Effects of Free-Air Carbon Dioxide Enrichment (FACE) on Photosynthesis, Phenology and Yield of Winter Wheat

Oliver Knopf, Juan Romero, Antony Castro, …, Einhard Kleist, Hendrik Poorter, Uwe Rascher, Onno Muller

7th International Plant Phenotyping Symposium

28th of September 2022

Why elevated CO_2?

- By 2060: 600 ppm [CO_2] (RCP8.5), >10 billion people.
- The **leaf** & ear are the sites where plants **transform light from the sun into substance.**
- Until today this is the **main food source** for animals and humans.

$$6CO_2 + 12H_2O \Rightarrow C_6H_{12}O_6 + 6O_2 + 6H_2O$$

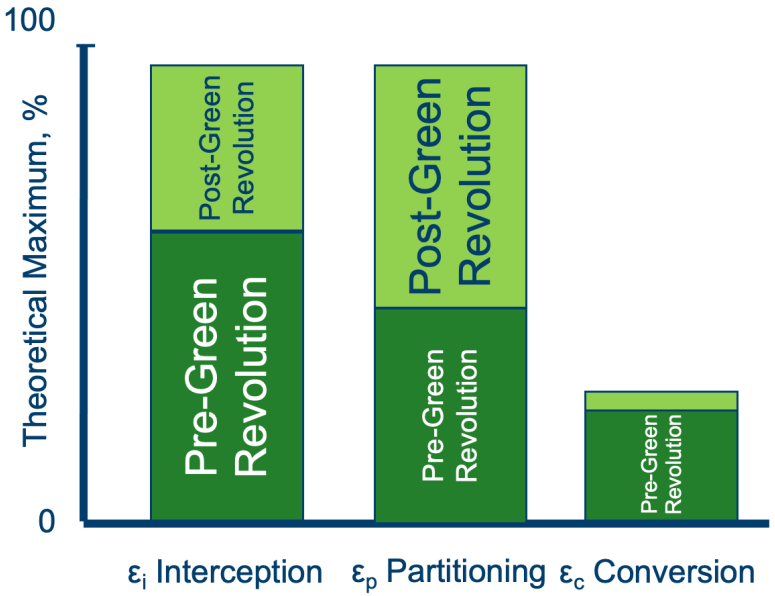
Helmholtz Climate Initative, https://ufz.pageflow.io/co2-budget

How are typical **breeding traits** of winter wheat genotypes affected by [eCO_2]:

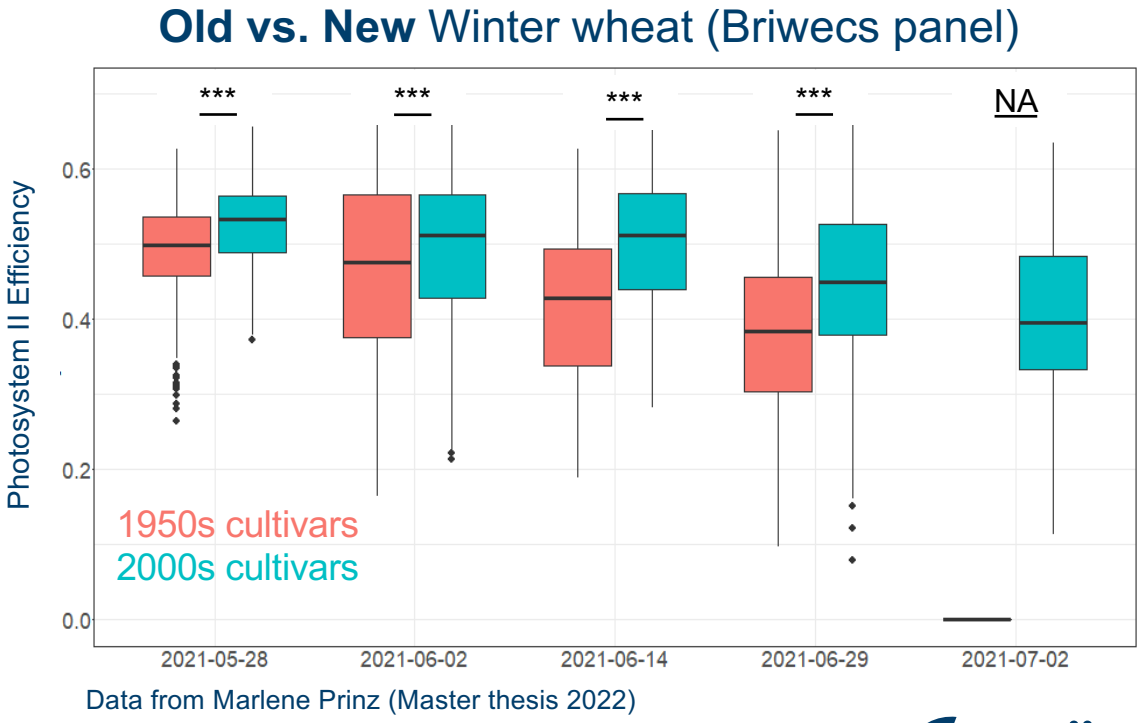
1. Biomass, Grain Yield and Plant Height
2. Photosynthetic Efficiency
3. Quality

Breeding progress measured in PSII Efficiency

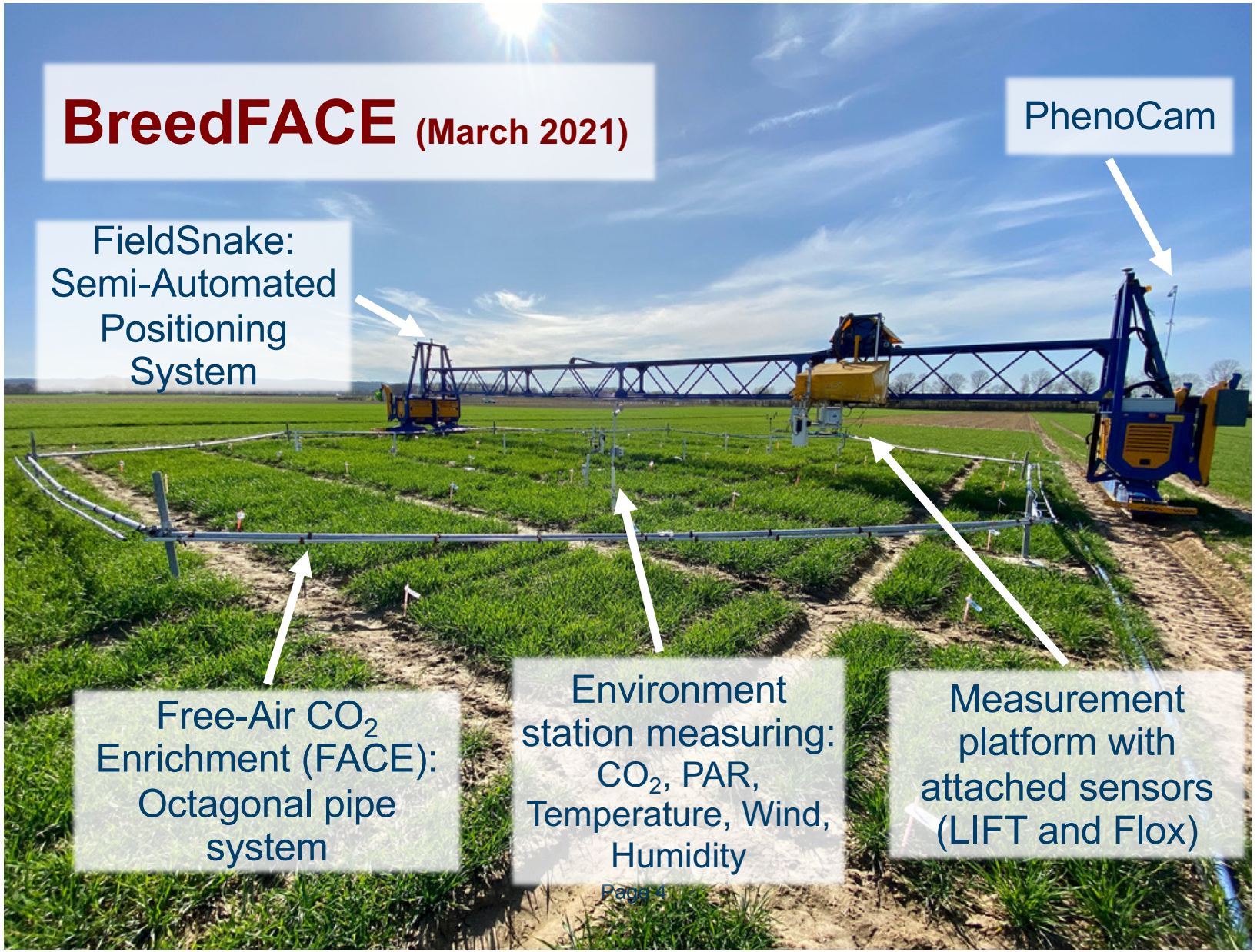
- **Increased Light interception efficiency** contributes to improved Photosynthesis.
- **Light conversion efficiency** still offers large **potential** for crop **improvement**.



Adapted from Zhu, Long & Ort (2010).



Data from Marlene Prinz (Master thesis 2022)



Site:
Campus Klein-Altendorf, Rheinbach, Germany.

Measurement object:

Triticum aestivium
- Apostel
- Asory
- Campesino
- Foxx
- Hyvega
- Informer
- KWS Emerick
- LG Inital
- Moschus
- RGT Reform

Treatments:
- Control CO_2 [~400 ppm]
- Elevated CO_2 [~600 ppm]

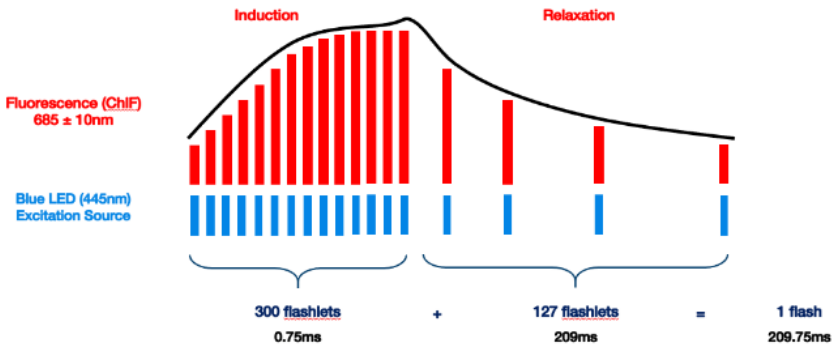
Design:
- 3 replications
- 30 plots per ring
- Size: 2 x 3 m
- Core harvest 2 x 1.5 m

JÜLICH Forschungszentrum

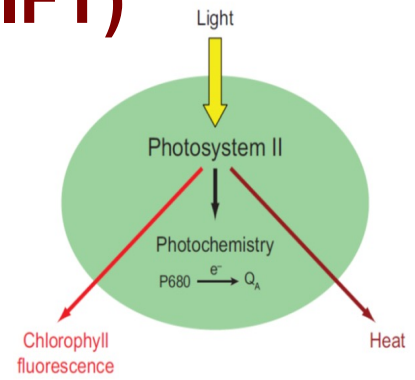
Light-Induced Fluorescence Transient (LIFT)

A field-based high-throughput system to monitor chlorophyll fluorescence (Chl F) at the canopy level in natural environments.

- **Active** and **non-destructive** measurement system with an **excitation light** source (blue LED 445 nm).
- **High time resolution** (< 1 s) assessment of photosynthetic performance at a distance.
- 420 flashlets per measurement => **Transient**

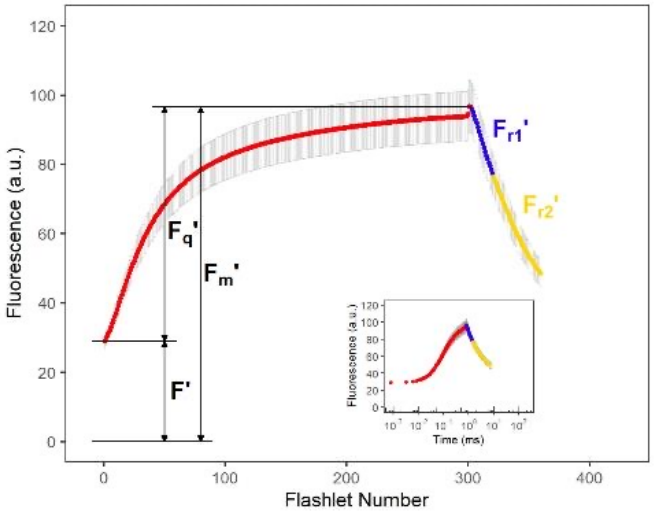


Source: Nicolas Zendonadi



Baker 2008, Chlorophyll Fluorescence: A Probe of Photosynthesis In Vivo

LIFT-REM Fluorometer (Soliense Inc., USA).

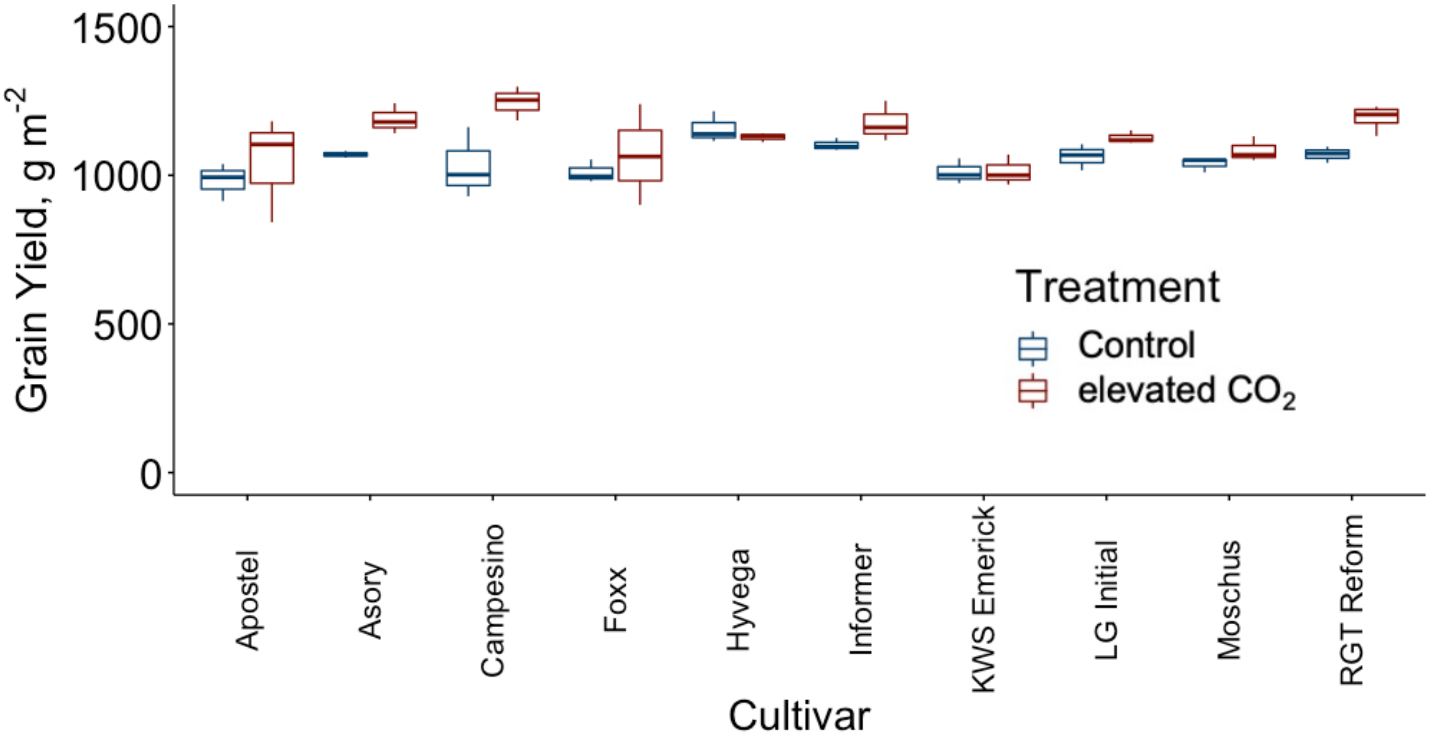


$$\frac{Fq'}{Fm'} = \frac{Fm' - F'}{Fm'}$$

PSII operating efficiency

Grain Yield 2021

- CO_2 effect: Overall grain yield increase **+7%** **($p < .01$)



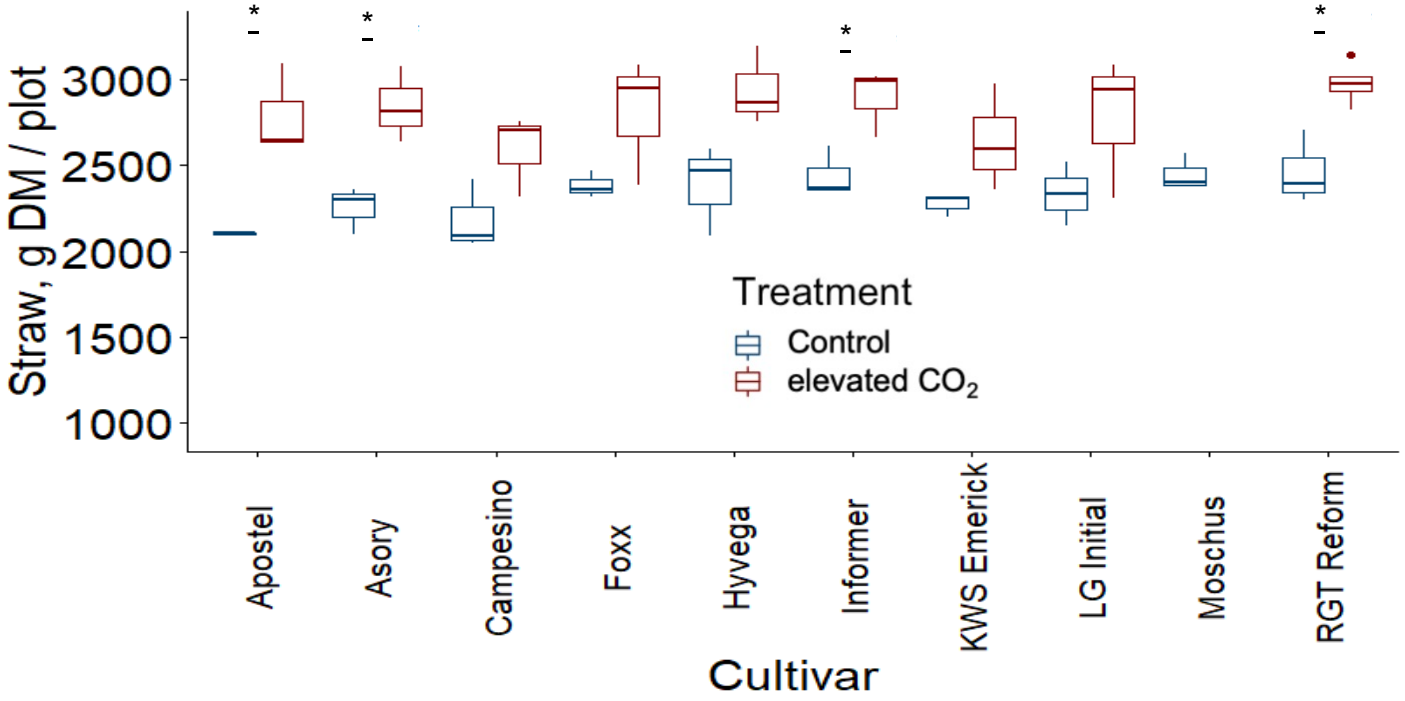
Core harvest 12th of August 2021

Cultivar	Δ Yield
Campesino	20.8%
RGT Reform	11.4%
Asory	11.0%
Informer	6.7%
Apostel	6.2%
LG Initial	6.0%
Foxx	5.7%
Moschus	4.4%
KWS Emerick	0.2%
Hyvega	-2.5%

Grain Yield
The figure shows the yield (g m^{-2}) of 10 different winter wheat cultivars (*Triticum aestivum*) treated with elevated [CO_2] (~600 ppm) and control which was grown at ambient [CO_2] (~400 ppm) in 2021. Plants were grown in the BreedFACE experimental field at Campus Klein-Altendorf, Rheinbach, Germany (n = 3).

Straw Yield 2021

- CO_2 effect: Overall increase in straw biomass **+21.6%** ***($p < .001$)

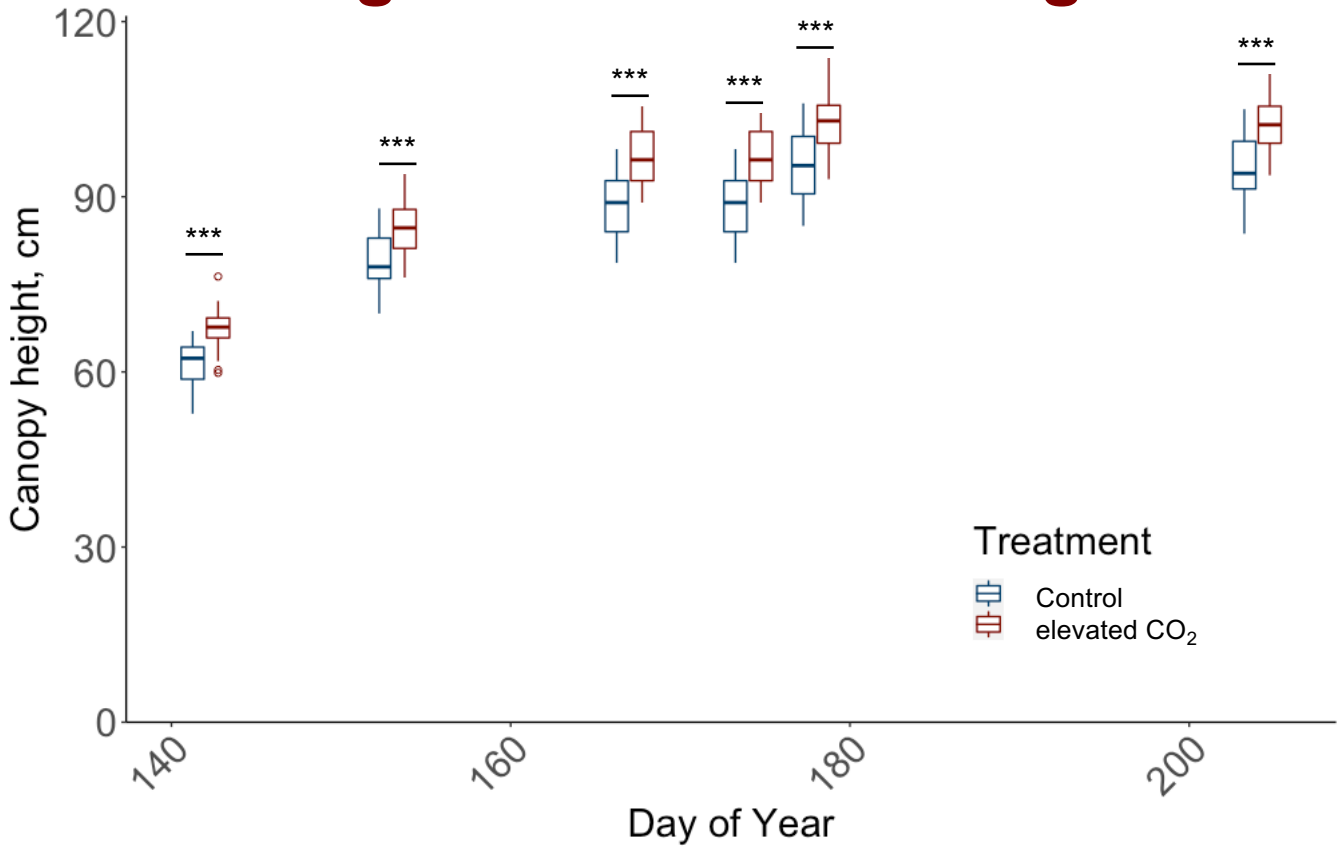


Core harvest 12th of August 2021

Cultivar	Δ Yield
Apostel	32.9%
Asory	26.3%
Hyvega	23.4%
RGT Reform	20.8%
LG Initial	19.2%
Campesino	18.8%
Informer	18.4%
Foxx	17.9%
KWS Emerick	16.3%
Moschus	NA

Straw Yield
The figure shows the average straw yield (g dry matter / plot) of winter wheat (*Triticum aestivum*) grown under elevated [CO_2] (~600 ppm) and control conditions at ambient [CO_2] (~400 ppm) in 2021. Plants were grown in the BreedFACE experimental field at Campus Klein-Altendorf, Rheinbach, Germany. Cultivar independent comparison of average height, error on mean, Welch Two Sample t-test, not significant = ns, $p < 0.05$ *, $p < 0.01$ **, $p < 0.001$ *** ($n = 3$).

Plant Height over the Growing Season



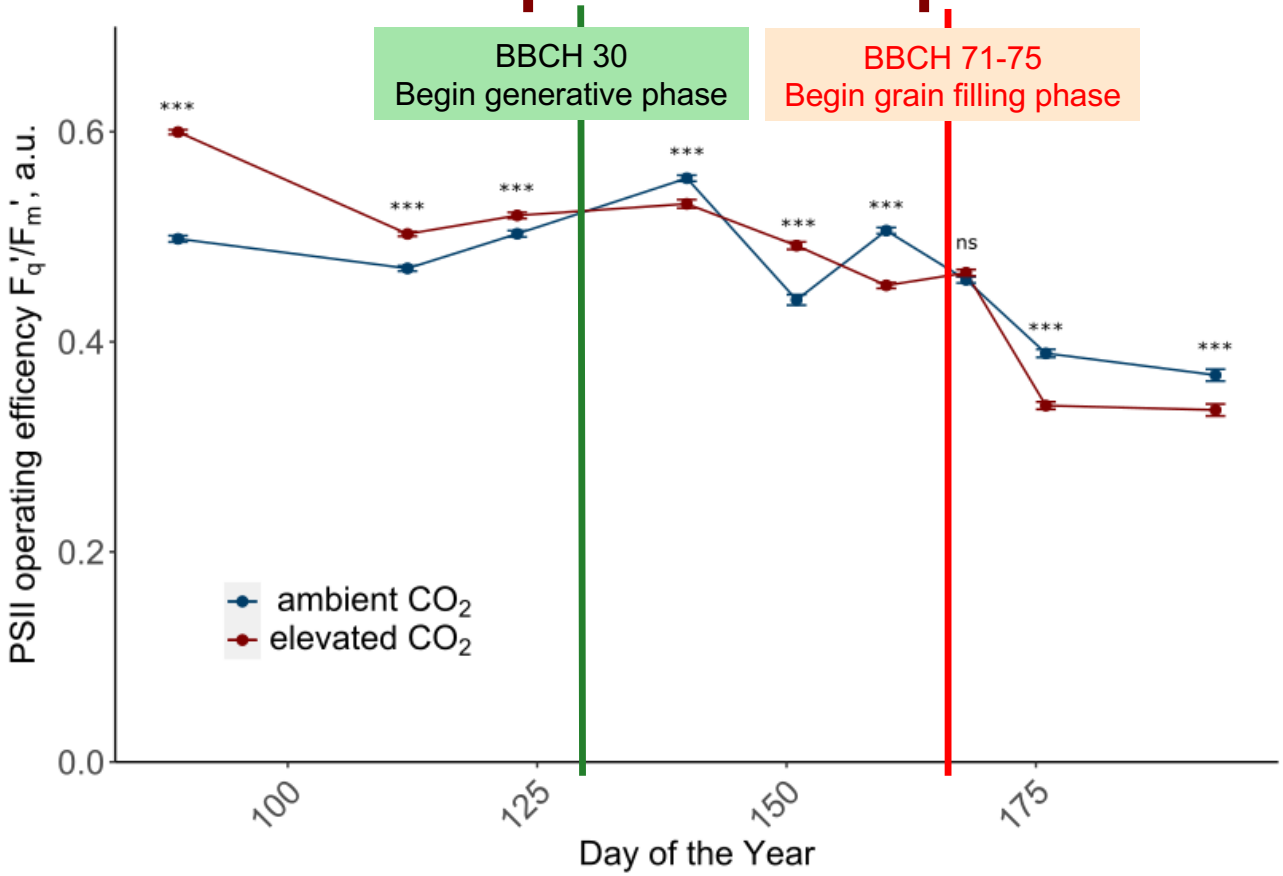
➢ Plants grown under elevated CO_2 were **significantly taller** (7.3 cm) than plants grown under control conditions.

Cultivar	Δ Height
Campesino	13.2%
Hyvega	10.2%
Asory	9.9%
Foxx	9.8%
RGT_Reform	9.8%
Apostel	9.7%
LG_Initial	7.3%
Moschus	6.2%
KWS_Emerick	5.9%
Informer	4.6%

Canopy Height
The figure shows the average plant height (cm) of winter wheat (*Triticum aestivum*) grown under elevated [CO_2] (~600 ppm) and control conditions at ambient [CO_2] (~400 ppm) in 2021. Plants were grown in the BreedFACE experimental field at Campus Klein-Altendorf, Rheinbach, Germany. Cultivar independent comparison of average height, error on mean, Welch Two Sample t-test, not significant = ns, $p < 0.05$ *, $p < 0.01$ **, $p < 0.001$ *** ($n = 9$).

JÜLICH Forschungszentrum

Seasonal development of Fq´/Fm´

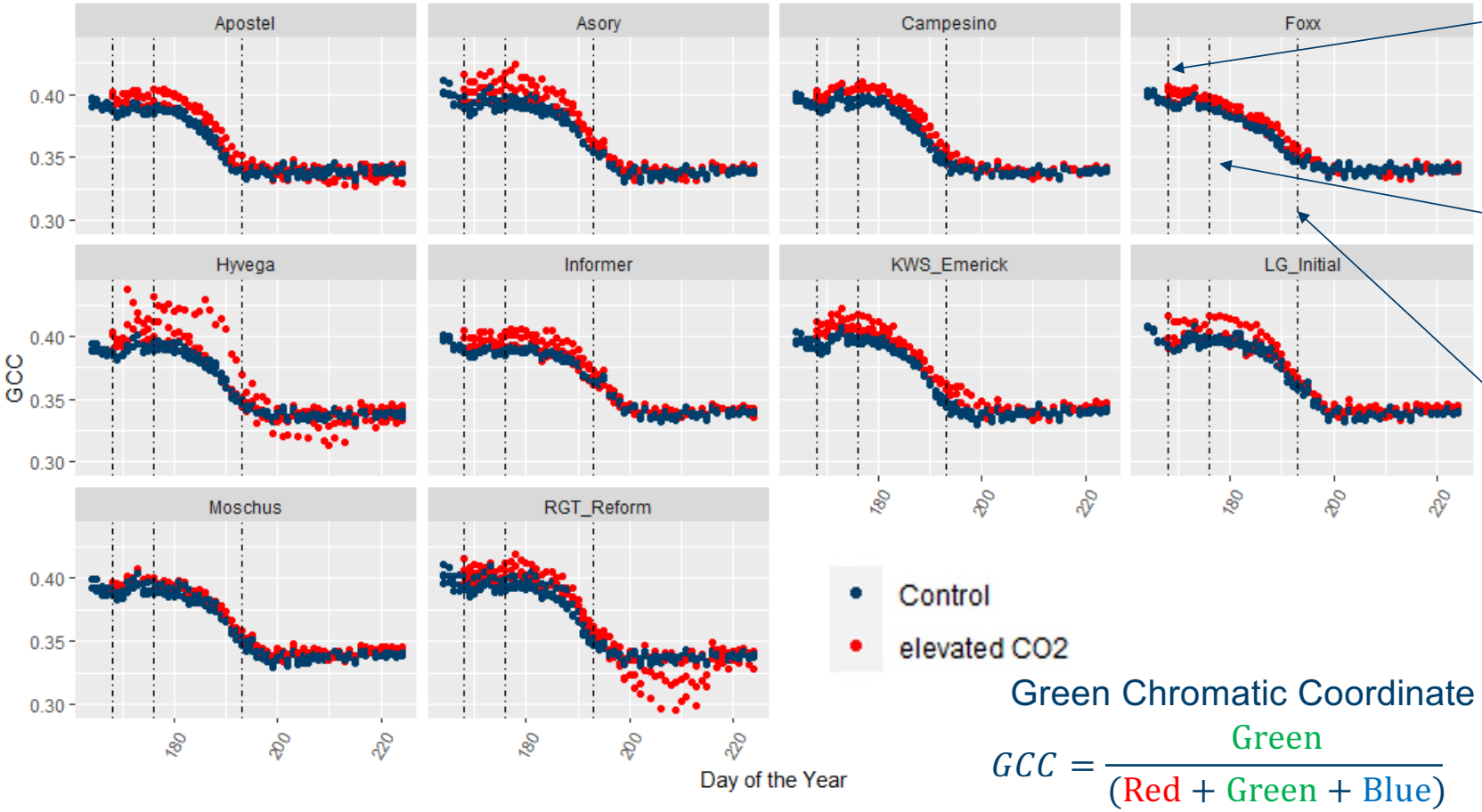


- **Fq'/Fm'** of winter wheat was significantly **higher** under **eCO_2** during the **vegetative** growth period.
- During **generative growth Fq'/Fm'** is varying for different cultivars.
- During **senescence Fq'/Fm'** was **significantly decreased** under **eCO_2**

PSII Operating Efficiency in response to CO_2
The figure shows the mean quantum efficiency of PSII under elevated CO_2 measured with a LIFT-REM device for 10 different winter wheat cultivars (*Triticum aestivum*) treated with elevated [CO_2] (~600 ppm) and control which was grown at ambient [CO_2] (~400 ppm) in 2021. Plants were grown in the BreedFACE experimental field at Campus Klein-Altendorf, Rheinbach, Germany. Cultivar Independent comparison, error bars indicate the SE, Bonferroni adjusted t-test, not significant = ns, $p < 0.001$ *** (n = 3, total number of measurements = 8'901).

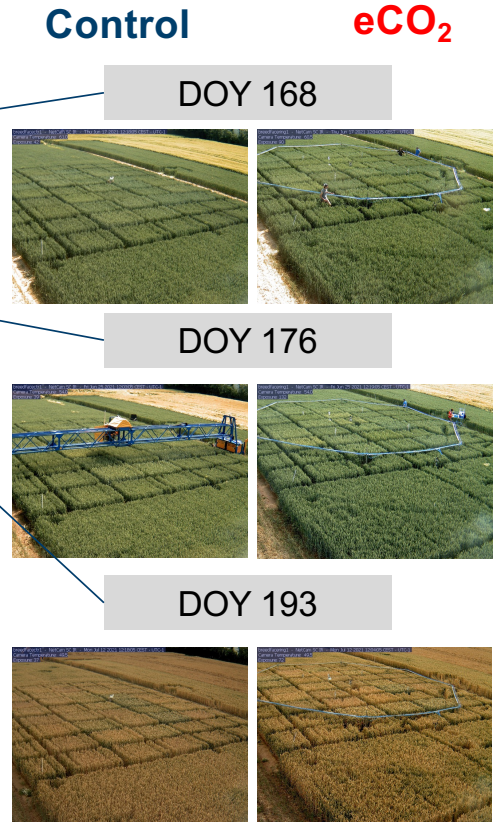
Greenness tracked with PhenoCams

- Greenness index (**GCC**) retrieved from region of interests (**ROI**) in the pictures.



Green Chromatic Coordinate

$$GCC = \frac{\text{Green}}{(\text{Red} + \text{Green} + \text{Blue})}$$



JÜLICH Forschungszentrum

What are we actually observing with our sensors?

Field of view

FloX Adapter
Upside

FloX Adapter
Downside

LIFT

Effect caused by (work in progress):
- More Biomass?
- Reallocation of resources from leaves to ears?

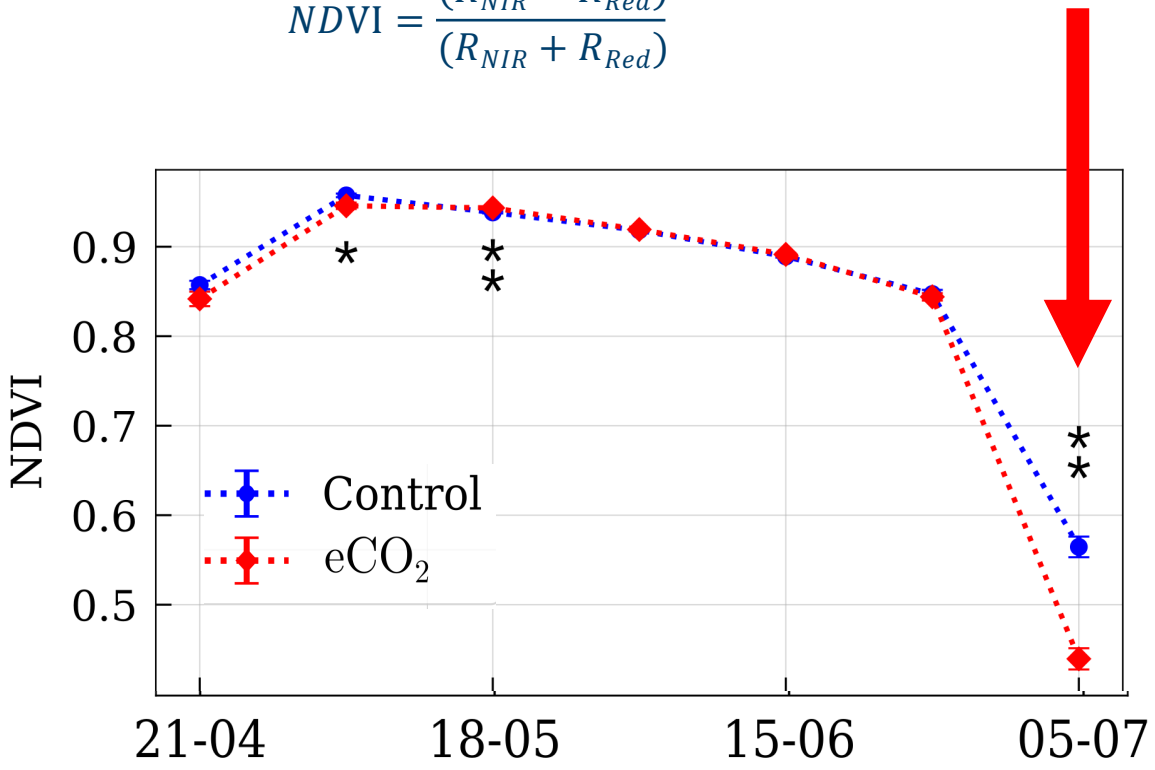
Leaves

Ears

Passive Chl F measurements - FloX

NDVI = Normalized Difference Vegetation Index

$$NDVI = \frac{(R_{NIR} - R_{Red})}{(R_{NIR} + R_{Red})}$$



Preliminary Data analysis of 2022

TechSpecs: FloX (2x spectrometers)

FULL Module: Reflectance and VIs

- 400 – 800 nm range
- Spec. Res. 0.65 nm
- SNR ~ 250

FLUO Module: SIF at O_2-A and O_2-B lines

- 650 – 800 nm range
- Spec. Res. 0.17 nm
- SNR ~ 1000

JÜLICH Forschungszentrum

Summary

- Most cultivars show significant **increases** in
  - **Straw Biomass**,
  - **Grain Yield** and
  - **Plant Height** under elevated CO_2 (Ainsworth et al. 2021, Poorter et al., 2022).
- **PhenoCams** are able track phenological changes in crops (Liu et al. 2018) **but,** the **perspective matters!**
- **Chlorophyll Fluorescence (Chl F)** retrieved parameters (Fq'/Fm') and **vegetation indices** indicate an **earlier onset** of senescence for cultivars grown **under elevated CO_2.**

Outlook

- **Diurnal** measurements
- Analysis of **Sun-Induced Fluorescence** measurements and include **environmental** factors.
- Combine with **quality** traits, e.g. protein content, baking characteristics.

Thanks to…

Onno Muller, Uwe Rascher, Hendrik Poorter, Ulrich Schurr, Einhard Kleist, Sandra Markwitz, Angelina Steier, Michael Quarten, Nils Müller, Lars Zinken, David Lenzen, Patrick Hostnik, CKA staff, KIT and LfL Team.

The BigBaking Project

Beauftragt durch Bundesministerium für Ernährung und Landwirtschaft

GFPi

LfL

KIT Karlsruher Institut für Technologie

1863 LANG-DOERFLER-BAUER

Saatzucht Streng-Engelen GmbH & Co. KG

SECOBRA Saatzucht

syngenta SEEDS

BREUN SAATZUCHT

strube research

… and for your attention.