

Photosynthesis: Physiology and Metabolism

Edited by

Richard C. Leegood

*Robert Hill Institute,
University of Sheffield,
United Kingdom*

Thomas D. Sharkey

*Department of Botany,
University of Wisconsin,
U.S.A.*

and

Susanne von Caemmerer

*Research School of
Biological Sciences,
Australian National University,
Australia*



KLUWER ACADEMIC PUBLISHERS
DORDRECHT / BOSTON / LONDON

Contents

Preface	xiii
Color Plates	CP1
1 Introduction	1–8
<i>Richard C. Leegood, Thomas D. Sharkey and Susanne von Caemmerer</i>	
Summary	1
I. An Overview of Pathways and Mechanisms	2
II. The Impact of Genetic Manipulation	6
References	7
2 The Calvin Cycle and Its Regulation	9–51
<i>William Martin, Renate Scheibe and Claus Schnarrenberger</i>	
Summary	10
I. Introduction	10
II. The Enzymes of the Calvin Cycle	12
III. Calvin Cycle Gene Organization, Expression, and Regulation in Eubacteria	19
IV. Calvin Cycle Expression in Plants	20
V. Enzyme Interactions and Multienzyme-like Complexes	28
VI. Biochemical Regulation in Chloroplasts	31
VII. Studies of Calvin Cycle Enzymes with Antisense RNA	34
VIII. Concluding Remarks	35
Acknowledgment	36
References	36
3 Rubisco: Assembly and Mechanism	53–83
<i>Harry Roy and T. John Andrews</i>	
Summary	54
I. Introduction	54
II. Rubisco's Discordant Molecular Phylogeny	56
III. The Folding and Assembly of Rubisco	56
IV. The Catalytic Mechanism of Rubisco	60
V. Conclusion	77
References	77
4 Rubisco: Physiology in Vivo	85–113
<i>Susanne von Caemmerer and W. Paul Quick</i>	
Summary	86
I. Introduction	86
II. Rubisco and CO ₂ Assimilation Rate, a Quantitative Relationship	86
III. In Vivo Regulation of Rubisco Carbamylation and Activity	96

	IV. Rubisco Content of Leaves of Plants Grown in Different Environmental Conditions	101
	V. Rubisco and C ₄ Photosynthesis	103
	VI. Rubisco and CAM Photosynthesis	105
	VII. The Role of Rubisco in C ₃ -C ₄ Intermediates	106
	VIII. Conclusion	107
	References	107
5	Photorespiration	115–136
	<i>Roland Douce and Hans-Walter Heldt</i>	
	Summary	115
	I. Introduction	116
	II. The Photorespiratory Pathway	116
	III. Glycine Oxidation	121
	IV. Transfer of Reducing Equivalents from the Mitochondria and the Chloroplasts to the Peroxisomes	128
	V. The Compartmentation of Peroxisomal Metabolism	130
	VI. Transfer of Metabolites Across the Peroxisomal Boundary Membrane	130
	VII. Concluding Remarks	131
	Acknowledgments	132
	References	132
6	Metabolite Transport Across the Chloroplast Envelope of C₃-Plants	137–152
	<i>Ulf-Ingo Flügge</i>	
	Summary	137
	I. Introduction	138
	II. Plastidic Phosphate Translocators	138
	III. Transport of Glucose	144
	IV. Dicarboxylate Translocators	145
	V. Transport of Nucleotides	147
	VI. Other Translocators	147
	VII. Channels in Chloroplast Envelope Membranes	148
	VIII. Concluding Remarks	149
	Acknowledgments	150
	References	150
7	Photosynthesis, Carbohydrate Metabolism and Respiration in Leaves of Higher Plants	153–175
	<i>O. K. Atkin, A. H. Millar, P. Gardeström and D. A. Day</i>	
	Summary	154
	I. Introduction	154
	II. Supply and Utilization of Mitochondrial Substrates in Leaves	155
	III. Mitochondrial Function in the Light and Dark	160
	IV. Nitrogen Metabolism, Photosynthesis and Respiration	168
	References	170

8	Regulation of Carbon Fluxes in the Cytosol: Coordination of Sucrose Synthesis, Nitrate Reduction and Organic Acid and Amino Acid Biosynthesis	177–203
	<i>Christine H. Foyer, Sylvie Ferrario-Méry and Steven C. Huber</i>	
	Summary	178
	I. Introduction	178
	II. Sucrose-P Synthase	184
	III. Phosphoenolpyruvate Carboxylase	190
	IV. Nitrate Reductase	192
	V. Glutamine Synthetase and Glutamate Synthase	195
	VI. Plasma Membrane H ⁺ -ATPase	197
	VII. Conclusions	197
	Acknowledgment	199
	References	199
9	Starch Metabolism in Leaves	205–231
	<i>Richard N. Trethewey and Alison M. Smith</i>	
	Summary	206
	I. Introduction	206
	II. The Occurrence and Function of Transitory Starch	206
	III. The Structure of Transitory Starch	208
	IV. The Synthesis of Transitory Starch	210
	V. The Degradation of Transitory Starch	218
	VI. Conclusions	225
	Acknowledgments	225
	References	225
10	Control of Photosynthesis, Allocation and Partitioning by Sugar Regulated Gene Expression	233–248
	<i>Ian A. Graham and Thomas Martin</i>	
	Summary	233
	I. Introduction	234
	II. Carbohydrate Regulation of Gene Expression in Source and Sink Tissues	234
	III. Influence of Other Metabolites on Sugar Regulated Genes	236
	IV. Hormones and Sugar Regulation	237
	V. Sugar Sensing	238
	VI. Signal Transduction	243
	VII. Sugar Response Elements in Gene Promoters	244
	VIII. Sugar Sensing Mutants	244
	IX. Conclusions	245
	References	245

11	Intercellular Transport and Phloem Loading of Sucrose, Oligosaccharides and Amino Acids	249–274
	<i>Christian Schobert, William J. Lucas, Vincent R. Franceschi and Wolf B. Frommer</i>	
	Summary	249
	I. Introduction	250
	II. Photoassimilate Movement from the Mesophyll to the Phloem	250
	III. Phloem Loading	260
	IV. Regulation of Assimilate Export	265
	V. Conclusions	270
	Acknowledgments	270
	References	270
12	Regulation of Sugar Alcohol Biosynthesis	275–299
	<i>Wayne H. Loescher and John D. Everard</i>	
	Summary	275
	I. Introduction	276
	II. Primary Physiological Roles	276
	III. Metabolism	279
	IV. Developmental Regulation and Primary Roles	282
	V. Localization of Synthetic and Degradative Steps	283
	VI. Membrane Transport	283
	VII. Secondary Physiological Roles	284
	VIII. Regulation at the Molecular Level	289
	IX. Conclusions and Considerations for Future Research	292
	Acknowledgments	292
	References	293
13	Fructans: Synthesis and Regulation	301–320
	<i>A. J. Cairns, C. J. Pollock, J. A. Gallagher and J. Harrison</i>	
	Summary	301
	I. Introduction	302
	II. The Distribution and Structure of Fructan	302
	III. Physiology and Enzymology of Fructan Metabolism	303
	IV. The Control of Fructan Metabolism	311
	V. Fructan Biosynthesis in Transgenic Plants: A Physiological Perspective	315
	VI. Concluding Remarks	317
	Acknowledgement	318
	References	318
14	Acquisition and Diffusion of CO₂ in Higher Plant Leaves	321–351
	<i>John R. Evans and Francesco Loreto</i>	
	Summary	322
	I. Introduction	322
	II. Boundary Layer—CO ₂ Diffusion to the Leaf Surface	323
	III. Stomata—CO ₂ Diffusion into the Leaf	325

IV. Internal—CO ₂ Diffusion Within the Leaf	330
V. C ₄	344
Acknowledgments	346
References	346
15 Carbonic Anhydrase and Its Role in Photosynthesis	353–367
<i>John R. Coleman</i>	
Summary	353
I. Introduction	354
II. Enzyme Types, Structures And Kinetics	354
III. Localization, Regulation of Expression and Role	356
References	365
16 CO₂ Acquisition, Concentration and Fixation in Cyanobacteria and Algae	369–397
<i>Murray R. Badger and Martin H. Spalding</i>	
Summary	370
I. Supply of CO ₂ in an Aquatic Environment	370
II. Efficient CO ₂ Capture Mechanisms Evolved Following Changes in Atmospheric CO ₂ and O ₂	371
III. Co-Evolution of CCMs and Rubisco	372
IV. Operation of CCMs in Cyanobacteria	376
V. Components and Adaptation of the CCM in Green Microalgae	381
VI. Diversity of CCM Function in Green and Non-Green Algae	387
References	391
17 Photosynthetic Fractionation of Carbon Isotopes	399–434
<i>Enrico Brugnoli and Graham D. Farquhar</i>	
Summary	400
I. Introduction	400
II. Carbon Isotopes in Nature—The Global Carbon Cycle	401
III. Definitions	402
IV. Photosynthetic Fractionation of Carbon Isotopes	405
V. Variation in Isotope Composition Within the Plant	414
VI. Carbon Isotope Discrimination and the Ratio of Intercellular and Atmospheric Partial Pressures of CO ₂	417
VII. Water Use-Efficiency, Productivity and D in C ₃ Species	422
VIII. Carbon Isotope Discrimination and Physiological Ecology of Photosynthesis	425
IX. Concluding Remarks	426
Acknowledgments	426
References	426
18 C₄ Photosynthesis: Mechanism and Regulation	435–457
<i>Robert T. Furbank, Marshall D. Hatch and Colin L. D. Jenkins</i>	
Summary	435
I. Introduction	435
II. Mechanism and Function of C ₄ Photosynthesis	436

III. Regulation of Individual Enzymes	439
IV. Integrated Regulation of C ₄ Photosynthesis	448
References	453
19 Transport During C₄ Photosynthesis	459–469
<i>Richard C. Leegood</i>	
Summary	459
I. Introduction	459
II. Intercellular Metabolite Transport in C ₄ Plants	460
III. Gaseous Fluxes Between Bundle-Sheath and Mesophyll	463
IV. Intracellular Metabolite Transport in C ₄ Plants	464
V. Concluding Remarks	467
References	467
20 Developmental Aspects of C₄ Photosynthesis	471–495
<i>Nancy G. Dengler and William C. Taylor</i>	
Summary	471
I. Introduction	472
II. Formation of Tissue Pattern	475
III. Cell Pattern within Tissues	476
IV. Bundle Sheath and Mesophyll Cell Structural Differentiation	477
V. Compartmentation of Photosynthesis	481
VI. Gene Regulation Mechanisms	483
VII. Future Directions and Model Experimental Systems	490
Acknowledgments	491
References	491
21 The Physiological Ecology of C₄ Photosynthesis	497–532
<i>Rowan F. Sage and Robert W. Pearcy</i>	
Summary	498
I. Introduction	499
II. Physiological Considerations	499
III. Primary Environmental Controls—Temperature and Light	507
IV. Secondary Environmental Controls—Water Supply, Salinity, Nitrogen	514
V. The Functional Role of Photosynthetic Subtype	521
VI. C ₄ Photosynthesis in the Future	522
VII. Conclusion: C ₄ Plants and the Human Factor	525
Acknowledgment	526
References	526
22 CO₂ Assimilation in C₃-C₄ Intermediate Plants	533–550
<i>Russell K. Monson and Stephen Rawsthorne</i>	
Summary	533
I. Introduction	534
II. The Distribution of C ₃ -C ₄ Intermediates and the Advantages of CO ₂ Assimilation in C ₃ -C ₄ Plants	534

III. Photorespiratory Metabolism and Compartmentation in C ₃ Versus C ₃ -C ₄ Intermediate Species	535
IV. C ₃ -C ₄ Gas-Exchange Patterns as a Result of the Unique Compartmentation of Photorespiratory Metabolism	537
V. The Biochemical Intermediacy of <i>Flaveria</i> C ₃ -C ₄ Intermediates and its Relationship to Reductions in Photorespiration	541
VI. Intercellular Metabolite Movement in C ₃ -C ₄ Leaves	543
VII. Carbon Isotope Discrimination Patterns in C ₃ -C ₄ Intermediates	544
VIII. C ₃ -C ₄ Intermediates and the Evolution of C ₄ Photosynthesis	545
IX. Concluding Statement	547
References	548
23 Induction of Crassulacean Acid Metabolism—Molecular Aspects	551–582
<i>John C. Cushman, Tahar Taybi and Hans J. Bohnert</i>	
Summary	551
I. Introduction	552
II. Permutations and Metabolic Plasticity of CAM	553
III. Control of CAM Induction	553
IV. Genes, Transcripts, and Proteins	560
V. Regulation of CAM Gene Expression	561
VI. Signal Transduction	566
VII. Future Prospects	571
VIII. Conclusions	573
Acknowledgments	573
References	574
24 Ecophysiology of Plants with Crassulacean Acid Metabolism	583–605
<i>Anne M. Borland, Kate Maxwell and Howard Griffiths</i>	
Summary	583
I. Introduction: Traditional Understanding and Approaches	584
II. H ₂ O: Cellular Limitations Imposed by Deficit and Excess	586
III. CAM as a Carbon Concentrating Mechanism: Morphological and Biochemical Considerations	588
IV. Daily Integration of Environmental Conditions	593
V. Seasonal Integration of CAM Performance and Productivity	596
Acknowledgments	601
References	601
Index	607