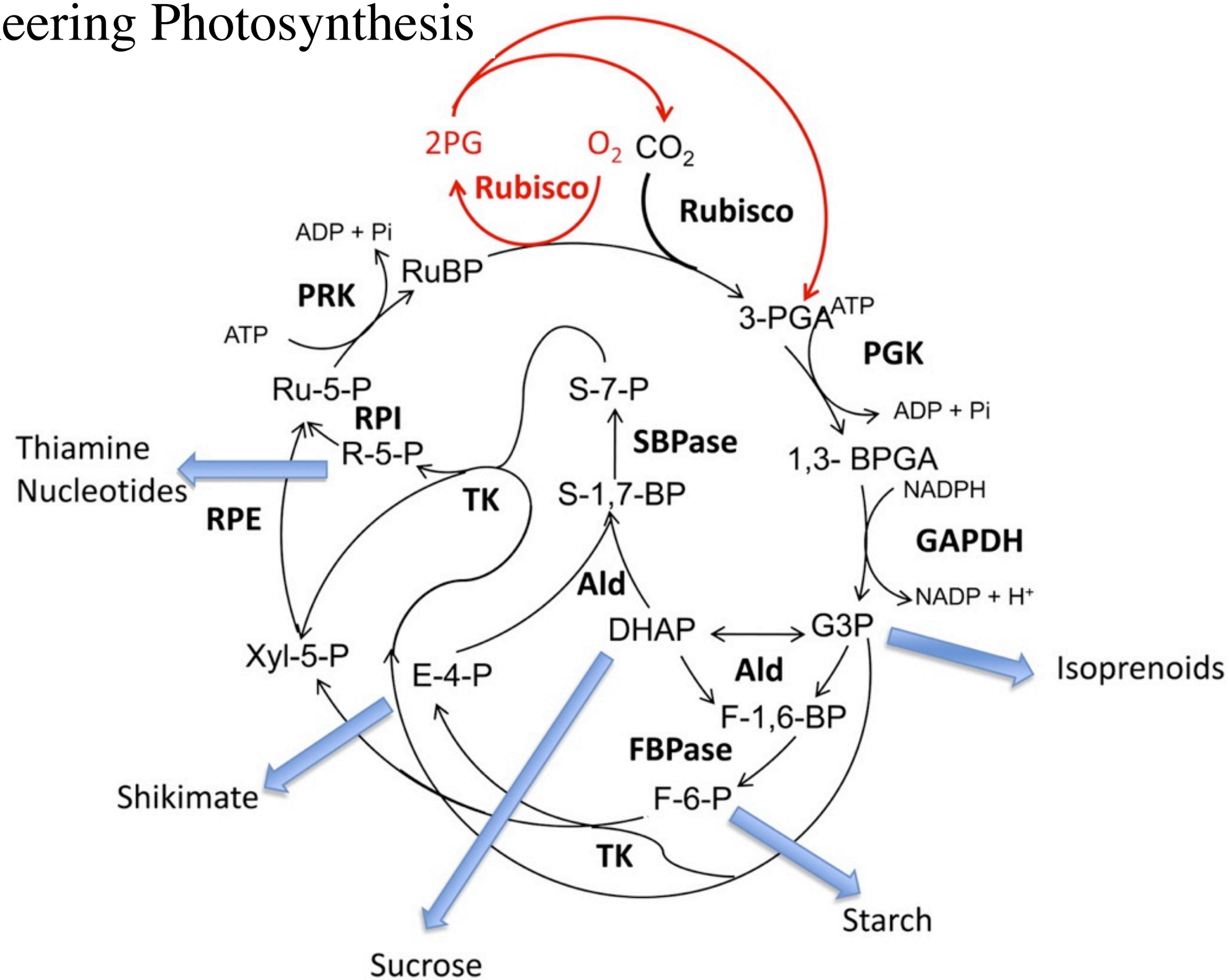
Bioengineering Photosynthesis



Increasing Photosynthetic Carbon Assimilation in C_3 Plants to Improve Crop Yield: Current and Future Strategies.
By Christine A. Raines Plant Physiology January 2011 vol. 155 no. 1 36-42

The C_3 cycle. The carboxylation reaction catalyzed by Rubisco fixes CO_2 into the acceptor molecule RuBP, forming 3-PGA. The reductive phase of the cycle follows with two reactions catalyzed by 3-PGA kinase (PGK) and GAPDH, producing G-3-P. The G-3-P enters the regenerative phase catalyzed by aldolase (Ald) and either FBPase or SBPase, producing Fru-6-P (F-6-P) and sedoheptulose-7-P (S-7-P). Fru-6-P and sedoheptulose-7-P are then utilized in reactions catalyzed by TK, R-5-P isomerase (RPI), and ribulose-5-P (Ru-5-P) epimerase (RPE), producing Ru-5-P. The final step converts Ru-5-P to RuBP, catalyzed by PRK. The oxygenation reaction of Rubisco fixes O_2 into the acceptor molecule RuBP, forming PGA and 2-phosphoglycolate (2PG), and the process of photorespiration (shown in red) releases CO_2 and PGA. The five export points from the pathway are shown with blue arrows.

Bioengineering Photosynthesis

OPINION PAPER

Christoph Peterhansel, Christian Blume, and Sascha Offermann
Photorespiratory bypasses: how can they work?
J. Exp. Bot. (2013) 64 (3): 709-715 doi:10.1093/jxb/ers247

REVIEW PAPERS

Martin A. J. Parry, P. John Andralojc, Joanna C. Scales, Michael E. Salvucci, A. Elizabete Carmo-Silva, Hernan Alonso, and Spencer M. Whitney
Rubisco activity and regulation as targets for crop improvement
J. Exp. Bot. (2013) 64 (3): 717-730 doi:10.1093/jxb/ers336

Maureen R. Hanson, Benjamin N. Gray, and Beth A. Ahner
Chloroplast transformation for engineering of photosynthesis
J. Exp. Bot. (2013) 64 (3): 731-742 doi:10.1093/jxb/ers325

Veronica G. Maurino and Andreas P. M. Weber
Engineering photosynthesis in plants and synthetic microorganisms
J. Exp. Bot. (2013) 64 (3): 743-751 doi:10.1093/jxb/ers263

G. Dean Price, Jasper J.L. Pengelly, Britta Forster, Jiahui Du, Spencer M. Whitney, Susanne von Caemmerer, Murray R. Badger, Susan M. Howitt, and John R. Evans
The cyanobacterial CCM as a source of genes for improving photosynthetic CO2 fixation in crop species
J. Exp. Bot. (2013) 64 (3): 753-768 doi:10.1093/jxb/ers257

Moritz Meyer and Howard Griffiths
Origins and diversity of eukaryotic CO2-concentrating mechanisms: lessons for the future
J. Exp. Bot. (2013) 64 (3): 769-786 doi:10.1093/jxb/ers390

Jan Zarzycki, Seth D. Axen, James N. Kinney, and Cheryl A. Kerfeld
Cyanobacterial-based approaches to improving photosynthesis in plants
J. Exp. Bot. (2013) 64 (3): 787-798 doi:10.1093/jxb/ers294

Fanny Ramel, Alexis S. Mialoundama, and Michel Havaux
Nonenzymic carotenoid oxidation and photooxidative stress signalling in plants
J. Exp. Bot. (2013) 64 (3): 799-805 doi:10.1093/jxb/ers223

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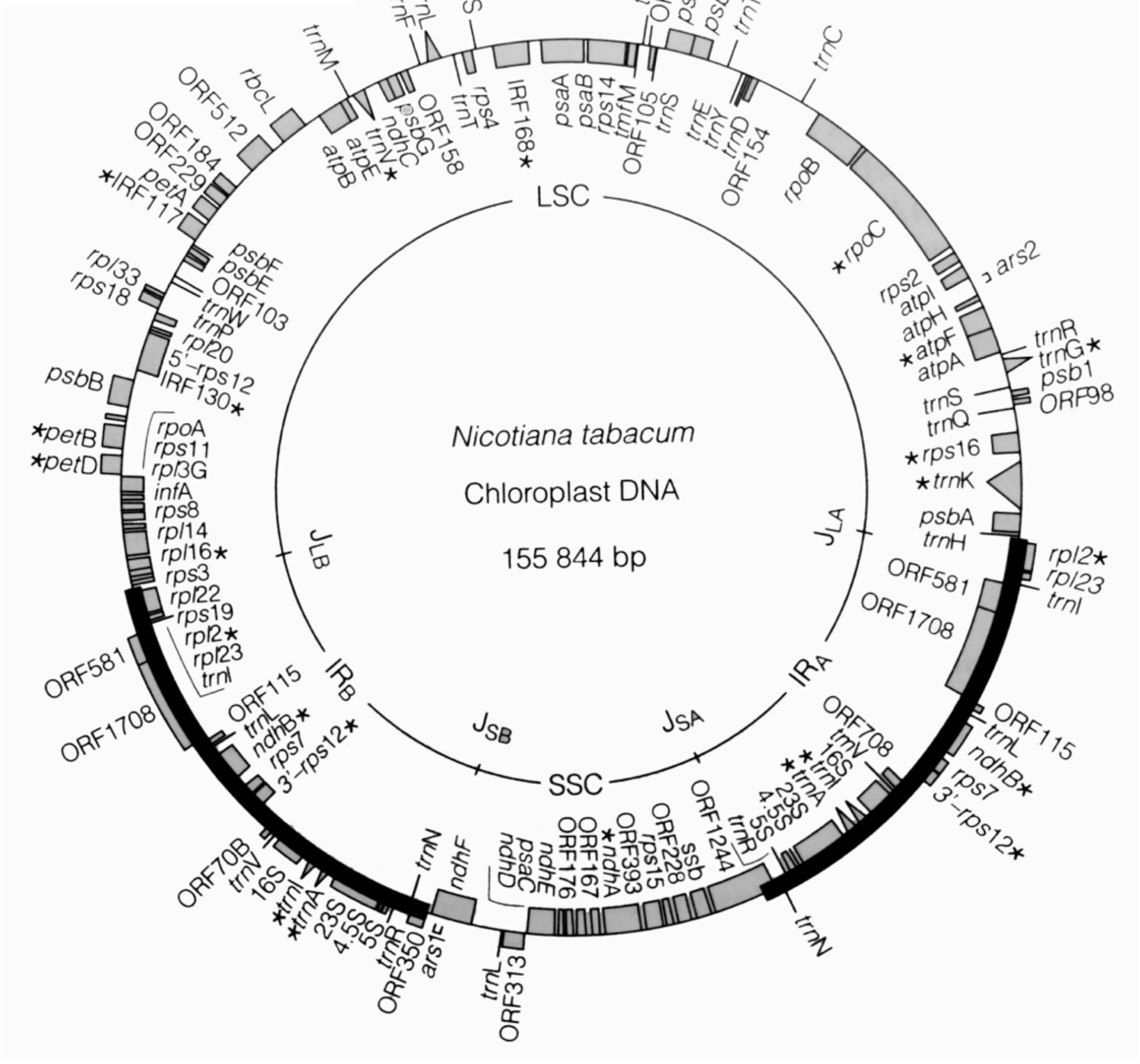
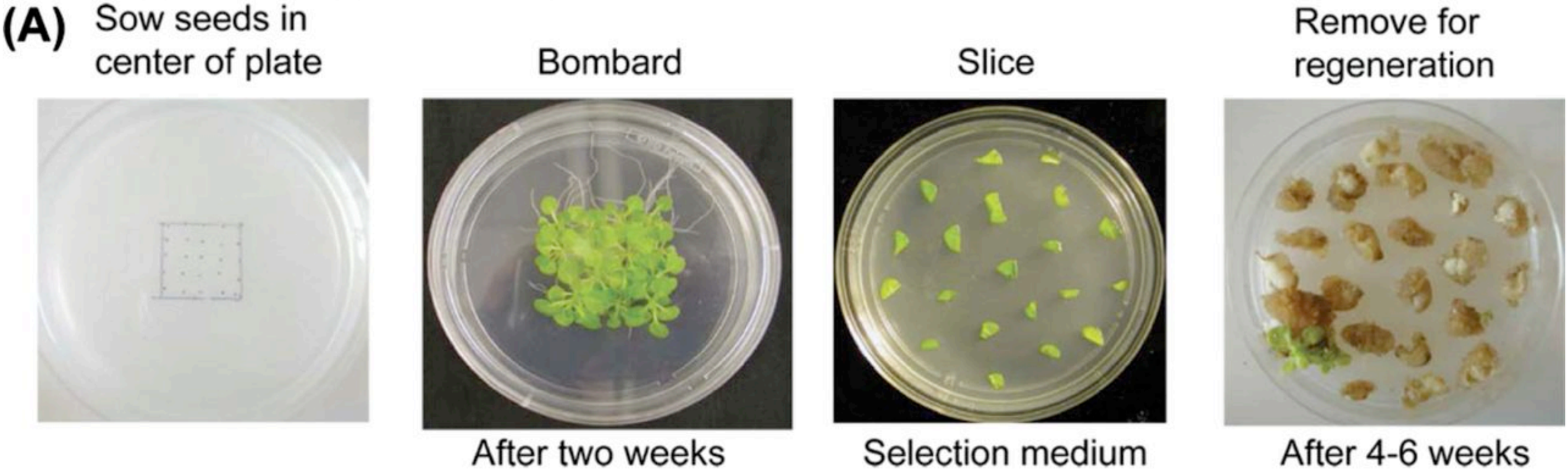


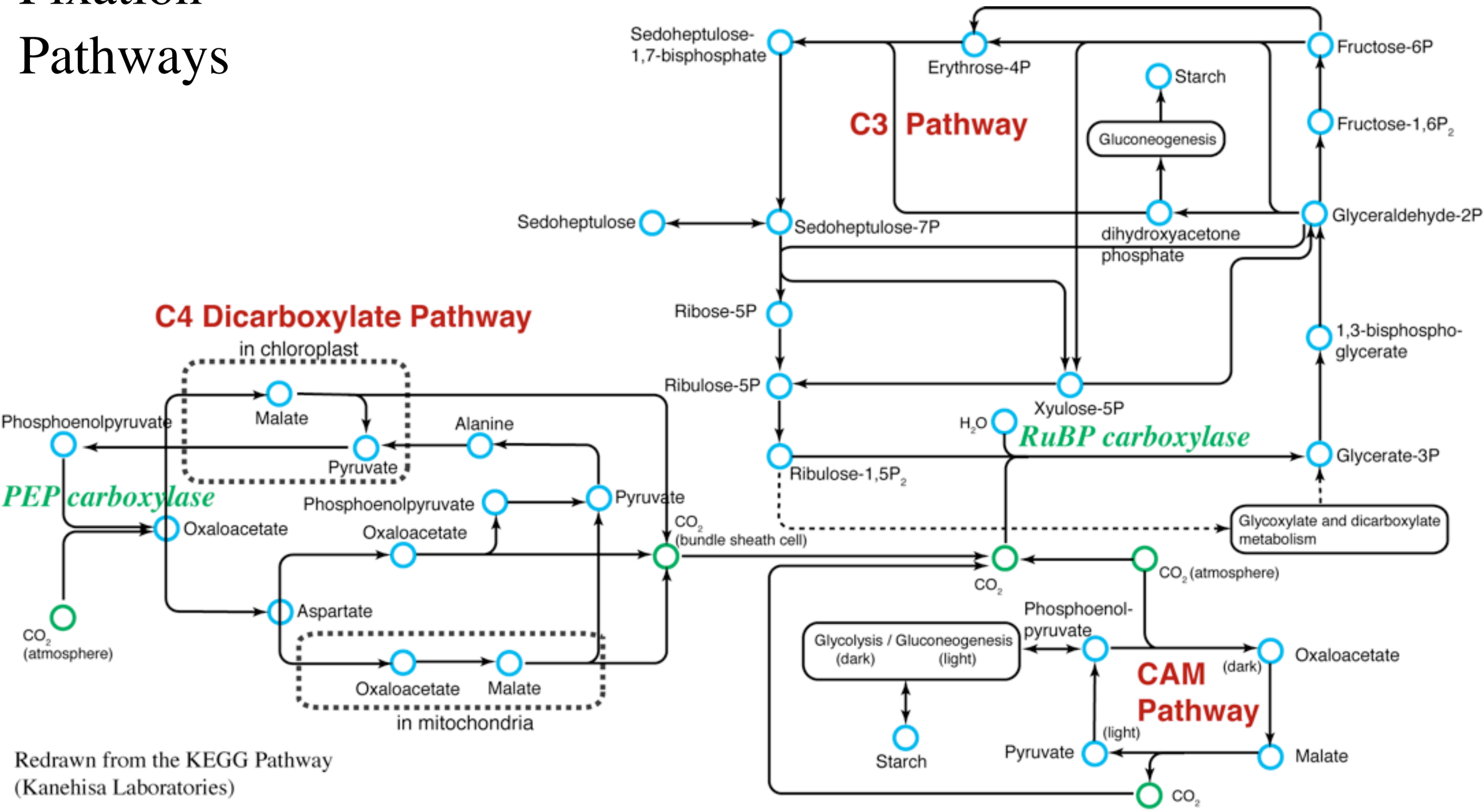
Bioengineering Photosynthesis



Chloroplast transformation for engineering of photosynthesis. By Maureen R. Hanson, Benjamin N. Gray and Beth A. Ahner. Journal of Experimental Botany (2013) Volume 64. Pages 731-742.

Plastid transformation. (A) Steps in generating tobacco transplastomic plants are illustrated. Young seedlings growing on culture media are bombarded with gold particles and leaf slices are then placed on spectinomycin selection medium. Initial regenerants often require a second round of selection in order to obtain homoplasmic transplastomic plants, though we have sometimes obtained homoplasmic transgenic plants after the first round of selection. (B) A typical plastid transformation vector ptrnI-RT is designed for transgene insertion between the plastid *trnI* and *trnA* genes of the rRNA operon in the inverted repeat of the plastid genome. A multi-cloning site is included between the T7g10 5′ untranslated region (UTR) and *psbA* 3′ UTR for transgene regulation, and an *aadA* expression cassette flanked by *loxP* sites is included for spectinomycin-/streptomycin-based selection of plastid transformants. A similar vector was used for expression of Cel6A and BglC in transgenic tobacco (Gray *et al.*, 2009, 2011).

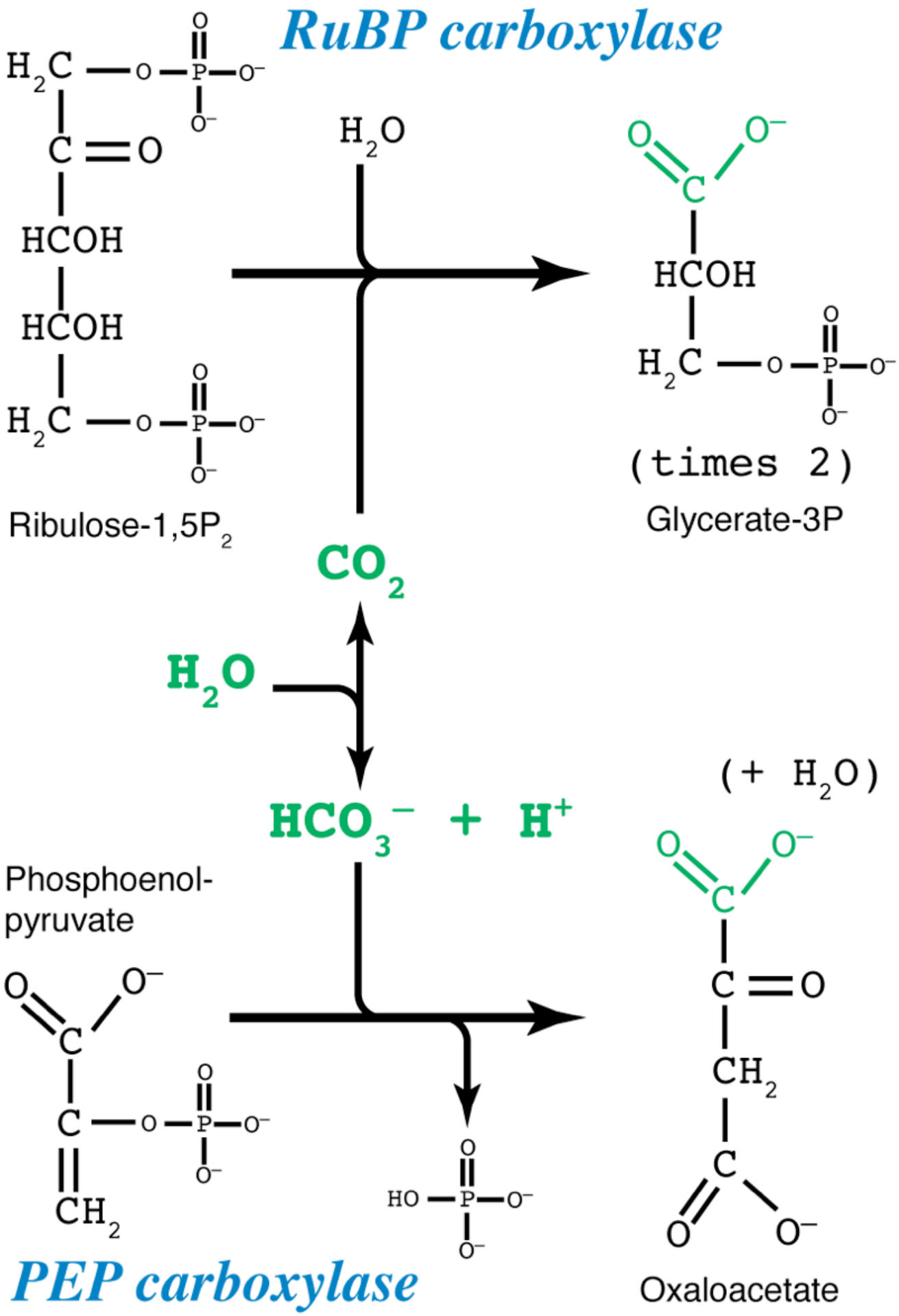
Carbon Fixation Pathways



Redrawn from the KEGG Pathway
(Kanehisa Laboratories)

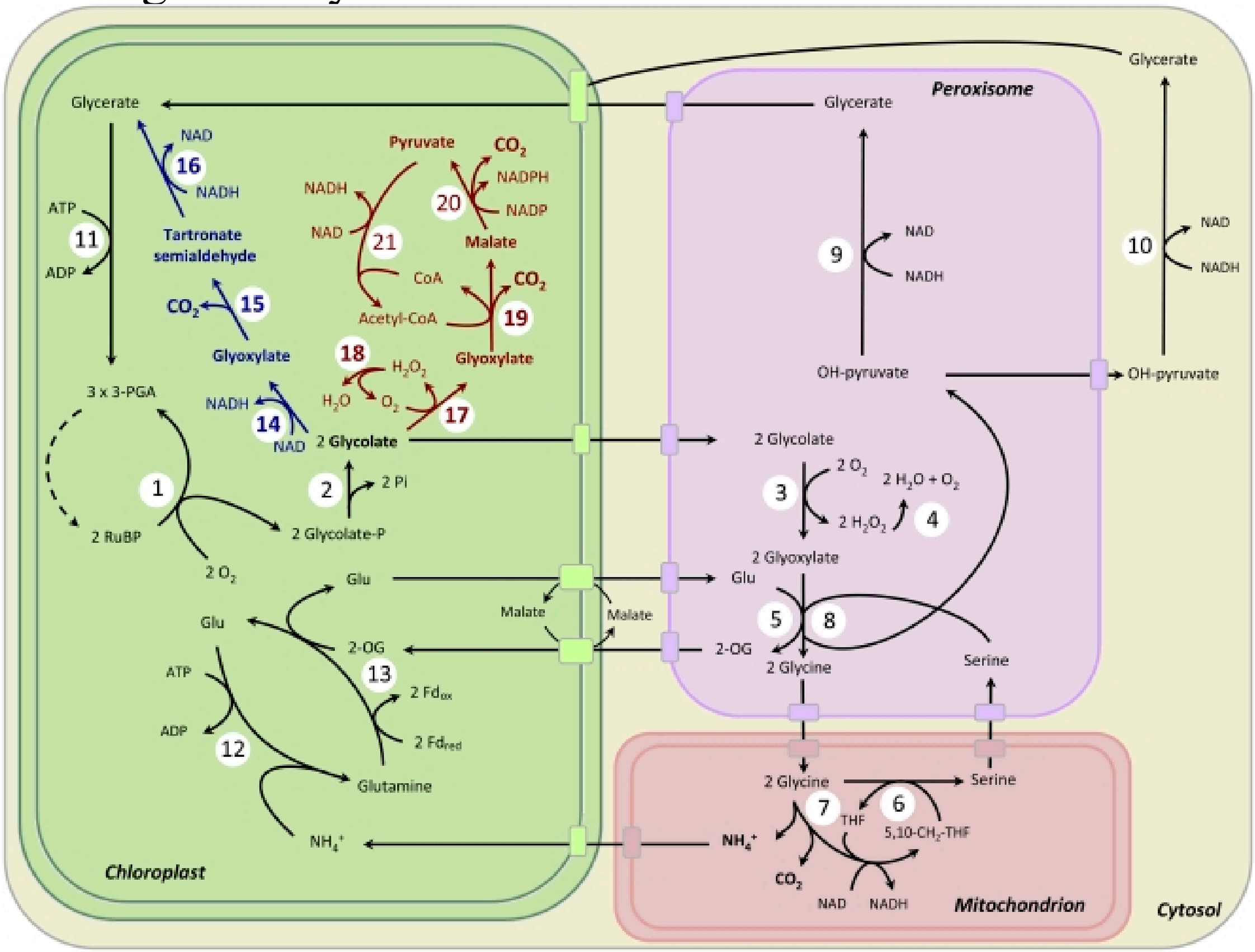
Kanehisa and his lab have created a really useful metabolic map of carbon dioxide fixation and cycles. The diagram is re-drawn from the original, which includes EC numbers and links to enzyme properties.

Carbon Fixation Pathways



These are the crucial enzymes: RuBisCO for C3 carbon fixation, PEPCase for C4 carbon fixation. Note that the carbon substrates are completely different (carbon dioxide versus bicarbonate)

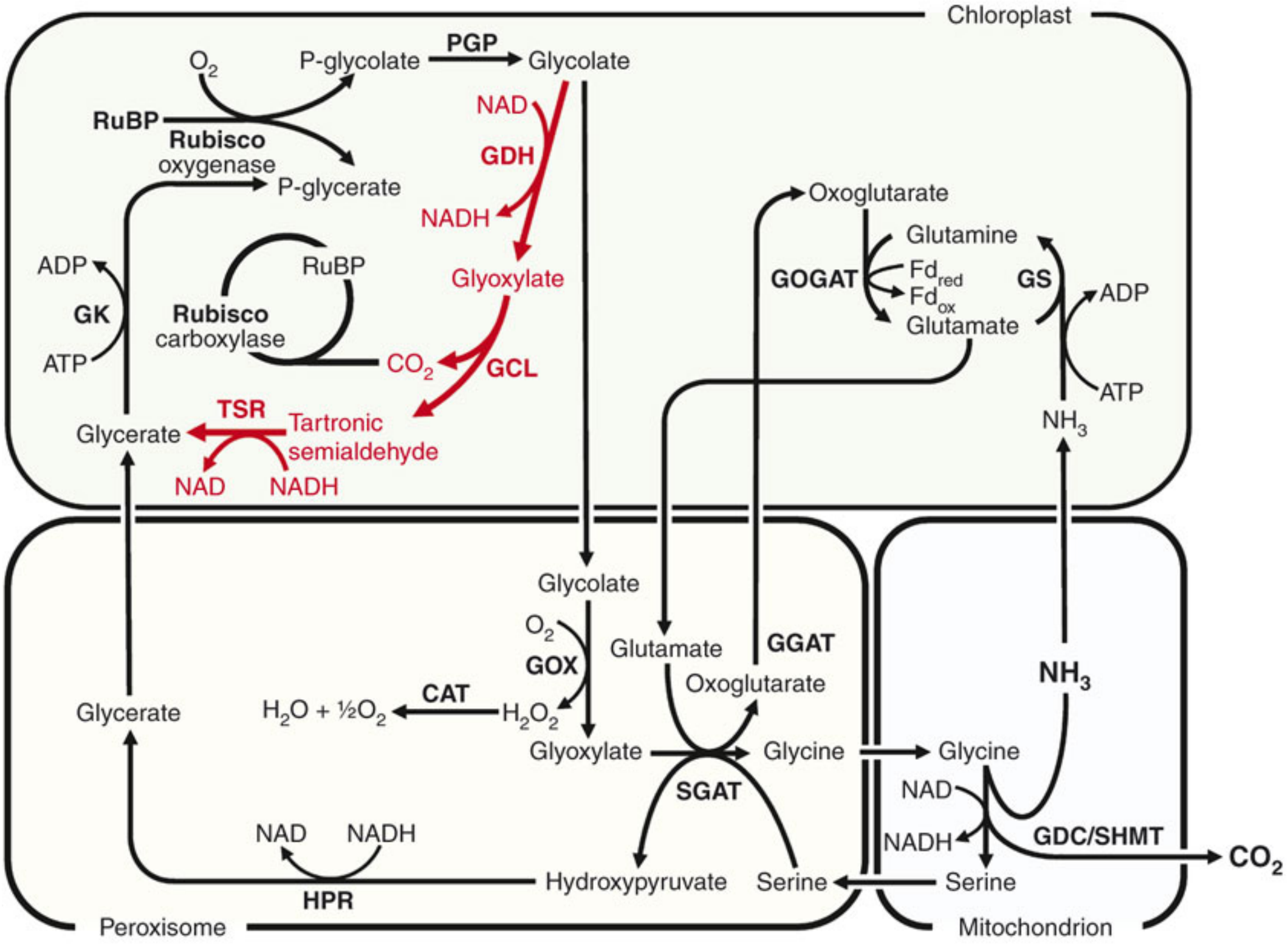
Bioengineering Photosynthesis



Photorespiration redesigned. By C. Peterhansel and VG Maurino. Plant Physiology 2011 Vol. 155. Pages 49-55.

The photorespiratory pathway (black) short circuited by the bacterial glycolate pathway (blue) and alternatively by the intracholorplastic glycolate oxidation pathway (red). Enzymes overexpressed for the full functioning of these pathways are highlighted in bold. 1, Rubisco; 2, 2-PG phosphatase; 3 and 17, GO; 4 and 18, catalase; 5, Glu-glyoxylate aminotransferase; 6, Gly decarboxylase; 7, Ser hydroxymethyl transferase; 8, Ser-glyoxylate aminotransferase; 9 and 10, hydroxypyruvate reductase; 11, glycerate kinase; 12, Gln synthetase; 13, Gln-oxoglutarate aminotransferase; 14, GlcDH; 15, glyoxylate carboligase; 16, tartronate semialdehyde reductase; 19, malate synthase; 20, NADP-malic enzyme; 21, pyruvate dehydrogenase. THF, Tetrahydrofolate; 5,10-CH_2-THF, 5,10-methylenetetrahydrofolate. **Nota Bene. At Step 15, two 2C glyoxyklates are combined to form the 3C tartronate semialdehyde. The CO2 can be recycled by RuBisCO.**

Bioengineering Photosynthesis



Chloroplastic photorespiratory bypass increases photosynthesis and biomass production in Arabidopsis thaliana. By Rashad Kebeish, Markus Niessen, Krishnaveni Thiruveedhi, Rafijul Bari, Heinz-Josef Hirsch, Ruben Rosenkranz, Norma Stäbler, Barbara Schönfeld, Fritz Kreuzaler and Christoph Peterhänsel. Nature Biotechnology (2007) Vol. 25 Pages 593-599

Figure 1: The *E.coli* glycolate catabolic pathway (red) superimposed on plant photorespiration (black). Rubisco, ribulose-1,5-bisphosphate carboxylase/oxygenase; RuBP, ribulose-1,5-bisphosphate; PGP, phosphogycolate phosphatase; GOX, glycolate oxidase; CAT, catalase; GGAT, glyoxylate/glutamate aminotransferase; GDC/SHMT, glycine decarboxylase/serine hydroxymethyl transferase; SGAT, serine/glyoxylate aminotransferase; HPR, hydroxypyruvate reductase; GK, glycerate kinase; GS, glutamine synthetase; GOGAT, glutamate/oxoglutarate aminotransferase; Fd_{red}, reduced ferredoxin; Fd_{ox}, oxidized ferredoxin; GDH, glycolate dehydrogenase; GCL, glyoxylate carboxyligase; P-glycerate; phosphoglycerate; TSR, tartronic semialdehyde reductase.

Bioengineering

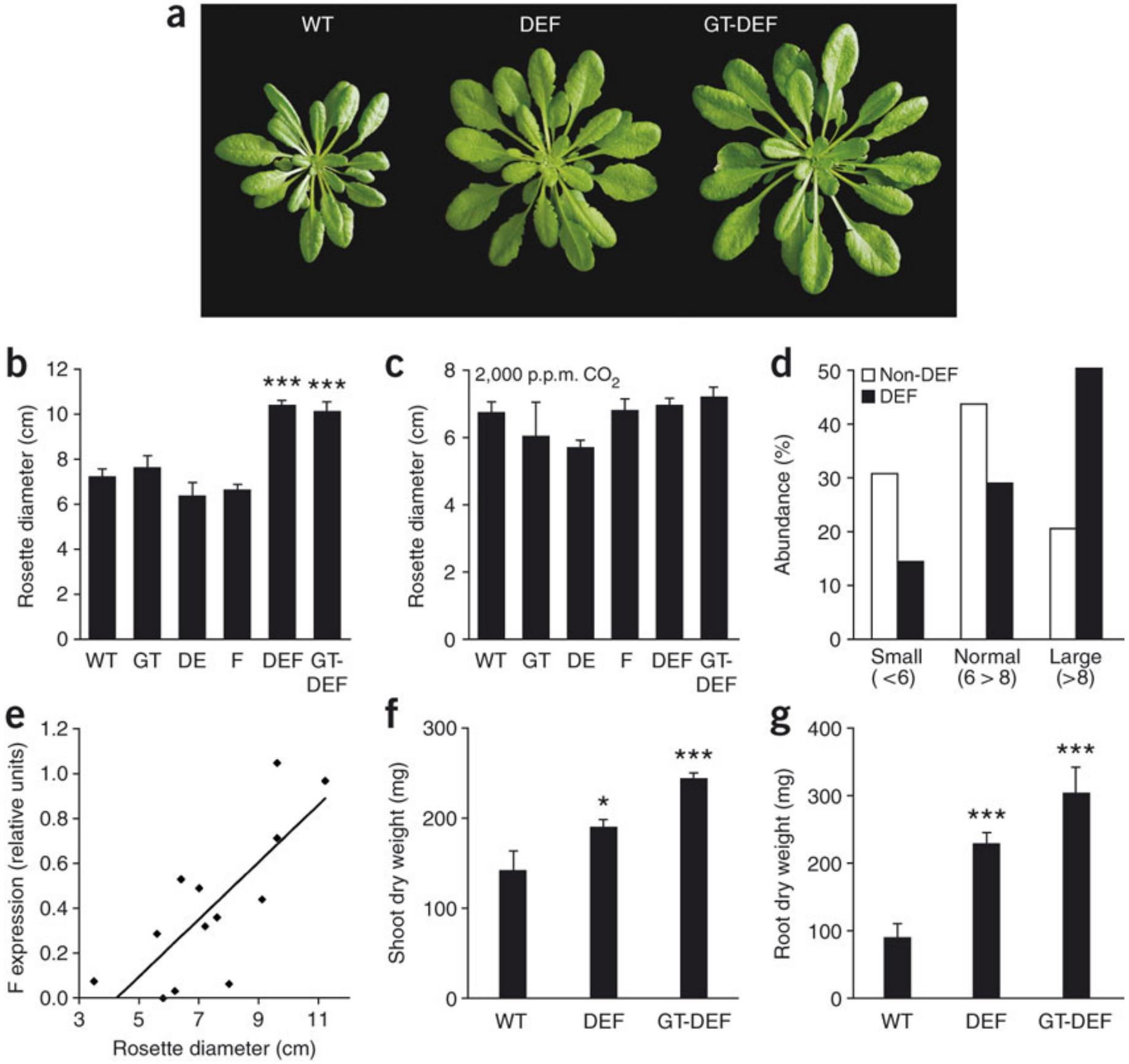


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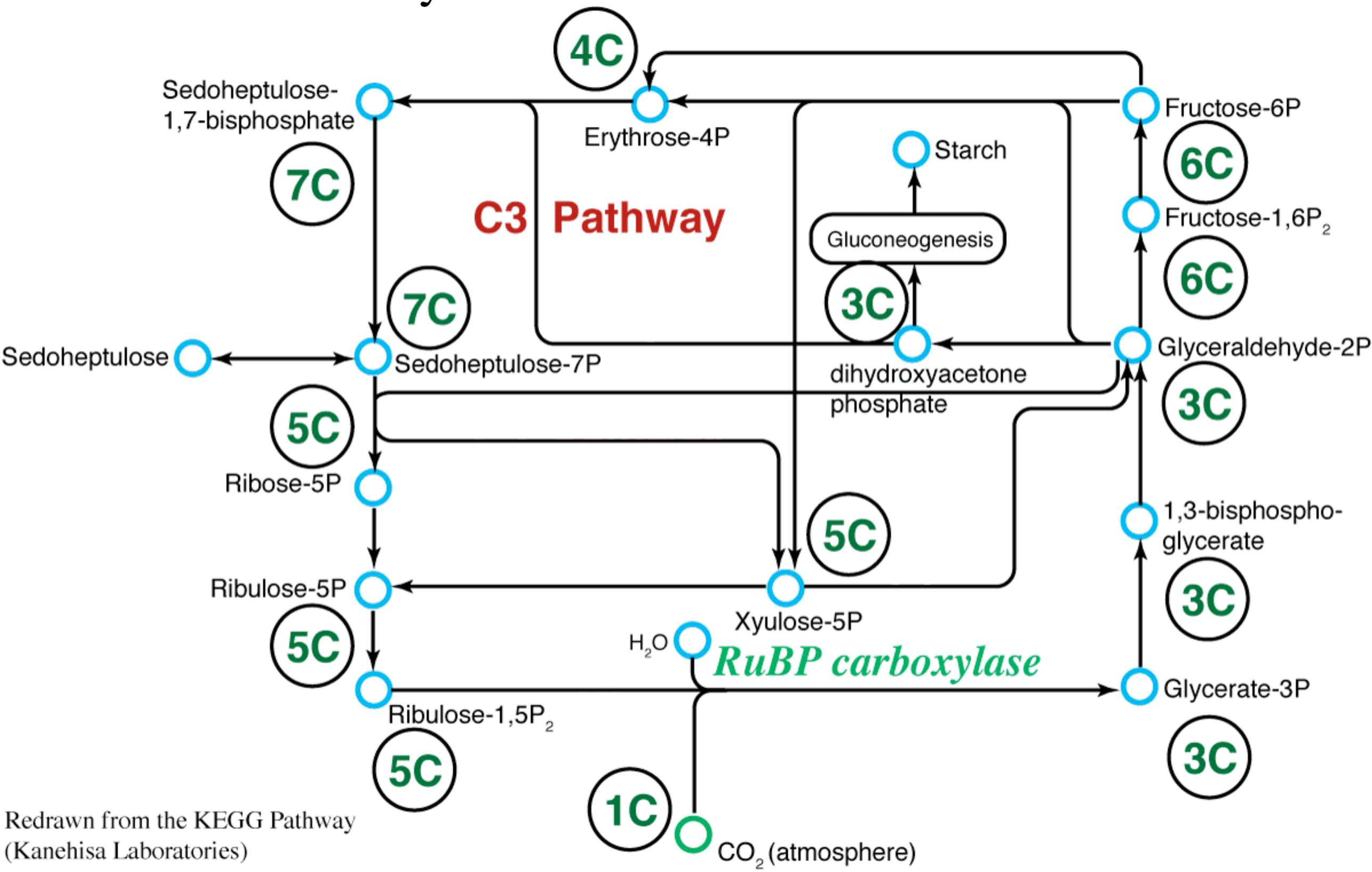
Figure 3: Growth parameters of transgenic (DEF, GT-DEF) and wild-type (WT) lines. (**a**) Representative photographs of selected transgenic plants. (**b**) Rosette diameters of plants grown at ambient conditions. (**c**) Rosette diameters of plants grown at elevated CO_2 (2,000 p.p.m.). (**d**) Abundances of small (<6 cm rosette diameter), normal (6-8 cm) and large (>8 cm) plants in a segregating population dependent on the genotype. DEF, plants containing the DE and F transgenes; non-DEF, all other genotypes. (**e**) Correlation of abundance of transcript encoding the F subunit of GDH with rosette diameter in descendants from a segregating population. (**f**) Shoot dry weights of plants grown under ambient conditions. (**g**) Root dry weights of plants grown under ambient conditions. DEF, plants overexpressing subunits D, E, and F of *E. coli*glycolate dehydrogenase; GT-DEF, plants overexpressing the complete *E. coli* glycolate catabolic pathway as shown in Figure 1. Each data point represents at least five independent plants. Error bars indicate s.e.m.; *, $P < 0.05$; **, $P < 0.01$; ***, $P < 0.001$ according to Student's *t*-test. Plants were selected on appropriate antibiotics for 2 weeks and then grown in soil for 6 weeks. Plants analyzed in **d** and **e**were directly grown in soil without antibiotic selection.

C3 Fixation Pathway



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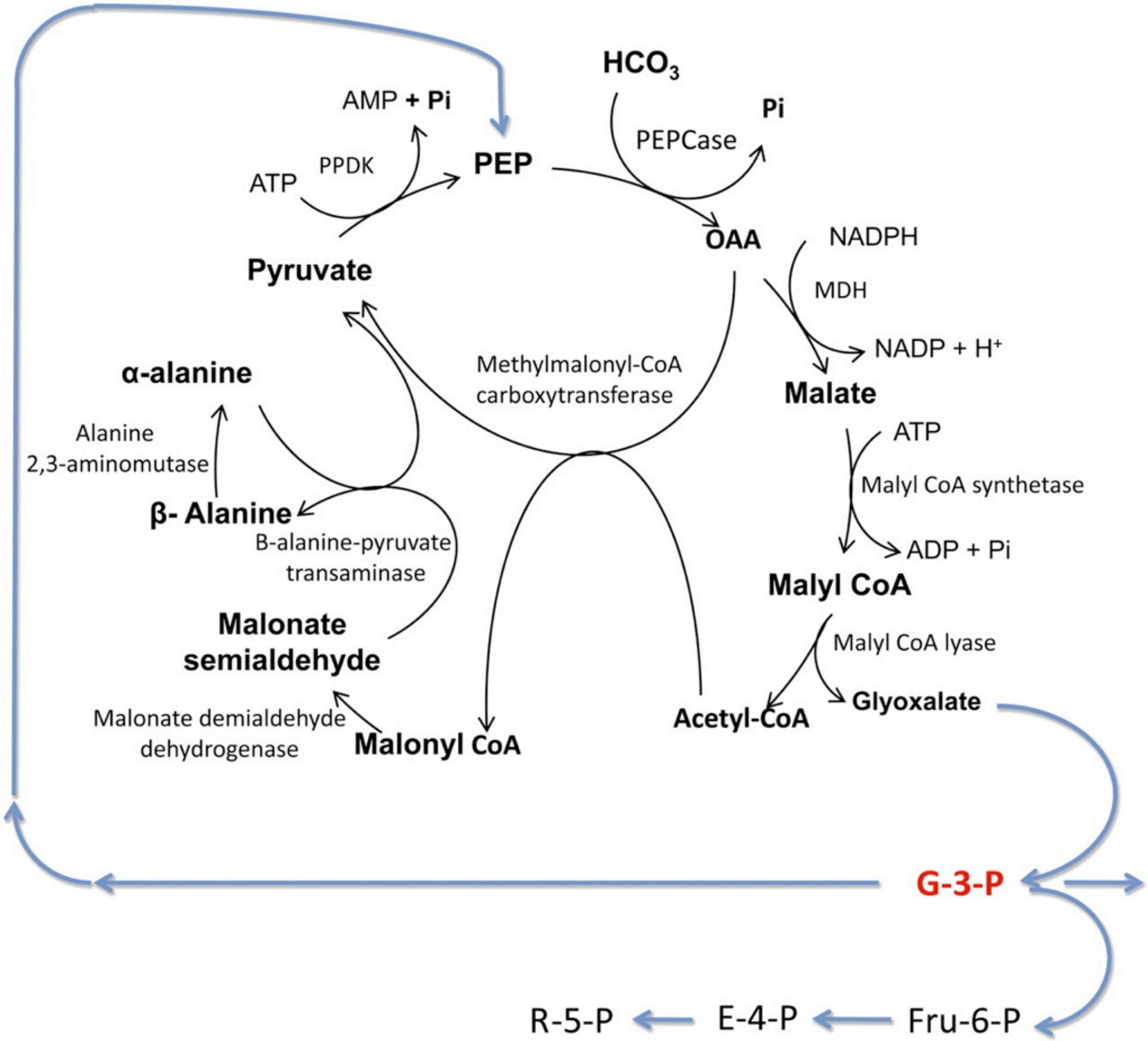
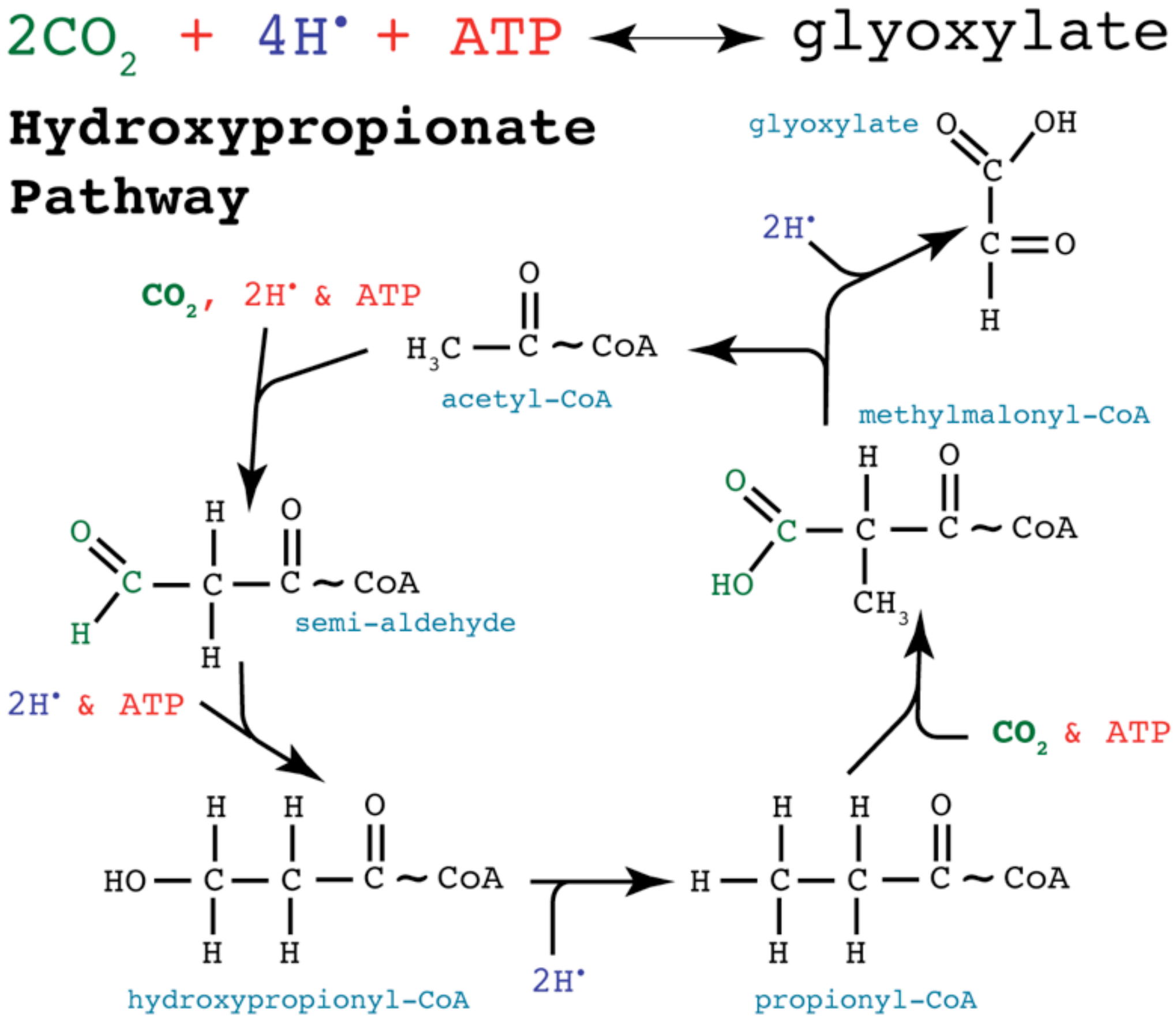
Bioengineering Photosynthesis --De Novo Pathways



Increasing Photosynthetic Carbon Assimilation in C_3 Plants to Improve Crop Yield: Current and Future Strategies.
By Christine A. Raines. Plant Physiology 2011 Volume155 Pages 36-42

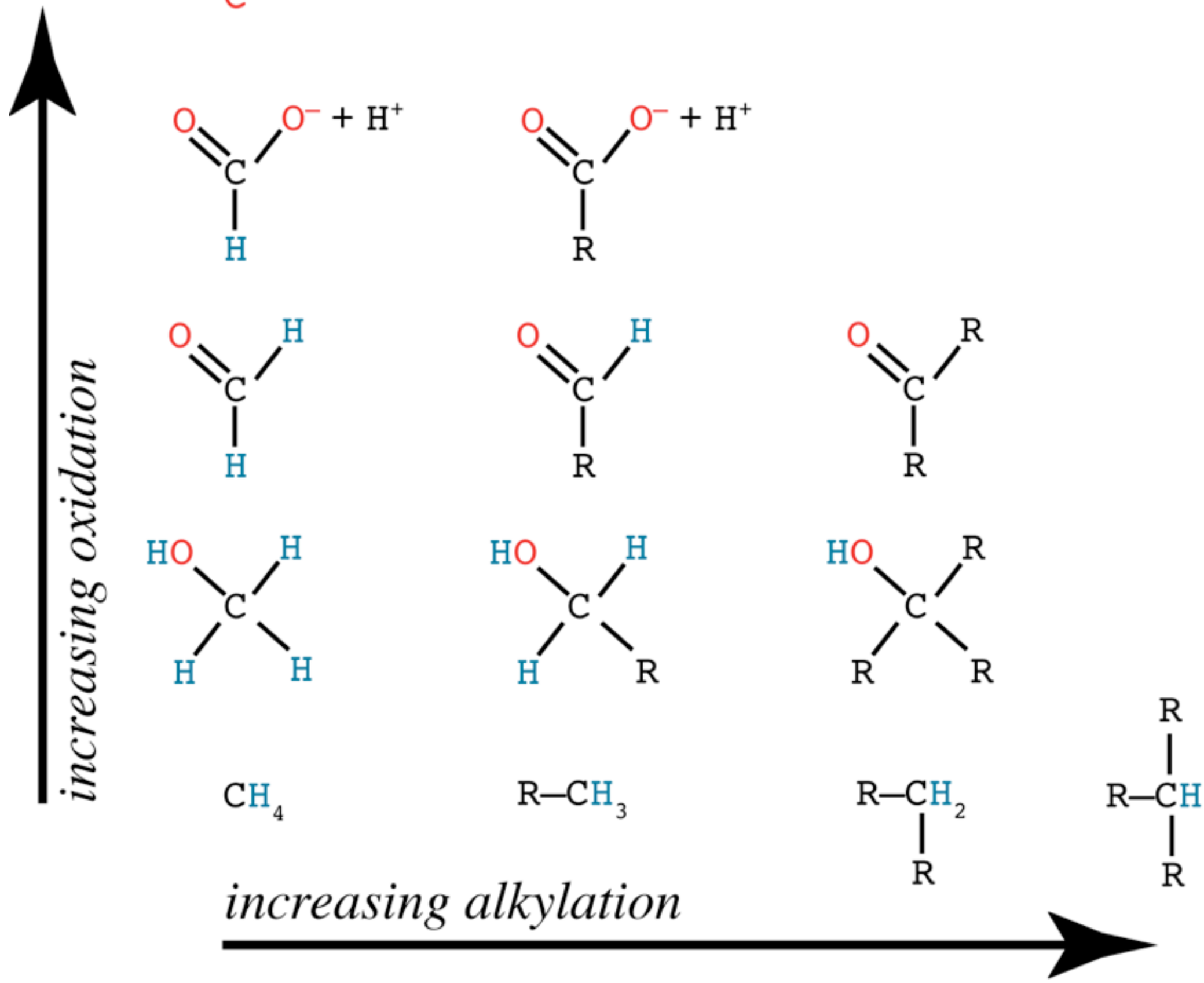
Rubisco-independent carbon assimilation. C_4-glyoxalate (MOG) cycle—a model-developed hypothetical carbon fixation pathway. This pathway uses the enzyme phosphoenolpyruvate carboxylase (PEPCase) to fix atmospheric CO_2 into oxaloacetate and the only output product of this cycle is glyoxalate. PPDK, Pyruvate phosphate dikinase; MDH, malate dehydrogenase. The arrows in blue are speculative routes for carbon that may be need to be engineered to maintain the MOG cycle in addition to linking with a partial C_3 cycle to provide the intermediates for biosynthesis of isoprenoids (G-3-P), shikimate (E-4-P), Suc (G-3-P), starch (Fru-6-P), and nucleotides (R-5-P). Adapted from Bar-Even et al. (2010).

Alternative Carbon Fixation Pathways



One of the alternative pathways is shown in simplified form. Note that this and other unusual pathways are found in atypical organisms, often requiring far more reductive conditions than are usual in the 'normal' photosynthesizers.

Carbon Fixation Pathways



Carbon Oxidation

Carbon Oxidation and Alkylation.

Carbon Fixation Pathways