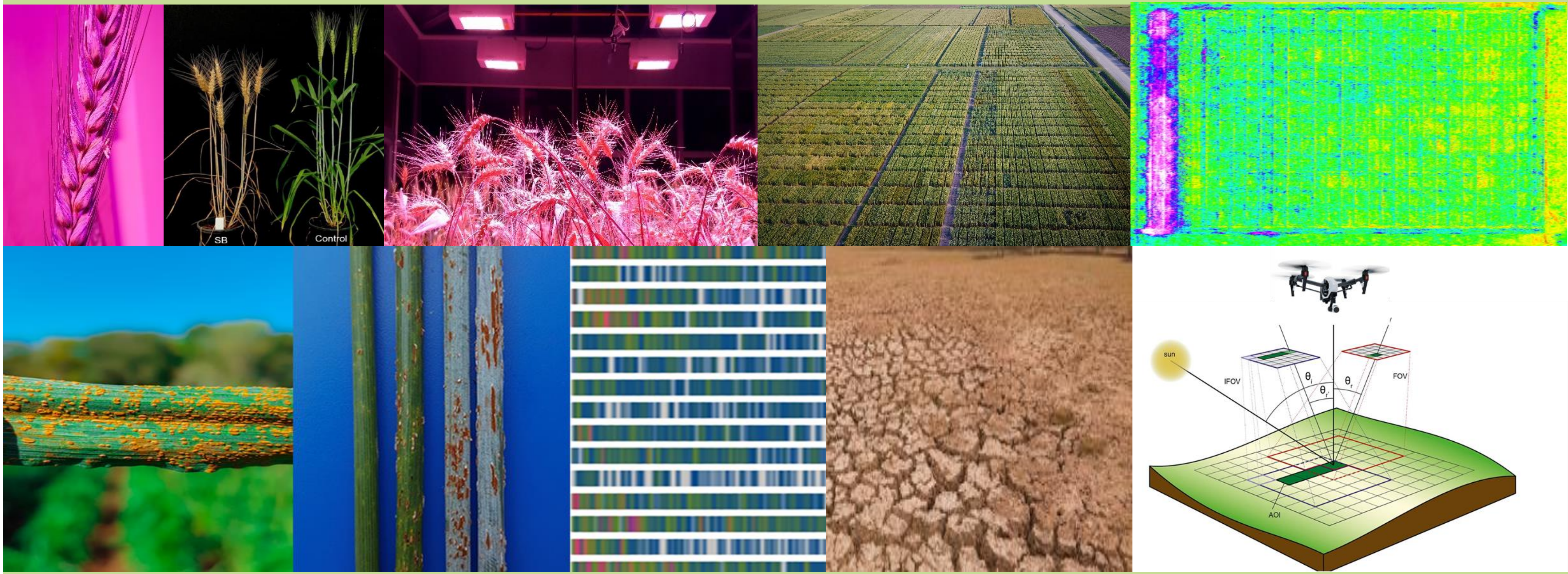
Opportunities & Challenges of Wheat Improvement Programme



Dr. Zahid Mahmood
Wheat Programme, NARC, Islamabad

HICKEY LAB

The University Of Queensland
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Queensland Alliance for Agriculture & Food Innovation

Queensland Government

Does **WHEAT** matters ?

Importance of **Wheat** the **King** of Cereals

- **40 % world’s population rely on wheat**
- **Grown in ~ 250 million Ha worldwide**
- **In Pakistan per capita consumption in Pakistan 120 kg/year**
- **72% of the total calories' intake from wheat**
- **10.3 % share to Agriculture and 2.2 % in GDP**
- **Annual productions is 27 Million tons**
- **Monetary Value: 611 billion rupees**
- **1% gain or loss in wheat= 6.1 billion rupees**

Background & Challenges

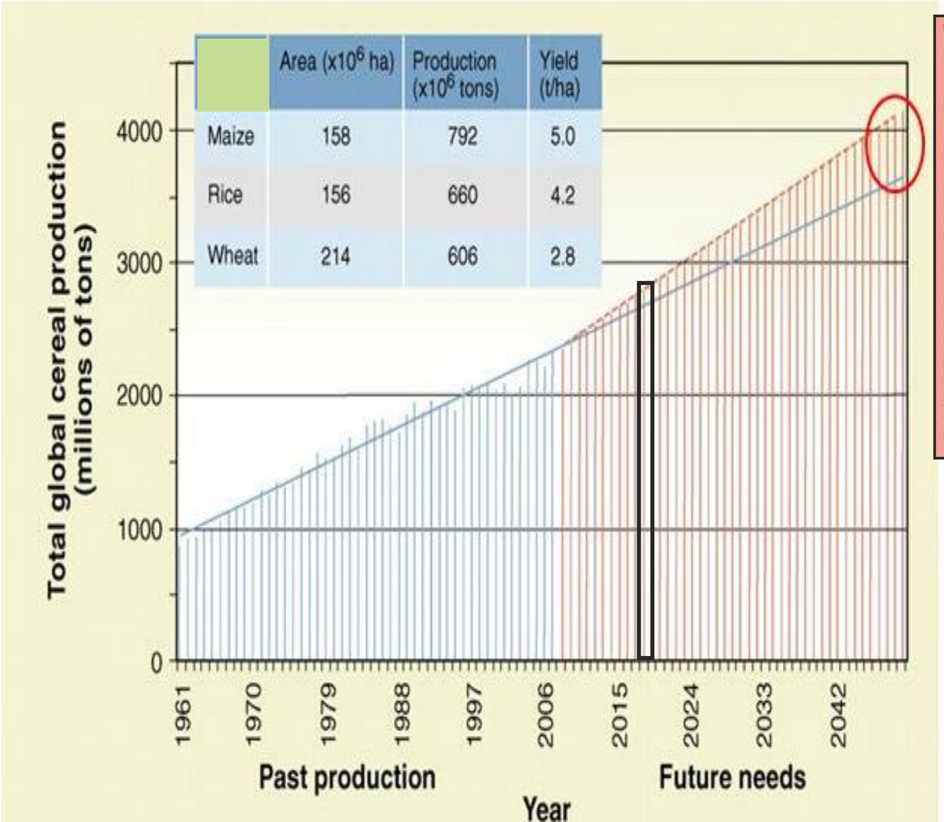
60% Increase in demand for wheat by 2050

-20% Potential yield decease from climate change

Biotic & Abiotic Factors

2% Rate of genetic gain needed to meet projections

<2% Current rate of gain



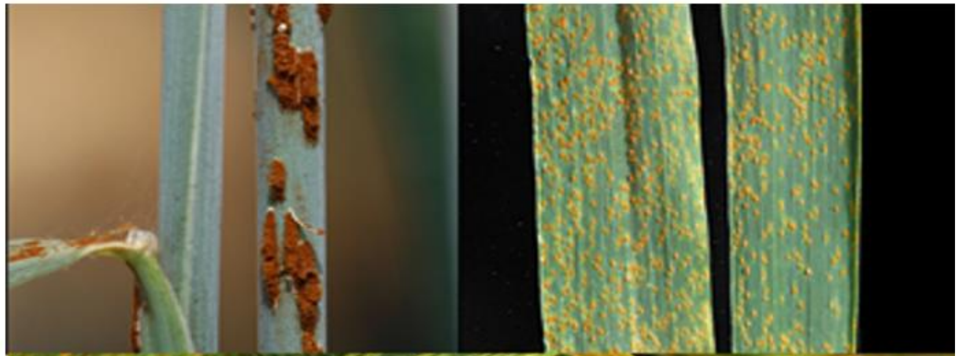
	Area (x10^6 ha)	Production (x10^6 tons)	Yield (t/ha)
Maize	158	792	5.0
Rice	156	660	4.2
Wheat	214	606	2.8

Will require a 60+% increase in wheat production to meet food demands by 2050

Challenges in Wheat Production

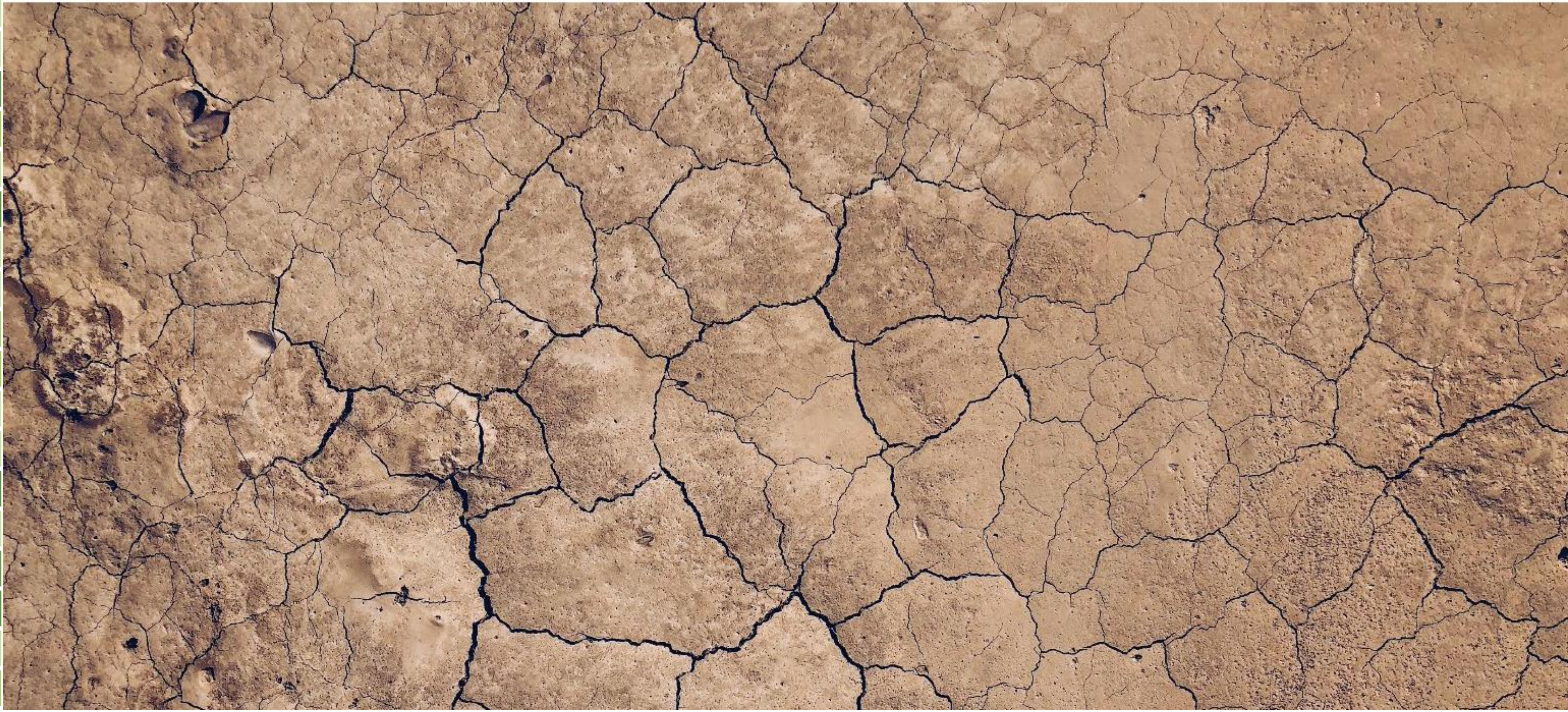
- **Biotic Stresses:**
  - Diseases especially wheat rusts (Yellow rust, Leaf rust & Stem rust)
  - Weeds, Insect & Pests
- **Abiotic Stresses:**
  - Heat (Terminal Heat Stress & Temperature fluctuation)
  - Drought (Sever drought and erratic rains)
  - Soil salinity
- **Production Management**
  - Late planting, use of non-certified seed, inadequate & imbalance use of inputs and poor management practices
- **Bio-fortification:** To overcome malnutrition



By 2050, we need to feed 10 billion people

In the face of rapidly evolving diseases and climate change

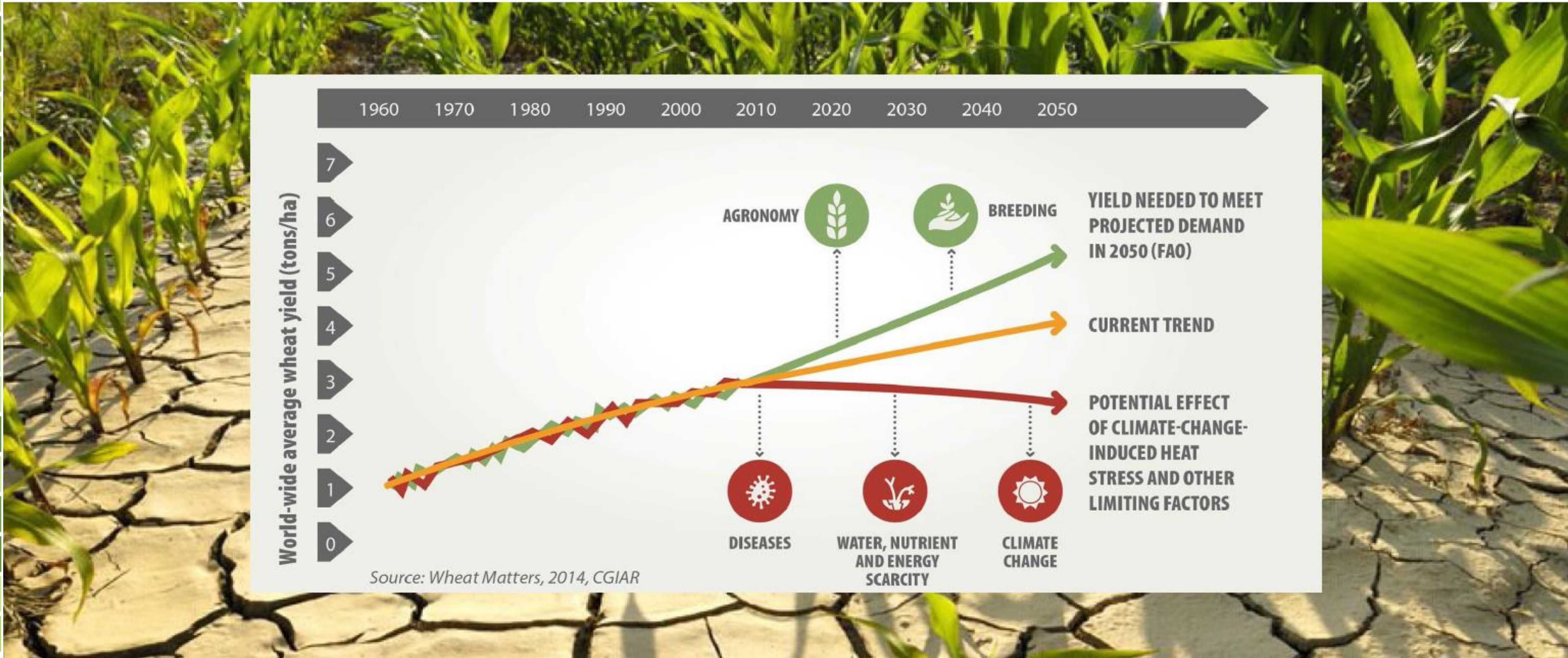



Plant breeders are delivering climate resilient, high yielding crop varieties

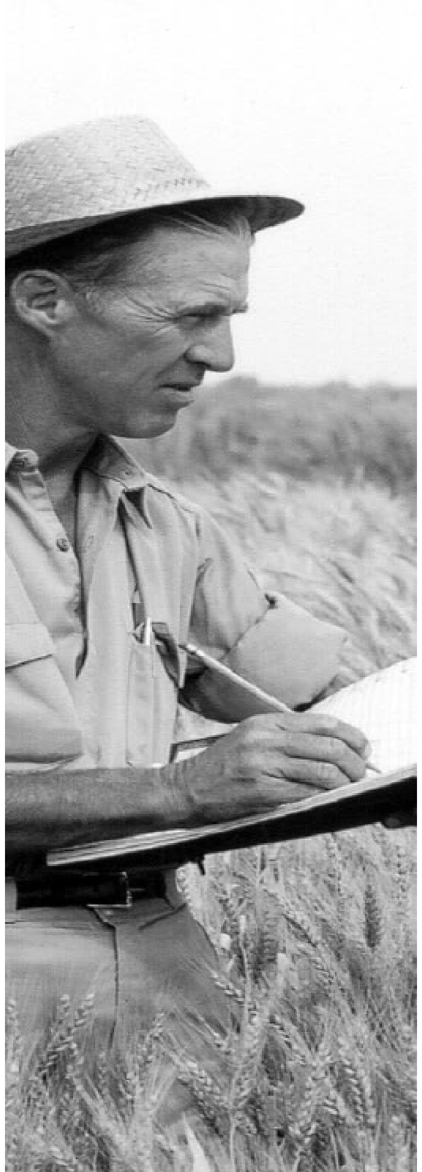
Wheat programme Experimental Fields at NARC, Islamabad

We are developing climate resilient, high yielding wheat varieties

The rate of genetic improvement must increase



How do plant breeders achieve genetic gain?



Selection Intensity (↑)
Increase to a limit
Need big populations

Selection Accuracy (↑)
Precise phenotyping
Reduce error
Correct for environment

Genetic Gain Over Time (↑)

$$R_t = \frac{i r \sigma_A}{y}$$

Genetic Variance (↑)
Mixed (not all good)
Bring in new genes
Essential

Years per cycle (↓)
Shuttle breeding (2 generations per year)
Speed breeding (4-6 generations per year)

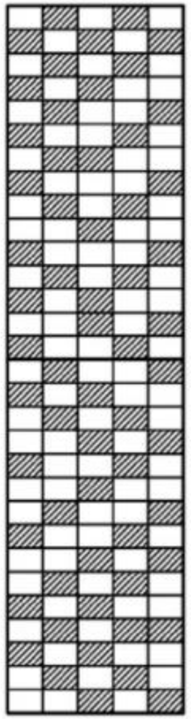
Selections intensity from diverse crop germplasm

Selection intensity (*i*)

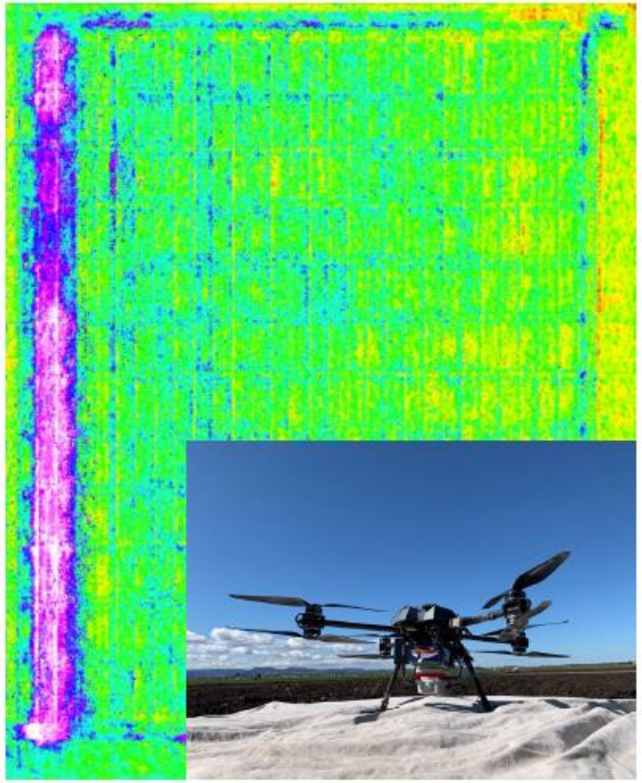
Examples of technologies to increase selection intensity

Equipment

P-rep trial designs



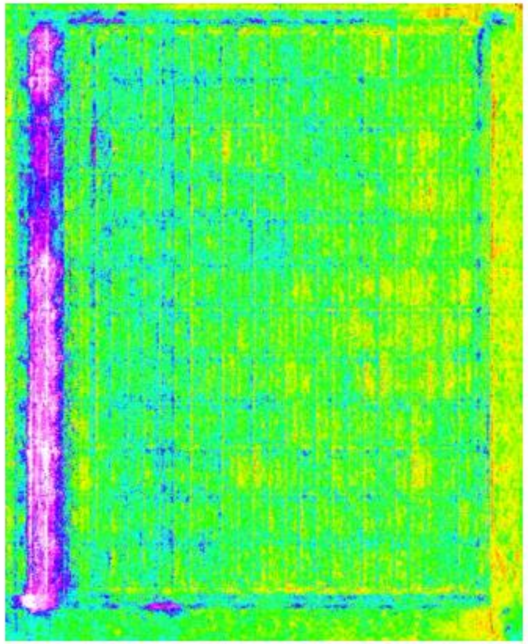
High-throughput phenotyping



Genomic prediction

Selection intensity (*i*)

How can high-throughput phenotyping accelerate genetic gain?



Selection Intensity **Selection Accuracy**

$$R_t = \frac{i r \sigma_A}{y}$$

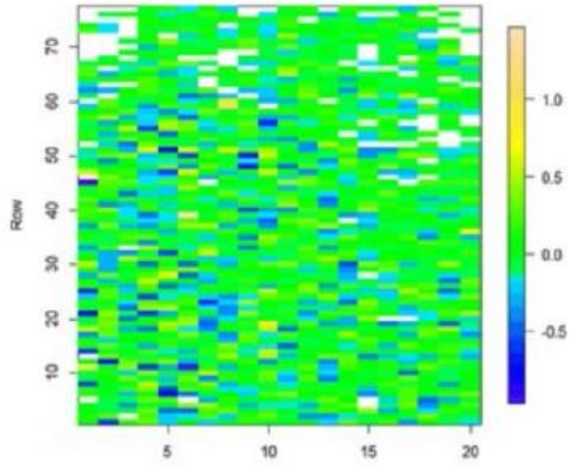
Genetic Variance

Years per cycle

Selection accuracy (*r*)

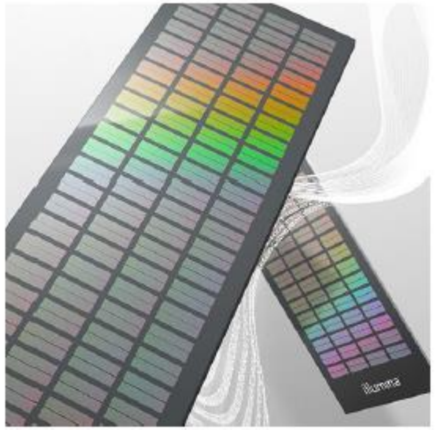
All about increasing heritability and obtaining more reliable phenotypes

Spatial analyses to adjust for environment



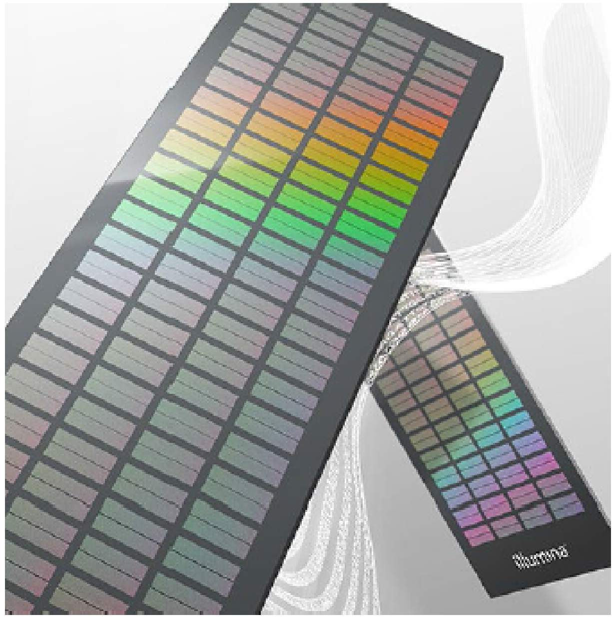
Replicated testing across the target environment (METs)

Genomic prediction



Selection accuracy (*r*)

How can genomic prediction accelerate genetic gain?



Selection Intensity

Selection Accuracy

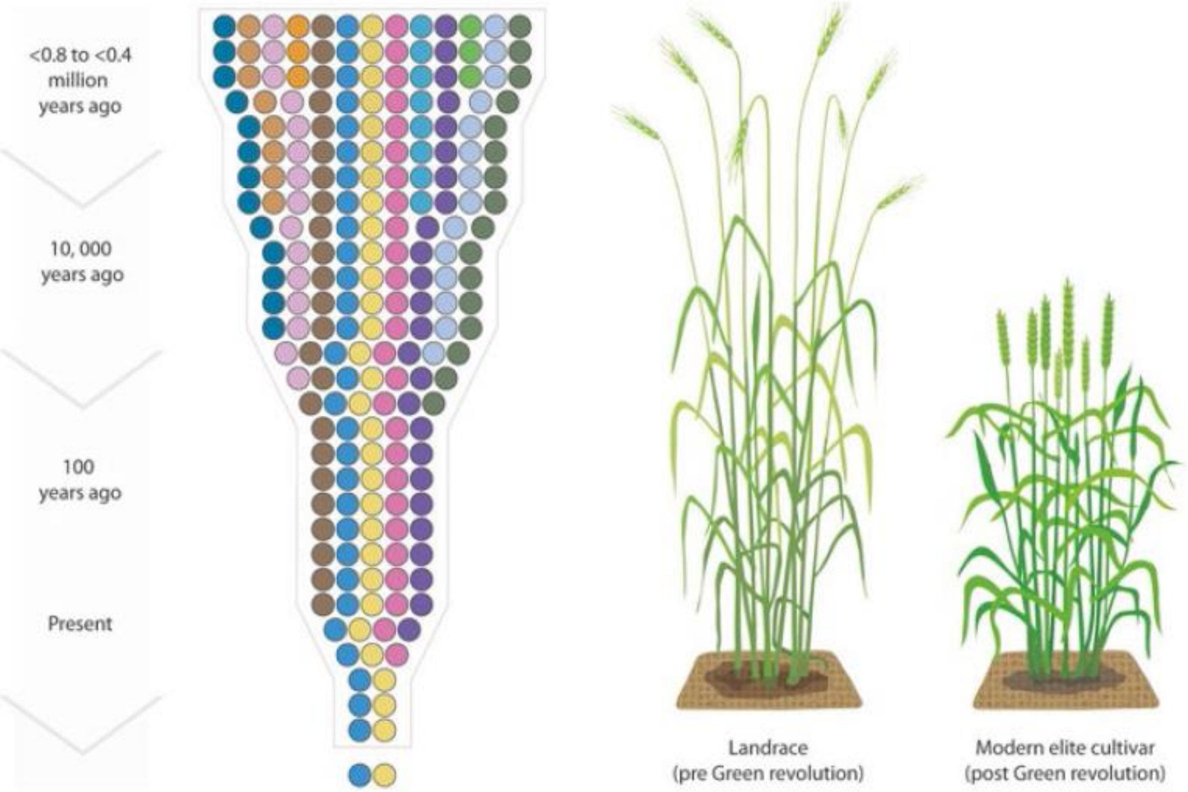
$$R_t = \frac{ir\sigma_A}{y}$$

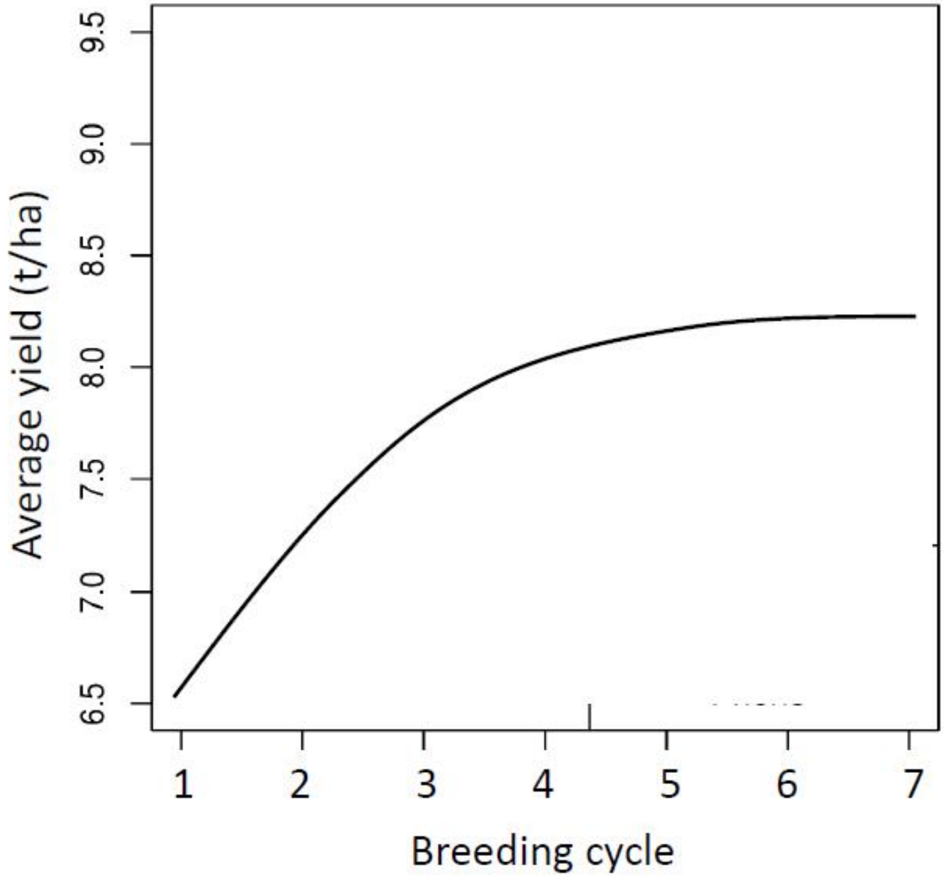
Genetic Variance

Years per cycle

Genetic variance (σ_A)

Maintaining genetic variance and bringing in new genetics for new traits





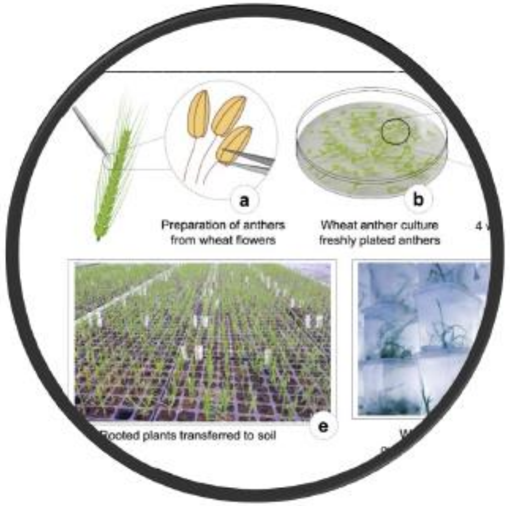
Voss-Fels et al. (2019) *BMC Biology* 17:18

Years per cycle (L)

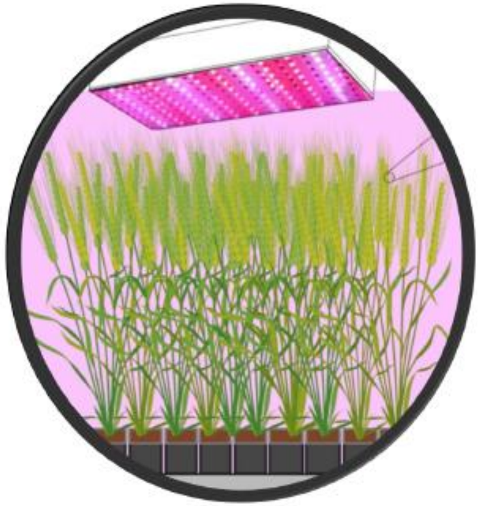
Technologies to reduce the length of the breeding cycle

Shuttle breeding

Doubled haploids

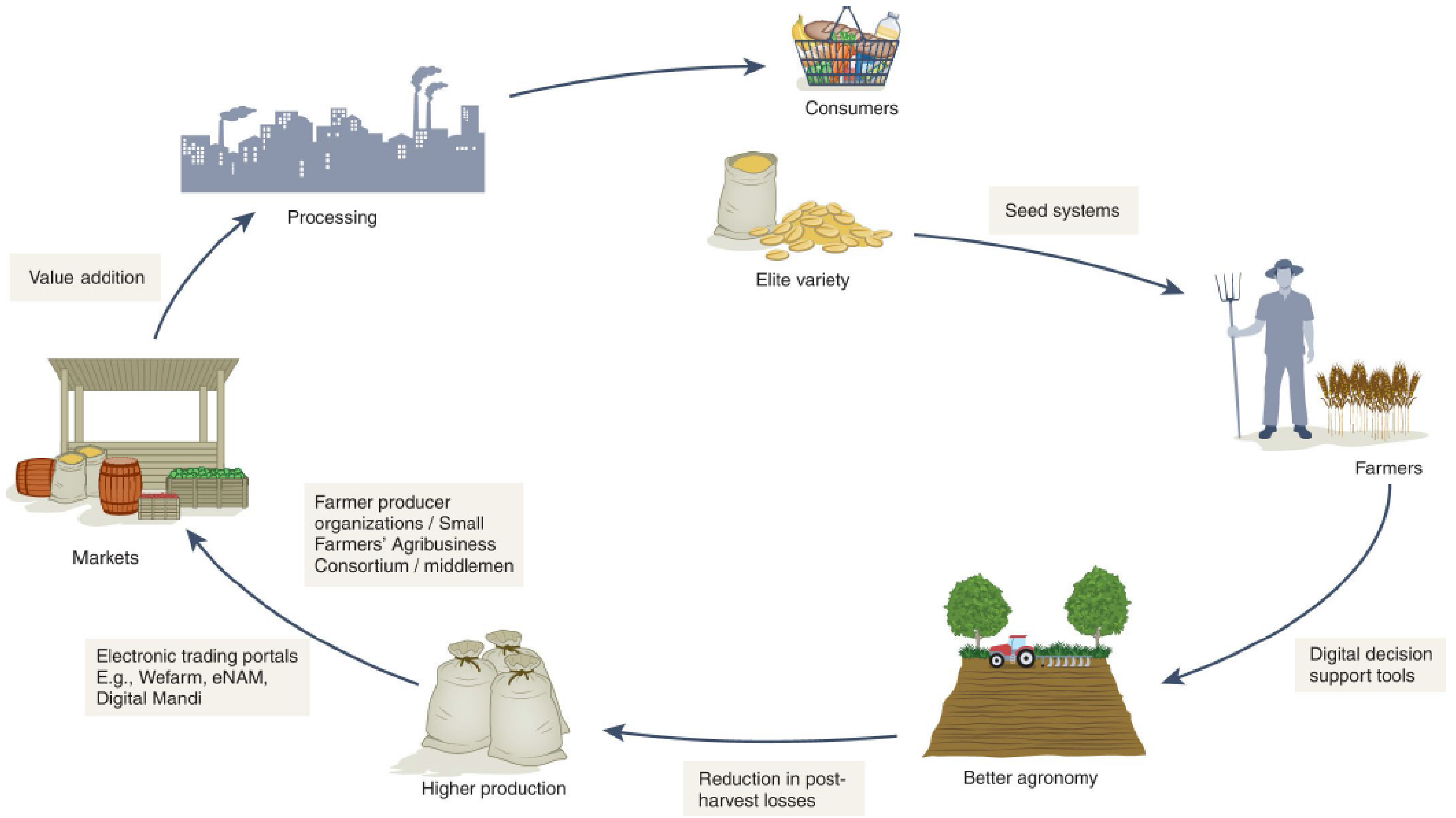


Speed breeding



Genomic selection

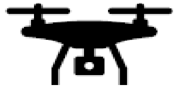
Plant breeding is part of the agriculture value chain

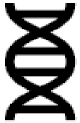


Varshney et al. (2021) *Nature Biotechnology* 39:1179-1181

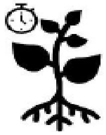
Selection accuracy

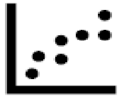
The "Breeder's Equation"





$$\text{Genetic gain over time}(R_t) = \frac{\text{Genetic variation } (\sigma_A) \times \text{Selection intensity } (i) \times \text{Selection accuracy } (r)}{\text{Years per cycle } (y)}$$





- Speed breeding reduces generation interval and increases genetic gain

Opportunities

Crop cycles per year

In *Speed Breeding* we provide constant PAR (light) & controlled temperature to accelerate plant development in glasshouse
Speed breeding enables up to 6 generations of wheat/year

EVOLUTION OF SPEED BREEDING

150 years ago	1980s	1990s	2000s	2010s and beyond
Botanists first grow plants under artificial light, with flowering occurring sooner in many species when light is constant	A partnership exploring plant growth on space stations leads to the development of a dwarf wheat line for rapid cycling under constant light	The effects of LEDs on plant growth is studied, improving the cost efficiency of rapid cycling systems	The term is coined, and protocols optimising light quality, intensity and length + temperature are established for many crop species	The first spring wheat variety developed using speed breeding is released, while other species continue to be bred using this system

“SPEED BREEDING”

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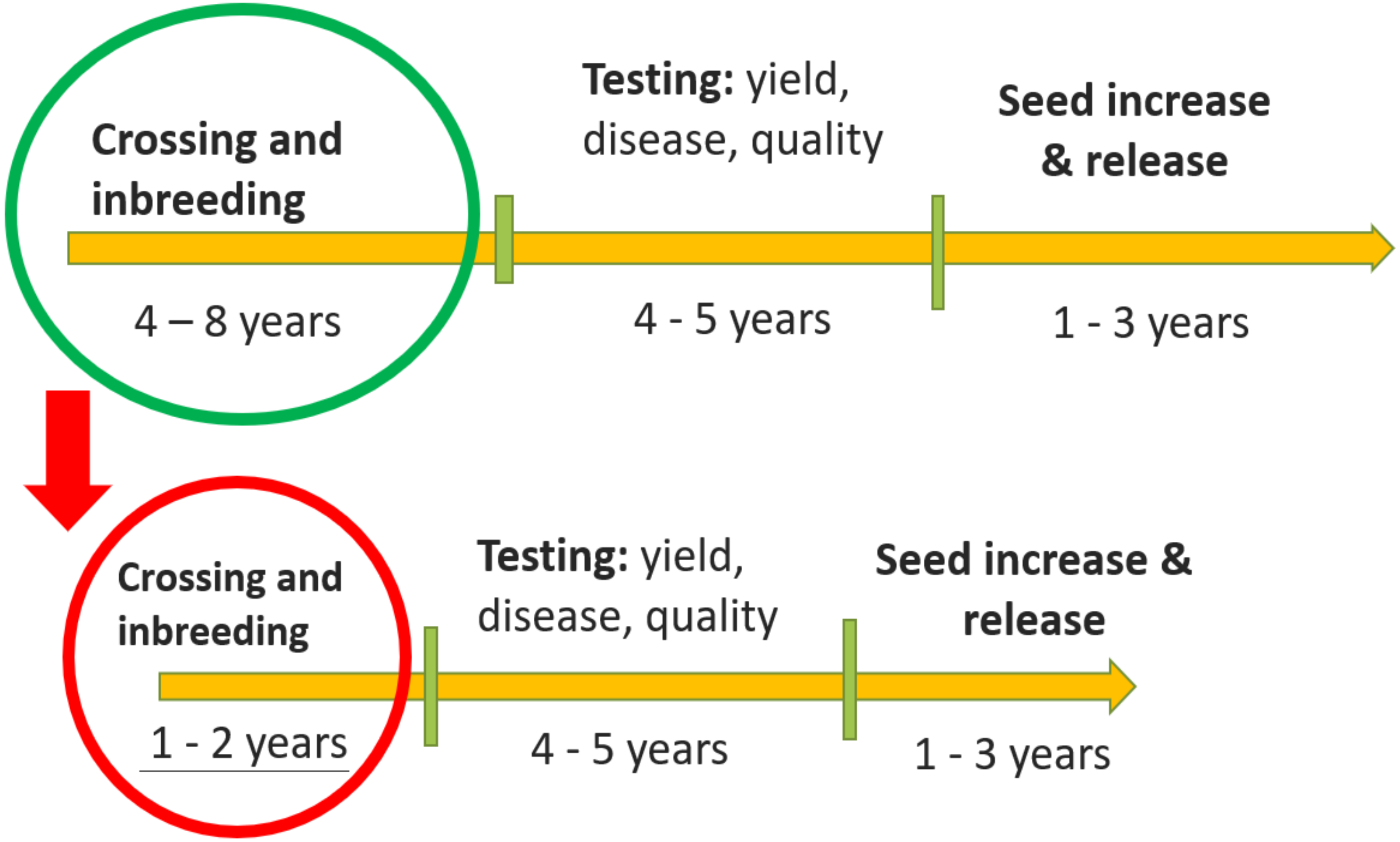
TRADITIONAL & *SPEED BREEDING* PIPELINES



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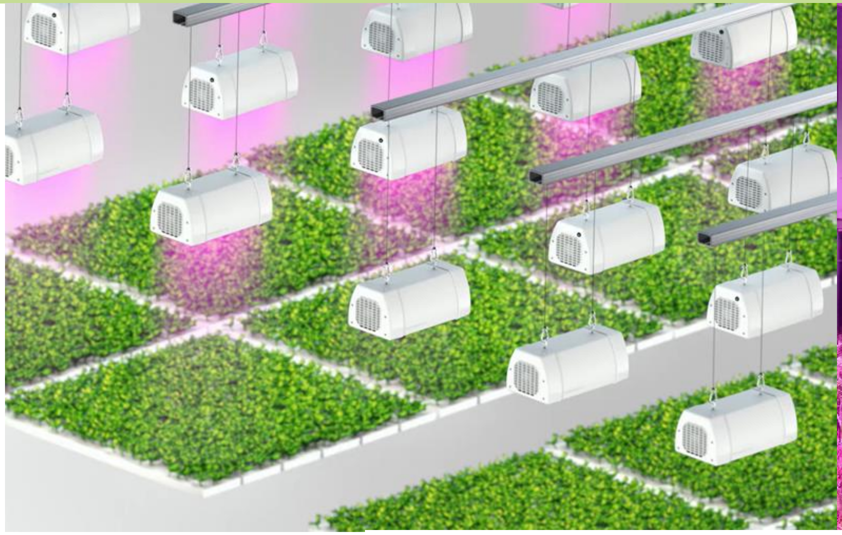
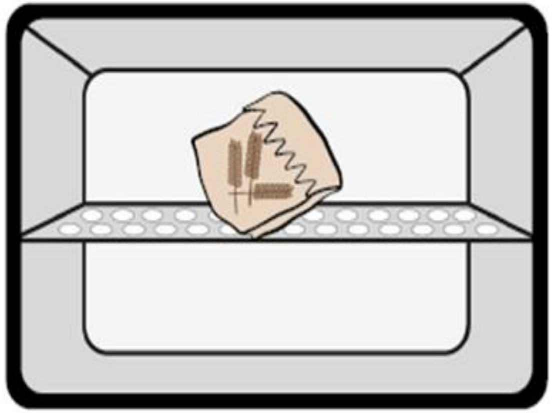
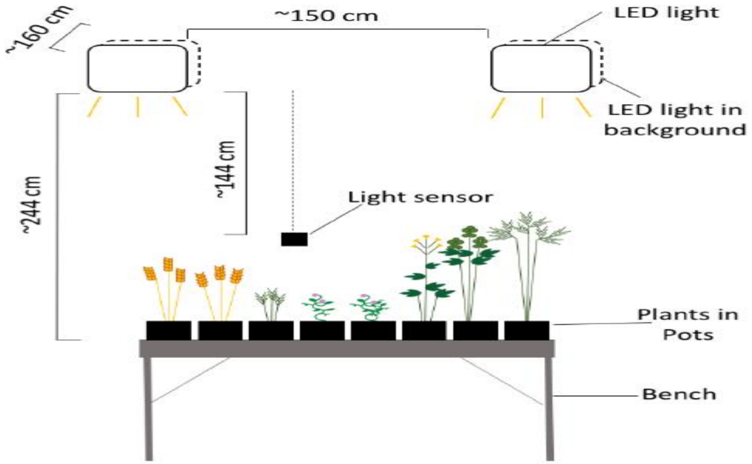
Major Factors in Acceleration of Growth in SB

- Extended Photoperiod
- Light spectrum
- Optimum temperature
- Optimum humidity
- Scaling of fixtures
- Potting mixture
- Harvesting time

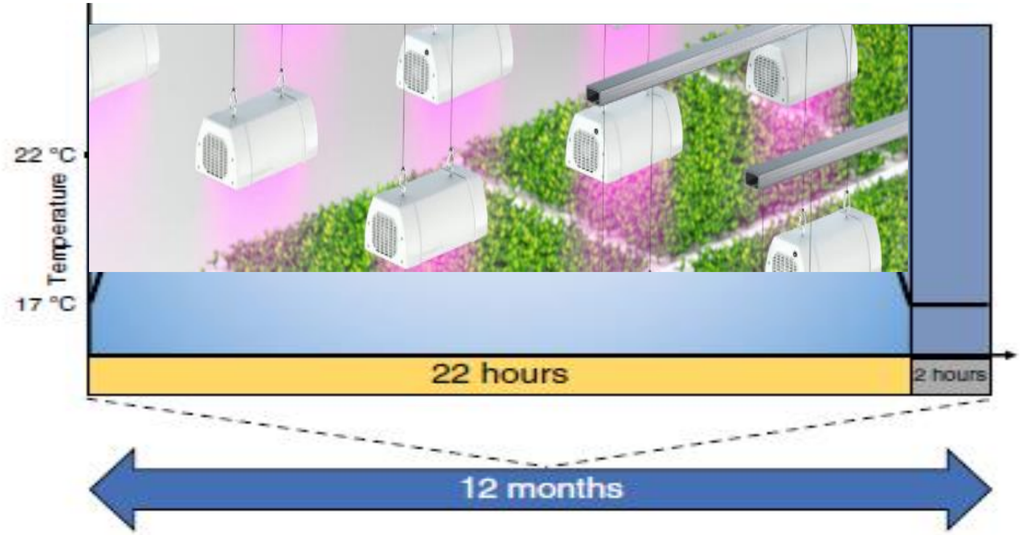


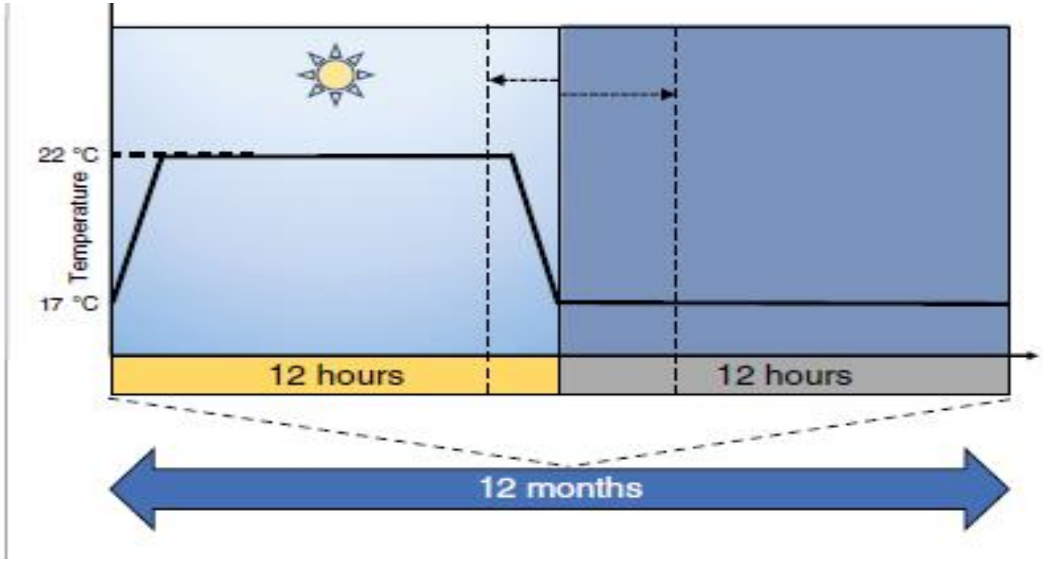


~3 days



Photoperiod in Speed Breeding Glasshouse & Normal Glasshouse





Watson & Ghosh et al. (2018) Nature Plants **4**, 23–29

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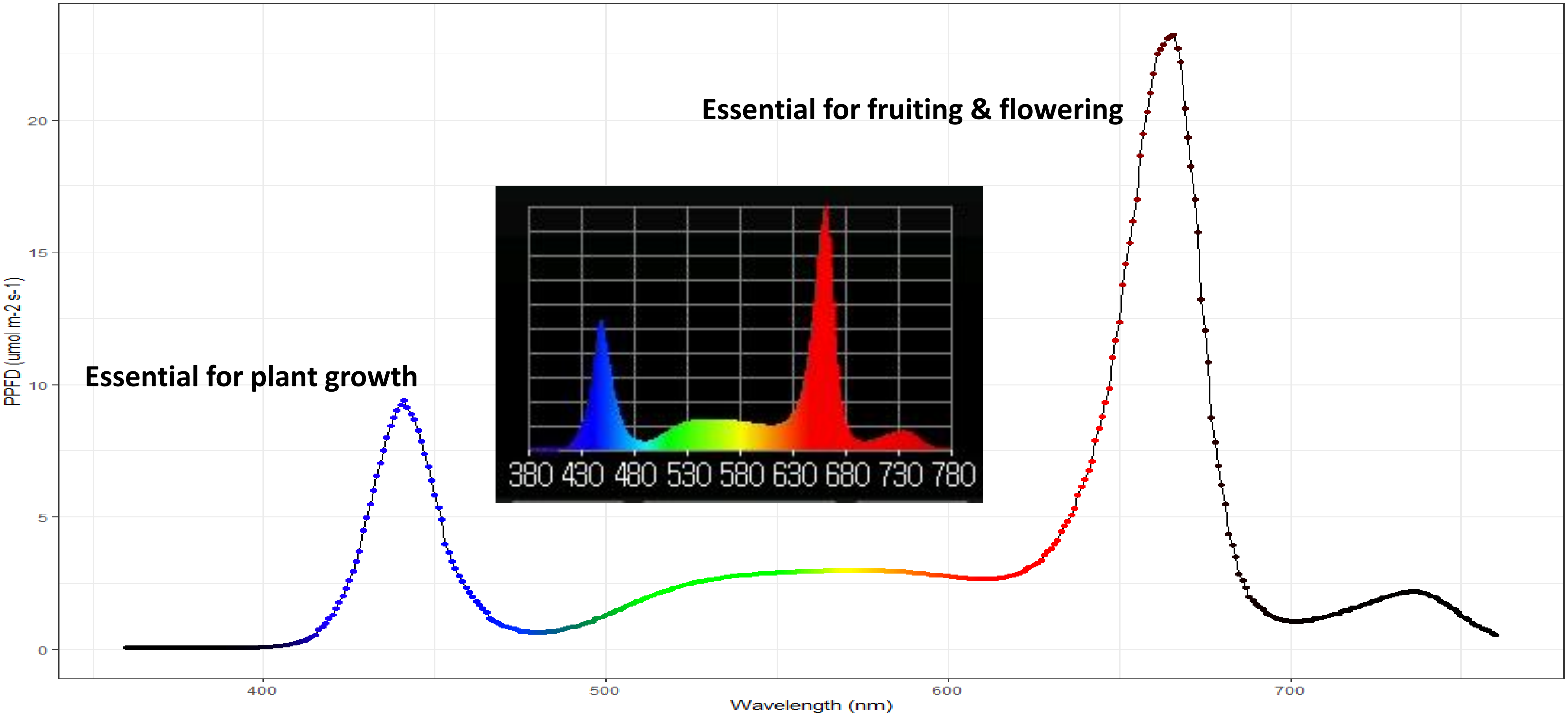
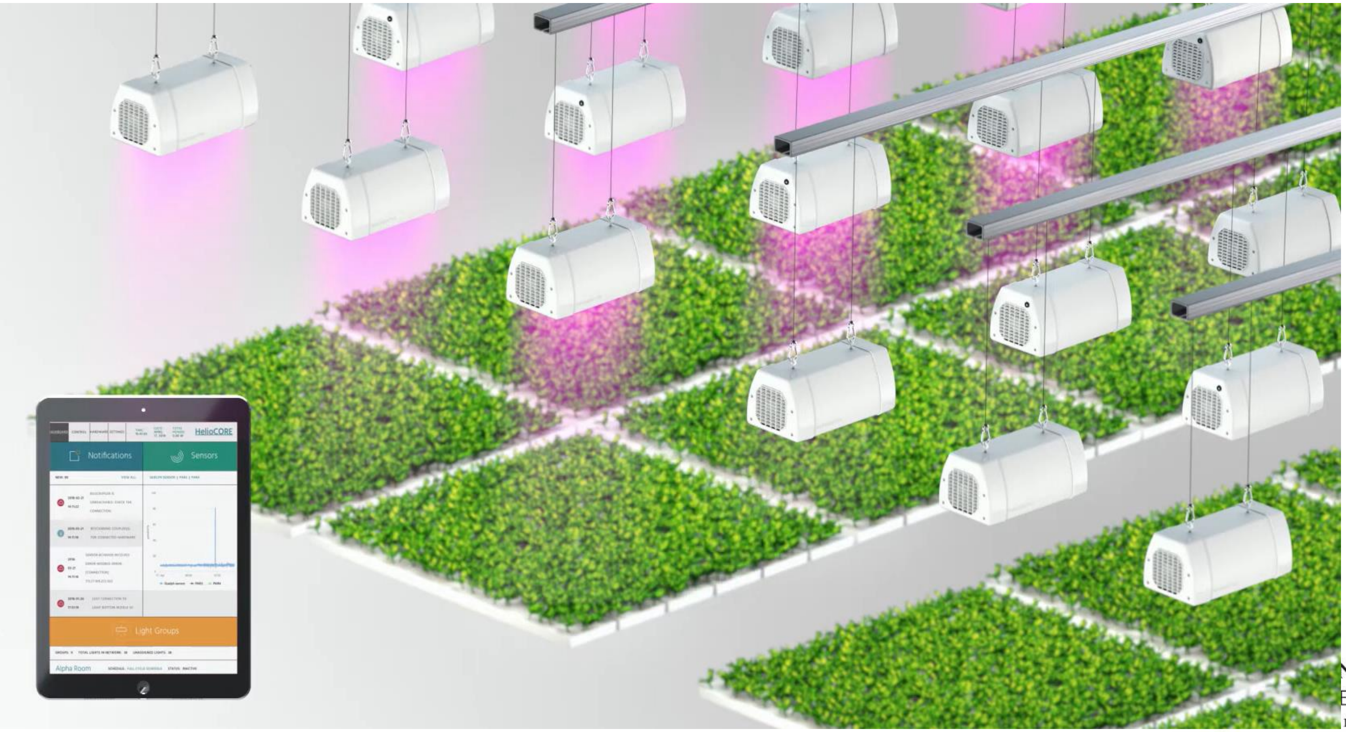
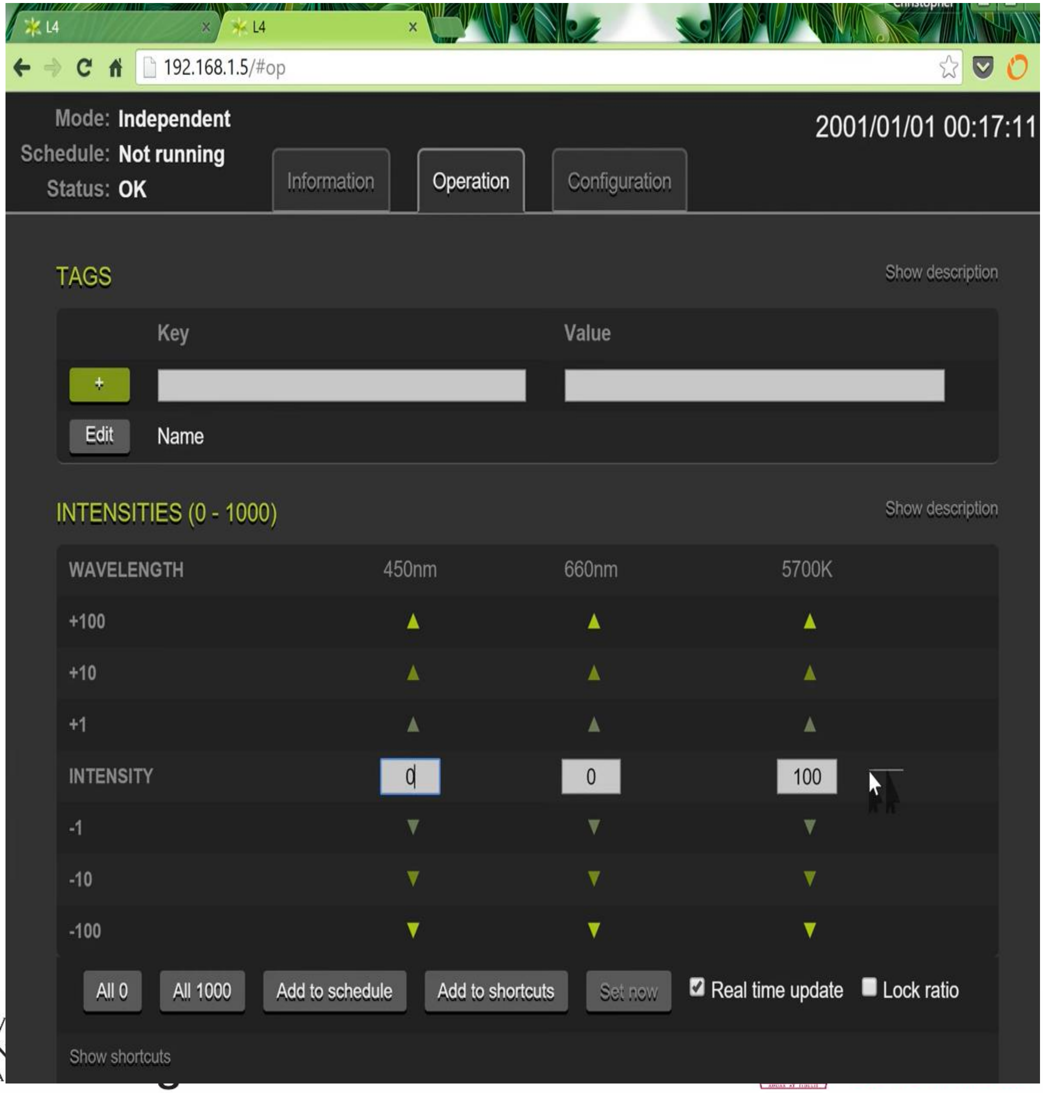
Light Quality: key areas of the spectrum for plants



Spectrum of LED Grow Lights

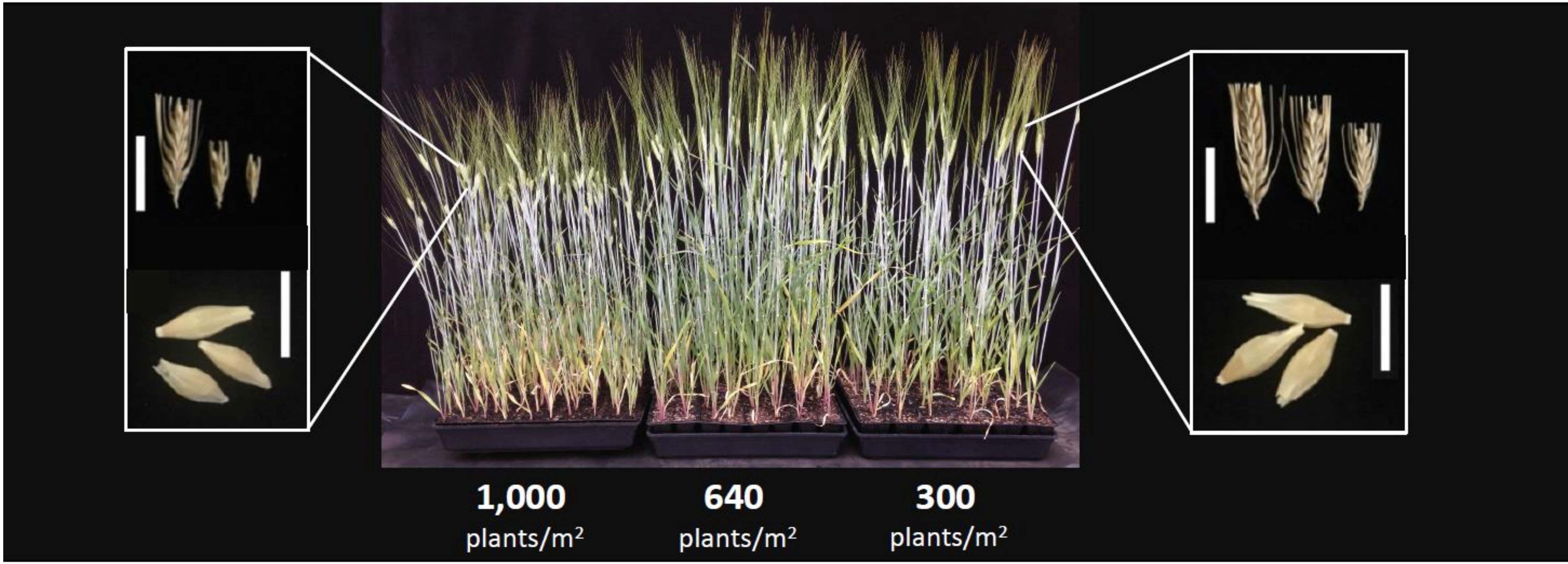
LED Grow light spectrum is fully programable & controllable by software





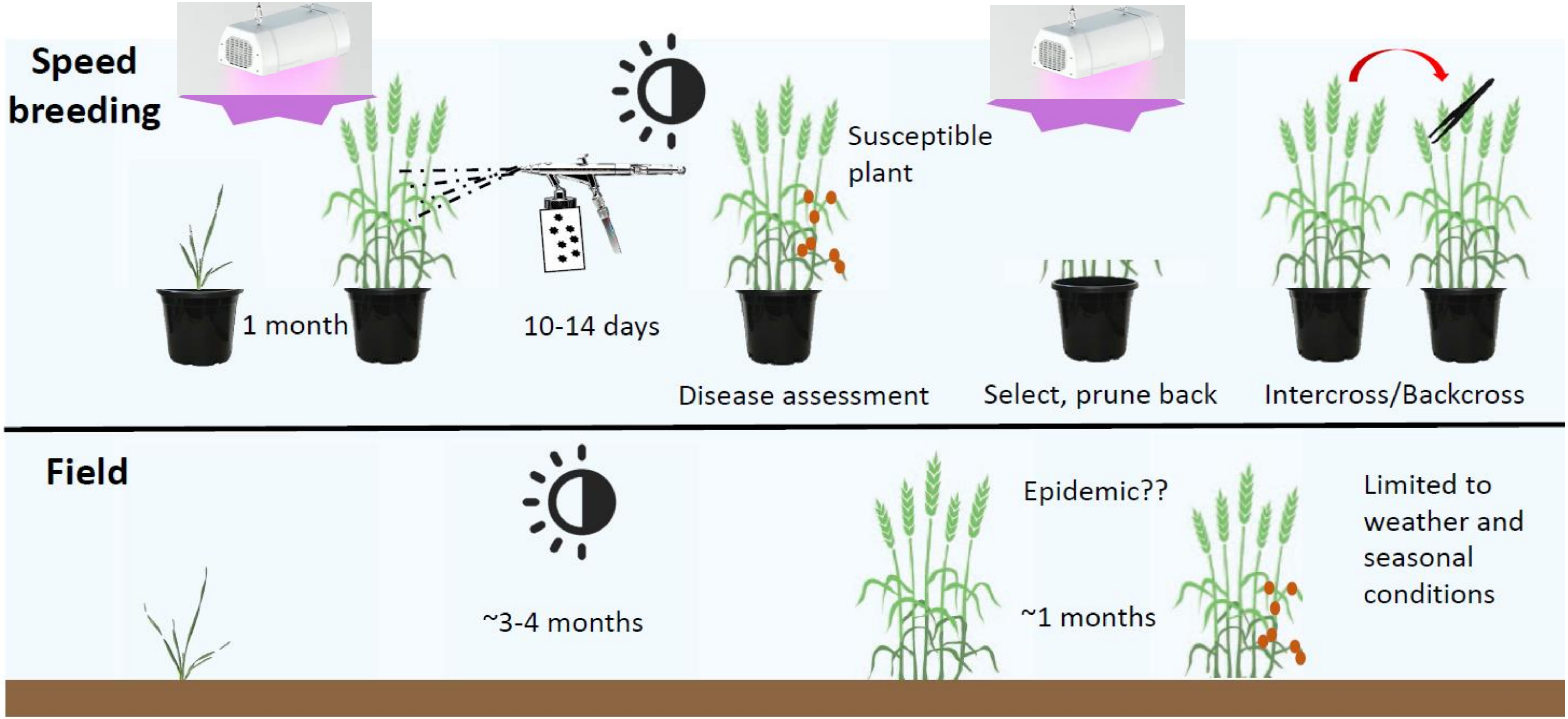
Creating "plant factories"

Ideal for SSD in breeding programs to reduce cost per plant



Ghosh and Watson et al. (2018) *Nature Protocols* **13**, 2944–2963

Rapid screening for adult plant resistance (APR)



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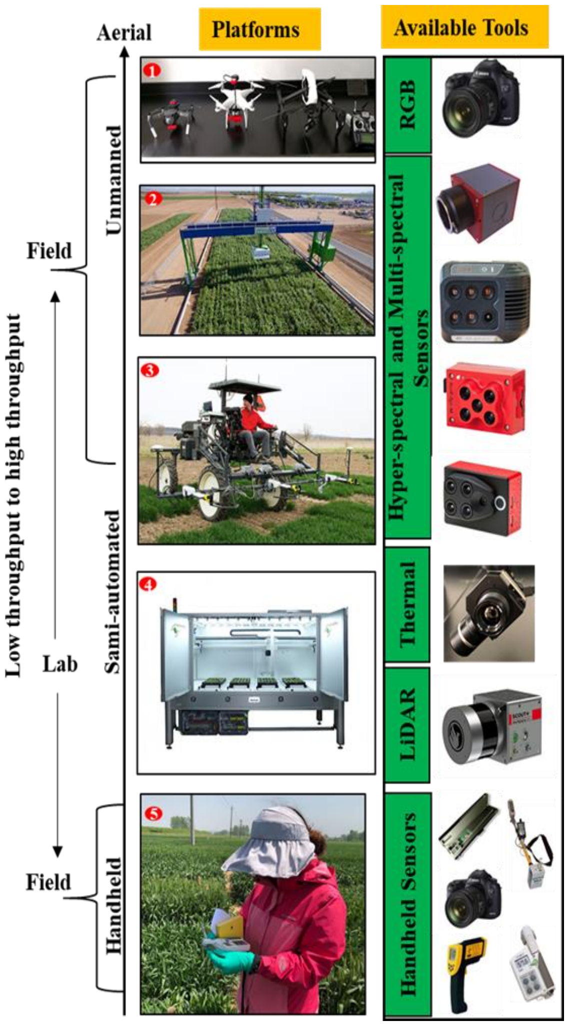
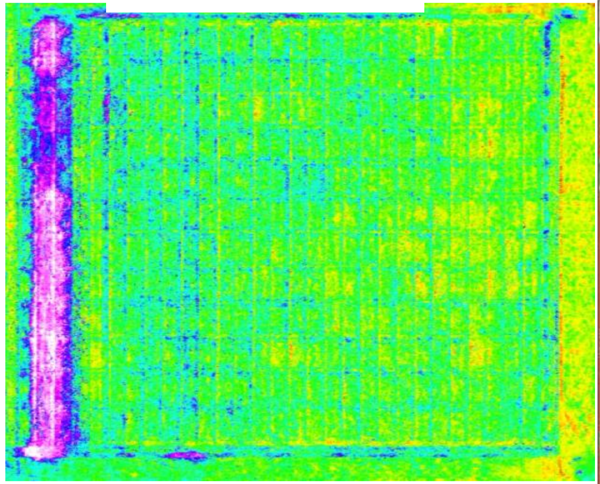
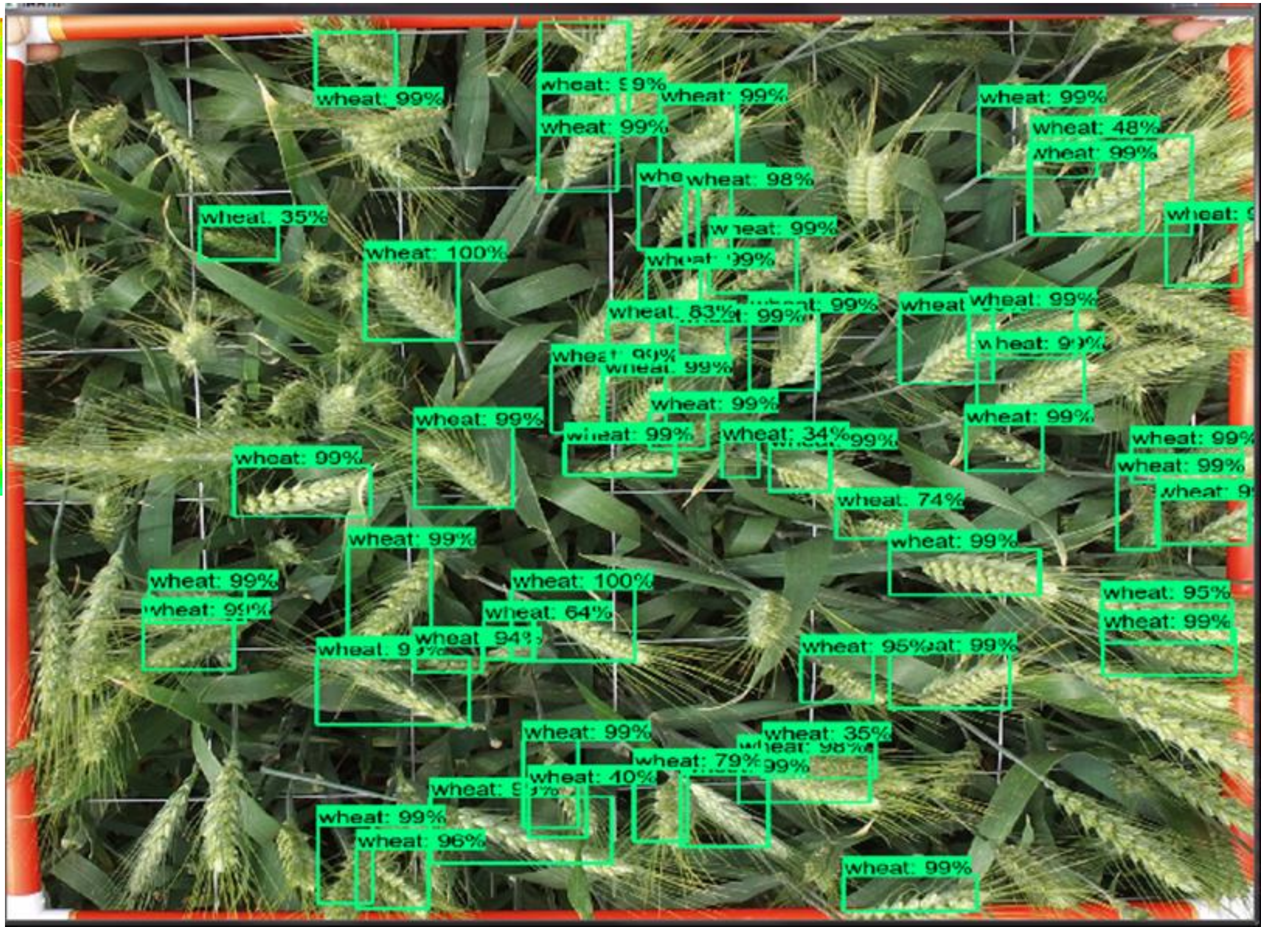
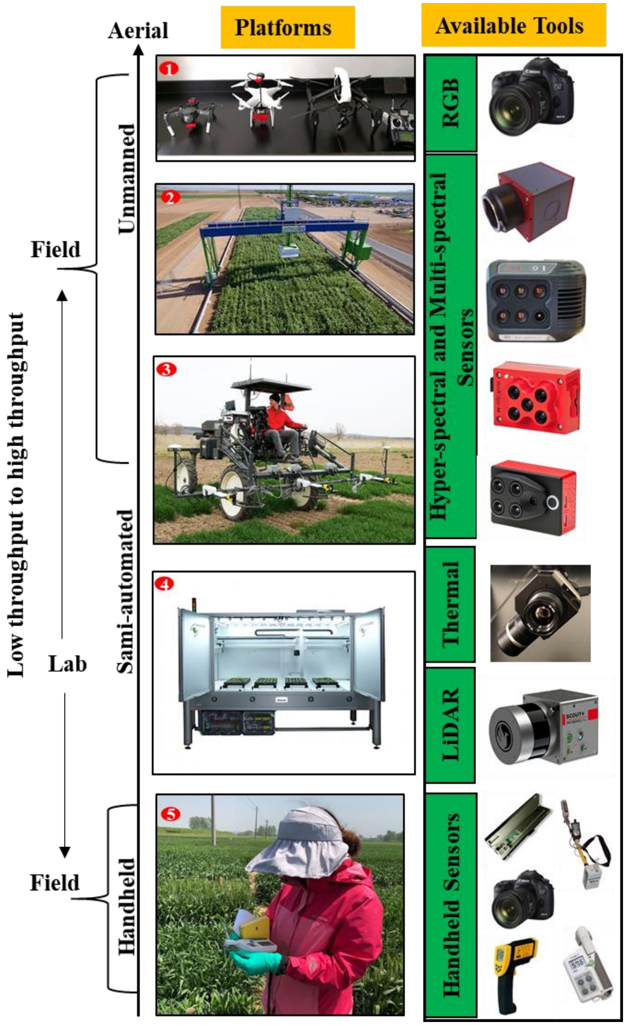
Opportunities: UAV based platforms for high throughput accurate phenotyping & other technologies

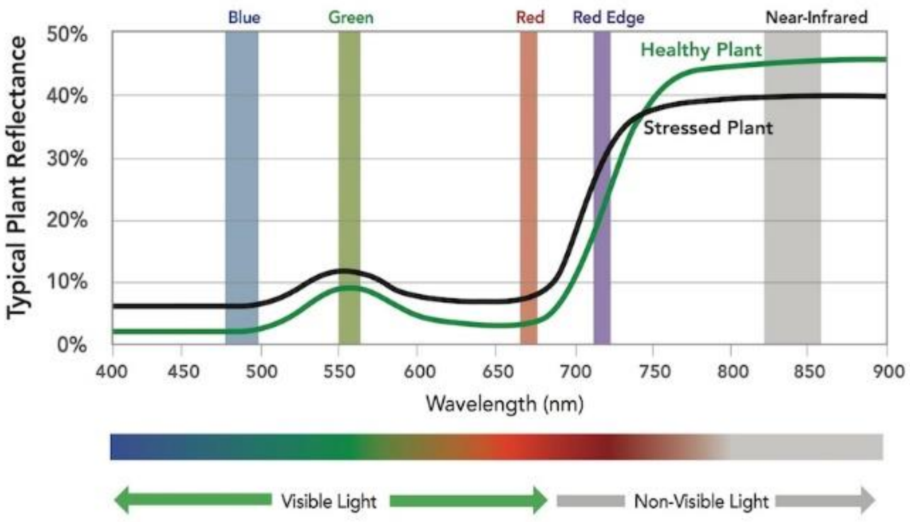






UAV based high throughput phenotyping platforms

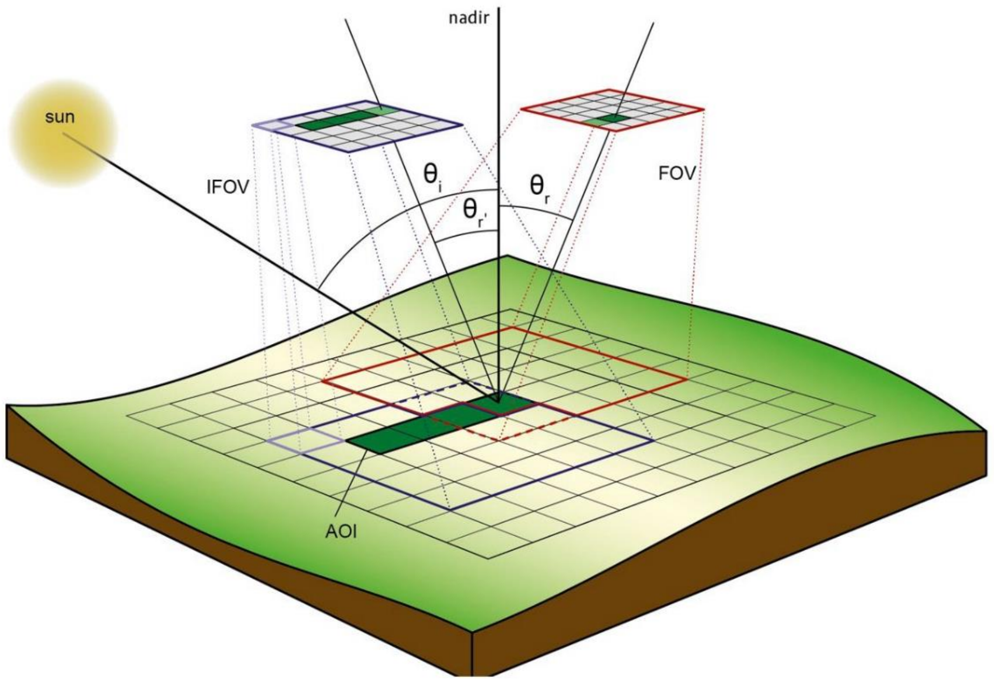


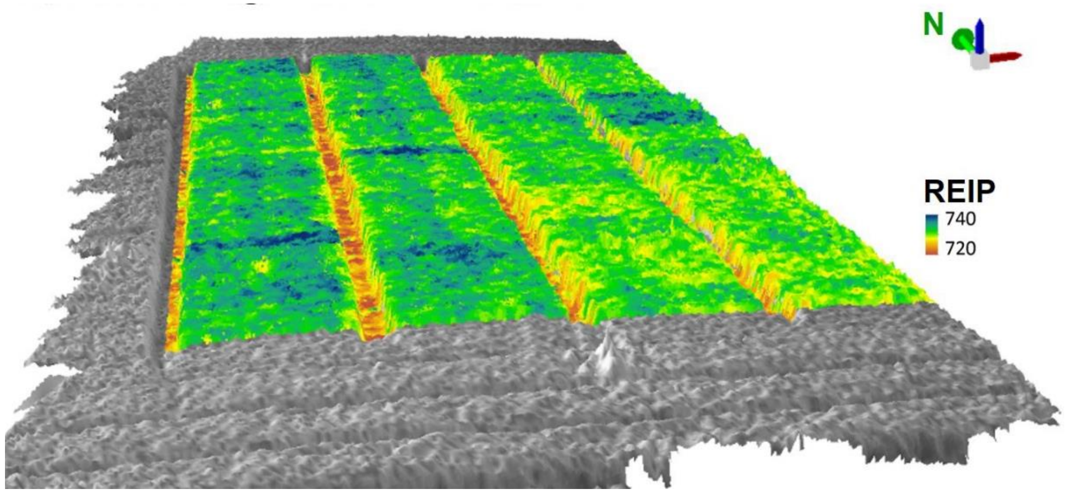


- **Can assist early selection in field through NDVI, CT, pigment, senescence rate, stay-green, plant height, spike number, ground cover**
- **Cover large experimental plots at multiple time and location**
- **Accelerate the accuracy for genetic analysis**

Concept of 2D and 3D mosaic maps for traits detection

- For accurate visualization of crop canopy traits through maximum pixel capture.
- Allow to measure multiple aspect of crop canopy





Platforms

- **Ground platform**

Greenseeker

IRT

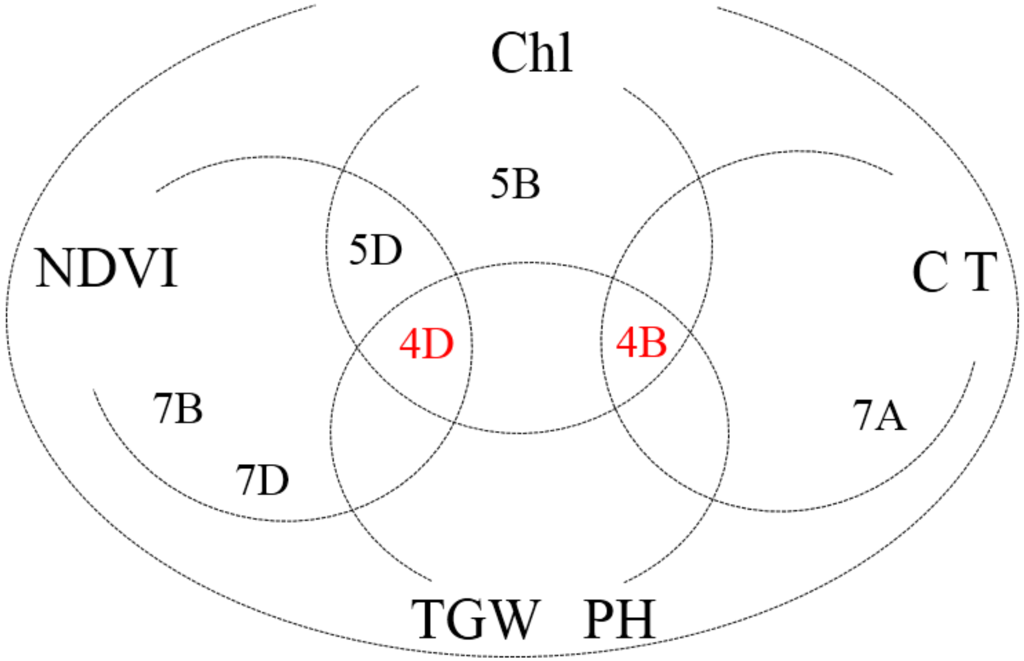
Ceptometer

SPAD

- **Aerial platforms**

Use of machine Learning

Spike number from machine learning



QTL for yield traits

- **Machine Learning strategy for spike counting**
- **UAV-base data for QTL and design for KAPS markers for breeding**

Pakistan’s 1st Speed Breeding Facility & UAV based HTP at NARC to Fast-Track Varietal Development






Take home messages

- **New technologies** offer opportunities to ‘tweak’ elements of the breeder’s equation and accelerate genetic gain
- **Speed Breeding** and **genomic selection** can reduce length of breeding cycle
- **UAV platforms** enable more accurate phenotyping, evaluation of larger populations and traits can be used in innovative breeding approaches
- **High throughput phenome** data can increase within season yield prediction and selection for fast forward genetic gain
- **Machine learning** strategy for trait evaluation
- **Remote sensing** data can be used for both practical breeding and genomic analysis for morphological and physiological traits


THANK YOU
ZAHID MAHMOOD'S PHOTO