Sorghum: the safe bet for the future

Challenges and breeding strategies to improve sorghum for abiotic stress in Europe

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ABIOTIC STRESS OF SORGHUM IN EUROPE

What are the main challenges?

Juvenile cold stress

Reproductive cold stress

Drought stress

Lodging

JUVENILE COLD STRESS TOLERANCE

A critical adaptation trait for all sorghum types in Europe

→ Genetic variation is not the problem!

→ But how can we efficiently enhance it in hybrid cultivars?

Picture:

Reaction of different sorghum inbred lines to controlled cold stress (13/10 °C) for four weeks

JUVENILE COLD STRESS TOLERANCE

is a strongly quantitative trait!

→ Limited prospects of marker-assisted selection on per se performance

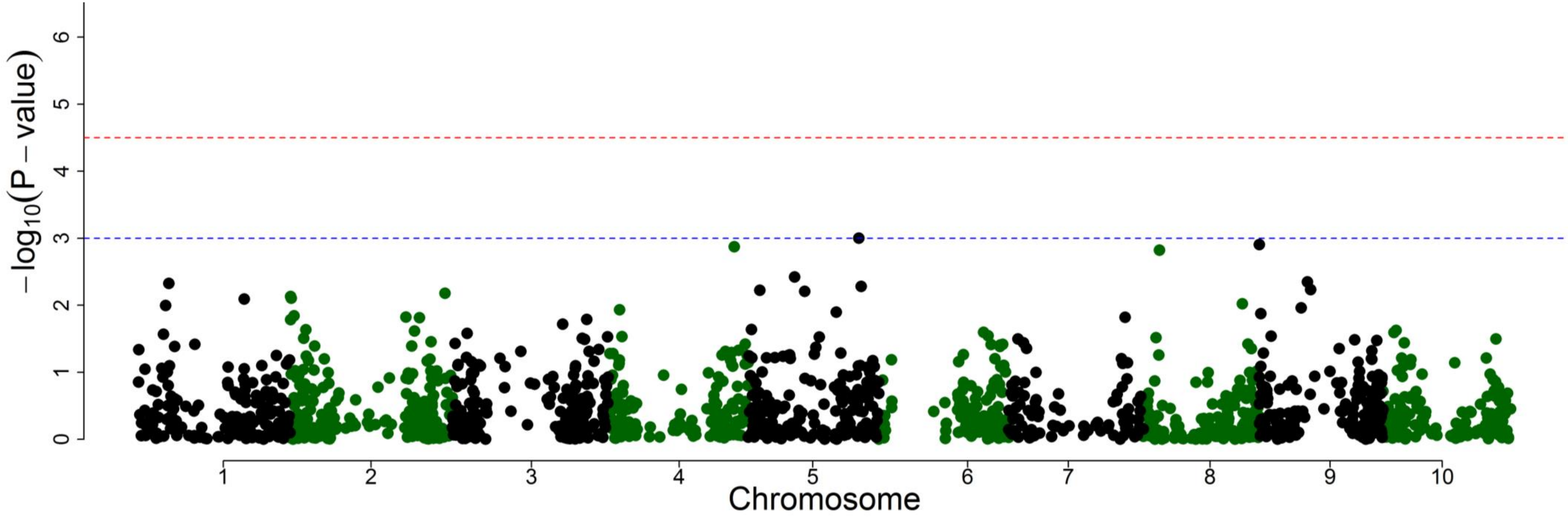


Figure:
Manhattan-Plot showing marker-trait associations for juvenile shoot dry weight under cold stress (field experiment) on a sorghum diversity set (n=379 inbred lines)

JUVENILE COLD STRESS TOLERANCE

is a strongly heterotic trait!

→ *Enhancements via classical hybrid breeding feasible*

→ *What are the most efficient strategies?*

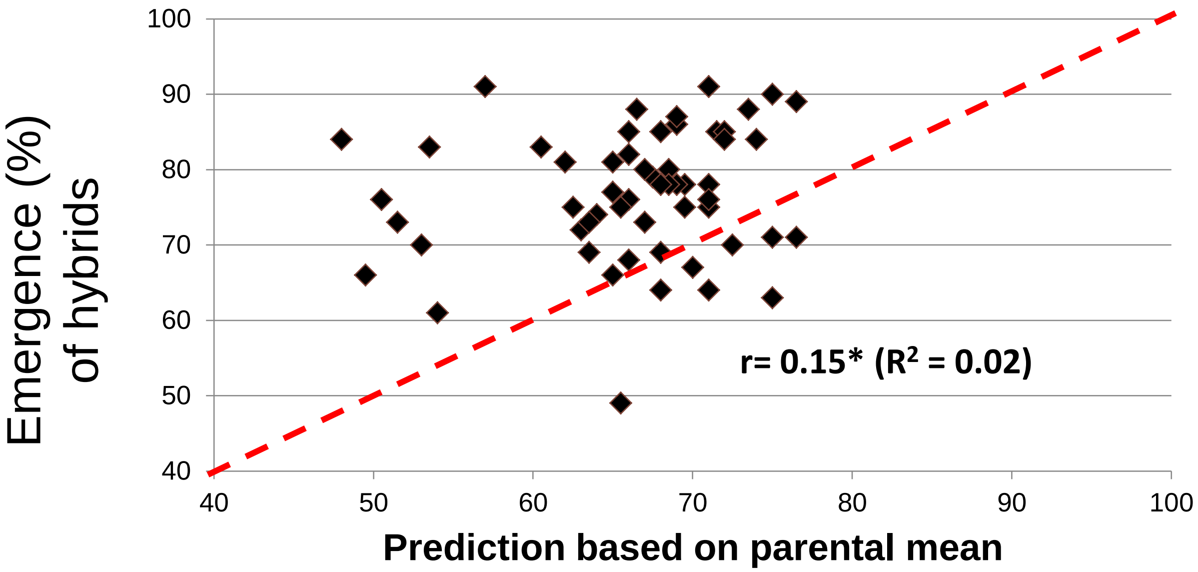
Cold stress reaction of inbred lines

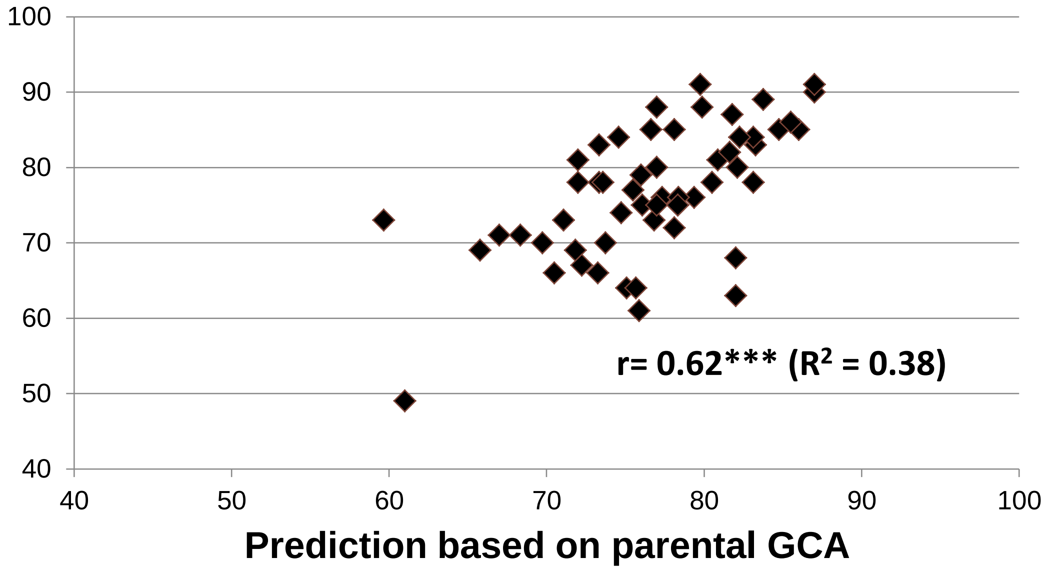
Cold stress reaction of their factorial hybrids

HETEROSIS FOR JUVENILE COLD TOLERANCE

Analysis of a diverse factorial (4 females, 16 restorers, 64 F_1-hybrids) for different cold tolerance traits, incl. field trials and controlled environment experiments

Emergence (field experiment)





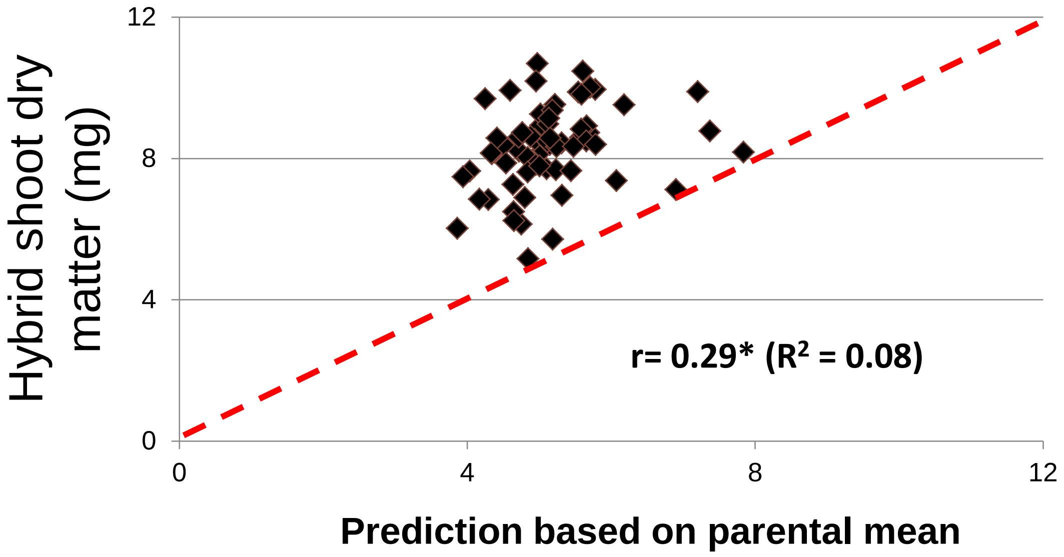
11 % midparent-heterosis in average
r (*per se*: GCA): 0.90* for females and -0.02 for restorers

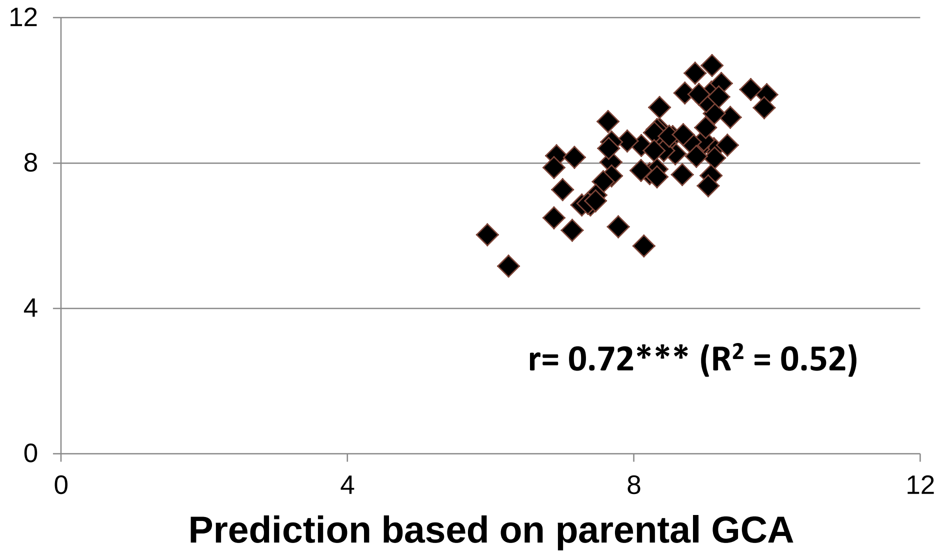
Windpassinger et al. (2016): Towards enhancement of early-stage chilling tolerance and root development in sorghum F1 hybrids. J Agro Crop Sci, doi:10.1111/jac.12171

HETEROSIS FOR JUVENILE COLD TOLERANCE

Analysis of a diverse factorial (4 females, 16 restorers, 64 F_1-hybrids) for different cold tolerance traits, both field trials and controlled environment experiments

Early shoot dry matter (climate chamber 13/10 °C)





61 % midparent-heterosis in average

r (*per se*: GCA): 0.73 for females and 0.27 for restorers

Windpassinger et al. (2016):
Towards enhancement of early-stage chilling tolerance and root development in sorghum F1 hybrids. J Agro Crop Sci, doi:10.1111/jac.12171

HETEROSIS FOR JUVENILE COLD TOLERANCE

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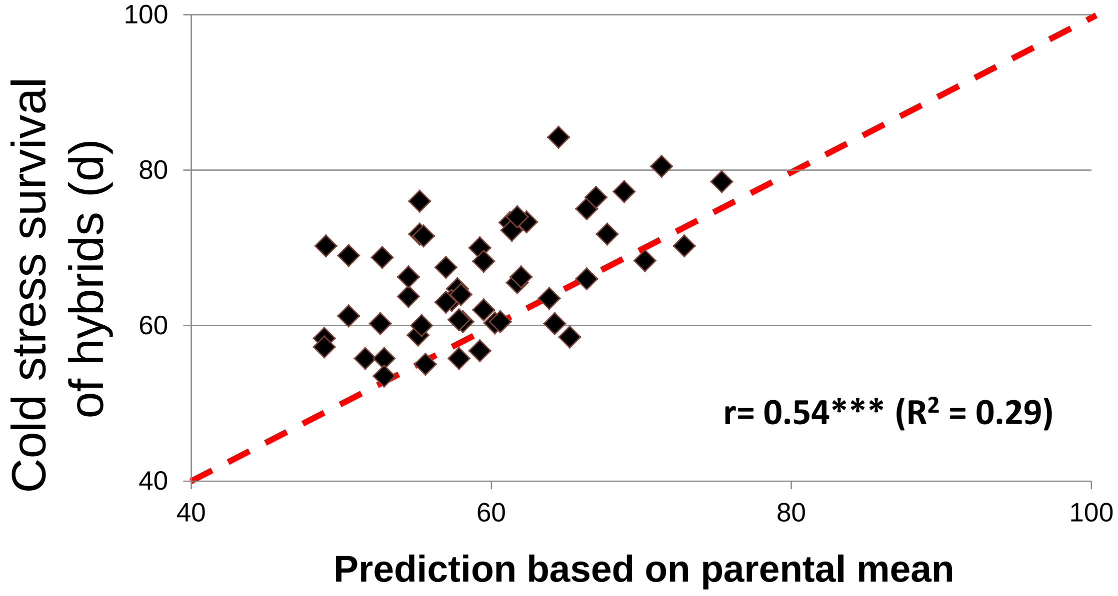
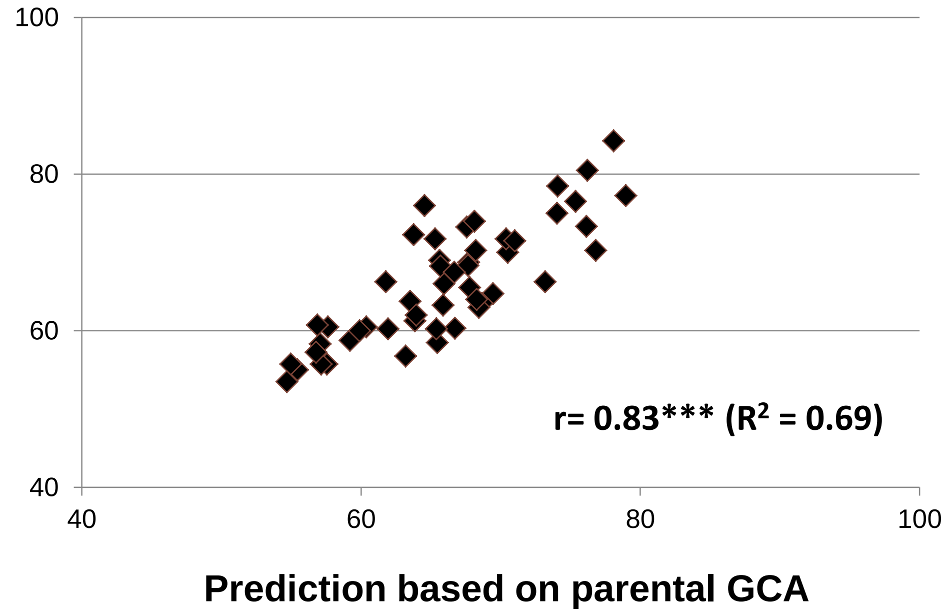
Cold stress survival (13/10 °C) after warm emergence

HETEROSIS FOR JUVENILE COLD TOLERANCE

Analysis of a diverse factorial (4 females, 16 restorers, 64 F_1-hybrids) for different cold tolerance traits, both field trials and controlled environment experiments

Cold stress survival after warm emergence





36 % midparent-heterosis in average
r (*per se*: GCA): 0.29 for females and 0.76*** for restorers

Windpassinger et al. (2016): Towards enhancement of early-stage chilling tolerance and root development in sorghum F1 hybrids. J Agro Crop Sci, doi:10.1111/jac.12171

HYBRID BREEDING FOR JUVENILE COLD TOLERANCE

What are the main findings?

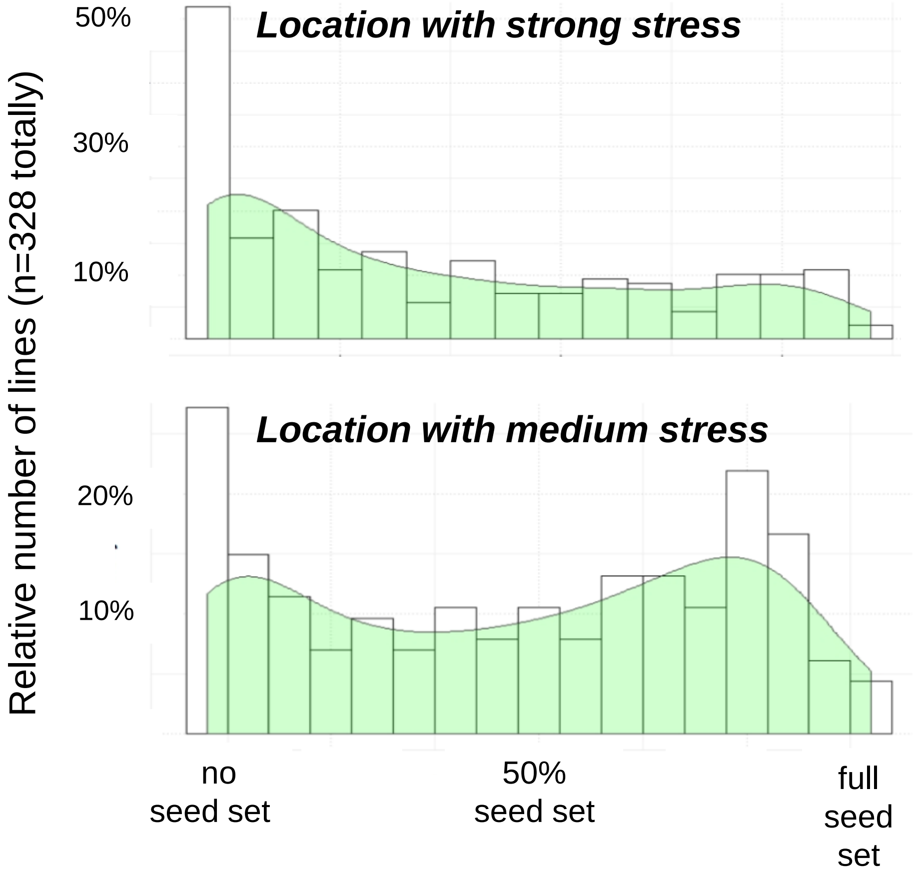
- Juvenile cold tolerance traits are heterotic
- Parental mean/*per se* tolerance are poor predictors of hybrid performance
- GCA:SCA ratio (i. e. additive vs. dominance effects) depends on specific trait
- Predominance of female effects for emergence and heterotrophic growth

What are the consequences for hybrid breeding?

- Selection on general combining ability (GCA) and establishment of heterotic pools are more recommendable than a too strict selection on line per se performance
- Focus on development of better adapted females

REPRODUCTIVE COLD STRESS TOLERANCE

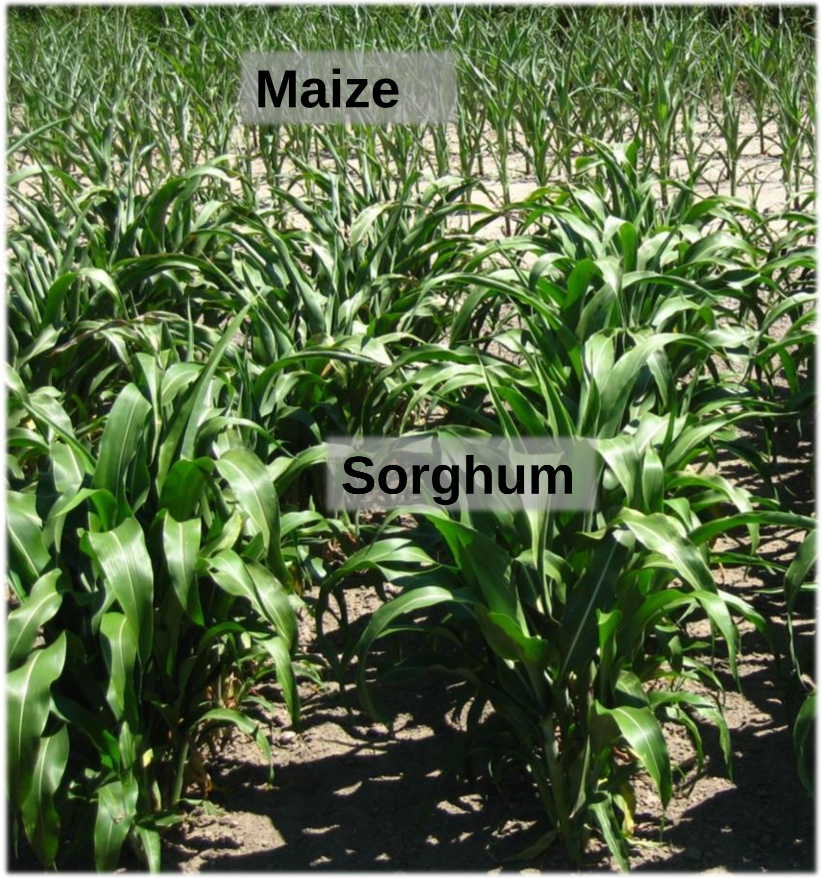
A crucial adaptation trait for grain and dual-purpose sorghum in Northern and high-altitude environments



DROUGHT STRESS TOLERANCE

One of sorghum´s biggest assets, but needs to be further enhanced!

Pre-flowering vs. post-flowering vs. permanent



PRE-FLOWERING DROUGHT STRESS TOLERANCE

Might be at least equally important as post-flowering drought in Central Europe, but less studied

Consequences:

- delay of flowering
- stunted panicles
- poor panicle exsertion
- infertile florets („head blight“)
- reduced pollen fertility

Panicle initiation starts within the shoot from 7-leaf-stage onwards!

Differences between two sorghum genotypes

Symptoms of pre-flowering drought stress

POST-FLOWERING DROUGHT STRESS TOLERANCE

Post-flowering drought stress: Stay-green vs. Dry-Down

Stay-green:

- important trait under terminal drought stress
- global breeding goal
- increases grain yield
- avoids lodging

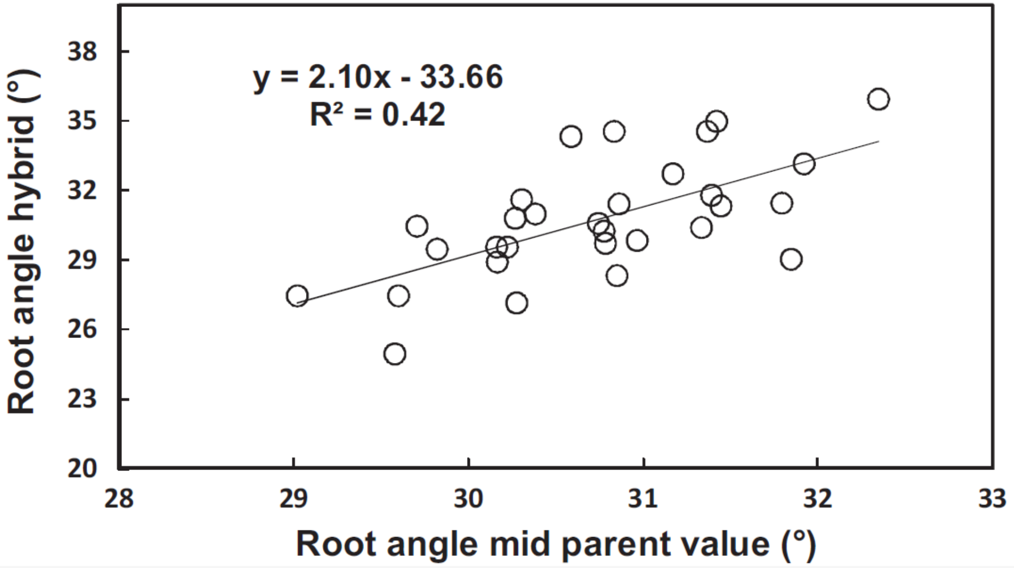
POST-FLOWERING DROUGHT STRESS TOLERANCE

Stay-green is a quantitative trait associated with:

- nodal root angle (Mace et al. 2011, Lopez et al. 2017)
- smaller canopy size and lower water extraction at pre-flowering (Borrell et al. 2014)
- less tillering (Jaeggli et al. 2017)
- dhurrin biosynthesis (Hayes et al. 2016)

Efficient phenotyping methods for nodal root angle (Singh et al. 2012) and QTL for stay-green (Borrell et al. 2014) have been identified.

But also here: Difficulty to predict hybrid root angle based on inbred lines (Singh et al. 2012).



Source of figure:
Singh et al. (2012):
Genetic control of nodal root angle in sorghum and its implications on water extraction. European Journal of Agronomy 42 (2012) 3-10

PHENOTYPING DROUGHT STRESS TOLERANCE

Simulating field conditions in a controlled environment

Drought stress phenotyping facility *„DroughtSpotter XXL (Phenospex)“* at Uni Giessen:

- exact measurements of transpiration
- adjustment to a specific field capacity or constant daily water supply
- enables to track water uptake in up to 5 min intervalls 24/7
- each container can be irrigated individually

LODGING RESISTANCE

Crucial trait, but poorly researched!

Important selection criterion for dual-purpose and biomass sorghum hybrids-
but only two relevant publications:

Gomez et al. 2017:
Identifying morphological and mechanical traits associated with stem lodging in bioenergy sorghum
(Bioenerg. Res. (2017) 10:635-647)

Esechie et al. 1977:
Relationship of stalk morphology and chemical composition to lodging resistance in sorghum
(Crop Science (1977), doi: 10.2135/cropsci1977.0011183X001700040032x)

LODGING RESISTANCE

Key findings

Lodging resistance is associated with:

- reduced height (*Esechie et al., Gomez et al.*)
- larger diameter: length ratio of basal internodes (*Esechie et al., Gomez et al.*)
- less internodes per plant (*Gomez et al.*)
- less internode volume (*Gomez et al.*)
- less stem rigidity (*Gomez et al.*)
- higher total nonstructural carbohydrates and lower stalk potassium and protein concentrations (*Esechie et al*.)

→ For reliable selection tools, more studies are needed!

→ What is the role of roots?

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