



**Yield10**  
BIOSCIENCE

**ASPB 2018**

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Transporter manipulation in food crops for increased yield

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## **Yield10 Bioscience (NasdaqCM:YTEN) is developing technologies to enhance global food security**

- Headquartered in Woburn, MA USA
- Oilseeds center of excellence in Saskatoon, Canada

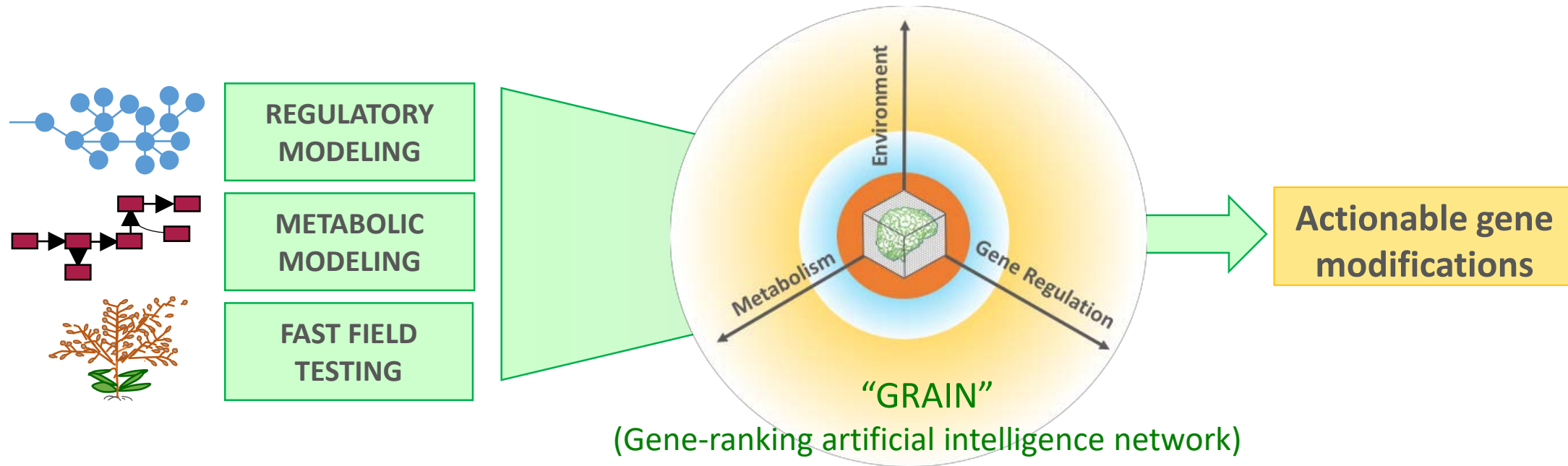
## **Yield10 brings extensive expertise and a track record in optimizing the flow of carbon in living systems to the agriculture sector to increase yield in key row crops**

- Yield10 is targeting step-change (10-20%) increases in seed yield
- Technology based on 20 years of cutting-edge crop metabolic engineering research
- 15 recent patent applications for increased crop yield
- Open innovation business model provides low hurdle for work with Ag majors

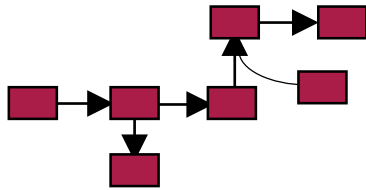
## **Yield10 focuses on its core strengths of advanced bioscience and innovation**

- Discover and de-risk yield technologies for major North American crops: corn and the two oilseed crops soybean and canola

# The Yield10 platform



- Increasing crop yield is an extremely complex and challenging problem
- Screening thousands of individual plant genes has not delivered commercial yield traits
  - However, the sector has used this approach to generate billions of individual data points
- Modifying combinations of genes, metabolic and/or regulatory, will be necessary
- GRAIN's purpose is to be able to convert vast amounts of data into actionable gene modifications



METABOLIC  
MODELING

## FLUX-BALANCE ANALYSIS

- Purely stoichiometric
- Optimize production of biomass, oil, protein, etc.
- View optimal metabolism (vs. observed metabolism)
- Show effects of local metabolic changes on entire plant

## KINETICS/THERMODYNAMICS

- Eliminate unrealistic reactions from flux-balance analysis
- Identify slow/difficult reactions within known metabolism
- Challenge conventional wisdom

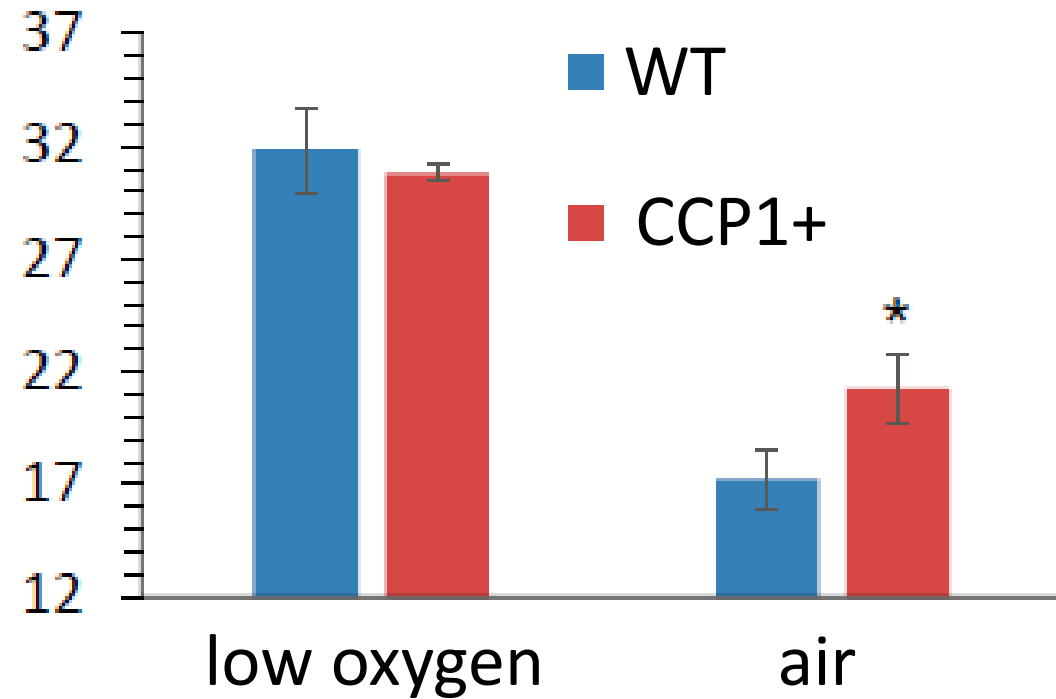
# CCP1 (C3003): Trait that increases seed yield

Crop	Expression	Trial	Group	Location	Best seed yield increase
Camelina	constitutive	field	Yield10	Canada	23%
Camelina	seed-specific	greenhouse	Yield10	Canada	24%
Camelina	seed-specific	field	Yield10	Canada	7%
Canola	constitutive	field	Yield10	Canada	13%
Camelina	constitutive	field	Schnell (Mich. St.)	U.S.	52%

## What is CCP1?

- Transporter found in some algal species
- Induced at low CO<sub>2</sub>
- Localizes to mitochondrial membrane

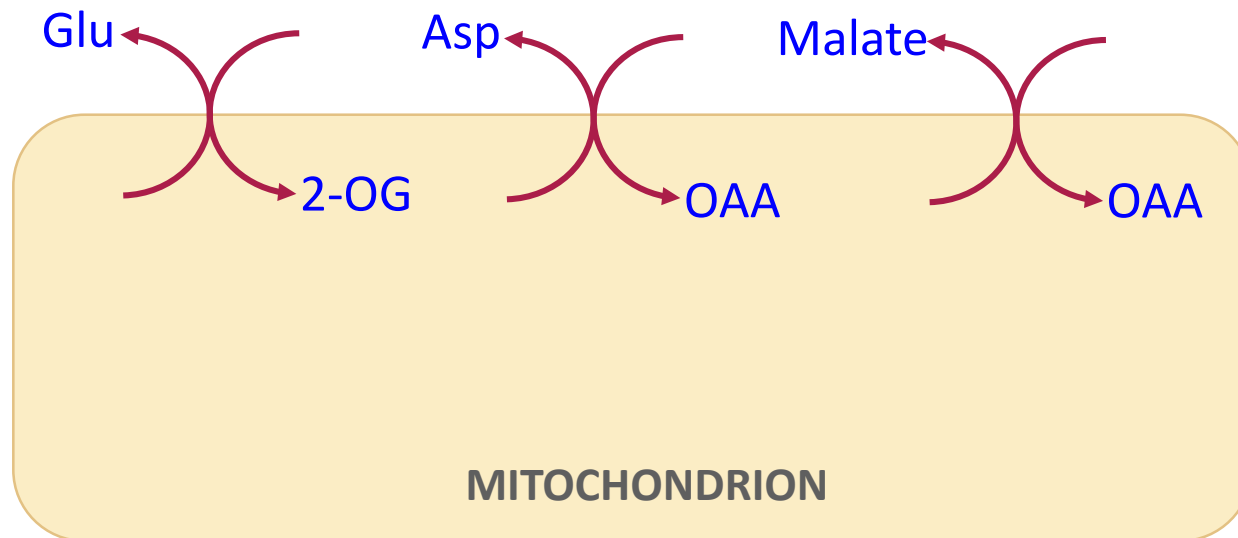
## Carbon assimilation in *Camelina* ( $\text{mmol m}^{-2} \text{s}^{-1}$ )



Data from laboratory of Prof. Danny Schnell (Michigan State Univ.)

## Flux-balance analysis, optimizing leaf biomass

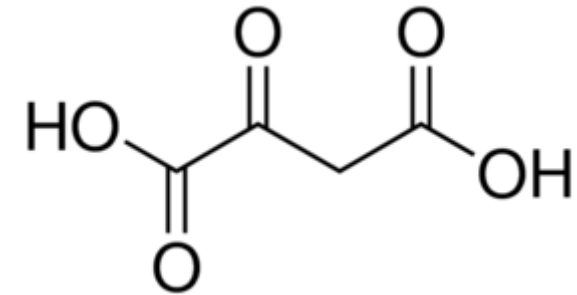
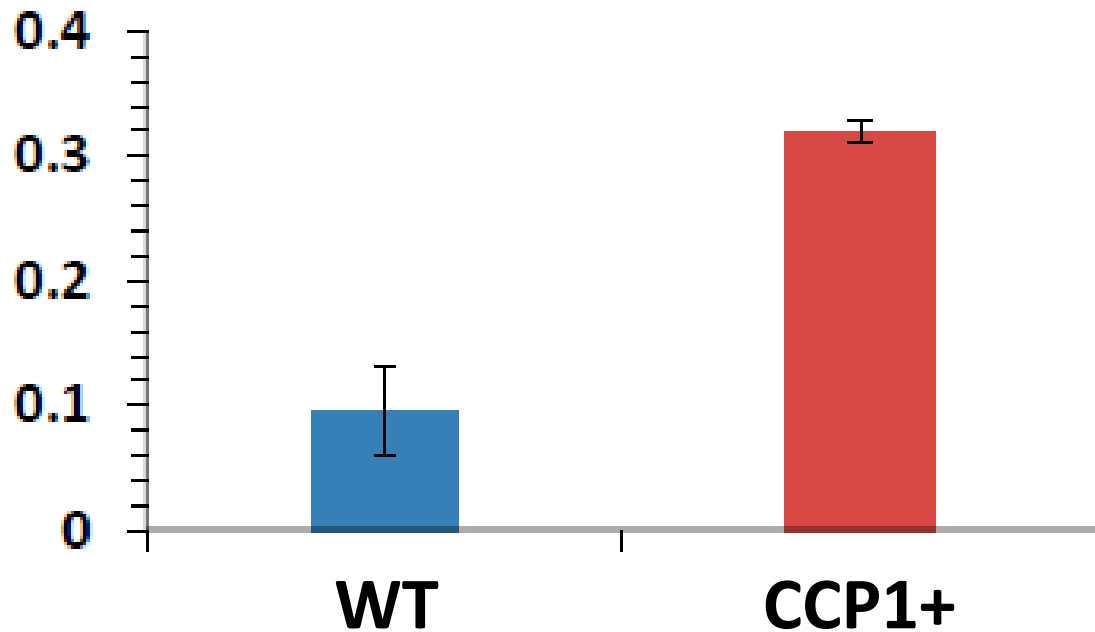
What mitochondrial factors should increase during photorespiration?



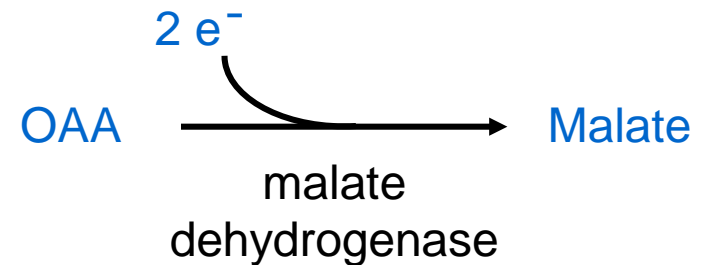
All of these remove electrons from the mitochondrion

# CCP1 facilitates OAA uptake into mitochondria

## Relative OAA uptake in mitochondria isolated from yeast cells



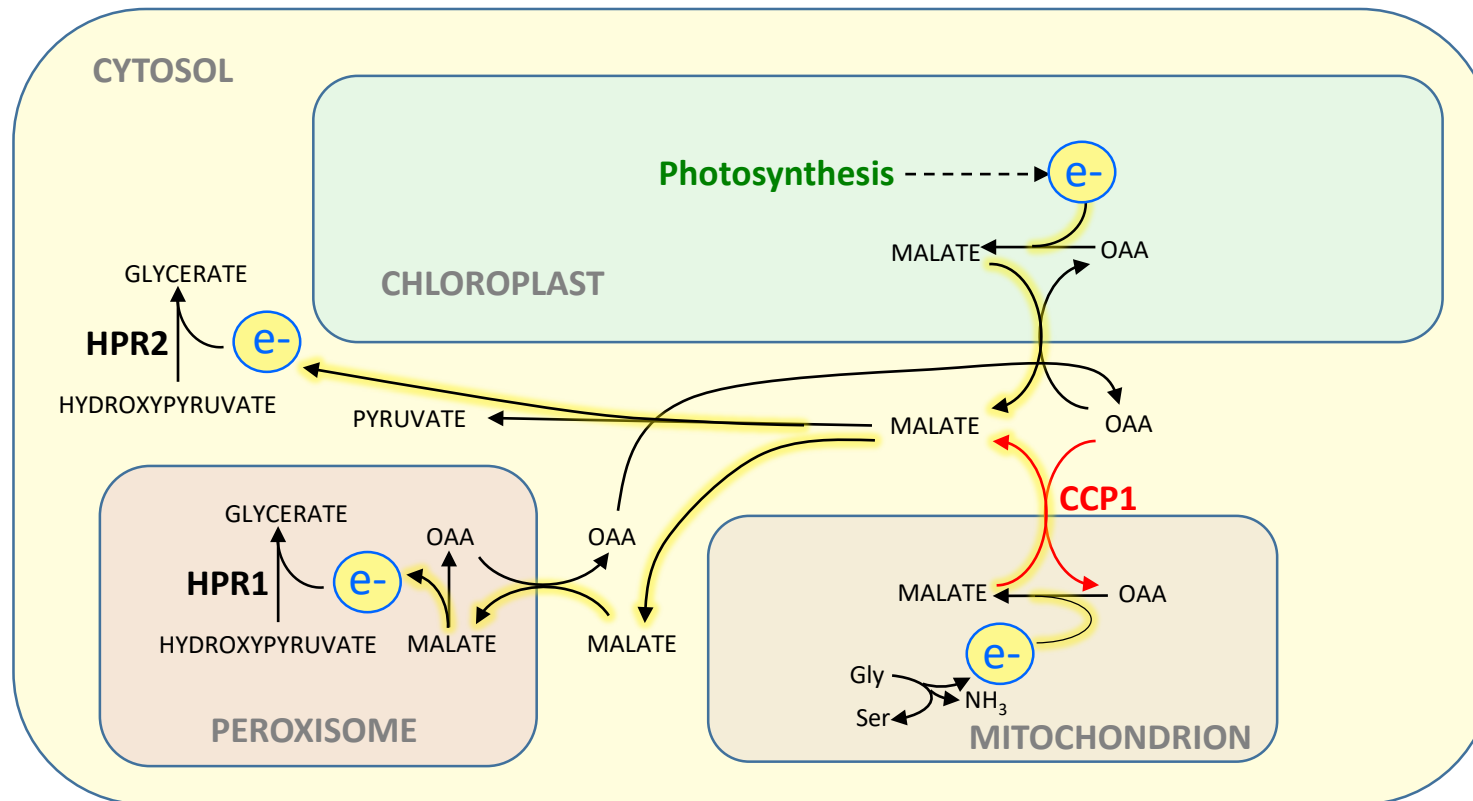
OAA (oxaloacetate) is an electron carrier





# Modeling suggests CCP1 role in optimum yield

- Collect electrons from mitochondrion and chloroplast
- Send to peroxisome or cytosol for hydroxypyruvate reductase (HPR)

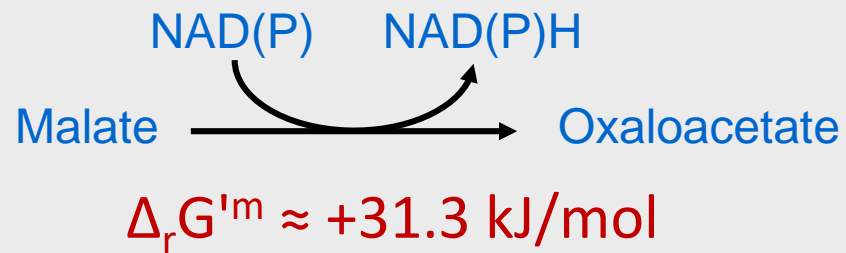


## **CCP1 may facilitate photorespiration**

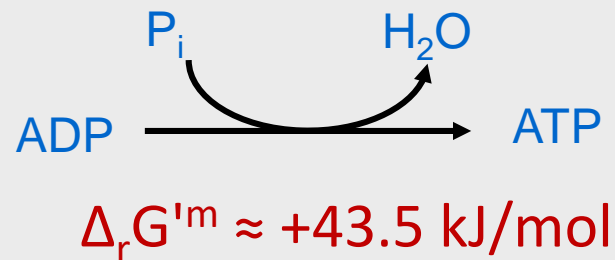
- HPR flux must be very high at times during photorespiration
- Modeling shows that lack of electron shuttling to HPR means >20% yield loss
- Accumulation of photorespiratory intermediates could also be a problem

The TCA cycle must run during sugar metabolism in the seed,  
but one of its steps is very unfavorable:

malate dehydrogenase  
(MDH)



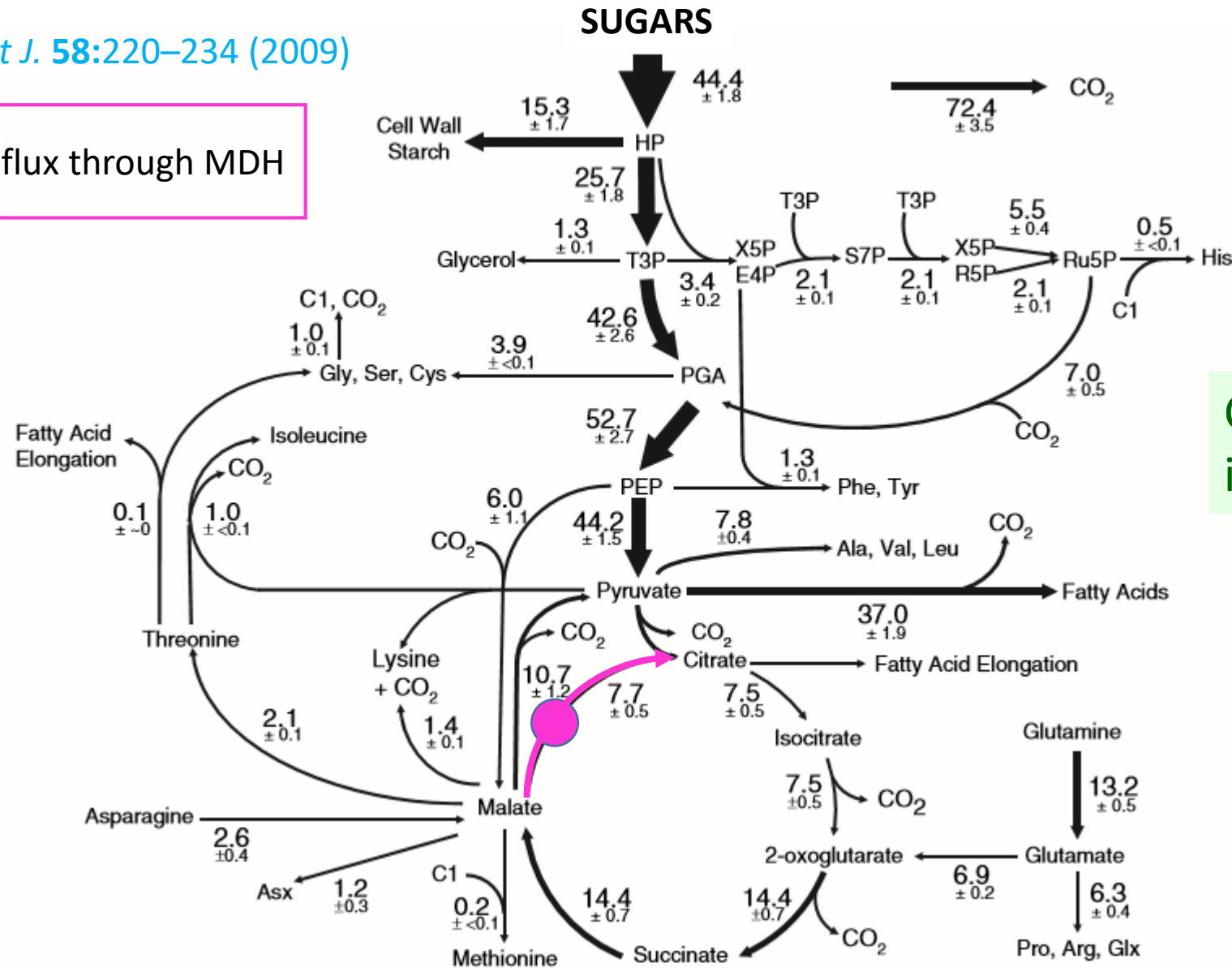
compare with  
spontaneous ATP formation



# Cultured soybean embryo flux data

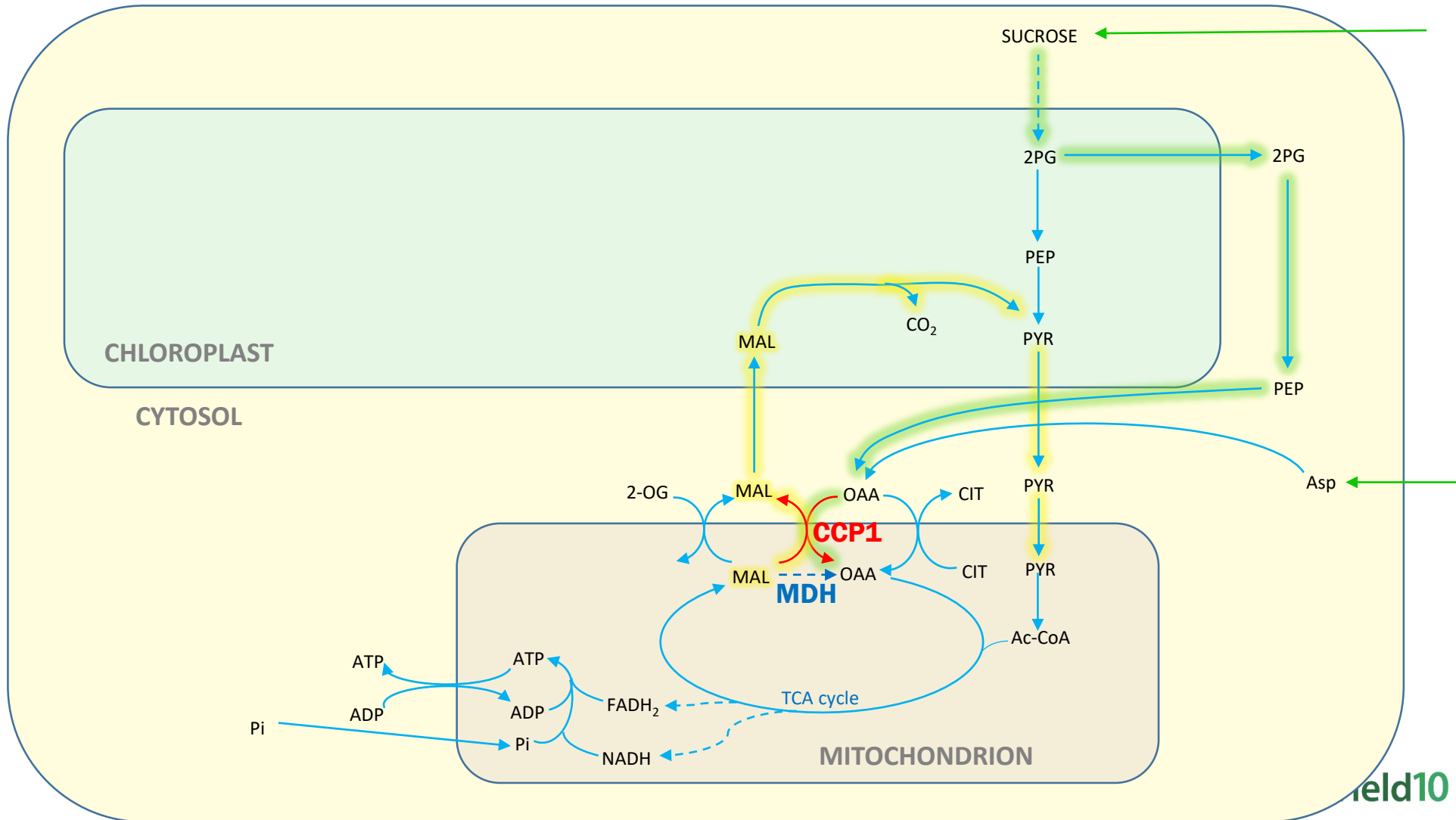
Allen et al., *Plant J.* 58:220–234 (2009)

● apparent flux through MDH



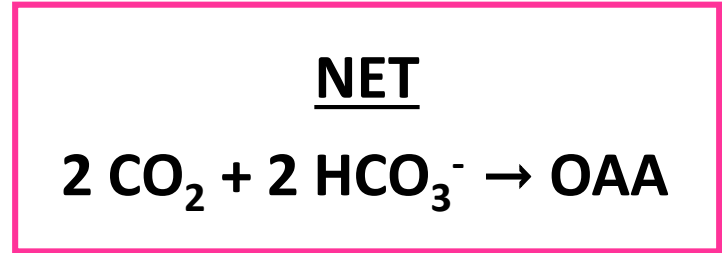
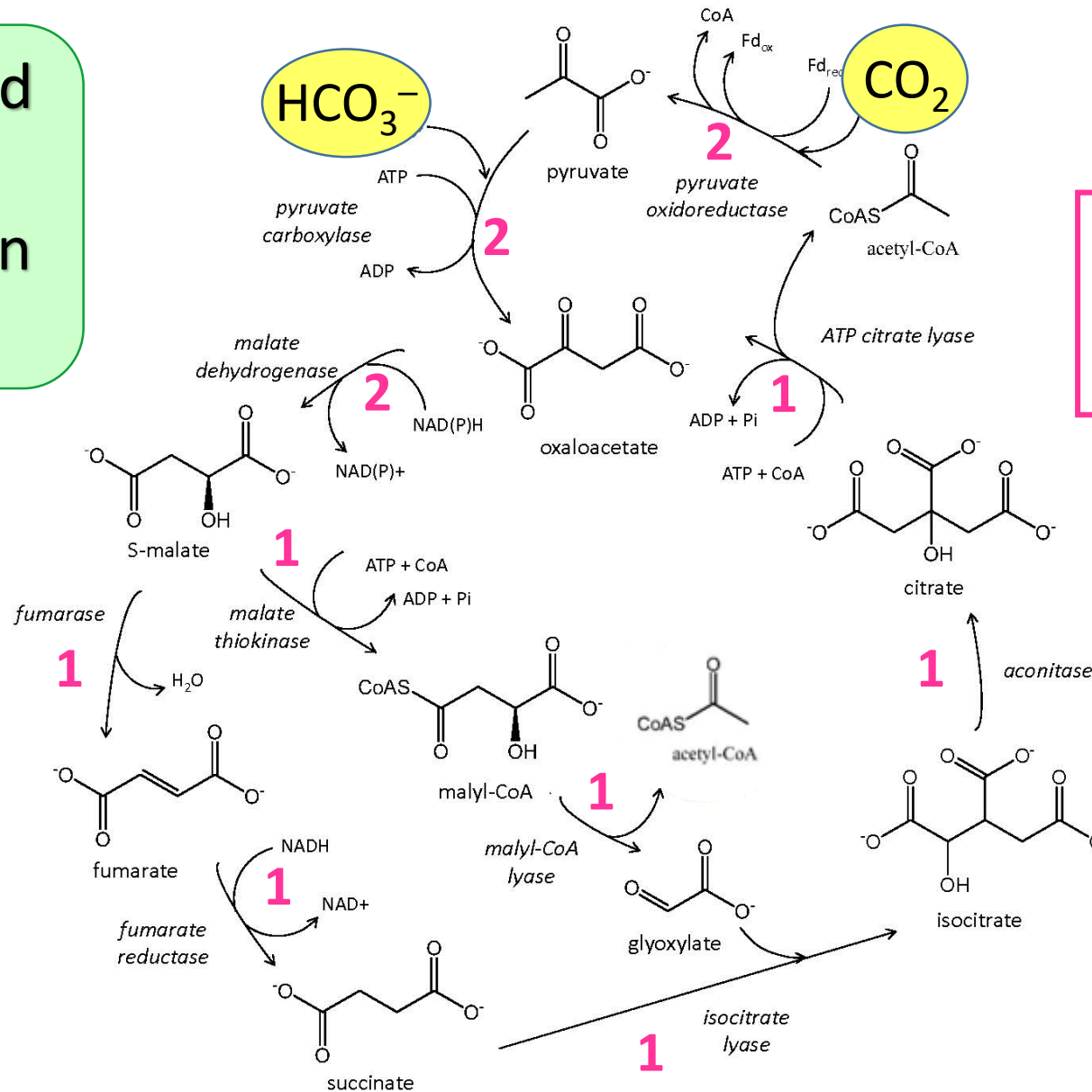
Carbon efficiency is already >90%

## CCP1 may increase sink strength, NOT carbon efficiency



# The reverse glyoxylate shunt (rGS)

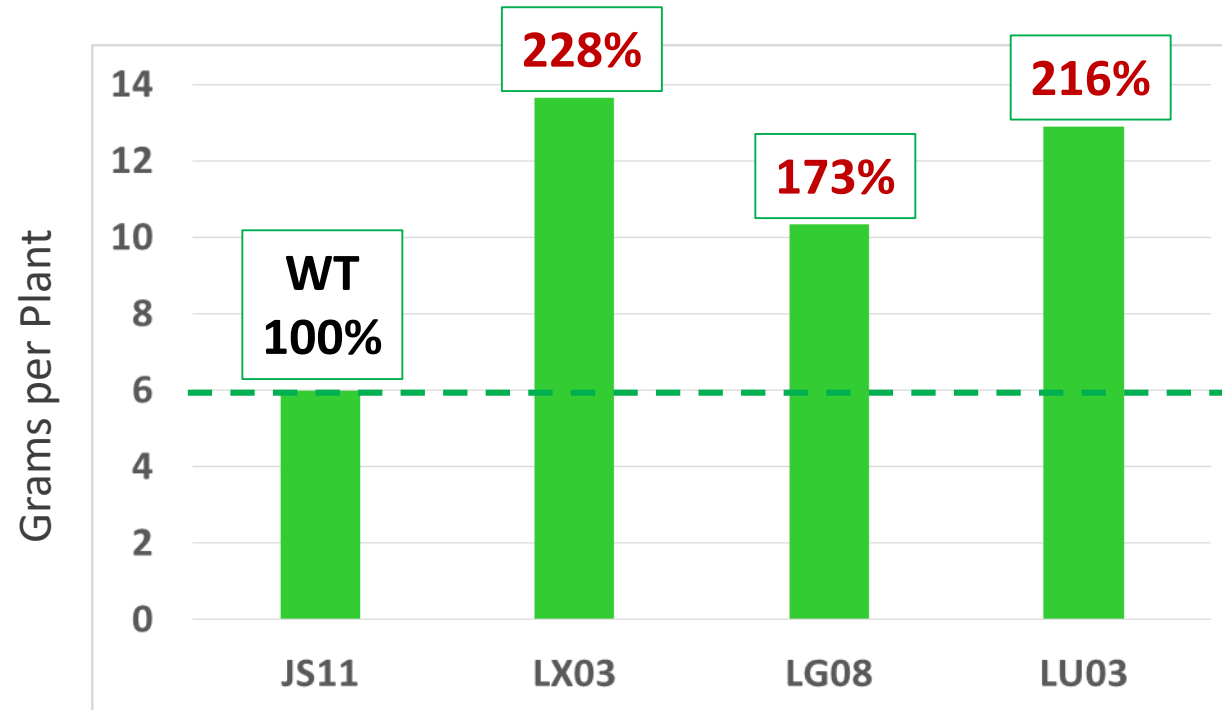
What if we could eliminate photorespiration altogether?



RELATIVE FLUXES

Maximum relative theoretical yield  
with rGS under photorespiratory conditions = **212%**

## Camelina greenhouse study: Best plants



Malik, M.R., Tang, J., Sharma, N. et al. *Plant Cell Rep.* (2018).  
<https://doi.org/10.1007/s00299-018-2308-3>

- Yield10 uses modeling and experimentation to identify and de-risk yield gene traits
- Metabolic modeling is a key part of this – but needs to be validated with results
- C3003 (CCP1) has shown significant oilseed yield increases in field trials
- Modeling has helped to explain its role and to suggest further targets
- The reverse glyoxylate shunt (rGS) pathway doubles seed yield in greenhouse studies, demonstrating that improving carbon conversion efficiency has high yield potential
- Top rGS yield increases agree with model's predictions



Thank you

Questions?

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