Heat tolerance is a key for high wheat yields in Europe under climate change

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Rothamsted Research
Food security: global food demand

(Ray et al, PLoS ONE, 2013)

2.4% yield increase per year required to double food production by 2050
Wheat yield stagnation in Europe

(Brisson et al, Field Crop Res 2010)
World record wheat yields

- In 1981, the world record wheat yield of 13.99 t/ha at a field scale was achieved in Scotland.
- In 2010, a NZ farmer had a new record of 15.64 t/ha (cv. Einstein).
- Average wheat yield in the UK is about 8 t/ha.
- 20:20 Wheat® aims to achieve yield potential of 20 t/ha in 20 years.
Adapting wheat for uncertain future

Challenges:

• Large uncertainty in predicting future environments and climates

• No clear targets for breeding: future threats to wheat production are unknown

• Candidate-cultivars can be only tested for the current, not future conditions

Key:

• Modelling is a powerful tool to design wheat ideotypes for a changing climate and identify targets for crop improvement
Modelling framework: wheat ideotypes

- Cultivars/Genetics
- Management
- Weather
- Soil

Sirius crop model

CMIP5 climate projections

LARS-WG weather generator

Local-scale weather

Ideotypes optimised for future climates
Sirius: crop simulation model

**INPUT**
- Cultivars
- Weather
- Soil
- Management

**MODEL**
- Canopy
- Phenology
- RUE & Biomass
- Water & N limitation
- Soil
- Grain yield & quality
- Extremes

**EXPLORATION**
- Model parameters
- Calibration & validation
- Optimizing ideotypes
- Inter-model comparison
- Inter-plant competition
- Impact of climate change
- Evolutionary algorithm
LARS-WG: downscaling climate projections

CMIP5 ensemble of Global Climate Models

Local-scale parameters derived from observed weather

Local-scale climate scenarios for impact assessments
Coding wheat ideotypes: cultivar parameters

**Phenology**
- phyllochron $\text{Ph}$: 70 - 140
- daylength response $\text{PP}$: 0.05 – 0.7
- duration of grain filling $\text{Gf}$: 500 - 900

**Canopy**
- max leaf size $\text{A}$: 0.003 – 0.01
- “stay green” $\text{S}$: 1-2

**Tolerance to drought**
- response of photosynthesis to water stress $\text{Wsa}$: 0.1 – 0.21
- leaf senescence $\text{Wss}$: 0.12 – 0.19

**Roots efficiency**
- water uptake $\text{Ru}$: 1 - 7
Optimisation: evolutionary algorithm

\{ \text{Ph}, \text{Pp}, \text{Gf}, \text{A}, \text{S}, \text{Wsa}, \text{Wss}, \text{Ru} \}

**Objective:**

maximise 100yr mean yield for ideotypes with yield CV < 15% and HI95 < 0.63

**Stopping rule:**

search stops when Y95 exceeds a target, or no further improvement is possible

Optimization for a single site requires evaluation of \(~50,000\) ideotypes. However, the algorithm may converge to a local, not global, optimum. Therefore, we start with 20 “parents” randomly scattered in the parameter space.
Target environments: Europe, CMIP5, 2050

- Maximum temperature, °C
- Monthly precipitation, mm

Rothamsted, UK
Seville, Spain

SL
RR

Month
1 2 3 4 5 6 7 8 9 10 11 12

Monthly precipitation, mm
0 20 40 60 80 100

Monthly temperature, °C
0 10 20 30 40

City locations:
- Rothamsted, UK
- Seville, Spain

Map indicating target environments across Europe.
Substantial increase in yield by 2050

Modelling predicts yield increase of **56-109 %** for ideotypes optimized for future climates compared with current wheat cultivars.
Effect of heat stress and drought around flowering on grain yield

High temperature and water stress during booting reduce grain number and grain weight in winter wheat

(Alghabari et al., J Agr Crop Sci 2013)
Heat tolerance is a key trait in S.Europe

In Seville, HT ideotypes can achieve 111% higher yield potential compared with HS, in Debrecen yield CV increased by 265% for HS ideotypes

(Stratonovitch & Semenov, JxB 2015)
Effect of temperature during 3-day transfers to controlled environment cabinets during anthesis on (A) grain yield and (B) grains per spikelet (C) grain weight of S.European (MV Emese, Renesansa) and UK wheat cultivars (Mercia, Savannah)

(Semenov et al., J Cer Sci 2014)
CMIP5: uncertainty in climate projections

(IPCC AR5 WG1)
Quantifying uncertainty in predictions

Sensitivity to heat stress around flowering and grain filling will seriously limit wheat yield potential in S.Europe

(Semenov & Stratonovitch, Clim Res 2015)
Key messages

• Wheat yield potential can be substantially increased in Europe by 2050.

• Increase in light use efficiency, extended duration of grain filling and optimal phenology are key factors. In water-limited environments, increased drought tolerance will be needed.

• To achieve the high yield potential in S.Europe, tolerance to heat stress is required. Sensitivity to heat stress not only reduces mean yield, but increases its variability.

• Identified key traits for wheat improvement are robust and unaffected by the uncertainty in CMIP5 climate projections.
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