Extensive exploration of wild relatives' diversity for wheat breeding: a story from the gene bank to the field

The activities of the Molecular Breeding Laboratory, Arid Land Research Center, Tottori University

Contents

- The beginning (background)
- Hexaploid wheat, the MSD population production and evaluation
- Tetraploid wheat, the MDL population production and evaluation
- Ongoing activities

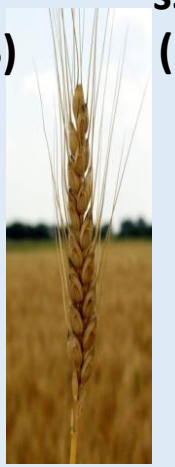
Wheat evolution and re-synthesis

Evolution of bread wheat

8,500 BP

Triticum turgidum
ssp. *durum*
(2n=4x=28, AABB)
Cultivated

Aegilops tauschii
ssp. *strangulata*
(2n=2x=14, DD)
Wild



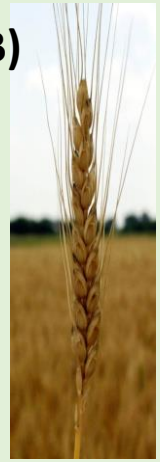
Triticum aestivum
(2n=6x=42 AABBDD)

Re-synthesis of bread wheat

Now

Triticum turgidum
ssp. *durum*
(2n=4x=28, AABB)

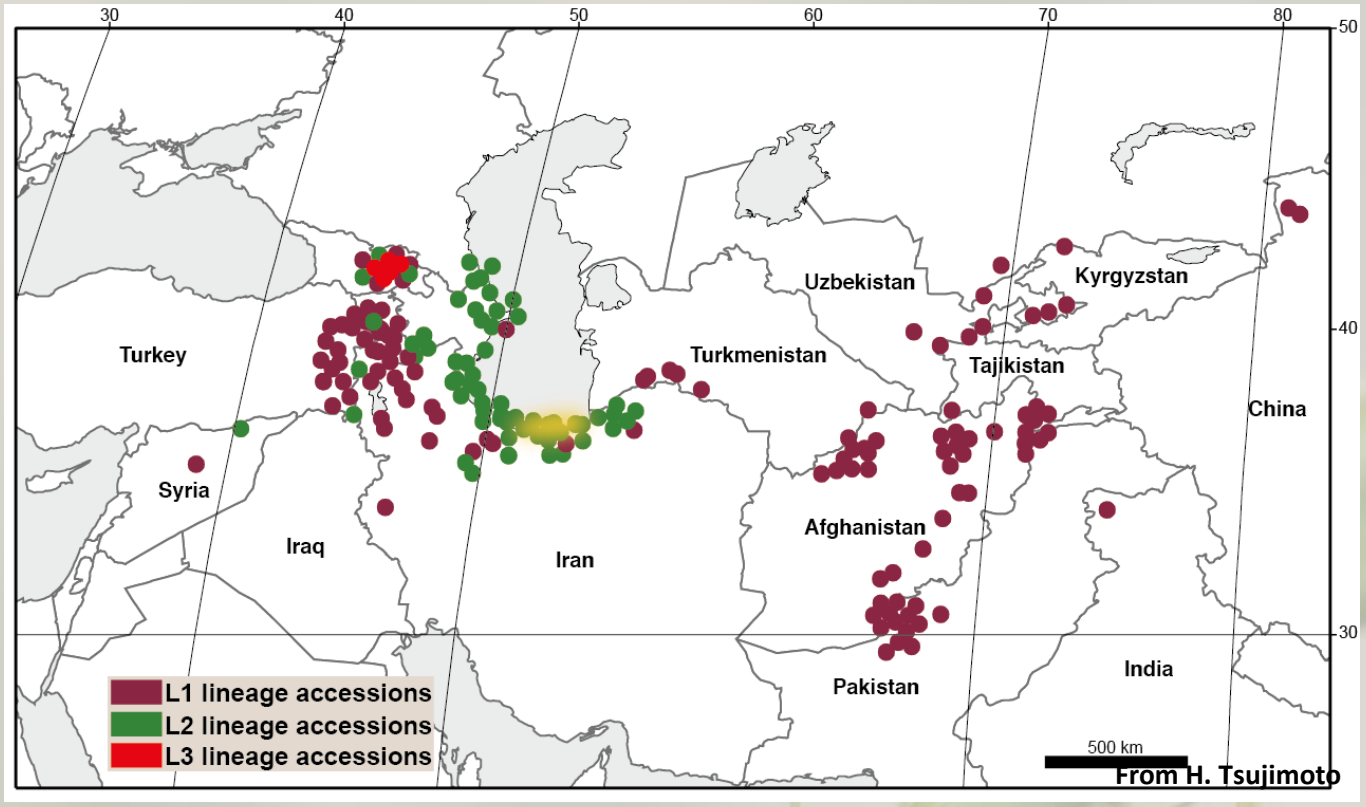
Aegilops tauschii
(2n=2x=14, DD)



Synthetic wheat
(2n=6x=42 AABBDD)

From H. Tsujimoto

The beginning: Geographical distribution of *Ae. tauschii*



- Wide diversity
- Potential to widen the narrow genetic diversity of bread wheat

The beginning: Drought tolerance in *Ae. tauschii*

Breeding Science 61: 347–357 (2011)
doi:10.1270/jsbbs.61.347

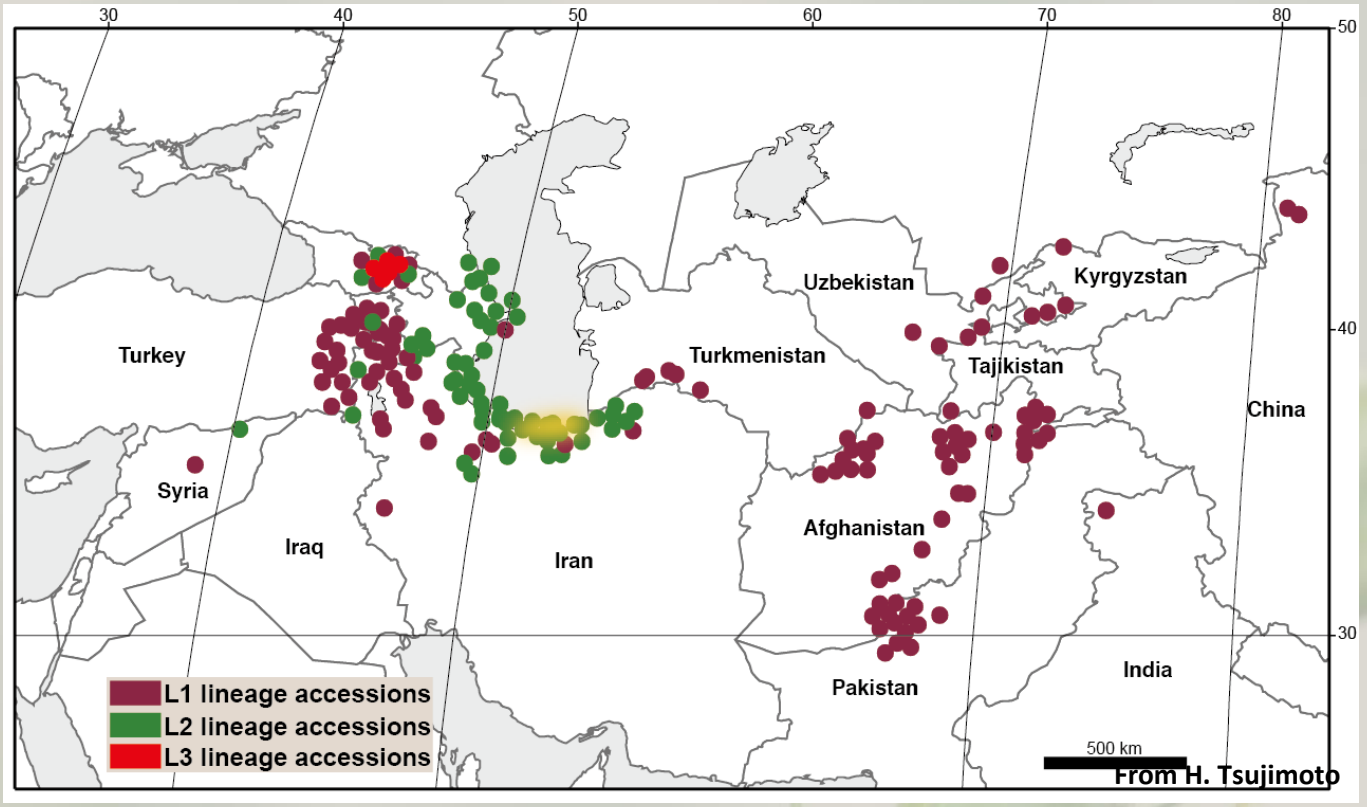
Applicability of *Aegilops tauschii* drought tolerance traits to breeding of hexaploid wheat

Quahir Sohail[1)], Tomoe Inoue[2)], Hiroyuki Tanaka[3)], Amin Elsadig Eltayeb[1)], Yoshihiro Matsuoka[4)] and Hisashi Tsujimoto*[1)]

- **33 *Ae. tauschii* accessions and their corresponding synthetic wheat (SW) lines**
- **No correlation between the diploid traits and their corresponding SW**
- **Regardless of the *Ae. tauschii* adaptation, SW could possess desired traits**

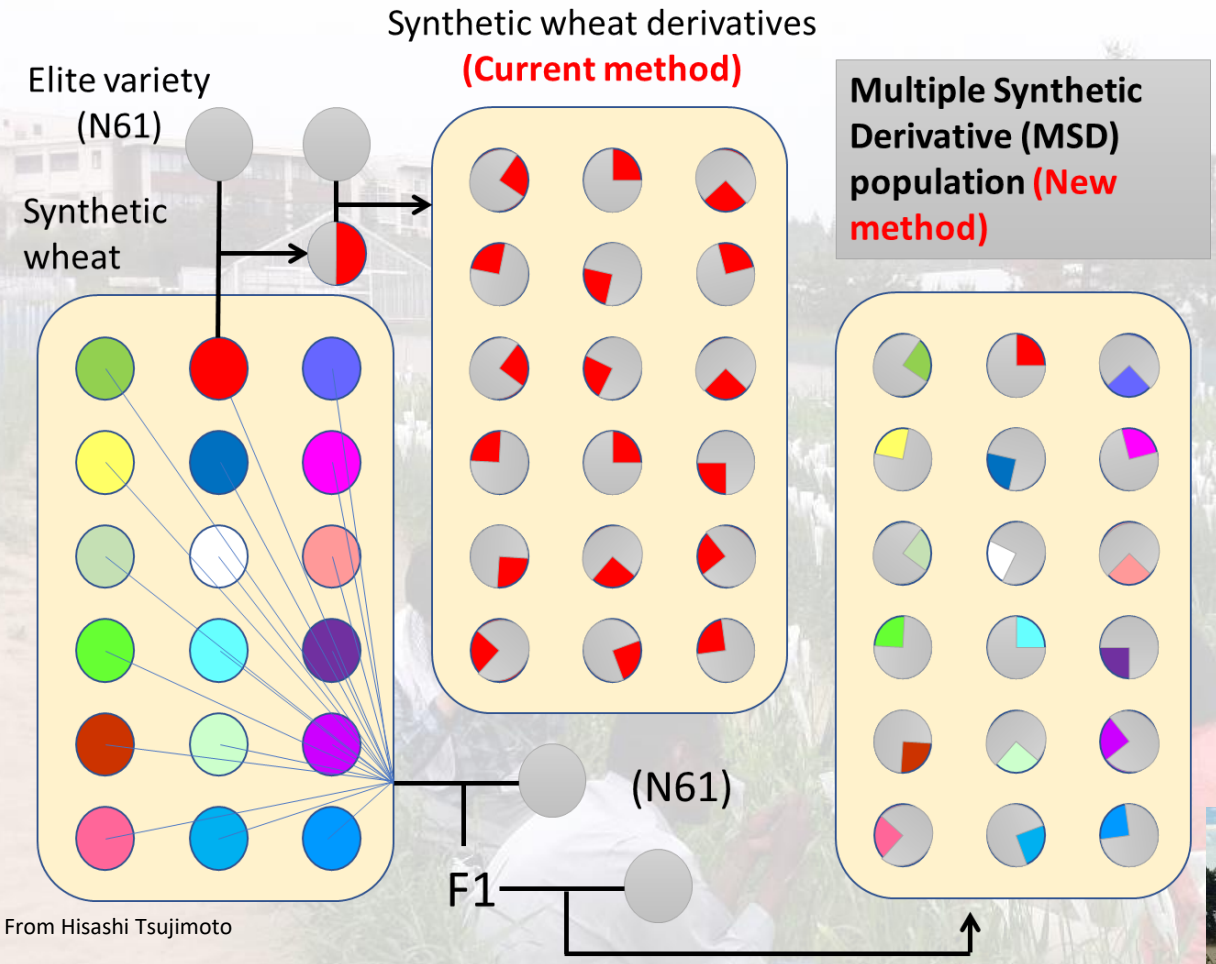
➢ **SW is agronomically poor, therefore the SW traits should be evaluated in the elite background (dilute the wild traits)**

The beginning: Geographical distribution of *Ae. tauschii*



- How to introduce this wide diversity into wheat?
- How to compare the impact of different *Ae. tauschii* accessions?

Hexaploid wheat: The Multiple Synthetic Derivatives Population (MSD)



10 plants from each BC_1F_1

↓

10 seeds from each plant

100 seeds from each cross

↓

A mixed population of 4300 lines

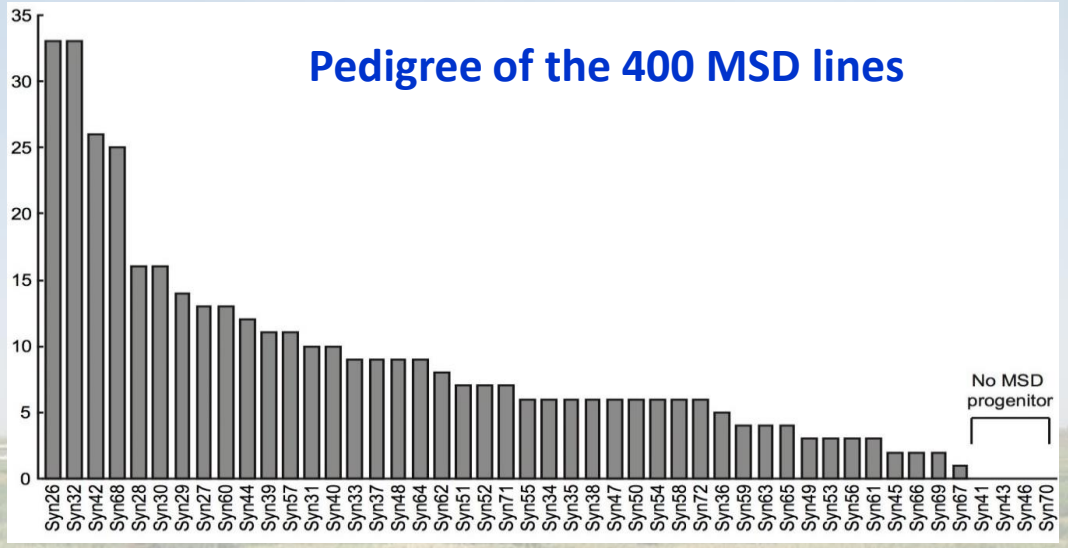
75% from Norin 61 and 25% from *Ae. tauschii*

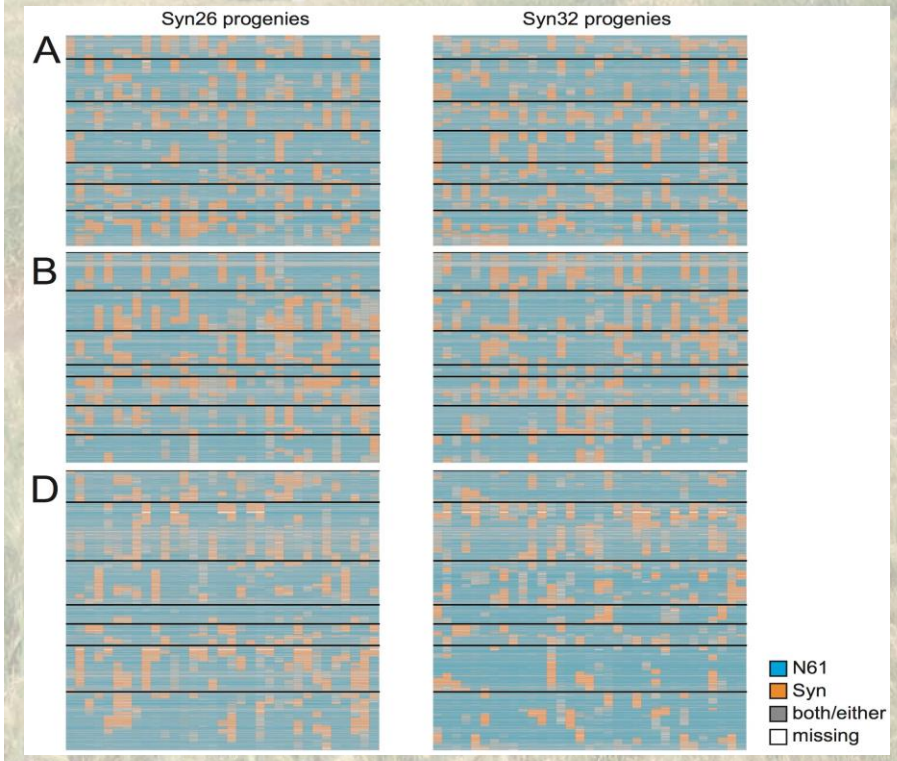
- **Not very difficult to produce**
- **Maintained as bulk, and very easy to handle**
- **Good for selection**

The Multiple Synthetic Derivatives Population (MSD)

For validation:

- Selected 400 lines randomly
- Genotyped (DArT-seq)

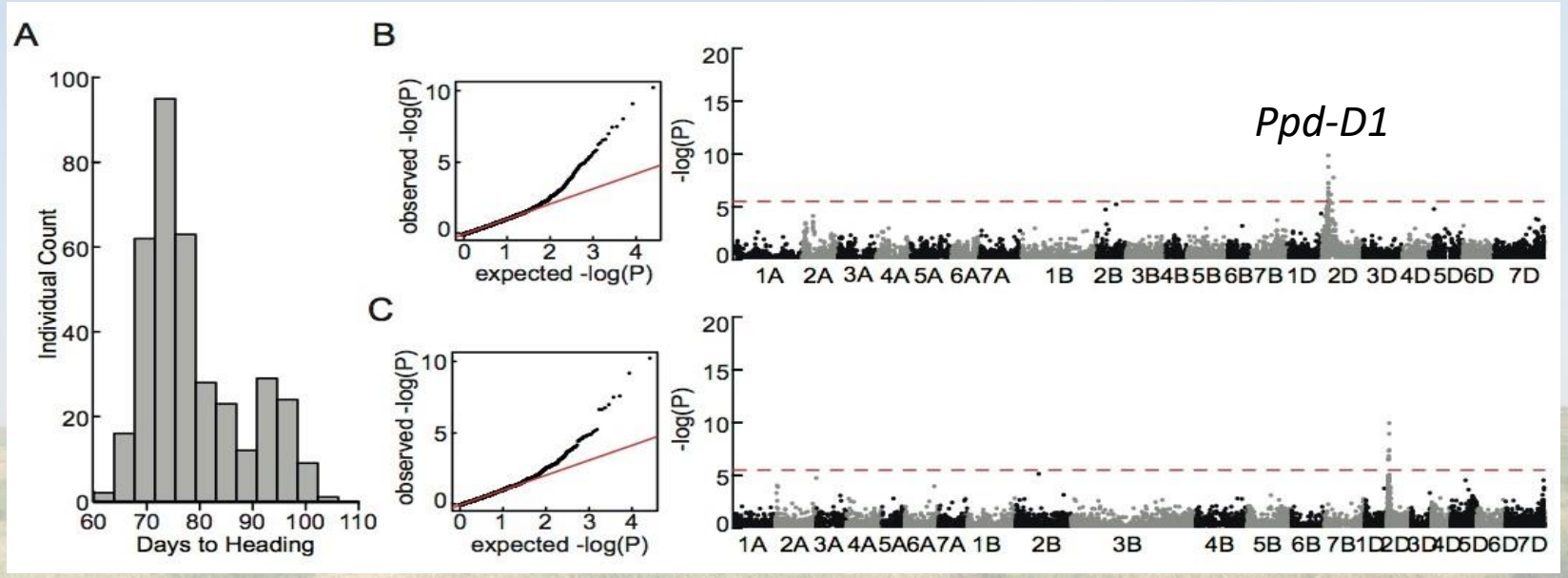


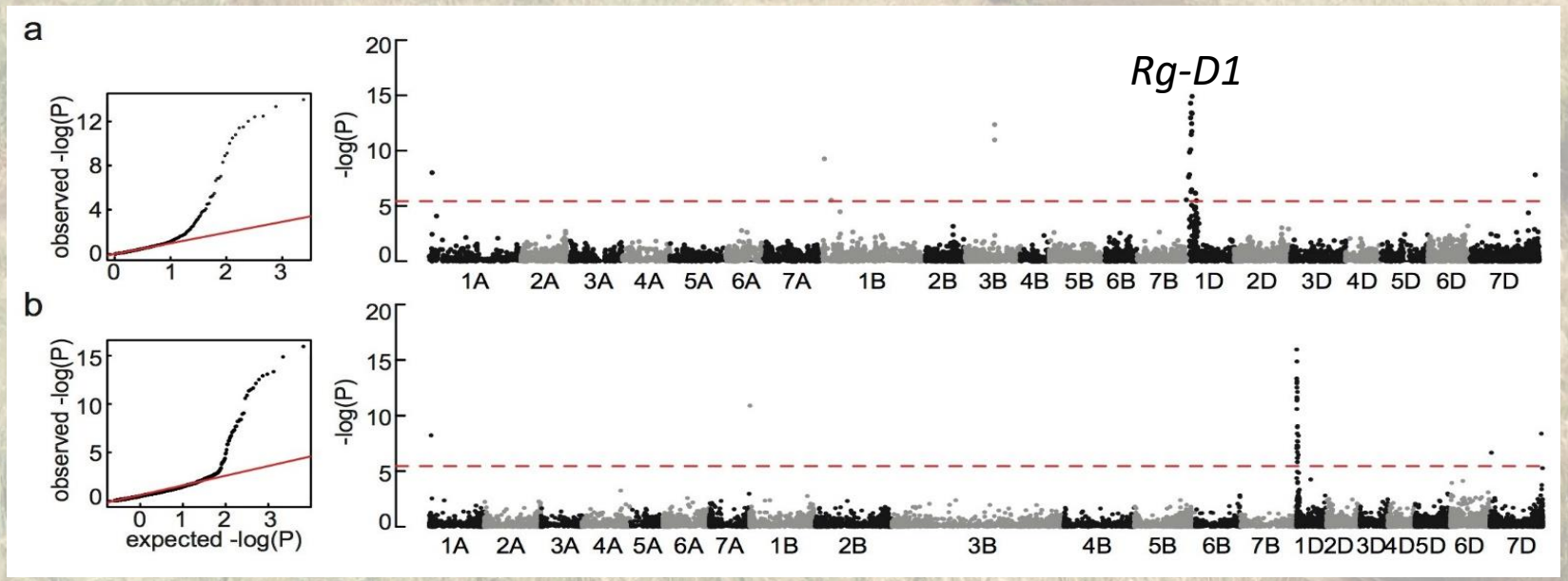


Graphical genotyping of MSD individuals in families Syn26 and Syn 32. The *Ae. tauschii* wild genome was successfully transmitted to the MSD individuals.

Gorafi et al. 2018

The Multiple Synthetic Derivatives Population (MSD)

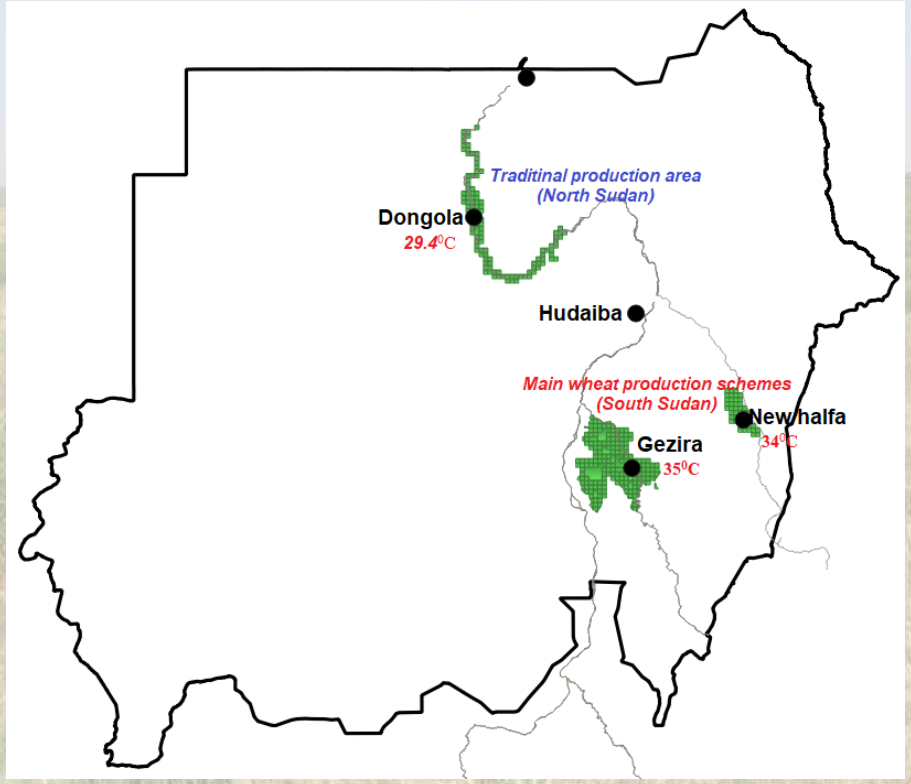




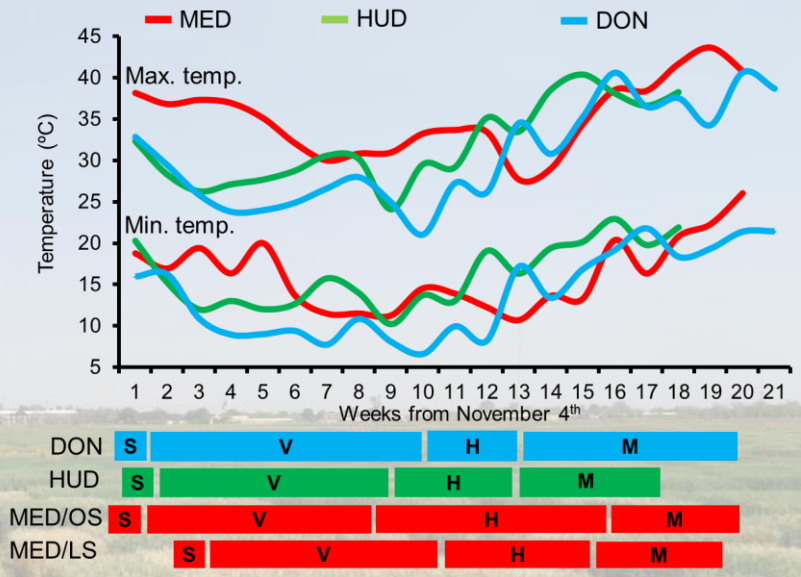
Gorafi et al. 2018

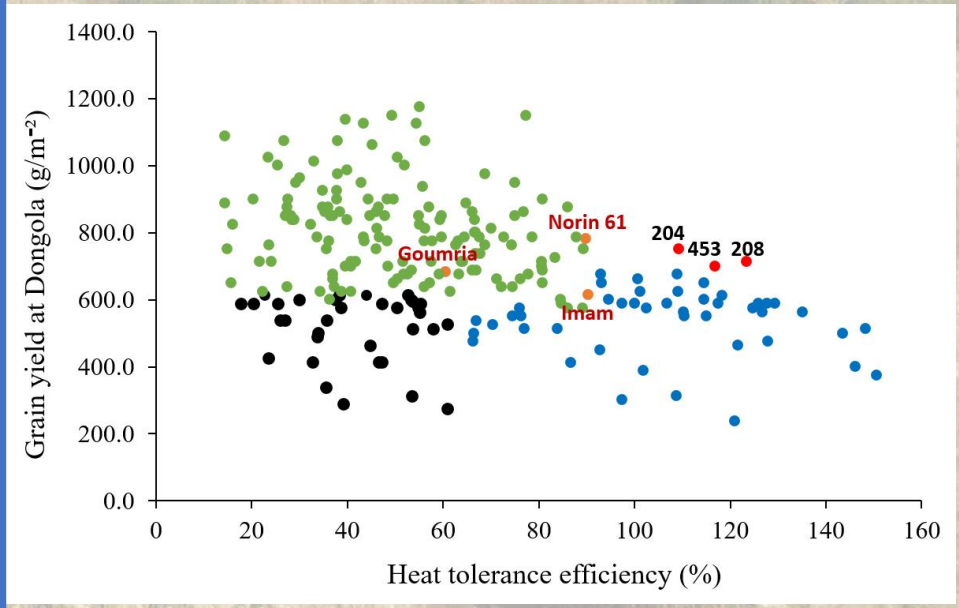
The MSD: heat stress

- Phenotyped in 4 environments in Sudan in 2015/2016
- Augmented RCBD



-Hottest wheat-growing environment
-Gradient in temperature from North to South





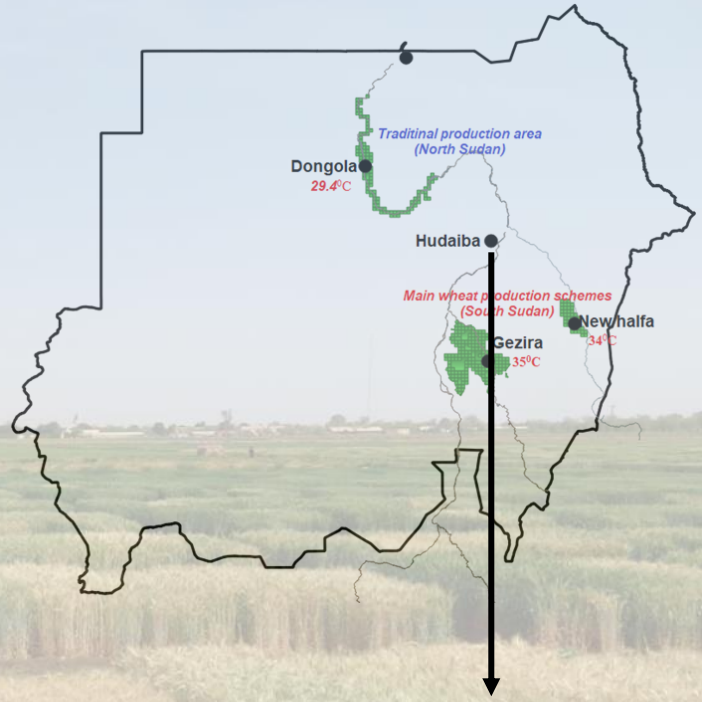
Identification of heat-tolerant lines

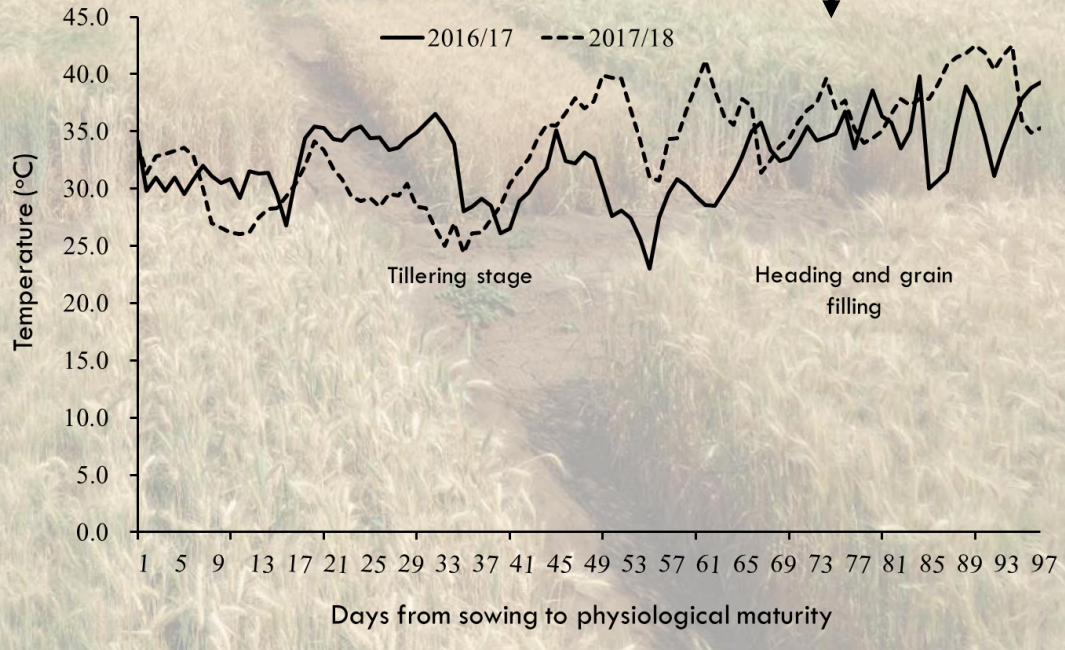
Elbashir et al. 2017

The MSD: Combined heat salinity

- In Hudeiba, Sudan
- 247 MSD lines, N61, Imam and Gomeria
- Alpha lattice design with 4 replication

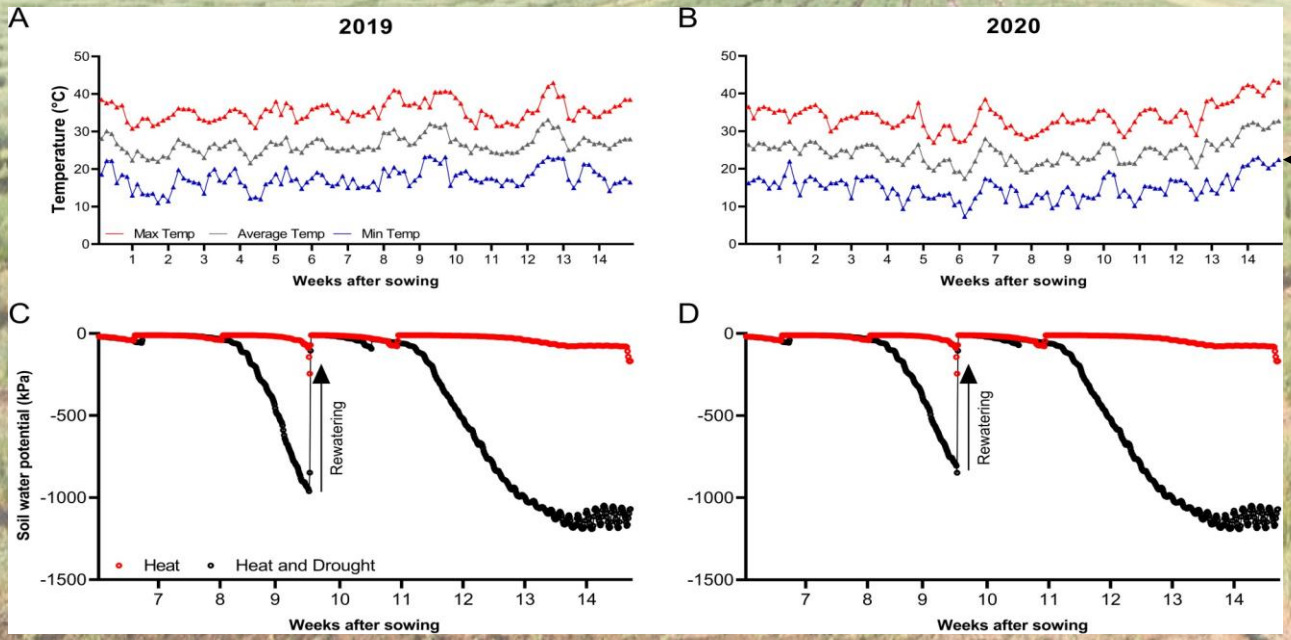
2016/2017: 4.9 dsm^{-1}
2017/2018: 3.6 dsm^{-1}

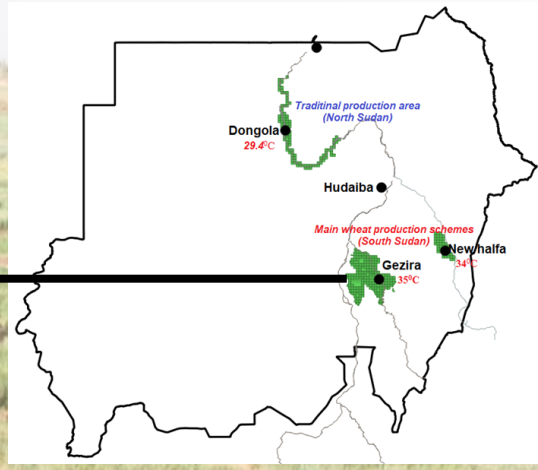




The MSD: Combined heat-drought

- **Two seasons, 145 MSD lines and five checks**
- **Alpha-lattice with 2 replications, post-flowering drought**

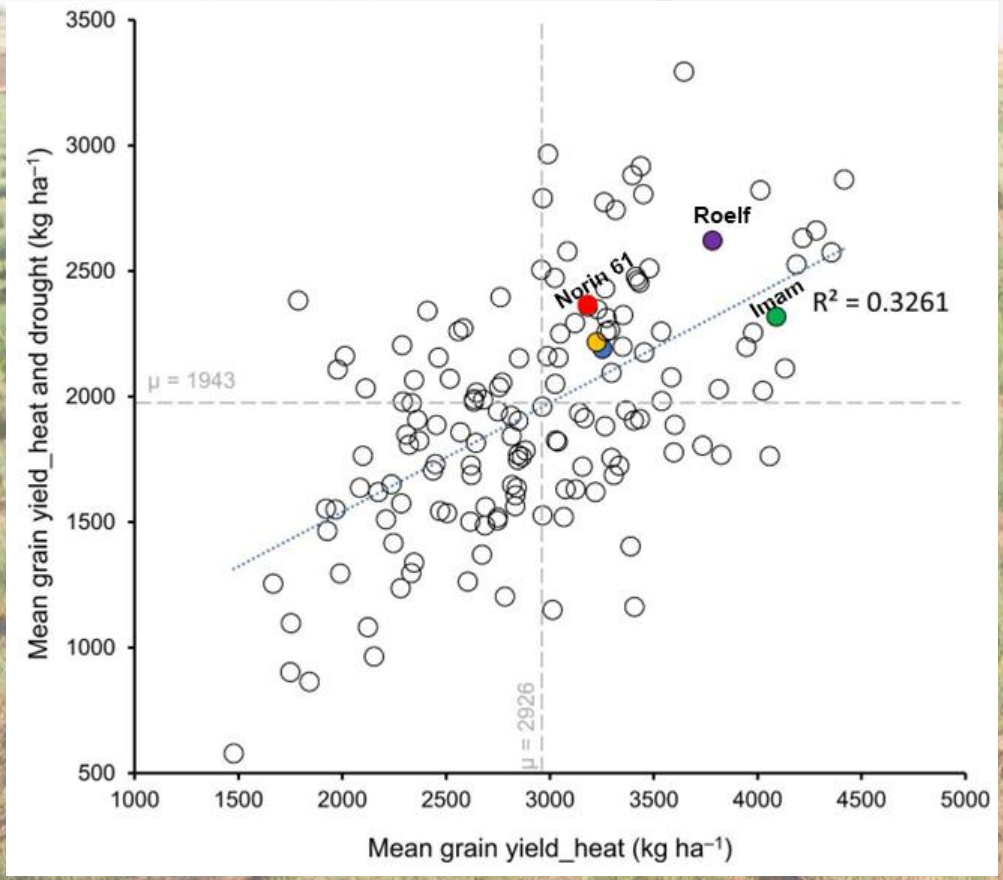




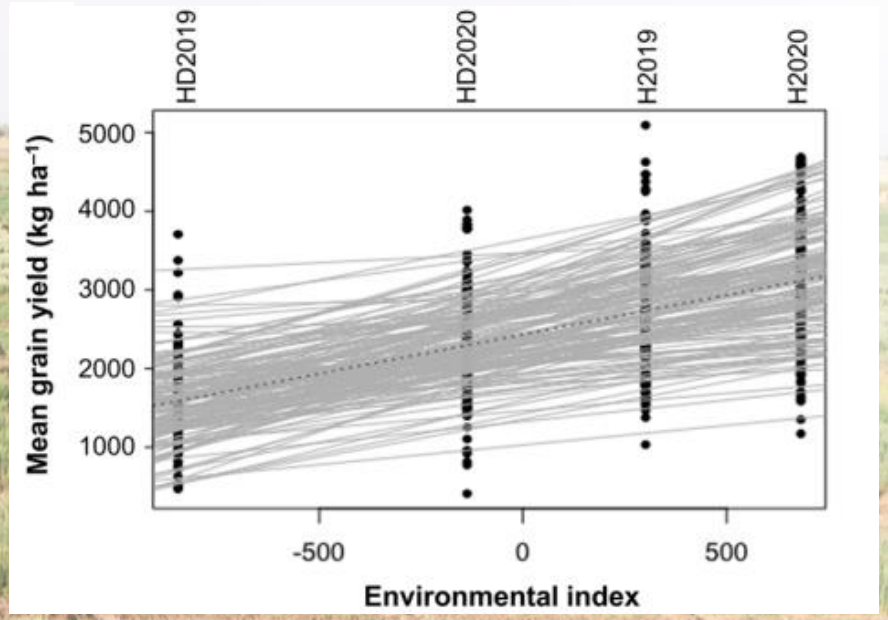
Air temperatures and soil water potential in the two seasons

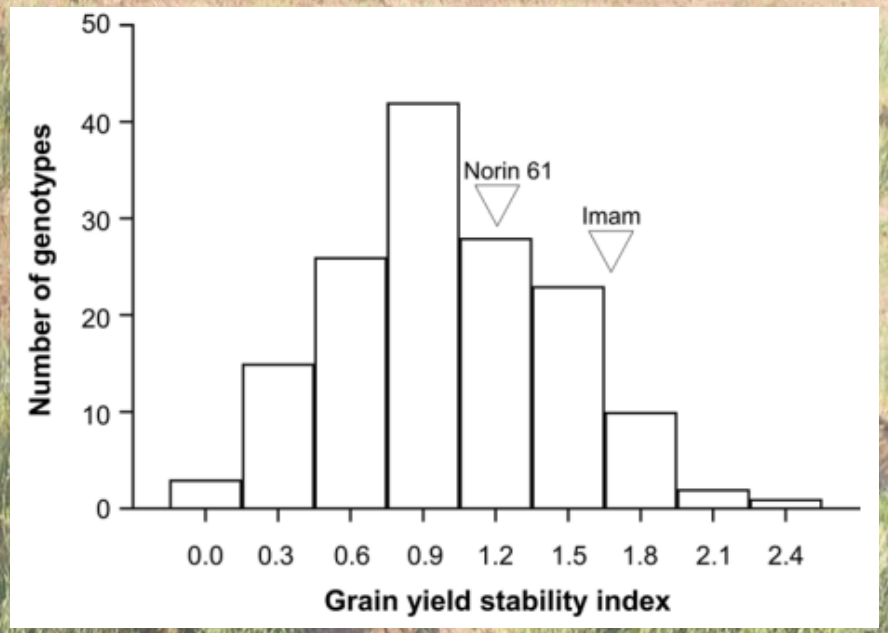
Itam et al. 2022

The MSD: Combined heat-drought



Performance of the MSD lines and check cultivars under heat and combined heat-drought stress for two seasons

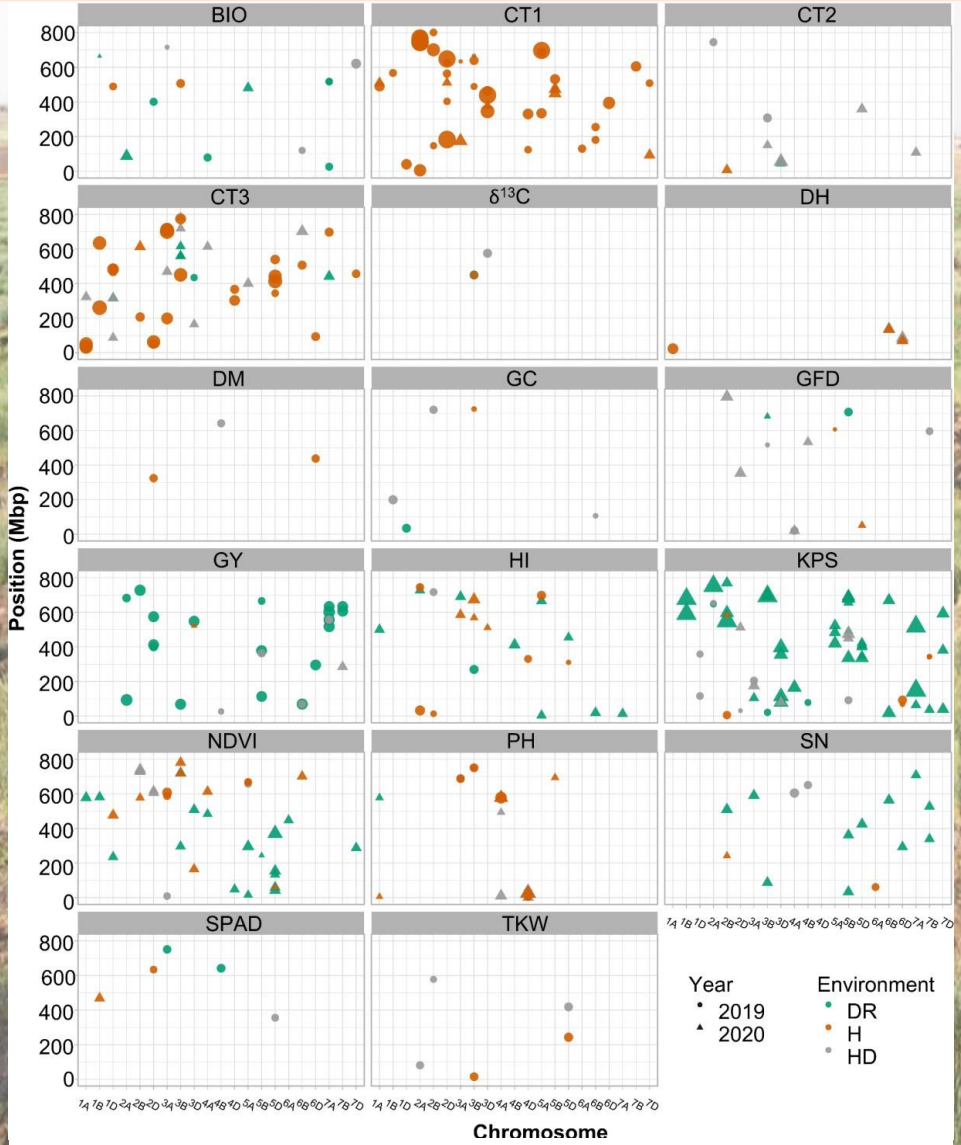




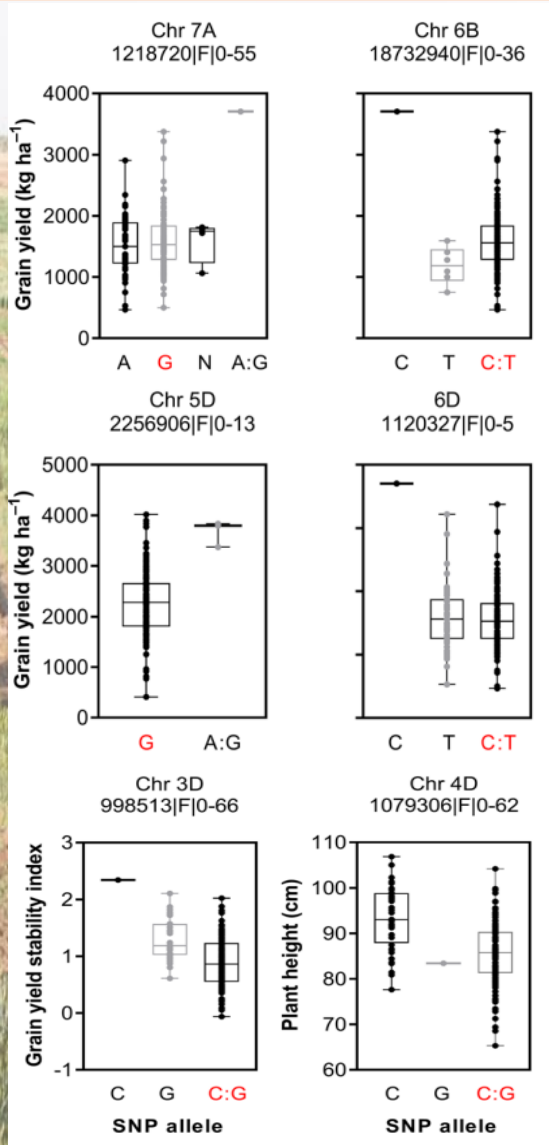
Yield stability index across the four environments

Itam et al. 2022

The MSD: Combined heat-drought



Physical positions of MTAs under heat (H) and combined heat–drought (HD) conditions, and in the drought response under heat stress (DR).



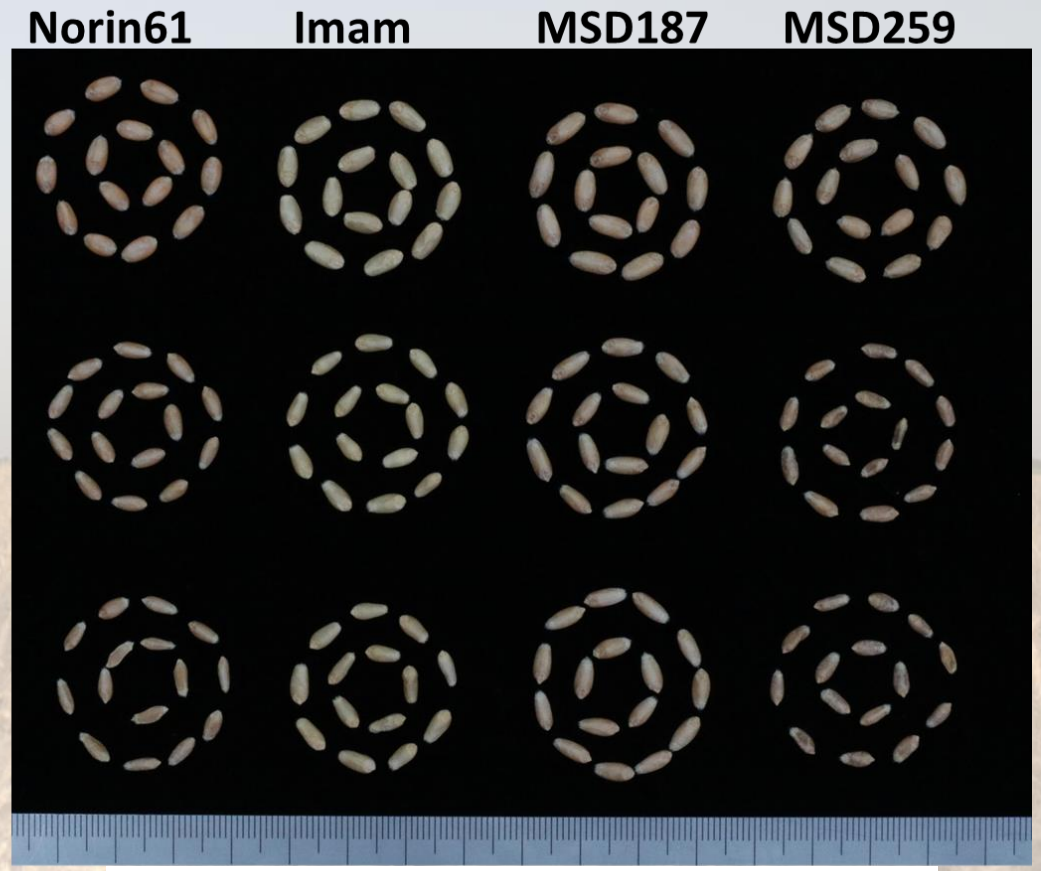
Effect of selected stable MTAs on grain yield, grain yield stability index, and plant height Effect

Itam et al. 2022

The MSD: Seed characteristics and end-use quality

From the same HD experiment

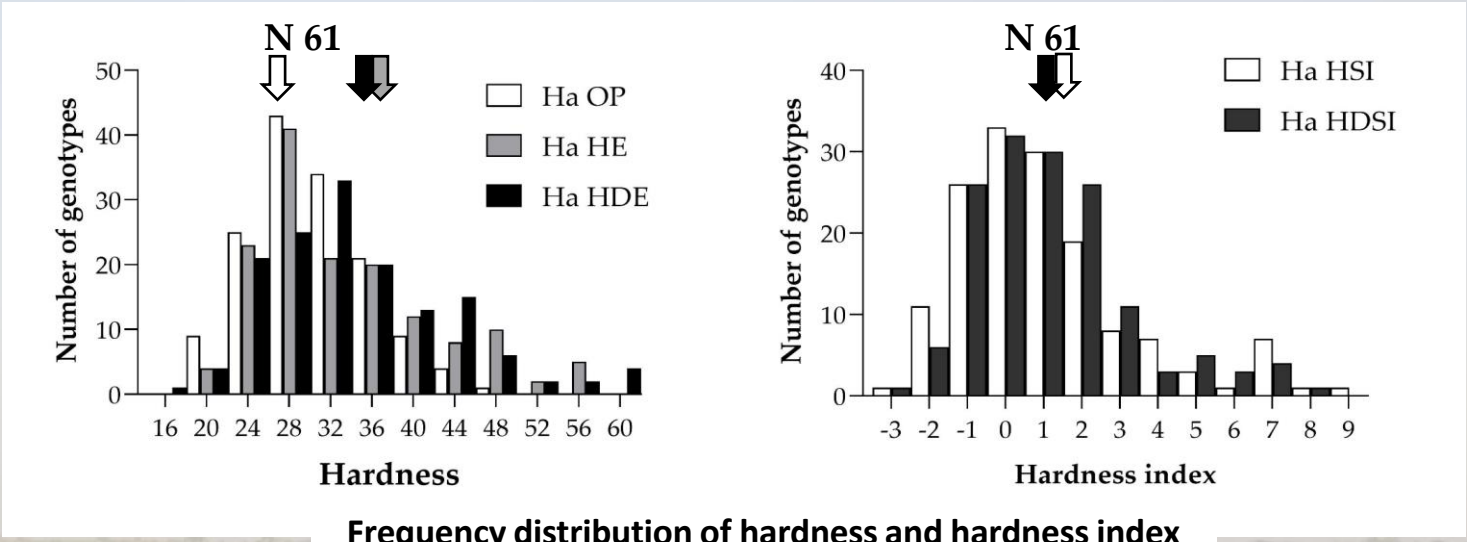
- Seed shape-related traits (SmartGrain software)
- Seed hardness (SKCS)



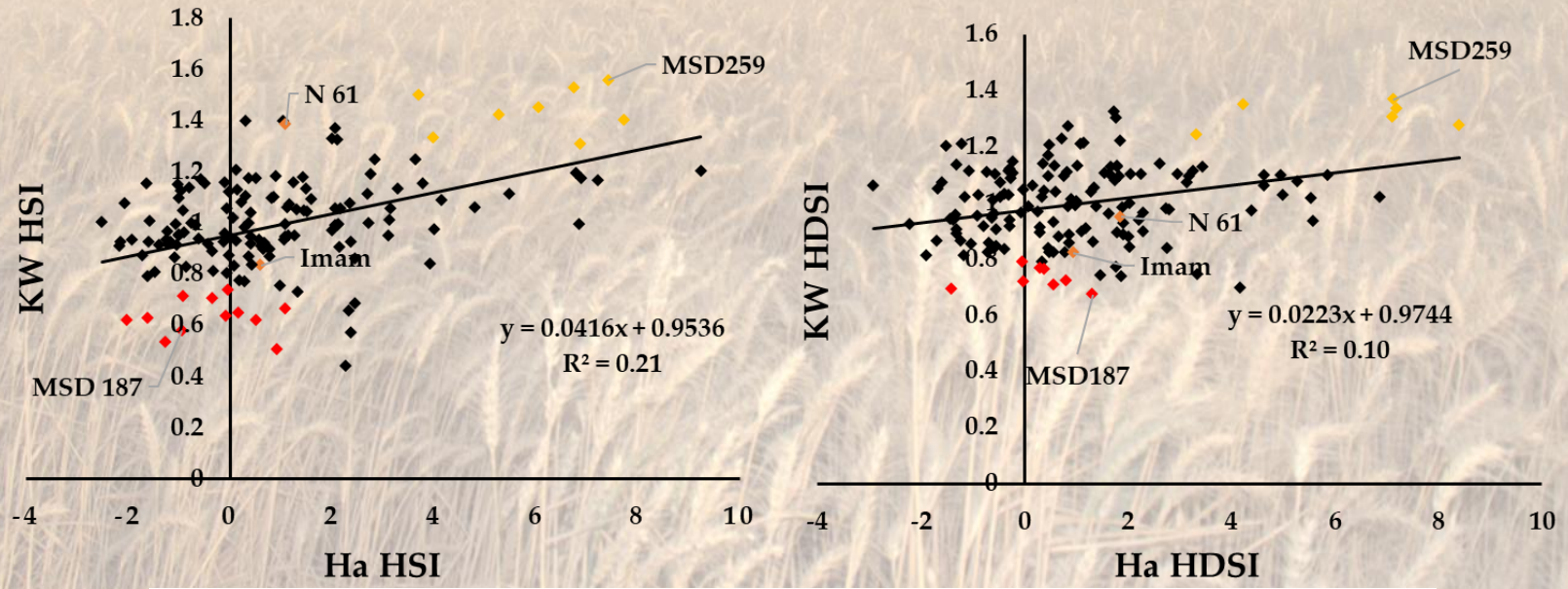
Variation in kernel weight and shape-related traits

Elhadi et al. 2022a

The MSD: Seed characteristics and end-use quality



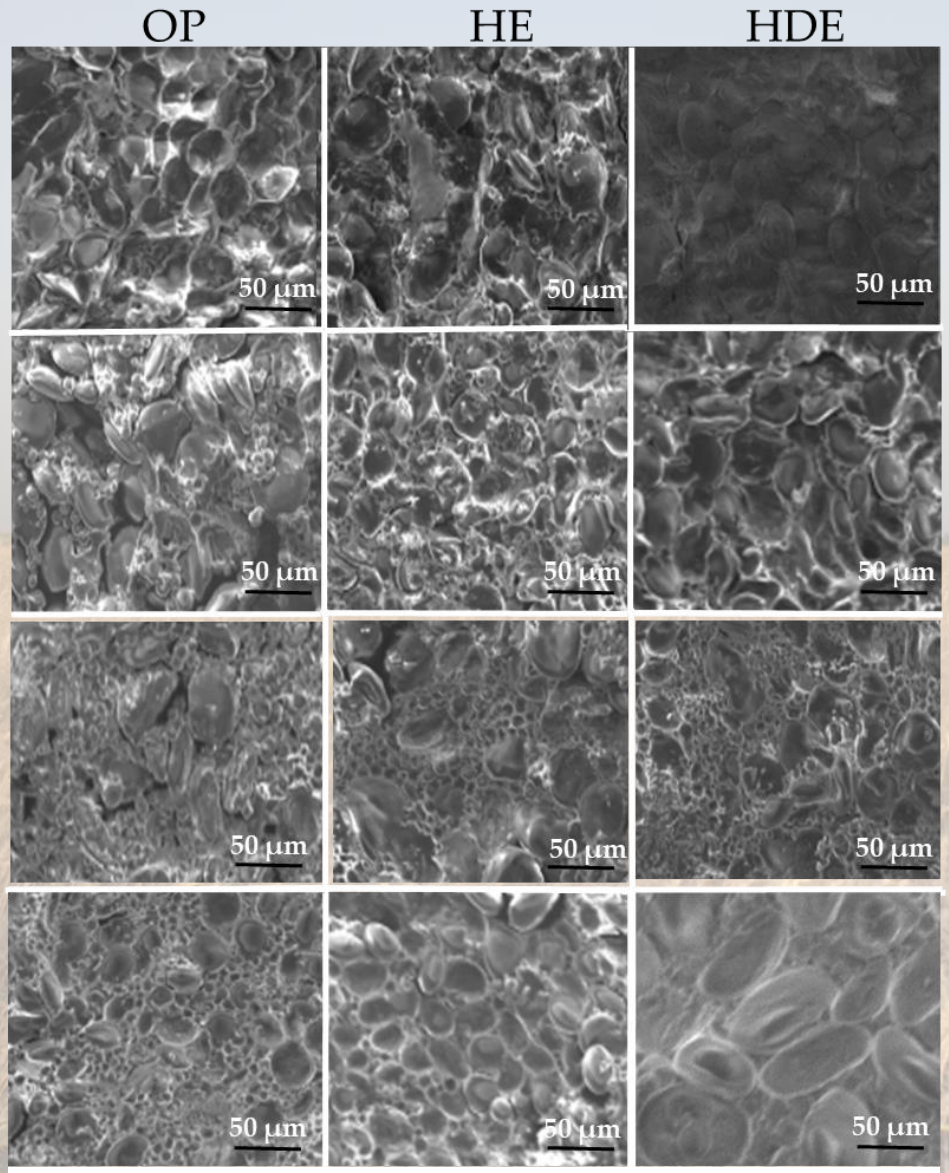
Frequency distribution of hardness and hardness index



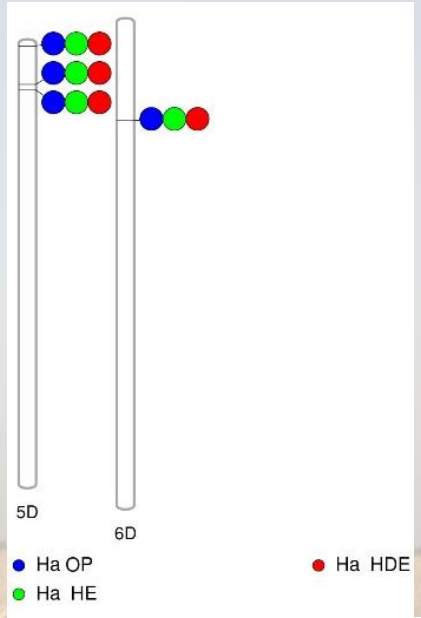
Relationship between kernel weight and hardness heat and heat-drought indices

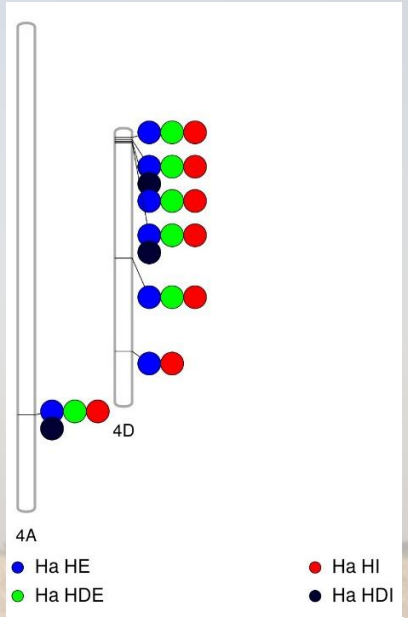
Elhadi et al. 2022b

The MSD: Seed characteristics and end-use quality



Scanning electron microscope showing the internal structure of wheat endosperm





MTAs associated with seed hardness under all conditions

Elhadi et al. 2021b; Suliman et al. 2022

The MSD: Summery and ongoing research

The MSD population

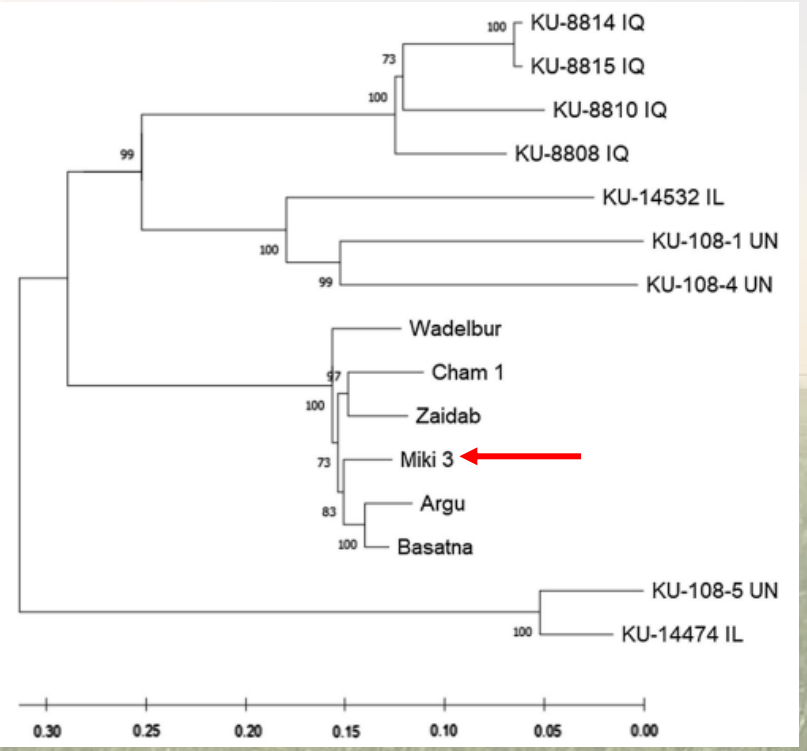
- Includes the diversity of 43 *Ae. tauschii* accessions in a uniform A and B genetic background
- Could be efficient in mobilizing the genetic diversity from gene-bank to the field
- Was a good option to explore and utilize the genetic variation of *Ae. tauschii* in a short time and more practical less expensive way
- Is a good resource for wheat breeding, QTL analysis and gene identification
- It was easy to see the impact of the *Ae. tauschii*
- Increasing the outcrossing rate in the MSD is essential to maximize the diversity and increase the recombination rate

Ongoing activities

- Heat-phosphorous deficiency
- Heat-nitrogen efficiency
- Metabolome analysis in selected lines
- RILs developed for validation

Tetraploid wheat: The Multiple derivatives lines (MDL)

Phylogenetic relationship between the MDL parents and some Sudanese cultivars



10 plants from each BC_1F_1

↓

10 seeds from each plant

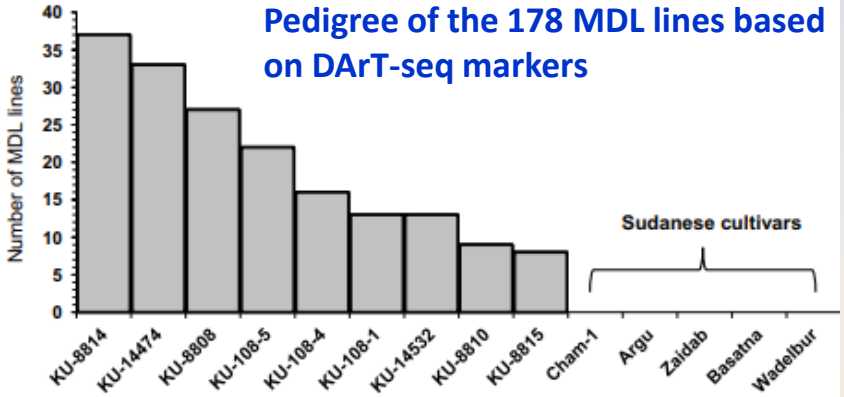
100 seeds from each cross

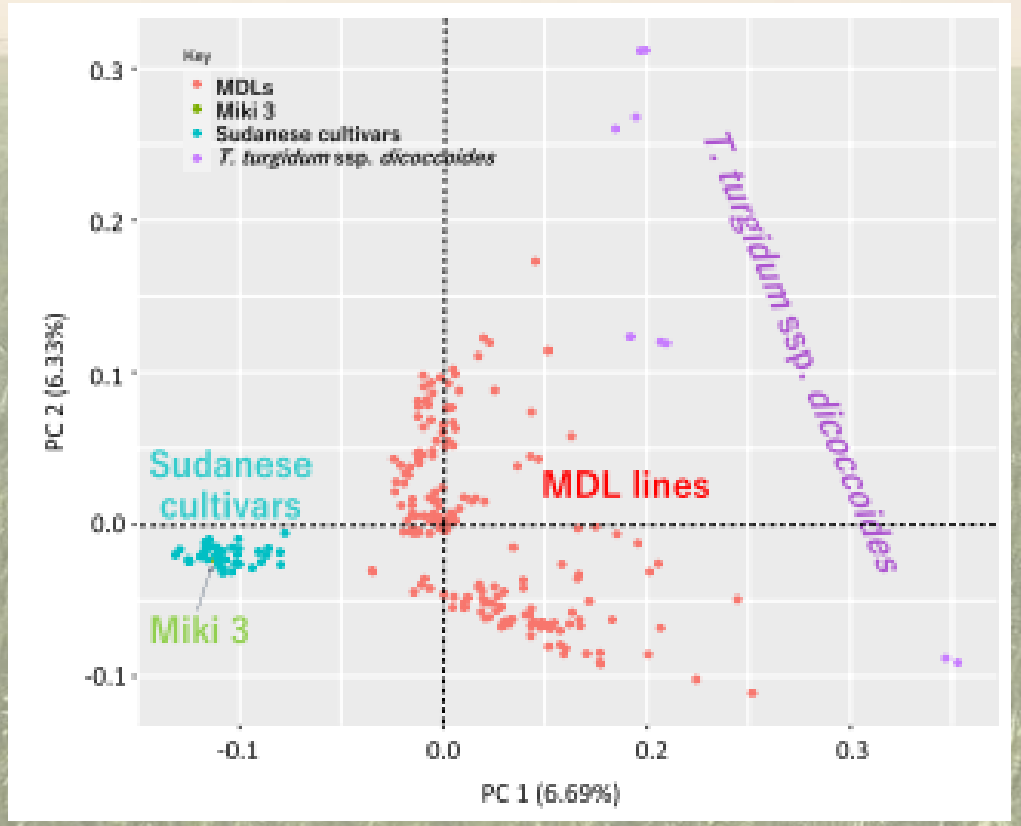
↓

A mixed population of 900 lines

75% from Miki 3 and 25% from wild emmer wheat

Pedigree of the 178 MDL lines based on DArT-seq markers

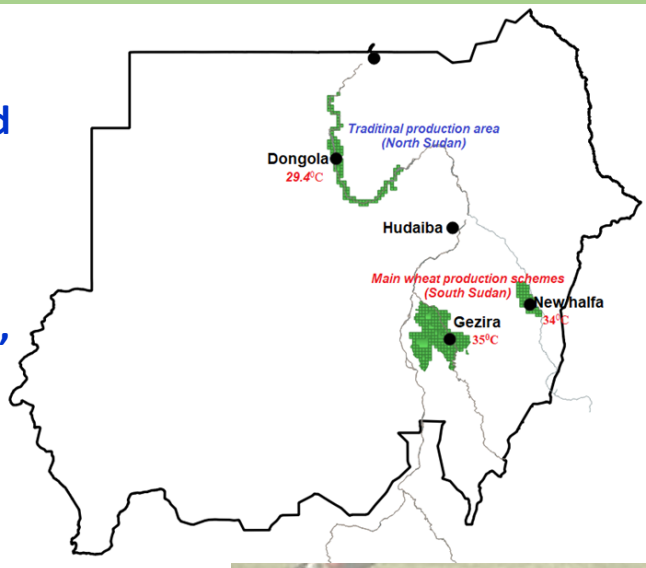


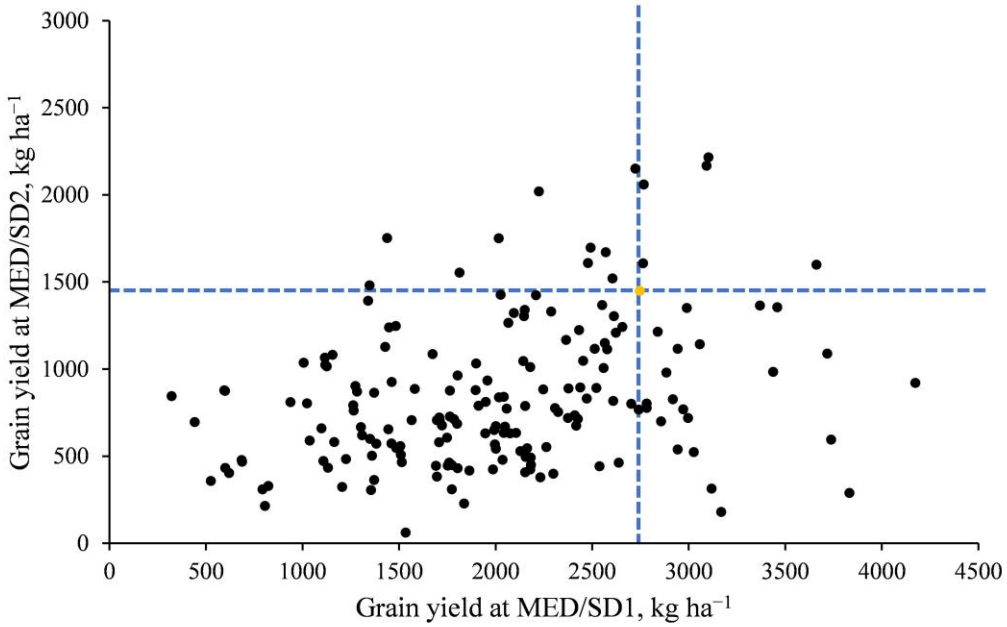


PCA analysis of diversity in the 178 MDLs

The MDL: Heat stress

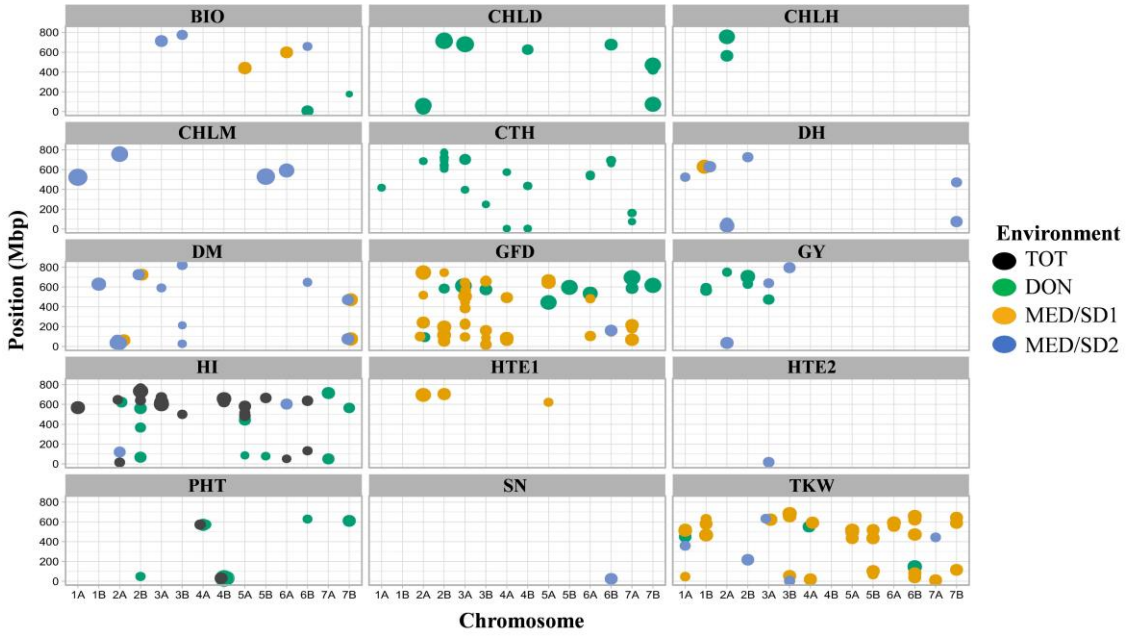
- 178 MDLs and checks
- Four environments in Japan (1) and Sudan (3)
- Alpha-lattice design with 2 replications
- Morphological, physiological, yield, and yield components



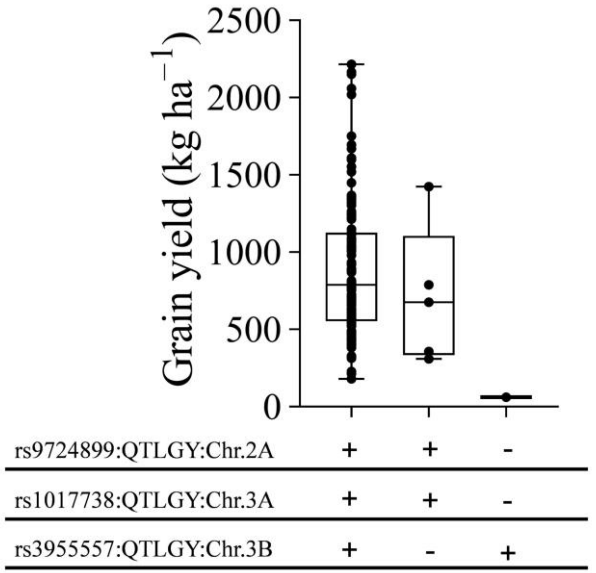


Performance of the MDLs under heat and severe heat stress

Tetraploid wheat: The Multiple derivatives lines (MDL)



Physical positions of markers associated with evaluated traits in the four environments



Effect of different GY alleles combinations

- **Similar to the MSD the MDL was effective in harnessing the wild emmer genes/alleles to improve the tetraploid wheat**

The MSD and MDL

- **Both were efficient in mobilizing the diversity**
- **Combining the diversity of MSD and MDL may provide interesting germplasm**
- **More precise phenotyping may provide better resolution and enable dissecting the tolerance traits**
- **Speed breeding and genomic selection**

- Cold winter
- Annual rainfall above 1000 mm
- No stress
- Was possible because of a very strong collaboration with the ARC of Sudan

Arid Land Research Center https://www.alrc.tottori-u.ac.jp/english/e_index.php

Laboratory of Molecular Breeding http://www.alrc.tottori-u.ac.jp/staff203/englishpage-index.html

Laboratory of Arid Land Plant Resources http://www.alrc.tottori-u.ac.jp/plant/index.html

Wheat SATREPS project https://sites.google.com/tottori-u.ac.jp/wheat-satreps-sudan-japan/home

Prof. Hisashi Tsujimoto tsujim@tottori-u.ac.jp

Yasir Gorafi yasirserag@tottori-u.ac.jp