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
Arabidopsis 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

### Introduction

- Plant tissue culture
- Plasticity and totipotency
- The culture environment
- Plant cell culture media
- Plant growth regulators

### Culture types

- Callus
- Cell-suspension cultures
- Protoplasts
- Root cultures
- Shoot tip and meristem culture
- Embryo culture
- Microspore culture

### Plant regeneration

- Somatic embryogenesis

CASE STUDY 2.1 Cereal regeneration via somatic embryogenesis from immature or mature embryos

### Integration of plant tissue culture into plant transformation protocols

### Summary

### Further reading

## 3 Techniques for plant transformation

### Introduction

**Agrobacterium-mediated gene transfer**

The biology of Agrobacterium

### The Ti plasmid

- Ti-plasmid features

**The process of T-DNA transfer and integration**

- Step 1. Signal recognition by Agrobacterium
- Step 2. Attachment to plant cells
- Step 3. Induction of vir genes
- Step 4. T-strand production
- Step 5. Transfer of T-DNA out of the bacterial cell
- Step 6. Transfer of the T-DNA and Vir proteins into the plant cell and nuclear localization
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 Bacillus thuringiensis approach 134

The use of B. thuringiensis as a biopesticide 138

Bt-based genetic modification of plants 138

CASE STUDY 6.1 Resistance of Bt maize to the European corn borer and other pests 140

The problem of insect resistance to Bt 141

The environmental impact of Bt 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

- Anatomical defences
- Pre-existing protein and chemical protection
- Inducible systems
- Systemic responses

### Biotechnological approaches to disease resistance

- Protection against pathogens
- Antimicrobial proteins
- Transgenic crops for food safety
- Induction of HR and SAR in transgenic plants

**CASE STUDY 7.1** The BASF potato

**Developments for the future**

- Other transgenic approaches
- Future prospects for breeding

**CASE STUDY 7.2** Xanthomonas spp.

**Summary**

**Further reading**

## 8 Reducing the effects of viral disease

- Introduction
- Types of plant virus
- RNA viruses
- Entry and replication: points of inhibition
- How has the agricultural community dealt with viruses?

**CASE STUDY 8.1** Developments in the sugar beet industry

**The transgenic approach: PDR**

- Interactions involving viral proteins

**CASE STUDY 8.2** Arabis mosaic virus

- RNA effects

**Some non-PDR approaches**

**CASE STUDY 8.3** DNA viruses

**What has been commercialized in Western agriculture?**

- Yellow squash and zucchini
- Papaya
- Potato
- Risk

**Summary**

**Further reading**
9 Strategies for engineering stress tolerance

Introduction
The nature of abiotic stress
The nature of water-deficit stress
Different abiotic stresses create a water deficit
CASE STUDY 9.1 Glycine betaine production
Targeted approaches to manipulating tolerance to specific water-deficit stresses
Alternative approaches to salt stress
CASE STUDY 9.2 Na⁺/H⁺ antiporters improve salt tolerance in transgenic plants
Alternative approaches to cold stress
CASE STUDY 9.3 The COR regulon
Tolerance to heat stress
Secondary effects of abiotic stress: the production of ROS
Strategy 1: Expression of enzymes involved in scavenging ROS
Strategy 2: Production of antioxidants
Summary
Further reading

10 The improvement of crop yield and quality

Introduction
The genetic manipulation of fruit ripening
CASE STUDY 10.1 The genetic manipulation of fruit softening
CASE STUDY 10.2 The genetic modification of ethylene biosynthesis
CASE STUDY 10.3 Modification of colour
CASE STUDY 10.4 Golden Rice
Engineering plant protein composition for improved nutrition
The genetic manipulation of crop yield by enhancement of photosynthesis
Manipulation of light harvesting and the assimilate distribution: phytochromes
Direct manipulation of photosynthesis: enhancement of dark reactions
Summary
Further reading
11 Molecular farming

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

Index 367
| aroA gene | 88, 119 |
| arogenate | 115, 255 |
| *Arthrobacter globiformis* | 218–20 |
| ascorbate | 230–4, 243, 256 |
| monodehydroascorbate | 231–2 |
| dehydroascorbate | 230–2 |
| peroxidase | 230–4 |
| ascorbic acid | 230–2 |
| monodehydroascorbate | 231–2 |
| dehydroascorbate | 230–2 |
| peroxidase | 230–4 |
| 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 | 273, 275 |
| *Bacillus amyloliquefaciens* | 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 | 248 |
| 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 |
| gene-to-gene interactions, HR response | 164–5, 168–9 |
| biotransforms | 157 |
| Bipolaris maydis, and leaf blight | 156, 159 |
| blight | 156–161, 175–80 |
| Bollard | 139, 142–5 |
| Boraux, Norman E. | 250, 345 |
| Botrytis spp | 173 |
| Brassica napus | 255 |
| biosynthesis | 107–8 |
| chloroplast | 310 |
| genome | 1–4 |
| proteome produced in chloroplasts | 310 |
| starch | 268, 270 |
| transformation | 71–2 |
transgenic proteins expression
levels 300
transit peptide 22, 26, 117–9
see also photosynthesis
chlorophyll 107, 232
chlorsulphuron 108, 110, 125–7
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
genostructure 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
cytoschrome P450 123, 281
cytokinins (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
eliciton 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-α, 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
calcone 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 ammonium, 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
phosphate 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
IPR254-5
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
herologous 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
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
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,
leptin 150-3, 164, 274-5
legislation
  EU 323, 331-8
  UK 332-3
  USA 338-9
legumin box 26
legumin mRNA 20
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, 159, 140, 143,
  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
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

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 antimiCrobes 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

persistent 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

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 antimiCrobes 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

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 antimiCrobes 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

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 antimiCrobes 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
Index

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
cooprotein-mediated resistance 183
ingenhancing 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)
cooprotein-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
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 targeting to ER 298
vacular 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 259, 305
StarLink 139–41, 301
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, 221, 229, 233–4
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 repressable 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 mosaic virus (TMV)
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
a-tocopherol 230, 231–2, 255–6
tolerance
virus infections 197
tomato 125
diseases 159–60, 192, 199
edible vaccines and biopharmaceuticals 287, 301–5
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)
coop 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) 193
coated 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
coated 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

yield
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) 193
coat protein-mediated resistance 193
commercialization of resistance 204
cross-protection 189
risk studies 207
zwitterion 217
The genetic manipulation of plants together with the establishment of in vitro plant regeneration systems facilitates efforts to engineer secondary product metabolic pathways. Advances in the cloning of genes involved in relevant pathways, the development of high throughput screening systems for chemical and biological activity, genomics tools and resources, and the recognition of a higher order of regulation of secondary plant metabolism operating at the whole plant level facilitate strategies for the effective manipulation of secondary products in plants. Here, we discuss advances in engineer