Optimizing Shoot Architecture and Canopy

FG-Y-3

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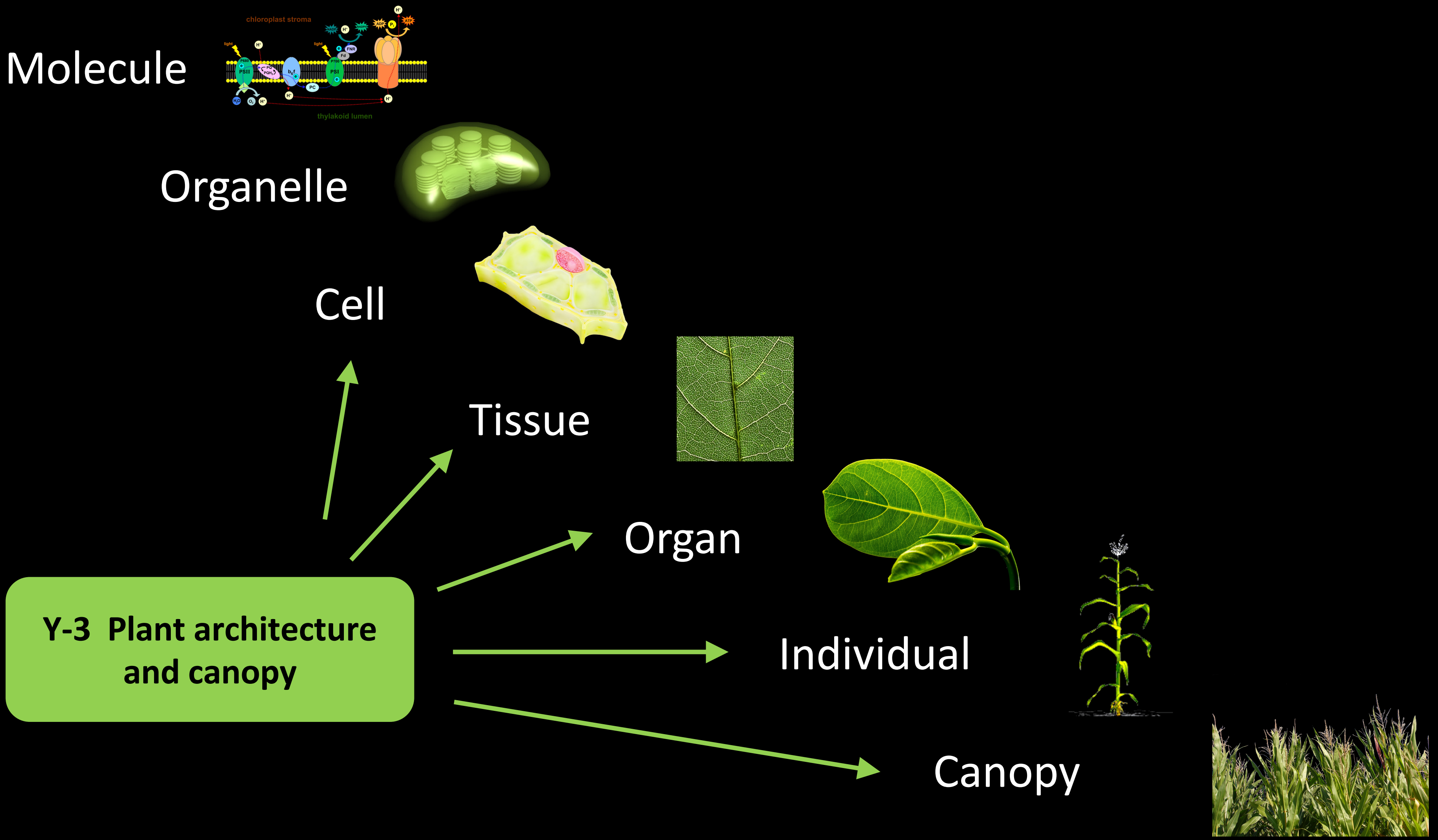
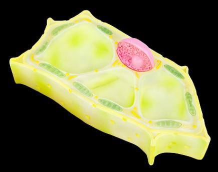
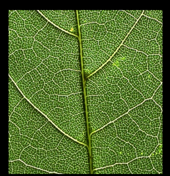
Photosynthesis is a multiscale process



Improving photosynthesis is a multiscale challenge : Cell, tissue, and organ level





Cell & Anatomy
Hair
Cuticule
Stomate
Vasculature
Cell size
Cell organisation
Air spaces
Cell wall

Leaf Size
Length
Width
Thickness

Leaf Shape
Centroïd position
Dissection

CO_2, water, nutrients, assimilates transport within the leaf

Gas and thermic exchanges through the boundary layer

Light interception and diffusion within the leaf

Photosynthetic versus support tissues

Improving photosynthesis is a multiscale challenge :
Plant and Canopy (population) level

Plant Architecture
Branches
Leaves
Fruits
Seeds

Canopy
Density
Heterogeneity (intra/inter cultivar, interspecific)
Growth dynamics

Photosynthetic versus support tissues

Source / Sink organs

Harvestable fraction

Intra canopy physical parameters (light, temperature, hygrometry)

Response and resilience to biotic and abiotic stresses

All the parameters defining yield are affected by plant architecture and canopy structure

Monteith equation

$$\text{Yield} = \text{St} . \varepsilon_i . \varepsilon_c . \varepsilon_p$$

St = solar irradiation energy

ε_i = light interception efficiency
eg: leaf area, leaf angle...

ε_c = light energy conversion into biomass efficiency
eg: support vs photosynthetic tissues, vascular density, cell wall

ε_p = harvestable fraction
eg: branch number, size/number of fruits, seeds

Towards a fine understanding of the mechanisms leading to shoot architecture

Main Achievements

A good knowledge of the main molecular and genetic actors controlling the developmental processes leading to shoot architecture establishment

branching, vascular patterning and differentiation, leaf size and shape…

Open questions, challenges, limitations

- Level of conservation of actors and roles between species, in particular from models to crop?
- How are these regulatory mechanisms challenged by environmental signals to allow plant adaptation?
- What about biological processes important for crops and not present in classical models?

Analysing the basis of domestication and pushing it further

Main Achievements

Studying natural variation and domestication has allowed identifying biological processes key for yield and the molecular actors at play

Based on this, and on the understanding of the regulatory mechanisms, domestication could be pushed further

branching, plant size, fruit/seed number and size...

Open questions, challenges, limitations

- Maintain and characterise the natural genetic diversity that can be a source for potential alleles of interest
- Identify new key traits and their genetic determinants
- Reinforce the genome editing toolbox and resolve plant regeneration bottleneck

Linking plant anatomy and architecture to photosynthesis

Main Achievements

The effects on photosynthesis of plant architecture and anatomy modifications were analysed

leaf angle, leaf shape, vascular density, mesophylle anatomy …

Open questions, challenges, limitations

- These approaches still remain scarce
- Do not provide a mechanistic insigth into the relationship between anatomy/architecture and photosynthesis
- Challenging, because it involves interdisciplinary approaches

Integrating modelling and phenotyping at the whole plant level

Main Achievements

Identification of QTL/genes relevant for plant architecture in field conditions
Eco-physiological models predicting optimal plant architecture for maximization of photosynthesis, plant growth and yield under specific conditions

Open questions, challenges, limitations

- Further increase the complexity of the models to better integrate environmental variations and agricultural management practices
- Increase the power of phenotyping in relevant growth conditions. What scale of phenotyping for which aim?
- What aim for modelling : improve prediction of outcome or contribute to the understanding of the underlying mechanisms?

General Action Points for a future research

Bridging the scientific communities to provide a global view

Because photosynthesis and yield are very interconnected processes, more integrated, multi-scale research bridging the different scientific communities needs to be developed

Phenotyping and modelling could provide a mid-point where different communities may interact

Going beyond the studies of model species in controlled conditions

Interplay between regulatory mechanisms, development and environment

Developing accurate and relevant phenotyping

Mimic in a reproducible way fluctuating environmental conditions and perform phenotyping at the appropriate scale

Increasing the benefits of the modelling approaches

Simulate plant architectural development based on knowledge at the molecular level and use this to identify key processes or genes for breeding high-yield cultivars

Specific Action Points for a future research

Forster understanding on the impact of key architectural traits on photosynthesis to provide possible general paths for improvement.

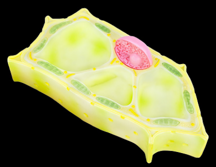
- plant architecture (size, branches), leaf number, size, shape and anatomy
- go beyond quantification of the photosynthesis to provide a functional link between the architectural link and the effect on photosynthesis

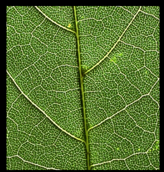
Characterise plant architectural acclimation to light conditions and the feedback effects of architecture on light and other microclimate conditions

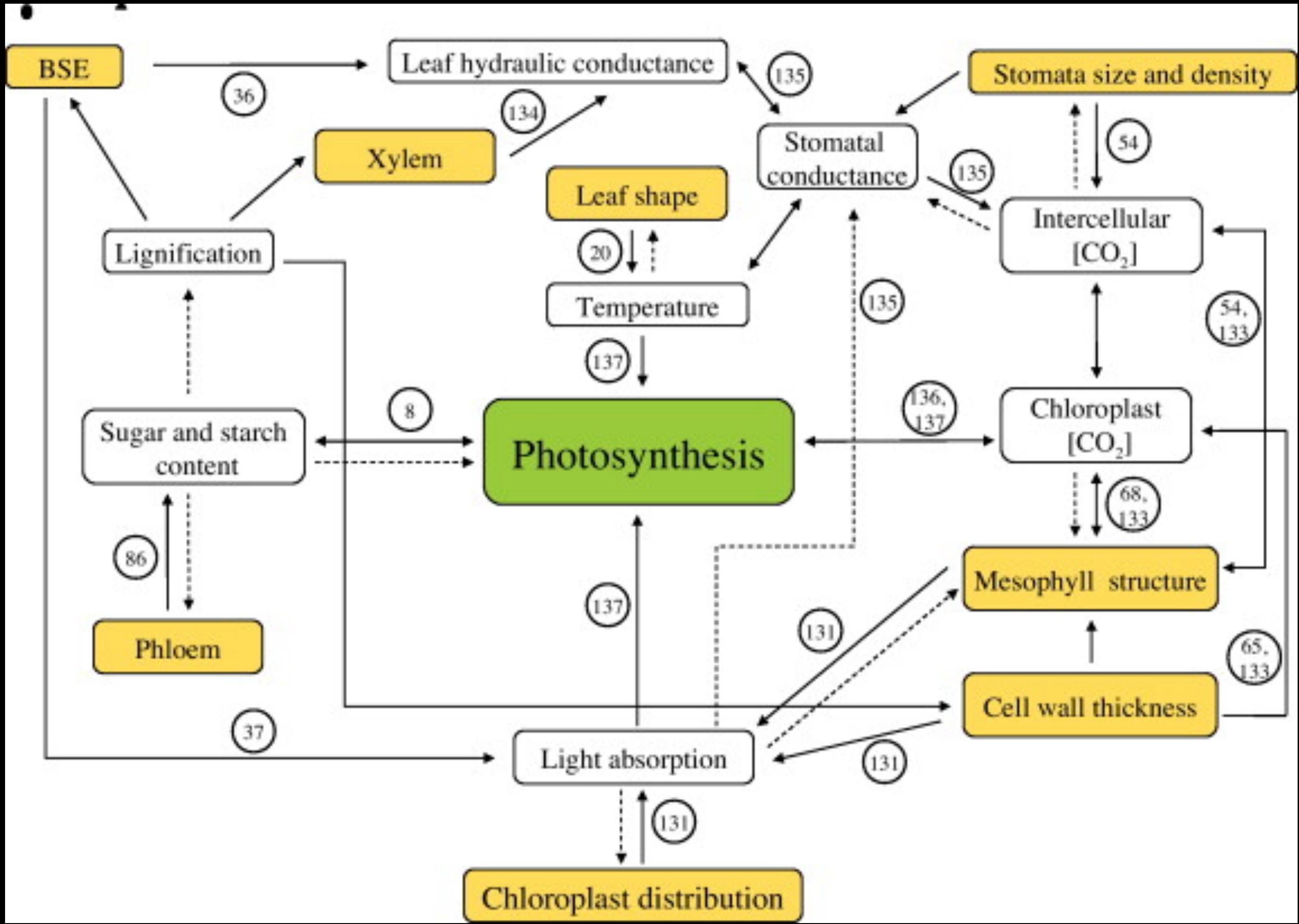
Define a few case scenarii that will be investigated at an integrated level

Defining the what (plant), the where (is it cultivated), the how (the practices) and the why (the usage) should be done by all the stakeholder involved. The contribution of multiple architectural traits at different scales could be investigated for these few scenarii.

Improving photosynthesis is a multiscale challenge : Cell, tissue, and organ level

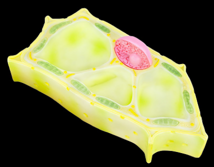


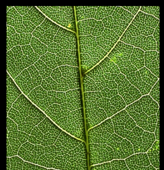




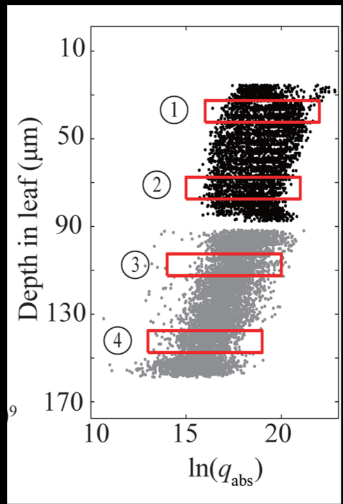
Tholen et al., 2012

Improving photosynthesis is a multiscale challenge : Cell, tissue, and organ level



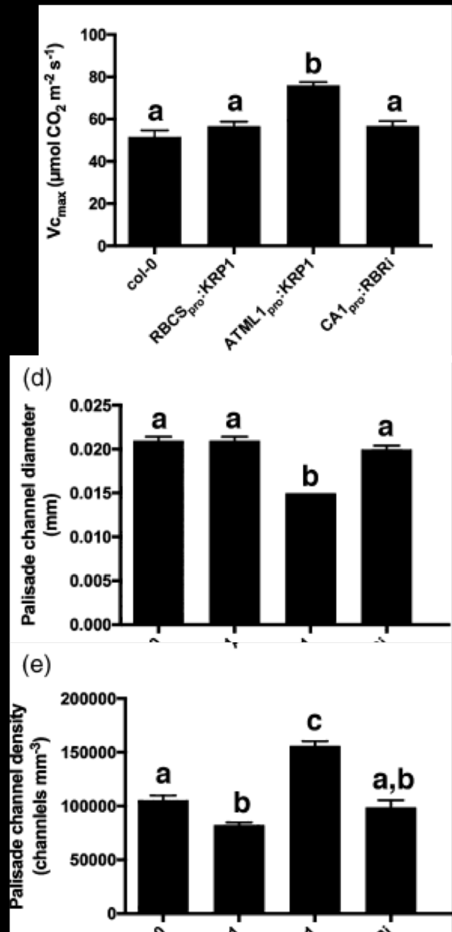


Light absorption and leaf anatomy



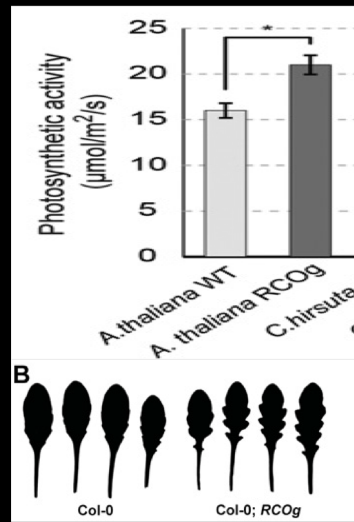
Xiao et al., 2016

Photosynthesis and air spaces in the mesophylle



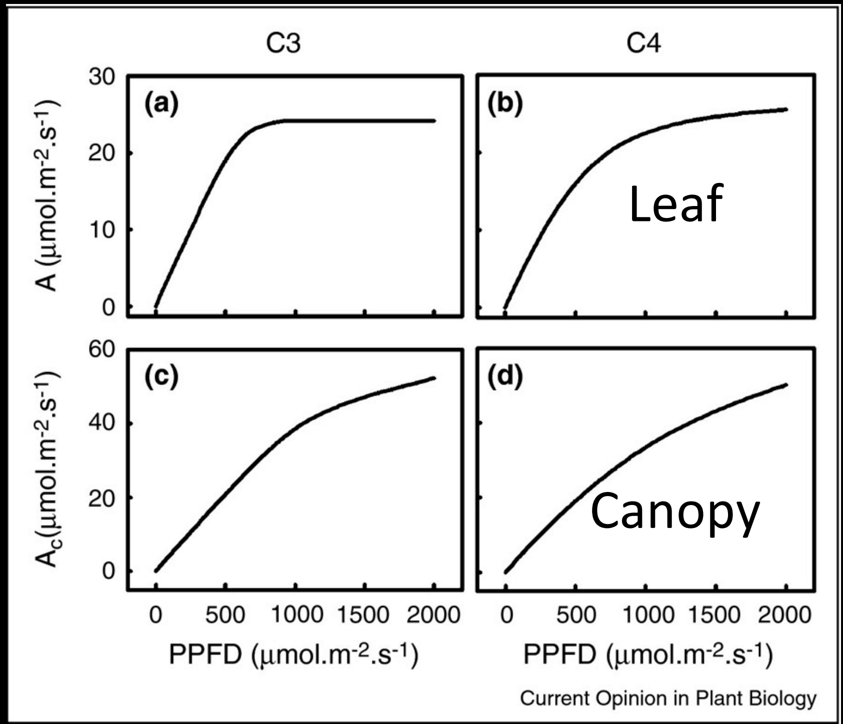
Lehmeier et al., 2017

Photosynthesis and leaf shape

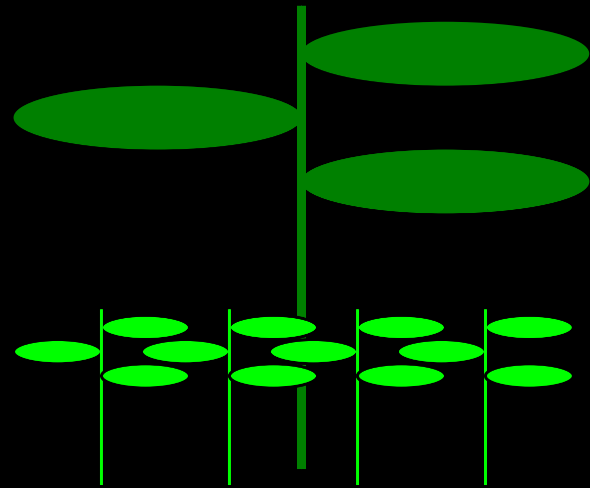


Vuolo et al., 2016

Improving photosynthesis is a multiscale challenge : Plant and Canopy level



The canopy
is not just the sum of *n* leaves

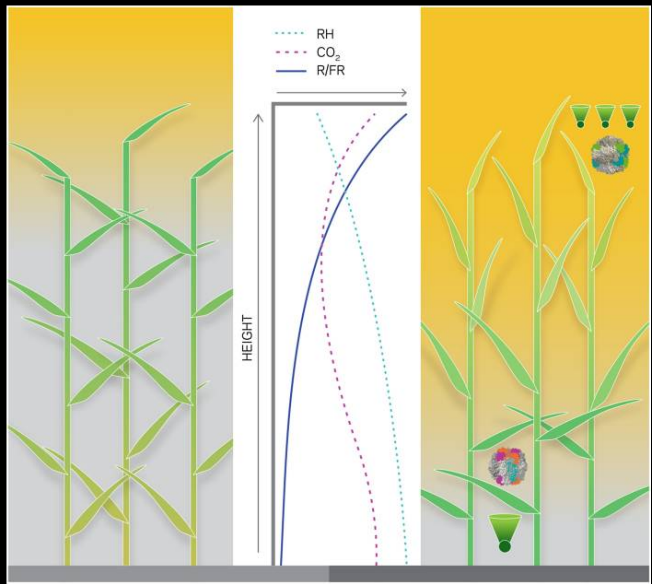


Optimising photosynthesis
for an individual
is not optimising for the canopy

Zhu et al., 2012

Improving photosynthesis is a multiscale challenge : Plant and Canopy level

The Smart Canopy Concept :
adapt to the heterogeneity of microenvironments inside a canopy

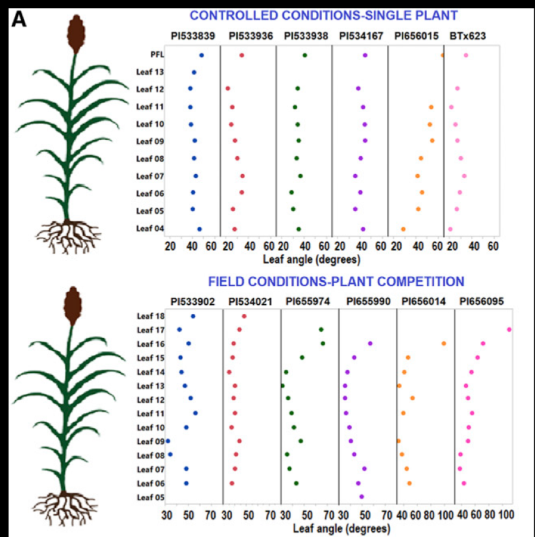


Top : upright leaves
Bottom : horizontal leaves

Top : light green leaves, smaller antennas
Bottom : dark green leaves
larger antennas

Top : Rubisco with high catalytic rate
Bottom : Rubisco with high specificity.

=> Increase the developmentally-regulated differentiation of physiological and morphological leaf traits



Mantilla-Perez et al., 2020