Precision phenotyping: promising physiological traits that can be used in strategic crossing

Gemma Molero
Wheat Physiology, Global Wheat Program

IWYP

CIMMYT

Conceptual Model of Yield Potential

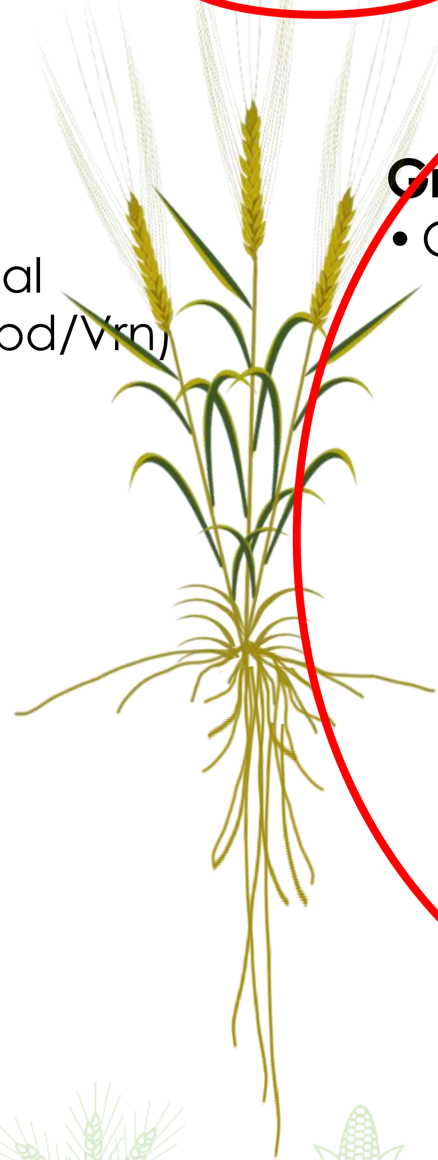
YIELD = LI x RUE x HI

Pre-grainfill (HI):

- Spike Fertility
  - grain no./weight potential
  - phenological pattern (Ppd/Vrn)
  - Avoid floret abortion (?)
- Lodging resistance
- Abort weak tillers

Grain-filling (HI/RUE):

- Partitioning to grain (HI)
- Adequate roots for resource capture (HI/RUE)



BIOMASS

Grain-filling (RUE/LI):

- Canopy photosynthesis (RUE/LI)
  - light distribution
  - N partitioning
  - spike photosynthesis
  - stay green

Pre-grainfill (RUE/LI):

- Light interception (LI)
- CO_2 fixation (RUE)
  - Rubisco

Adapted from Reynolds et al., 2012

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Exploring genetic diversity for biomass and traits related to canopy photosynthesis

The overarching goal is to **introduce sources of alleles** for high final biomass and other photosynthetic related traits into elite genetic backgrounds

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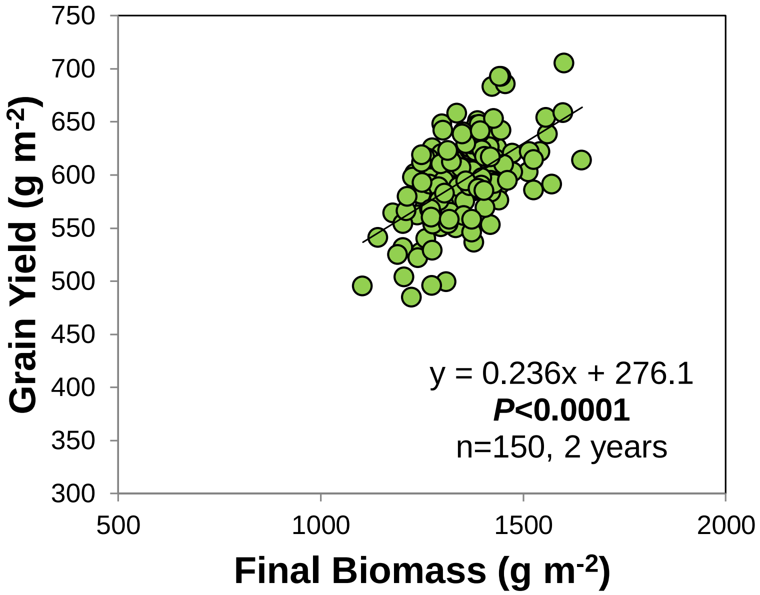
i. Screen a diverse set of genetic resources for good expression of final biomass

Final Biomass is highly correlated with grain yield under favorable conditions



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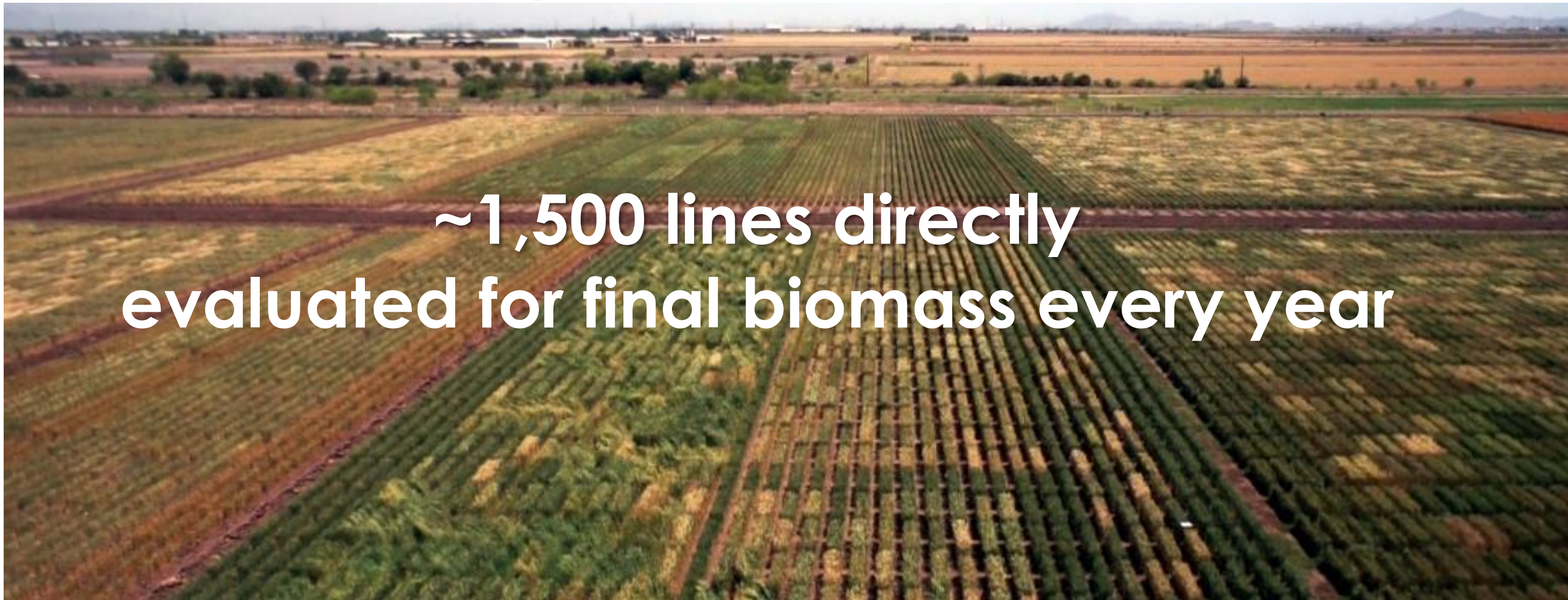
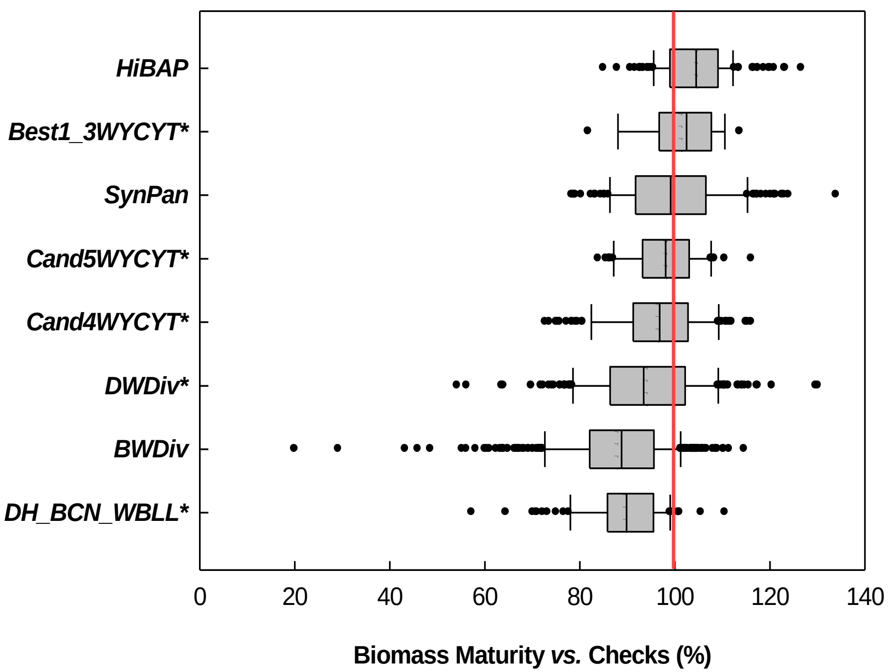
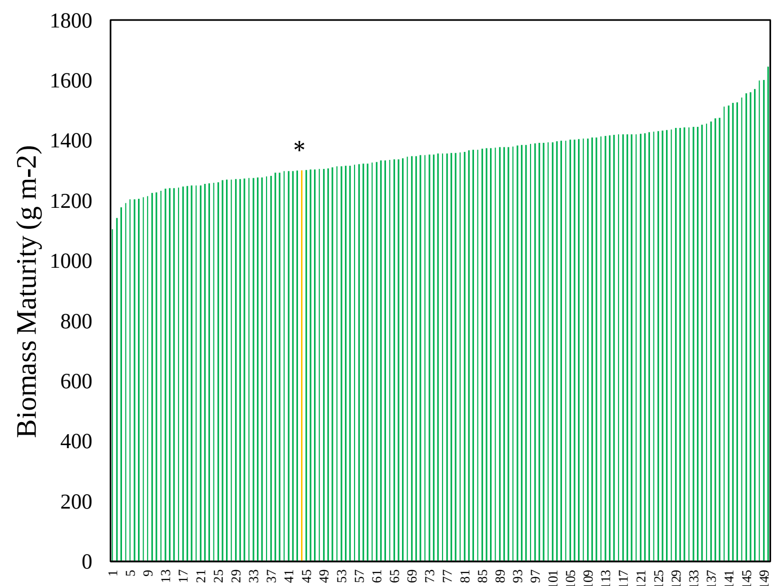


Large phenotipic variation in Biomass

Lines showing up to **34% higher biomass** in comparison with elite checks (Sokoll&Borlaug100)

HiBAP: High Biomass Panel created where **69% of the lines showed higher biomass** than the best check





Combined analysis 2015-2016 & 2016-2017

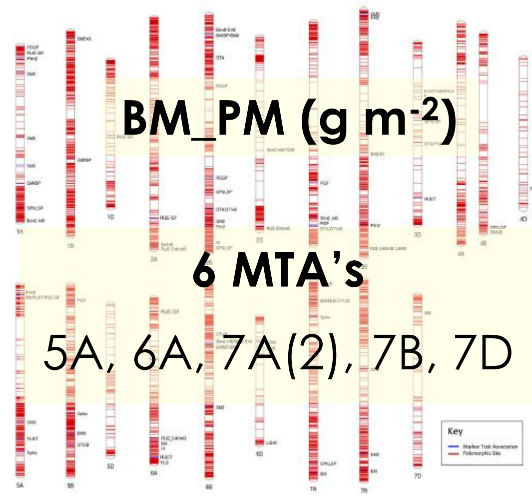
Highest biomass lines have synthetic and landrace material in their pedigrees

	%BM vs. best checks	Heritability	P value (Gen)
HiBAP			
C80.1/3*QT4118//KAUZ/RAYON/3/2*TRCH/7/CMH79A.955/4/AGA/3/4*SN64/CNO67//I NIA66/5/NAC/6/RIALTO	127		
CHEWINK #1	123		
KACHU #1/4/CROC_1/AE.SQUARROSA (205)//BORL95/3/2*MILAN/5/KACHU	123		
C80.1/3*QT4118//KAUZ/RAYON/3/2*TRCH/7/CMH79A.955/4/AGA/3/4*SN64/CNO67//I NIA66/5/NAC/6/RIALTO	121	0.414	**0.000**
DPW 621-50 -India	120		
BCN/WBLL1//PUB94.15.1.12/WBLL1	120		
WBLL4//OAX93.24.35/WBLL1/5/CROC_1/AE.SQUARROSA (205)//BORL95/3/PRL/SARA//TSI/VEE#5/4/FRET2	119		
MEX94.27.1.20/3/SOKOLL//ATTILA/3*BCN/4/PUB94.15.1.12/WBLL1	118		
SynPAN			
68.111/RGB-U//WARD/3/FGO/4/RABI/5/AE.SQUARROSA (778)	134		
ALTAR 84/AE.SQUARROSA (895)	124		
CETA/AE.SQUARROSA (796)	123		
CETA/AE.SQUARROSA (273)	123	0.656	**0.000**
68.111/RGB-U//WARD/3/FGO/4/RABI/5/AE.SQUARROSA (778)	121		
CROC_1/AE.SQUARROSA (466)	121		
GARZA/BOY//AE.SQUARROSA (350)	121		
68.111/RGB-U//WARD/3/FGO/4/RABI/5/AE.SQUARROSA (788)	120		
BWDiv			
VORB//PARUS/PASTOR	115	0.731	**0.000**
MEX94.2.19/PUB94.15.1.12	112		
DWDiv			
GIZA 8 (Durum) - Saudi Arabia	130		
COULTER (Durum) - Canada	130	0.782	**0.000**
D86135/2*ACO89 (Durum) -Mexico	121		

Orange: primary synthetics or synthetics derived lines
Green: landraces or landraces derived lines
Yellow: lines with synthetic and landrace background in their pedigree.

Highest biomass lines have synthetic and landrace material in their pedigrees

HiBAP, n=150, 2 years, Y15-16&Y16-17



Type	YLD	DTA	TGW	HI	Height	BM_PM
Elite	597^{A}	76^{B}	42.6^{C}	0.473^{A}	98.5^{D}	1346^{B}
Landrace derivatives	592^{A}	**79^{A}**	**45.7^{B}**	**0.450^{C}**	**103.3^{A}**	**1394^{A}**
Synthetic derivatives	594^{A}	76^{B}	**45.6^{B}**	**0.463^{B}**	**100.5^{C}**	1358^{AB}
Synthetic+Landrace derivative	593^{A}	76^{B}	**48.2^{A}**	**0.459^{B}**	**101.7^{B}**	**1389^{A}**

Molero et al., 2019. *Plant Biotechnology Journal*

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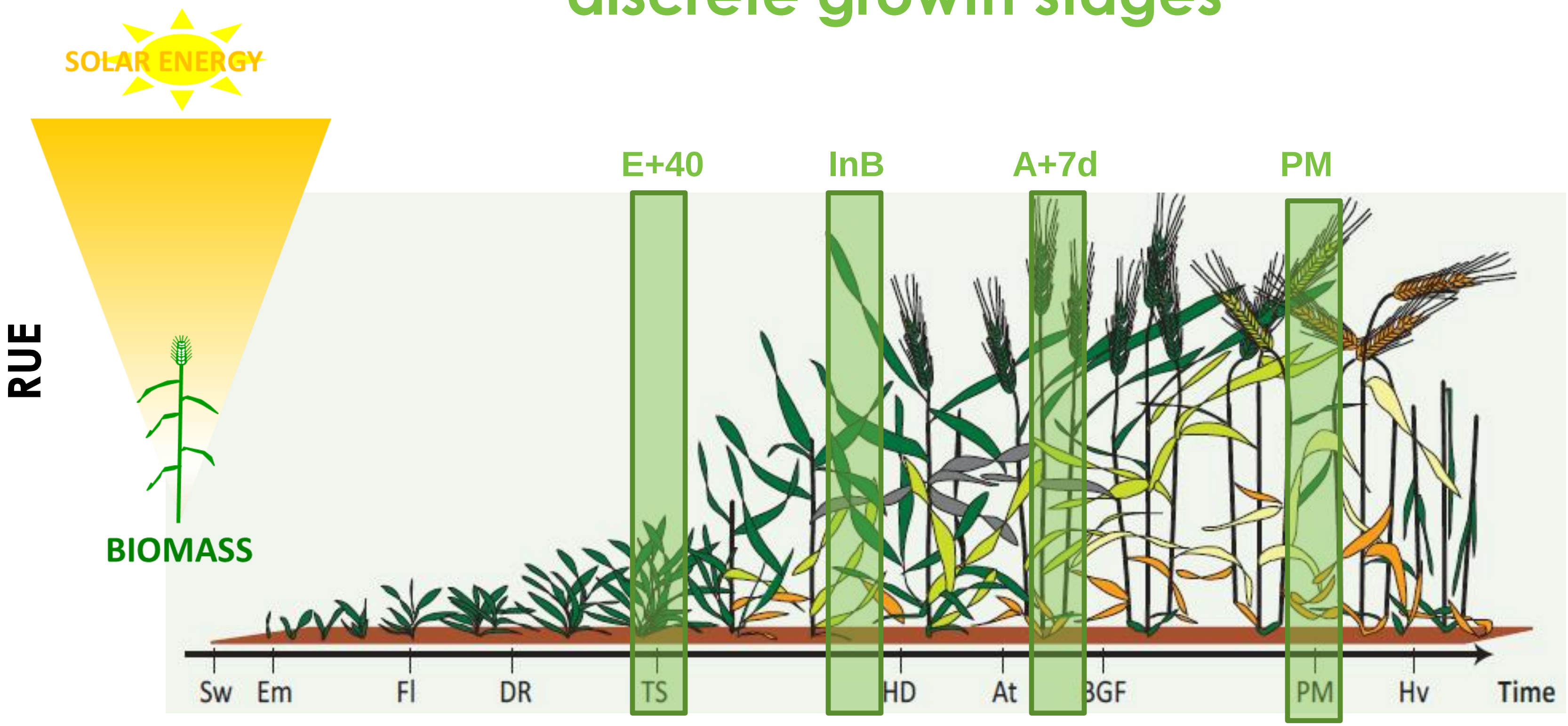
ii. Characterize lines for expression of LI and RUE at discrete growth stages



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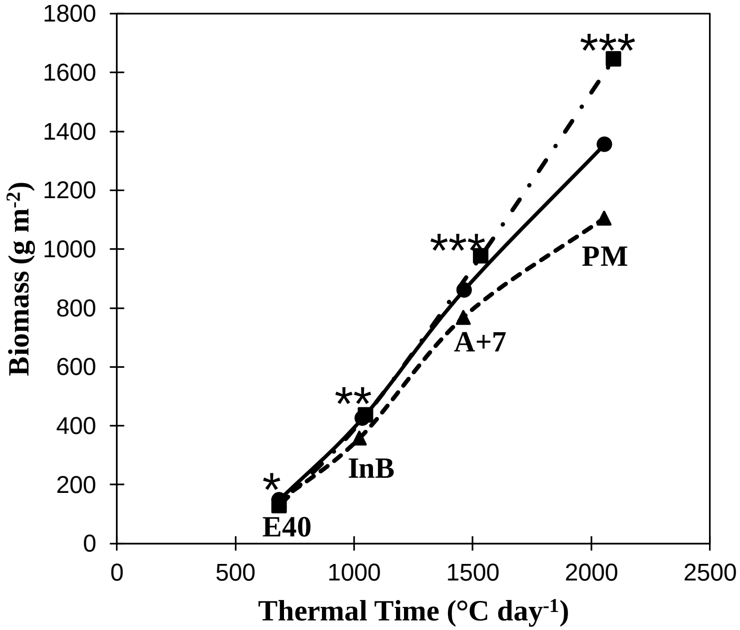
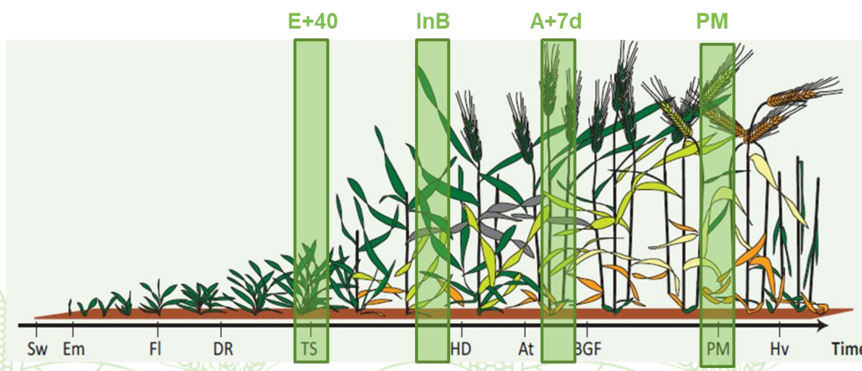


HiBAP, n=150, 2 years

	BME40	BMInB	BMA7	BMPM
Heritability (*h*²)	0.240	0.342	0.498	0.414
Correl with Yield	-0.014	-0.119	0.097	**0.561**
Correl with BM_PM	0.153	**0.303**	**0.25**	1



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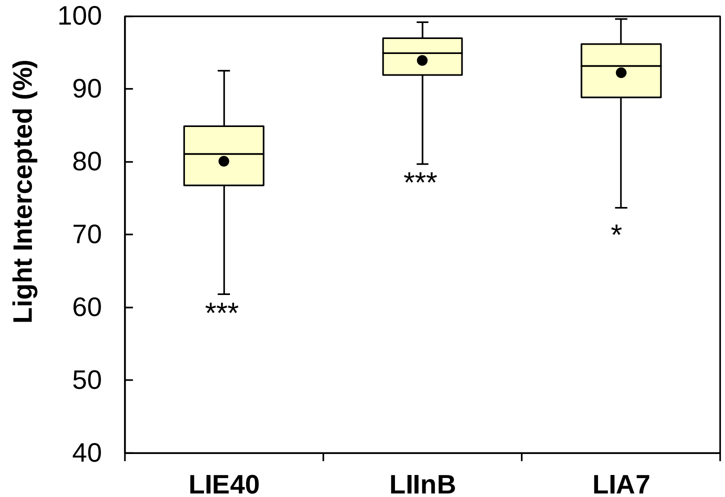
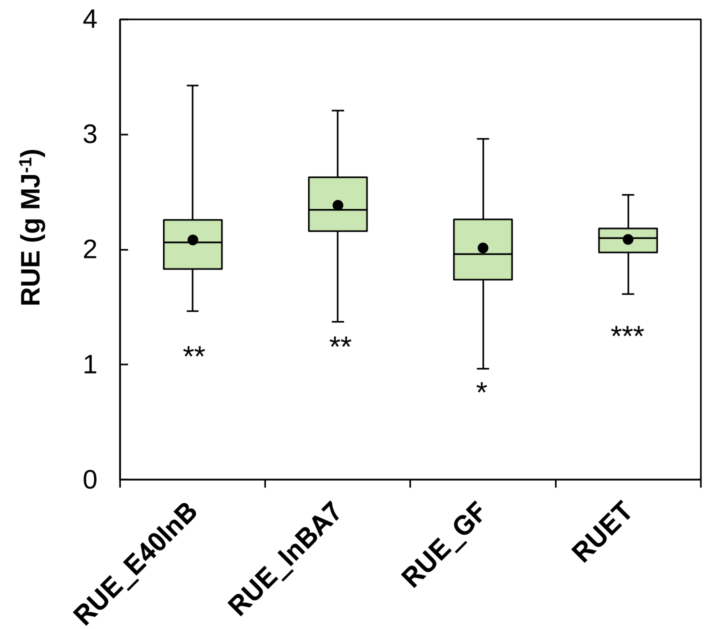
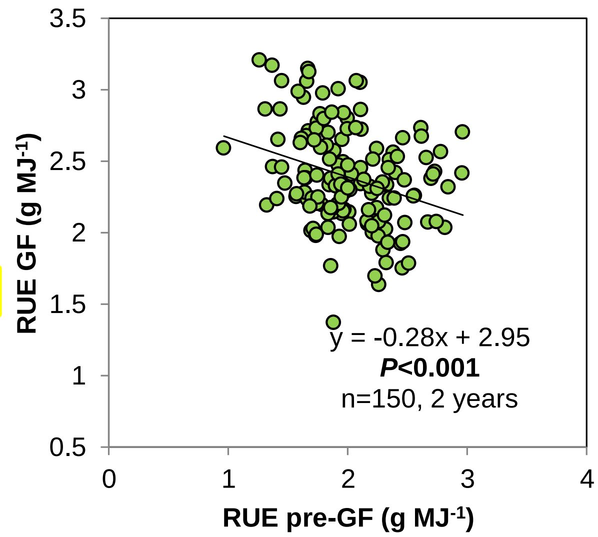




ii. Characterize lines with high biomass for expression of LI and RUE at discrete growth stages

HiBAP, 2 years

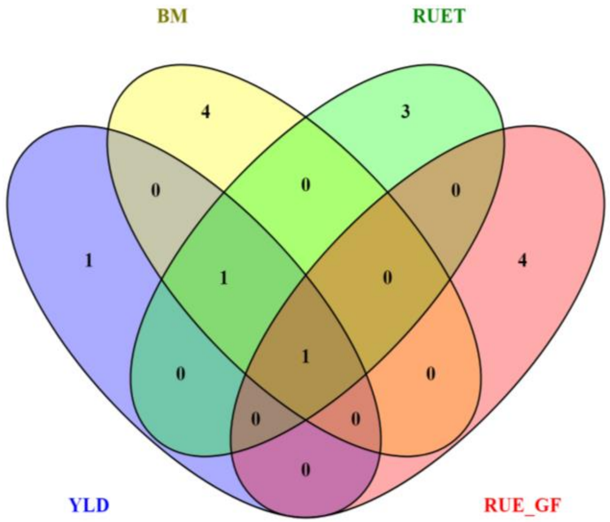
	RUE E40InB	RUE InBA7	RUE GF	RUE Total	LI E40	LI InB	LI A7
YLD	0.145	0.113	**0.533**	**0.609**	0.008	-0.019	-0.046
Height	0.061	0.044	0.139	**0.265**	**0.27**	**0.253**	**0.254**
HI	0.006	0.119	**-0.219**	-0.160	-0.062	**-0.374**	**-0.378**
TGW	**0.162**	0.028	**0.274**	**0.453**	**0.292**	0.019	0.118
GM2	-0.008	0.070	0.068	-0.024	**-0.278**	-0.093	**-0.195**
BME40	0.159	-0.038	-0.108	-0.008	**0.355**	-0.059	0.019
BMInB	**0.268**	**-0.204**	-0.078	-0.005	**0.347**	**0.374**	**0.27**
BMA7	**0.427**	**0.721**	**-0.248**	**0.378**	**0.167**	0.003	0.15
BMPM	0.143	0.027	**0.742**	**0.773**	0.101	**0.331**	**0.291**

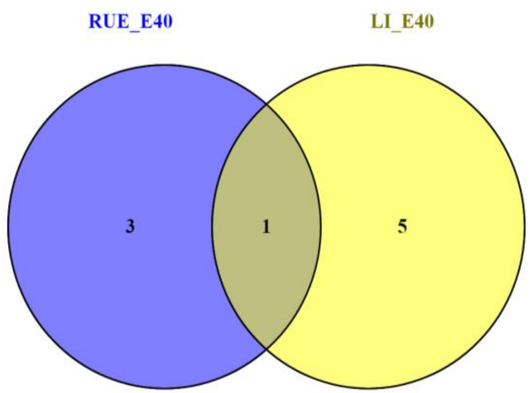


Identification of MTAs related with biomass, LI and RUE

HiBAP, n=150, 2 years

Trait	Number of MTAs	Chromosomes
Agronomic		
Grain Yield (kg ha^{-1})	3	5A, 6A, 7A
Plants m^{-2}	4	1A, 2B, 3B, 5A
Stems m^{-2} E40	2	2B, 6B
Stems m^{-2} InB	4	1A, 2D, 3A, 6B
Source		
BM_E40 (g m^{-2})	**2**	**1B, 3B**
BM_InB (g m^{-2})	**3**	**2A, 4B, 7A**
BM_PM (g m^{-2})	**6**	**5A, 6A, 7A(2), 7B, 7D**
RUE_E40InB (g MJ^{-1})	**4**	**2A, 2D, 3B. 6A**
RUE_GF (g MJ^{-1})	**5**	**1A, 1D, 2A, 5A, 6A**
RUET (g MJ^{-1})	**5**	**3D, 5A(2), 6A, 7A**
LI_E40 (%)‡	**6**	**1B, 3B(3), 5A, 6D**





Molero, Joynson et al., 2019. *Plant Biotechnology Journal.*

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Flats

	YLD g/m2	BM g/m2	HI	TGW	GM2	SM2	Height cm	DTA
Erect	471	1029	.44	25.3	19170	400	87	75
Floppy	442	972	.45	30.4	14960	302	94	72
%E vs F	**6.6**	**5.8**	-2.3	-16.7	28.1	33	-7.5	4.2

Beds

	YLD g/m2	BM g/m2	HI	TGW	GM2	SM2	Height cm	DTA
Erect	482	1463	.33	36.2	13410	310	88	75
Floppy	490	1469	.34	36.3	13500	301	93	76
%E vs F	-1.6	-0.5	-3.0	-0.3	-0.7	3.0	-5.4	-1.3

R. Richards, unpublished data

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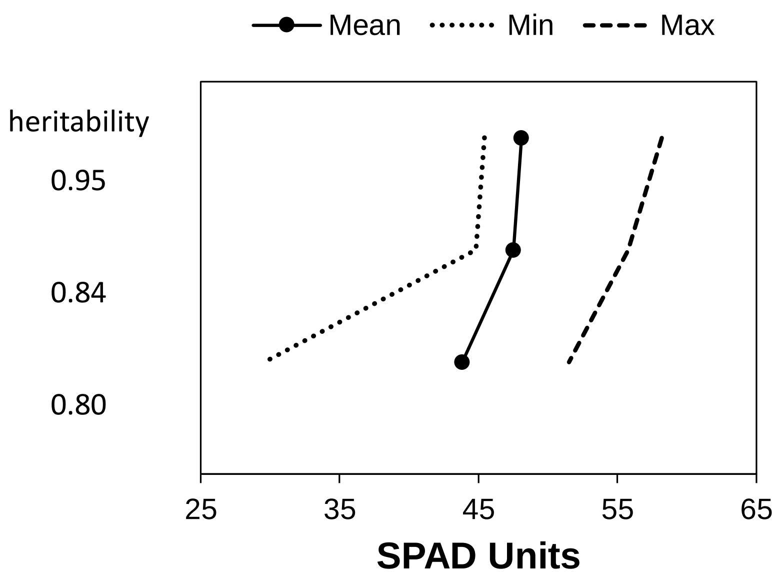
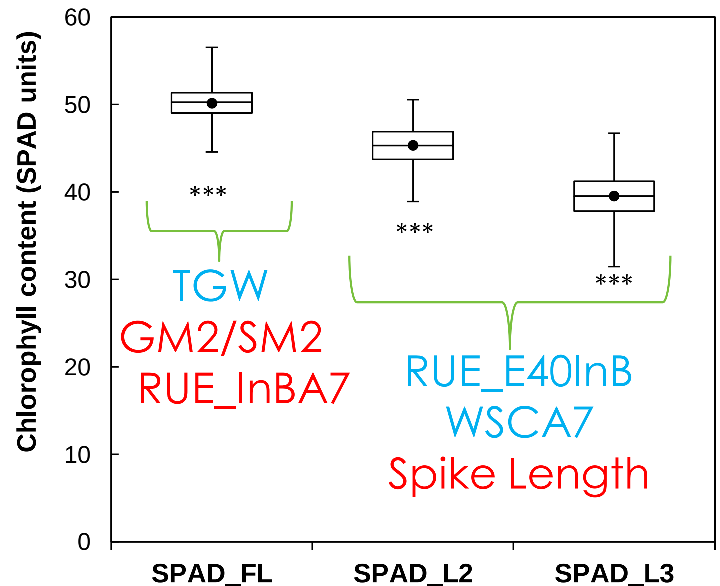
iii. Evaluate lines for canopy architecture traits that permit a more vertically uniform photosynthetic rate down the leaf canopy

Use of spectral reflectance at leaf level

SPAD-502 (650 nm, 940 nm)

HiBAP





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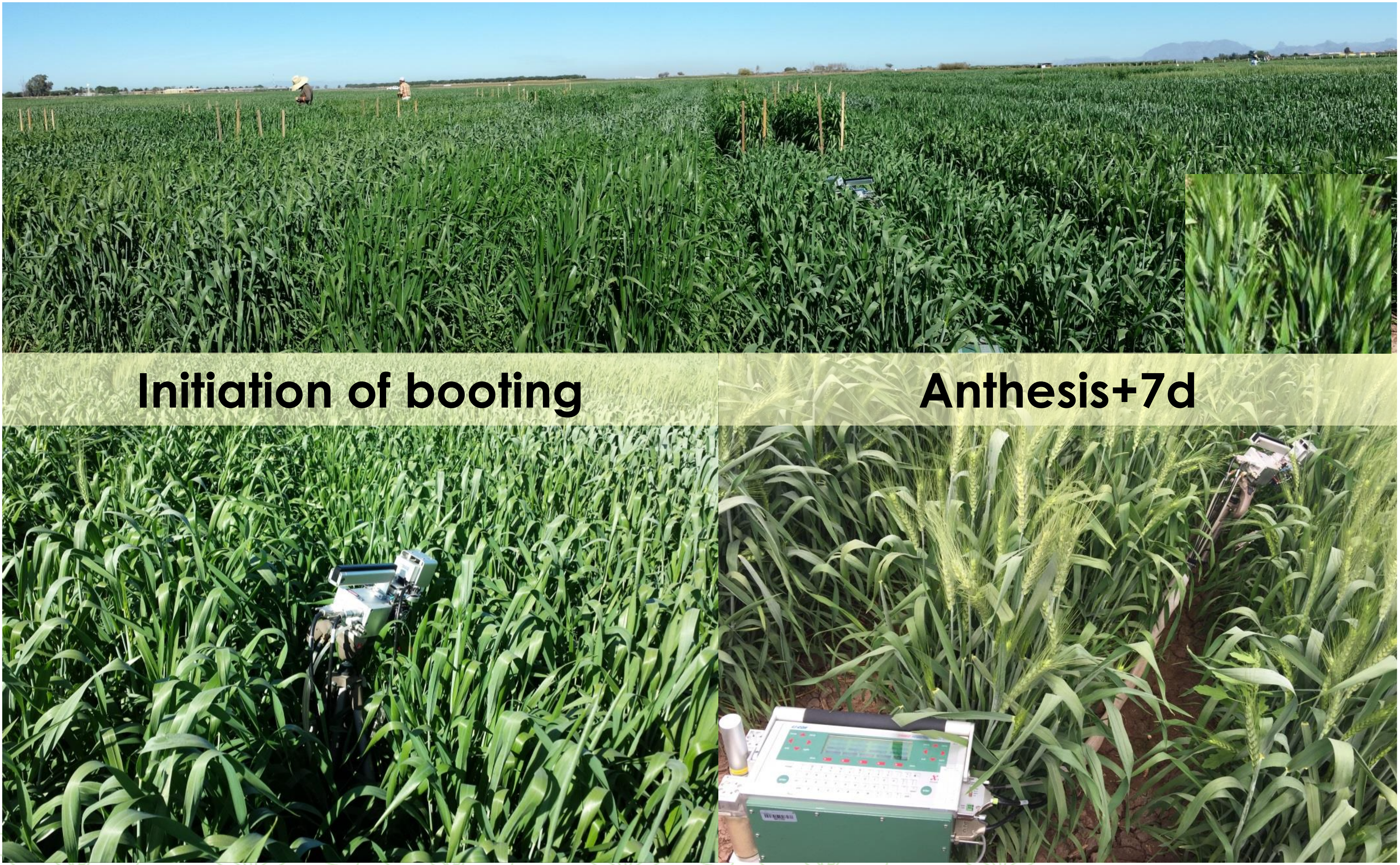
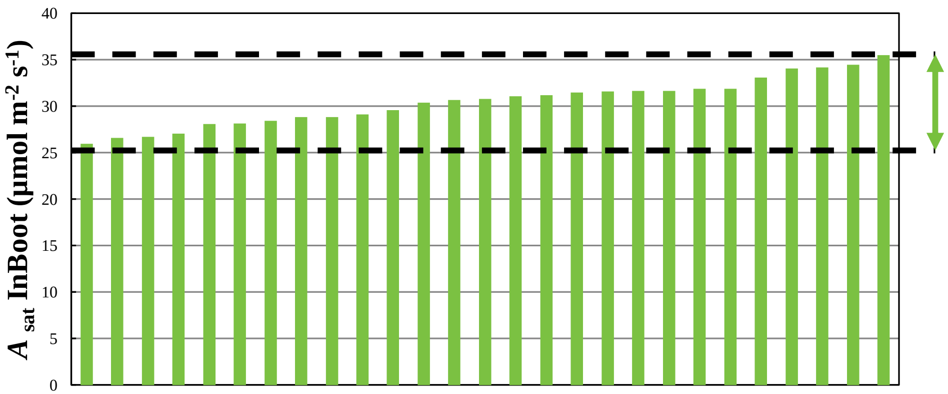
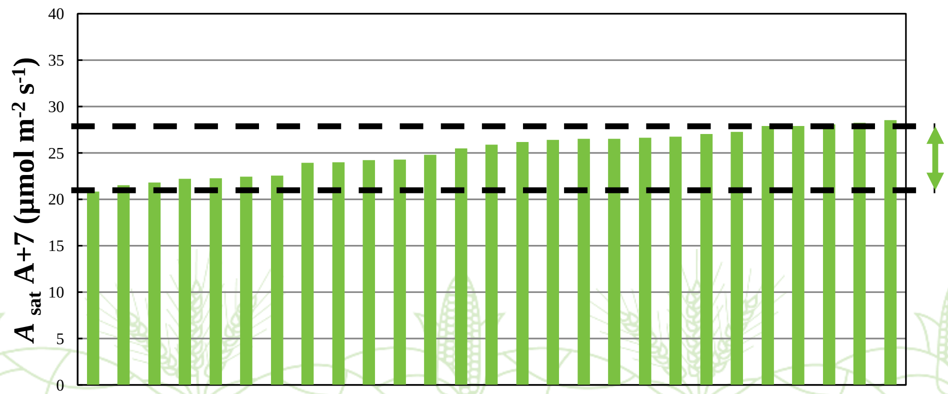


iv. Screen lines for flag leaf and spike photosynthesis

CIMCOG I, 27 Elite Lines (2 years)





PSTails, 80 Lines (2 years)

	Photo µmol CO2 m^{-2} s^{-1}	Cond mol H2O m^{-2} s^{-1}
H^2	0.378	0.446
Min	17.6	0.181
Mean	27.6	0.441
Max	32.0	0.618
G	**0.014**	**0.004**
G x Y	**0.000**	**0.000**
Y	0.266	0.082
r with YLD	**0.54**	**0.45**
r with TGW	0.18	0.01
r with HI	**0.39**	**0.37**
r with BM	**0.48**	**0.40**
r with GM2	**0.45**	**0.48**

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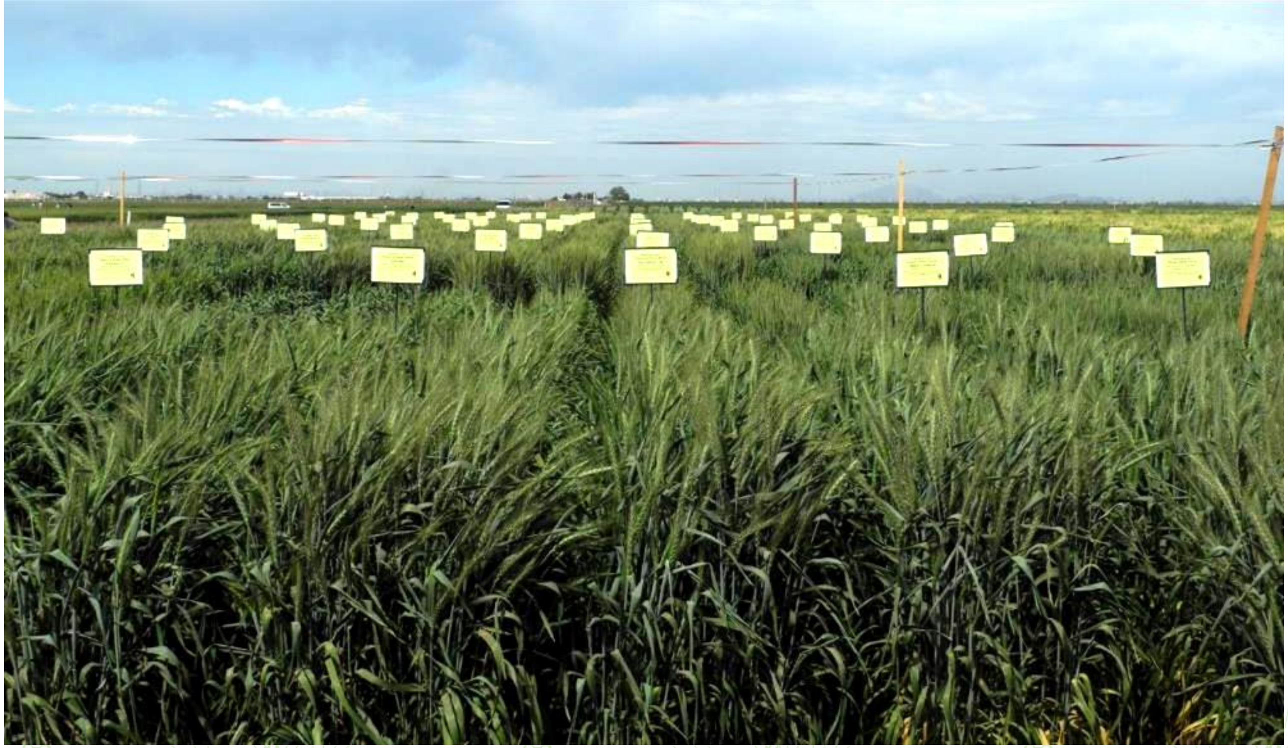
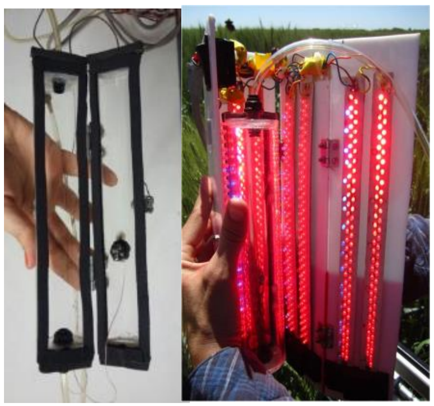
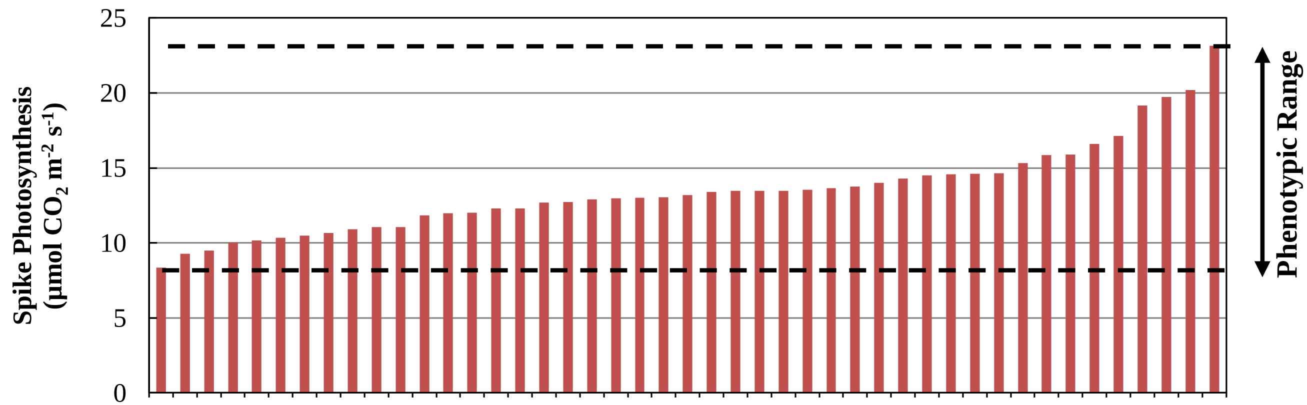
iv. Screen lines for flag leaf and spike photosynthesis



Elite spring bread wheat spikes intercept up to 45% of sun light

Phenotypic selection for Spike Photosynthesis

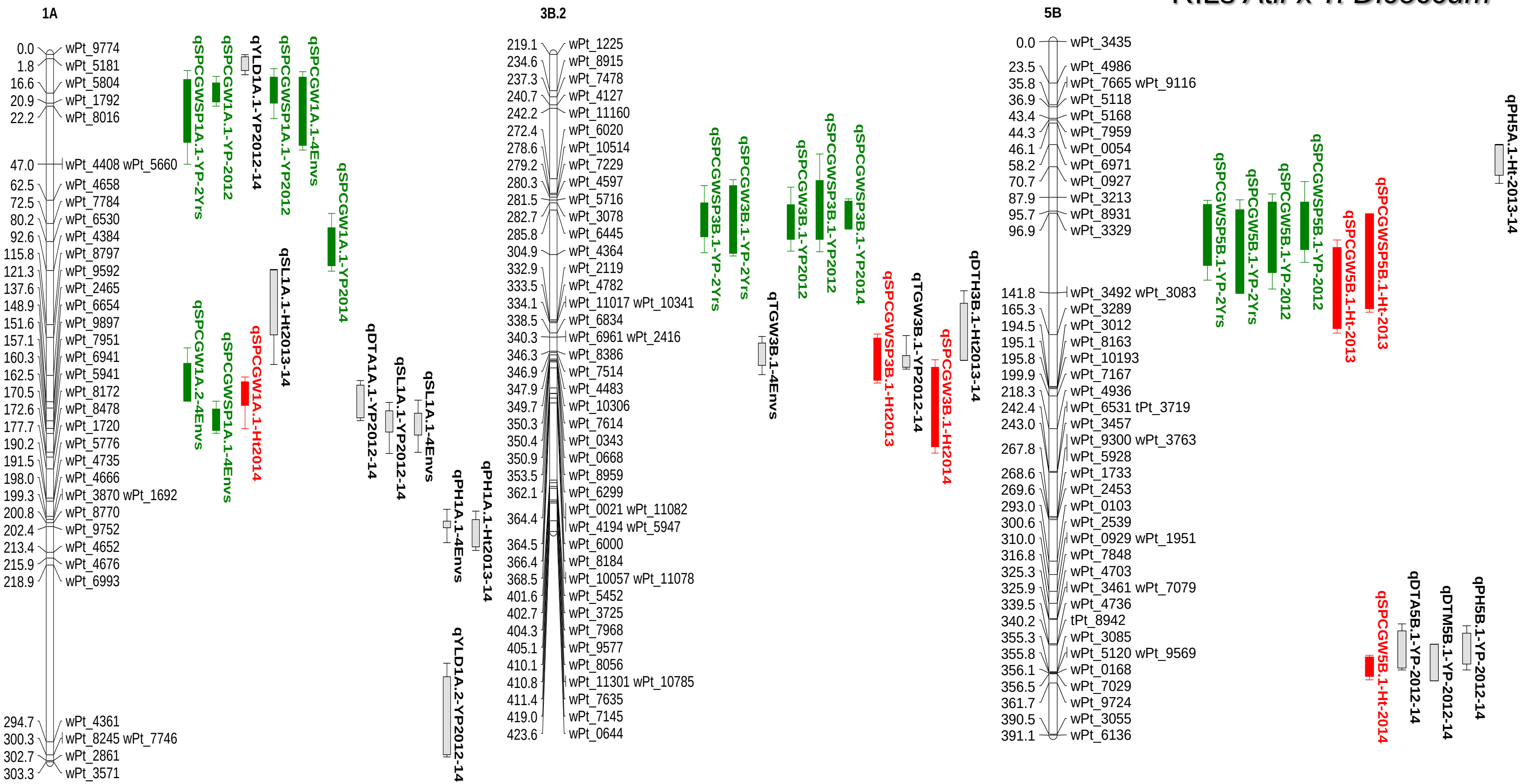




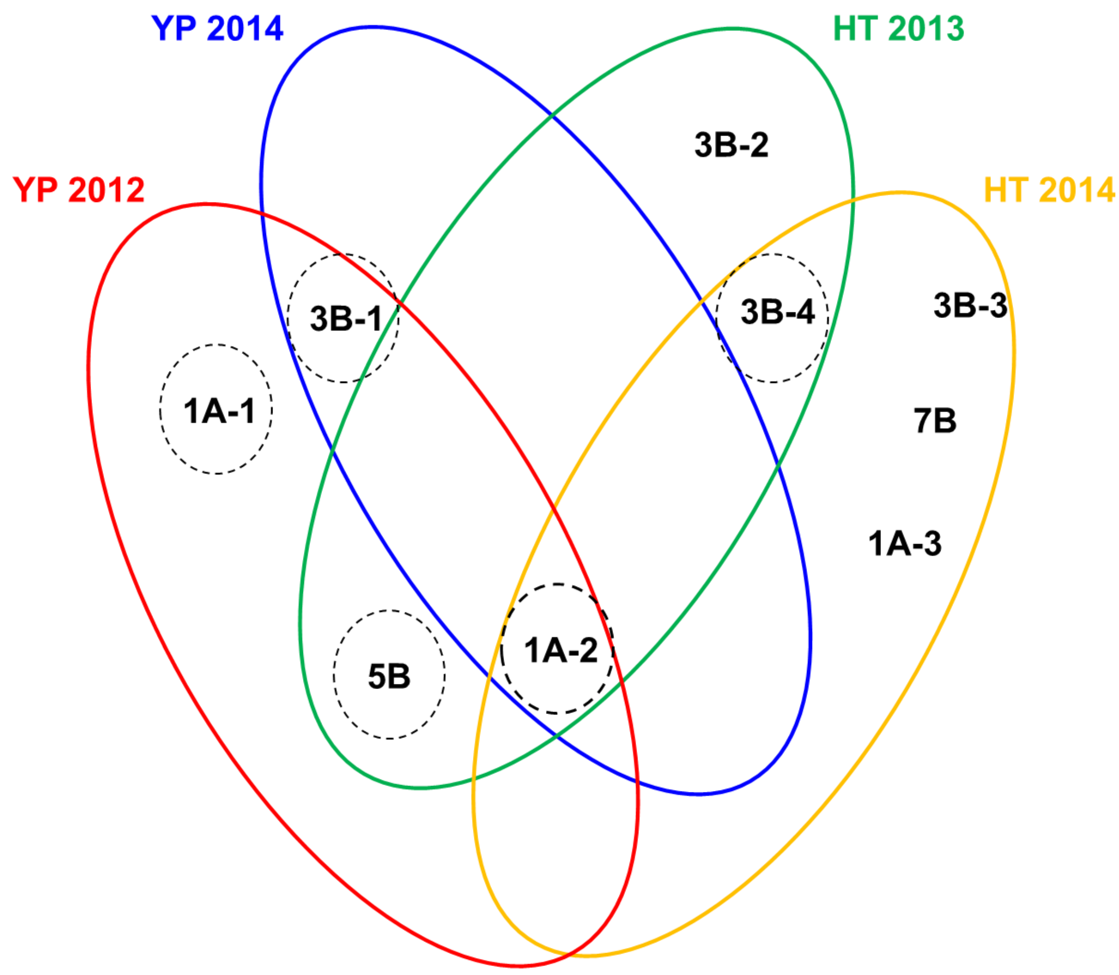
		SPC$_{GWSP}$ (%)						
	Env	Mean	Min	Max	h^2	Gen	Year	G × Y
PADs POP								
2011-12 & 2012-13	**YP**	22.9	9.0	35.8	0.826	***	ns	ns
2012 & 2013	**Heat**	33.2	20.0	42.5	0.775	***	ns	ns
CIMCOG I								
2011-12 & 2012-13	**YP**	40.6	30.0	51.9	0.776	***	*	ns
2012	**Heat**	40.3	32.1	48.1	0.284	***	-	-
CIMCOG II								
2013-14 & 2014-15	**YP**	33.0	22.5	45.7	0.672	***	ns	ns
2014 & 2015	**Heat**	35.3	27.7	51.1	0.172	**	*	*
RILs Atil/Dicc								
2011-12 & 2013-14	**YP**	34.1	17.5	48.3	0.600	***	*	ns
2013 & 2014	**Heat**	27.6	18.0	50.2	0.380	*	**	ns

Identification of QTLs for Spike Photosynthesis

RILs *Atil* x *T. Dicoccum*



Consistent QTLs for YP and Heat



RILs *Atil* x *T. Dicoccum*

Molero et al., to be submitted

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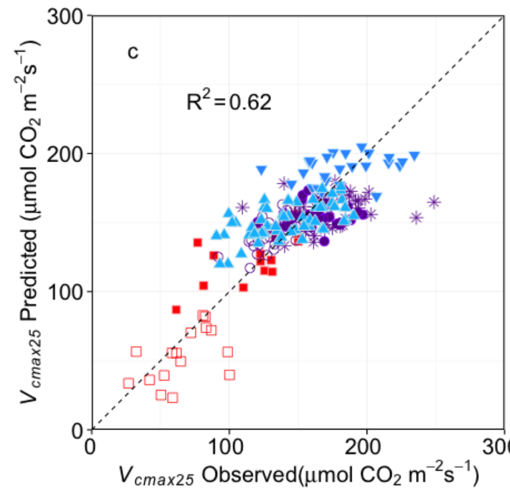
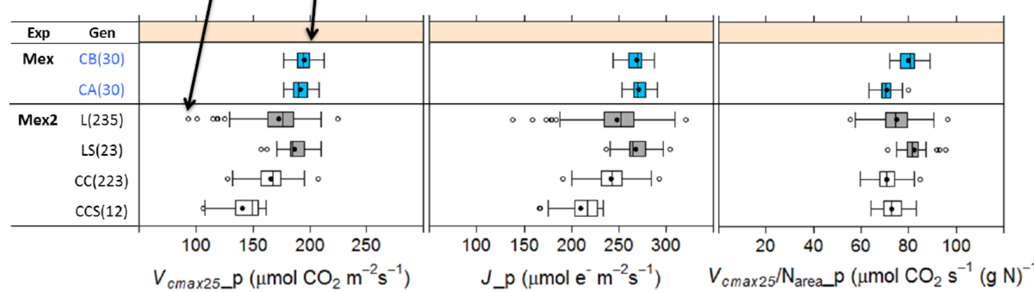


Bigger variation for Landrances than elite wheat genotypes



Silva-Perez, Molero et al., 2018, JXB

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iv. Evaluate diverse genotypes for Rubisco capacity and efficiency using high-throughput tools

Use of spectral reflectance at leaf level

HiBAP, 2 years

FieldSpec3 (350-2500nm)

	YLD	TGW	HI	BM	GM2
Vcmax25	ns	<0.01	ns	<0.05	<0.05
Vcmax25/Narea	ns	ns	ns	ns	ns
J	ns	<0.01	ns	<0.05	<0.01
J/Narea	ns	ns	ns	ns	ns
LMA_O	ns	ns	<0.001	ns	<0.01
Nmass_O	ns	<0.01	ns	ns	<0.01
SPAD_Calc	ns	<0.001	ns	<0.05	<0.01

Silva-Perez, Molero et al., 2018, JXB

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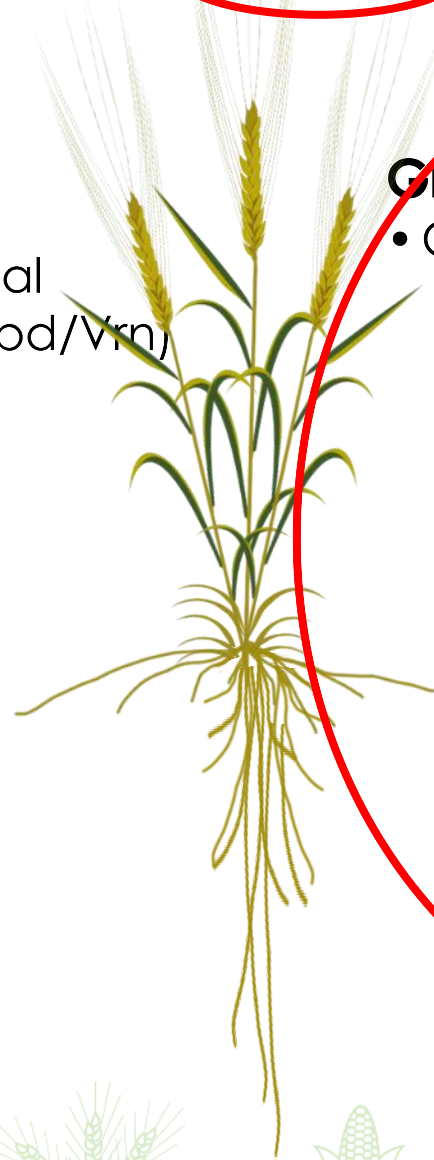
BIOMASS



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  - Rubisco

Adapted from Reynolds et al., 2012

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Use of phenotypic data in physiological Pre-Breeding

- ✓ Genetic Variation
- ✓ Good heritability estimates
- ✓ Correlated with YLD/Biomass (not necessarily)

Use of phenotypic data in physiological Pre-Breeding

Trait	*P (GEN)*	h^2	*r YLD*	*r BM*
A_{sat} InB Flag leaf	***	0.65	0.227	0.245
A_{sat} A+7 Flag leaf	***	0.38	**0.540**	**0.450**
A_{sat} A+7 Spike†	**	0.72	0.287	0.354
Spike Photo contribution	***	0.66	-0.204	-0.133
RUEpre-gf	***	0.54	0.28	**0.602**
RUEgf	**	0.62	**0.587**	**0.803**
Biomass at InB	***	0.90	0.085	**0.391**
Biomass at A+7	***	0.54	0.003	**0.340**
Biomass at PM	***	0.74	**0.709**	-

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Strategic crossing

Strategic crossing

Physiology crossing block for drought used to direct crosses

	Drought yield	Biomass anthesis	Canopy temperature depression: vegetat.	Canopy temperature depression: grainfill	Carbon isotope discrim.	Stem carbohydr. transloc.	Water extraction (30-120cm)	Spectral reflectance: RARSa (Chla)	Spectral reflectance: Water Index (WI)
	g/m2	g/m2	°C	°C	(‰)	% stem DW	% of avail.	(au)	(au)
JUN/GEN	338	424	**19.2**	21.8	**-23.1**	13.3	84	0.63	1.108
CROC/AE.SQ.(224)//OPATA	278	510	19.8	22.6	-22.5	**19.1**	79	0.64	1.091
BABAX	**354**	**647**	19.3	22.2	-22.8	13.9	83	0.57	1.12
KLEIN CACIQUE	247	638	20.1	23.3	-22.6	3.4	82	**0.53**	1.120
TIE CHUAN 1	211	407	20.2	22.5	-22.3	14.7	**78**	0.65	1.100
ATTILA	307	536	19.7	22.3	-22.9	16.1	82	0.58	**1.12**
WEEBILL1	348	513	19.3	**21.7**	-22.5	17.5	83	0.63	1.102
Correlation with yield		**0.21**	**-0.74**	**-0.60**	**-0.64**	**0.32**	**-0.62**	**-0.02**	**0.27**

Jun/Gen X Croc/Ae.Sq//Opata

Traits considered for 2019 related with Biomass for increasing Yield Potential

- Biomass/day
- Yield/day
- Biomass
- Leaf photosynthesis
- Spike photosynthesis
- Stomatal conductance, Ci
- Fluorescence
- Vcmax (Rubisco)
- RUEpre-gf, RUEgf, RUE_Total
- BMInB, BM A+7
- Canopy architecture (erect)

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International yield trials data
4th WYCYT (2016/17)

	Clusters based on G x E for yield					
Cluster of sites	C1	C2	C3	C4	C5	**Combined**
Best PT line (t/ha)	4.96^{ns}	5.45*	7.41*	5.89^{ns}	8.05*	**5.44***
Borlaug (t/ha)	5.29	4.46	5.45	5.65	7.28	**5.09**
% over Borlaug	-6.2%	22.3%	36.0%	4.2%	10.6%	**6.9%***

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Thanks!

iv. Screen lines for flag leaf and spike photosynthesis