Photosynthesis, Plant Acclimation & Crop Productivity

N. Huner,

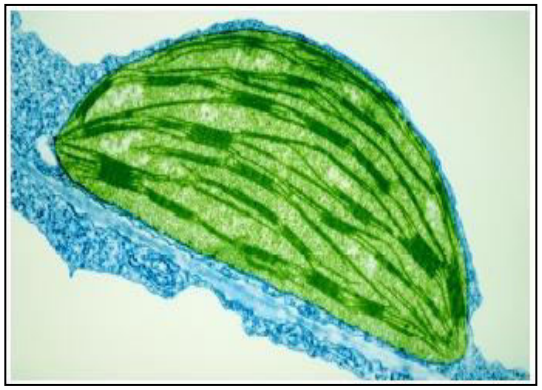
Dept. of Biology & Biotron Centre for Experimental Climate Change Research

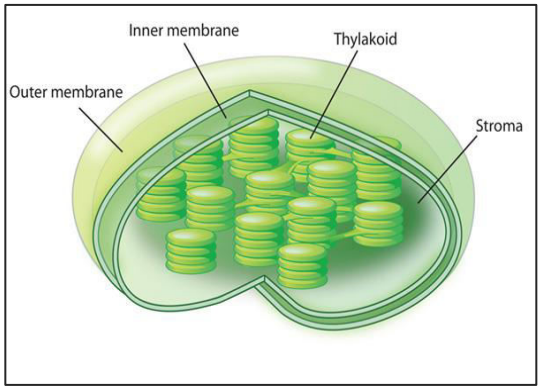
SUMMARY

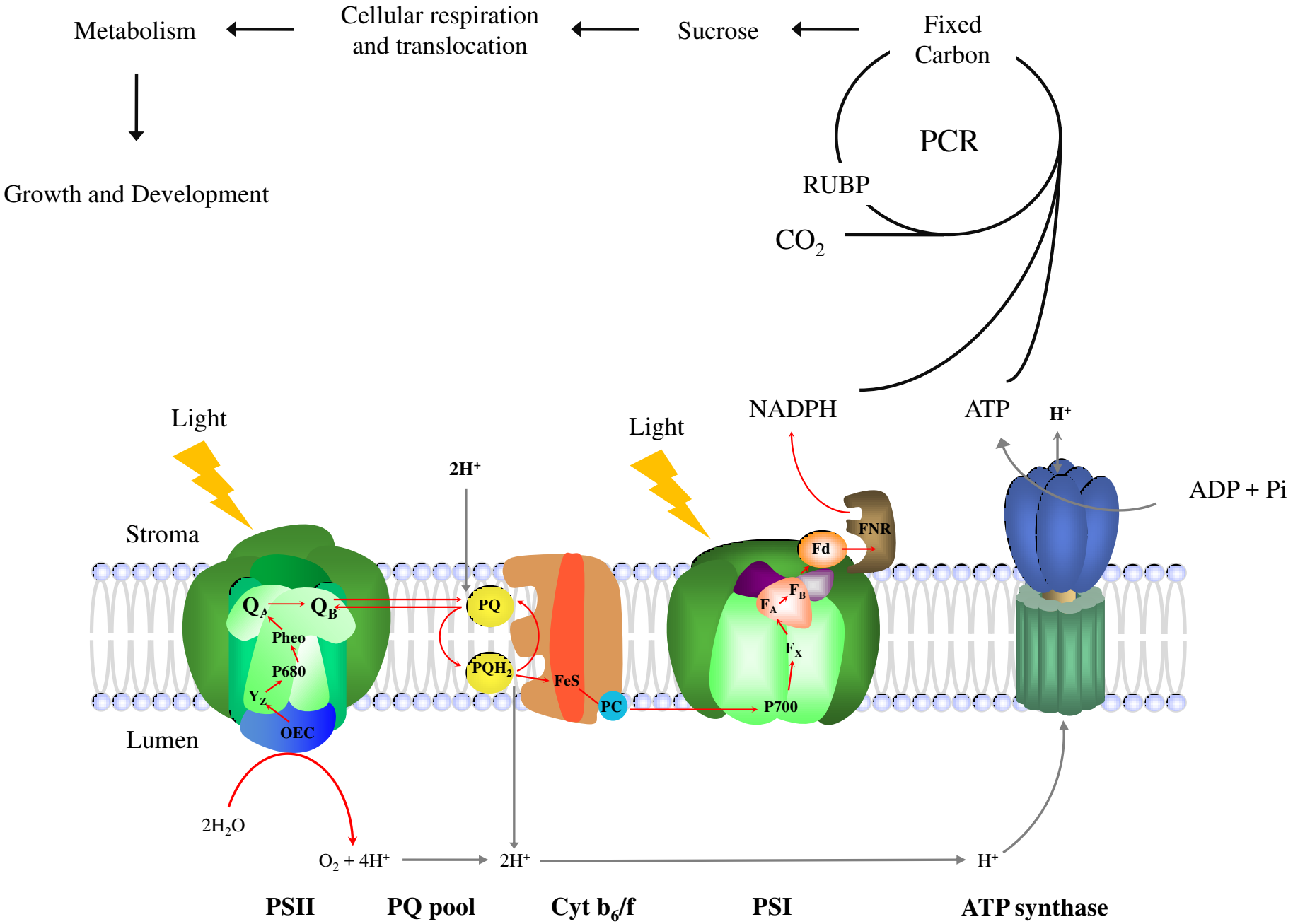
1. Photosynthesis and Energy Conversion
2. Acclimation & Photosynthetic Performance
3. CBFs, Dwarf Phenotype & Photosynthetic Performance
4. Seed Yields: Controlled Environments vs the Field
5. Future Experiments

PHOTOSYNTHESIS & SOLAR ENERGY CONVERSION

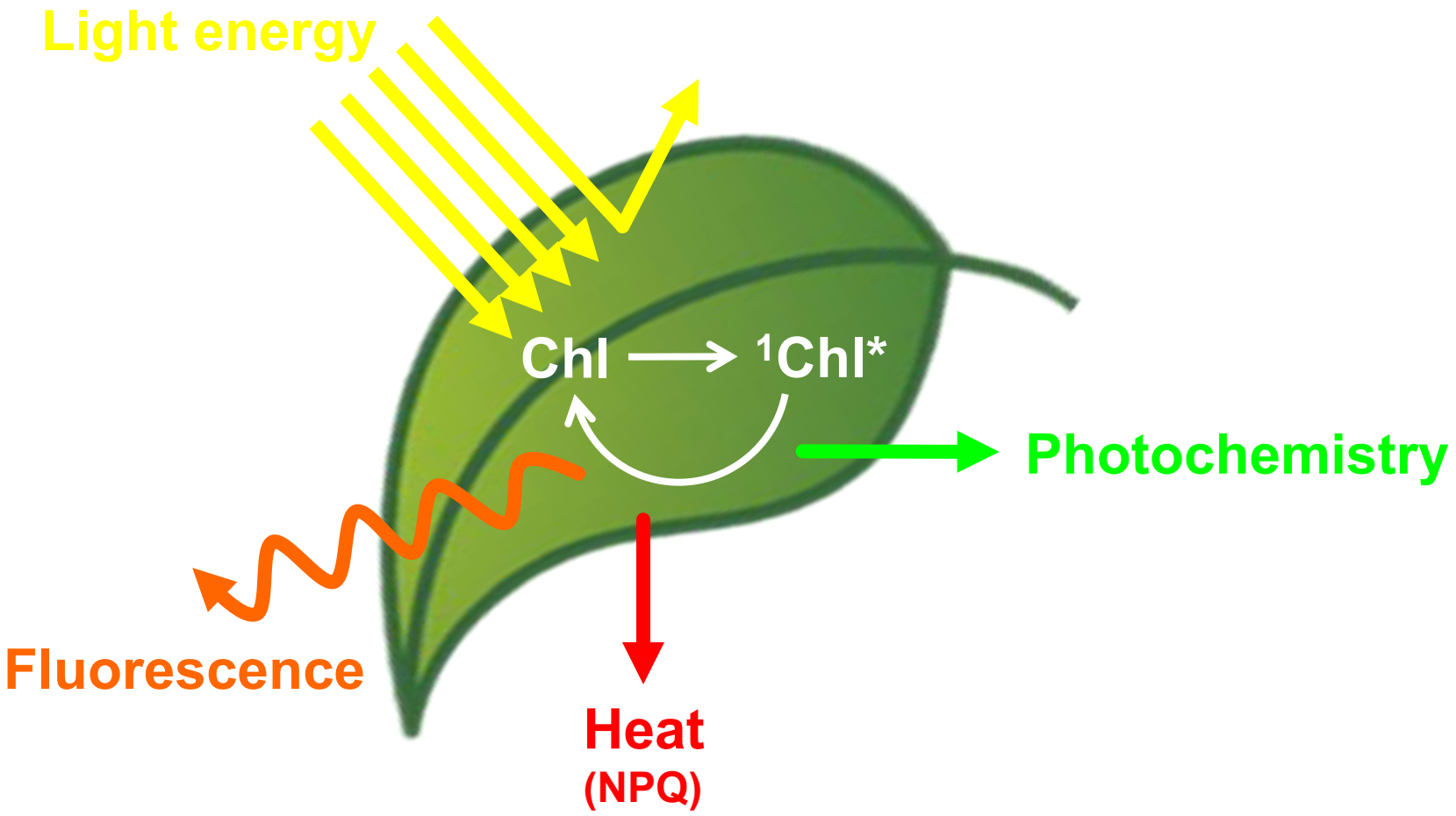
The Chloroplast



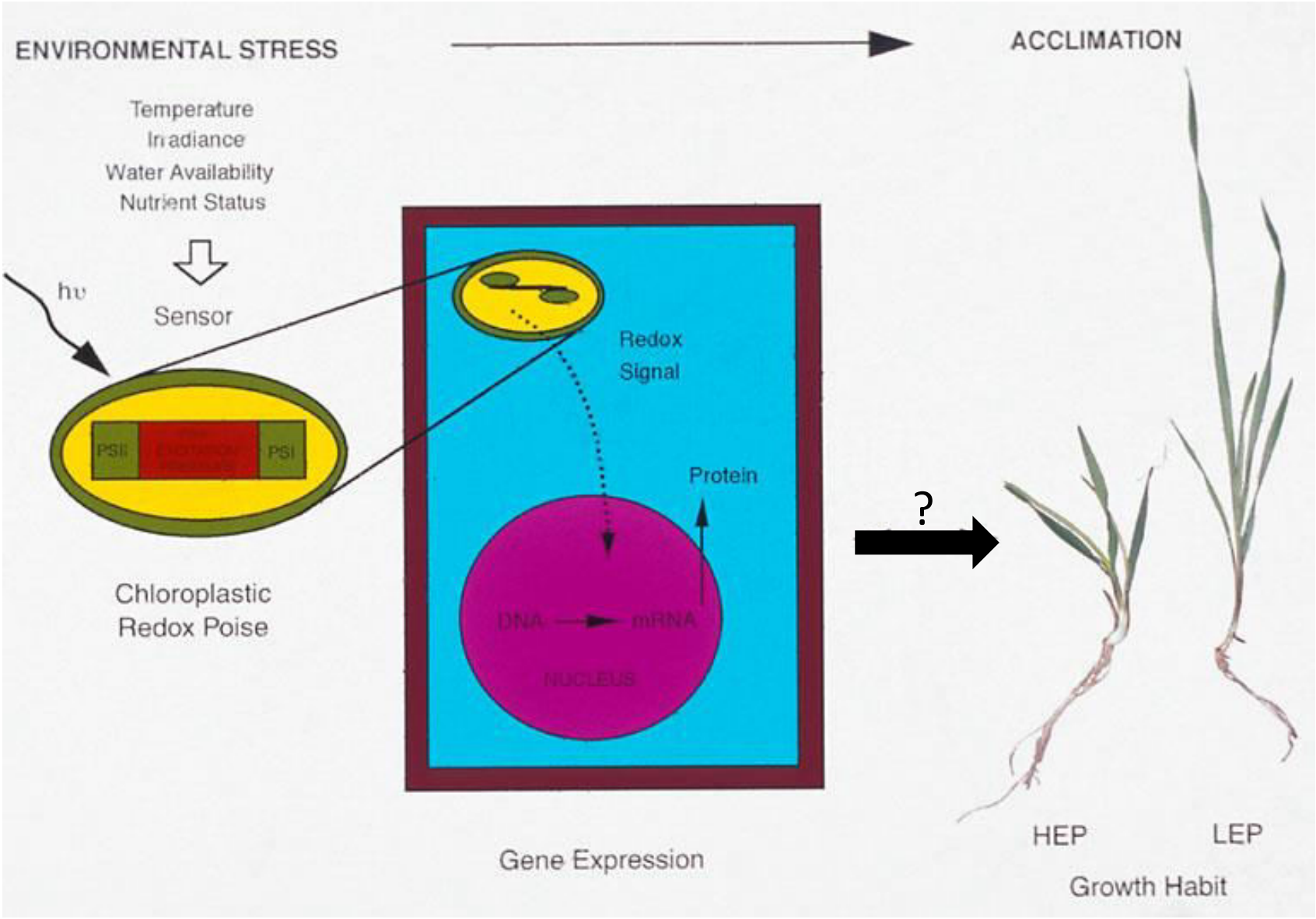



Metabolism
Cellular respiration and translocation
Sucrose
Fixed Carbon
PCR
RUBP
CO_2
Growth and Development
Light
Light
NADPH
ATP
H^+
ADP + Pi
Stroma
$2H^+$
FNR
Fd
F_B
F_A
F_X
Q_A
Q_B
PQ
Pheo
P680
Y_Z
OEC
PQH_2
FeS
PC
P700
Lumen
$2H_2O$
$O_2 + 4H^+$
$2H^+$
H^+
PSII
PQ pool
Cyt b_6/f
PSI
ATP synthase

Fate of absorbed light energy

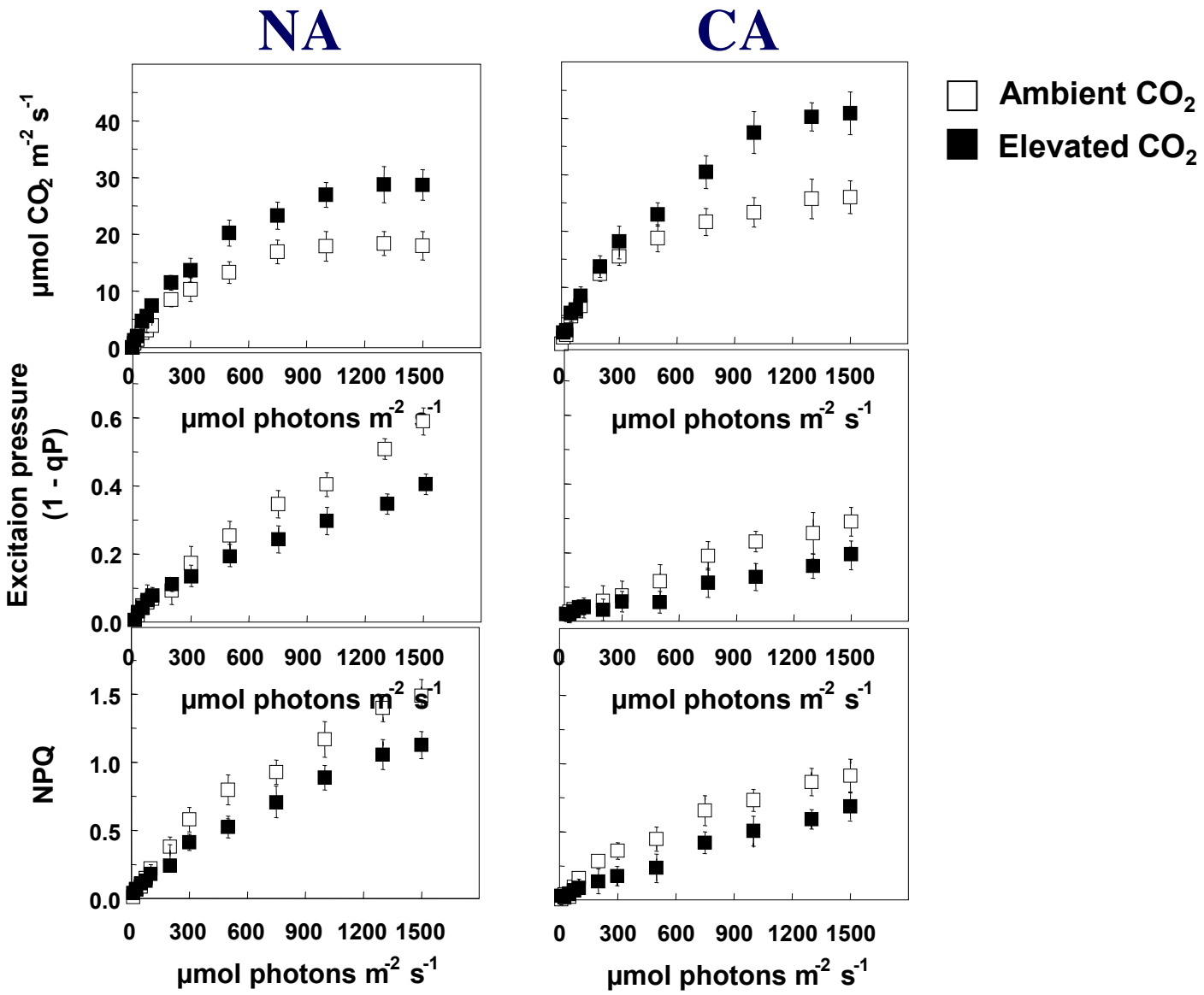


PHOTOSYNTHESIS, ACCLIMATION AND DWARF PHENOTYPE



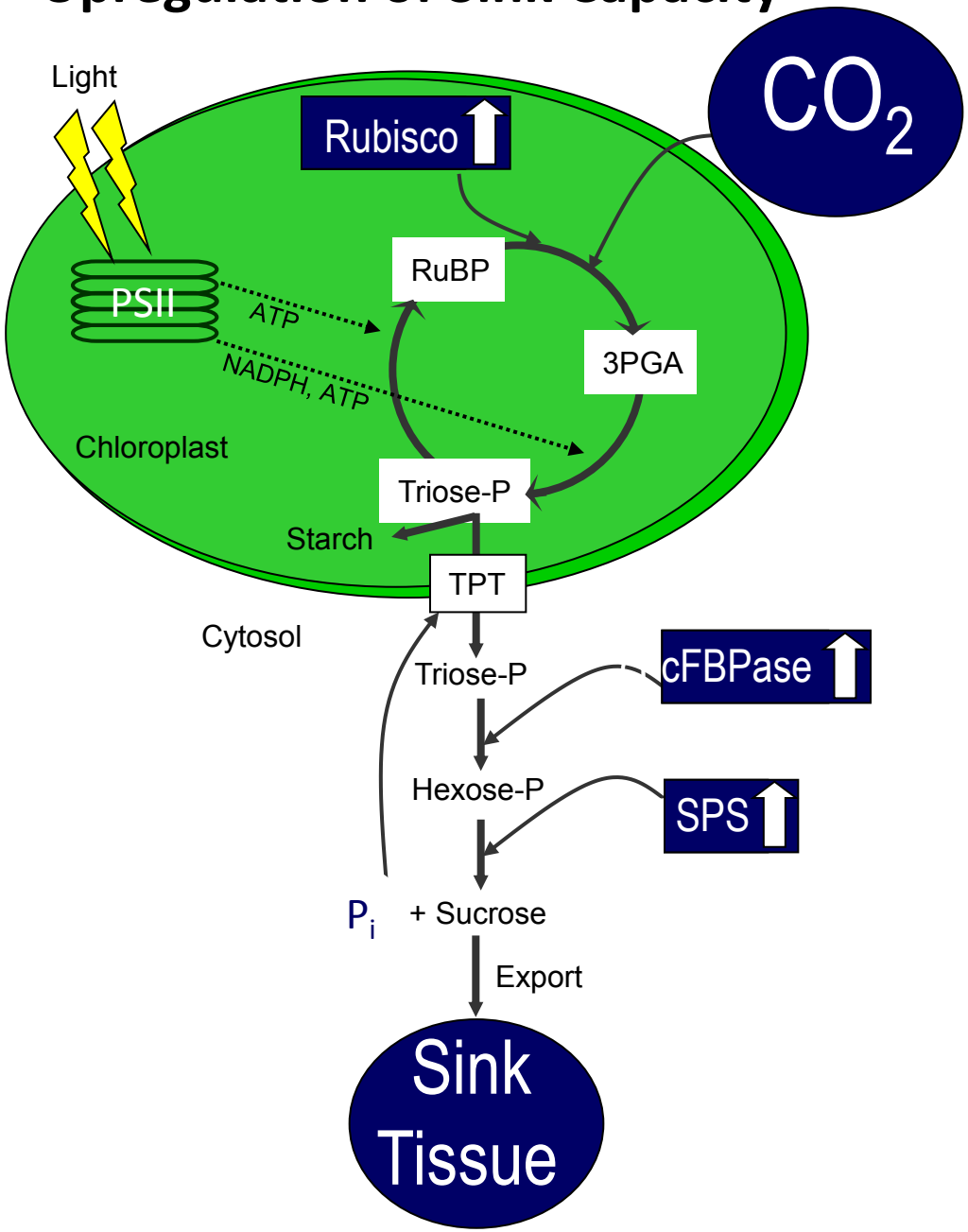
Huner et al. (1998)

LIGHT RESPONSE CURVES: WINTER RYE



Dahal et al. 2012

Upregulation of Sink Capacity

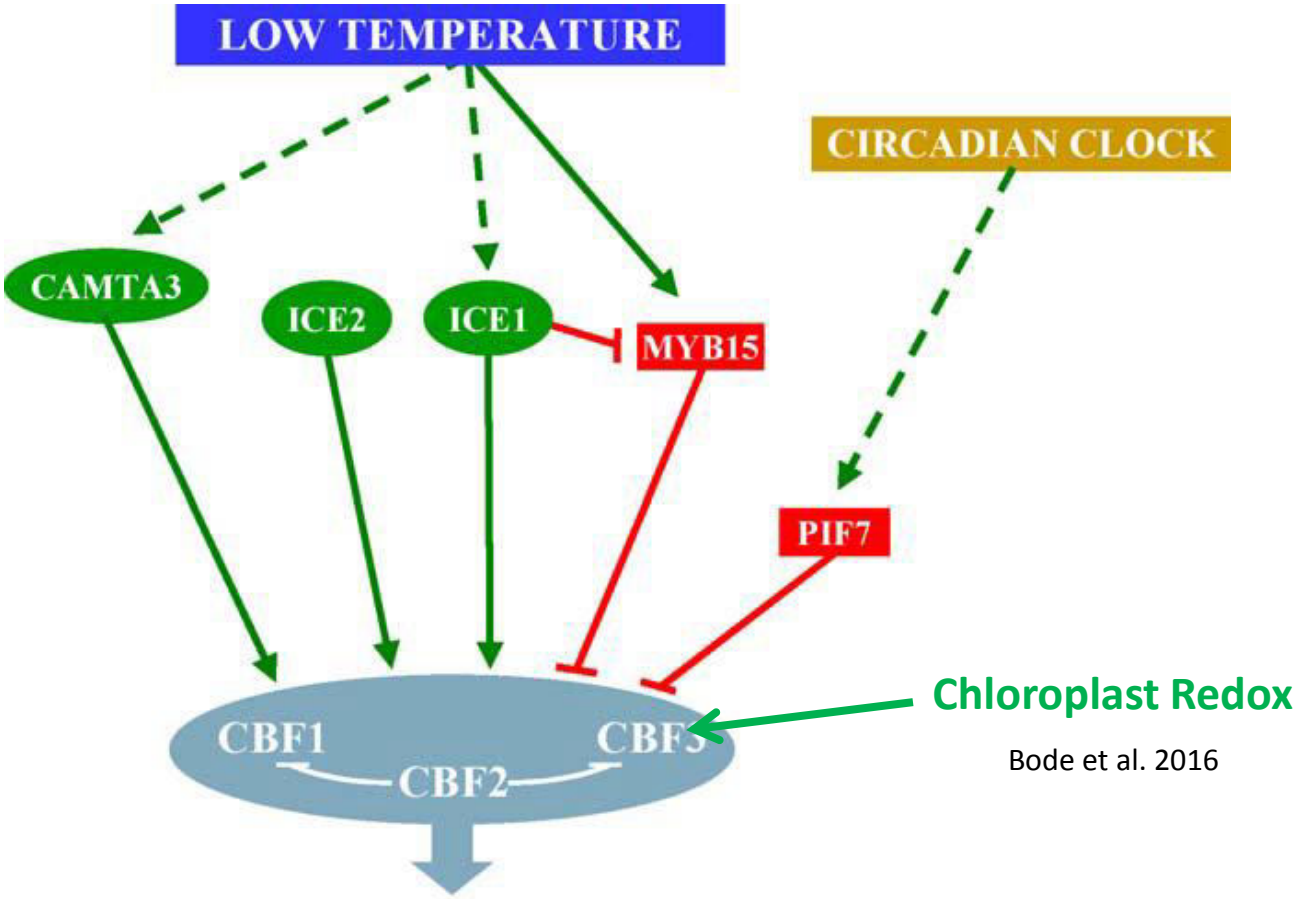


Hurry
Strand et al. 1997
Stitt & Hurry 2002
Strand et al. 2003
Ruelland et al 2009

Gray
Gray & Heath 2005

Huner
Savitch et al. 1997
Dahal et al. 2012
Dahal et al 2014
Bode et al. 2015

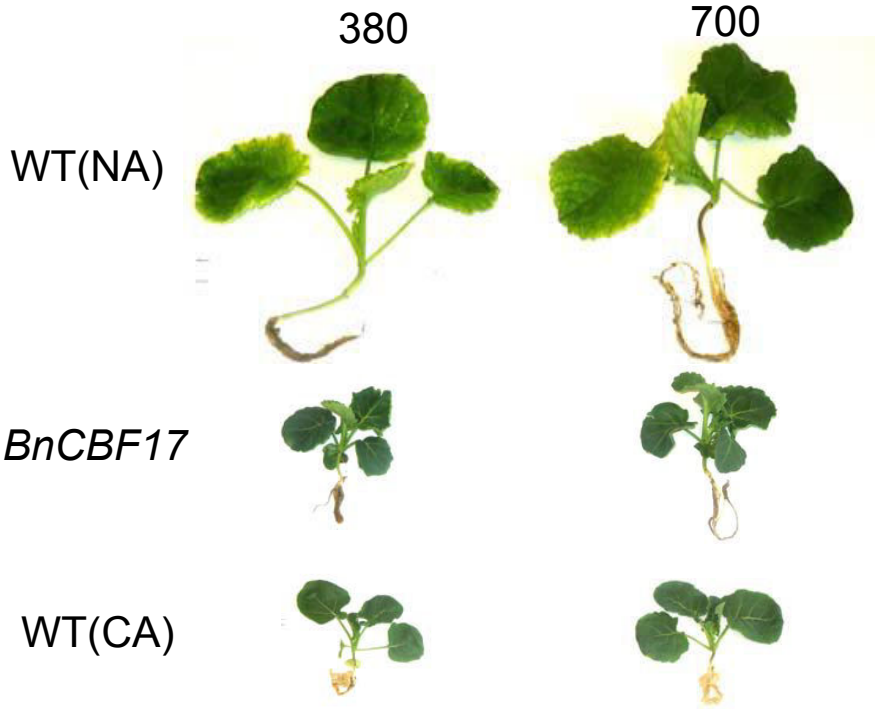
CBFs, COLD ACCLIMATION & THE DWARF PHENOTYPE

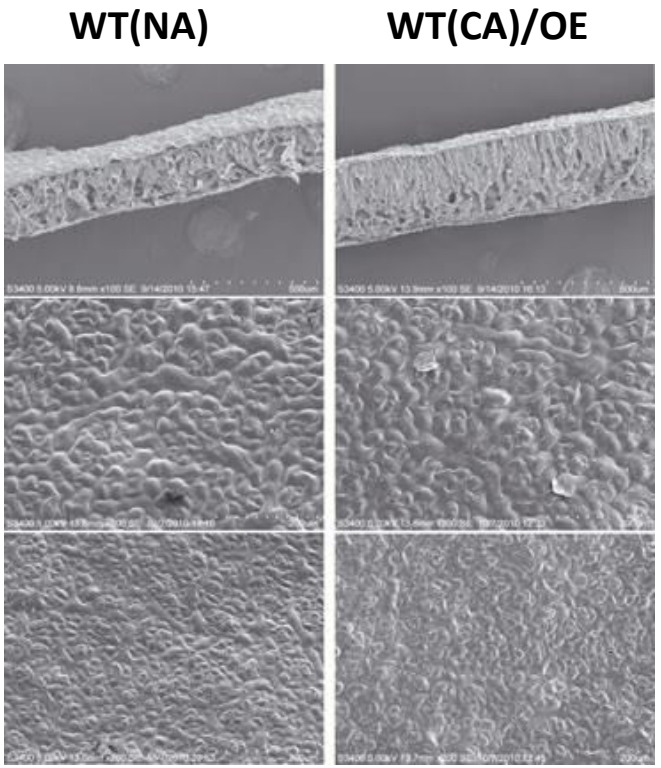


Medina et al. 2011
Lee et al. 2012

CBFs, COLD ACCLIMATION, PHOTOSYNTHESIS & PHENOTYPE

Brassica napus Phenotypes



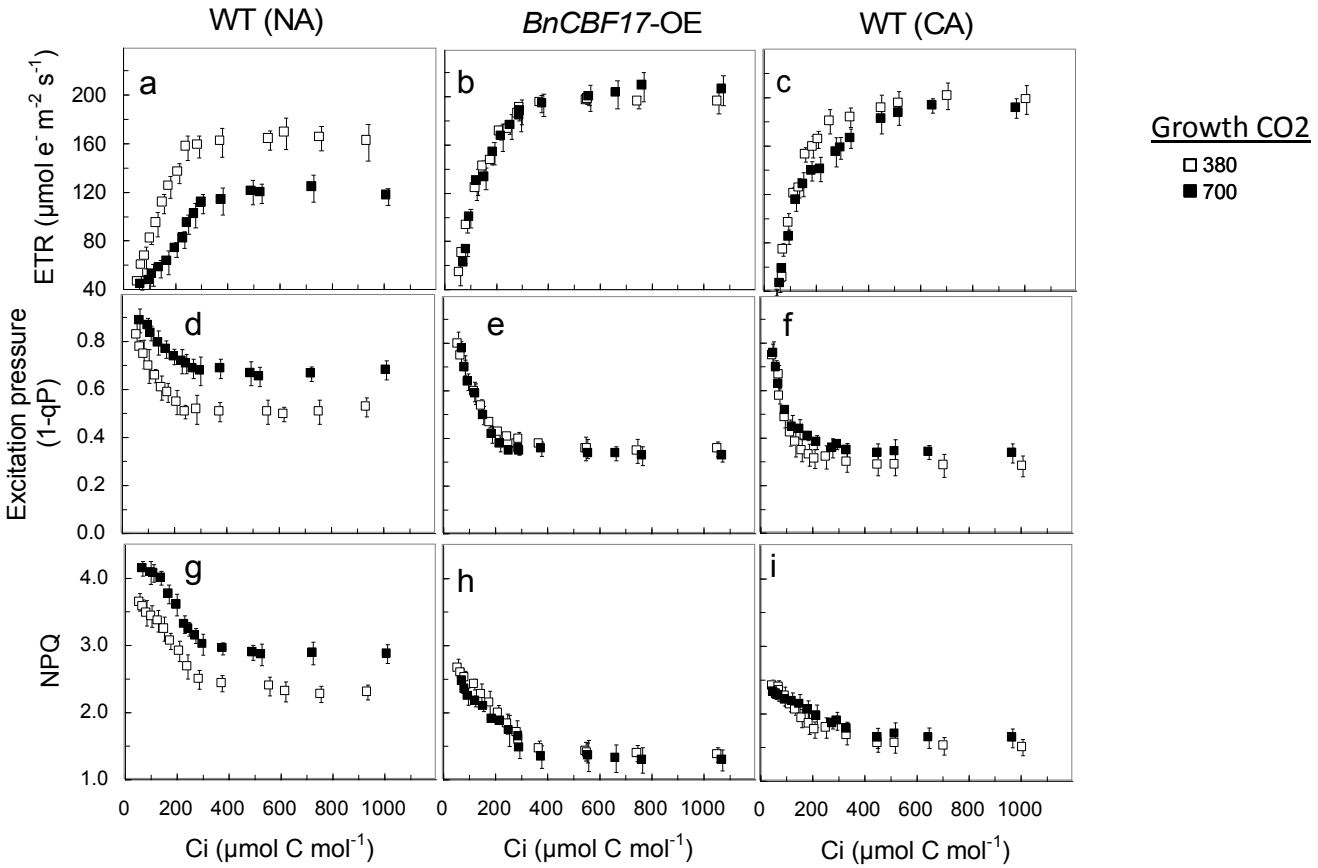


Yamaguchi-Shinozaki & Shinozaki 1994
Thomashow 1999
Gilmour et al. 2000

Savitch et al. 2005
Dahal et al. 2012

CBF-OE MIMICKS PHOTOSYNTHETIC PERFORMANCE

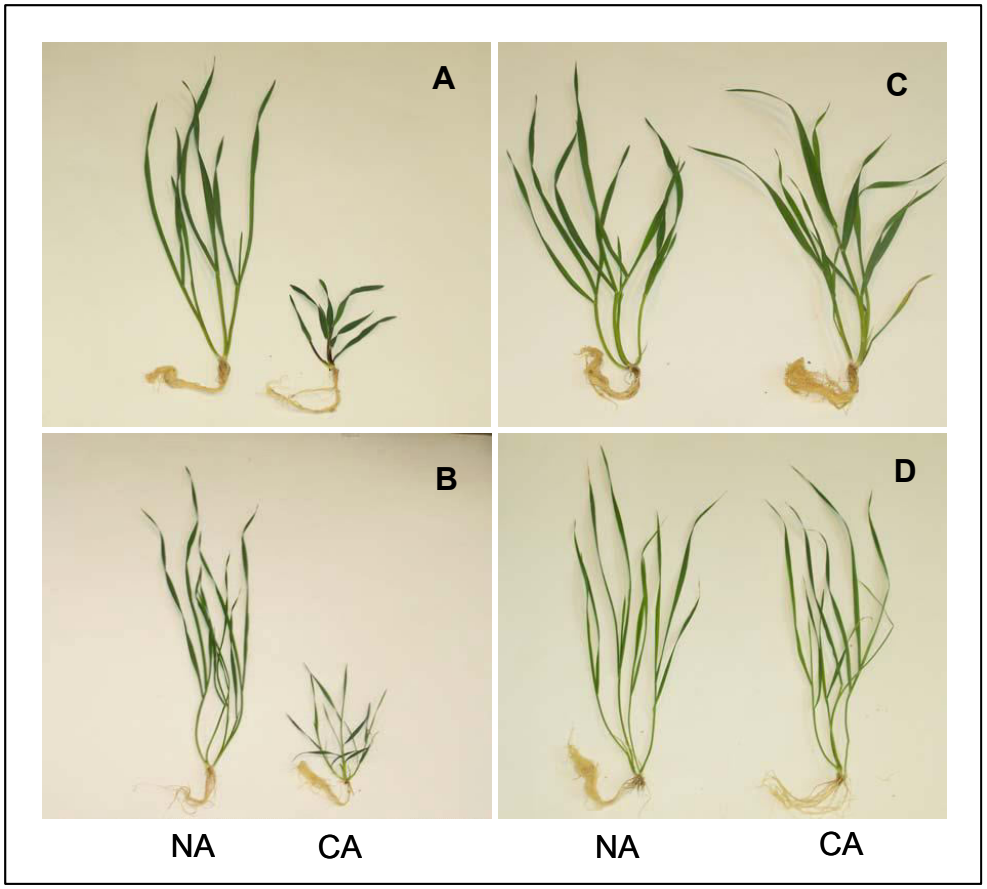
CO2 RESPONSE CURVES: ENERGY UTILIZATION



Dahal et al. 2012

WHAT ABOUT SEED YIELD?

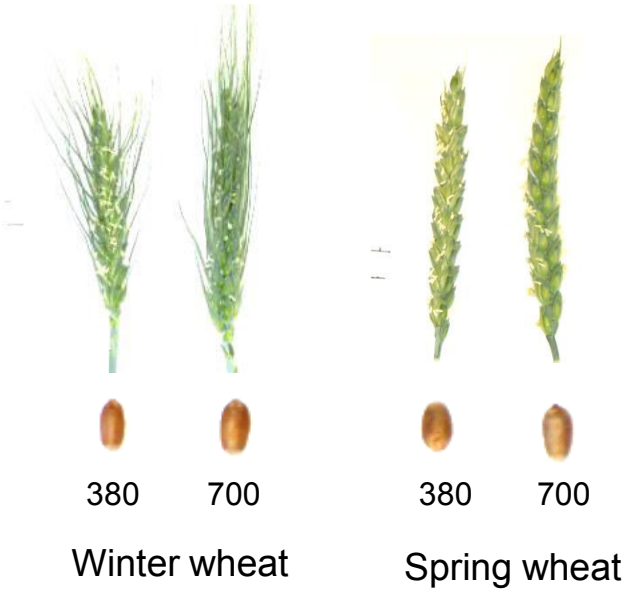
WINTER vs SPRING PHENOTYPES



Dahal et al. 2012

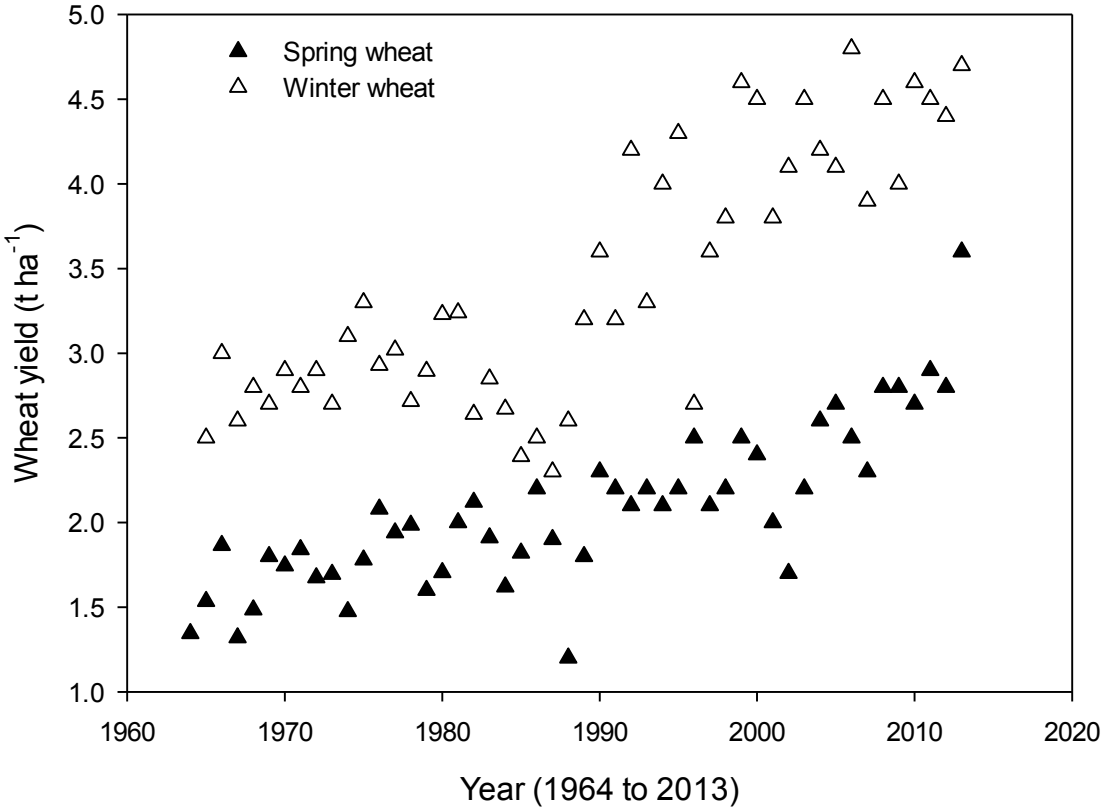
WINTER vs SPRING PRODUCTIVITY: CONTROLLED CONDITIONS

Cultivar	Growth CO2	Tillers/Plant	Panicles/Plant	Seeds/Panicle	Seed Yield (g/plant)
Winter	380	15 +/- 2	12 +/- 2	30 +/- 3	**9.2 +/- 1.2**
	700	21 +/- 2*	17 +/- 1*	35 +/- 3	**14.8 +/- 2.1***
Spring	380	12 +/- 1	7 +/- 1	34 +/- 2	**6.6 +/- 0.4**
	700	17 +/- 3*	9 +/- 2	42 +/- 3*	**9.4 +/- 0.9***



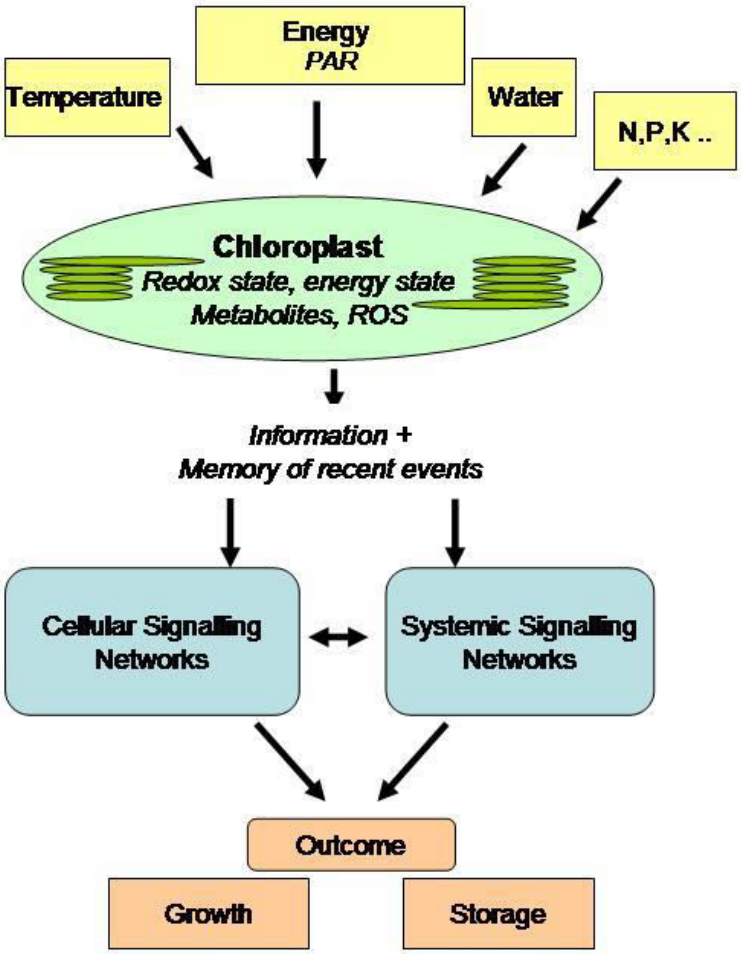
Dahal et al. 2014

YIELDS OF WHEAT IN CANADA: FIELD CONDITIONS



Statistics Canada website:
http://www5.statcan.gc.ca/cansim/pick-choisir

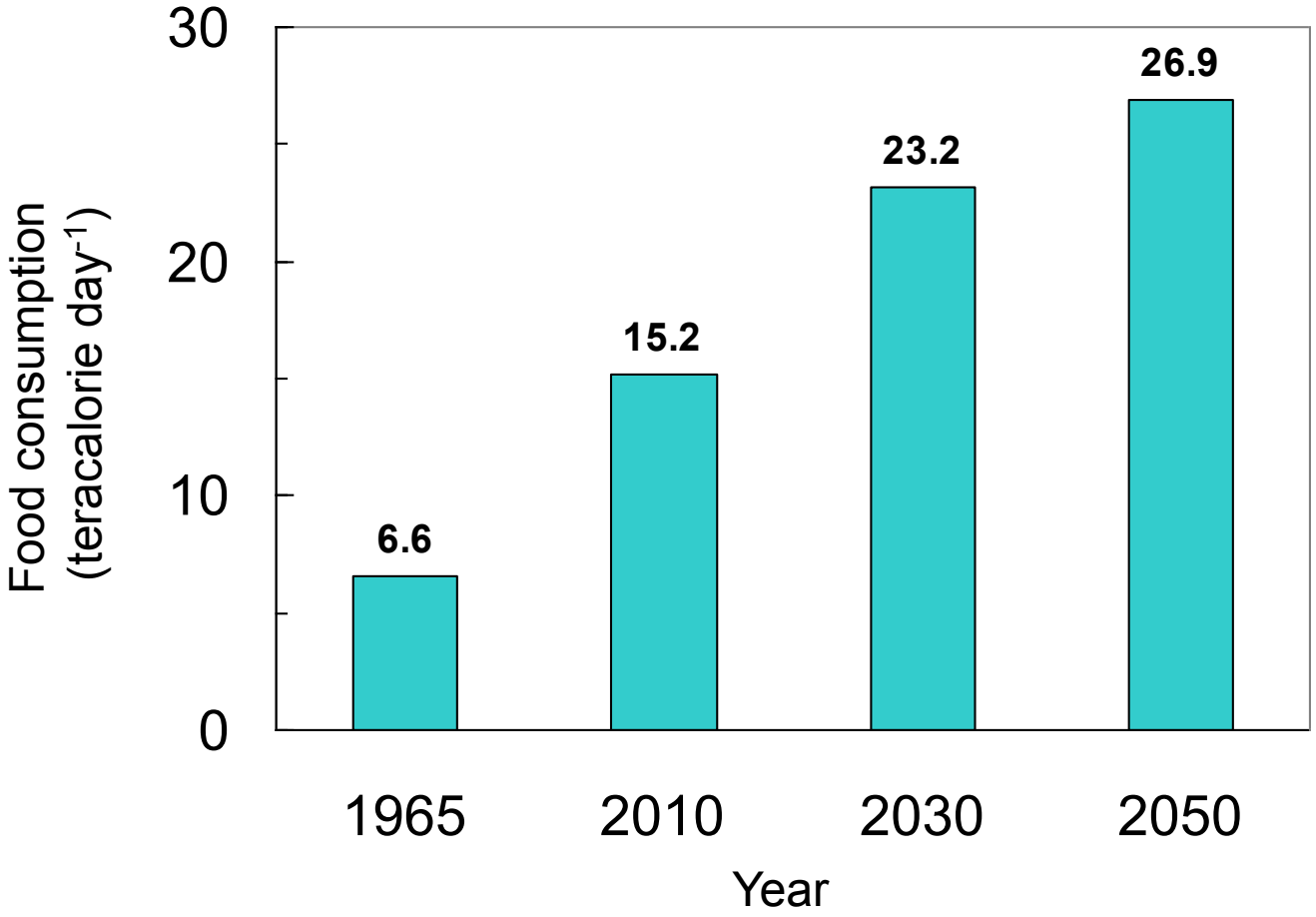
Plant Stress, CBFs & the Grand Design of Photosynthesis



Murchie et al. 2009

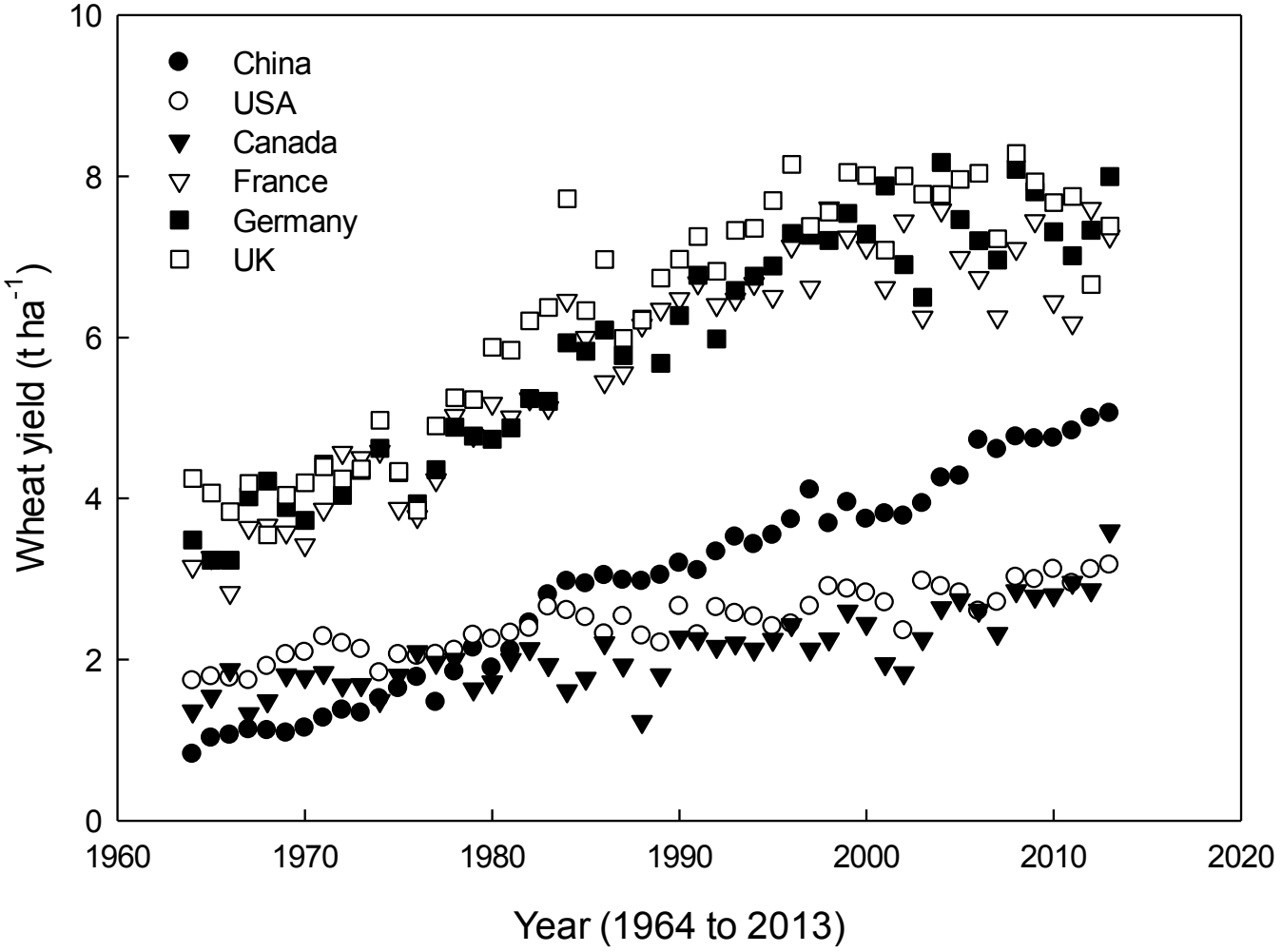
Arnon (1982) Sciences
Anderson et al (1995) Photosyn Res
Huner et al (1998) Trends in Plant Sci
Pfannschmidt (2003) Trends in Plant Sci
Brautigam et al. (2009) Plant Cell
Murchie et al (2009) New Phytol
Rosso, Bode et al (2009) Plant Cell
Huner et al (2014) Frontiers in Chem
Dietz (2015) J Exp Bot
Bode et al. (2015) Photosyn Res, in press

Projected World Food Requirements



Murchie et al. 2009

HISTORICAL WHEAT YIELDS



FAOSTAT Database

FUTURE RESEARCH

THE BIOTRON EXPERIMENTAL CLIMATE CHANGE RESEARCH CENTRE



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UQAM
Khalil Kane
Fathey Sarhan

Queens
Bill Plaxton
Vicki Knowles

FINANCIAL AND INFRASTRUCTURE SUPPORT







Canada Foundation for Innovation
Fondation canadienne pour l'innovation

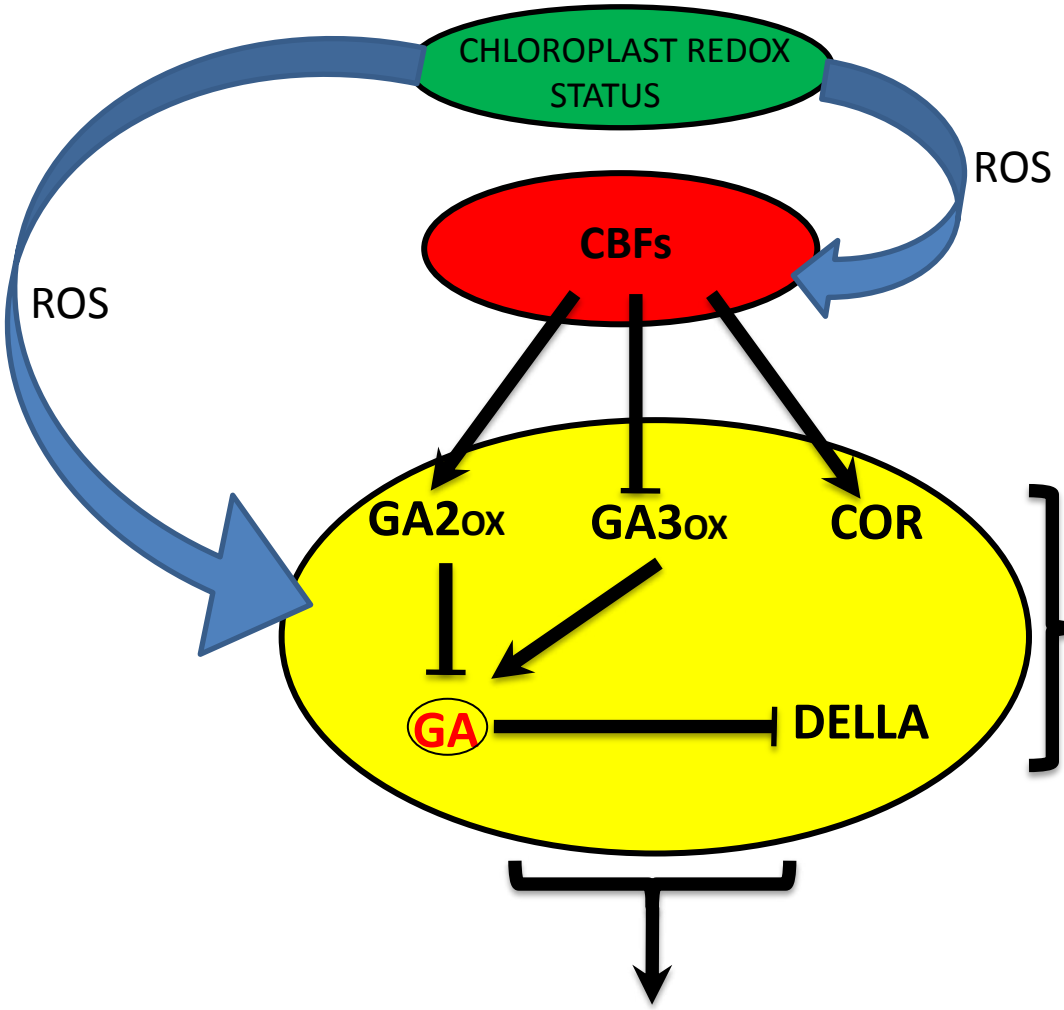








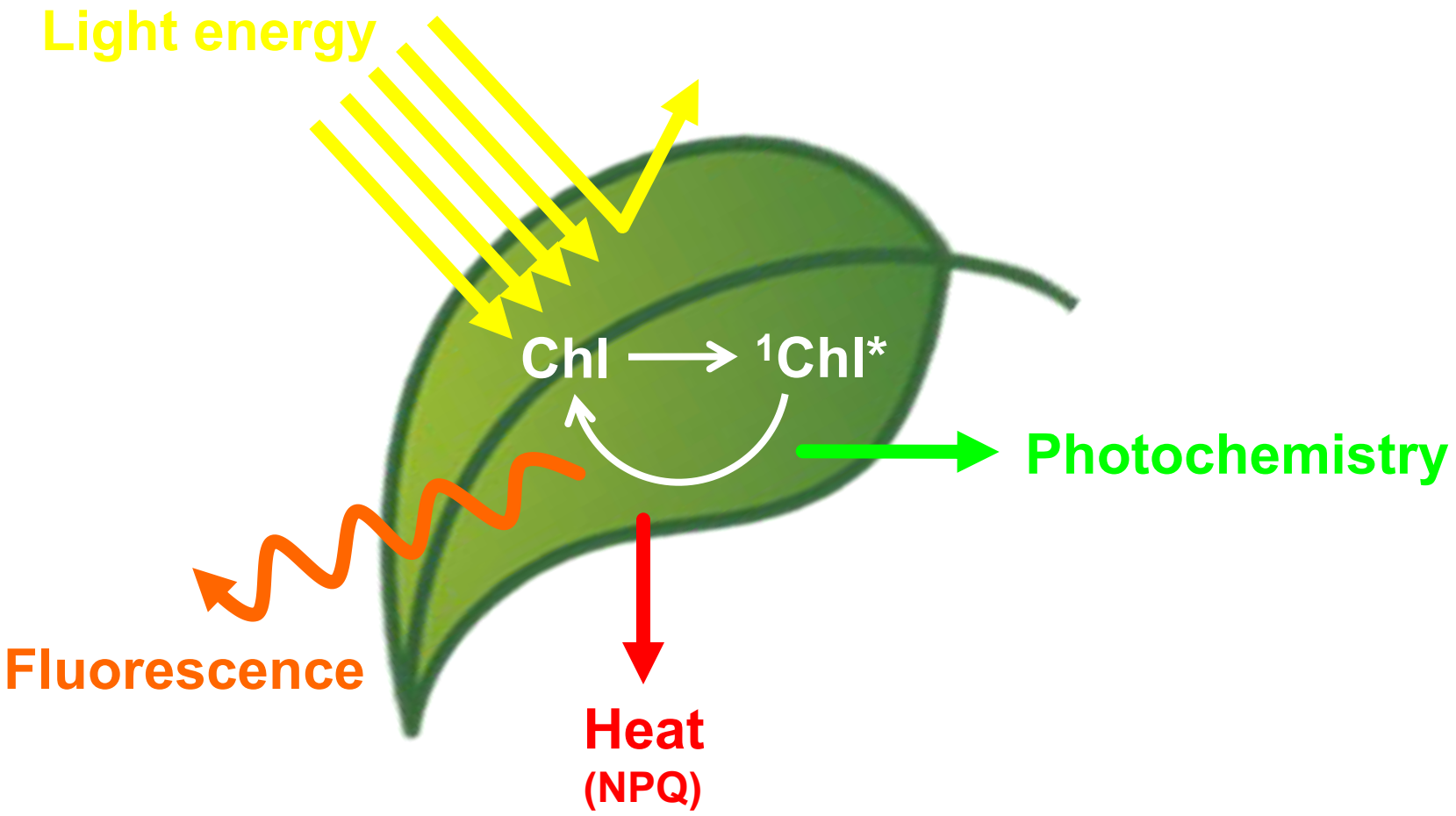
THE CHLOROPLAST, CBFs & THE MAINTENANCE OF CROP PRODUCTIVITY ?



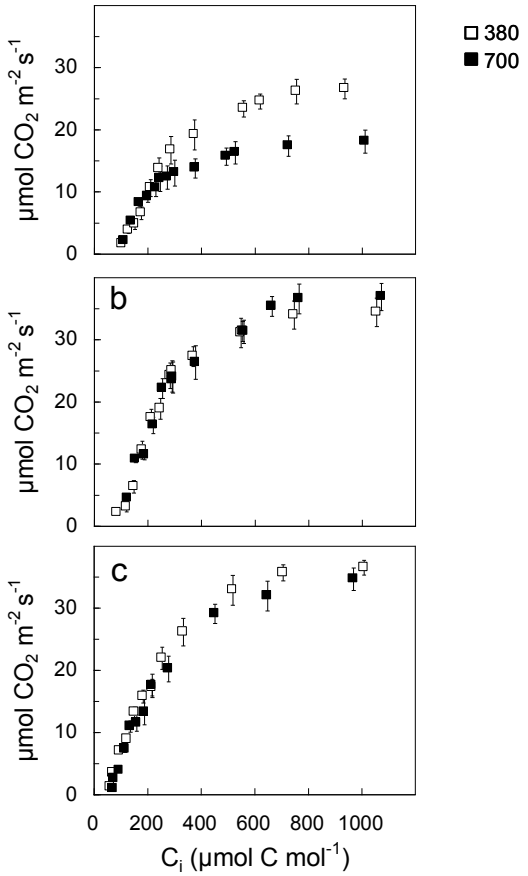
Peng & Harberd (1997) Genes & Dev
Peng et al. (1997) Plant Physiol
Peng et al. (1999) Nature
Hedden (2003) Trends Genetics
Hussain & Peng (2003) J Plant Growth Regulation

Archard et al. 2008
Bode et al. 2015

Fate of absorbed light energy



a


380
700
µmol CO2 m-2 s-1
0
10
20
30
b
c
0
200
400
600
800
1000
Ci (µmol C mol-1)

TEN TOP WHEAT PRODUCERS
(Year 2012)

Country	Million Metric Tons (Yield x Area)
1. China	125.6
2. India	94.9
3. USA	61.8
4. France	40.3
5. Russia	37.7
6. Australia	29.9
7. Canada	27.0
8. Pakistan	23.5
9. Germany	23.5
10. Turkey	20.1

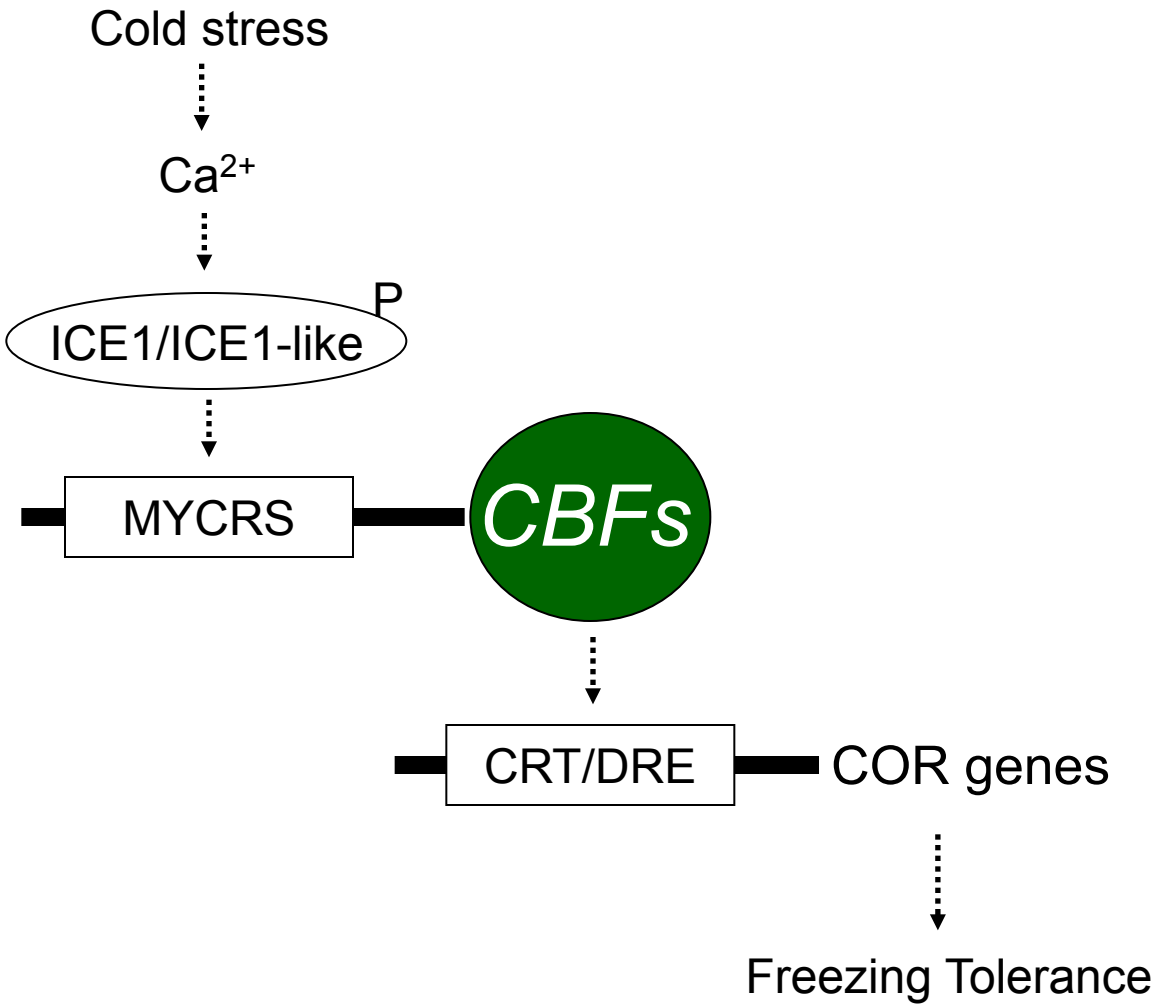
FAOSTAT Database

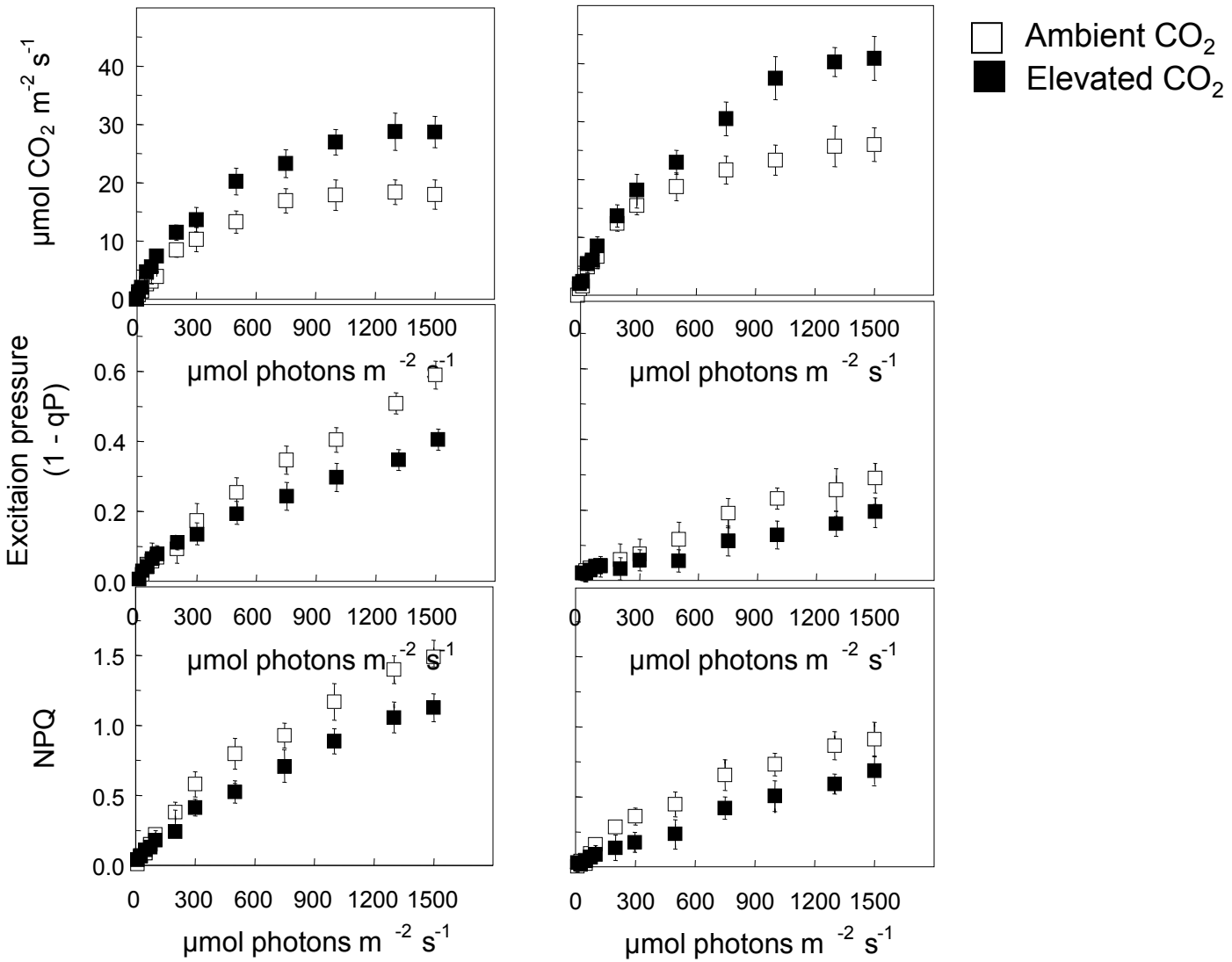
WINTER vs SPRING WHEAT : POTENTIAL GRAIN YIELDS

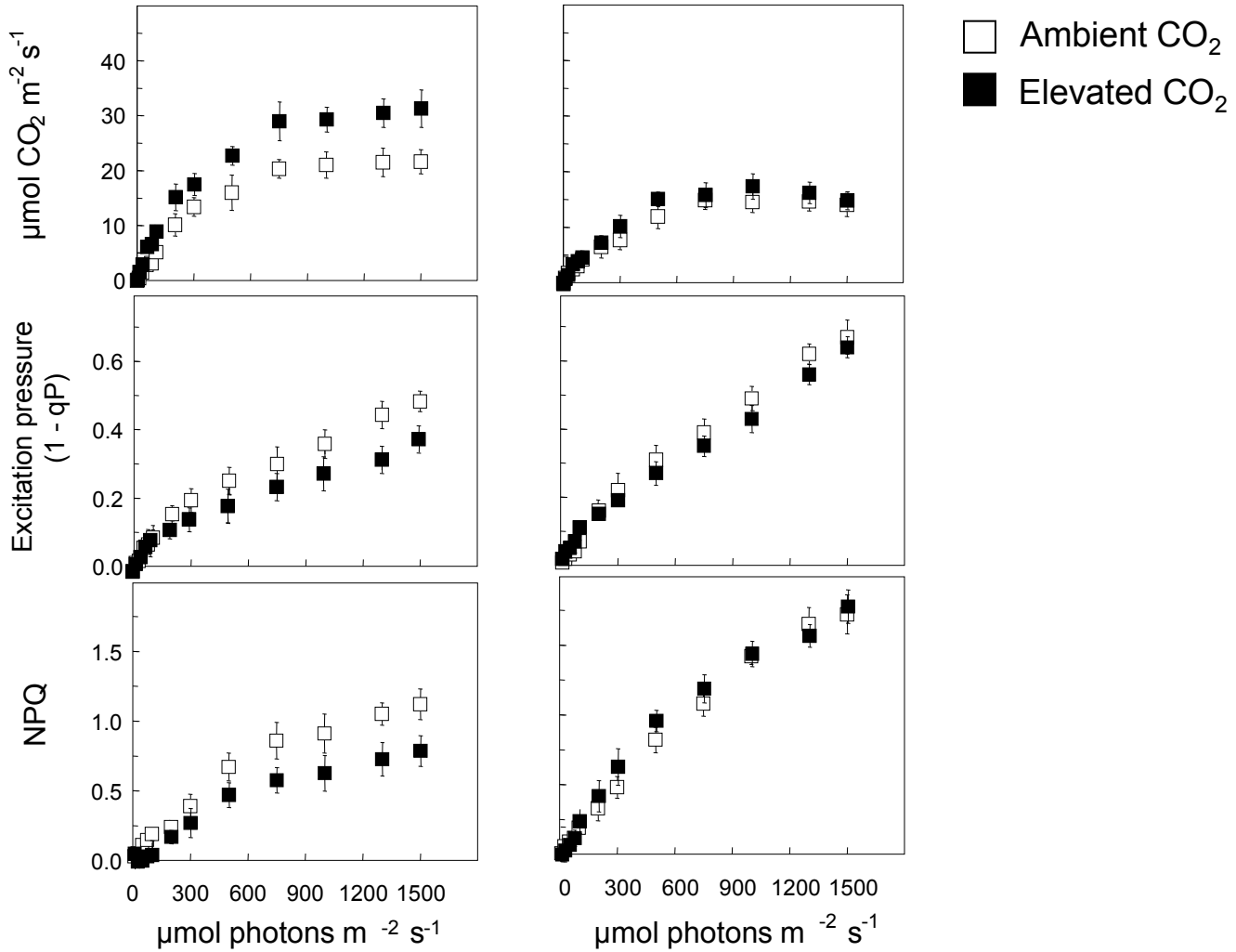
Cultivars	Growth CO_2 (μmol C mol^{-1})	Tiller No. $plant^{-1}$	Effective panicle No. $plant^{-1}$	Grain No. $panicle^{-1}$	Grain yield (g $plant^{-1}$)
Norstar	380	15 ± 2	12 ± 2	30 ± 3	9.2 ± 1.2
	700	21 ± 2*	17 ± 1*	35 ± 2	14.8 ± 2.1*
Katepwa	380	12 ± 1	7 ± 1	34 ± 2	6.6 ± 0.4
	700	17 ± 3*	9 ± 2	42 ± 3*	9.4 ± 0.9*

Growth CO_2 / Temperature	ETR ($\mu mol\ e^-\ m^{-2}\ s^{-1}$)	Respiration rates (μmol C evolved $m^{-2}\ s^{-1}$)	Water use efficiency (A/g_s)
380/NA	153 ± 16^a	2.48 ± 0.12^a	34 ± 5^a
380/CA	218 ± 10^b	3.64 ± 0.27^c	94 ± 12^c
700/NA	158 ± 4^a	2.87 ± 0.16^b	89 ± 14^b
700/CA	207 ± 7^b	3.79 ± 0.22^c	131 ± 19^d

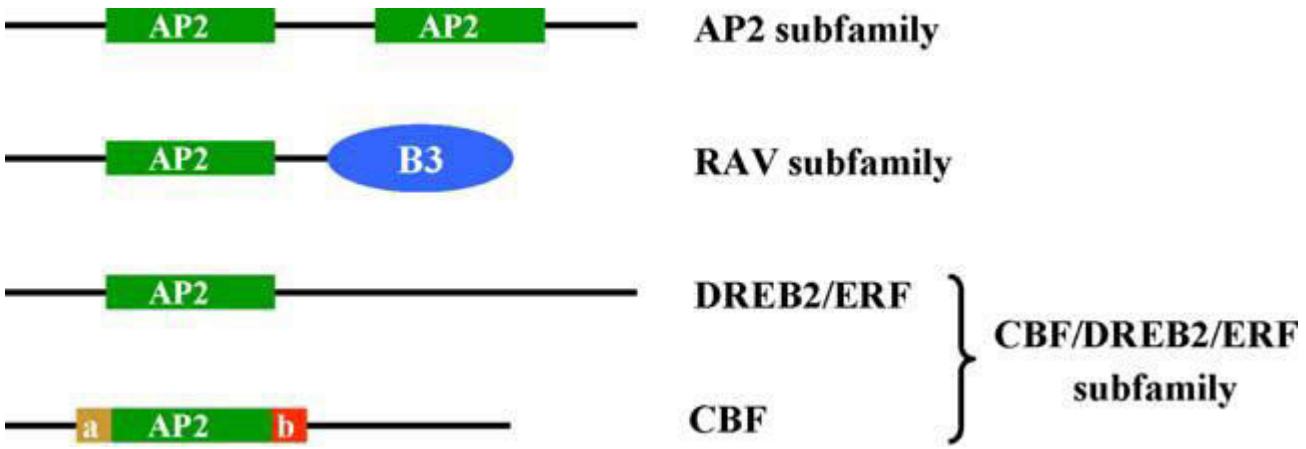
CBFs REGULATE THE *COR* REGULON




Ambient CO_2
Elevated CO_2
µmol CO_2 m^{-2} s^{-1}
Excitaion pressure (1 - qP)
NPQ
µmol photons m^{-2} s^{-1}
0
300
600
900
1200
1500
10
20
30
40
0.0
0.2
0.4
0.6
0.5
1.0
1.5


Ambient CO_2
Elevated CO_2
µmol CO_2 m^{-2} s^{-1}
Excitation pressure (1 - qP)
NPQ
0
10
20
30
40
0.0
0.2
0.4
0.6
0.5
1.0
1.5
0
300
600
900
1200
1500
µmol photons m^{-2} s^{-1}

CBF/DREB2/ERF are subfamilies of the AP2 Family of Transcription Factors



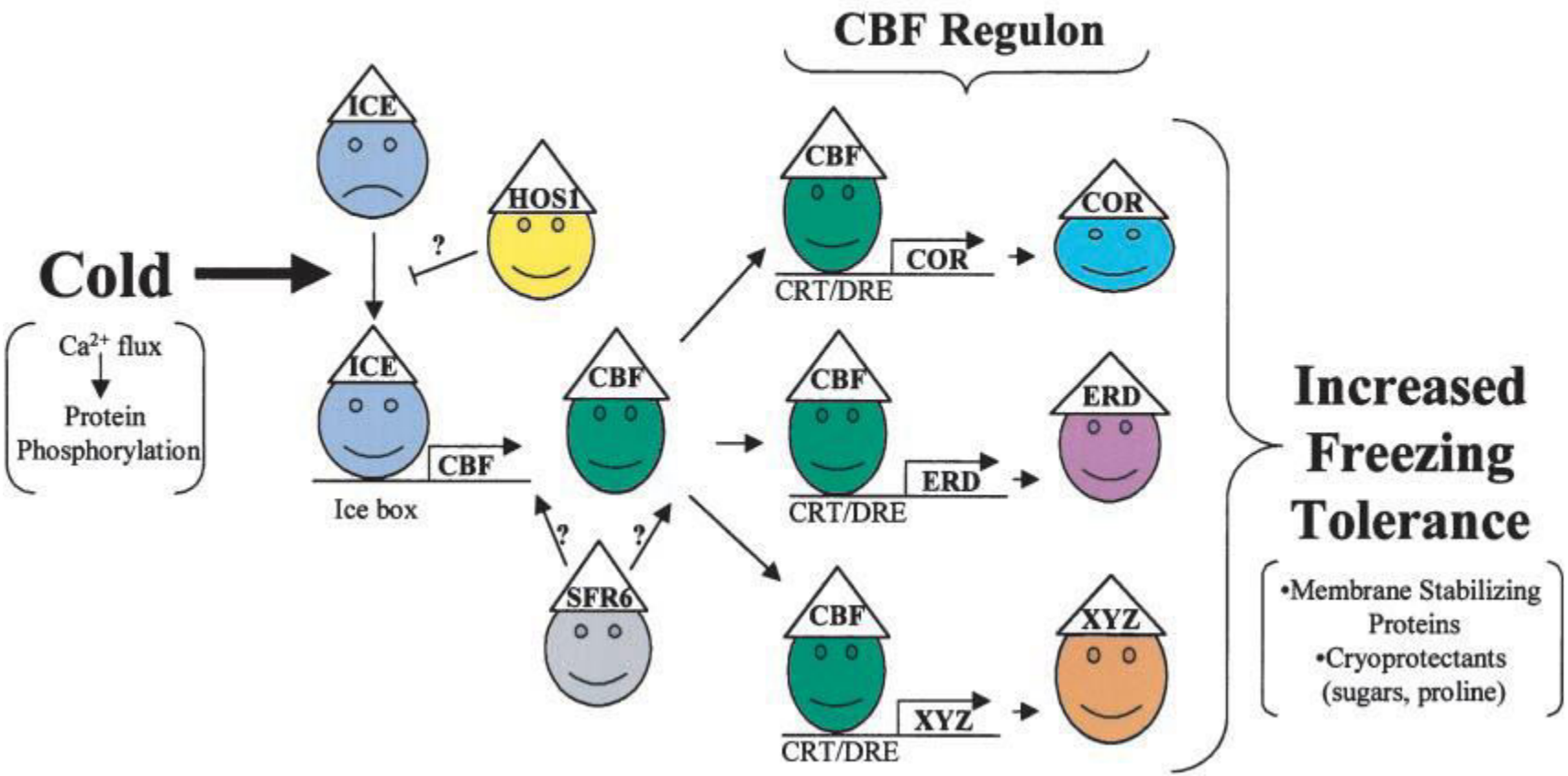
AP2 = AP2/ERF DNA-binding domain.

B3 = B3 DNA-binding domain for RAV.

a and **b** boxes = signature CBF sequences (**PKKPAGR** and **DSAWR**)

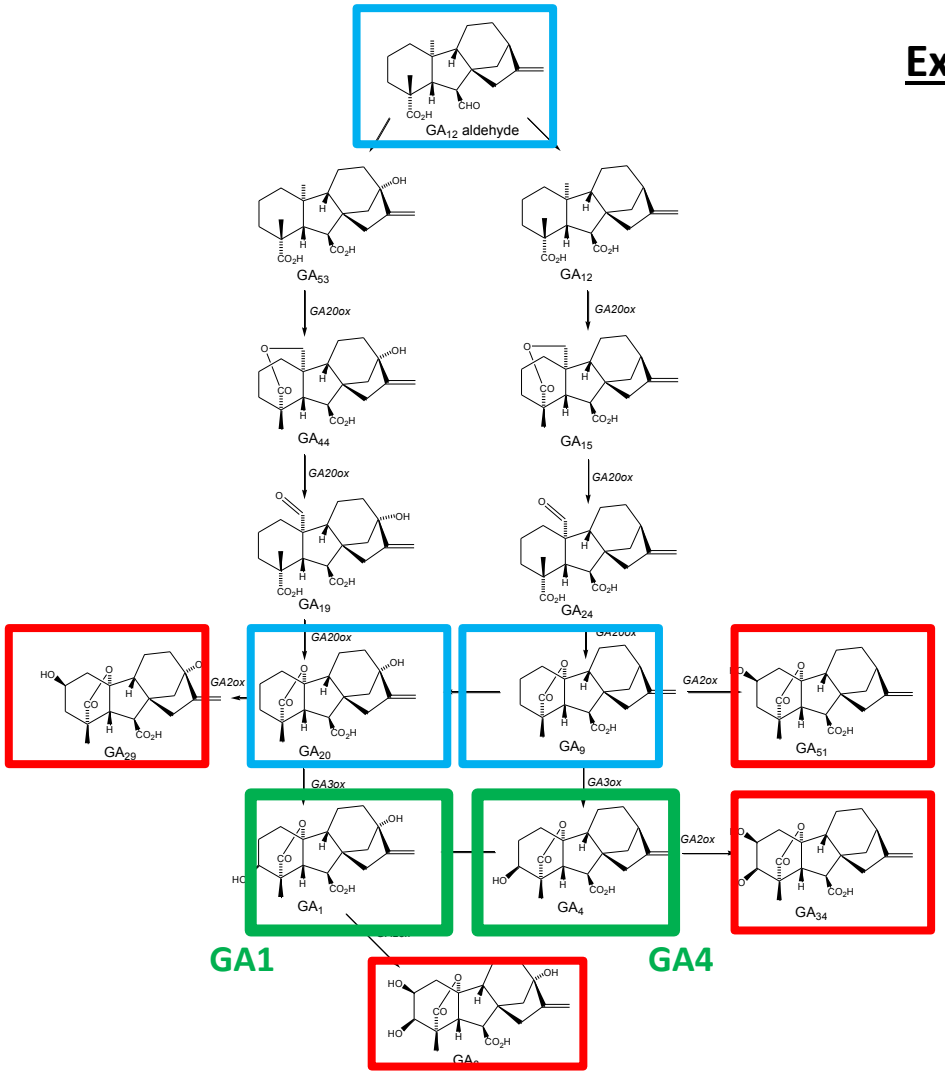
Medina et al 2011

CBF Cold Acclimation Pathway



Thomashow 2001

DWARF PHENOTYPE: CHLOROPLAST REDOX STATUS & GA BIOSYNTHESIS



Excitation Pressure

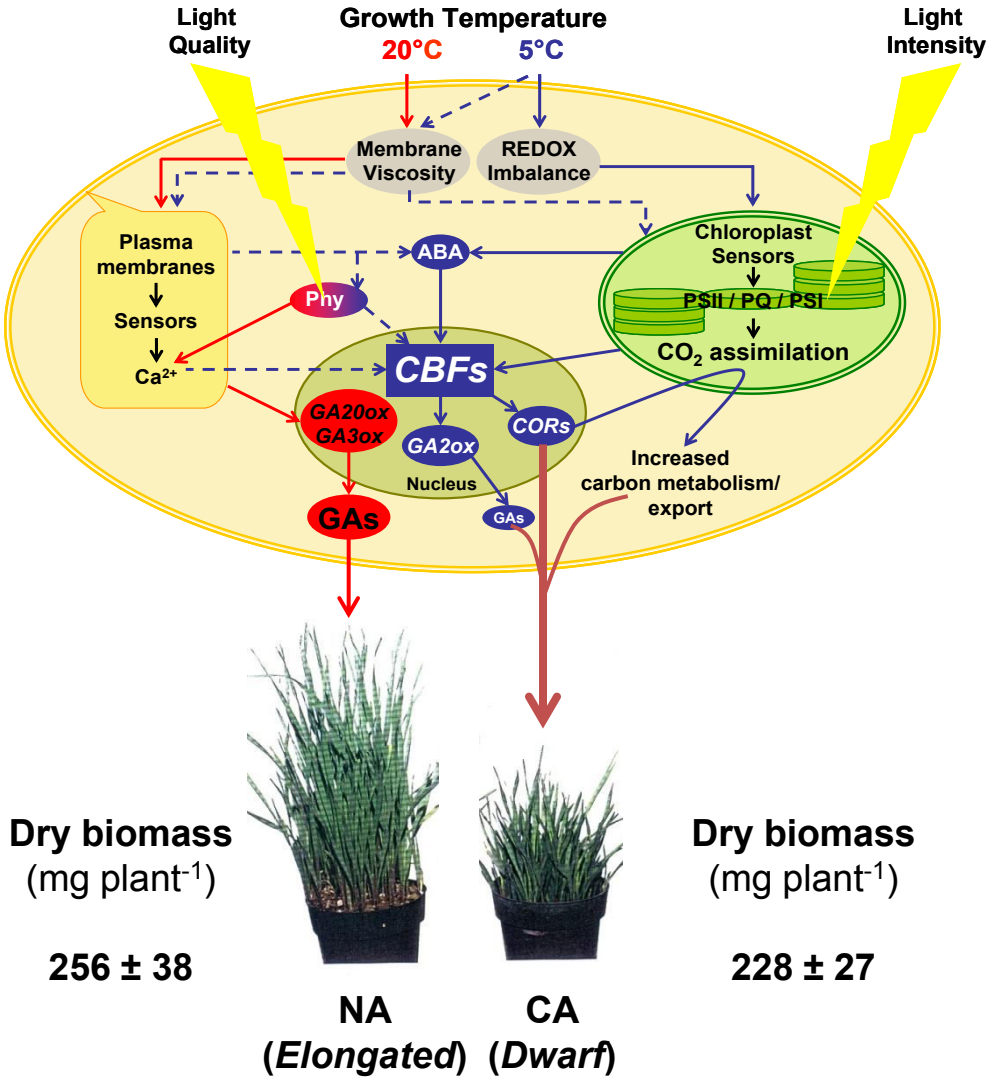
↑ GA2ox

↓ GA3ox

Bode et al. 2015

Archard et al. 2008
Kurepin et al. 2013

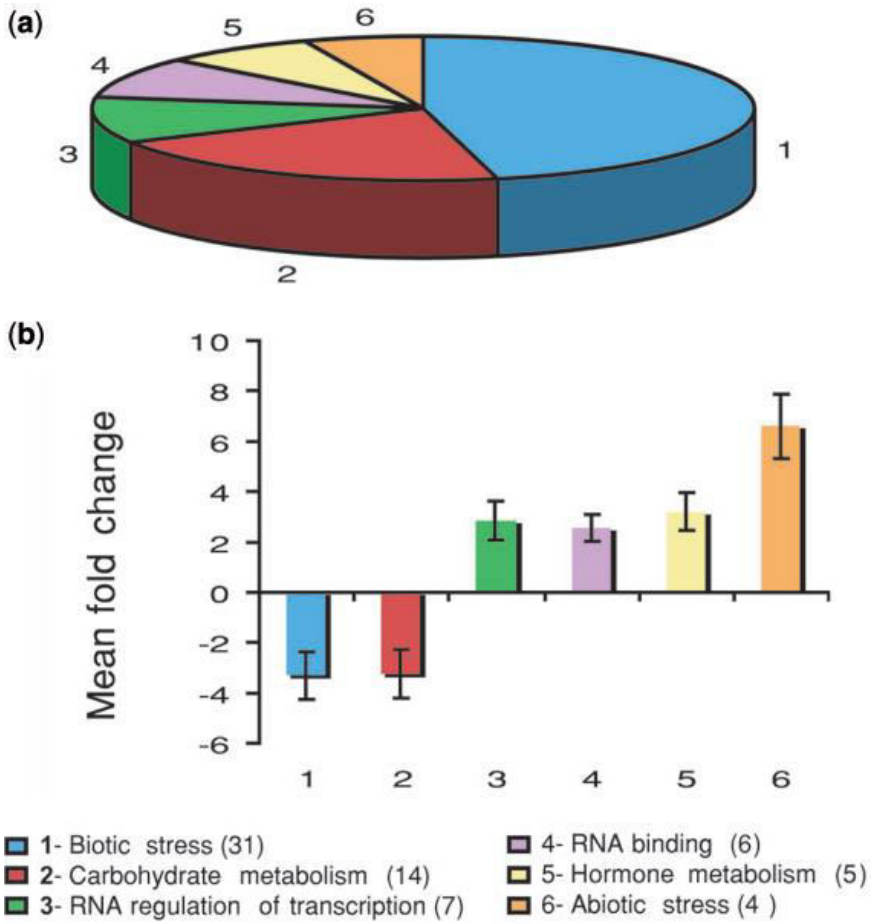
CBFs INTEGRATE MULTIPLE REGULATORY NETWORKS



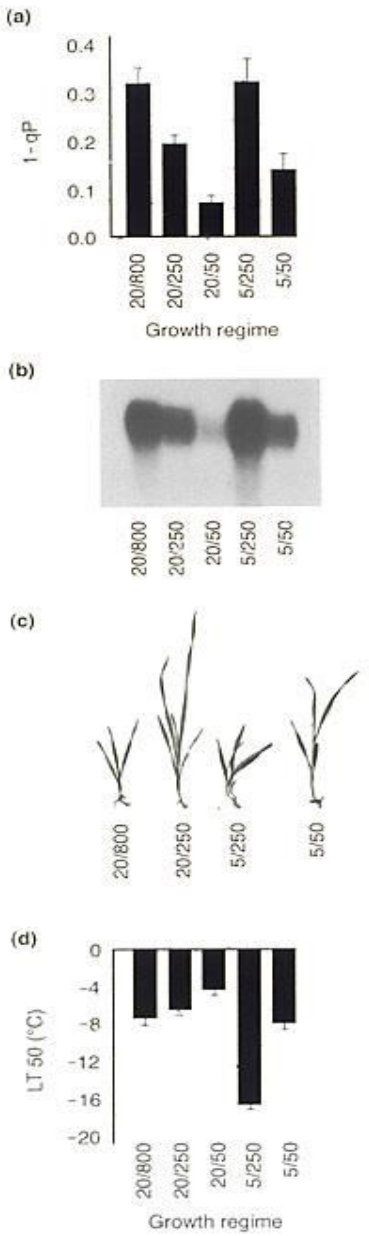
Kurepin et al 2013

Long-Term Growth Under Elevated CO2 Suppresses Biotic Stress Genes in Non-Acclimated, But Not Cold-Acclimated Winter Wheat

Kane et al. (2013)



Cold Acclimation of Winter Cereals: The Whole System Changes



↑ Biomass/leaf area

↑ Photosynthetic capacity

↑ Resistance to Photoinhibition

↑ Respiration

↑ Translocation

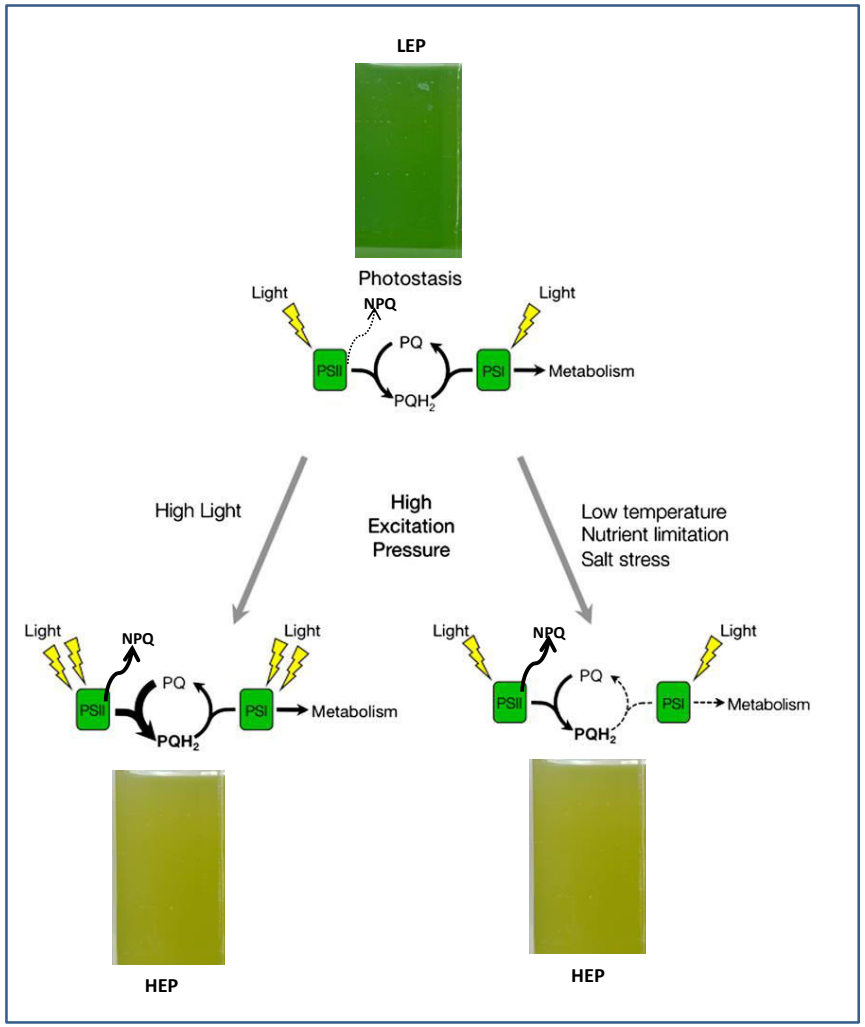
↑ WUE

↓ Photorespiration

↓ Feedback Inhibition

Huner et al. (1998)

PART I:
EXCESSIVE EXCITATION, EXCITATION PRESSURE & CHLOROPLAST REDOX REGULATION



Rosso et al. 2009

Figure 1

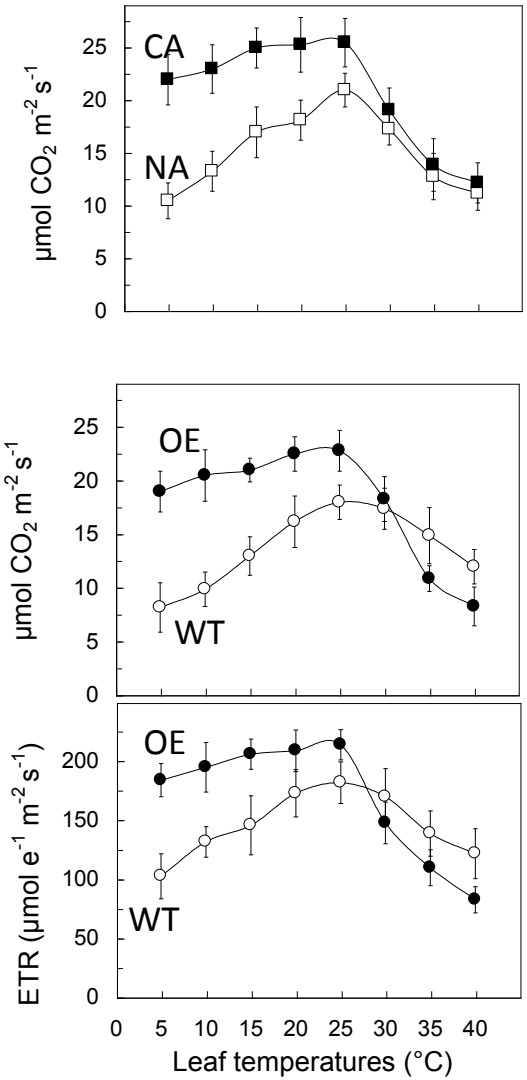
REGULATION OF VARIEGATION IN *Arabidopsis thaliana*



Rosso et al. 2009

CBF-OE MIMICKS PHOTOSYNTHETIC PERFORMANCE

IV. TEMPERATURE RESPONSE CURVES



Winter Rye

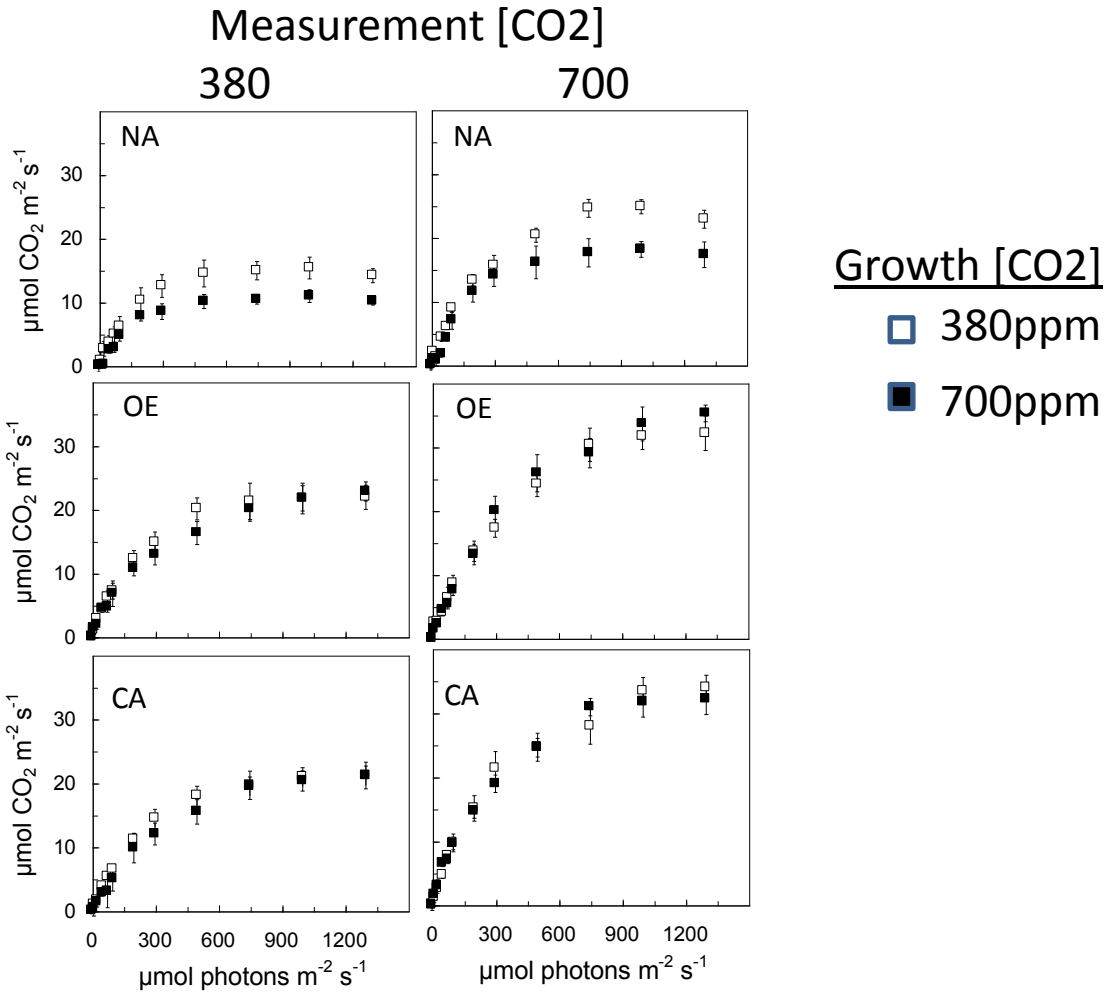
Brassica napus

Brassica napus

Dahal et al. 2012

CBF-OE MIMICKS PHOTOSYNTHETIC PERFORMANCE

I. LIGHT RESPONSE CURVES: CO2 ASSIMILATION



Dahal et al. 2012

CBF/DREB/ERF are subfamilies of the AP2 Family of Transcription Factors

AP2 Superfamily (145)



ERF family | AP2 family | RAV family | Soloist



Signature CBF Sequences

DNA Binding Motifs

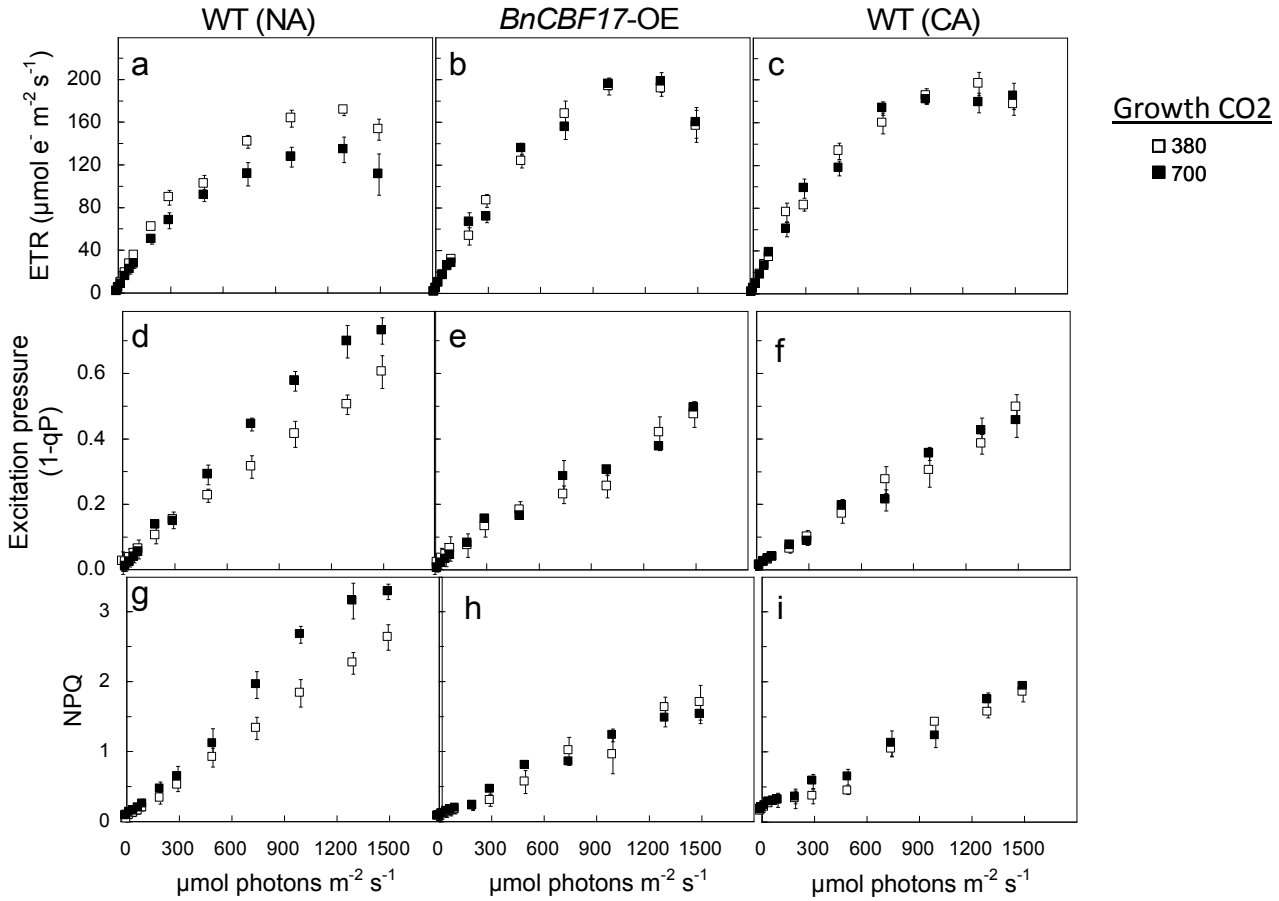
AGCCGCC (ERFs)

A/GCCGAC (CBFs/DREs)

Thomashow (2010)
Medina et al. (2011)
Licausi et al. (2013)

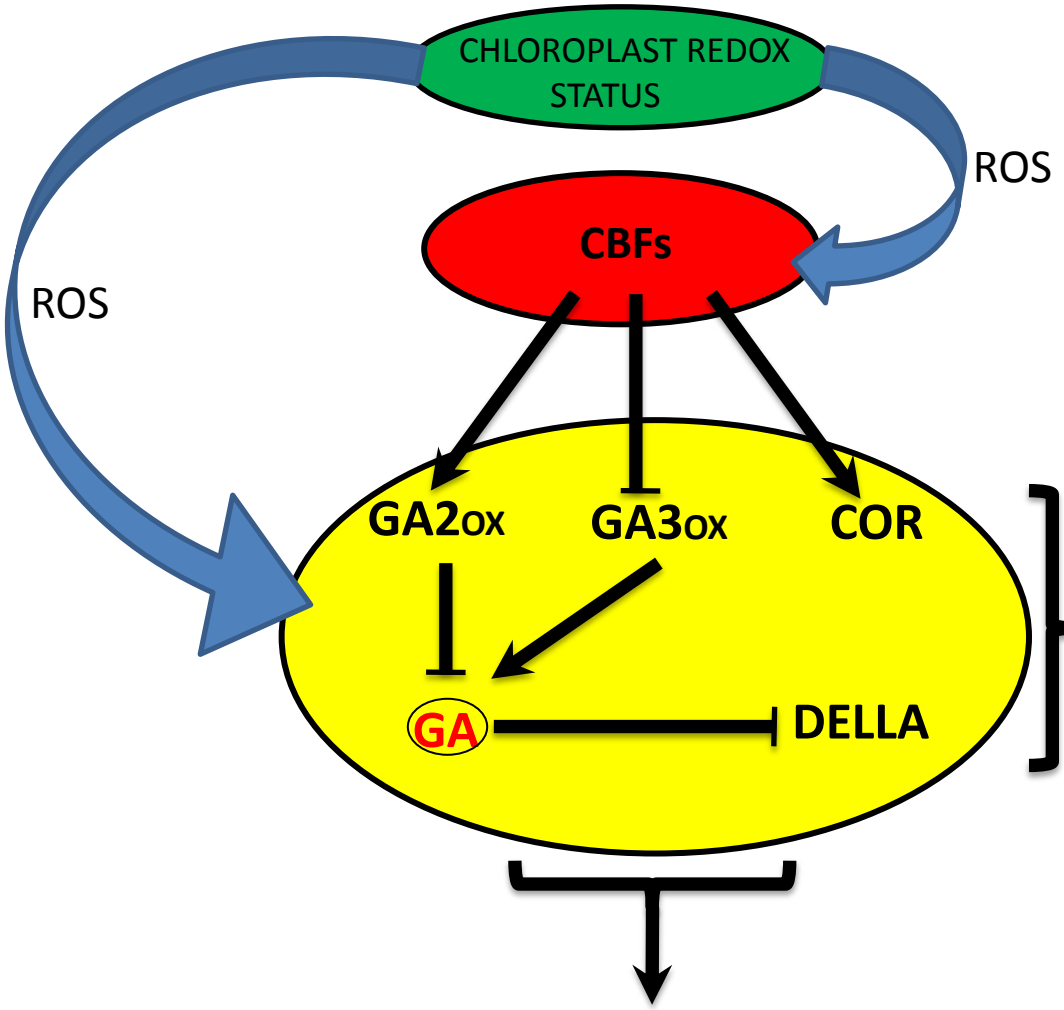
CBF-OE MIMICKS PHOTOSYNTHETIC PERFORMANCE

II. LIGHT RESPONSE CURVES: ENERGY UTILIZATION



Dahal et al.2012

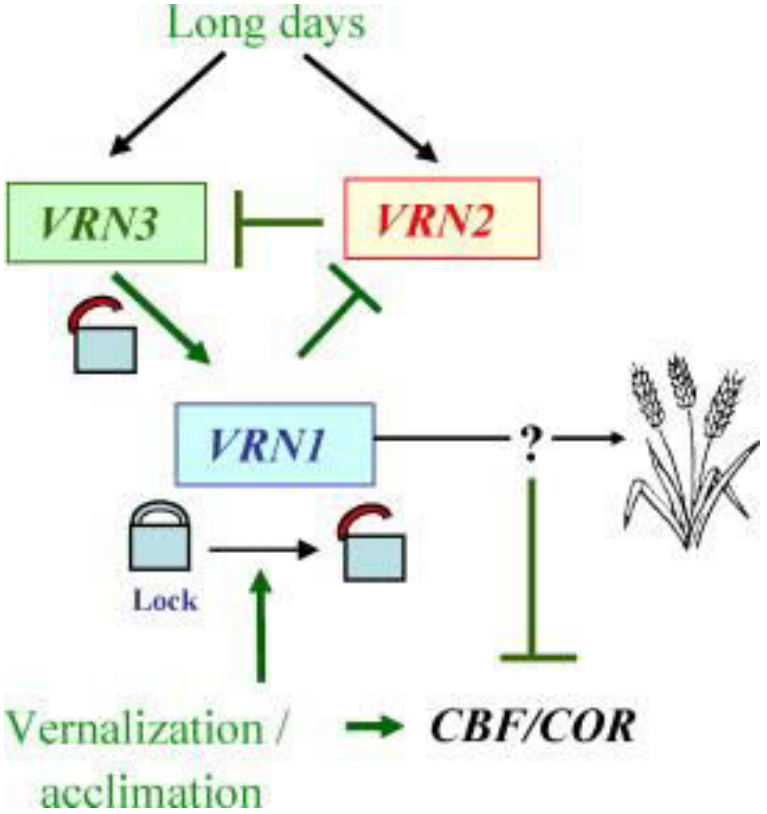
CBFS & THE 'GREEN REVOLUTION'



Peng & Harberd (1997) Genes & Dev
Peng et al. (1997) Plant Physiol
Peng et al. (1999) Nature
Hedden (2003) Trends Genetics
Hussain & Peng (2003) J Plant Growth Regulation

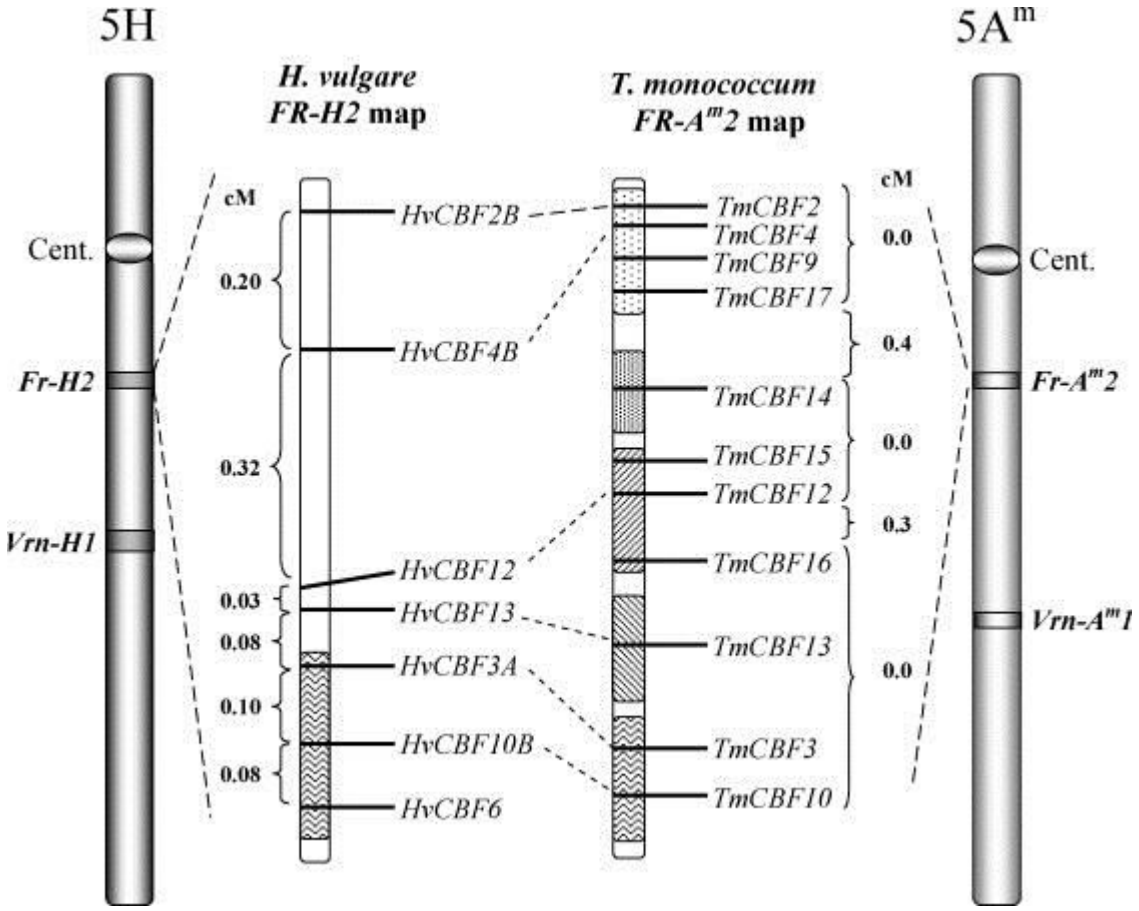
Archard et al. 2008
Bode et al. 2015

Vernalization-Induced Flowering by VRN Genes and their Putative effect on COR / CBF Genes.



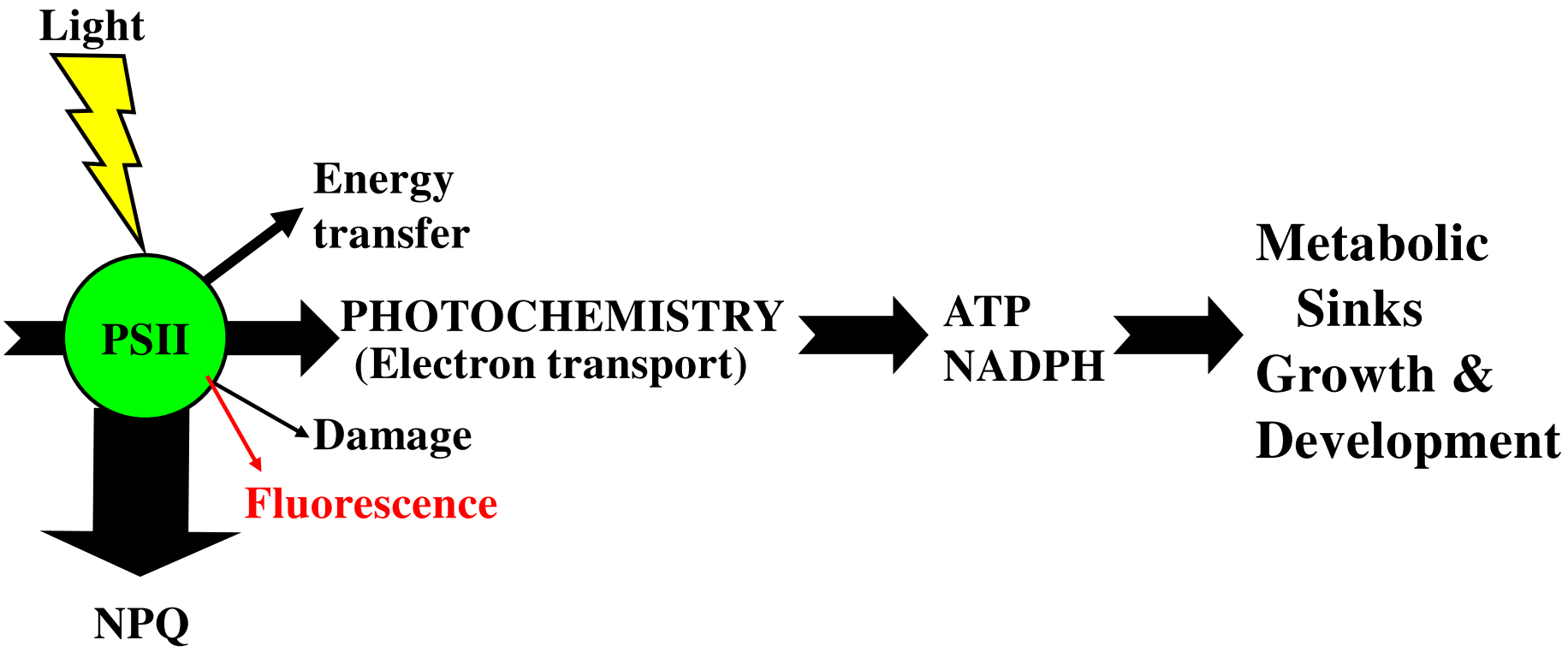
Galiba et al. 2009

Genetic Map for Vernalization & Freezing Tolerance

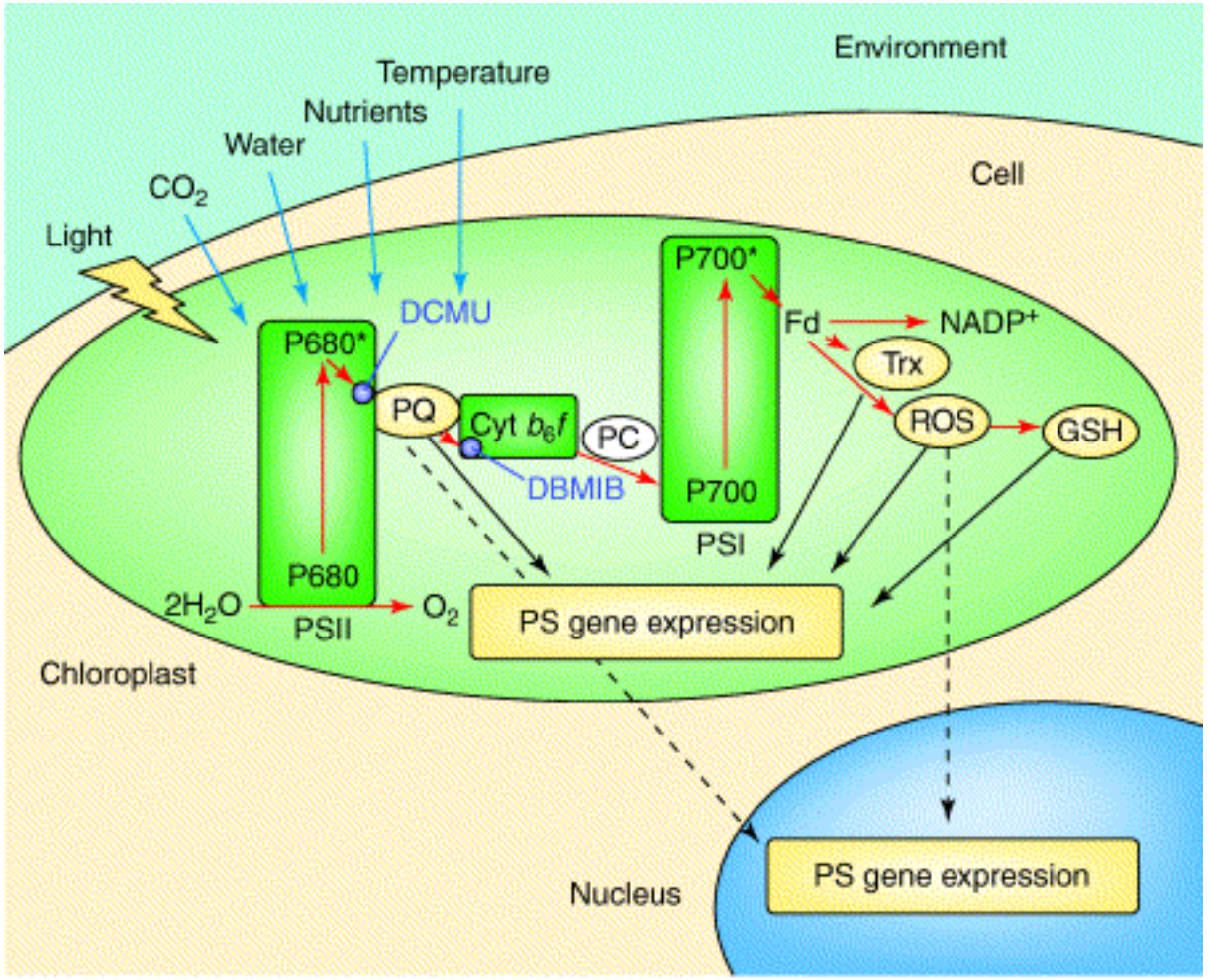


Galiba et al. 2009

Energy Allocation

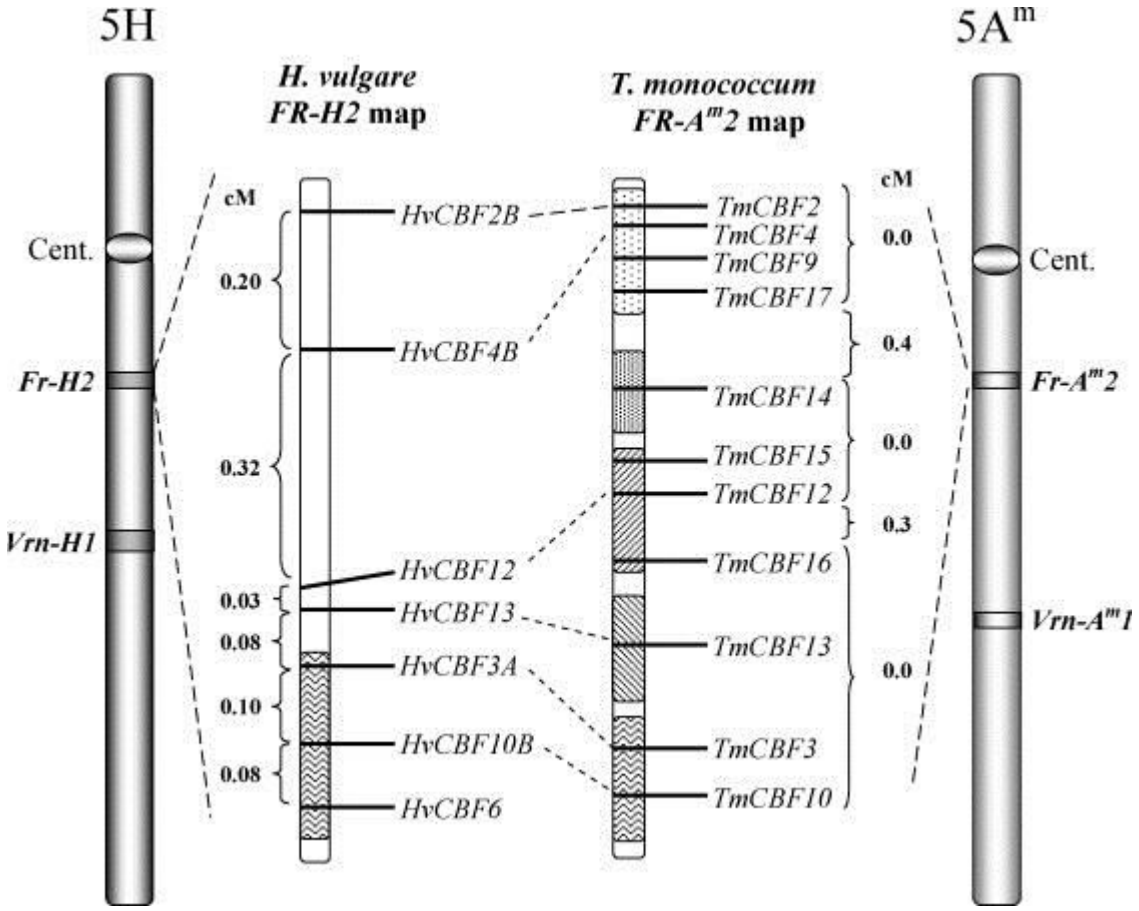


PHOTOSYNTHETIC ENERGY BALANCE



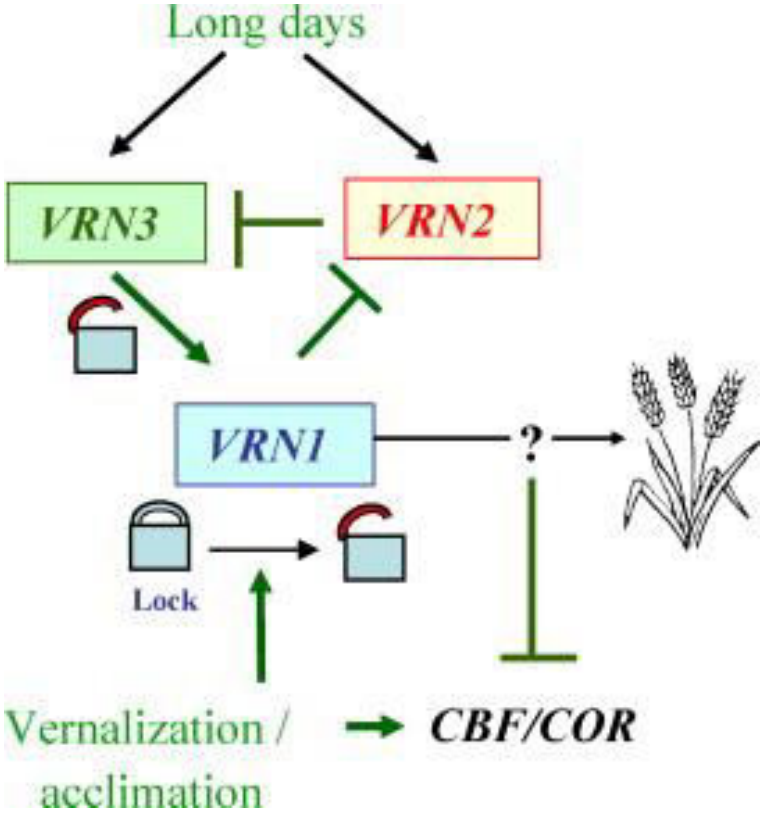
TRENDS in Plant Science

Genetic Map for Vernalization & Freezing Tolerance



Galiba et al. 2009

Vernalization-Induced Flowering by VRN Genes and their Putative effect on COR / CBF Genes.



Galiba et al. 2009

SEMI-DWARFISM AND OVEREXPRESSION OF *GAI*



Hedden 2003