

Plant Biotechnology: the genetic manipulation of plants

Second edition

Adrian Slater

Nigel W. Scott

Mark R. Fowler

De Montfort University

OXFORD
UNIVERSITY PRESS

List of abbreviations

xix

1 Plant genomes: the organization and expression of plant genes 1

Introduction	1
DNA, chromatin, and chromosome structure	1
Chromatin	4
An introduction to gene structure and gene expression	6
Gene structure and expression in a eukaryotic protein-coding gene	6
Translation	10
Regulation of gene expression	16
Chromatin conformation	16
Gene transcription	16
RNA modification, splicing, turnover, and transport	18
Translation	20
Post-translational modification	21
Localization	21
Protein turnover	21
Conclusions	22
Implications for plant transformation	22
Examples of promoter elements used to drive transgene expression	26
Protein targeting	26
Heterologous promoters	26
Genome size and organization	27
<i>Arabidopsis</i> and the new technologies	28
Genome-sequencing projects—technology, findings, and applications	28
Biotechnological implications of the AGI	31
Crop plant genome sequencing	31
Summary	33
Further reading	34

2 Plant tissue culture 37

Introduction	37
Plant tissue culture	37
Plasticity and totipotency	37
The culture environment	38
Plant cell culture media	39
Plant growth regulators	41
Culture types	44
Callus	44
Cell-suspension cultures	45
Protoplasts	46
Root cultures	46
Shoot tip and meristem culture	46
Embryo culture	46
Microspore culture	47
Plant regeneration	48
Somatic embryogenesis	48
CASE STUDY 2.1 Cereal regeneration via somatic embryogenesis from immature or mature embryos	50
Organogenesis	51
Integration of plant tissue culture into plant transformation protocols	51
Summary	52
Further reading	53

3 Techniques for plant transformation 54

Introduction	54
<i>Agrobacterium</i>-mediated gene transfer	54
The biology of <i>Agrobacterium</i>	54
The Ti plasmid	56
Ti-plasmid features	56
The process of T-DNA transfer and integration	59
Step 1. Signal recognition by <i>Agrobacterium</i>	60
Step 2. Attachment to plant cells	60
Step 3. Induction of <i>vir</i> genes	60
Step 4. T-strand production	60
Step 5. Transfer of T-DNA out of the bacterial cell	60
Step 6. Transfer of the T-DNA and Vir proteins into the plant cell and nuclear localization	60

Practical applications of <i>Agrobacterium</i>-mediated plant transformation	61
CASE STUDY 3.1 <i>Agrobacterium</i>-mediated transformation of tobacco	62
Transformation	64
Direct gene-transfer methods	66
Particle bombardment	67
CASE STUDY 3.2 Biolistic transformation of rice	68
Polyethylene glycol-mediated transformation	72
Electroporation	73
Silicon carbide fibres: WHISKERS™	73
Summary	74
Further reading	74

4 Vectors for plant transformation **77**

Introduction	77
Desirable features of any plasmid vector	77
Development of plant transformation vectors	79
Basic features of vectors for plant transformation	79
Promoters and terminators	79
Selectable markers	86
Reporter genes	87
Origins of replication	91
Co-integrative and binary vectors	91
Families of binary vectors	91
Optimization	92
Arrangement of genes in the vector	95
Transgene copy number	98
Transgene position	98
Transgene features	98
Clean-gene technology	100
Summary	100
Further reading	101

5 The genetic manipulation of herbicide tolerance **105**

Introduction	105
The use of herbicides in modern agriculture	106
What types of compounds are herbicides?	107

Strategies for engineering herbicide tolerance	111
CASE STUDY 5.1 Glyphosate tolerance	111
CASE STUDY 5.2 Phosphinothricin	121
Prospects for plant detoxification systems	123
Commercialization of herbicide-tolerant plants to date	124
CASE STUDY 5.3 Engineering imidazolinone tolerance by targeted modification of endogenous plant genes	126
The environmental impact of herbicide-tolerant crops	127
The development of super-weeds	129
Summary	130
Further reading	131

6 The genetic manipulation of pest resistance 133

Introduction	133
The nature and scale of insect pest damage to crops	134
GM strategies for insect resistance: the <i>Bacillus thuringiensis</i> approach	134
The use of <i>B. thuringiensis</i> as a biopesticide	138
<i>Bt</i> -based genetic modification of plants	138
CASE STUDY 6.1 Resistance of <i>Bt</i> maize to the European corn borer and other pests	140
The problem of insect resistance to <i>Bt</i>	141
The environmental impact of <i>Bt</i> crops	145
The Copy Nature strategy	146
CASE STUDY 6.2 Cowpea trypsin inhibitor	149
Insect-resistant crops and food safety	153
Summary	153
Further reading	153

7 Plant disease resistance 156

Introduction	156
Plant–pathogen interactions	157
Prokaryotes	158
Fungi and water moulds	158
Viruses	160
Existing approaches to combating disease	160

Natural disease-resistance pathways: overlap between pests and diseases	162
Anatomical defences	162
Pre-existing protein and chemical protection	162
Inducible systems	163
Systemic responses	170
Biotechnological approaches to disease resistance	172
Protection against pathogens	173
Antimicrobial proteins	174
Transgenic crops for food safety	176
Induction of HR and SAR in transgenic plants	177
CASE STUDY 7.1 The BASF potato	178
Developments for the future	179
Other transgenic approaches	179
Future prospects for breeding	179
CASE STUDY 7.2 <i>Xanthomonas</i> spp.	180
Summary	181
Further reading	182

8 Reducing the effects of viral disease **184**

Introduction	184
Types of plant virus	184
RNA viruses	186
Entry and replication: points of inhibition	188
How has the agricultural community dealt with viruses?	189
CASE STUDY 8.1 Developments in the sugar beet industry	190
The transgenic approach: PDR	192
Interactions involving viral proteins	192
CASE STUDY 8.2 Arabis mosaic virus	194
RNA effects	197
Some non-PDR approaches	202
CASE STUDY 8.3 DNA viruses	203
What has been commercialized in Western agriculture?	204
Yellow squash and zucchini	204
Papaya	205
Potato	205
Risk	206
Summary	208
Further reading	209

9 Strategies for engineering stress tolerance	212
Introduction	212
The nature of abiotic stress	214
The nature of water-deficit stress	214
Different abiotic stresses create a water deficit	215
CASE STUDY 9.1 Glycine betaine production	218
Targeted approaches to manipulating tolerance to specific water-deficit stresses	222
Alternative approaches to salt stress	222
CASE STUDY 9.2 ^Q Na ⁺ /H ⁺ antiporters improve salt tolerance in transgenic plants	223
Alternative approaches to cold stress	224
CASE STUDY 9.3 The COR regulon	224
Tolerance to heat stress	228
Secondary effects of abiotic stress: the production of ROS	229
Strategy 1: Expression of enzymes involved in scavenging ROS	232
Strategy 2: Production of antioxidants	234
Summary	234
Further reading	234
10 The improvement of crop yield and quality	237
Introduction	237
The genetic manipulation of fruit ripening	238
CASE STUDY 10.1 The genetic manipulation of fruit softening	240
CASE STUDY 10.2 The genetic modification of ethylene biosynthesis	243
CASE STUDY 10.3 Modification of colour	247
CASE STUDY 10.4 Golden Rice	251
Engineering plant protein composition for improved nutrition	256
The genetic manipulation of crop yield by enhancement of photosynthesis	258
Manipulation of light harvesting and the assimilate distribution: phytochromes	258
Direct manipulation of photosynthesis: enhancement of dark reactions	261
Summary	263
Further reading	263

11 Molecular farming	267
Introduction	267
Carbohydrates and lipids	267
Carbohydrate production	267
CASE STUDY 11.1 Starch	268
CASE STUDY 11.2 Polyfructans	272
Metabolic engineering of lipids	276
CASE STUDY 11.3 Bioplastics	282
Molecular farming of proteins	285
Production systems	286
CASE STUDY 11.4 The oleosin system: hirudin and insulin production	289
Medically related proteins	296
CASE STUDY 11.5 Custom-made antibodies	300
CASE STUDY 11.6 Edible vaccines	304
Economic and regulatory considerations for molecular farming	307
Summary	311
Further reading	312

12 Science and society: public acceptance of genetically modified crops	316
Introduction	316
Public concerns	316
The current state of transgenic crops	318
Who has benefited from these first-generation GM crops?	318
What will drive the development of the future generations of GM crops?	322
Concerns about GM crops	323
Antibiotic-resistance genes	323
Herbicide resistance and super-weeds	324
Gene containment	325
Big business	328
Food safety	330
The regulation of GM crops and products	331
The EU	331
The USA	338
Summary	340
Further reading	340

13 Beyond genetically modified crops	343
Introduction	343
‘Greener’ genetic engineering	343
Genetic manipulation of complex agronomic traits	345
Identification of genes associated with desirable traits	348
Genetic mapping	348
Quantitative trait loci	352
Investigating gene function by reverse genetics	354
Insertional mutagenesis	354
TILLING	355
Understanding gene function within the genomic context: functional genomics	357
Transcriptomics	357
Proteomics	360
Interactomics	362
Metabolomics	362
Systems biology	362
Summary	363
Further reading	363
<i>Index</i>	367

- A**
- ABA, *see* abscisic acid
- abscisic acid 6–7
- disease resistance 166
- regulation of gene expression 25–6, 227
- response elements 25–6
- stress resistance 226
- synthesis 245
- in tissue culture 42–3
- ACC oxidase 238–9
- ACC synthase 243–5
- ACC 243
- ACCase, *see* acetyl CoA carboxylase
- acclimation, cold 224–6
- acetoxyhydroxyacid synthase (AHAS), *see* acetolactate synthase (ALS)
- acetolactate synthase (ALS) 88, 108–10, 125–6
- acetosyringone 60
- acetyl CoA carboxylase (ACCase) 108–9, 277
- ACNFP, *see* Advisory Committee on Novel Food and Processes
- ACRE, *see* Advisory Committee on Release into the Environment
- ADP-glucose 268–71; *see also* starch synthesis
- Advisory Committee on Novel Foods and Processes 323, 333
- Advisory Committee on Releases to the Environment 101, 333
- Affymetrix GeneChip 358
- AFLP, *see* amplification fragment length polymorphism
- African cassava mosaic virus 159
- agar 41, 47
- AgriEvo 121, 123, 141, 120, 124, 139
- Agrobacterium rhizogenes* 65, 161, 194
- Agrobacterium tumefaciens* 55–8
- CP4 gene 117, 120–1, 125
- crown gall disease 54–6, 158, 161
- ocs* gene 119
- plant transformation 52, 54–5, 61–7, 79, 91
- strains 60, 64
- super-virulent 64
- T-DNA 55–67, 79–80, 91–4, 98–100, 139, 158, 354
- Ti plasmid 55–9, 63, 80, 91–2, 148, 245
- Vir proteins 56–60, 79, 91–2
- Agrobacterium*-mediated transformation 52, 54–5, 61–7, 79, 91
- agrochemical industry 106, 121, 127
- albumin
- engineering endosperm proteins 257
- human serum 305–6
- Alcaligenes eutrophus* 113, 268, 282–4
- alfalfa
- defensin gene 175
- economics of antibody production 309
- herbicide tolerance 125
- insect resistance 151
- oxidative stress 232–4
- somatic embryogenesis 48–9
- vaccine production 295
- yield 281
- alternative splicing 18–19
- amino acid 10–15, 21, 38–42, 256–8; *see also* specific named amino acids
- essential 107–8
- aromatic 111, 114, 116
- branched chain, 108, 113, 126
- polymers 285–6
- aminocyclopropane, *see* ACC
- aminomethylphosphonic acid (AMPA) 119–20
- ammonia 24, 107, 122
- AMPA, *see* aminomethylphosphonic acid
- amplification fragment length polymorphism (AFLP)
- in plant breeding 179, 351–2
- α -amylase 20, 25
- inhibitor 150–1, 165
- signal peptide 300–1
- anatomical defence 162
- Animal and Plant Health Inspection Service 309, 338
- anthocyanins, and flower colour 246, 248–9
- anthranilate 115
- antibiotic resistance
- concerns about selectable marker genes 323–4, 334, 337, 343–4
- as selectable marker 68–9, 86–8
- antibodies
- custom-made antibodies 300–3
- disease resistance 179, 202
- medically related proteins 296–300, 309–10
- plant antibodies 261
- production systems 279–80
- protein arrays 361
- starch modification 271
- anticodon 12–16
- antimicrobial proteins 163–4
- disease resistance 174
- in transgenic plants 174–6
- see also* defensin proteins, PR proteins
- antioxidant 230–4
- antisense RNA 96–7, 197–204, 240–7, 271, 280
- APETALA 346
- APHIS, *see* Animal and Plant Health Inspection Service
- apomixis 326, 329
- apple trees, disease resistance and transgenic plants 173, 175
- Arabidopsis*
- genome 28–32, 357–60
- transformation *in planta* 64
- arabis mosaic virus (ArMV), coat protein-mediated resistance 190–2
- arachidonic acid 281
- arginine vasopressin 307
- Argonaute 7–8

- aroA* gene 88, 119
 aroenate 115, 255
Arthrobacter globiformis 218–20
 ascorbate 230–4, 243, 256
 monodehydroascorbate 231–2
 dehydroascorbate 230–2
 peroxidase 230–4
 ascorbic acid, *see* ascorbate, vitamin C
 asters yellow 158; *see also*
 phytoplasma, plant diseases
 asulam 108
 atrazine 108, 110, 123–5
 autoimmune disease 310
 auxin; *see also* indoleacetic acid
 classification of 42
 herbicide action 109, 116
 in crown gall disease 55–7
 regulation of gene expression 19,
 25, 85
 response elements 19, 25
 in tissue culture 42–5, 51
 in tobacco transformation 63, 65
 T-DNA biosynthetic genes 56–7,
 245, 247
 Aventis 121, 139–41
 avidin, production in genetically
 engineered plants 294–5, 309
 avirulence 164–5, 168–9; *see also*
 gene-to-gene interactions, HR
 response
- B**
- Bacillus amyloliquifaciens* 273, 275
Bacillus anthracis 310
Bacillus subtilis 120, 221, 268, 272–3
Bacillus thuringiensis 134–8, 142,
 321, 344; *see also* Bt
 bacterial pathogens of plants 158–9;
 see also specific names
 bait test 190
bar gene 88, 123, 125
 barley
 codon usage 14
 diseases of 158–9
 genome 27, 33
 PR proteins in transgenic plants
 165, 173–4
 RIP 174
 stress resistance 213, 220, 223
 tissue culture 47
 α -thionin 174
 barley yellow dwarf virus (BYDV) 159
 coat protein-mediated resistance
 193
 Basta 110, 112, 121–2, 125
 beet necrotic yellow vein virus
 (BNYVV)
 bait test 189–90
 coat protein-mediated resistance 193
 molecular techniques for detection
 191
 rhizomania 189
 rhizomania resistant crops 191
 risk of recombination 208
 structure 188
 Bellagio Apomixis Declaration 329
 betaine aldehyde dehydrogenase
 218–20
 selectable marker for chloroplast
 transformation 72, 89
 betaine, *see* glycine betaine
 betalains, and flower colour 248
 Bialaphos 86, 108, 121–2; *see also*
 glufosinate, phosphinothricin
 binary vectors 91–101, 195–6
 basic features 91–3
 evolution of 93
 families of 92–5
 optimization of components 92–9
 biofortified rice 255
 biolistics 66–71
 gene rearrangement 67
 transformation of rice 68–71
 see also direct gene transfer,
 particle bombardment
 biopesticide 138
 biopharmaceuticals 286, 305–7
 bioplastics 282–5
 biotrophs 157
Bipolaris maydis, and leaf blight 156,
 159
 blight 156–161, 175–80
 Bollgard 139, 142–5
 Borlaug, Norman E. 250, 345
Botrytis spp 173
Brassica napus (canola, oilseed rape)
 220, 290–1; *see also* oilseed rape
 Brazil nuts 257
 bromoxynil 88, 108, 113, 123–5
 Bt cotton 138, 141, 144–5; *see also*
 Bollgard, cotton
 Bt crops 138–46, 306; *see also*
 individual crops
 Bt genes 135–9; *see also* *cry* genes
 Bt maize 140–6; *see also* maize
 bulk enzymes 285
- C**
- cacao swollen shoot virus (CSVV)
 159
 Calgene 125, 238–42
 callus 44–52
 Calvin cycle 259–62
 manipulation of enzymes 262
 cancer
 anticancer antibodies 300
 anticancer biopharmaceuticals
 305
 canola, *see* oilseed rape
 carbohydrate
 crop yield 258–62
 molecular farming 267–76
 in tissue culture 41
 β -carotene 230–2, 246–52
 carotenoid
 biosynthesis 107–8, 232, 246–7,
 347
 flower colour 248
 fruit 247
 Golden Rice 251–5
 carrot 49–50, 310; *see also* somatic
 embryogenesis
 CAT, *see* chloramphenicol
 acetyltransferase
 catalase 230
 cauliflower mosaic virus (CaMV)
 classification and structure 185
 35S promoter 23, 69, 80, 103, 117,
 119, 139, 144, 147–9, 152, 240,
 273
 structure/activity relationship
 80–1
 virus resistance 194–5
 CBF transcription factor 225–7, 360
 celery 218
 CEL-1 nuclease 355
 cell culture 37–43
 cell suspension culture 66, 74
 cellulases, production in genetically
 engineered plants 242
 chalcone synthase 25, 199, 248
 chicory 272–4
 chilling 220–2, 224–7; *see also* cold
 stress
 chitinase 164
 PR proteins 164–5
 in transgenic plants 173–4
 chloramphenicol acetyltransferase
 81, 87, 91
 chloroplast 107–8
 genetic engineering 310, 325–6,
 344
 genome 1–4
 proteins produced in chloroplasts
 310
 starch 268, 270
 transformation of 71–2

- transgenic proteins expression levels 300
transit peptide 22, 26, 117–9
see also photosynthesis
- chlorophyll 107, 232
- chlorsulphuron 108, 110, 125–7
- choline 217–20
dehydrogenase (CDH) 218–20
monooxygenase (CMO) 218–20
oxidase (COD) 218–20
-O-sulphate 217
- chorismate 114–5
- chromatin 1, 4–5, 16, 58, 61, 98; *see also* gene expression
- chromoplast 107
- cis* elements 16–7, 24–6
- citrus tristeza virus (CTV)
coat protein-mediated resistance 193
cross protection 189
- Cladosporium fulvum* 177
- clean-gene technology 95, 100–1, 310, 324–5
- coat protein-mediated resistance (CPMR) 193–4
arabis mosaic nepovirus case study 194–97
multiple pathogen-derived resistance strategies 198
risk of transcapsidation 206
virus-like particles (VLPs) 193
see also genome structure
- codon 11–21
- codon usage 14, 99, 276, 290
- co-integrative vectors 91
- cold stress 213, 224–7; *see also* chilling
- Coleoptera 134–5, 138, 140, 142, 151
- co-linearity 32
- Colorado beetle 134, 139, 142
- comovirus
movement proteins 187–8
structure and translation strategy 187–8
- compatible solute 216–8, 221–2; *see also* osmolyte, osmoprotectant
- concerns about GM crops
antibiotic resistance 101, 323–4
Golden Rice 253
herbicide resistance 128–30, 324–5
pest resistance 145–6
- Copy Nature strategy, and insect resistance 146–8, 152
- COR regulon 224–227
- corn rootworm 139, 142
- corn, *see* maize
- Corynebacterium* spp. 158
- co-suppression 197–9, 241–2, 263, 280
- cotton
herbicide resistant 117, 119, 125, 127
insect damage 134, 139, 141–5, 149, 153
see also Bt cotton, Bollgard, bollworm, leafworm
- cowpea mosaic virus (CPMV)
capsid structure 187, 195
genome structure and translation strategy 187–8
movement proteins 188
vector for protein synthesis 293, 302
- cowpea trypsin inhibitor (CpTI) 148–51
- Cre-*lox* 100
- crown gall disease 55–6
- CRT/DRE 225–7
- cry* gene 134–48
cry1Aa 135, 136–7
cry1Ab 135, 136, 139–40, 142, 146, 148
cry1Ac 135, 136, 139–40, 142, 144–5, 148
cry1F 135, 140
cry2A 135
cry3A 135, 137, 139
cry3Bb 135, 139–40, 142
cry9C 135, 139, 140–1
- Cry protein 134–48; *see also cry* gene, and individual *cry* genes
- Crystalline protein (ICP), *see* Cry protein
- cucumber mosaic virus (CMV)
coat protein-mediated resistance 193
commercialization of resistance 204
non-PDR approaches 202
post-transcriptional gene silencing 201–2
risk studies of transgenic plants 207
satellite RNA 189, 198
- cucumber, PR proteins in transgenic plants 165
- C-value paradox 27
- cyclodextrin 269–72
- cytochrome P450 123, 281
- cytokinin(s)
classification 42–3
in inducible gene expression 84
- in manipulating senescence 261
in plant tissue culture 44–5, 51
in tobacco transformation 63
selectable marker 87, 89
T-DNA biosynthetic genes 55, 57
cytoplasmic male sterility (CMS) 156, 159
CMS-T 156

D

- dark reaction 258–63
manipulation 261
- De Kalb 140
- defective interfering RNAs 198
- defensins 162–5, 175
elicitor response 163
PR proteins 164–5, 172–4, 181
- DEFRA, *see* Department for Environment, Food and Rural Affairs
- dental caries 298, 300
- deoxyribonucleic acid 1
chloroplast 2–4
genomic 1–10
mitochondrial 2–4
promiscuous 2
structure of 4–5
transcription of, *see* transcription
- Department for Environment, Food and Rural Affairs 333, 338
- detoxification 111–2, 116, 119–21, 122–5, 130–1, 231
- DHFR, *see* dihydrofolate reductase
- Dicamba 42, 109
- Dicer RNase 7–9, 200–1
- 2,4-dichlorophenoxyacetic acid (2,4-D) 42, 109, 113, 125; *see also* auxin
- dihydrofolate reductase (DHFR) 88, 116
- dihydropteroate synthesis 88, 108
- Diptera 134–5, 138
- direct gene transfer 54, 64, 66–71, 74
see also biolistics, electroporation, protoplasts, silicon carbide fibres
- directed evolution, *see* molecular evolution
- disease resistance pathways 162–72
- DNA, *see* deoxyribonucleic acid
- drought 170, 213–33, 274, 276, 360–3
- DuPont 120, 125, 139

dwarfing
 cereal 247–9, 346
 potato 261
 tomato 247

E

E. coli, *aroA* gene 88, 119
 economics of molecular farming 281,
 286, 307–9
 edible vaccines 303–5
 electroporation 66, 73, 92
 elicitors
 inducible 163–6
 endogenous 163–5
 exogenous 163–6
 embryo culture 46
 embryogenic callus 46, 50, 68–70,
 74
 endoplasmic reticulum 21–2, 99, 117,
 257, 277
 modification of fatty acids 277
 modification of proteins 257
 endosperm 31, 44
 biofortified cereals 255–7
 Golden rice 251–3
 polyfructans 275
 starch 269
 endotoxin- δ , *see* Cry protein
 enhancers
 gene 17
 increased transcription 111, 195
 35S promoter 80–1
 Ti-plasmid 56–7
 Translational 273
 enolpyruvylshikimate 3-phosphate
 (EPSP) 114
 enolpyruvylshikimate 3-phosphate
 synthase (EPSPS) 88, 109–14,
 116–20, 121
 environmental impact 100
 herbicide-resistant plants 109,
 127–31
 Bt crops 145–6
 insect resistance to Bt 141–5
 Copy Nature strategy 146
 Environmental Protection Agency
 (EPA) 141, 144–5, 339
 Environmental Risk Assessment
 (ERA) 331–3
 EPA, *see* Environmental Protection
 Agency
 EPSP, *see* enolpyruvylshikimate 3-
 phosphate
 EPSPS, *see* enolpyruvylshikimate 3-
 phosphate synthase

ERA, *see* Environmental Risk
 Assessment
 erucic acid 277–80
Erwinia spp. 158, 174–5, 251, 274
 fireblight 158, 175–6, 181
 target for antimicrobial proteins
 174–5
 EST, *see* expressed sequence tag
 ethylene 170–1, 178, 238–47, 263
 in tissue culture 42–3
 European corn borer (ECB) 134,
 139–42, 321
 exon 9–10, 30
 expressed sequence tag (EST) 357

F

fatty acid, synthesis 279–81
 FCA 19
 FDA, *see* Food and Drug
 Administration
 field trials 319, 337
 fungal resistance 175, 178
 herbicide-resistant crops 321–2
 insect-resistant crops 139, 148
 fireblight 158, 175–6, 181
 transgenic resistance in fruit trees
 175–6
 flavonoids 115–6, 248, 284
 FlavrSavr tomato 238, 242
 flax 125, 158, 168, 267, 285
 flowering, acceleration of 345, 354
 flowers
 ornamentals and flower colour 245
 FLP-*frt* 100
 Food and Drug Administration
 (FDA) 302, 339
 free radical, *see* reactive oxygen
 species (ROS)
 scavenger 231
 freezing stress 212–5, 220–7, 233
 fructan 217, 221, 267–81, 311; *see*
 also oligofructan, polyfructan
 fruit ripening 43, 238–9
 functional genomics 29, 124, 357–63
 fungal pathogens of plants 159, 164,
 173–4
 fungicides, use in USA 160
Fusarium spp. 159, 174–5, 176
 mycotoxins 176

G

gai/GAI 247–9, 346
 Gateway™ vectors 94–5, 97

gelling agents 41
 gene
 amplification 116
 duplication 30, 116
 structure 6–10
 gene containment 325–8
 gene expression 10–22
 chromatin 4–5, 58, 61, 98
 codon usage 14, 90, 140, 276, 290
 control of 6–22
 gene-for-gene hypothesis 168
 gene shuffling 120
 gene silencing 6–9, 67, 80, 95, 101,
 272
 chalcone synthase 199
 plastid transformation 71–2, 344
 RNAi 96–7
 small RNAs 6–9
 virus and PDR 197–202
see also transcriptional gene
 silencing, post transcriptional
 gene silencing
 gene stacking, *see* pyramiding
 genetic code 14
 genetic mapping 348
 genetic markers 348
 genetically modified crops
 area cultivated 318–21
 benefits 318–22
 concerns 323–31
 antibiotic resistance 323–4
 herbicide resistance 324–5
see also concerns about GM
 crops
 future developments in 322–3
 gene transfer, horizontal 129–30
 genome sequencing 27–34, 179, 181,
 343, 348, 357
 genome sizes 27–8
 GFP, *see* green fluorescent protein
 gibberellin(s) 42–3, 246–7, 346
 β -glucanase
 PR proteins 164–5, 173–4
 induction by elicitors 164–7
 use in transgenic plants 173–4
 glucocerebrosidase 306
 β -glucuronidase 87–90, 205, 228,
 290, 294–5
 glufosinate ammonia, *see* Basta,
 phosphinothricin
 glutamate 115, 122
 glutamine 12, 41, 108, 221
 glutamine synthetase (GS) 108,
 110, 122–3, 221
 glutathione 49, 230–1, 234, 256
 conjugation 124
 peroxidase 233–4

- reductase 233–4
 synthetase 233
 -S-transferase 123–4, 233
 glycine 4–2
 group of herbicides 108, 110–1,
 120, 125
 glycine betaine 218–21
 glycosylation 21, 287–300
 glyoxylate, breakdown product of
 glyphosate 119–20
 glyphosate
 acetyltransferase 120–1
 mode of action 110–15
 oxidoreductase (GOX) 119–21
 structure 110
 tolerance 116–21, 124–5
 usage 128
 GNA, *see* snowdrop lectin
 Golden Rice 65, 249, 251–5
 Humanitarian Board 254
 IPR 254–5
 green fluorescent protein (GFP)
 reporter gene 87, 90
 selectable marker 89
 sequence optimization 99
 Green Revolution 250
 guard hypothesis 167, 177
 GUS, *see* β -glucuronidase
- H**
- HASTY 7–8
 heat shock 225–6
 heat-shock protein (HSP) 226, 228
 heat-shock element (HSE) 84, 226,
 228
 heat-shock factor (HSF) 228
 heat stress 228
 tolerance 228
 HEN1 7–8
 herbicide
 broad spectrum 107, 111, 121
 super-weeds 324–5
 tolerance 105–31
 toxicity 109, 122–3, 128
 see also individual herbicides
 heterologous encapsidation 206
 high dose/refuge management
 scheme 143–5
 hirudin, production in *B. napus*
 287–90
 histone 4–5, 16, 61
 Hoechst 121, 123
 Homoptera 134, 151
 hydrogen peroxide 178, 218, 229–34
 hydroxyl radical 229–32
- hypersensitive response (HR) 157,
 163–5, 167–72, 177–8
 induction in transgenic plants
 177–8
 protein interactions 168
- I**
- identity preservation 280, 308
 idiotype vaccine 300–2
 imazapyr 108, 126
 imazathapyr 110, 126
 imidazolinone 108, 109–10, 125, 126
 immunoglobulins, *see* antibodies
 inclusion bodies; *see also* Cry protein,
 crystal protein
 indole-3-acetic acid (IAA) 42, 57,
 109, 116, *see also* auxin
 inducible disease resistance 163–70
 insect
 larva 134–5, 138–9
 larva midgut 136–8
 resistance to Bt 141–4
 see also Coleoptera, Diptera,
 Homoptera, Lepidoptera,
 Orthoptera
 insecticidal crystal protein (ICP), *see*
 Cry protein
 Integrated Pest Management (IPM)
 142
 intellectual property rights (IPR) 254
 interactomics 362
 International Rice Genome
 Sequencing Project 32
 International Service for the
 Acquisition of Agri-biotech
 Applications 318, 321,
 inter-simple sequence repeat (ISSR)
 352
 intron 9–10, 19–20, 27, 30, 87,
 cryptic 90, 97–9
 IRGSP; *see* International Rice
 Genome Sequencing Project
 ISAAA, *see* International Service for
 the Acquisition of Agri-
 biotech Applications
- J**
- jasmonic acid 170–1, 178, *see also*
 methyl jasmonate
 sequence elements 25
 Jerusalem artichoke 268, 272–3, 275
 Joint Regulatory Authority (JRA) 333
 JRA, *see* Joint Regulatory Authority
- K**
- kanamycin 63–4, 86, 93, 123, 195,
 337
Klebsiella ozaenae 113
Klebsiella pneumoniae 268, 272
- L**
- LEAFY 345–6, 354,
 lectin 150–3, 164, 274–5
 legislation
 EU 323, 331–8
 UK 332–3
 USA 338–9
 legumin box 26
 legumin mRNA 20
 Lepidoptera 134, 135, 138, 142, 149,
 151
 LibertyLink 121, 123, 125; *see also*
 phosphinothricin
 light-regulated gene expression 26
 Lightning herbicide 126
 lignin 115–6, 121
 linoleic acid 278–9, 281
 linolenic acid 278–9, 281
 lipid, biosynthesis 107, 109, 276–281
 localization, protein 16, 22, 117–9,
 225–6, 274–5
 luciferase 87, 90
 lycopene 238–9, 241, 246–7, 251–2
 lymphoma 300, 302
 lysine 12, 89, 256–8, 286
- M**
- macronutrients 39–40
 maize
 chloroplast genome 2–4
 diseases of 156, 159, 176
 herbicide resistant 119, 120, 123,
 125, 126, 130
 insect resistance 134, 139, 140, 141,
 142, 145, 146, 148, 151
 mitochondrial genome 2–4
 molecular farming 268, 271, 273,
 275, 276, 287, 294–5, 309, 311
 relative genome size 27
 maltose 41, 49–50
 mannitol 217–8, 221, 269–70
 MARS, *see* matrix attachment regions
 massively parallel signature
 sequencing (MPSS) 358
 material transfer agreement (MTA)
 95, 254

matrix attachment regions (MARs) 98
 media 39–41
Medicago falcata, see alfalfa
 meristem culture 46
 messenger ribonucleic acid (mRNA) 6, 9–13, 18–21, 96–8, 185–7, 239–41, 357–60; *see also* ribonucleic acid
 turnover 18–20
see also transcription, translation;
 metabolomics 362–3
 methionine 11–12, 14, 21, 243, 256–8
 methyl bromide 161
 methyl jasmonate 22–3, 84, 170
 microarray 358, 361
 micronutrients 39–41, 255
 microsatellites, in breeding 179, 349
 microspore culture 47
 microRNA 6–8, 200–2
 miRNA, *see* microRNA
 mitochondria, genome of 2–4
 molecular breeding 346
 molecular evolution 120
 Monarch butterfly 145–6, 344
 monoculture 133, 156, 170, 325
 disease resistance 1568
 Monsanto 111, 119–20, 125, 139–40, 142, 144, 204–5, 283, 321, 327–8
 movement protein
 virus encoded 185–7, 203, 292, 294
 MPSS, *see* massively parallel signature sequencing
 mRNA, *see* messenger ribonucleic acid
 MS, *see* Murashige and Skoog
 Murashige and Skoog (MS) 40, 49, 50, 63
 mutant 29, 117, 119, 124–5, 193–4, 202–4, 247–9, 271, 275, 280, 354–7
 mutation 28–9, 111, 112, 126–7, 249, 107, 123, 354–7
 Mycogen 139–40

N

Na⁺/H⁺ antiport 223
 NaturGard 140
 necrotrophs 157
 nematodes 30, 135, 142, 161, 168, 188, 194
 nepovirus genome structure 195; *see also* arabis mosaic virus

Nicotiana tabacum, *see* tobacco
 nitrate reductase 38
 nitrilase 88, 113, 125
 nitrile 108, 125
 nopaline 55–7, 80, 195
 Novartis 140, 323
nptII gene 86, 88, 92, 324

O

Ochrobactrum anthropi 112
 octopine 55–7
 oil bodies 277; *also see* oleosin
 oilseed rape
 genome 27–8
 GM concerns 325
 herbicide resistance 119–25, 130
 insecticidal genes 151
 molecular farming 268, 276–89
 salt tolerance 223
see also *Brassica napus*, canola
 oleic acid 278–81
 oleosin 277, 289–99, production system 282–5, 296
 oligofructan 268–9, 275; *see also* fructan
 oncogenes, T-DNA 57, 79, 101, 179
 D-ononitol 217, 221
 organogenesis 46, 48–52, 63
 Orthoptera 134, 149–51
Oryza sativa, *see* rice
 oryzalin 108
 osmolyte 216–22, 226, 269; *see also* compatible solute, osmoprotectant
 osmoprotectant 217–22, 274; *see also* compatible solute, osmolyte
 osmotic adjustment 215, 217, 220–21
 osmotic potential 38, 46, 215–8
 osmotic stress 23, 215–22, 227, 276
 osmotin 142, 165, 221
 overexpression 111–7, 177, 223–6, 247, 255, 261, 271

P

palmitic acid 278
 papaya ringspot virus (PRSV)
 coat protein-mediated resistance 193
 commercialized resistance 205
 disease of citrus plants 189
 paraquat 108, 233–4
 particle bombardment 66–71, 73, 140, 285
 gene rearrangement 68
 transformation of rice 68–71
see also direct gene transfer, biolistics
pat gene 88, 122–3
 pathogen-associated molecular pattern (PAMP) 166–72
 pathogenesis-related proteins (PR proteins) 148, 168
 pear 175, 242
 pectin methylesterase (PME) 239, 241–2
 PEG-mediated transformation 72–3
 pest resistance 31–3, 133–55, 345; *see also* insect resistance
 petroselenic acid 280–1, 307–8
 petunia 88, 116–9, 151, 199, 249
 PGRs, *see* plant growth regulators
 phenylalanine 12, 111–5
 phosphinic acid 108, 110, 125
 phosphinothricin 88, 110, 112, 121–5
 phosphoenolpyruvate (PEP) 111, 114, 140, 148, 259, 262
 photosynthesis 107–8, 110, 122, 215–7, 222, 258–63; *see also* dark reaction, Rubisco, phytochromes
 phytase 255, 295–6
 phytochromes 258–61
 phytoene synthase 238–9, 246–7, 251–2, 263
 phytoplasmas 158
 aster yellow 158
Phytophthora spp. 158–61, 174–8
 picloram 42, 109
 pinitol 217, 269–70
 pink bollworm 139, 144–5
 Pioneer Hi-Bred 120, 125–6, 139
 plant-derived vaccines 302–5
 Plant Genetic Systems (PGS) 123
 plant growth regulators (PGRs) 41–4, 47, 51, 65, 245
 plant pathogens 66, 157–9, 164–70, 178, 180–1
 plant regeneration, *see* regeneration
 plant tissue culture, *see* tissue culture
 plant transformation, *see* transformation
 plant viruses 160, 184–209, 287, 292–3, 338
 plasmid vectors
 Gateway™ 94–5, 97
 pBIN19 91–3, 149, 195
 pBluescript 78
 pGreen 93
 plant transformation 62–5, 77–104

- pROK 2 149
see also binary vectors
- plasticity, developmental 37–8, 41, 51, 214
- plastid 2, 23, 71–2, 107, 117–9, 232, 251, 268
 plastid transformation 71–2
 pleiotropic effects of transgenes 121
- pollen 44, 47–8, 129–30, 140, 145–6, 148, 310, 326, 344, 362
- polyadenylation 9–10, 19, 98–9, 304, 310
- polyfructan 272–81; *see also* fructan
 polygalacturonase (PG) 238–9
- polyhydroxyalkanoate (PHA) 282
- polyhydroxybutyrate (PHB) 268, 282–3
- polymerase chain reaction (PCR) 95, 100, 355
 plant breeding 179
 virus detection 191, 195–6
- polymorphic DNA 350
Polymyxa betae, fungal vector for BNYVV 185
- post-transcriptional gene silencing (PTGS) 6–8, 199–209
 coat protein-mediated resistance 193–5
- post-translational modification 16, 21–2, 287, 289, 310, 312, 360–1
- potato
 antimicrobial proteins 174–6
 biopharmaceuticals 305–9
 breeding 161
 disease resistance 158–81
 herbicide resistance 125
 insect resistance 134, 139, 142, 148–53
 molecular farming 268–309
 vaccines 302–4
 viruses 205–8
 virus-free plants 189
 wound-inducible promoter 173
 yield 261
- potato leafroll virus (*Polerovirus*)
 coat protein-mediated resistance 205, 207
- potato virus X (PVX)
 coat protein-mediated resistance 192–4
- post-transcriptional gene silencing 199
 vectors for protein production 292
- potato virus Y (PVY)
 coat protein-mediated resistance 192–3
- commercialized resistance 161, 205
- post-transcriptional gene silencing 199–200
 reduction in tuber yield 189
 risk 207
- Potrykus, Ingo 253
- precautionary principle 334–5
- proline 12, 14, 41, 217–8, 221, 223, 226
- promoter analysis 24–6, 87
- promoter structure 2, 9–11, 16–7, promoter
 35S 23, 67, 80–5, 96, 117, 119, 123, 144, 147–9, 152, 173–4, 177, 194, 225, 240, 247, 251–2, 273, 282, 285–6, 288–9, 298, 306
 for Bt genes 139, 144, 147–9, 152
 inducible 81, 83–4, 89, 97
 abscisic acid 26, 85, 226,
 alcohol 82–3
 auxin 85
 copper 83,
 heat-shock 84
 senescence 84
 steroid 83
 tetracycline 82
 wound 84, 147, 173, 177
 tissue-specific 26, 69, 80, 83, 147, 194, 288
 endosperm-specific 251–2, 255
 oleosin 289, 292
 virus vectors, subgenomic 294, 301
- protease 149, 151, 153, 200, 290–1, 348
- protease inhibitor 149–51, 164–5
- protein domains 7, 18, 136–7, 142, 289
- protein stability 21, 303
- protein storage
 prolamins 257
 protein bodies 257
 vacuole 21–2, 257, 273–5
see also albumin
- proteomics 29, 95, 360, 362
- protoplasts 46, 52, 66, 72–3, 218, 225
 PEG 72
 in transformation 72
- provitamin A 230, 249–55; *see also*
 Golden Rice, vitamin A, β -carotene
- Pseudomonas* spp. 158–9, 180, 285
- antimicrobial proteins 166
 R protein interactions 166–7
 transgenic resistance 166
 typeIII proteins 168,
- PTGS, *see* post transcriptional gene silencing
- pTOM clones 238–9
 pTOM5 247
 pTOM6 240, 243
 pTOM13 233–4
Puccinia graminis 159
 Pusztai, A. 152, 242, 330
 pyramiding 141, 180–1, 225, 347
- Q**
- quantitative trait locus (QTL) 352–4
- R**
- random amplified polymorphic DNA (RAPD), in plant breeding 179–80, 350
- rape, *see* oilseed rape
- reactive oxygen species (ROS) 165, 172, 212–4, 221, 229–334
- receptor, Cry protein 137–8, 141, 148
- recombinases, site-specific 95, 98, 100, 327
- refuge, pest management 143–5
- regeneration 37–8, 46–8, 50–3, 61–3, 70–4, 87, 123, 325
 importance of genotype 50
 plant transformation 48–52
- replicase complex
 virus proteins 187
 function 188
 target for ribozymes 198
- reporter genes 22, 24, 68, 79, 80, 87, 90, 93, 101
- resistance genes, disease 84, 86, 100, 131, 144–8, 150, 181, 191–2
 HR and inducible systems 164, 170, 172
 pyramid breeding 179
 transgenic plants 178, 180, 202–3, 209
- restriction fragment length polymorphisms (RFLP), in plant breeding 179–80, 350–1
- reverse genetics 354
- Rhizobium* spp. 66, 157
- Rhizoctonia* spp. 157, 159
 transgenic resistance 174
- rhizomania 190–1; *see also* BNYVV
- ribonucleic acid 1, 6–22; *see also*
 messenger ribonucleic acid
 alternative splicing 18–9
 antisense 8, 96–7, 197–201, 204, 240–7, 263, 271, 280
 processing 10, 20, 98

- synthesis 6–10, 197, 208
 translation 6, 10–16
 ribosome-inactivating protein (RIP)
 174
 rice
 biolistics 68–71
 C3 photosynthesis 262
 chitinases and glucanases 173
 coat protein-mediated resistance
 183
 engineering nutritional qualities
 251–6
 gene rearrangement 67
 insect resistance 132, 148–9, 151–3
 secondary products 163
 signal sequence 300
 virus diseases 159–60
 yield 287
 see also Golden Rice
 rice genome sequencing 32–3
 rice stripe virus (RSV)
 coat protein-mediated resistance
 193
 rice tungro virus complex 153,
 159–60, 193
 rice yellow mottle virus (RYMV)
 coat protein-mediated resistance
 193
 ricolenic acid 281
 Ri plasmid 65
 RISC, *see* RNA-induced silencing
 complex
 risk assessment 130, 331–5
 risk; *see also* concern
 effect of satellite sequences 198
 transcapsidation and
 recombination 206–8
 RITS, *see* RNA-induced
 transcriptional silencing
 complex
 RNA, *see* ribonucleic acid
 RNA-directed methylation 9
 RNAi, *see* RNA interference
 RNA-induced silencing complex
 (RISC) 7–9, 200–1
 RNA-induced transcriptional
 silencing complex 9
 RNA interference 6, 96–7, 179
 RNA viruses
 structure, classification and
 expression systems 166, 186
 root culture 46
 Roundup 110–2
 Roundup Ready crops 117, 119, 121,
 125, 128
 R-RS 100
 Rubisco 4, 25, 258–9, 282, 284
 manipulation in C3/C4 systems
 259, 262
 Rubisco activase 19
- ## S
- SAG promoter (senescence-related)
 261; *see also* promoter,
 inducible
 SAGE, *see* serial analysis of gene
 expression
 salinity 170; *see also* salt stress
 salt stress 212–4, 233–4
 saprophytes 158
 satellites, RNA 185
 cross-protection 189
 RNA protection 197–8
 virus genome component 185
 scab 159, 161
 resistant potato 161
 secondary products as antimicrobials
 163
 secretory antibodies, IgA 298–9,
 303
 selectable markers 64, 68, 79, 86–7,
 92–3, 101, 323–4, 337, 344
 for plastids 72
 sequence tagged sites (STS), in plant
 breeding 179
 serial analysis of gene expression
 (SAGE) 357
Serratia marcescens, source of
 chitinase gene 173
 shikimate pathway, shikimate 3-
 phosphate 114, 116
 shoot tip culture 46
 signal sequences
 human serum albumin 306
 immunoglobulin 298
 targeting to ER 298
 vacuolar 273
 signal transduction cascades, map
 kinases 166–7
 silicon carbide fibres (Whiskers™)
 66, 73
 simple sequence repeat (SSR) 349
 single chain antibodies 286, 297, 300
 single-nucleotide polymorphism
 (SNP) 349, 352
 siRNA, *see* small interfering RNA
 small interfering RNA 8, 200–2
 snowdrop lectin (GNA) 151–3
 SNP, *see* single-nucleotide
 polymorphism
 somatic embryogenesis 43, 46,
 48–52, 362
 alfalfa 49
 carrot 49
 cereal 50
 somatotrophin 305
 expression levels in chloroplasts
 310
 sorbitol 41, 217, 221–2
 Southern corn leaf blight 156, 159
 spinach 218, 220, 309
 splicing 7, 10, 16, 18–20
 squash
 coat protein-mediated resistance
 193
 commercialized virus resistance 204
 SSR, *see* simple sequence repeat
 stable expression systems for protein
 production 139, 288
 starch 263
 modified 268, 270–2
 plastids 107
 synthesis 267–8
 starch branching enzyme (SBE) 270,
 271
 starch synthase 269, 271
 StarLink 139–41, 330
 stearic acid 280
Streptococcus mutans
 secretory antibodies and dental
 carries 298
Streptomyces 88–9, 112, 123, 158
 stress
 abiotic 131, 212–5, 229, 231, 234,
 276, 362
 biotic 106, 212–4, 366
 oxidative 212–3, 221, 229, 231–4
 temperature 212–5, 224–7,
 water deficit 212–8, 220–2, 229, 276
 stress tolerance 212–36; *see also*
 stress, individual stress
 tolerances
 S-triazine 110, 125
 subgenomic promoter, TMV 186–7,
 195, 301
 substantial equivalence 331, 334–6
 subunit vaccines, plant derived 286
 sucrose, in tissue culture 39–41, 50
 sugar alcohol 217, 268–70, 283, 296
 sugar beet 45, 125, 130, 190–1, 193,
 208, 213, 221, 268, 273–5
 see also beet necrotic yellow vein
 virus
 sulphonylureas 88, 109, 126
 super weeds 86, 129, 324–5
 superoxide 229–34,
 dismutase (SOD) 229–30, 233
 sweet potato 151, 189, 256, 271,
 274–5

- synteny 32–3
 systemic acquired resistance 170–1
 systemic response 162, 170
 transgenic plants 178
 systems biology 363
- T**
- ta-siRNA, *see trans-acting small interfering RNA*
 TATA box 11, 16–7, 81–2, 228
 taxonomy, virus 184
 T-DNA
 border sequences 56–7, 59–60, 62–3
 clean gene technology 100
 structure 55–9
 transfer 59–61
 technology property rights (TPR) 254, 327; *see also* Material Transfer Agreement (MTA)
 terminator technology 318, 326, 329
 tetracycline inducible promoter 82, 327
 tetracycline repressible promoter 82
 TGS, *see* transcriptional gene silencing
 Ti plasmid 55–61
 TILLING 355–7
 tissue culture 37–53
 tobacco
 Agrobacterium-mediated transformation of 62–3
 Calvin cycle and photosynthesis 261–2
 chloroplast map 3
 chloroplast expression 310
 budworm 134, 139, 144–5, 149
 herbicide resistance 119–20, 127
 hornworm 134, 142
 insect resistance 1134, 139, 142, 144, 148–51
 molecular farming 268, 273–4, 276, 281, 284, 286–7
 organogenesis 51
 pharmaceutical production in 287, 289, 298, 300–7, 311
 phytochromes 260
 resistance to bacteria 174, 176
 resistance to fungi 165, 173–7
 resistance to viruses 192–3, 195–9, 202, 209
 yield 287
 tobacco etch virus (TEV)
 post-transcriptional gene silencing 199
- tobacco mosaic virus (TMV)
 antibody production 300–2
 coat protein-mediated resistance 192–5, 203, 208–9
 movement protein 188, 194
 N gene 209
 structure and expression systems 186
 translation enhancer 195
 vectors for protein synthesis 292, 294
 α -tocopherol 230, 231–2, 255–6
 tolerance
 virus infections 197
 tomato 125
 diseases 159–60,
 edible vaccines and
 biopharmaceuticals 287, 301–5
 genome 27
 insect resistance 134, 139, 148, 151–2
 resistance proteins 165
 ripening 237, 251
 virus resistance 199, 202
 tomato spotted wilt virus (TSWV) 159
 coat protein-mediated resistance 193, 199
 post-transcriptional gene silencing 202
 totipotency 37–8
trans-acting small interfering RNA 8–9
 transcapsidation 195, 206–7
 transcription 4–6, 9–11 16–8, 20, 23
 transcription factor(s) 11, 16–8, 192, 197, 199, 201, 331, 357, 360
 transcriptional gene silencing 6, 9, 97, 197, 199, 201
 transcriptomics 29, 179, 181
 transfer RNA 6
 transformation 20, 22, 25, 32–3, 37, 44–6, 48, 50–3, 54–76
 transgenes
 copy number 61, 67, 71, 73, 98
 position 98, 192
 features 98
 transgenic crops, *see* genetically modified crops
 transient expression; protein synthesis 66, 100, 204, 288
 idiotypic vaccine 301
 plant derive vaccines 302
 translation 4, 6–7, 10–6, 20–1, 23, 29, 99, 107, 117, 195, 201, 273
 repression by uORFs 20
- trehalose 89, 217, 221–2, 268–70, 276
 triacylglycerol (TAG) 277–8
Trichoderma spp., source of chitinase gene 173
 trichosanthin 305–6
 tRNA, *see* transfer RNA
 trypsin 149, 290, 292, 295, 309
 trypsin inhibitor 149–51, 165, 305
 tryptophan 12, 111, 115–6
 turgor potential 215
 tyrosine 111, 115, 255
- U**
- United States Department of Agriculture (USDA) 309, 311, 327–9
- V**
- vaccines 285–310
 vacuolar targeting 22, 273–6
 vacuole 21–2, 123, 218, 222–3, 257, 268, 270–5, 282, 284–5
 vectors, binary, *see* binary vectors
Venturia spp., scab in fruit trees 173
Verticillium spp. 175
 virulence genes 60–4
 virus classification and structure 185
 virus-like particles (VLPs)
 coat protein-mediated resistance 193
 arabis mosaic virus 195
 TMV resistance 193–4
 virus replication
 antisense 198
 effect of satellite RNA 197
 viscosity, tomato paste 241–2
 vitamin A 230, 249
 deficiency 251
 see also Golden Rice, β carotene, provitamin A
 vitamin biosynthesis 107
 vitamin C, 230–1; *see also* ascorbic acid
 vitamin E, 230; *see also* α -tocopherol
 vitamins, in tissue culture 38–9, 41, 44
- W**
- water deficit, *see* stress, water deficit
 water potential 214–5
 water shell 216

- watermelon mosaic 2 virus (WMV2)
 coat protein-mediated resistance
 193
 commercialization of resistance
 204
 PTGS 202
 weedkiller, *see* herbicide
 weeds 106–7, 111, 121–2
 herbicide resistant 123, 129; *see*
also super weeds
 volunteer 121, 129
 wheat 47, 149, 151, 165, 174, 176,
 178, 223, 249–50, 256, 272,
 287
 electroporation 73–4
 coat protein-mediated resistance
 193, 209
 diseases 158–9
 genome 27, 33
 global warming 322
 photosynthesis 362
 soil-borne wheat mosaic virus
 (SBWMV) 193
 yield 212–3
 Whiskers™ 73
- X**
- Xanthomonas* spp. 158–9, 169,
 177
 resistance to 180
 xenobiotic 123, 229
 xylanases 295
- Y**
- yield⁹
 antibodies 299
 crop 106, 133, 148, 222, 234, 237
 biomass 287, 295, 309,
 economics of biopharmaceuticals
 286, 307–9
 hirudin 289–90, 305
 protein yield from engineered
 plants 288–9, 292–4, 306, 309
 YieldGard 139–42
- Z**
- Zea mays*, *see* maize
 zeaxanthin 230
 Zeneca 238, 241–2
 zucchini yellow mosaic virus
 (ZYMV)
 coat protein-mediated resistance
 193
 commercialization of resistance 204
 cross-protection 189
 risk studies 207
 zwitterion 217