# Focus Group S-5: Improving heat tolerance

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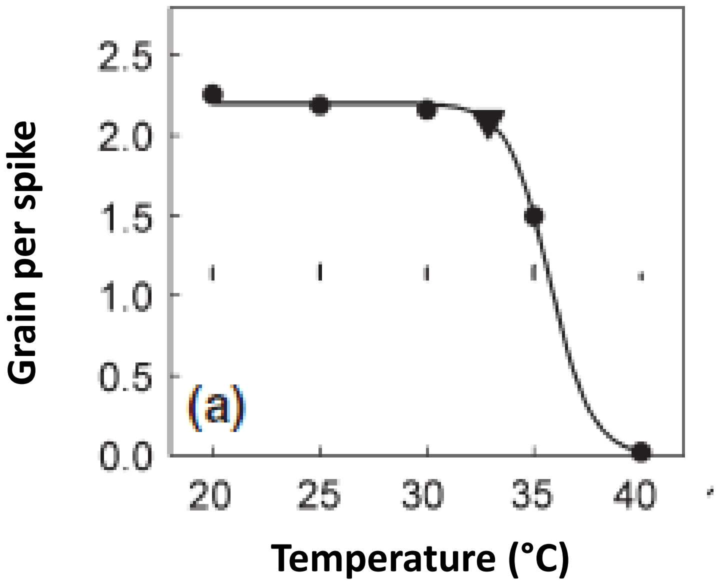
# Threshold and optimum temperatures

Heat stress in crops occurs when temperatures increase above a <u>threshold</u> or an <u>optimum</u> for processes that determine growth and yield

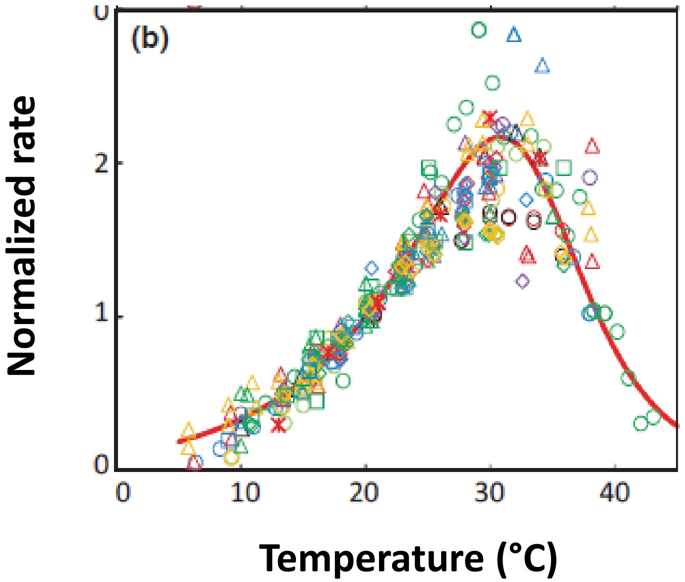
## <u>Threshold</u> like response




*Alghabari et al., JACS 2014*

⇨ Reproductive processes

## <u>Optimum</u> like response




*Parent & Tardieu et al., NP 2012*

⇨ Photosynthesis / respiration

⇨ Development processes

# Very short heat events can have dramatic consequences on crop production and quality

**1 day where $T_{max}$ > 35°C can reduce wheat yield by 33%**

Meta-analysis of 600 wheat field trials in Australia

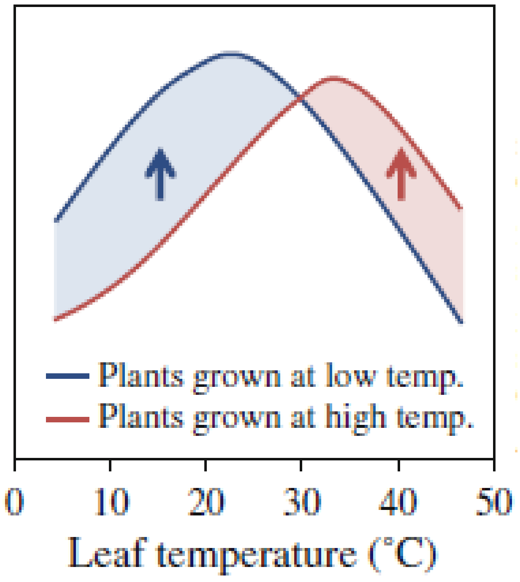
| Temperature effect | Average reduction in grain yield | |
| --- | --- | --- |
| | Flowering (%) | Grain filling (%) |
| One day where maximum temperature > 30 °C | 15.0 | 5.0 |
| One day where maximum temperature > 35 °C | 33.1 | 7.1 |

*Hunt et al., FCR 2018*

# Acclimation and interactions with other stresses

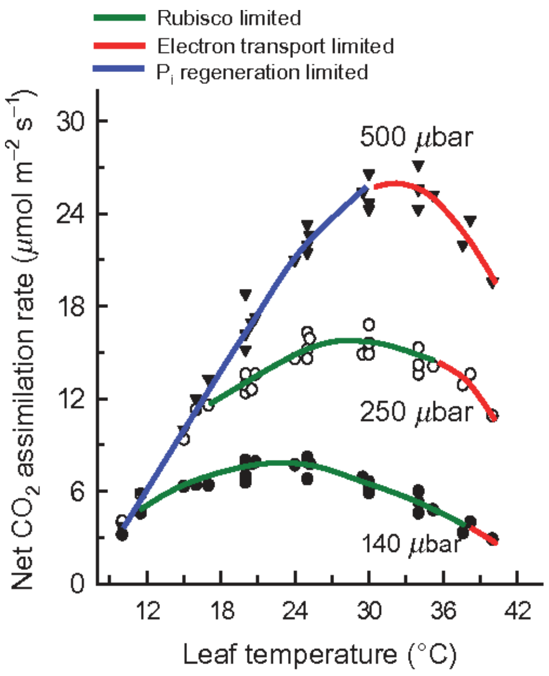
## In the field threshold and optimum temperatures change all the time!

### Acclimation to growing *T*



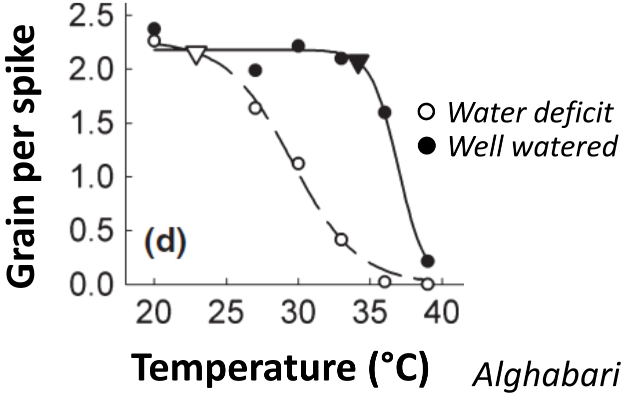

*Yamori et al., Photosynth. Res 2014*

### Interaction with $CO_2$

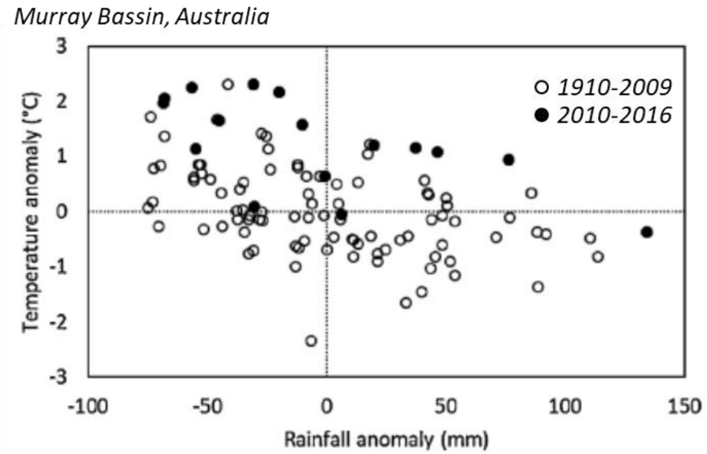



*Sage & Kubien, PCE 2007*

### Interaction with water




*Alghabari et al., JACS 2014*

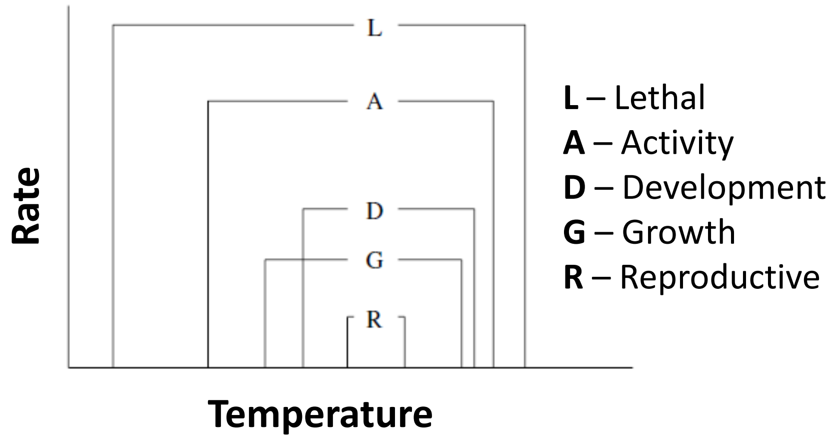



*Hunt et al., FCR 2018*

⇨ **Need to integrate knowledge across heat shock, heat wave, and long-term warming**

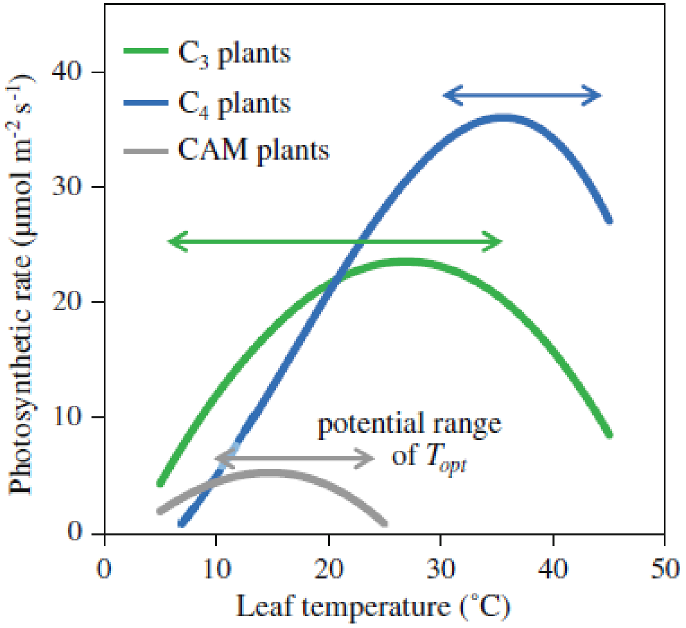
# T thresholds and optima varies with processes and between species and genotypes

**Different processes have different T optimum or thresholds**




*Porter & Semenov PTRS 2005*

**Genetic variability of *T* responses (inter >> intra-specific)**




*Yamori et al., Photosynth. Res 2014*



*Hunt et al., FCR 2018*

# Plant response and adaptation to heat stress

Climate change impact

## Occurrence of heat stress

- Increased air temperature
- Increased soil temperature
- Loss of soil moisture
- Adverse soil physical properties
- Altered canopy properties

## Plant responses

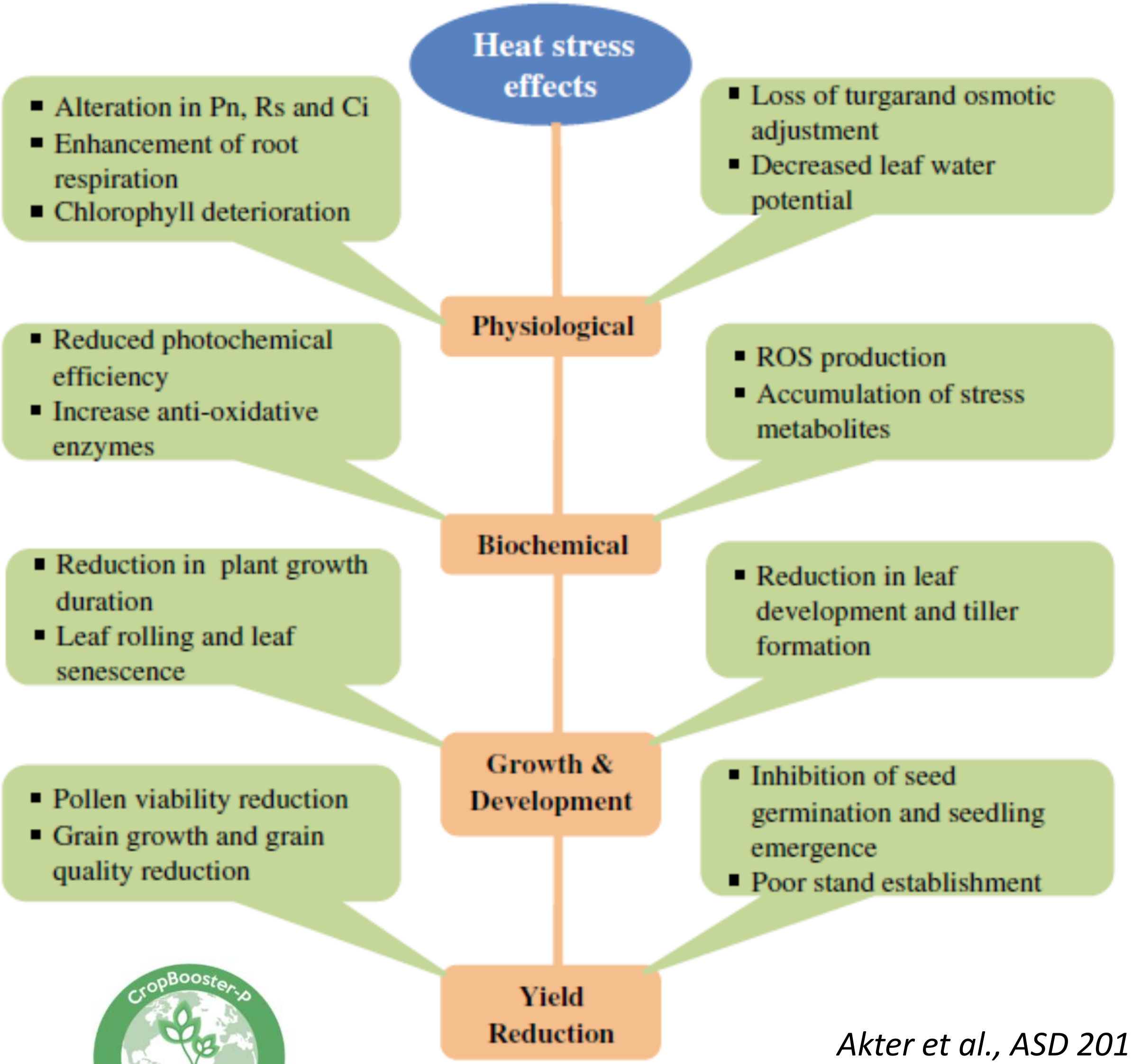
- Poor plant establishment
- Plant tissue dehydration
- Decreased photosynthesis
- Leaf senescence
- Pollen sterility
- Reduced grain growth

## Adaptation to heat stress

- Crop and cultivar choice
- Modified sowing date
- Irrigation
- Antioxidant defense
- Osmo-protectants
- Transpiration colling

*Akter et al., ASD 2017*

# A large number of processes at different scales are involved in plant heat response and tolerance




*Akter et al., ASD 2017*

# Most relevant unresolved research questions

## At the agronomic level

- Under which **agro-climatic scenarios** is heat stress tolerance desirable?
- What are **consequences of agroecological/multiservices cropping systems** on heat stress tolerance and resilience?
- How to **develop G x M systems more resilient to heat shocks** and better adapted to future climate scenarios with increased risk of extreme climate events?
- Can **plant/crop canopy architecture** influence microclimate favourably, e.g. by shading of sensitive organs/processes? (links with crop management strategies - crop mixture, agroforestry, agrivoltaism,…)

# Most relevant unresolved research questions

## At the Physiological level

- How **do temperature thresholds or optima change** when crops are exposed to **other stressors**?
- Can we **optimize trade-offs between traits for heat and drought adaptation** (given uncertain conditions)?
- Is there a need for **organ/tissue level protection** (e.g. leaf/ear wax) to heat stress or is tolerance **at whole plant level** needed?
- Where is **temperature perception** detected to drive plant heat stress responses?
- What is the benefit of heat stress **transcriptional acclimation or memory** at upper scales?

*Hunt et al., FCR 2018*

# Most relevant unresolved research questions

## At the genetic level

- Is there enough **genetic variation in the current elite gene pool** used by breeders to improve heat tolerance in current and future climate/management conditions?
- Can there be **cross-generational epigenetic acclimation**? Can pre-acclimated seed be produced?
- Can **gene evolution** that appended during species adaptation to environment with high risks of heat stress be re-enacted using the most up-to-date techniques of molecular breeding?

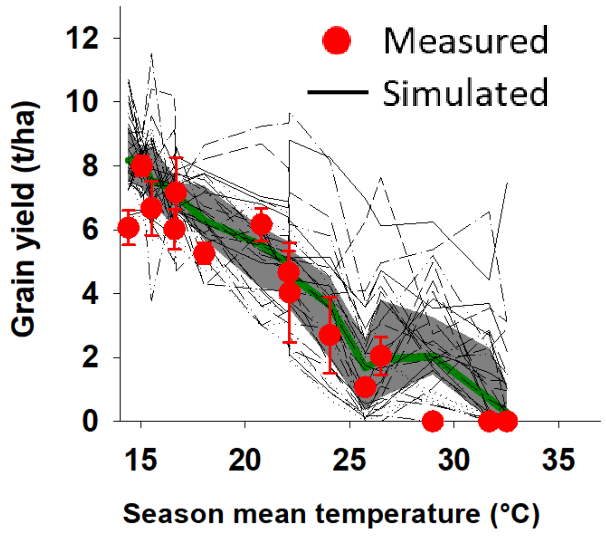
# Most relevant unresolved research questions

## At the cellular and molecular level

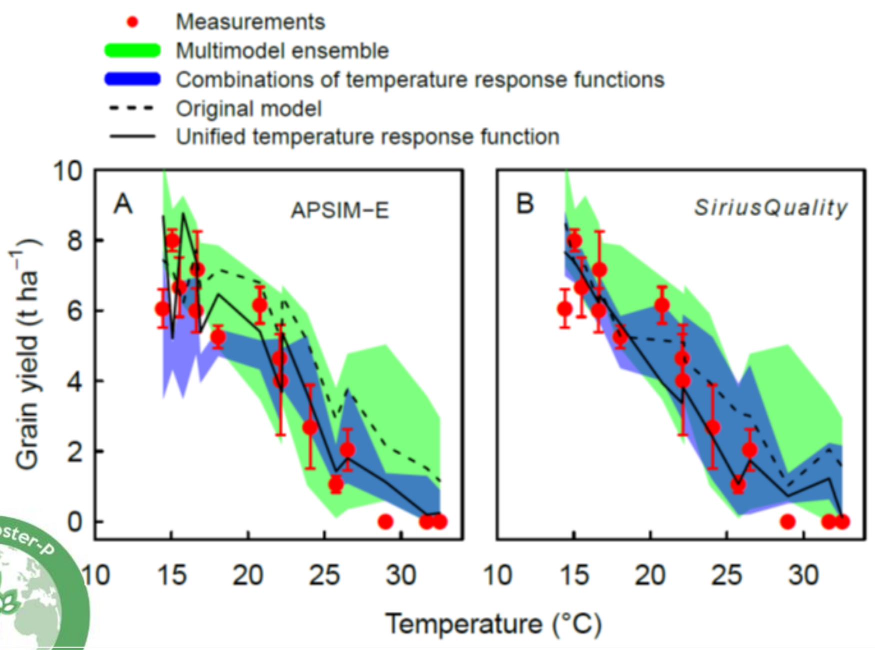
- How is the **temperature perceived and signalled**, which organs are involved?
- How does **heat stress link with other stress**? Is cross-adaptation likely among several stresses?
- What is the **cellular and molecular basis of thermosensitivity** of reproductive tissues?
- How can we avoid heat effects on **membrane fluidity**?
- Can we avoid heat effects on **intrinsic protein stability** by introducing key factors of resistant plants with increased structural stability into crops?

# What needs to be done to solve the scientific questions?

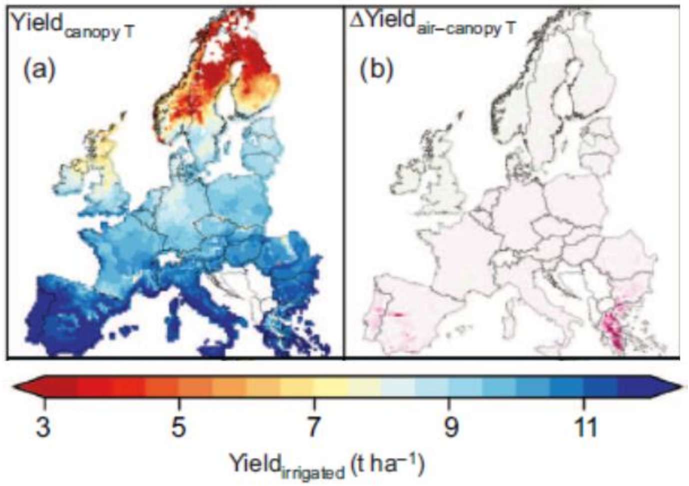
- **Improve crop growth models** by considering **acclimation** of key processes (e.g. fertility) to heat
- **Improve crop growth models** by considering the response to **combined stress** (e.g. heat x drought, heat x high evaporative demand)
- **Analyse risk scenarios to identify relevant heat stress scenarios** (crop growth stages, duration, intensity) and possible interactions with other stressors to better target researches




*Asseng et al. 2015 NCC*




*Wang et al. 2017 Nat. Plant*



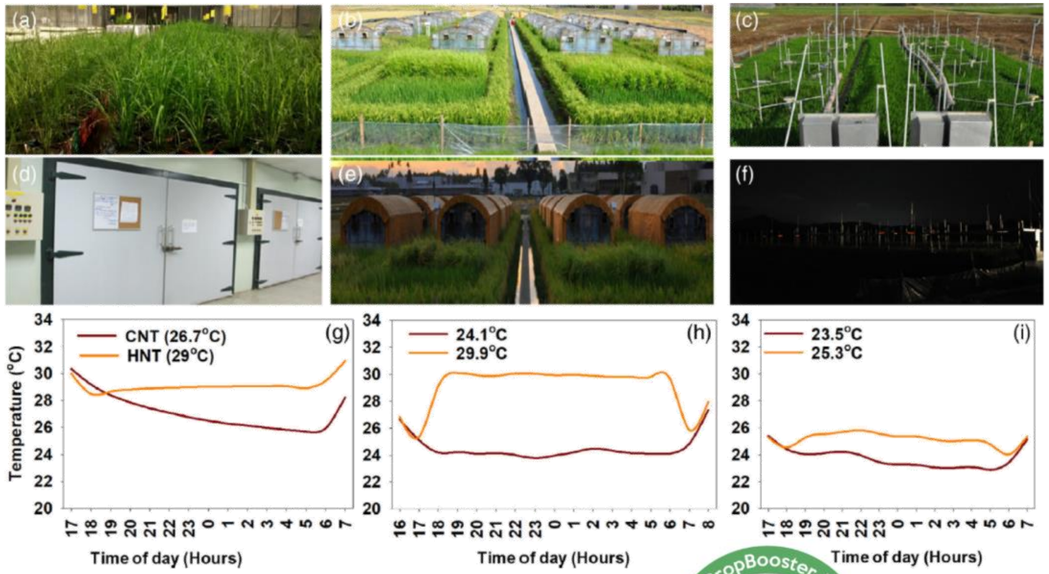

*Siebert et al. ERL 2017*

# What needs to be done to solve the scientific questions?

## Heat stress are unpredictable and in most environment have low probabilty

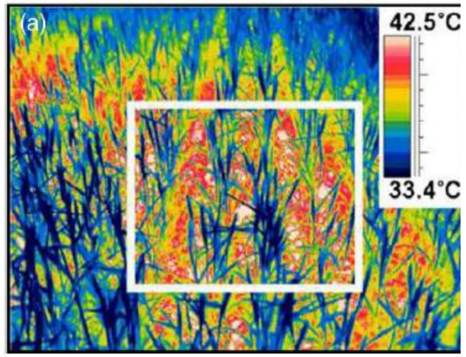
- Develop methods to **apply high temperature treatments in the field and in controlled environments**
- Develop methods and tools to **screen and analyse large populations efficiently for heat tolerance** and resilience (genetic markers, phenomics, metabolomics, sensors)

*Walk-in growth chambers* *Field-based temperature-controlled tents* *Temperature free air controlled enhancement (T-FACE)*

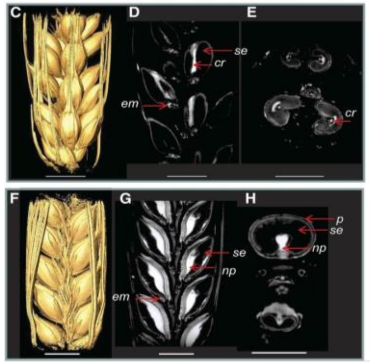



*Impa et al., PCE 2021*

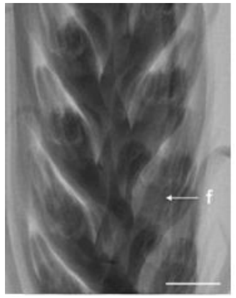
*Infra-red thermometry*




*NMR imagery*




*X-ray tomography*



*Rolletchek et al., PlantPhys 2015*

*Tracy et al., Plant Methods 2017*

# What needs to be done to solve the scientific questions?

- Develop **non-disruptive prebreeding strategies for heat stress tolerance** to efficiently tap in exotic allele pools? (including cross species analyses for trait and physiological/molecular processes identification/characterisation)
- **Integrate knowledge and tools across heat shock, heat wave, and long-term warming** studies

# Projects with application relevance

- Increase the frequency and **pyramid specific morphological traits** (constitutive and easy to phenotype) that exist in current cultivars or breeding germplasms but at low frequency and that are rarely combined in the same genotype
- Establish **screening and prebreeding strategies** to identify genotypes that are temperature resilient but do not depend on extensive irrigation
- Identify **how crops sense temperature** in order to generate an effective strategy to generate microclimate-based approaches that would mitigate the impact of heat stress under field conditions
- Develop new genetic and agronomic solutions to **improve microclimates of crops** to minimize the effects of heat and drought stress

Long coleotile

*Rebetzke et al., Euphytica 199*

Glaucousness
(epicuticular wax)

Leaf rolling

Erect leaf

*Hunt et al., FCR 2018*

Crop mixtures

Agroforestry

Agrovoltaims