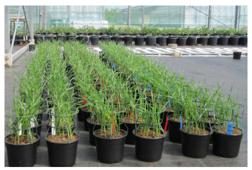
Interaction of environmental factors affecting wheat performance
- A case for multidisciplinary research efforts

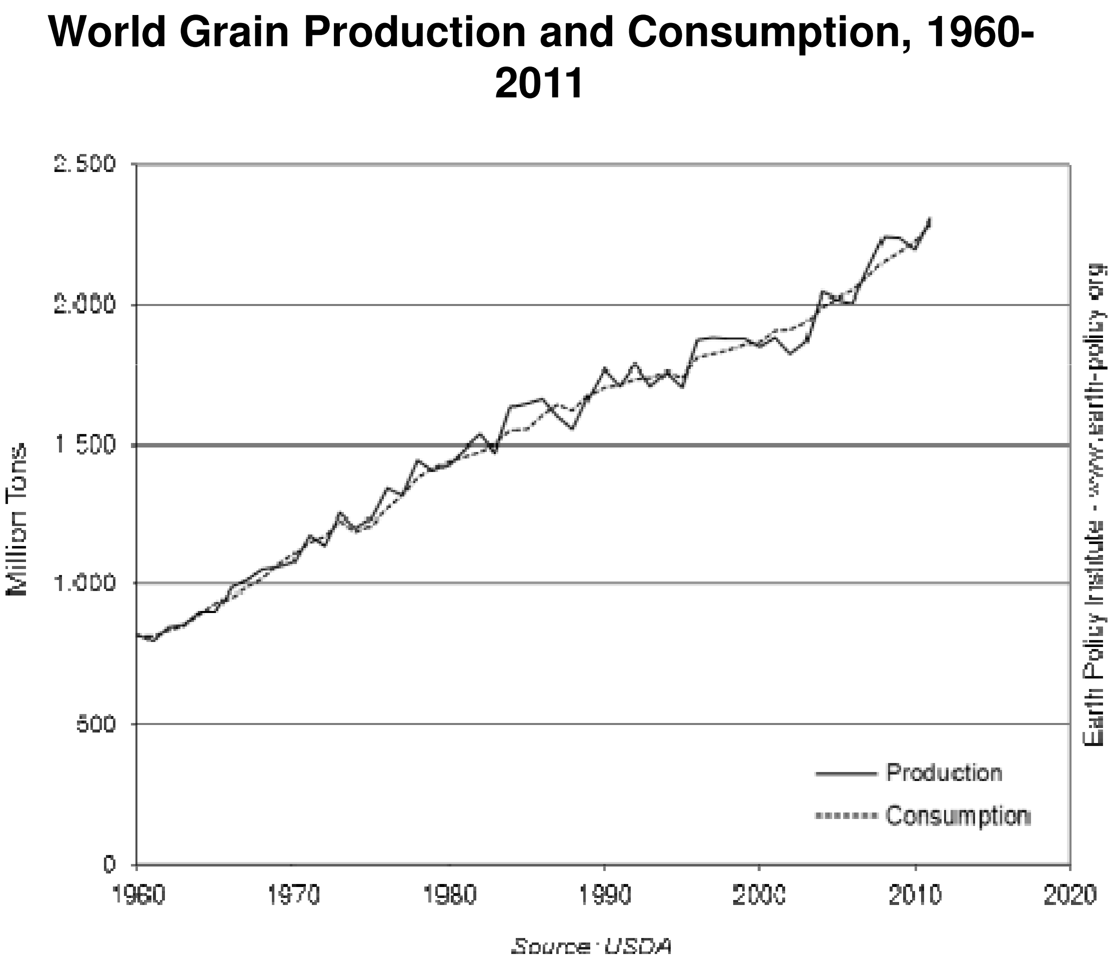
Topic:
There has been recent progress in individual scientific disciplines, but these advances within single disciplines, alone, cannot solve the challenges of increasing yield

Therefore multidisciplinary approaches must be implemented to tackle major constraints to achieving sufficient grain yield in the future



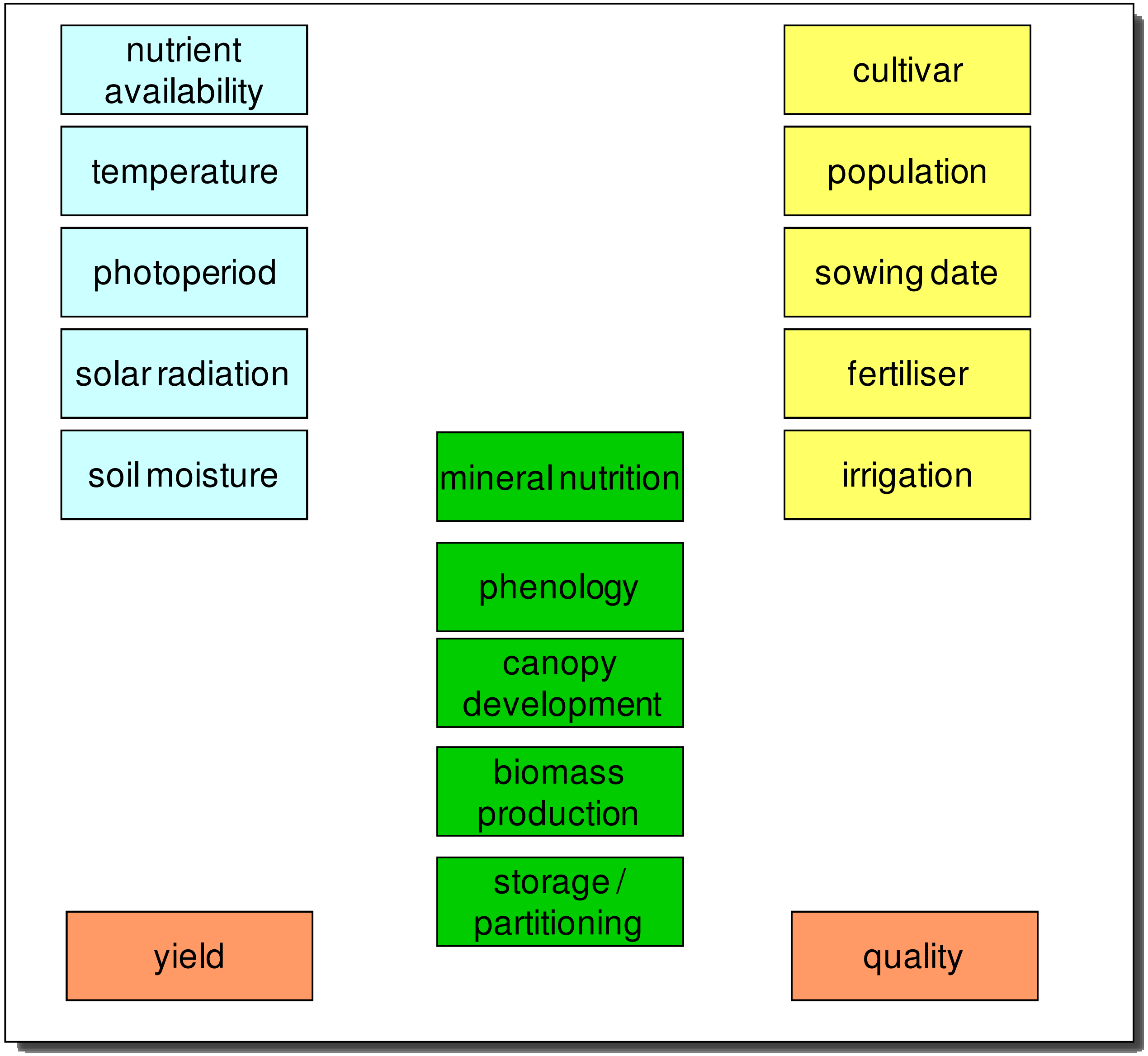
Bernd Wollenweber
Aarhus University
Department of Agroecology

Grain production and consumption



- Dangerously small margin between grain consumption and grain production
- We face long-term trends that:
  - increase food demand
  - limit food production

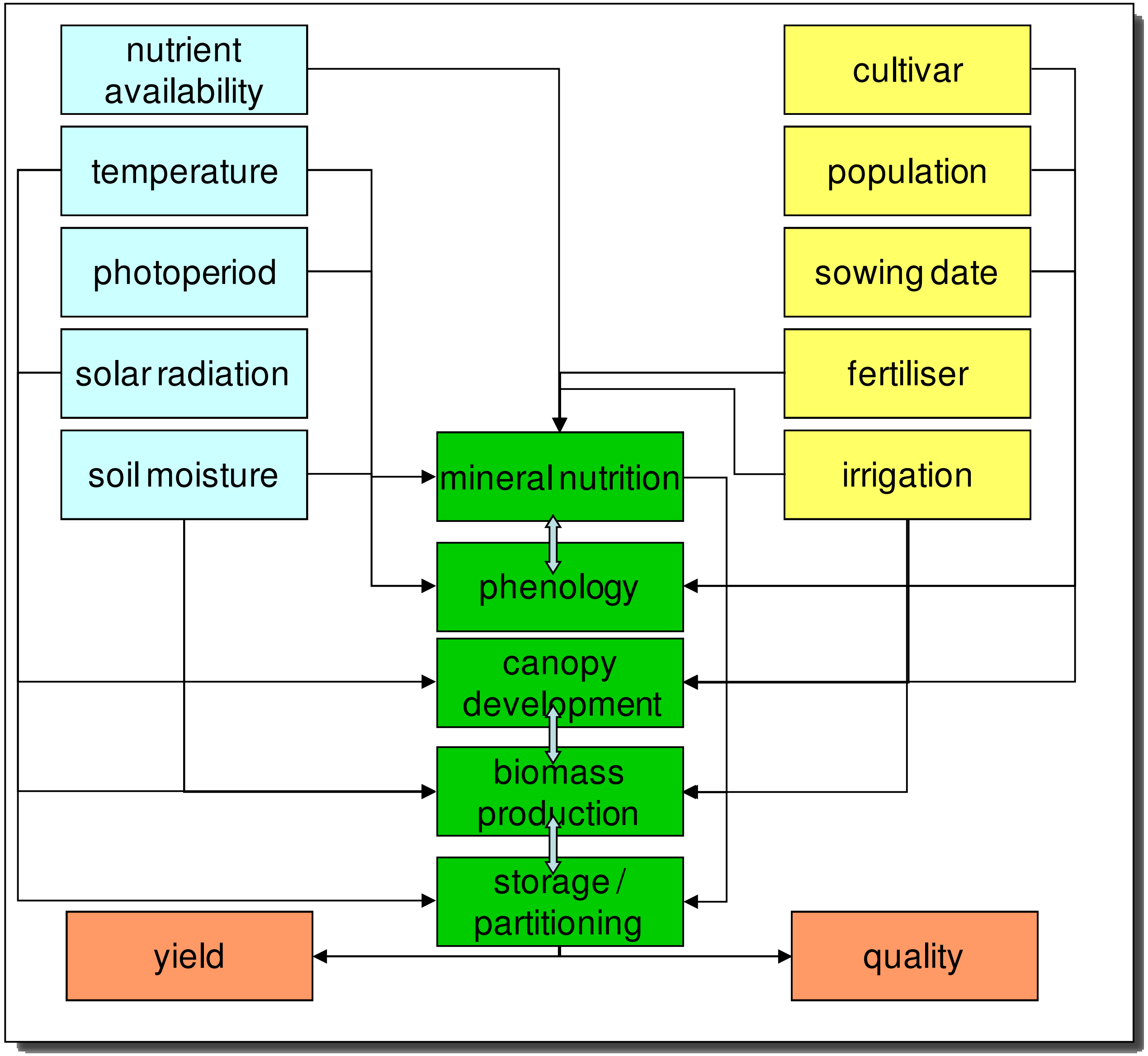
Environmental and agronomical constraints to crop yield and quality



Agronomical factors and environmental constraints will influence the levels of a wide range of *(in)organic compounds* in crops that in turn affect key *physiological processes* and may finally affect grain yield and quality

Hay, R; Porter, J. (2006) The Physiology of crop yield 2nd ed.

Environmental and agronomical constraints to crop yield and quality



Agronomical factors and environmental constraints will influence the levels of a wide range of (*in)organic compounds* in crops that in turn affect key *physiological processes* and may finally affect grain yield and quality

Consequence:

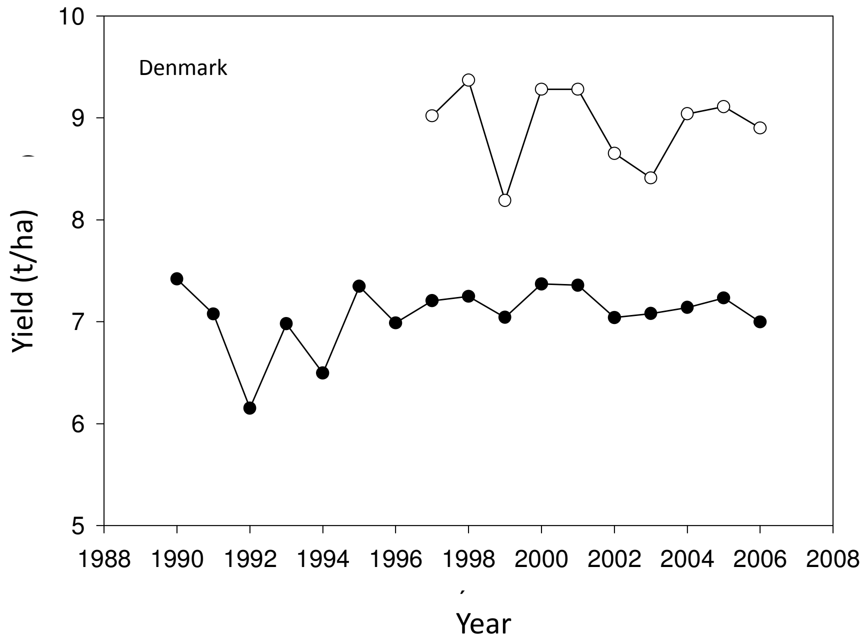
The need to focus on

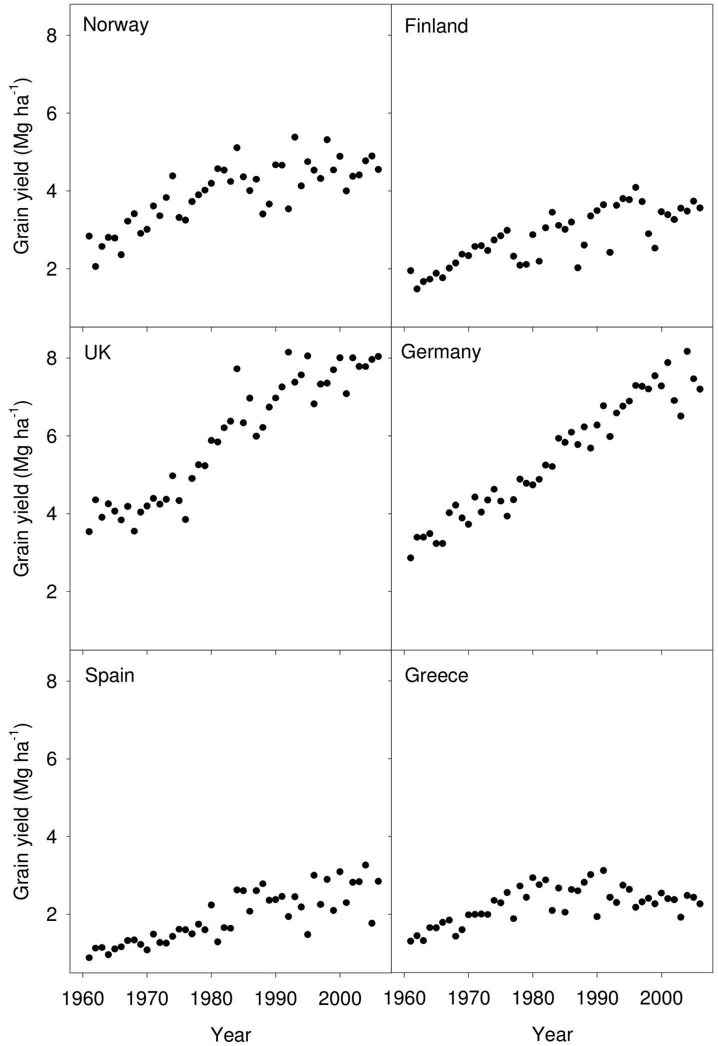
G x E x M

Hay, R; Porter, J. (2006) The Physiology of crop yield 2nd ed.

Constraints to crop yield and quality

Stagnation of yield in winter wheat





Constraints to crop yield and quality

Plant Science 210 (2013) 159–176

Contents lists available at SciVerse ScienceDirect

Plant Science

journal homepage: www.elsevier.com/locate/plantsci

Review

Plant science and agricultural productivity: Why are we hitting the yield ceiling?

Stève de Bossoreille de Ribou[a], Florian Douam[a], Olivier Hamant[a], Michael W. Frohlich[a,b], Ioan Negrutiu[a,*]

FOOD SECURITY

Global crop improvement networks to bridge technology gaps

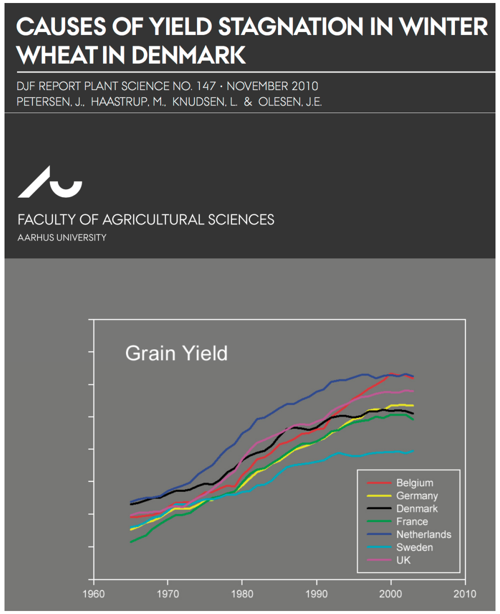
Matthew P. Reynolds[1,*], Jonathan Hellin[1], Bram Govaerts[1], Petr Kosina[1], Kai Sonder[1], Peter Hobbs[2] and Hans Braun[1]

[1] International Maize and Wheat Improvement Center (CIMMYT, Int.). Km. 45 via México-Veracruz. Texcoco, CP56120, Edo de México, México

[2] Cornell University, Ithaca, New York, USA

* To whom correspondence should be addressed. E-mail: m.reynolds@cgiar.org

Journal of Experimental Botany, Vol. 63, No. 1, pp. 1–12, 2012
doi:10.1093/jxb/err241



REVIEW PAPER

www.jxb.oxfordjournals.org

Raising yield potential of wheat. I. Overview of a consortium approach and breeding strategies

Matthew Reynolds[1,*], David Bonnett[1], Scott C. Chapman[2], Robert T. Furbank[3], Yann Manès[1], Diane E. Mather[4] and Martin A. J. Parry[5]

GM as a route for delivery of sustainable crop protection

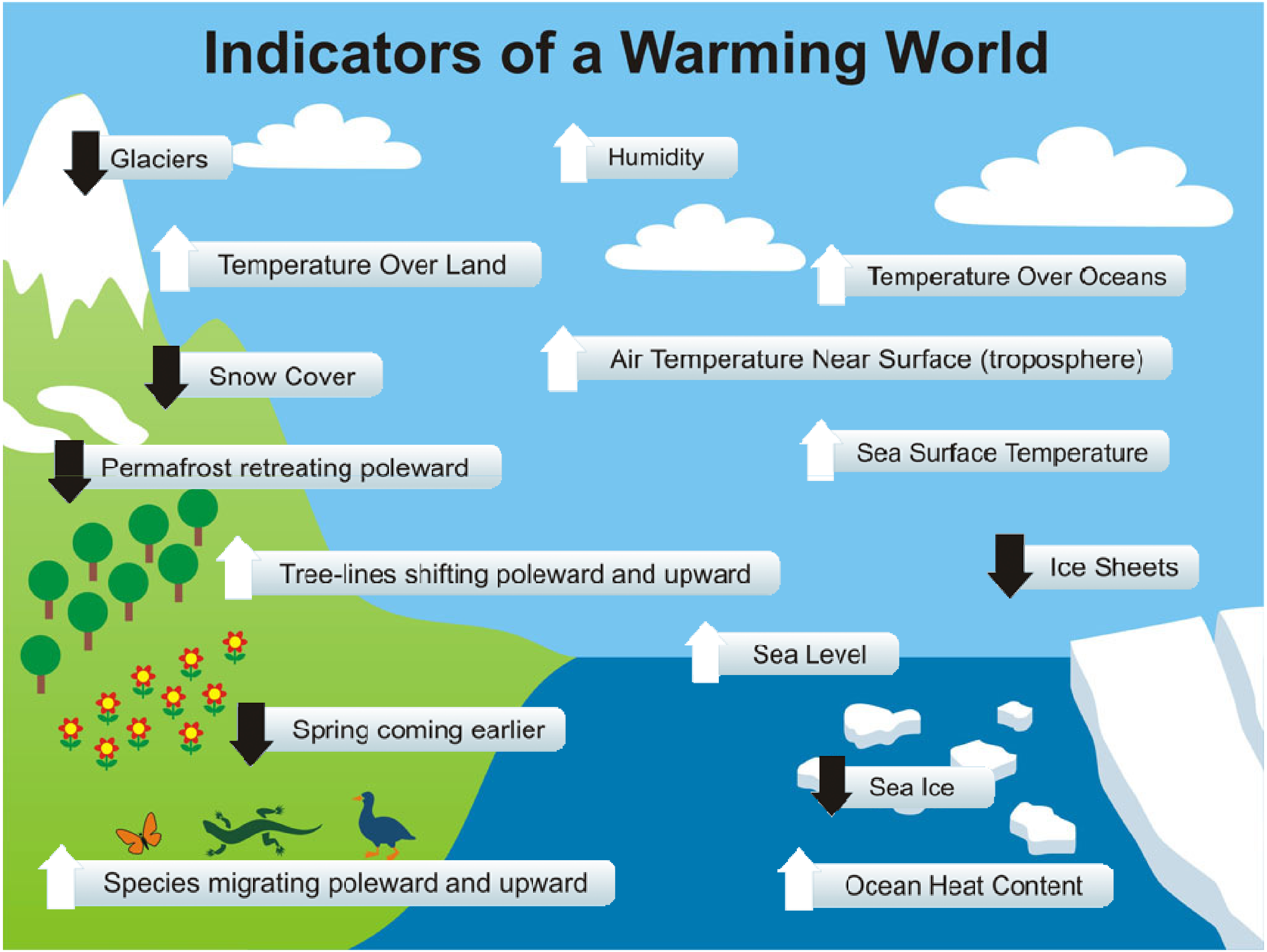
Toby J. A. Bruce*

Biological Chemistry Department, Rothamsted Research, Harpenden, Herts AL5 2JQ, UK

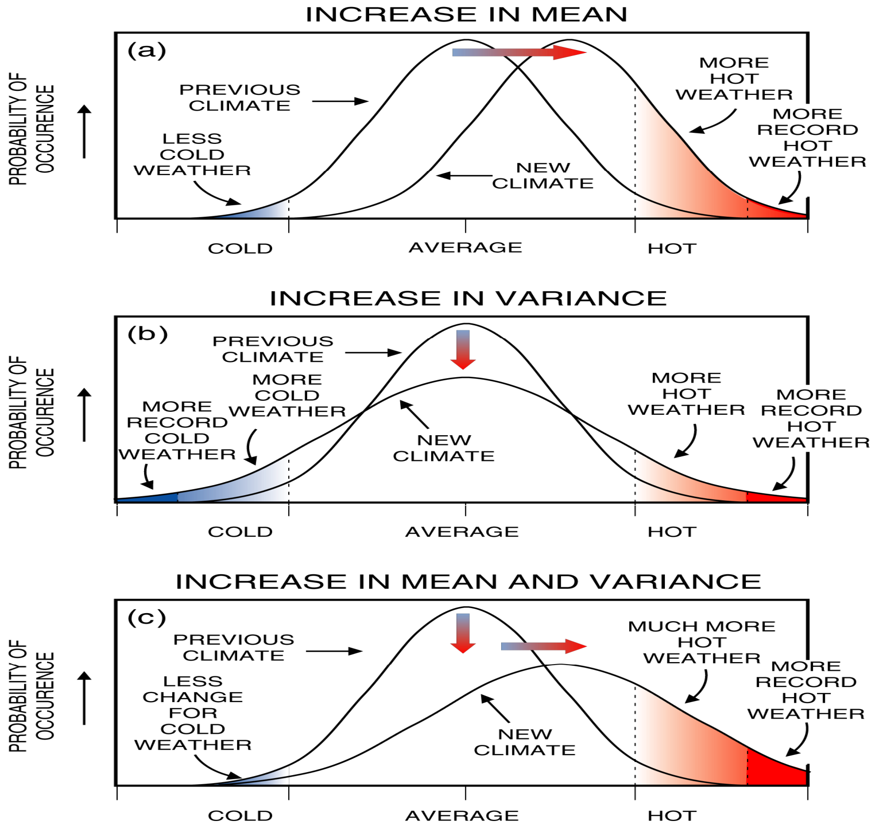
* To whom correspondence should be addressed. E-mail: toby.bruce@rothamsted.ac.uk

Journal of Experimental Botany, Vol. 63, No. 2, pp. 537–541, 2012
doi:10.1093/jxb/err281

Olesen, J. & Wollenweber, B. (2010) Environmental changes and impacts on yield of winter wheat. *In: Causes of yield stagnation in winter wheat in Denmark. Petersen, J., Haastrup, M, Knudsen, I. & Olesen, J. (eds.) DJF Rapport 147, pp. 35-53.*

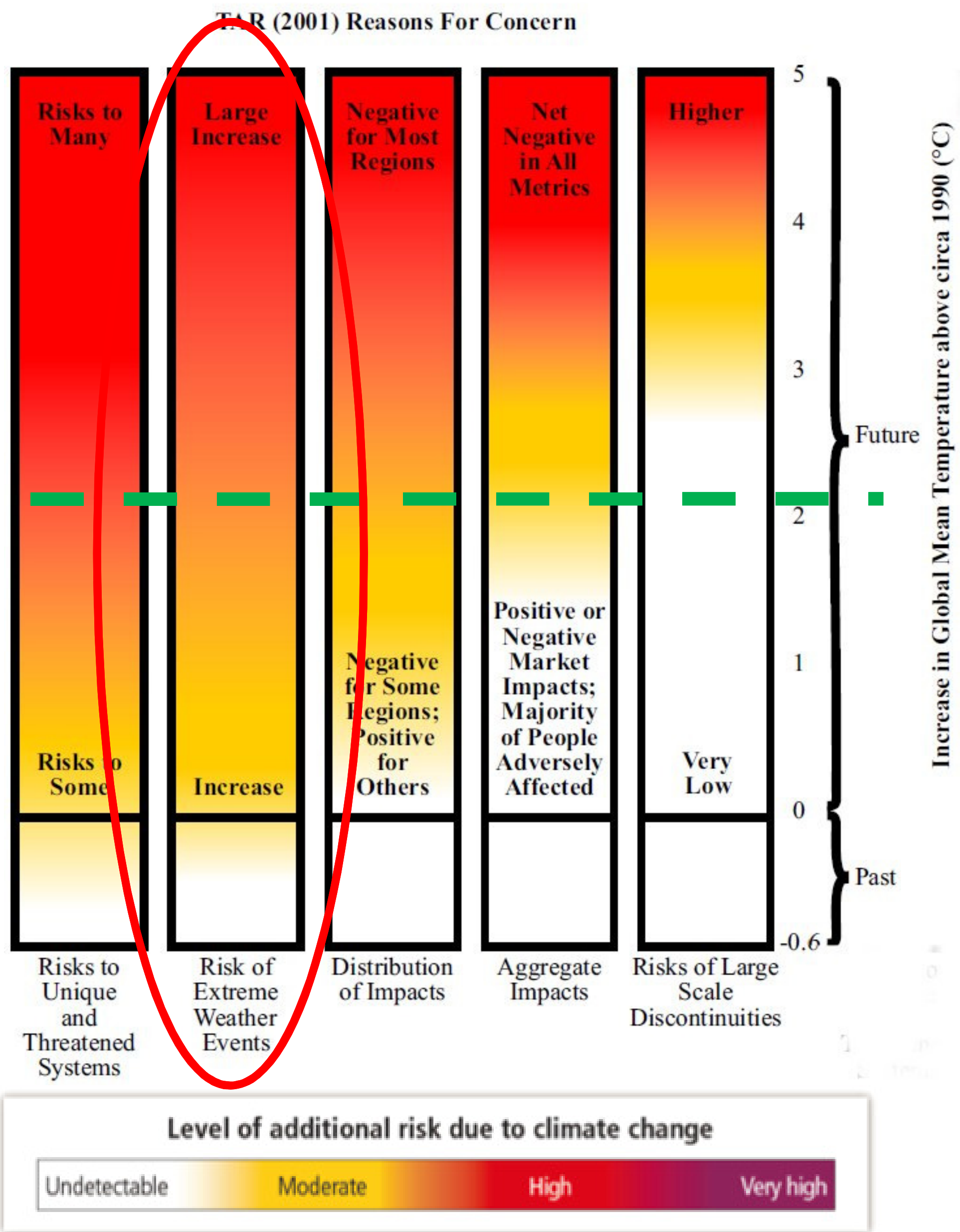

Indicators of a Warming World
Glaciers
Humidity
Temperature Over Land
Temperature Over Oceans
Snow Cover
Air Temperature Near Surface (troposphere)
Sea Surface Temperature
Permafrost retreating poleward
Tree-lines shifting poleward and upward
Ice Sheets
Sea Level
Spring coming earlier
Sea Ice
Species migrating poleward and upward
Ocean Heat Content

Climate change: What are the risks?



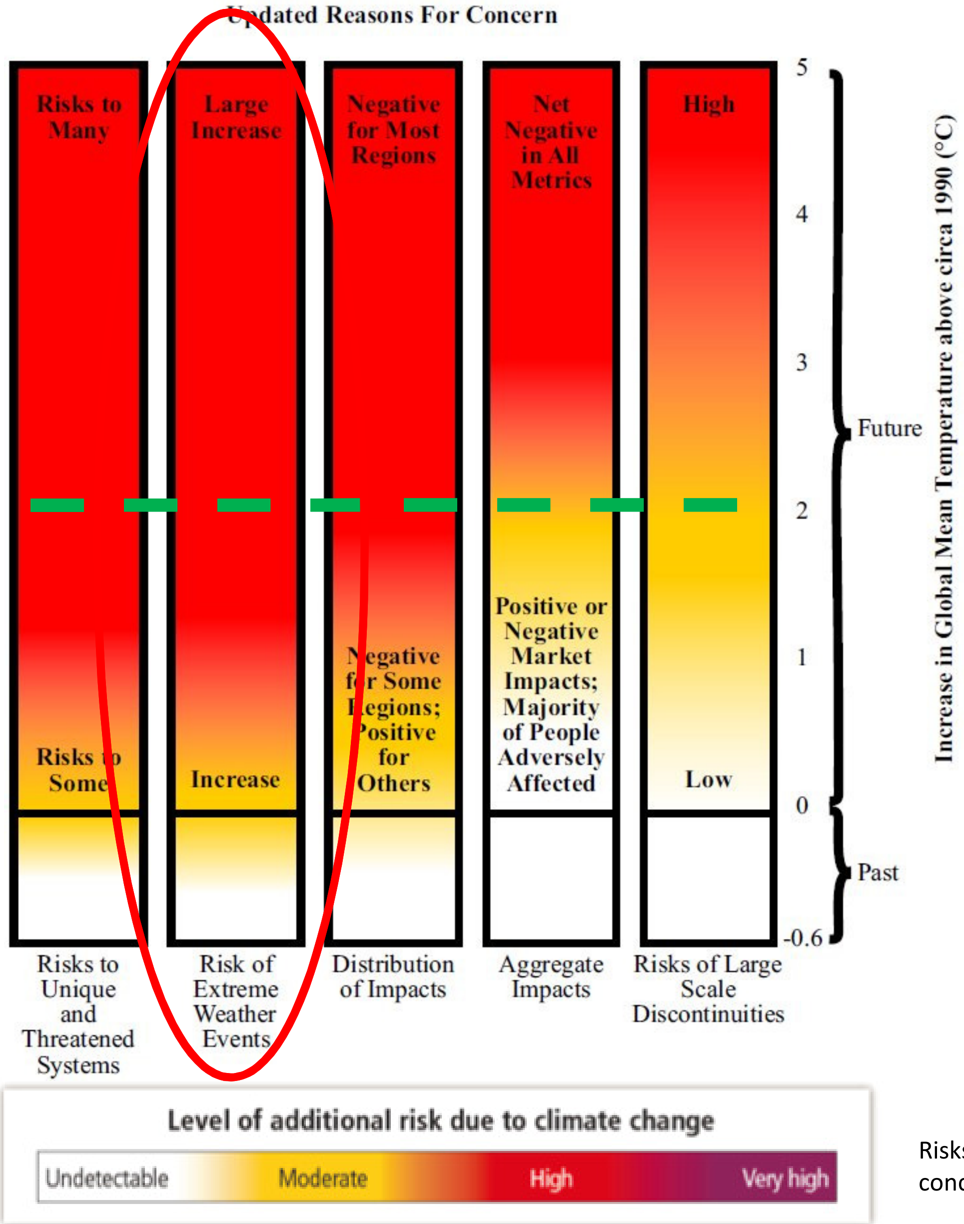
Climate change will increase the **frequency**, **intensity** and **duration** of periods with extreme climatic conditions

Climate change: What are the risks?



2001

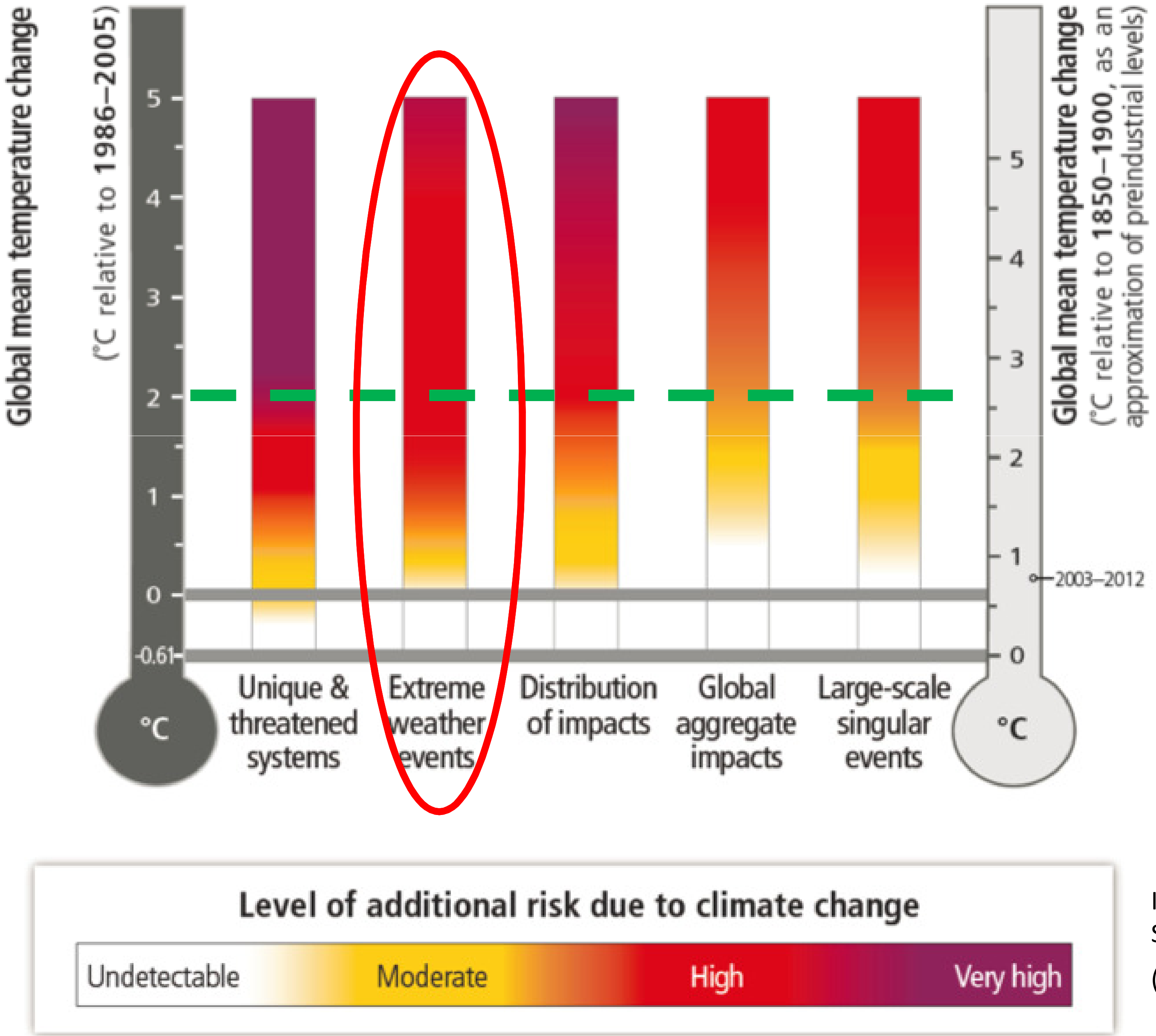
Climate change: What are the risks?



2009

Risks from climate change, by reason for concern [Smith *et al*. PNAS 2009]

Climate change: What are the risks?



2014

IPCC WGII AR5
Summary for Policymakers
(2014)

Climate change: Paradigm shift

Earlier research concluded that the initial stages of climate change would bring net benefits to global agriculture due to carbon fertilization and longer growing seasons

Newer experimental studies have sharply reduced older estimates of carbon fertilization effects

The effect of temperature on many crops has been found to involve thresholds, above which yields rapidly decline

Temperature thresholds

Table 1
Summary of mean (±se) of lethal minimum (*T*Lmin), lethal maximum (*T*Lmax), base (*T*min), optimum (*T*opt) and maximum (*T*max) temperatures for various processes and phenological phases in wheat

Processes		Mean temperature (±se) (°C)	*n*
Lethal limits	*T*Lmin	−17.2 (1.2)	17
	*T*Lmax	47.5 (0.5)	2
Leaf initiation	*T*min	−1.0 (1.1)	12
	*T*opt	22.0 (0.4)	9
	*T*max	24.0 (1.0)	5
Shoot growth	*T*min	3.0 (0.4)	5
	*T*opt	20.3 (0.3)	6
	*T*max	>20.9 (0.2)	6
Root growth	*T*min	2.0	1
	*T*opt	<16.3 (3.7)	3
	*T*max	>25.0 (5.0)	3
Phenological phases			
Sowing to emergence	*T*min	3.5 (1.1)	8
	*T*opt	22.0 (1.6)	11
	*T*max	32.7 (0.9)	10
Vernalization	*T*min	−1.3 (1.5)	6
	*T*opt	4.9 (1.1)	11
	*T*max	15.7 (2.6)	7
Terminal spikelet	*T*min	1.5 (1.5)	2
	*T*opt	10.6 (1.3)	5
	*T*max	>20.0	1
Anthesis	*T*min	9.5 (0.1)	3
	*T*opt	21.0 (1.7)	2
	*T*max	31.0	1
Grain-filling	*T*min	9.2 (1.5)	6
	*T*opt	20.7 (1.4)	7
	*T*max	35.4 (2.0)	5

n is the number of literature sources used to calculate means and se.

ELSEVIER
European Journal of Agronomy 10 (1999) 23–36
European Journal of Agronomy

Temperatures and the growth and development of wheat: a review

John R. Porter [a,*], Megan Gawith [b]

Global Change Biology
Global Change Biology (2014) **20**, 408–417, doi: 10.1111/gcb.12389

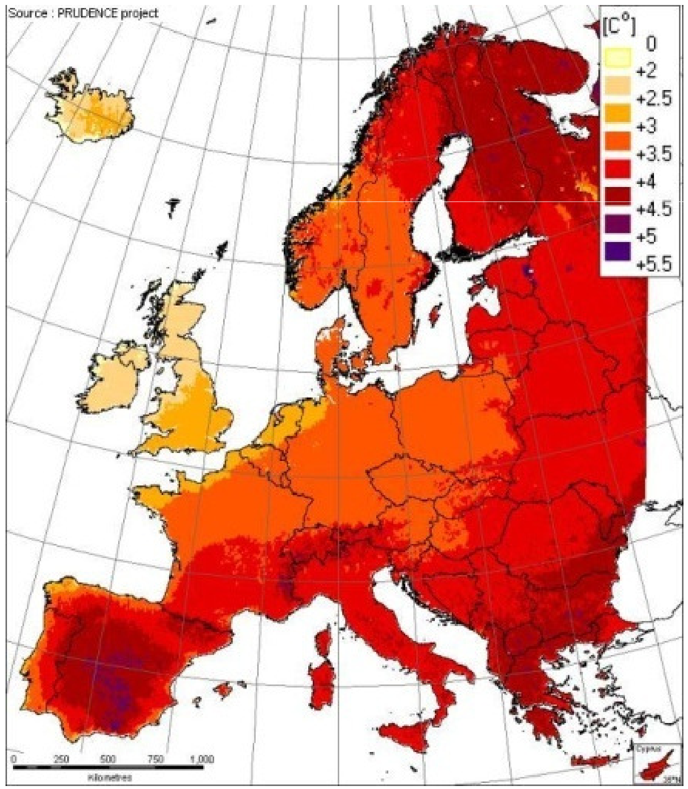
Temperatures and the growth and development of maize and rice: a review

BERTA SÁNCHEZ*, ANTON RASMUSSEN† and JOHN R PORTER†

Drought and heat waves reduce crop yield

Crop yields can drop by 3 – 5% with every 1°C increase in temperature

Temperature change forecast 2071-2100 period, relative to the 1961-1990 period



© European Communities, 1995-2009. Image Source: The PESETA Project

..Global maize and wheat production declined by 3.8% and 5.5%, respectively…

Climate trends were large enough in some countries to offset a significant portion of the increases in average yields that arose from technology, CO_2 fertilization, and other factors…

Climate Trends and Global Crop Production Since 1980
David B. Lobell, Wolfram Schlenker, Justin Costa-Roberts
Sciencexpress 5 May 2011


The Economis
NOVEMBER 27TH–DECEMBER 3RD 2010
How to liv
climate c
The Economi
DECEMBER 5TH–11TH 2009
Stoppi
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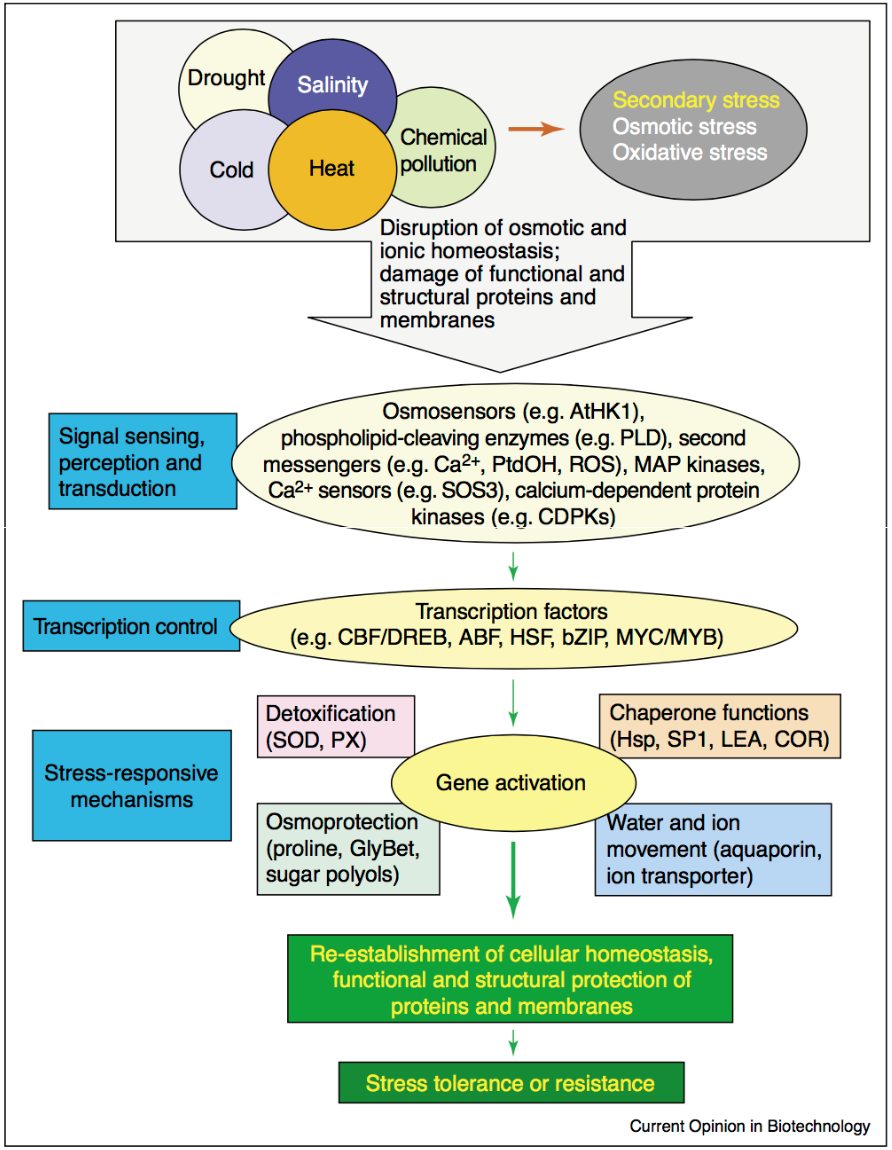
A 14-PAGE SPECIAL REPORT
The Economist
NOVEMBER 21ST–27TH 2009
Economist.com
Dealing with America's deficit
Obama's timid trip to Asia
Remote control for your car
Peter Drucker, still king of the gurus
The scientist who saw Nessie
How to feed the world

The response to environmental stress is complex



Imposition of stress – Proposition for research

- Biotic stress vs. abiotic stress
- Abiotic Stress Interactions:

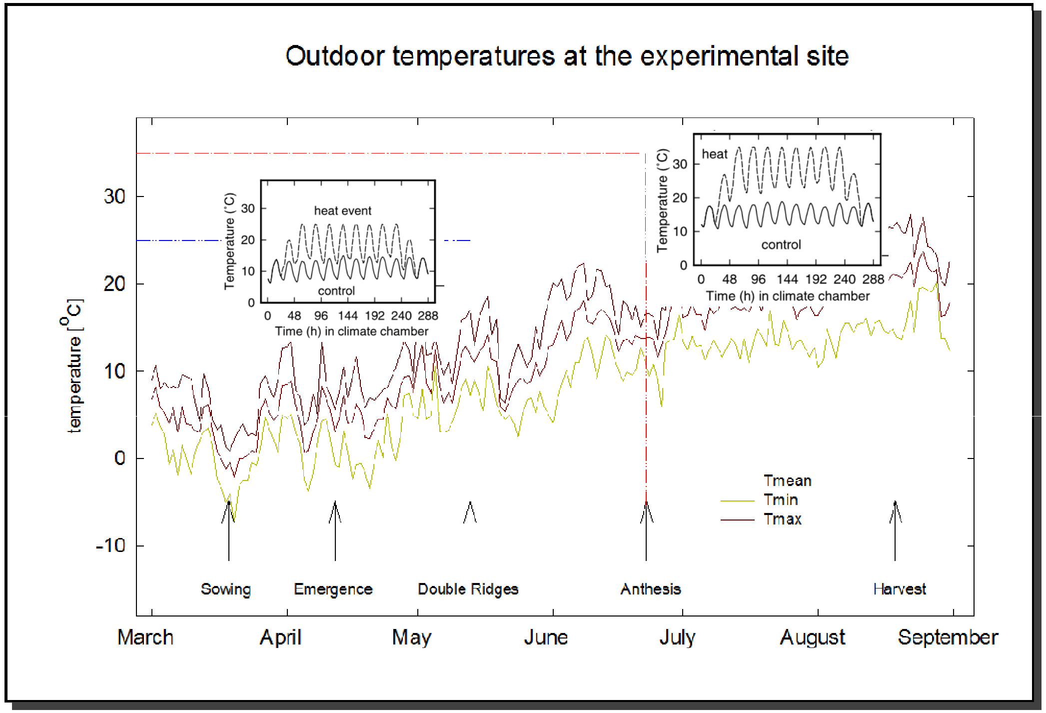
  single vs. multiple stress **events**

  single vs. multiple stress **types**

Little is known about the **interaction** of these stresses and the consequences for crop quality

Interaction of high-temperature events

Climate Change, Climatic Variability and Agriculture in Europe:
An integrated Assessment (CLIVARA)



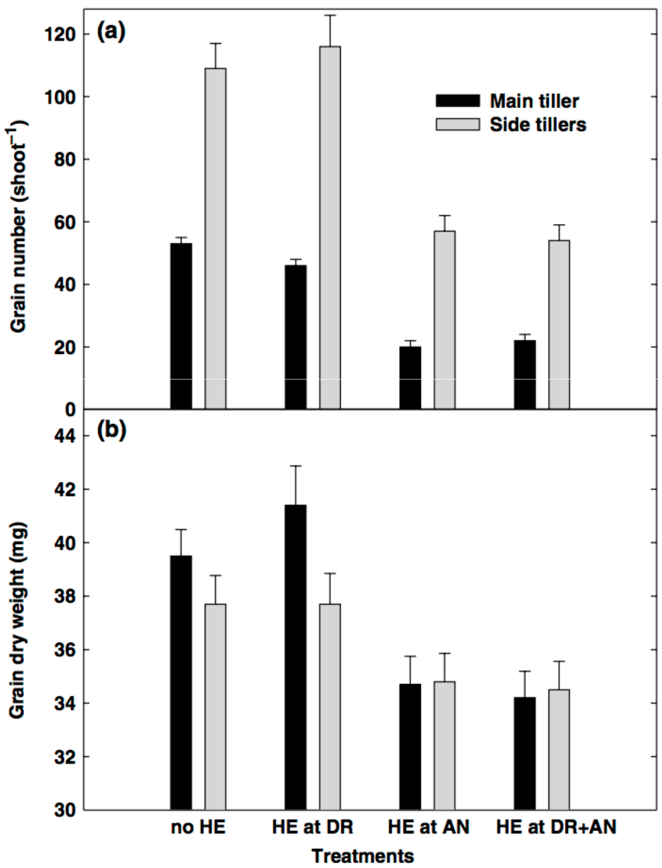
Anthesis

Final harvest

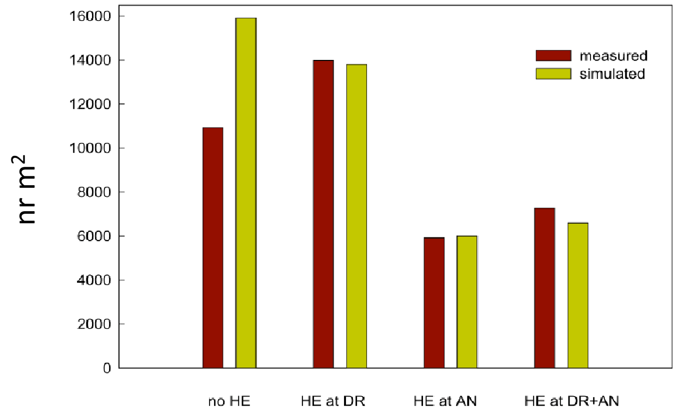
Double-ridge stage
(the spikelet formation phase, in which two bracts mark the end of the spikelet)

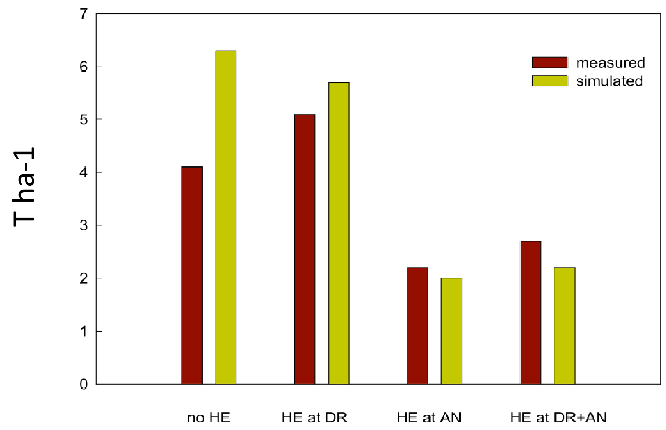
Interaction of high-temperature events

Climate Change, Climatic Variability and Agriculture in Europe:
An integrated Assessment (CLIVARA)



Simulated and measured number of grains





Lack of interaction between extreme high-temperature events at vegetative and reproductive growth stages in wheat.
Wollenweber, B., Schellberg, J. and Porter, J.R. *Journal of Agronomy and Crop Science* 189, 1-11 (2003)

Interaction between stress events & stress types

Water deficits:

Exploring the asynchronous protein metabolism in single kernels of wheat studied by NMR spectroscopy and chemometrics.
Winning, H.; Viereck, N.; Wollenweber, B.; Larsen, F.H.; Jacobsen, S.; Søndergaard, I.; Balling Engelsen, S.
Journal of Experimental Botany 60: 291-300 (2009)

Global dimming:

Long-term low radiation decreases leaf photosynthesis, photochemical efficiency and grain yield in winter wheat.
Mu, H.; Jiang, D.; Wollenweber, B.; Dai, T.; Jing, Q.; Cao, W.
Journal of Agronomy and Crop Science 196: 38-47 (2010)

Effects of shading on morphology, physiology and grain yield of winter wheat.
Li, H; Jiang, D.; Wollenweber, B.; Dai, T.; Cao, W.
European Journal of Agronomy 33:267-275 (2010)

Waterlogging + water deficits:

Effects of post-anthesis drought and waterlogging on accumulation of high molecular-weight glutenin subunits and glutenin macro polymer content in wheat grain.
Jiang, D, Yue, H., Wollenweber, B., Tan, W., Dai, T., Jing, Q., Cao, W.
Journal of Agronomy and Crop Science 195 (2): 89-97 (2009)

Waterlogging pretreatment during vegetative growth improve tolerance to waterlogging after anthesis in wheat.
Li, C; Jiang, D.; Wollenweber, B.; Li, Y.; Dai, T.; Cao, W.
Plant Science 180: 672-678 (2011)

High-temperature + water deficits:

Implications of high-temperature events and water deficits on protein profiles in wheat (Triticum aestivum L. cv. Vinjett) grain.
Yang, F., Dysted Jørgensen, A., Li, H., Søndergaard, I., Finnie, C., Jiang, D., Wollenweber, B., Jacobsen, S.
Proteomics 11: 1684-1695 (2011)

Interaction between stress events & stress types

Temperature-extremes are more important than CO_2-increases for crop yields

Critical temperature thresholds need identification

The study of adaptation to extreme weather conditions requires a more integrated research approach

Lack of interaction between extreme high-temperature events at vegetative and reproductive growth stages in wheat.
Wollenweber, B., Schellberg, J. and Porter, J.R. *Journal of Agronomy and Crop Science* 189, 1-11 (2003)

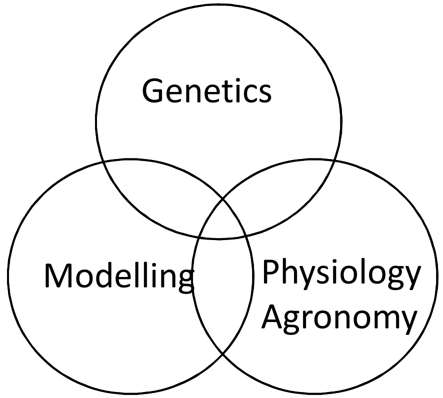
The need for an integrated research approach

Despite recent achievements in conventional plant breeding and genomics, the rate of increase of crop yields is declining.

Advances within single disciplines, alone, cannot solve the challenges of increasing yield.

There has been recent progress in individual disciplines, but multidisciplinary approaches must be implemented to tackle major constraints to achieving sufficient grain yield in the future.

The need for an integrated research approach



Advances in Genetics

enhanced marker technology
enhanced QTL detection methods
enhanced genotype to phenotype linkages

Advances in Physiology

the plants perspective (sensing stress)
complex trait physiology
prediction of consequences of genetic variation

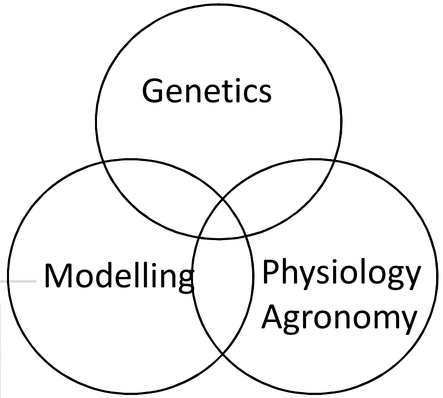
Advances in Modelling

Climate, agronomical, physiological & biochemical models

The need to understand the effects of gene function on crop performance under various environmental conditions and the processing of this knowledge into robust simulation models

Need for multidisciplinary research towards a second green revolution. Wollenweber, B., Porter, J.R. & Lübberstedt, T. *Current Opinion in Plant Biology 8: 337-341* (2005)
The Rubisco enzyme and agricultural productivity. Porter, J.R.; Wollenweber, B. *Nature 463: 876* (2010)

The need for an integrated research approach



Current Opinion in Plant Biology

Volume 8, Issue 3, June 2005, Pages 337–341

Commentary

Need for multidisc... revolution

Bernd Wollenweber[1], John...

[1] The Danish Institute of Agric... Centre Flakkebjerg, Slagelse, ...

[2] The Royal Veterinary and A... Alle, Taastrup, DK-2630, Den...

FAO Director-General appeals for second Green Revolution

Vast effort needed to feed billions and safeguard environment

13 September 2006, Rome/San Francisco – FAO Director-General Jacques Diouf today called for a second Green Revolution to feed the world's growing population while preserving natural resources and the environment.

Addressing a meeting of the World Affairs Council of Northern California in San Francisco, Dr Diouf said:

"In the next few decades, a major international effort is needed to feed the world when the population soars from six to nine billion. We might call it a second Green Revolution."

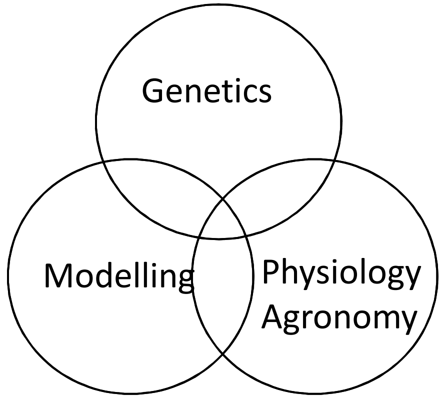
The San Francisco-based World Affairs Council of Northern California, which has 10 000 members, is one of the United States' leading non-governmental fora for discussion and debate of international affairs.

Contact:

Christopher Matthews
Information Officer, FAO
christopher.matthews@fao.org
(+39) 06 570 53762

FAO Director-General Jacques Diouf

Implementation – The ‘Heat-Wheat’ project



Strategic research objectives

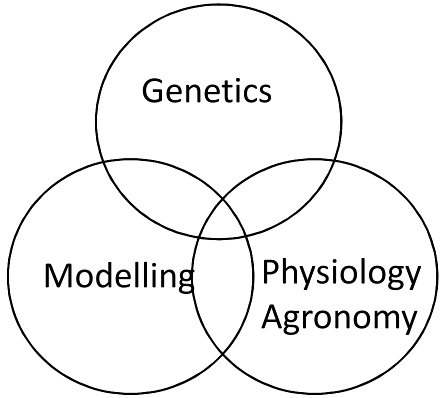
to exploit synergies between agronomic, physiological and genetic research and crop modeling

to screen for key regulatory processes of adaptation to high-temperature episodes

Key traits

Photosynthesis
Stress response
Grain yield and quality

‘Heat-Wheat’ project - Framework



Physiology - development of phenotyping tools

Screening for heat stress tolerance

Genetics - QTL’s

Introduction of genes by marker assisted backcrossing
Detailed mapping of major genes for stress tolerance

Agronomy - Impact assessment

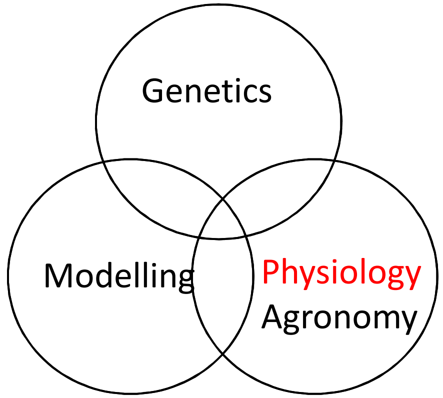
Genotypic stress responses on phenology, yield and quality

Modelling - Impact prediction

Modeling genotype responses to heat stress

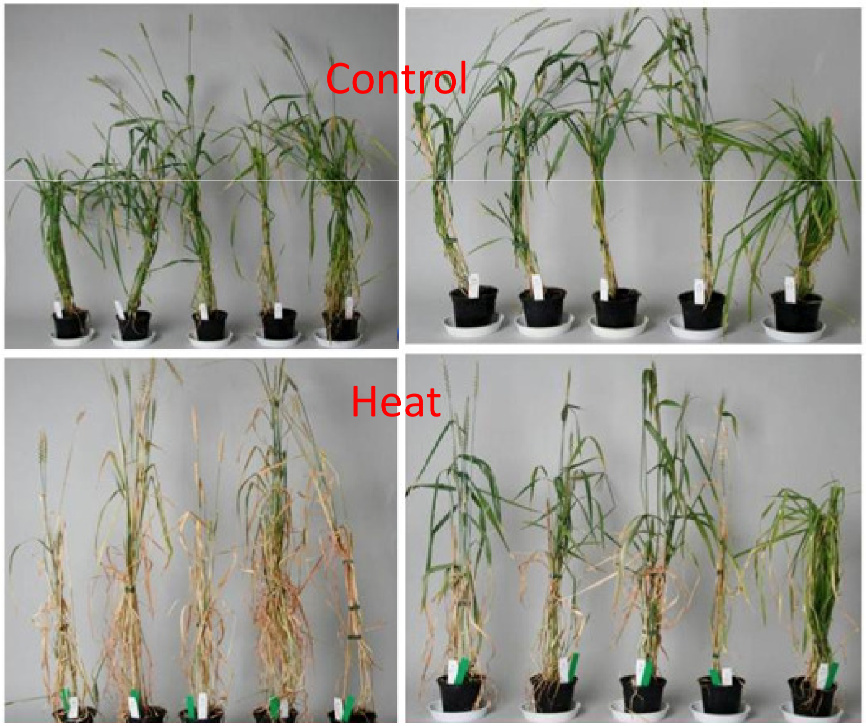
Phenotyping leaves

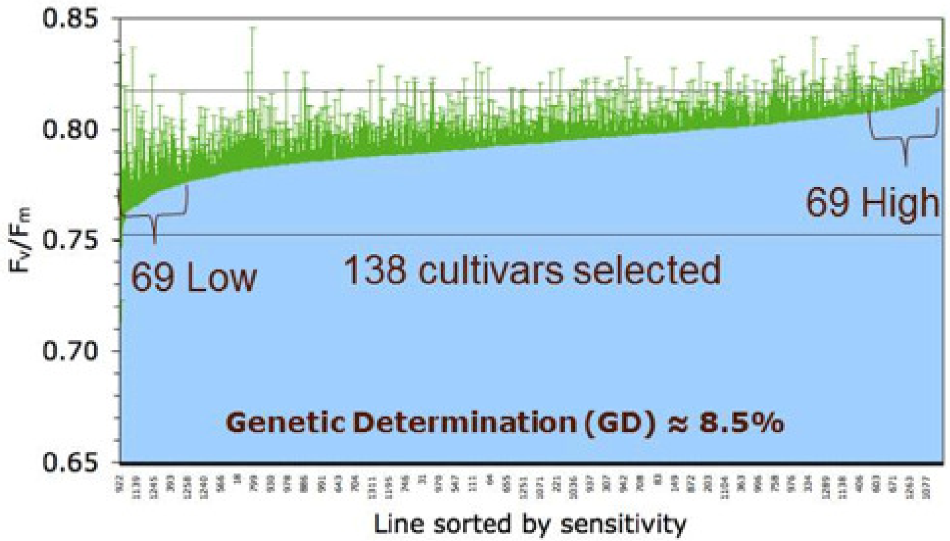
F_v/F_m (maximum quantum efficiency of PS_{II}) in leaves can be used as a phenotyping tool to screen for heat tolerance



1274 cultivars scanned –> 138 –> 41 cultivars selected

Lowest Performance Highest

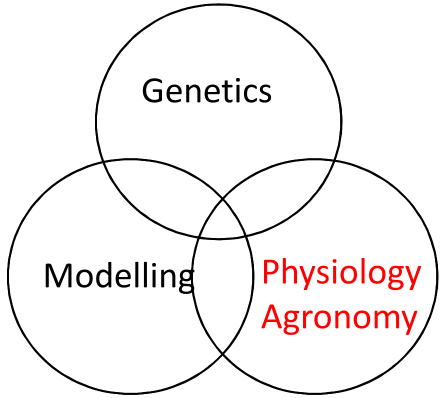




Phenotyping of wheat cultivars for heat tolerance using chlorophyll a fluorescence
Dew Kumari Sharma, Sven Bode Andersen, Carl-Otto Ottosen, Eva Rosenqvist *Functional Plant Biology*, ***39***, *936–947 (2012)*

Phenotyping grains

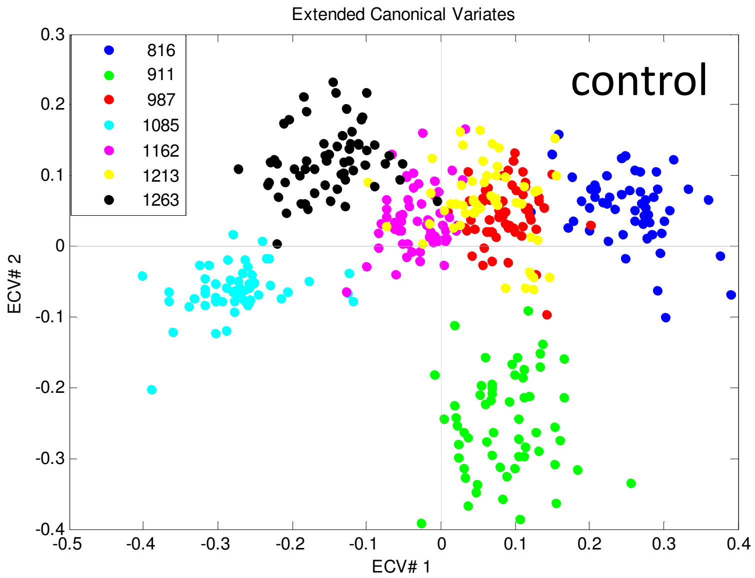
Heat stress effects on phenology and yield

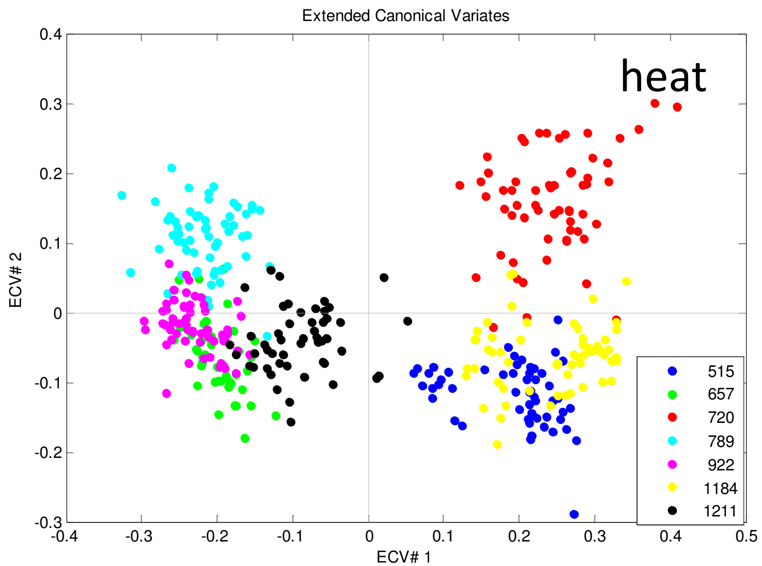


'Semi-field' experiments with 140 -> 15 cultivars

Single seed near infrared (NIR) transmission spectroscopy

ECVA score plot of two first components of selected samples for control and heat treatments

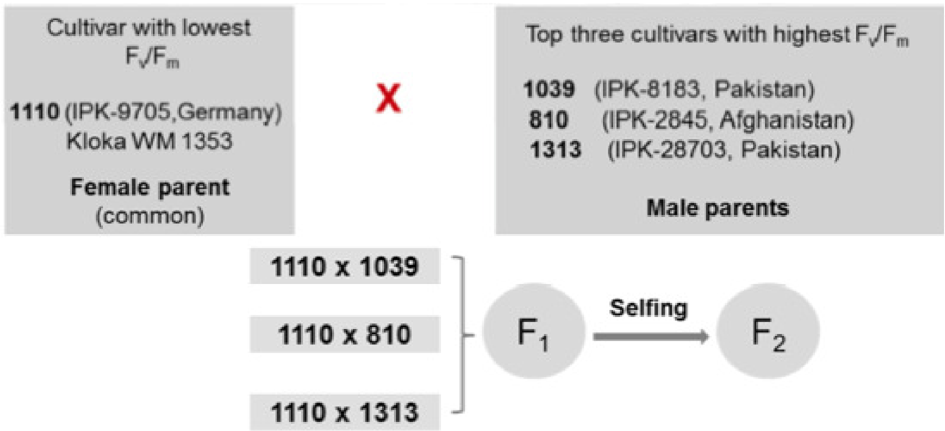


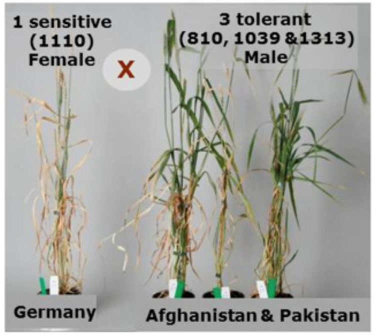


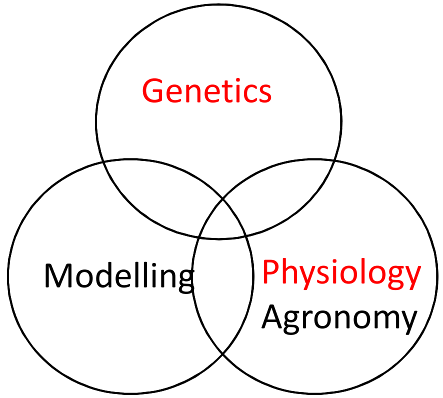
Identification of extreme winter wheat varieties using single seed near infrared (NIR) diffuse transmission spectroscopy in combination with Puchweins algorithm and extended canonical variates analysis (ECVA). Gislum, R.; Shetty, N.; Jørgensen, J.R.; Wang, X.; Li, H.; Wollenweber, B. *in preparation*

Genetics and Biotechnology

Generation of mapping population







Genotyping -> Linkage analysis -> QTL mapping

- 3 heat inducible QTLs related to F_v/F_m mapped

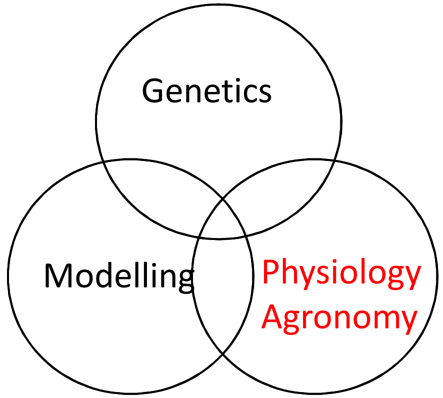
Dew Kumari Sharma (2013) -Heat tolerance in wheat: Linking physiological phenotyping to quantitative genetics. *PhD dissertation 2013*

Heat stress effects on phenology

Heat stress impact

‘Semi-field’ experiments 15 cultivars

Field experiment with 9 cultivars



>> Reduction in grain filling duration

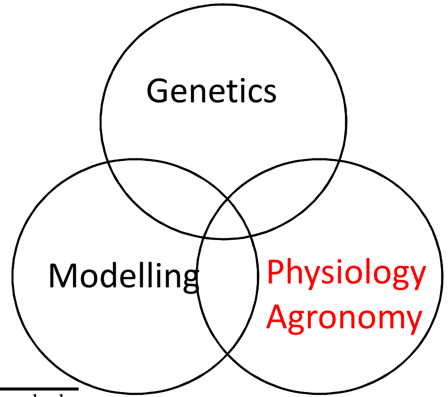
Cultivar number	Cultivar name	Source	Geographical origin	Height (cm)	GS31	GS65	GS92 Control	GS92 Heat	Treatment effect (ΔDays)
810	N/A	IPK	Afghanistan	100	31	53	107	104	-3
490	Balady 16	NGB	Denmark	75	31	54	107	102	-5
1039	C518	IPK	Pakistan	90	29	56	110	105	-5
1110	Kloka WM1353	IPK	Germany	95	28	57	110	102	-8
Taifun	Taifun	NGB	Denmark	64	32	58	112	105	-7
Tercie	Tercie	NGB	Denmark	67	33	58	112	106	-6
Vinjett	Vinjett	NGB	Denmark	76	31	59	107	102	-5
1216	N/A	IPK	Slovakia	94	27	60	114	106	-8
1159	8156 White	IPK	Turkey	76	32	61	115	109	-6
1194	Omskaja 9	IPK	Soviet Union	96	30	64	113	110	-3
882	N/A	IPK	Romania	110	31	64	117	110	-7
579	Postelberger Wechsel St. 61	IPK	Germany	120	33	69	118	111	-7
844	N/A	IPK	Afghanistan	122	35	70	130	118	-12
633	Hörnings Grüne Dame	IPK	Germany	110	40	84	130	123	-7
830	N/A	IPK	Afghanistan	97	42	84	133	125	-8

GS31: the start of stem elongation; GS65 is the mid-flowering stage; GS92 is maturity (BBCH scale); expressed as days after sowing (DAS).

Traits in spring wheat cultivars associated with yield loss caused by a heat stress episode after anthesis.
Vignjevic, M.; Wang, X.; Olesen, J.; Wollenweber, B. *Journal of Agronomy and Crop Science 201: 32-48 (2015)*

Heat-stress effects on yield

Genotype response -yield traits



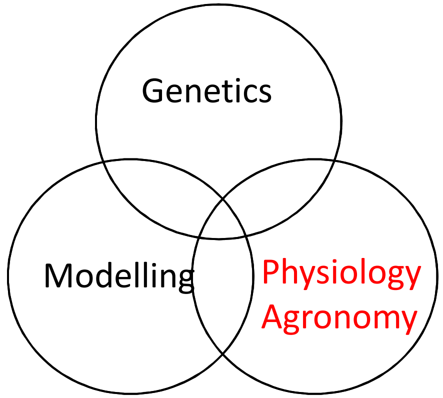
Average **grain weight** (GW, mg dry matter), **grain dry matter yield** (GY, mg plant^{-1}), **grain N yield** (GNY, mg plant^{-1}), **stem water soluble carbohydrates** (S WSC, mg plant^{-1}) and **harvest index** (HI) at maturity.

						TREATMENT EFFECTS				
	GW	GY	GNY	S WSC	HI	GW	GY	GNY	S WSC	HI
810	47 ^{abc}	1224 ^{de}	247 ^{bcde}	61 ^{e}	0.52 ^{d}	-4 ^{ef}	-171 ^{ef}	-73 ^{cd}	-2 ^{b}	-0.05 ^{bcd}
490	38 ^{fgh}	1044 ^{e}	287 ^{abcd}	67 ^{e}	0.48 ^{de}	-1 ^{f}	-116 ^{ef}	-70 ^{bcd}	296 ^{a}	-0.12 ^{fg}
1039	52 ^{a}	1339 ^{cd}	207 ^{ef}	55 ^{e}	0.49 ^{de}	-12 ^{bc}	-336 ^{cd}	-12 ^{abc}	-12 ^{b}	-0.06 ^{cde}
1110	36 ^{hi}	1317 ^{cd}	225 ^{de}	120 ^{e}	0.48 ^{de}	-4 ^{ef}	-164 ^{ef}	-30 ^{abcd}	-16 ^{bc}	-0.13 ^{fg}
Taifun	46 ^{bc}	1489 ^{bc}	291 ^{abc}	63 ^{e}	0.61 ^{ab}	-12 ^{b}	-195 ^{ef}	-56 ^{bcd}	-30 ^{bc}	-0.02 ^{abc}
Tercie	39 ^{efgh}	1958 ^{a}	276 ^{abcd}	35 ^{e}	0.65 ^{a}	-9 ^{cd}	-291 ^{def}	-60 ^{bcd}	1 ^{b}	-0.07 ^{cde}
Vinjett	44 ^{cde}	1677 ^{b}	320 ^{a}	42 ^{e}	0.54 ^{cd}	-16 ^{a}	-541 ^{a}	-93 ^{cd}	0 ^{b}	-0.14 ^{g}
1216	41 ^{defg}	1499 ^{bc}	240 ^{cde}	101 ^{e}	0.53 ^{cd}	-13 ^{b}	-491 ^{bc}	-47 ^{abcd}	-50 ^{bc}	-0.10 ^{def}
1159	39 ^{defgh}	1667 ^{b}	147 ^{fg}	16 ^{f}	0.59 ^{bc}	-5 ^{de}	-138 ^{ef}	43 ^{a}	5 ^{b}	0.01 ^{a}
1194	43 ^{cdef}	1571 ^{bc}	300 ^{ab}	224 ^{d}	0.35 ^{h}	-18 ^{a}	-560 ^{ab}	-130 ^{d}	79 ^{b}	-0.03 ^{ab}
882	33 ^{i}	1580 ^{bc}	231 ^{cde}	387 ^{bc}	0.44 ^{ef}	-12 ^{b}	-498 ^{ab}	-62 ^{bcd}	-336 ^{d}	-0.09 ^{efg}
579	37 ^{ghi}	1209 ^{de}	201 ^{ef}	281 ^{d}	0.41 ^{fg}	-6 ^{de}	-217 ^{ef}	-21 ^{abc}	-183 ^{cd}	-0.05 ^{bcd}
844	44 ^{bcd}	1320 ^{cd}	186 ^{efg}	1607 ^{a}	0.36 ^{gh}	7 ^{g}	-118 ^{f}	32 ^{ab}	**-1033** ^{f}	-0.02 ^{abc}
633	49 ^{ab}	1202 ^{de}	188 ^{efg}	1292 ^{b}	0.32 ^{h}	-10 ^{bc}	-248 ^{de}	-21 ^{abc}	-851 ^{e}	-0.02 ^{abcd}
830	50 ^{ab}	1097 ^{de}	138 ^{g}	1536 ^{a}	0.36 ^{gh}	-15 ^{ab}	-558 ^{ab}	-28 ^{abcd}	-240 ^{d}	-0.15 ^{g}

Also highest reduction in grain filling duration

Traits in spring wheat cultivars associated with yield loss caused by a heat stress episode after anthesis.
Vignjevic, M.; Wang, X.; Olesen, J.; Wollenweber, B. *Journal of Agronomy and Crop Science 201: 32-48 (2015)*

Heat-stress effects on photosynthesis



Effects of heat stress on net photosynthetic CO_2 assimilation rate (Pn), stomatal conductance (gs), transpiration rate (Tr), and chlorophyll content (SPAD) in leaves

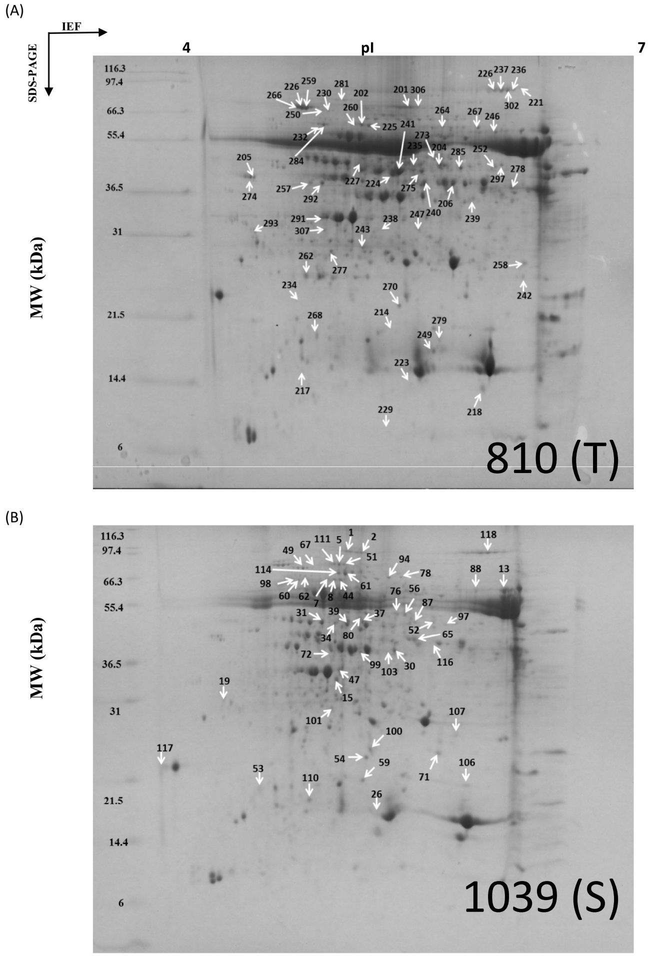
	Pn		gs		Tr		Chl content	
Varieties	Control	Heat	Control	Heat	Control	Heat	Control	Heat
490	20.1a^A	12.0bcd^B	0.74a^A	0.34b^B	2.0cd^B	3.9fg^A	53.0a^A	41.1d^B
579	13.5c^A	9.6d^B	0.26b^A	0.35b^A	2.0cd^B	7.3bc^A	49.2b^A	44.7c^B
633	13.5c^A	8.4d^B	0.40b^A	0.59ab^A	4.2b^B	8.0b^A	39.8c^A	30.5e^B
810	17.4ab^A	18.7a^A	0.51ab^A	0.74a^A	5.9a^B	11.9a^A	49.9b^A	47.9b^A
1039	15.2bc^A	1.6e^B	0.42b^A	0.03c^B	2.6cd^A	0.8h^B	48.7b^A	32.1e^B
1110	13.5c^A	12.1bcd^A	0.33b^A	0.36b^A	1.6cd^B	3.3g^A	48.4b^A	47.6b^A
1159	13.7c^A	10.3cd^B	0.38b^A	0.25bc^A	3.0bc^A	4.3efg^A	49.8b^A	42.5d^B
Taifun	11.7c^B	15.6ab^A	0.20b^A	0.35b^A	1.2d^B	5.9cde^A	53.8a^A	51.2a^B
Terice	12.7c^A	11.4cd^A	0.45b^A	0.42b^A	2.2cd^B	6.2bcd^A	54.3a^A	50.4a^B
Vinjett	13.1c^A	13.9bc^A	0.21b^B	0.48ab^A	1.8cd^B	5.2def^A	49.2b^A	42.0d^B
Varieties	***		**		***		***	
Treatments	***		ns		***		***	
Varieties × Treatments	***		**		***		***	

Pn (μmol CO_2 $m^{-2}s^{-1}$); gs (mol H_2O $m^{-2}s^{-1}$); Tr (mmol $H_2O m^{-2}s^{-1}$); Chl content (SPAD: Soil Plant Analysis Development meter value). Data are means of the three biological replicates (n=3). Different lowercase letters denote statistically significant differences (P<0.05) among varieties as analysed by Duncan's Multiple Range Test. Different superscript uppercase letters indicate statistically significant differences (P<0.05) between control and heat treatment within the same variety. **: significant difference at P<0.01. ***: significant difference at P<0.001. ns: no significant difference.

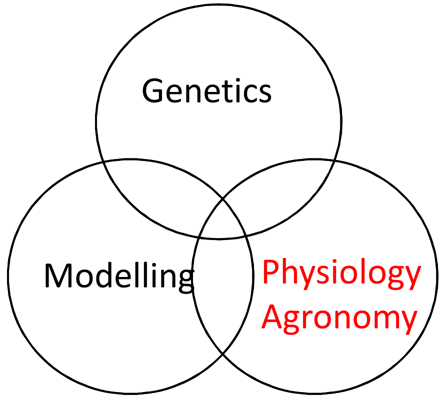
Decrease Increase

Wang X.; Dinler B.S.; Vignjevic M.; Jacobsen S.; Wollenweber B. (2015) Physiological and proteome studies of responses to heat stress during grain filling in contrasting wheat cultivars. *Plant Science 230*: 33-50.

Heat-stress effects on leaf proteins



2-DE gels of wheat leaf proteins
in variety 810 (A) and 1039 (B)



Rubisco activase
Rubisco small subunit
Rubisco large subunit

up-regulated in 810 (Tolerant)
down-regulated in 1039 (Susceptible)

Other identified proteins:
Heat shock proteins
Stress defense

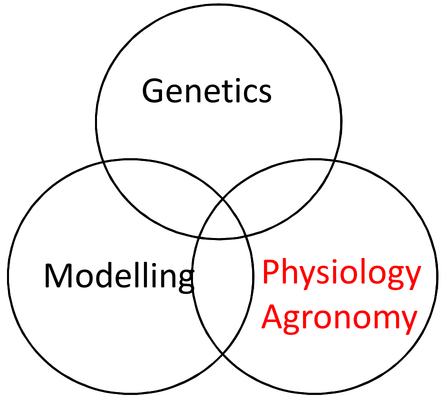
Wang X.; Dinler B.S.; Vignjevic M.; Jacobsen S.; Wollenweber B. (2015) Physiological and proteome studies of responses to heat stress during grain filling in contrasting wheat cultivars. *Plant Science 230*: *33-50.*

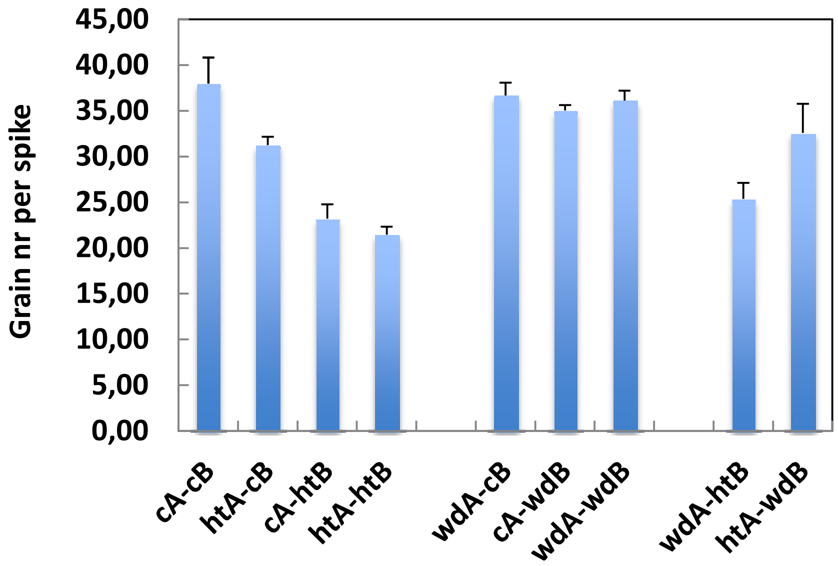
Multiple stress events and multiple stress types

Treatments

c: control; **wd**: water deficits; **ht**: high temperature

Treatments were applied at end of spikelet initiation (**A**) and/or anthesis (**B**)





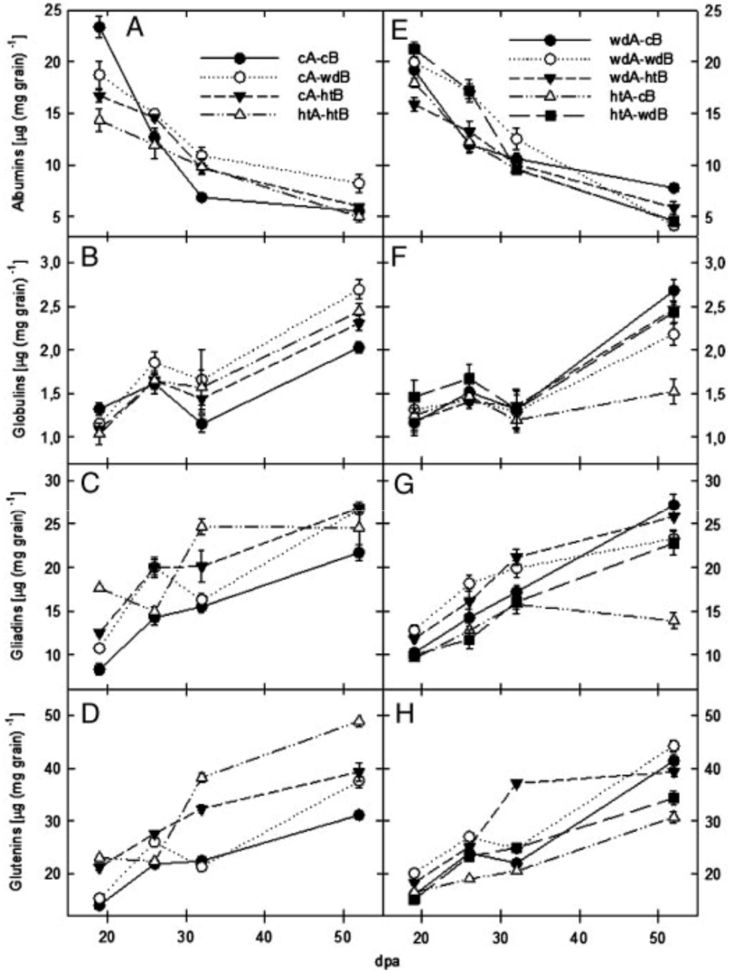
Changes in grain nr

Conclusions

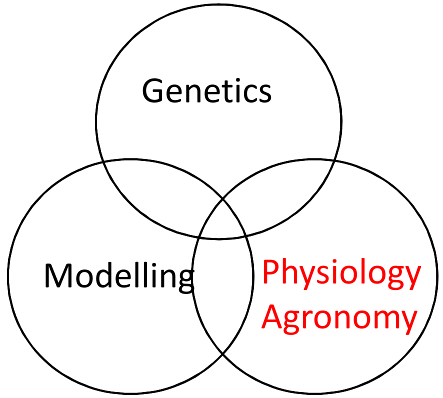
Heat had a larger impact than drought
Larger impact when applied at anthesis
Drought - no significant differences

Multiple heat and drought events affect grain yield and accumulations of high molecular weight glutenin subunits and glutenin macropolymers in wheat. Zhang, X.; Cai, J.; Wollenweber, B.; Liu, F.; Dai, T.; Cao, W.; Jiang, D. (2013) *Journal of Cereal Science 57: 134-140.*

Multiple stress events and multiple stress types



Accumulation of albumins, globulins, gliadins and glutenins in wheat grains under high- temperature and/or water-deficits applied at terminal spikelet and/or anthesis.



Changes in grain protein fractions

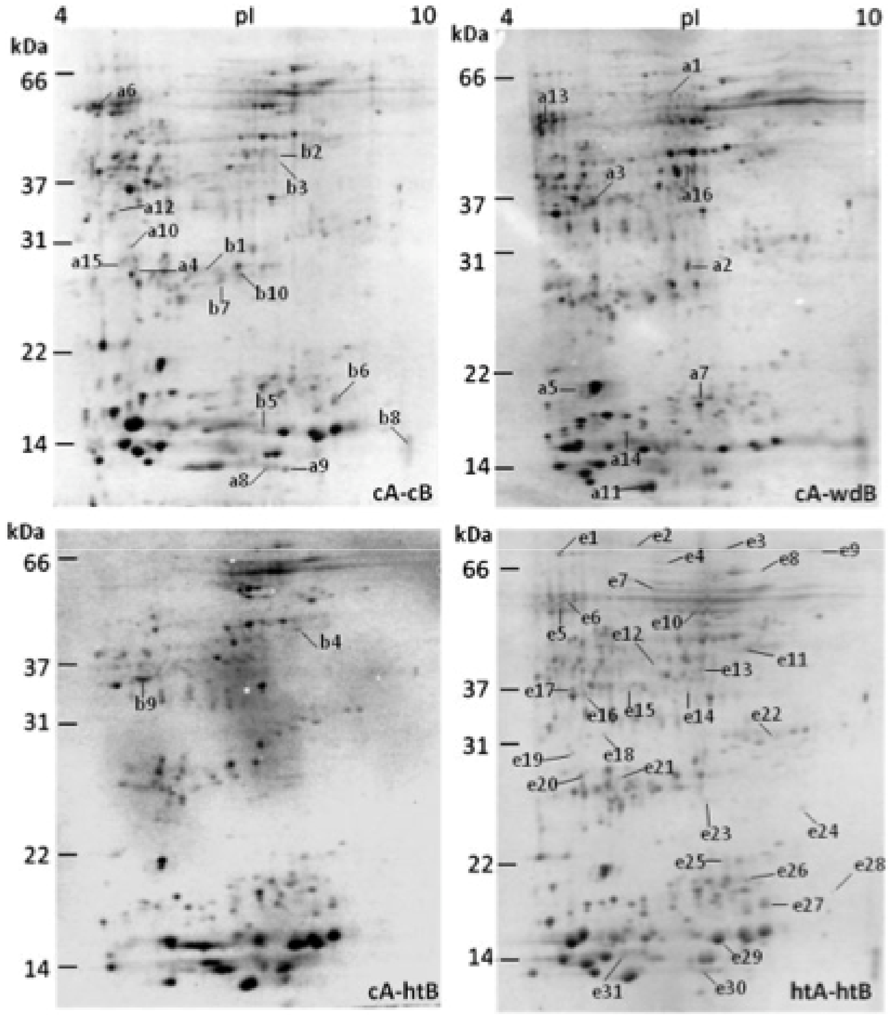
Conclusions

Albumin, globulin and gliadin contents:
Stress combinations did not have a significant effect compared to individually applied stresses

Stress combinations resulted in significantly higher contents of glutenins than in the single stress treatments

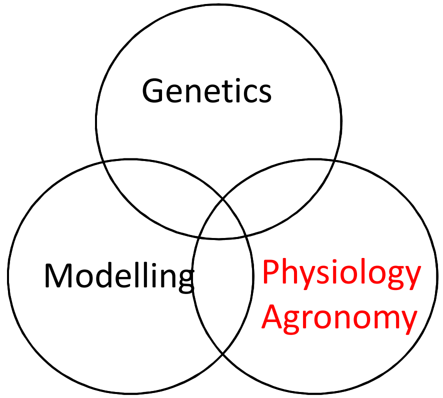
Implications of high-temperature events and water deficits on protein profiles in wheat (*Triticum aestivum* L. cv. Vinjett) grain
Yang F, Dysted-Jørgensen A, Li H, Søndergaard I, Finnie C, Svensson B, Jiang D, Wollenweber B, Jacobsen S *Proteomics 11: 1684-1695 (2011)*

Multiple stress events and multiple stress types



2-DE gels of the **albumin** fraction from wheat grains

Treatments: cA-cB cA-wdB cA-htB htA-htB



Changes in grain albumin fraction

Conclusions

Changes in grain protein contents strongly depended on the type of stress interactions applied

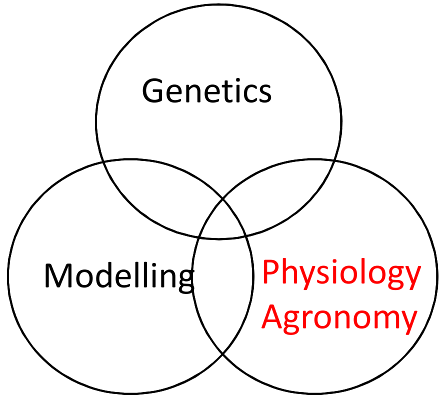
Identified proteins responsive to stress episodes play roles in:
anti-desiccation,
anti-oxidation,
carbohydrate metabolism

Implications of high-temperature events and water deficits on protein profiles in wheat (*Triticum aestivum* L. cv. Vinjett) grain
Yang F, Dysted-Jørgensen A, Li H, Søndergaard I, Finnie C, Svensson B, Jiang D, Wollenweber B, Jacobsen S *Proteomics 11: 1684-1695 (2011)*

Priming

Beneficial interaction of multiple stress events?

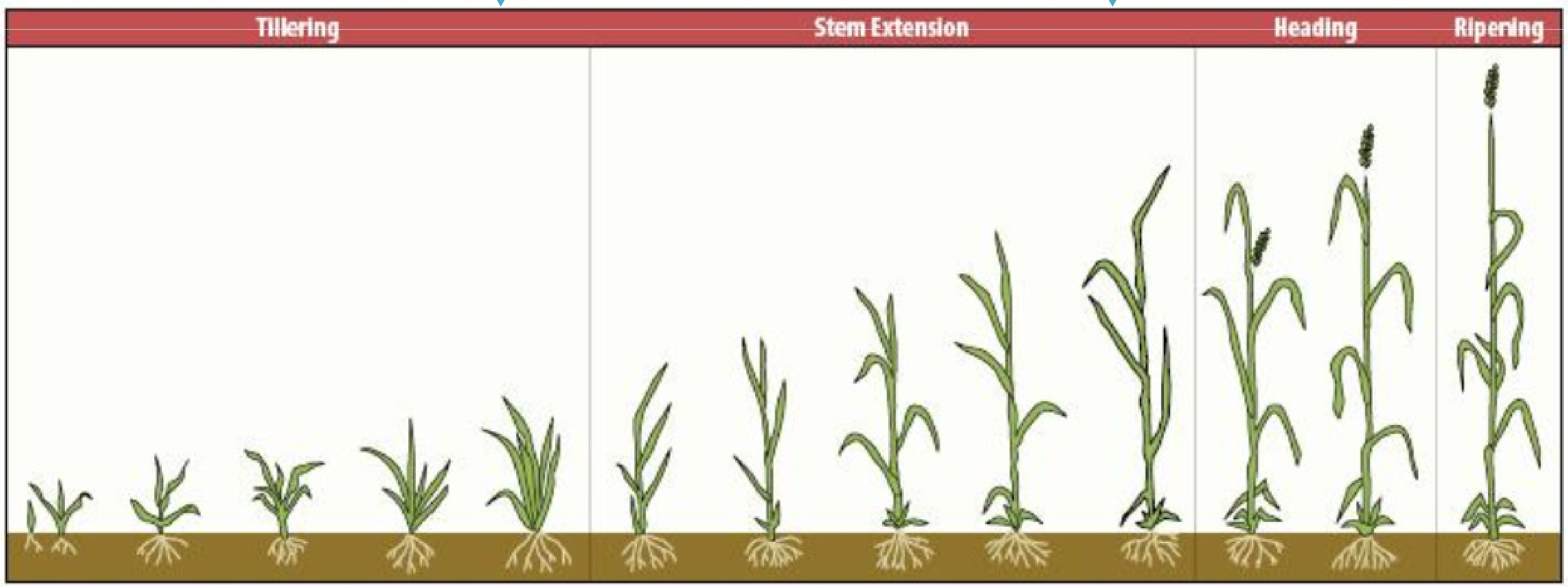
Pre-exposure to mild drought stress during vegetative growth



NN: Non-primed

NP: Priming at stem-elongation

PP: Priming at tillering and stem-elongation



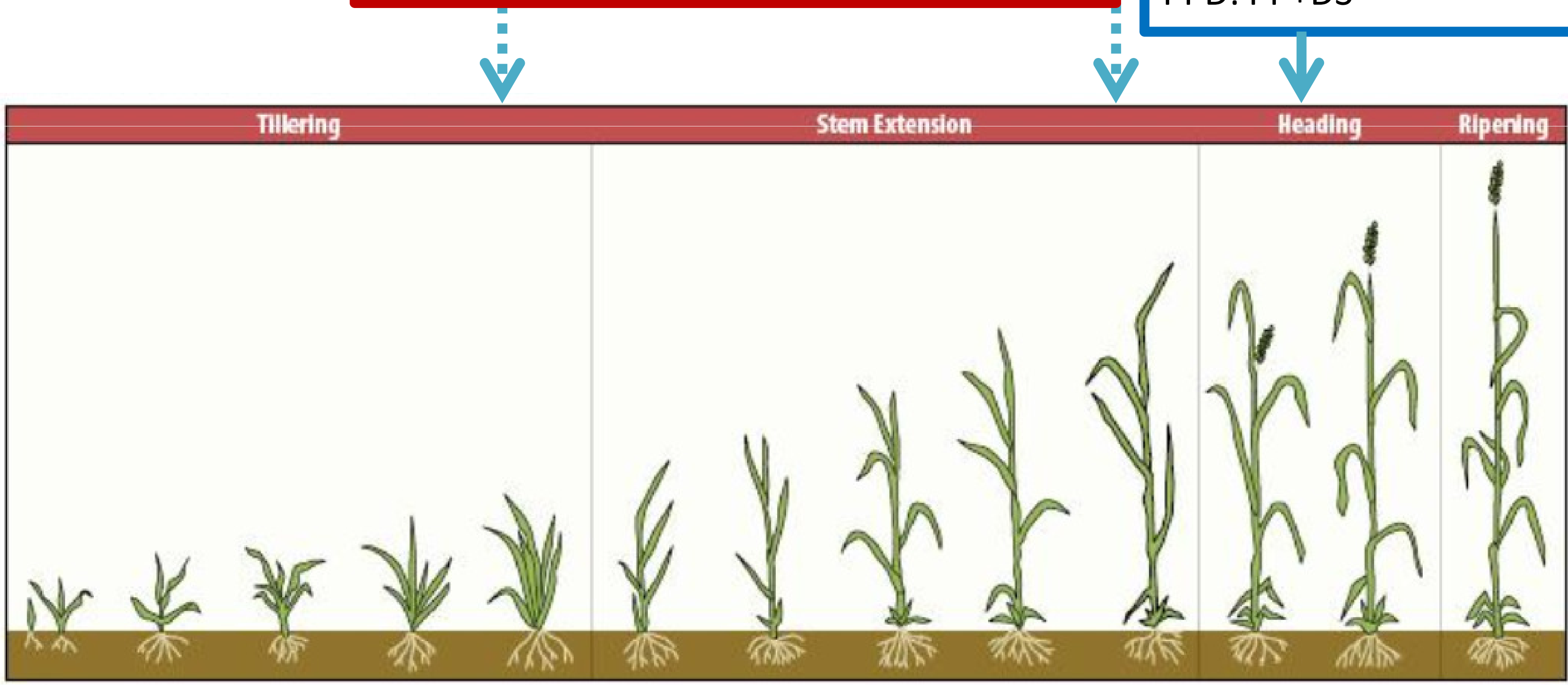
Priming

Beneficial interaction of multiple stress events?

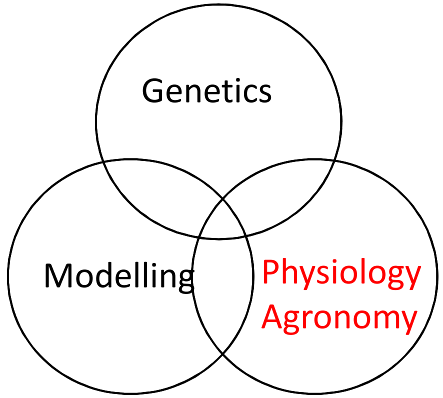
Pre-exposure to mild stress during vegetative growth –> effects on stress after anthesis

NN: Non-primed
NP: Priming at stem-elongation
PP: Priming at tillering and stem-elongation

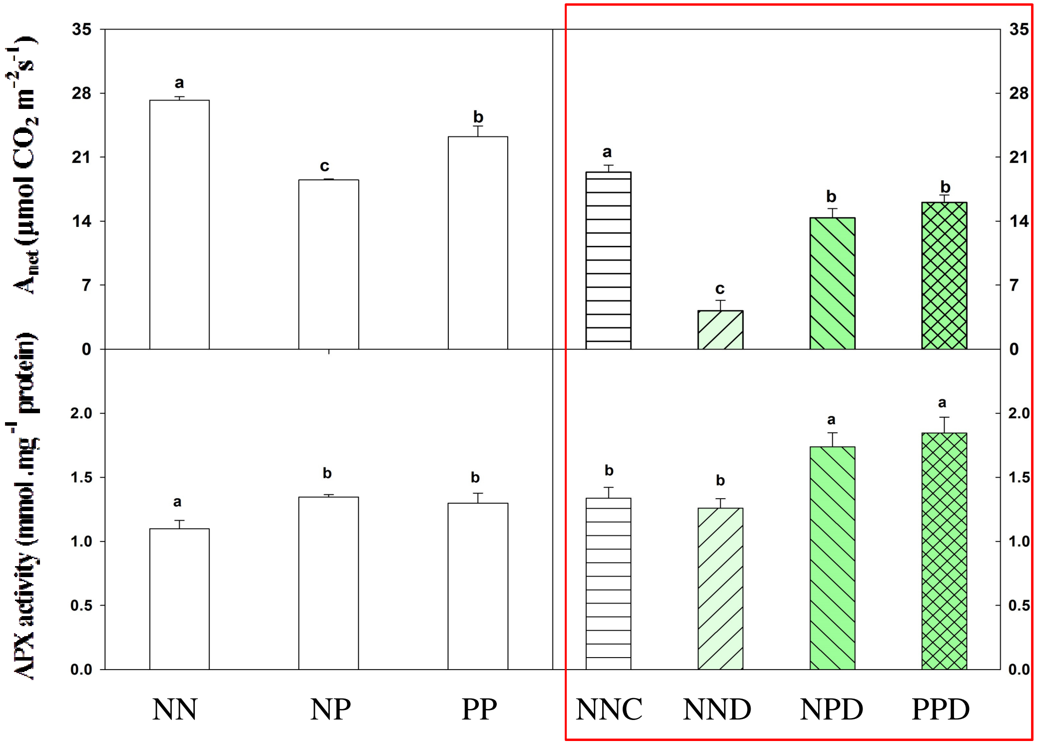
NNC: Control
NND: NN+DS (drought stress)
NPD: NP+DS
PPD: PP+DS



Priming



Primed plants improved photosynthesis
and ROS scavenging efficiency under drought stress



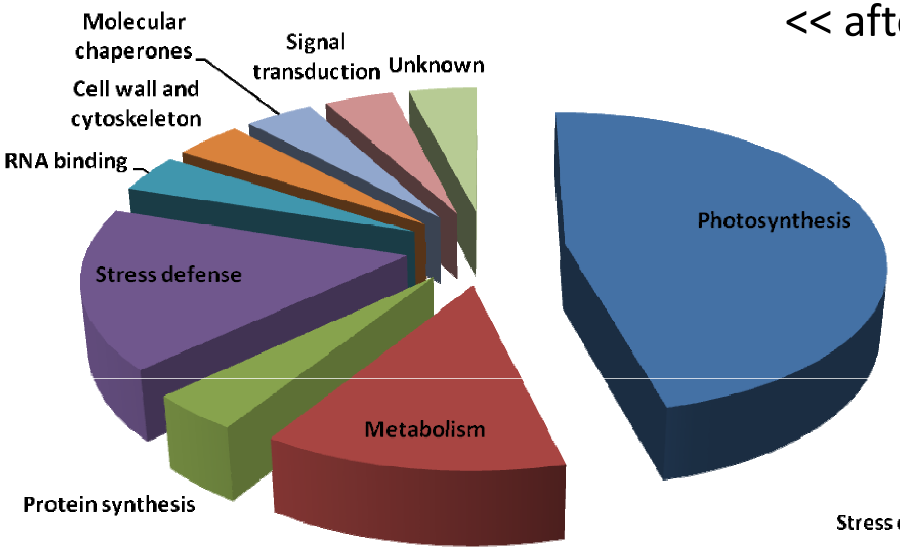
Effects of drought priming on photosynthesis rate (A_{net}) and Ascorbate peroxidase (APX) activity in wheat leaves under drought stress

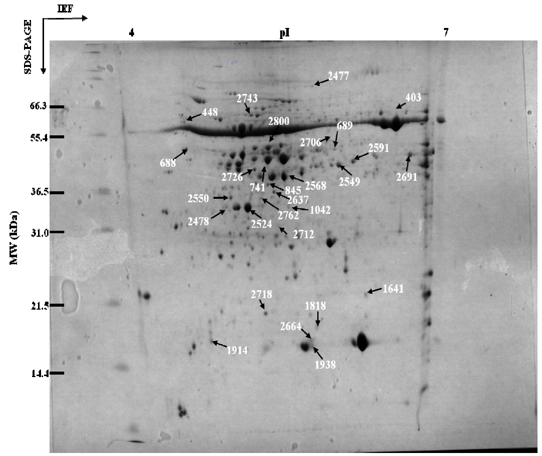
Improved tolerance to drought stress after anthesis due to priming before anthesis in wheat (Triticum aestivum L.) var. Vinjett
Wang,X.; Vigjevic, M.; Jiang, D.; Jacobsen, S.; Wollenweber, B. *Journal of Experimental Botany 65:6441-6456 (2015)*

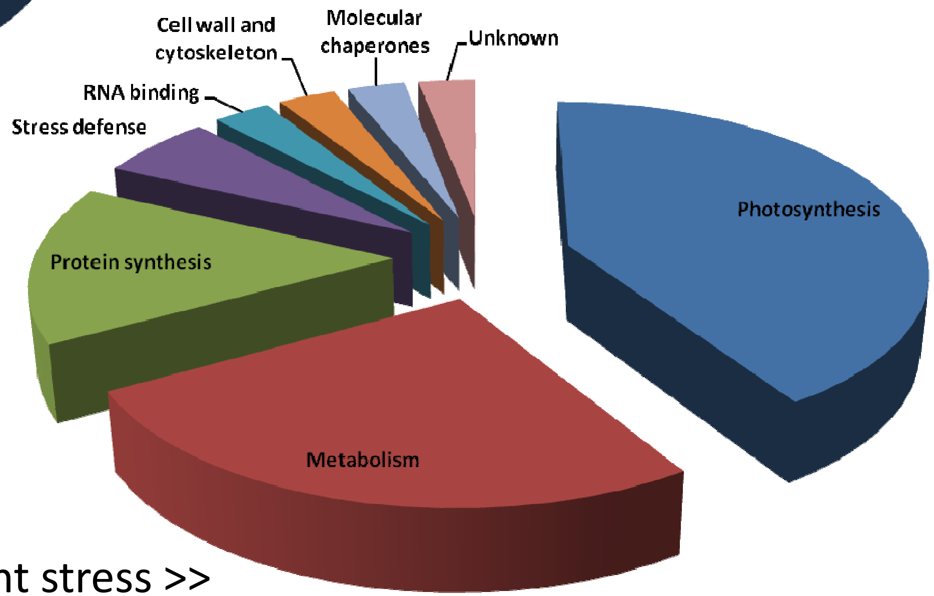
Priming

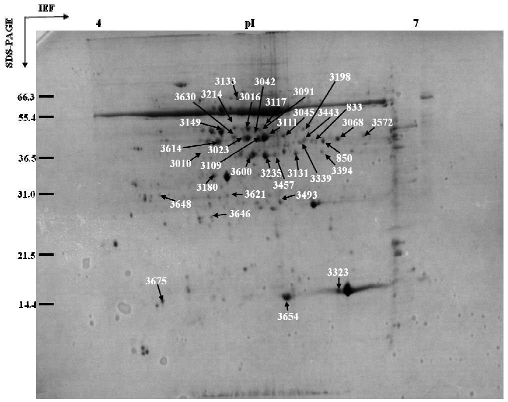
Differently expressed leaf proteins in primed plants

<< after priming >>





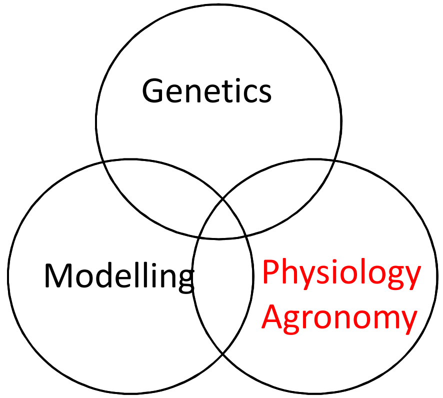




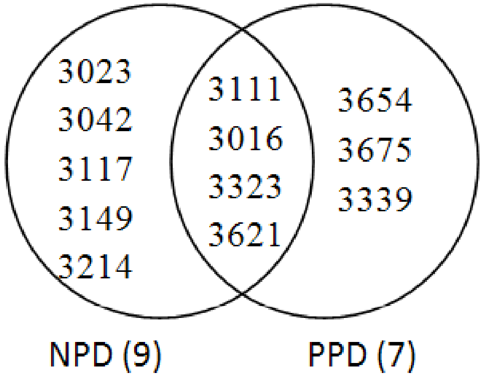
<< after drought stress >>

Priming

Primed plants modified protein expression



Up-regulated compared with NND



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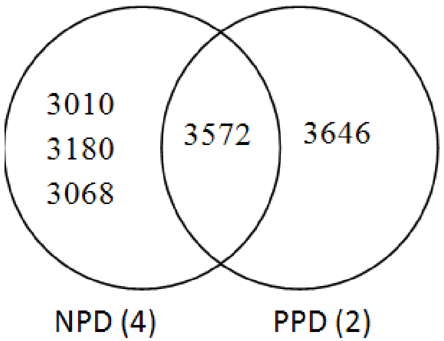
Rubisco activase

Rubisco small subunit

Ascorbate peroxidase

Down-regulated compared with NND



→

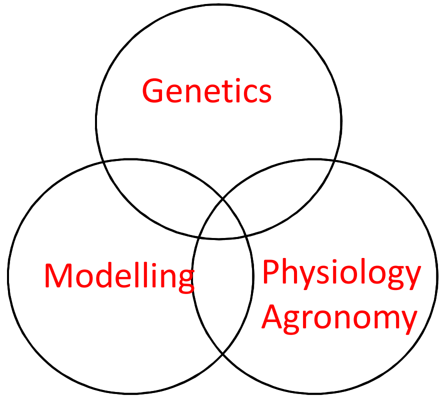
Cytosol fructose bisphosphate aldolase

Plastid glutamine synthetase isoform GS2c

Oxygen-evolving enhancer protein 1

Improved tolerance to drought stress after anthesis due to priming before anthesis in wheat (Triticum aestivum L.) var. Vinjett
Wang,X.; Vigjevic, M.; Jiang, D.; Jacobsen, S.; Wollenweber, B. *Journal of Experimental Botany 65:6441-6456 (2015)*

'Heat-Wheat' project - Conclusions



Physiology - Phenotyping tools established

Screening for heat stress with F_v/F_m
Single seed near infrared (NIR) transmission spectroscopy

Genetics - QTL's

3 heat inducible QTLs related to F_v/F_m mapped

Agronomy - Impact assessment

Genotype responses to heat and drought stress & combinations
Priming might have the potential to contribute to enhanced tolerance

Modeling - Impact prediction

Modeling genotype response to changes in temperature

Final 'take-home' message

To tackle the challenges facing society (energy, water, climate, food, health), **scientists and social scientists must work together**.

Yet research that transcends traditional academic boundaries is still unfashionable and poorly rewarded.

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DTU: Ljiljana Nesic[+], Anne Blicher

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DANIDA

China Scholarship Council
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Thank you!