffusion
 SDS *see* sodium dodecyl sulfate
 sea buckthorn, 114, 140
 berries, 144–8, 147, 148, 150
 sea urchin, 213
 seaweed, 263
 brown, 13
 sedimentation, 234
 SEDS *see* supercritical enhanced dispersion of solutions
 SEE *see* supercritical extraction of emulsions
 seeds
 essential oil sources, 25–6
 β-selinene, 186
 SEM *see* scanning electron micrograph
Semen sojae praeparatum, 348, 351–2, 353
 Sephadex, 325, 341, 343
 sepiolite, 205
 sesquiterpenes, 25, 74, 137
 sesquiterpenoids, 23, 24, 25
 S/F *see* solvent-to-feed ratio
 SFC *see* supercritical fluid chromatography
 SFE *see* supercritical fluid extraction
 SFEE *see* supercritical fluid extraction of emulsions
 SFME *see* solvent-free microwave extraction
 shikimates, 21
 shikimic acid derivatives, 21–2
 SHLE *see* superheated liquid extraction
 shrimp, pink, 423
 SI *see* supercritical impregnation
 silica, 164
 gel, 325, 341
 silicic acid, 182
 simplex centroid design (SCD), 207
 sitostanol, 39
S. japonica, 264
 SLE *see* solid–liquid extraction
Smilax china, 123
 soaking, 67–9, 85
 soap industry, 292
 sodium
 chloride, 271
 citrate, 266

- dodecyl sulfate (SDS), 266
phosphate, 271
sulfate, 159
solerone, 183
solid–liquid extraction (SLE), 172–3, 184, 190, 197, 254, 257
solid phase extraction (SPE), 166–7, 321–2, 322, 322, 406, 416–17
solid-phase microwave extraction (SPME), 173
solubility, 3, 60, 233, 260, 289
determined by pressure and temperature in SFE, 205–8
factor involved in scale-up of extraction processes, 373–4, 381–4
solvent
extraction solvents and solvent mixtures, 261–75
extraction solvent modification with additives, 263–7
solvent mixtures and non-conventional highly hydrophobic organic solvents, 267
tunable solvents, 271–4
main variable in extraction, 79–82, 85
parameter effect in SFE case study, 222–3
supercritical, used in SFE, 199–200, 200
solvent composition
parameter influence on MAE, 121–4, 128
solvent distribution
secondary scale-up criteria, 368, 368–9
solvent evaporation method, 300–1
solvent extraction method, 29
solvent flow rate, 209
secondary scale-up criteria, 370–1, 374
solvent-free microwave extraction (SFME), 123–4, 136, 136–8
solvent recycling, 390
solvent-to-feed ratio (S/F), 245
main variable in extraction, 82, 85
parameter affecting performance in ASE, 170–1
parameter affecting solvent flow rate in SFE, 209
parameter influence on MAE, 121, 124–5, 128
solvent toxicity, 286
solvent type
medium parameter in UAE, 101
parameter affecting performance in ASE, 167, 169–70
solvent velocity
primary scale-up criteria, 367
sonochemistry, 90, 98
sonotrode, 94
Sophora japonica, 354, 354–6, 356
sorbent-based extraction, 66
sorptive extraction, 253, 275
Sovová model, 261, 379, 392
Soxhlet extraction, 66, 69–73, 70, 83, 85, 172–3, 253, 256, 464–5
soybeans, 43, 68, 105, 182, 186, 222, 254, 268
germ, 256
lecithin, 309
oil, 33–4, 273–4
Spatholobus suberectus, 256
SPE *see* solid phase extraction
spearmint, 256
spectroscopic techniques, 66
sphingolipids, 37
spilanthol, 246
Spirulina, 220–3, 273
SPME *see* solid-phase microwave extraction
sponges, 248
spray-drying, 291–2, 292, 301
SSE *see* subcritical solvent extraction
SSI *see* supercritical solvent impregnation
stabilization techniques, vii, 420–3
stanols, 39
Staphylococcus aureus, 137
star anise, 25

- starch, 245
 static-accelerated solvent extraction
 (static ASE), 158–63, 160 (*see also*
 accelerated solvent extraction)
 commercial and laboratory-
 designed devices, 161–2, 161–3
 steps in process, 158–9, 160, 161
 static ASE *see* static-accelerated
 solvent extraction
 steam diffusion (SDf), 135
 steam distillation (SD), 20, 25–30,
 73–8, 74–7, 135, 173, 185, 443
 case study, 83–5, 85
 direct, 74
 dry, 74
 stearidonic acid, 38
Stephania kwangsiensis, 347, 347–8,
 349, 351
 (–)-stephanine, 348
 steroids, 239, 275, 341
 sterols, 39, 105, 182–4
 stilbenes, 3, 42–3
 stirring inside the extractor
 secondary scale-up criteria, 368
 subcritical solvent extraction
 (SSE), 157
 succinic acid, 270
 sugars, 3, 13, 15, 232
 sulfides, 3
 sulfones, 274
 sulfur, 232
 sunflower, 33
 oil, 33, 106–7, 267
 seeds, 105
 supercritical anti solvent process
 (SAS), 294–5, 303–4, 309–10
 integration of pressurized fluid-
 based technologies, 422–3, 424,
 425–9, 432–5, 438
 supercritical carbon dioxide (SC-
 CO₂), 200, 212, 224, 258, 293, 400,
 420
 case study, extraction from red
 pepper, 391–6, 393–5
 supercritical enhanced dispersion of
 solutions (SEDS), 295
 supercritical extraction of emulsions
 (SEE), 303–4, 310–11
 supercritical fluid chromatography
 (SFC), 315, 337, 339, 414
 supercritical fluid extraction
 (SFE), 29, 75, 165, 172, 176–7,
 196–224, 373
 applications, 209, 210–11, 212–13,
 214–15, 216–17, 218–19, 220
 agricultural and food by-
 products, 216–17, 218–19,
 220
 marine products, 213, 214–15,
 216
 plants, 209, 210–11, 212–13
 case study, 220–3, 391–6
 effect of extraction time, 220
 effect of pressure, temperature
 and modifier, 221–2
 effect of solvent, 222–3
 economic evaluation, 442, 450,
 451–60, 461, 462, 463–7, 468,
 469
 fundamentals of, 197–200
 physical properties of
 supercritical fluids, 197–9,
 198, 198
 supercritical solvents, 199–200,
 200
 instrumentation, 201, 201–3
 integration of pressurized fluid-
 based technologies, 404–6, 414,
 416–17
 parameters affecting the extraction
 process, 203–9
 raw material (particle size,
 porosity, location of the
 solute, moisture
 content), 204–5
 solubility (pressure and
 temperature), 205–8
 solvent flow rate (solvent-to-
 feed ratio), 209
 use of modifiers, 208–9
 recent trends and
 perspectives, 258–61

- supercritical fluid extraction of emulsions (SFE), 422, 438
supercritical fluids (SCF), vii, 60, 197, 258
micronization processes, 293–7
physical properties of, 197–9, 198, 198
processes in formulations, 303–5
supercritical impregnation (SI), 303, 303–4
supercritical solvent impregnation (SSI), 422
supercritical water extraction (SWE), 75
superheated liquid extraction (SHLE), 158, 176, 183, 185
case study, 187–90, 188, 189
comparison of SHLE with MAE and UAE, 189–90
influence of extraction pH, 189
optimisation of main variables, 187–8, 188
surfactants, 261, 265–7
SWE *see* supercritical water extraction
sweet potato, purple, *see* potato, purple sweet
synthetic dyes (*see also* coloring agents)
advantages, 4
safety concerns, 4–5
syringaldehyde, 185, 273
syringol, 273
syringyl, 168
Syzygium aromaticum, 20
- TAG *see* triacyl glycerols
tannins, 3, 42–3, 185, 239, 241, 244, 267, 275, 325
tara seed, 258
t-butyl amidine, 274
tea, 79, 81–2, 254, 463 (*see also* green tea)
Earl Grey, 29
- temperature
main variable in extraction, 61, 82, 85
medium parameter in UAE, 101, 107
parameter affecting performance in ASE, 167–9, 168
parameter affecting solubility in SFE, 205–8
parameter effect in SFE case study, 221–2
parameter influence on MAE, 121, 125–6, 128
primary scale-up criteria, 367
terpenes, 3, 21, 24, 25, 29, 37, 71, 74–5, 267
terpenoids, 21–5, 38, 182–4, 232, 245, 317, 320, 341, 401
 γ -terpinene, 30
tetrahydrofuran (THF), 122, 272
tetrapyrrole derivatives, 6
textiles
extracts of natural products, 1, 2, 3
Thar Technologies, 392
theophylline, 294
thermodynamics, 64, 233, 250, 260, 364
THF *see* tetrahydrofuran
thin-layer chromatography (TLC), 414
thioesters, 23
thrombosis, 20
Thymbra spicata, 186
thyme, 75, 124, 134, 173, 260, 267
oils, 28
thymol, 28, 260
Thymus vulgaris, 124, 134, 173
time
effect in SFE case study, 220
main variable in extraction, 82, 85, 107
parameter affecting performance in ASE, 167, 171–2
parameter influence on MAE, 121, 126, 128
Tinospora crispa, 341–3, 344–5

- TLC *see* thin-layer chromatography
 tobacco, 184
 tocopherols, 35–7, 39–40, 40, 217
 α -tocopherol, 39–40, 130, 220, 266
 δ -tocopherol, 130
 tocotrienols, 39–40
 toluene, 80
 tomato, 6, 10, 133, 217, 260
 paste, 133, 256
 total phenolic content (TPC), 145
 toxicity, 80, 261, 302
 TPC *see* total phenolic content
 treemoss, 21
 triacyl glycerols (TAG), 105, 213
 1,1,1-trichloroethane, 80
Trifolium, 187
 triglycerides, 20, 31
 triterpenic acids, 81, 122
 triticale bran, 260
 tritoniopsins A-D, 341, 344
 turmeric, 18, 173, 245–6, 259, 270
 oleoresin, 18
 powder, 18
 turmerone, 259
 tyrosine, 22, 42
 tyrosol esters, 37
- UAE *see* ultrasound-assisted extraction
 UASE *see* ultrasound-assisted Soxhlet extraction
 UASFE *see* ultrasound-assisted supercritical fluid extraction
 ultra-high-pressure extraction (UPE), 257
 ultrasonic bath systems, 94, 94, 96
 ultrasonic extraction reactor, 93–4, 99–100, 106
 ultrasonic intensity, 97, 99
 ultrasonic microwave-assisted extraction (UMAE), 132, 132–3, 255
 ultrasonic probe systems, 94–5, 95–6, 99, 100
 ultrasound, vii, 90–3
 diagnostic (high frequency), 90
 power (low frequency), 90, 97–9, 107
- ultrasound-assisted extraction (UAE), 89–109
 applications in food, 102–5, 103
 fruits and vegetables, 103–4
 herbs and spices, 104
 oleaginous seeds, 104–5
 comparison with other extraction methods, 172, 175–6, 189–90
 costs and investment in industrial ultrasound, 108–9
 economic evaluation, 443, 464, 464–5
 instrumentation, 93–6
 industrial scale, 95–6, 109
 laboratory scale, 94–5, 109
 matrix parameters, 102
 medium parameters, 100–2
 presence of dissolved gases, 101–2
 solvent type, 101
 temperature, 101, 107
 physical parameters, 96–100, 97
 amplitude, 97–8
 frequency, 97–9
 period of wave cycle, 97
 propagation velocity, 98
 shape and size of ultrasonic reactors, 99–100, 100
 ultrasonic intensity, 97, 99
 ultrasound power, 97–9, 107
 wavelength, 97
 recent trends and perspectives, 255–7
 ultrasound principles, 90–3
 ultrasound-assisted Soxhlet extraction (UASE), 71–3, 72
 ultrasound-assisted supercritical fluid extraction (UASFE), 256–7, 260
 ultrasound transducer, 93, 106
 piezoelectric, 93
 ultraviolet/visible (UV-vis), 328
 UMAE *see* ultrasonic microwave-assisted extraction

- United States Environmental Protection Agency (EPA), 69, 176
- United States Food and Drug Administration (FDA), 80, 286
- UPE *see* ultra-high-pressure extraction
- ursolic acid, 122
- Urtica dioica*, 13
- UV-spectrophotometer, 107
- UV-vis *see* ultraviolet-visible
- UV/vis spectrophotometry, 429
- vacuum liquid chromatography (VLC), 327
- vacuum microwave-assisted extraction (VMAE), 129, 129–30, 254
- vacuum microwave hydro-diffusion and gravity (VMHG), 140, 255
- vacuum microwave hydro-distillation (VMHD), 138
- valerian, 207
- Valeriana officinalis*, 207
- valerian oil, 31
- vanilla, 183
- vanillin, 22, 23, 185, 273
- vanillylamides, 42
- vapor pressure, 60
- vegetable extracts
- manufacturing cost, 450, **451–60**, 461, 463–4
 - oil, 70, 133
 - modifier, 209, 217, 260
- velocity effects
- secondary scale-up criteria, 369–70
- verbascoside, 184
- Verbascum phlomoides*, 8
- vetiver, 25
- vetivone
- α -vetivone, 25
 - β -vetivone, 25
- Vian, Abert, 254
- Vibracell, 95
- vine shoots, 187–90, **188**, 189
- violaxanthin, 6, 8
- viscosity, 80, 268, 296, 364
- vitamin(s), 36, 287
- A, 105, 305
 - C, 130, 254
 - E, 37, 39–40, 182, 220–2, 254
 - liposoluble, 182
 - supplements, 1
- Vitis vinifera*, 16, 185
- VLC *see* vacuum liquid chromatography
- VMAE *see* vacuum microwave-assisted extraction
- VMHD *see* vacuum microwave hydro-distillation
- VMHG *see* vacuum microwave hydro-diffusion and gravity
- volatile compounds
- natural products extracted by ASE, 177, 183–4
- von Soxhlet, Franz, 69
- vulgaxanthine I and II, 16
- walnut-tree leaves, 175
- water, 80–1, 255, 262–3, 268, 272, 326, 416
- accelerated liquid extraction, 167, 169–70, 173–4
 - modifier, 208, 212
 - supercritical fluid extraction, 197, 200, 224
- water distillation, 30, 73–8, 85
- water extraction and particle formation on-line (WEPO), 423
- water-in-oil-in-water (W/O/W) emulsion, 300
- wave guide, 119
- wavelength, 97
- waxes, 405
- WEPO *see* water extraction and particle formation on-line
- wheat germ oil, 36
- wine, 104

- winery industry, 163, 184
wood(s), 171
 essential oil sources, 26–7
W/O/W emulsion *see* water-in-oil-in-water emulsion
- xanthan, 264
xanthophylls, 6, 37, 81
Xylopia aromatic, 134
xylosidades, 263
- yerba mate, 43
Ylang-Ylang essential oil, 30
- Zanthoxylum bungeanum*, 124, 138
zeacarotene, 10
zeaxanthin, 8, 212, 216, 305
Zingiberaceae, 17
Zingiber officinale, 138, 187
zizanal, 25
Ziziphus jujube, 182