Regulation of Photosynthesis

Edited by

Eva-Mari Aro

University of Turku, Finland

and

Bertil Andersson

University of Stockholm/Linköping, Sweden



Contents

| Edi | torial | V | 1 |
|-----|---|---|---------------|
| Cor | ntents | vi | į |
| Pre | face | xvi | i |
| Col | or Plates | CP-1 | l |
| | rt I: Evolution, Complexity and Regulation of Photosyntheticulary | c | |
| 1 | Thylakoid Biogenesis and Dynamics: The Result of a Complex Phylogenetic Puzzle Reinhold. G. Herrmann and Peter Westhoff | 1–28 | 3 |
| Pa | Summary I. Introduction II. Aspects of Chloroplast and Plant Genome Evolution—Plant Genome Structure III. Functional Consequences of Genome Rearrangement—Regulatory Lev IV. The Impact of Multicellularity and Terrestrial Life upon Thylakoid Biogen V. Maintenance and Acclimation of Thylakoids VI. Outlook—New Approaches Acknowledgments References **Tt II: Gene Expression and Signal Transduction** | 2 rels 11 | 1 3 |
| 2 | Plastid RNA Polymerases in Higher Plants Karsten Liere and Pal Maliga Summary I. Introduction II. The Plastid-Encoded Plastid RNA Polymerase (PEP) III. The Nuclear-Encoded Plastid RNA Polymerase (NEP) IV. The Role of NEP and PEP in Plastid Gene Expression V. Unsolved Mystery: tRNA Transcription Acknowledgments References | 29-49 30 31 39 43 44 44 | 9 0 1 9 3 3 4 |

| 3 | Gene Expression Michael Malakhov and Chris Bowler | 51–66 |
|---|--|--|
| | Summary I. Introduction II. Activation of Phytochrome and Other Photoreceptors III. Second Messengers in Phytochrome Signal Transduction IV. Genetic Approaches to Dissect Phytochrome Signaling V. Nuclear-Localized Components of the Light Signaling Machinery VI. Interactions Between Phytochrome and Other Signaling Pathways VII. Concluding Remarks Acknowledgments References | 51 52 52 53 54 57 61 62 62 63 |
| 4 | Regulating Synthesis of the Purple Bacterial Photosystem Carl E. Bauer | 67–83 |
| | Summary I. Introduction II. The Purple Bacterial Photosystem III. The Photosynthesis Gene Cluster IV. Regulating Photosystem Synthesis V. Concluding Statements Acknowledgment References | 67 68 68 69 70 79 79 |
| 5 | Redox Regulation of Photosynthetic Genes Gerhard Link | 85–107 |
| | Summary I. Introduction II. Redox Regulation of Nuclear Genes for Photosynthetic Proteins III. Redox Regulation of Gene Expression Inside the Chloroplast IV. Outlook Acknowledgments References | 85 86 89 93 100 102 |
| 6 | Sugar Sensing and Regulation of Photosynthetic Carbon Metabolism Uwe Sonnewald | 109–120 |
| | Summary I. Photosynthetic Carbon Metabolism in C ₃ Plants II. Sink Regulation of Photosynthesis III. Sugar Regulation of Gene Expression Acknowledgment References | 109 110 112 114 118 118 |

| | 21–126 |
|--|--|
| Summary I. Introduction II. RNA Editing in the Chloroplast III. Polyadenylation and Degradation of mRNA in the Chloroplast Acknowledgments References | 121 122 122 126 132 133 |
| Regulation of Chloroplast Translation 13 Aravind Somanchi and Stephen P. Mayfield | 37–151 |
| Summary I. Introduction II. Translation in the Chloroplast—An Overview III. Translational Regulation in the Chloroplast IV. Mechanism of Translational Activation V. Conclusions and Perspectives References | 137 138 138 139 145 147 |
| rt III: Biogenesis, Turnover and Senescence | |
| Proteins Involved in Biogenesis of the Thylakoid Membrane Klaas Jan van Wijk | 3–175 |
| Summary Introduction Chloroplast Proteins Involved in Targeting and Insertion into the Thylakoid Membrane Peptidases and Proteases Responsible for Processing and Turnover Proteins involved in Folding and Post-translational Modifications Proteins Assisting in Protein and Cofactor Transport, Storage and Ligation | |
| VII. Proteomics as a Tool for Identification of Proteins involved in Thylakoid Biogenesis VIII. Conclusions and Perspectives Acknowledgments References | 167 168 169 170 170 |
| Peptidyl-Prolyl Isomerases and Regulation of Photosynthetic | |
| Functions 17 Alexander V. Vener | 7–193 |
| Summary I. Introduction II. Structure and Function of Peptidyl-Prolyl Isomerases (PPlases) III. Plant PPlases | 177 178 179 184 |
| | Gadi Schuster and Ralph Bock Summary 1. Introduction 11. RNA Editing in the Chloroplast 111. Polyadenylation and Degradation of mRNA in the Chloroplast Acknowledgments References Regulation of Chloroplast Translation Aravind Somanchi and Stephen P. Mayfield Summary 1. Introduction 11. Translation in the Chloroplast—An Overview 111. Translational Regulation in the Chloroplast 11. Mechanism of Translational Activation V. Conclusions and Perspectives References It III: Biogenesis, Turnover and Senescence Proteins Involved in Biogenesis of the Thylakoid Membrane Klaas Jan van Wijk Summary 1. Introduction 11. Chloroplast Proteins Involved in Targeting and Insertion into the Thylakoid Membrane III. Peptidases and Proteases Responsible for Processing and Turnover IV. Proteins involved in Folding and Post-translational Modifications V. Proteins Assisting in Protein and Cofactor Transport, Storage and Ligatic VI. Vesicles Formation, Low Density Membranes and Tubules VII. Proteomics as a Tool for Identification of Proteins involved in Thylakoid Biogenesis VIII. Conclusions and Perspectives Acknowledgments References Peptidyl-Prolyl Isomerases and Regulation of Photosynthetic Functions Alexander V. Vener Summary 1. Introduction 11. Structure and Function of Peptidyl-Prolyl Isomerases (PPlases) |

| | IV. PPlases and Photosynthetic Function | 187 |
|----|---|---------|
| | References | 190 |
| 11 | Role of the Plastid Envelope in the Biogenesis of Chloroplast | |
| | Lipids | 195–218 |
| | Maryse A. Block, Eric Maréchal and Jacques Joyard | |
| | Summary | 195 |
| | I. Introduction | 196 |
| | Lipid Composition of Chloroplast Membranes | 197 |
| | III. Biosynthesis of Chloroplast Glycerolipids | 200 |
| | IV. Chlorophyll Biosynthesis | 208 |
| | V. Plastid Prenylquinone Biosynthesis | 209 |
| | VI. Transport of Lipids From ER to Chloroplasts and Between Chloropla | |
| | Membranes | 210 |
| | VII. Lipid Modifications of Proteins in Chloroplasts | 211 |
| | VIII. Conclusion | 213 |
| | Acknowledgment | 214 |
| | References | 214 |
| 12 | Pigment Assembly—Transport and Ligation | 219–233 |
| | Harald Paulsen | |
| | Summary | 219 |
| | I. Introduction | 220 |
| | II. Assembly of Chlorophyll a/b-Protein Complexes | 220 |
| | III. Assembly of Chlorophyll a-Protein Complexes | 222 |
| | IV. How are Pigments Synthesized and Transported? | 223 |
| | V. How Do Pigments Find Their Correct Binding Site? | 225 |
| | VI. Are Pigments Involved in the Assembly of Multi-protein Complexes | |
| | of the Photosynthetic Apparatus? | 228 |
| | Acknowledgments | 230 |
| | References | 230 |
| 13 | Chlorophyll Biosynthesis—Metabolism and Strategies of | |
| | Higher Plants to Avoid Photooxidative Stress | 235–252 |
| | Klaus Apel | |
| | Summary | 235 |
| | I. Introduction | 236 |
| | II. Tetrapyrrole Biosynthesis and Photooxidative Stress | 236 |
| | III. Regulatory Steps in Tetrapyrrole Biosynthesis | 239 |
| | Tetrapyrrole Derivatives as Plastid Signals | 247 |
| | V. Outlook | 249 |
| | Acknowledgments | 249 |
| | References | 249 |
| 14 | Transport of Metals: A Key Process in Oxygenic Photosynthesis | 253-264 |
| | Himadri Pakrasi, Teruo Ogawa and Maitrayee Bhattacharrya-Pak | |
| | Summary | 253 |
| | I. Introduction | 254 |

| | II. Different Classes of Transporters III. Iron IV. Copper V. Manganese VI. Zinc VII. Magnesium VIII. Concluding Remarks Acknowledgments References | 254 257 258 259 260 261 262 262 262 |
|----|---|---|
| 15 | Chloroplast Proteases and Their Role in Photosynthesis Regulation Zach Adam | 265–276 |
| | Summary I. Introduction II. Substrates for Proteolysis III. Proteolytic Enzymes IV. Conclusions and Future Prospects Acknowledgments References | 265 266 268 271 273 273 |
| 16 | Senescence and Cell Death in Plant Development: Chloroplast Senescence and its Regulation Philippe Matile | 277–296 |
| | Summary I. Introduction II. Leaf Senescence III. Biochemistry of Breakdown in Senescing Chloroplasts IV. Programmed Cell Death V. Outlook References | 277 278 278 281 287 290 291 |
| Pa | rt IV: Regulation of Carbon Metabolism | |
| 17 | Dynamics of Photosynthetic CO₂ Fixation: Control, Regulation and Productivity Steven Gutteridge and Douglas B. Jordan | 297–312 |
| | Summary I. Crop Yields, Land Use and Population Growth II. Photosynthesis—Light, Capture, Action III. Modulating Rubisco Activity and the Response of Photosynthetic | 297 298 298 |
| | CO ₂ -fixation in planta IV. Modulating Activities of Other Enzymes of the PCR Cycle V. C ₄ Metabolism VI. Concluding Remarks Acknowledgment References | 303 305 307 309 310 310 |

| 18 | Chloroplastic Carbonic Anhydrases Göran Samuelsson and Jan Karlsson | 313–320 |
|----|---|---|
| | Summary I. Introduction II. Gene Families III. Structure IV. Inhibitors V. Carbonic anhydrase catalysed functions in Chloroplasts References | 313 314 314 315 316 316 |
| 19 | Thioredoxin and Glutaredoxin: General Aspects and Involvement in Redox Regulation Arne Holmgren | 321–330 |
| | Summary I. Introduction II. Thioredoxins III. Thioredoxin Reductases IV. Glutaredoxins Acknowledgments References | 321 322 322 325 326 329 329 |
| 20 | The Structure and Function of the Ferredoxin/Thioredoxin System in Photosynthesis Peter Schürmann and Bob B. Buchanan | 331–361 |
| | Summary I. Introduction II. Biochemical Setting for Thioredoxin-Linked Regulation III. Thioredoxin Regulated Processes IV. Structure and Function of the Proteins in the Regulatory Chain V. Target Enzymes VI. Mechanism for Reduction of Thioredoxins and Target Enzymes VII. Phylogenetic History of Thioredoxins and Photosynthetic Target Enzy VIII. Concluding Remarks Acknowledgments References | 332 333 333 334 343 350 mes 353 353 355 |
| 21 | Reversible Phosphorylation in the Regulation of Photosynthetic Phosphoenolpyruvate Carboxylase in C ₄ Plants Jean Vidal, Sylvie Coursol, Jean-Noël Pierre | 363–375 |
| | Summary I. Introduction II. C ₄ Phosphoenolpyruvate Carboxylase (PEPC) in the Physiological Context of C ₄ Photosynthesis III. Properties of C ₄ PEPC IV. C ₄ PEPC Activity is Reversibly Modulated in vivo by a Regulatory | 363 364 364 364 |
| | Phosphorylation Cycle | 366 |

| Ра | rt V: Acclimation and Stress Responses | |
|----|--|---|
| 22 | Photodamage and D1 Protein Turnover in Photosystem II Bertil Andersson and Eva-Mari Aro Summary I. Introduction II. Light-induced Inactivation and Damage to the Photosystem II Reaction Center III. Proteolysis of the Damaged D1 Protein IV. Location of Photosystem II Damage and Repair in the Thylakoid Memb V. Biogenesis and Assembly of the New D1 Copy into Photosystem II Acknowledgments References | 377–393 377 378 378 381 381 386 390 390 |
| 23 | Phosphorylation of Photosystem II Proteins Eevi Rintamäki and Eva-Mari Aro | 395–418 |
| | Summary Introduction Thylakoid Phosphoproteins Reversible Phosphorylation of Thylakoid Proteins Photosystem II and Light-Harvesting Complex II Protein Phosphorylation | 395 396 398 on in 406 407 411 412 412 |
| 24 | Novel Aspects on the Regulation of Thylakoid Protein Phosphorylation Itzhak Ohad, Martin Vink, Hagit Zer, Reinhold G. Herrmann and Bertil Andersson | 119–432 |
| | Summary Introduction Redox Control of Thylakoid Protein Phosphorylation Role of Thiol Redox State in Kinase Activation/Deactivation Process in Isolated Thylakoids Light-Induced Modulation of Thylakoid Protein Phosphorylation at the Substrate Level Thylakoid Protein Dephosphorylation and its Regulation Thylakoid Protein Phosphorylation and State Transition: Open Question Acknowledgments References | 419 420 420 424 425 427 ns 427 429 429 |

V. Significance of the Regulatory Phosphorylation of C₄ PEPC VI. Conclusions and Perspectives

References

370 373 373

| 25 | Conversion Marie Eskling, Anna Emanuelsson and Hans-Erik Åkerlund | 433–452 |
|----|--|---|
| | Summary I. Introduction II. The Xanthophyll Cycle, Enzymes and Pigments III. The Conversion of Violaxanthin Depends on Temperature and Light IV. The Role of the Xanthophyll Cycle Acknowledgments References | 433 434 434 441 442 447 |
| 26 | The PsbS Protein: A Cab-Protein with a Function of Its Own Christiane Funk | 453–467 |
| | Summary I. Introduction II. Early History of the PsbS Protein: A Mysterious Protein in Photosystel III. The psbS Gene and Gene Product IV. Pigment Binding V. The PsbS Protein: An Early Ligh Induced Protein or Light Harvesting Protein or a Protein of Its Own? VI. The Function of the PsbS Protein VII. Conclusion Acknowledgments References | 453 454 456 457 458 459 463 464 465 |
| 27 | Redox Sensing of Photooxidative Stress and Acclimatory Mechanisms in Plants Stanislaw Karpinski, Gunnar Wingsle, Barbara Karpinska and Jan-Erik Hällgren | 469–486 |
| | Summary I. Introduction II. Stress and Acclimation III. Concluding Remarks Acknowledgments References | 469 470 470 482 482 482 |
| 28 | The Elip Family of Stress Proteins in the Thylakoid Membranes of Pro- and Eukaryota Iwona Adamska | 487–505 |
| | Summary I. Introduction II. What is an Elip? Past and Present Definitions III. Division of Elip Family Based on Predicted Protein Structure IV. Genomic Organization of Elip Family in Arabidopsis thaliana V. Similarities and Differences Between the Elip and Cab Gene Families VI. Are Elips Chlorophyll-Binding Proteins? | 487 488 488 490 495 495 |

| | VII. Possible Physiological Functions of Elip Family Members VIII. Evolutionary Aspects IX. Concluding Remarks Acknowledgments References | 500 502 502 502 503 |
|----|---|---|
| 29 | Regulation, Inhibition and Protection of Photosystem I Yukako Hihara and Kintake Sonoike | 507–531 |
| | Summary I. Introduction II. Regulation of the Quantity of PS I III. Regulation of the Activity of PS I IV. Regulation of PS I Expression V. Inhibition of PS I by Environmental Factors VI. Protection of Photosystem I from Photoinhibition VII. Concluding Remarks Acknowledgments References | 508 508 509 513 513 519 521 524 525 |
| 30 | Regulation of Photosynthetic Electron Transport Peter J. Nixon and Conrad W. Mullineaux | 533–555 |
| | Summary I. Introduction II. Background Concepts III. Feedback Control of the Photosynthetic Electron Transport Chain IV. Regulation of Photosystem II Activity—The Bicarbonate Effect V. Cyclic Electron Flow VI. Chlororespiration and Cyanobacterial Respiration VII. Interaction between Chloroplasts and Mitochondria VIII. Questions for the Future References | 534 534 535 537 540 541 547 548 549 |
| | rt VI: Photosynthetic Regulation and Genomics—Method plications for the Future | ological |
| 31 | Functional Genomics in <i>Synechocystis</i> sp. PCC6803: Resources for Comprehensive Studies of Gene Function and Regulation Takakazu Kaneko and Satoshi Tabata | 557–561 |
| | Summary I. Introduction II. CyanoBase and CyanoMutants—Genome Information Databases III. Genome-wide Monitoring of Gene Expression by Proteome and | 557 557 558 |
| | Transcriptome Analyses References | 559 561 |

| 32 | Post-Genome Era Wolf-Rüdiger Scheible, Todd A. Richmond, lain W. Wilson and Chris R. Somerville | 3–592 |
|------|---|--|
| | Summary I. Introduction II. Arabidopsis Expressed Sequence Tags and Genome Sequencing Project III. Classical Arabidopsis Genetics in the Post-Genome Era IV. Assigning Gene Functions Using the Tools of Functional Genomics V. Reverse Arabidopsis Genetics VI. Conclusions and Outlook Acknowledgments References | 563 564 5 565 571 575 582 585 585 |
| Inde | ex | 593 |