Main issues of seed biology in a changing world

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Paris, France

CA19110

Sorbonne University
Paris

- A NEW UNIVERSITY WITH A CENTURIES-OLD TRADITION

Combining Humanities, Sciences and Medicine

In Education:

→**55,300 students,**
of which **10,800 are international**

→**53 bachelor's degrees**
of which **19 are bi-disciplinary**

→**33 master's degrees**
with more than **39 international specializations**

In Research:

→**3,400 academic researchers**

→**3,000 partner researchers**

→**135 research structures**

→**3,900 doctoral students**

- **ENGAGING WITH SOCIETY BY ASKING THE BIG QUESTIONS**

World-Class Science and Engineering

→ **1,560** professor-researchers

→ **19,600** students

→ **+85** laboratories

→ **Polytech-Sorbonne**
engineering school

→ **4 oceanic observatories**
on three coasts and in Paris

→ **2 institutes:** Astrophysics of Paris
and Henri Poincaré

- **Both basic and applied research:**
- Mathematics, Computer Sciences
  and Engineering
- Energy, Matter and the Universe
- Living Earth, Oceans & the Environment
- Life Sciences

- PUSHING THE BOUNDARIES OF WHAT WE KNOW

Seed Biology Team
Head : Christophe Bailly
Staff: 8 permanent positions
6 PhD

Created in the 70's

Species studied: wheat, corn, rapeseed, sunflower, barley, oat, tomato, pepper, bean, lettuce, pea, carrot, leek, onion,….

More than 500 publications in seed biology

Actual research:
Signaling role of reactive oxygen species
&
Role of post-transcriptional mechanisms
in the regulation of seed germination and dormancy

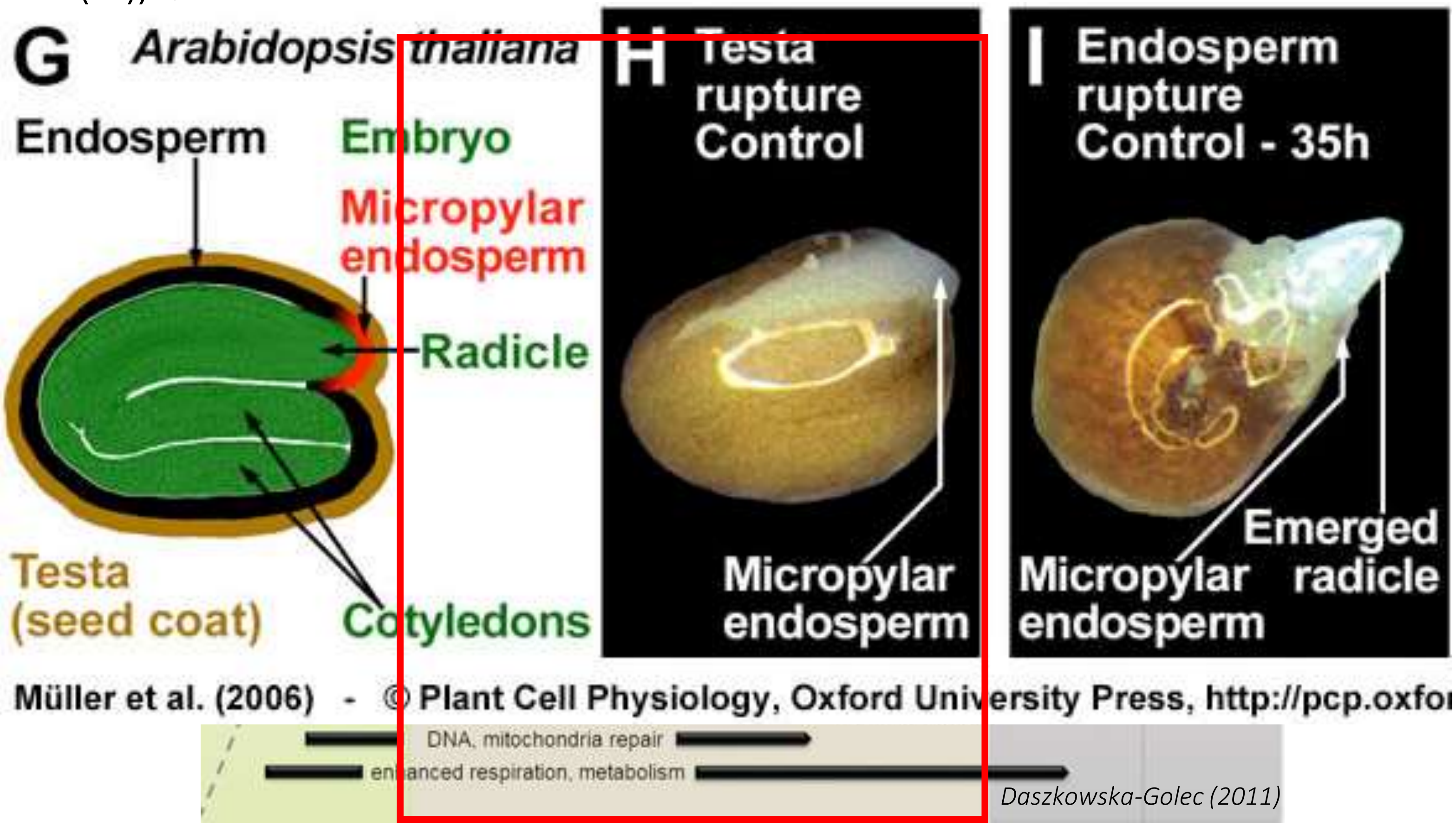
Seed germination: the most critical stage in plant life ?

Seed germination:

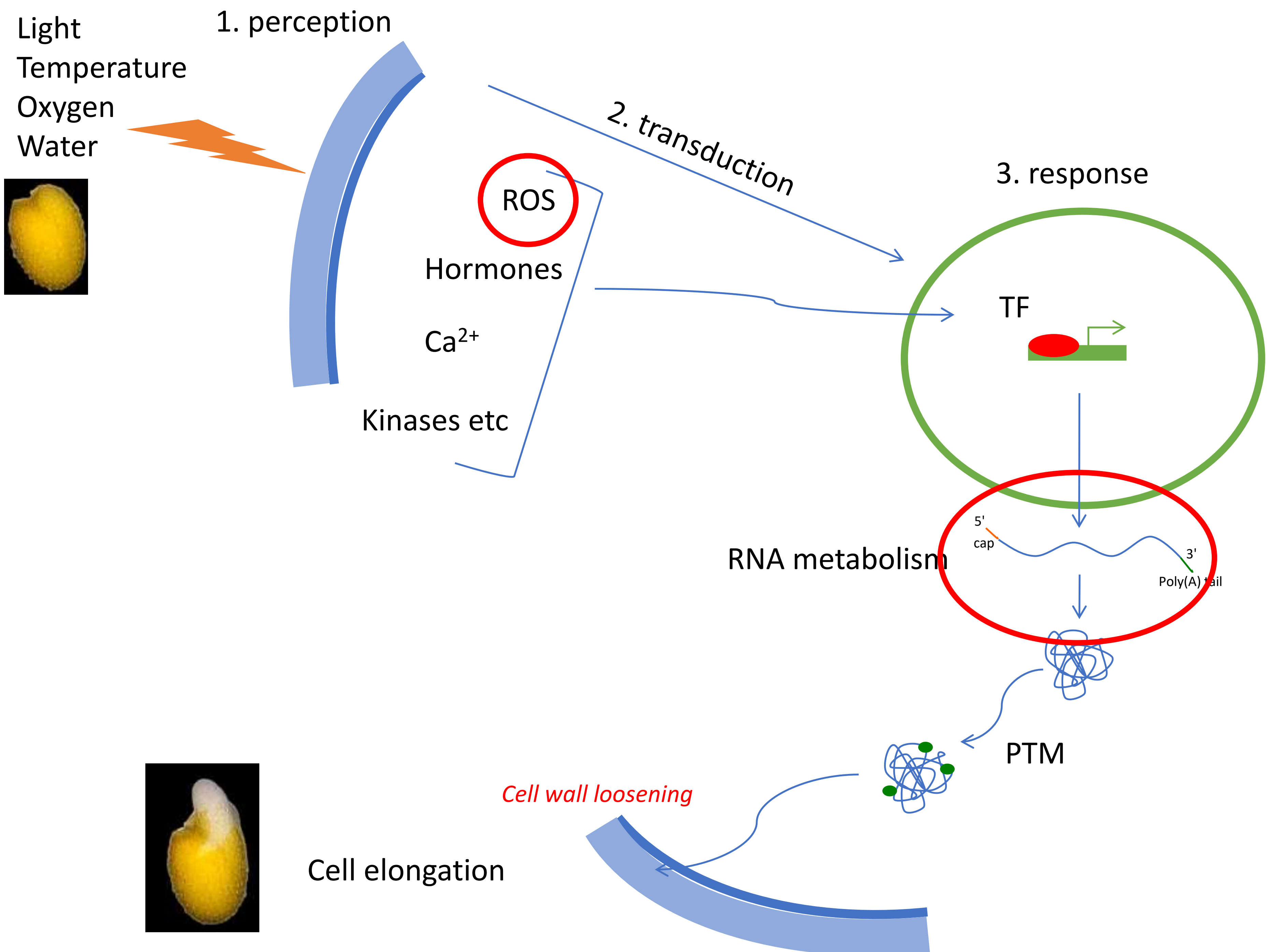
- Major developmental change in plants, permits obtaining a young growing plant from a quiescent seed

- Completed with the appearance of the embryo through the seed surrounding structure(s)

- Tightly regulated by external (light, temperature, oxygen) and internal (plant hormones: abscisic acid (ABA) and gibberrelins (GA)) factors

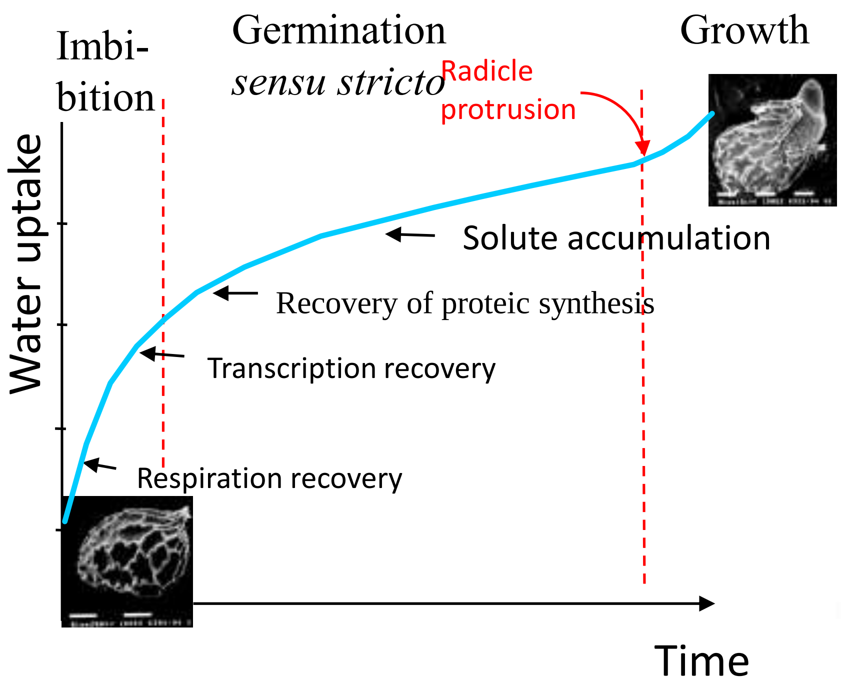


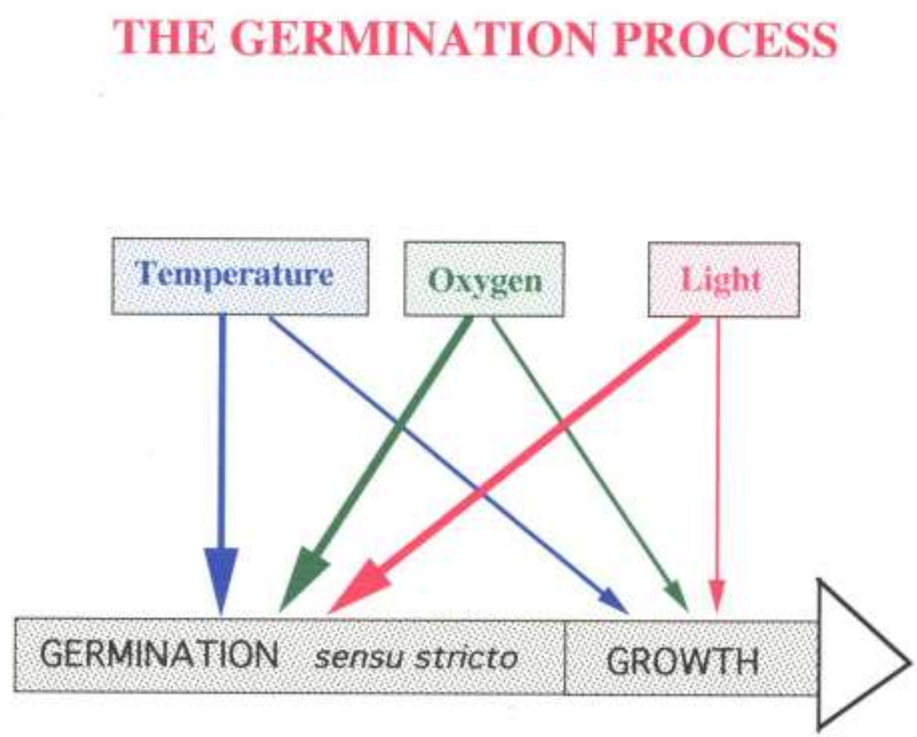
Daszkowska-Golec (2011)



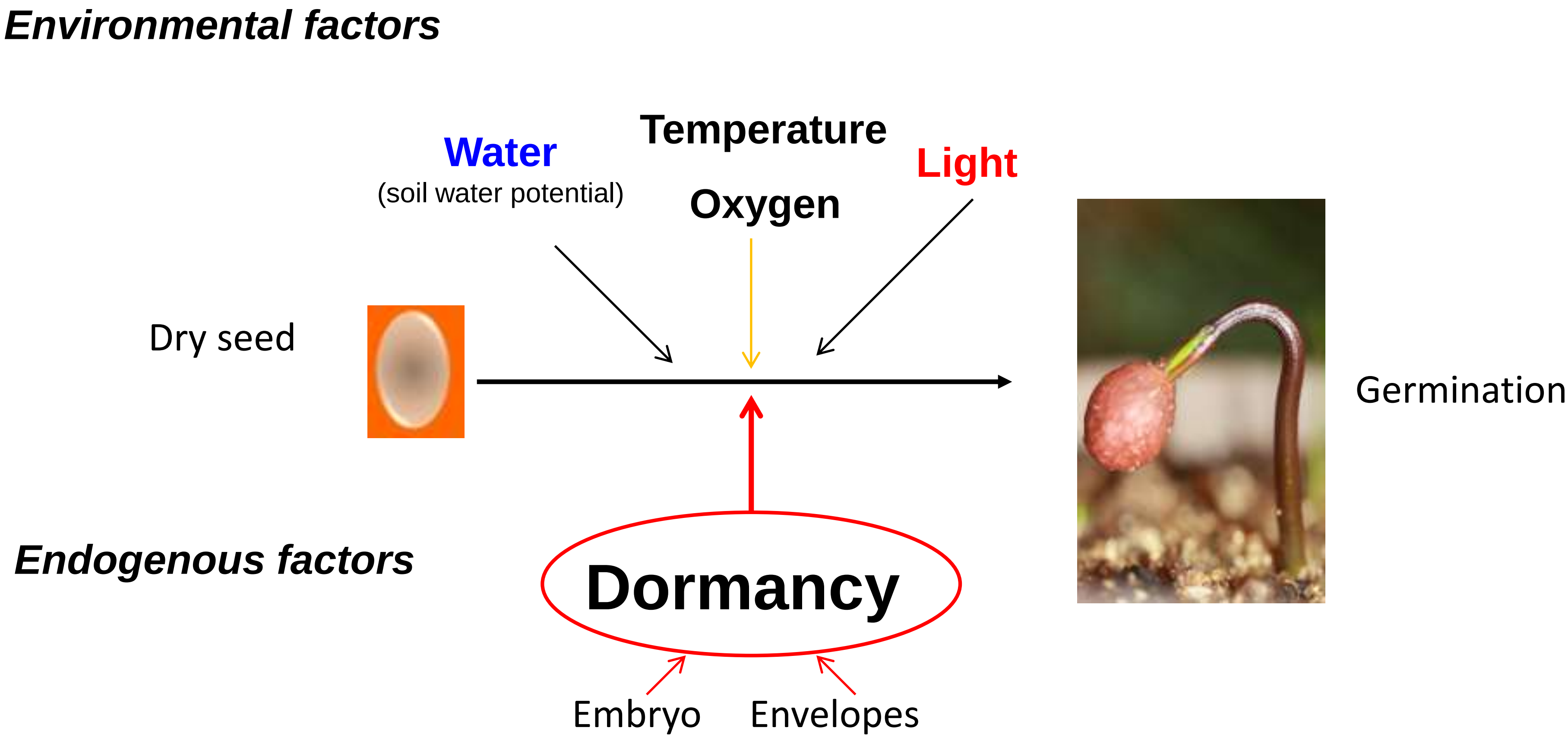
Light
Temperature
Oxygen
Water
1. perception
ROS
Hormones
Ca2+
Kinases etc
2. transduction
3. response
TF
5'
cap
RNA metabolism
3'
Poly(A) tail
PTM
Cell wall loosening
Cell elongation

Factors of germination:
Water, oxygen, temperature, light





Seed dormancy: a beneficial trait that alters ability to germinate



Quiescence: impossibility to germinate because environmental conditions are unappropriate (not enough water, temperature too low or too high, anoxia,)..

Dormancy: impossibility to germinate even when environmental conditions are apparently favourable.
Germination is possible, but in narrow conditions

Seed dormancy characteristics

Dormancy regulates germination, but it can led to false interpretations of seed batch quality

Dormancy, whether it comes from the embryo or the envelopes, is most often **a relative phenomenon**, expressed or not depending on the conditions under which the seed is placed.

A dormant seed germinates only in very specific conditions, while a non-dormant seed is much less sensitive to environmental factors.

The elimination of dormancy results in an **enlargement of the conditions** which ensure good germination.

Embryo dormancy alleviation:

Widening of the range of temperature and oxygen content of the atmosphere allowing germination

Cold stratification (imbibition at low temperature)

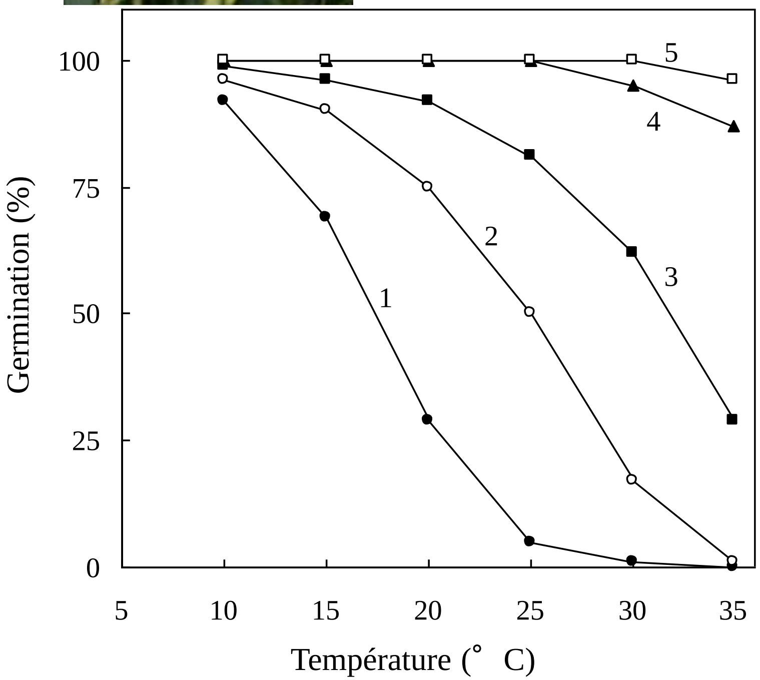
Dry after-ripening

Warm stratification (imbibition at high temperature)

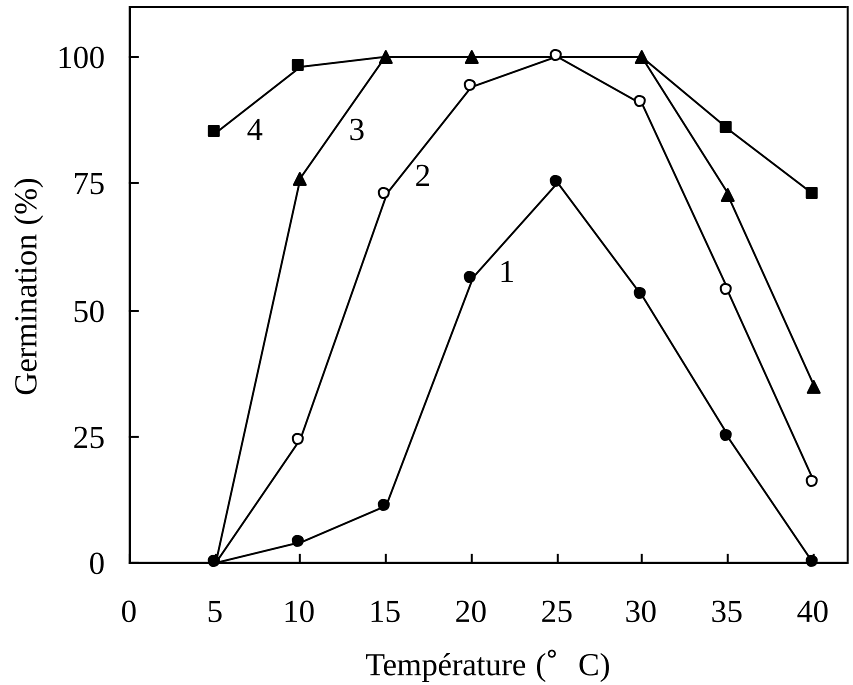
Treatment of imbibed seeds with with GA, ethylene, cyanide, alcohol, smoke…,

Examples of primary dormancy and alleviation during dry storage

barley



sunflower



1 – harvest (dormant seeds)
2, 3, 4 et 5 – different durations of dry storage

Seed quality and success of germination: a challenge for seed industry

WHAT ARE HIGH QUALITY SEEDS ?

They are seeds :

1 - which germinate all

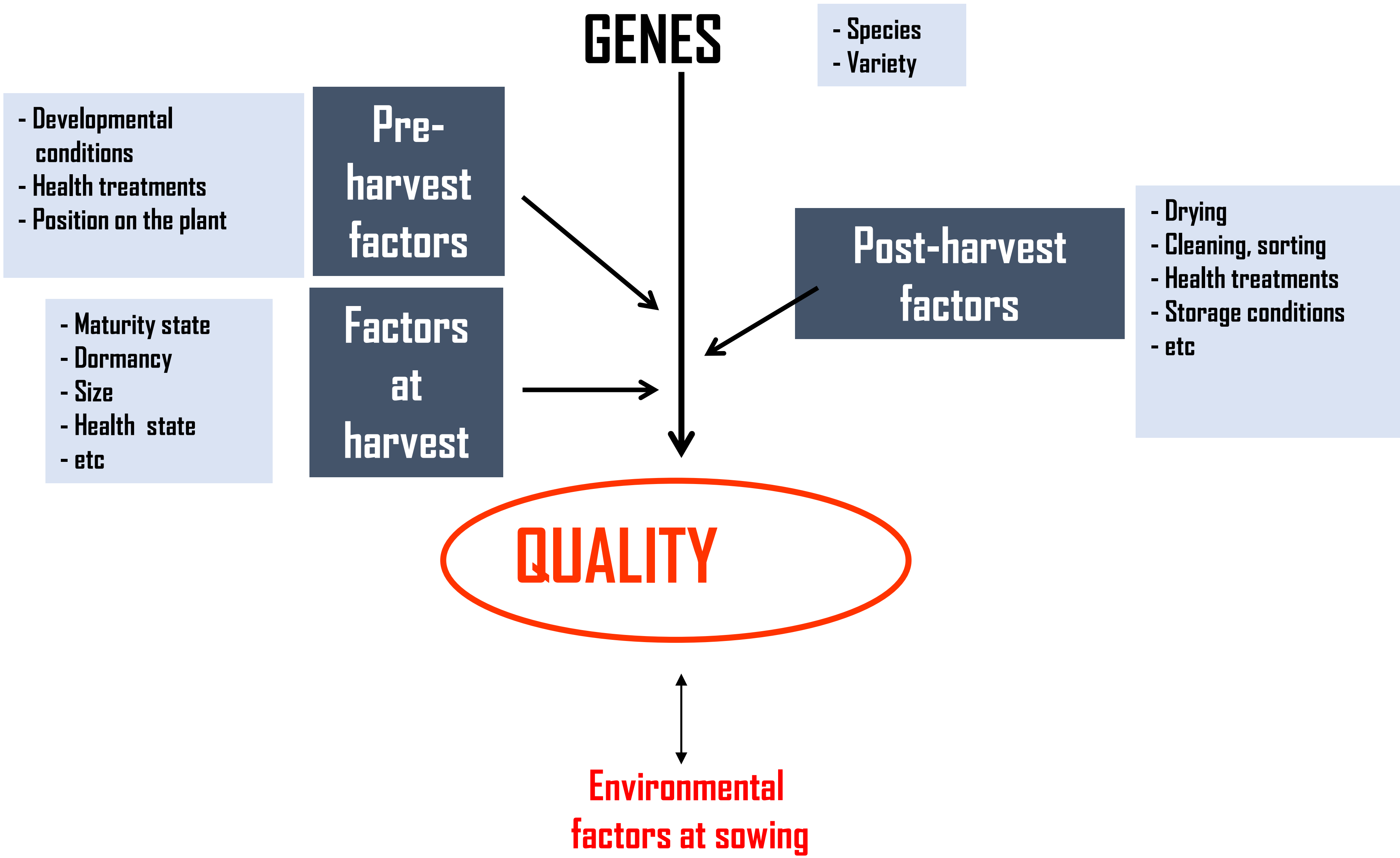
2 - which germinate quickly

3 - which give rise to normal and vigorous seedlings

4 - which are little sensitive to external factors (temperature, oxygen availability, water potential of the soil, ...), and then which germinate in a wide range of environmental conditions

5 - which can be easily stored

For seed companies a major challenge toward improving crop yield is a better control of seed vigor


GENES
- Species
- Variety
- Developmental conditions
- Health treatments
- Position on the plant
Pre-harvest factors
Post-harvest factors
- Drying
- Cleaning, sorting
- Health treatments
- Storage conditions
- etc
- Maturity state
- Dormancy
- Size
- Health state
- etc
Factors at harvest
QUALITY
Environmental factors at sowing

HOW TO EVALUATE SEED QUALITY ?

VIABILITY

- Germination in optimal conditions (ISTA tests)

VIGOR

- Germination rate (homogeneity, T_{50}, ...)
- Germination in non optimal conditions :
  - *Germination at non optimal temperature*
  - *Germination in hypoxia*
  - *Sensitivity to water potential of the medium*
  - *Sensitivity to various stresses* (chilling, cold test, ...)

STORABILITY

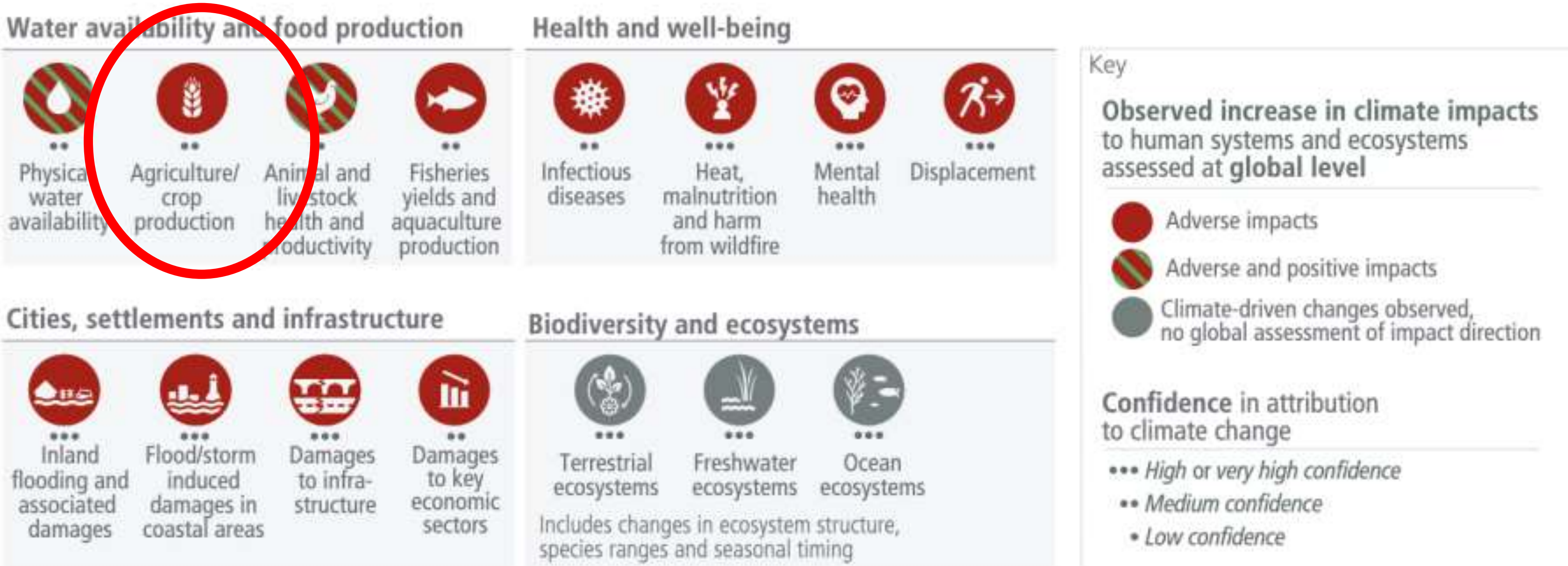
- Sensitivity to ageing (accelerated ageing or controlled deterioration)

Challenges of seed biology in a changing climate

Climate change: impacts are diverse

Adverse impacts from human-caused climate change will continue to intensify

a) **Observed widespread and substantial impacts and related losses and damages attributed to climate change**

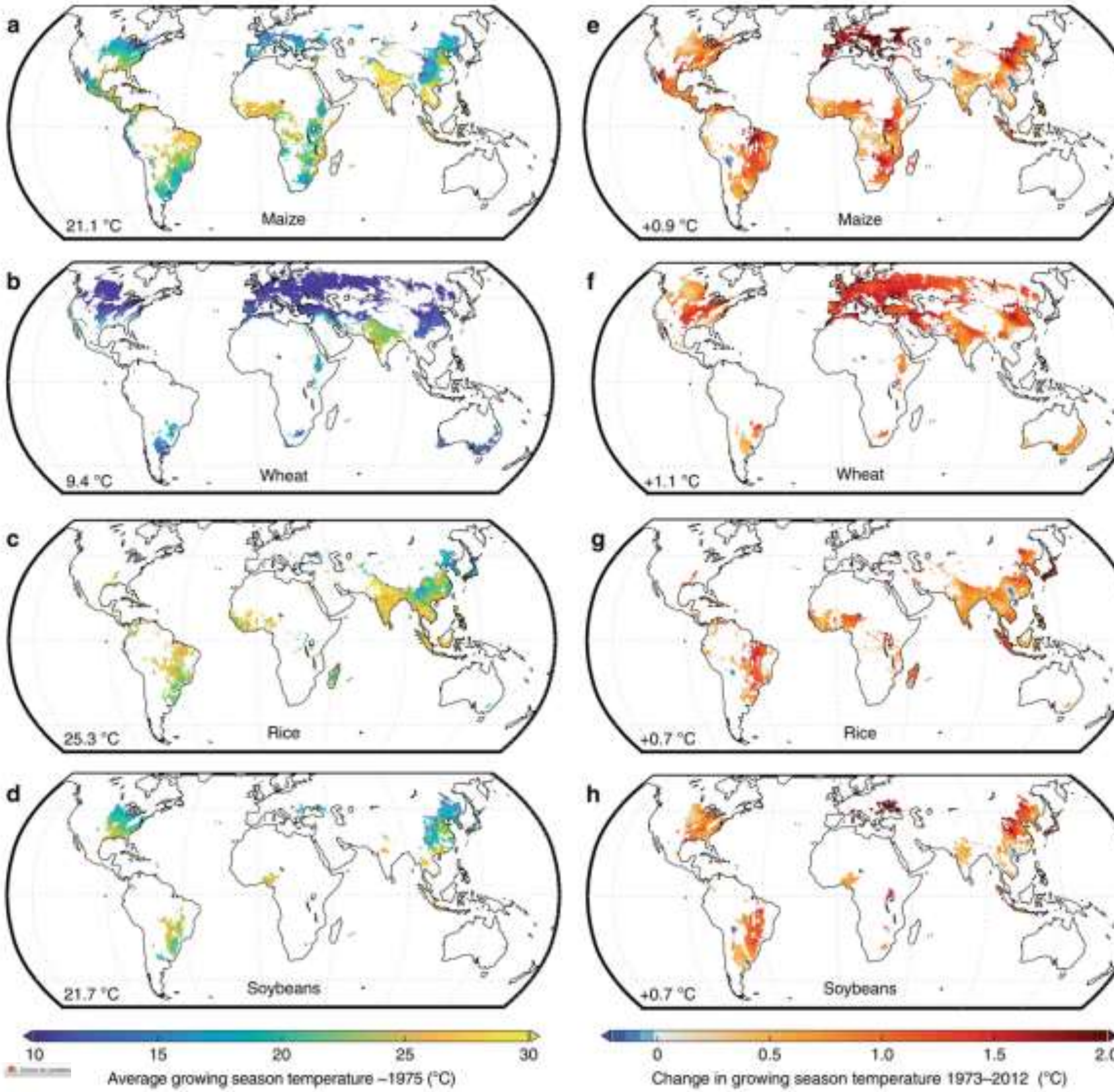


IPCC, 2021

Average growing season temperatures are modified by climate change

Fig. 2: Growing season temperatures and temperature trends.

From: Climate adaptation by crop migration



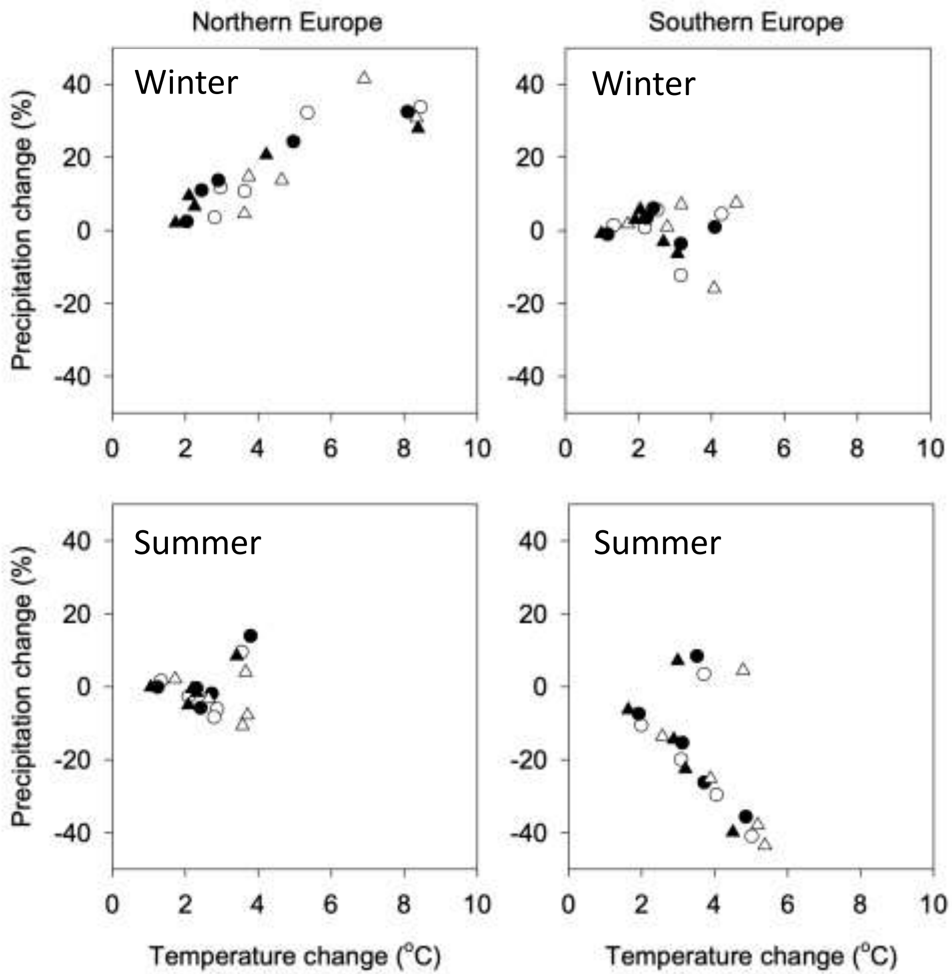
ARTICLE

OPEN

Climate adaptation by crop migration

Lindsey L. Sloat, Steven J. Davis, James S. Gerber, Frances C. Moore, Deepak K. Ray, Paul C. West & Nathaniel D. Mueller

Projected climate change 2040-2069 in Europe



AGRICULTURAL IMPACTS AND ADAPTATIONS TO CLIMATE CHANGE IN EUROPE

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Mitig Adapt Strateg Glob Change (2010) 15:657–679
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ORIGINAL ARTICLE

Impact and adaptation opportunities for European agriculture in response to climatic change and variability

Marco Moriondo · Marco Bindi · Zbigniew W. Kundzewicz · M. Szwed · A. Chorynski · P. Matczak · M. Radziejewski · D. McEvoy · Anita Wreford

2030-2060

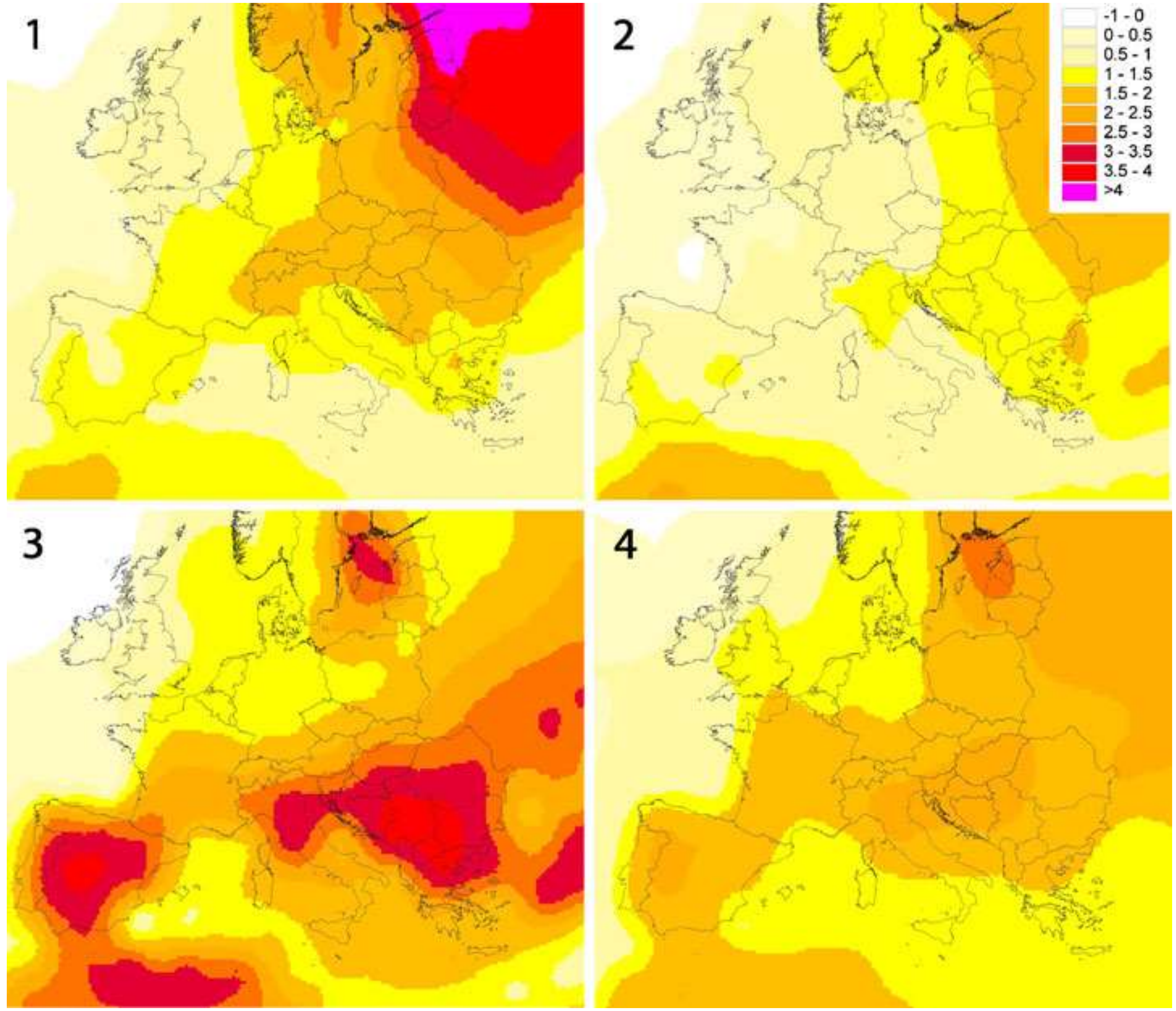
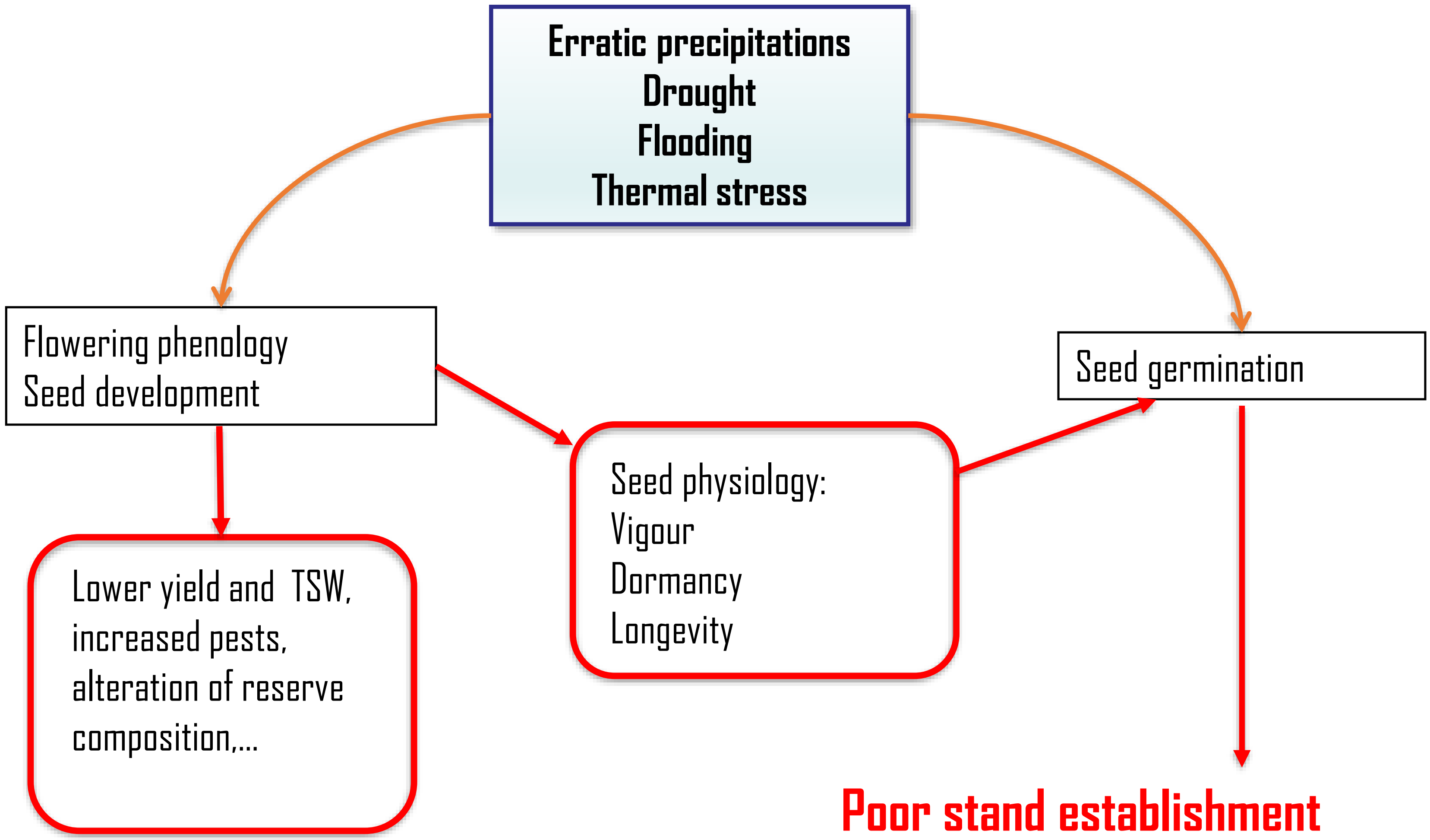


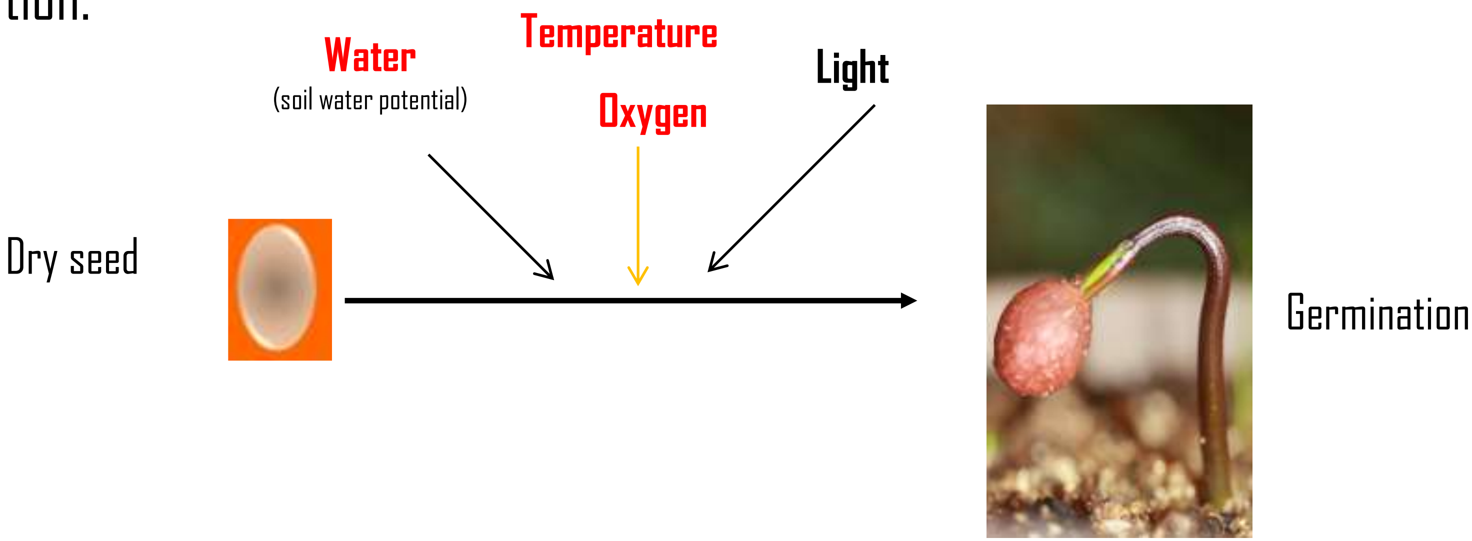
Fig. 4 Average seasonal change in temperature (°C) simulated by HadCM3 for the period 2030–2060 with respect to the relevant baseline 1975–2005. Legend: 1=winter (DJF); 2=spring (MAM); 3=summer (JJA); 4=autumn (SON)

Climate change and seed biology



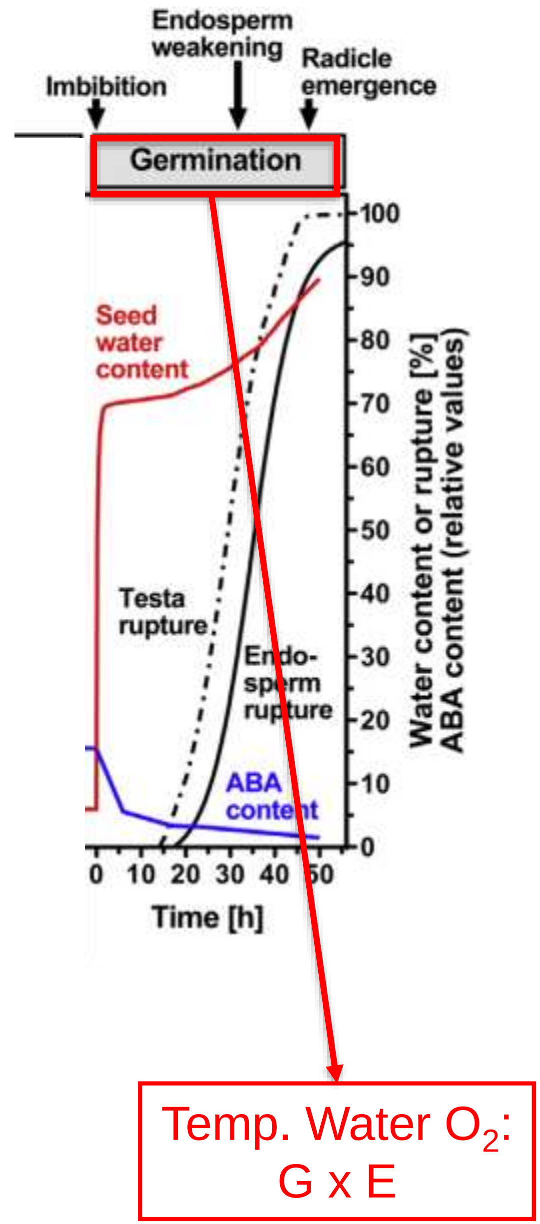
Climate change will directly trigger the regulation of seed germination factors

During germination:



But also before germination…. because seed germinability results from a multifactorial combination of G X E cues

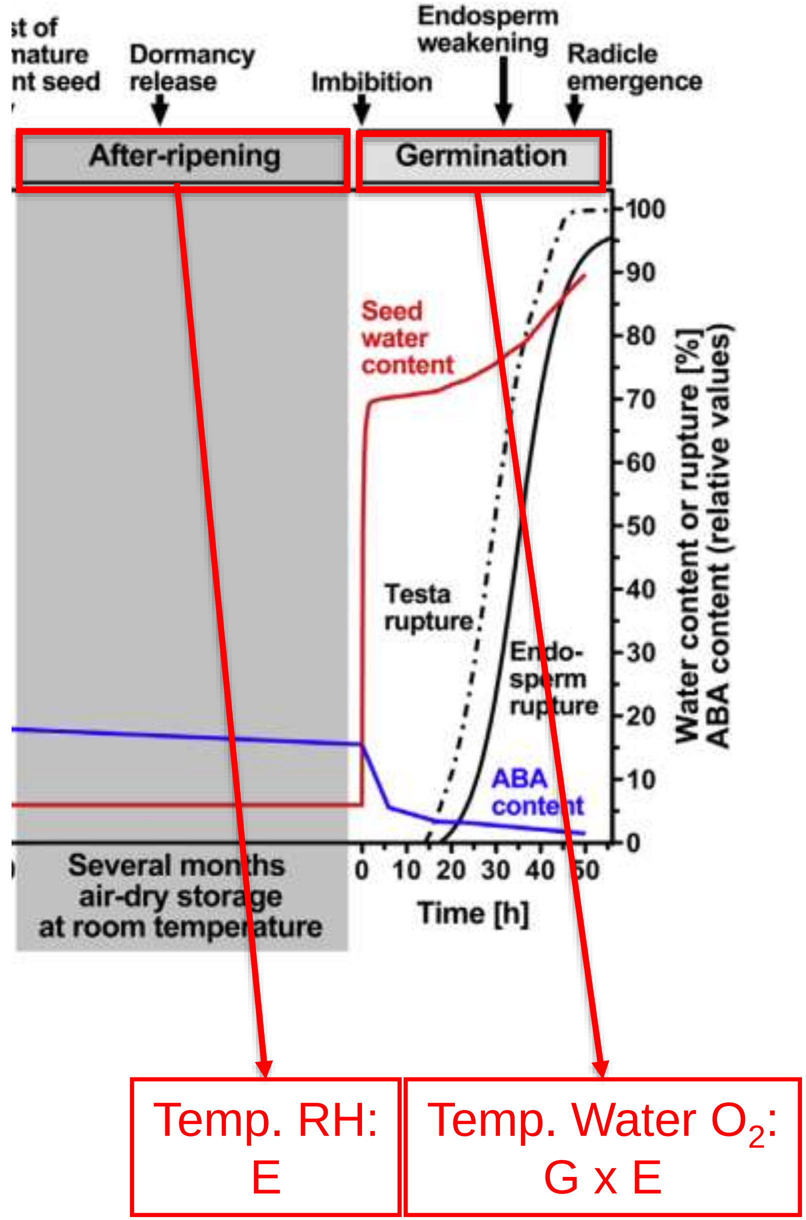
Germinability: a multifactorial combination of G X E cues



Development of Dormancy

K Graeber, K Nakabayashi, and G Leubner-Metzger, Royal Holloway University of London, Egham, UK

Germinability: a multifactorial combination of G X E cues



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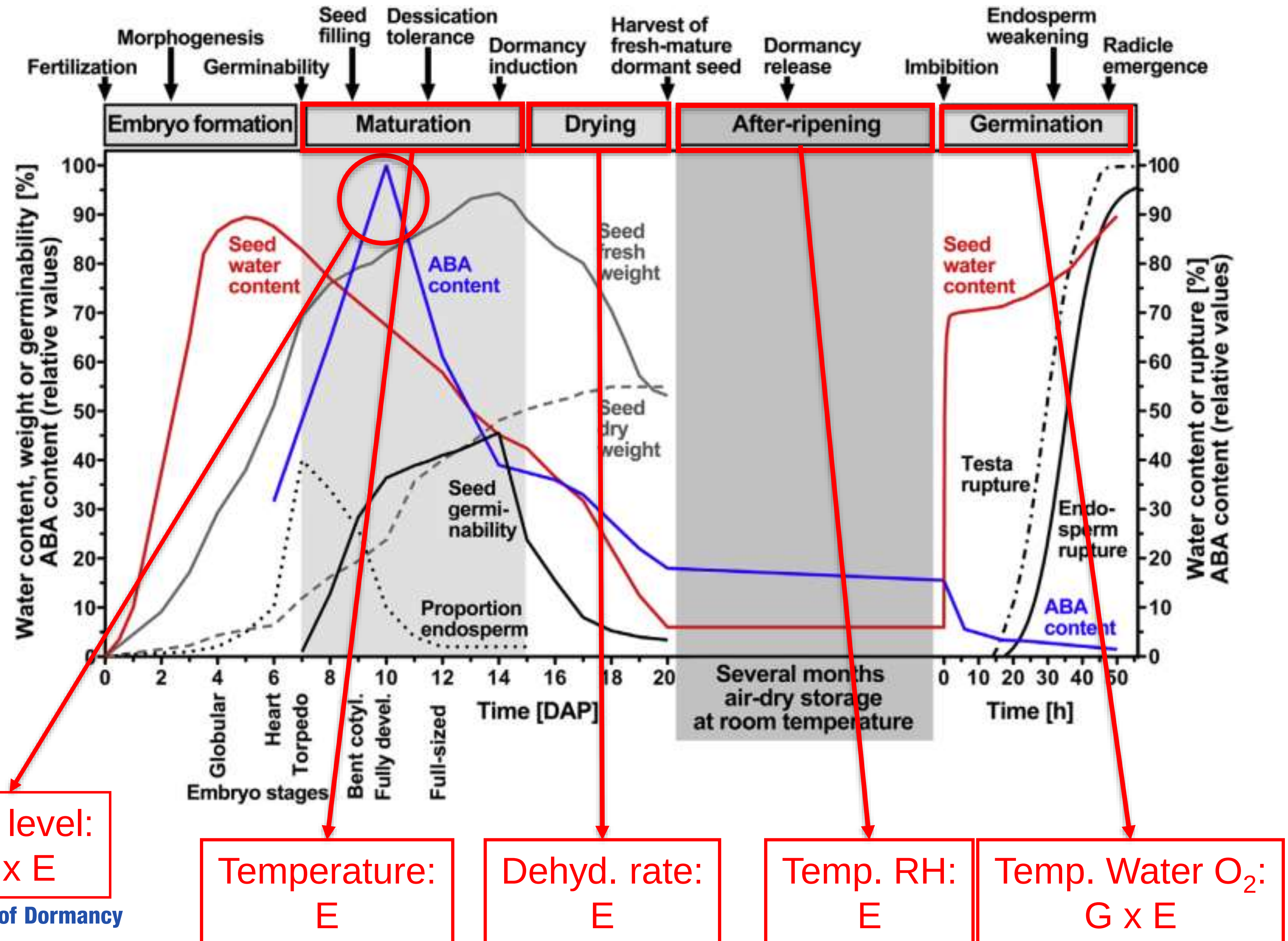

Development of Dormancy

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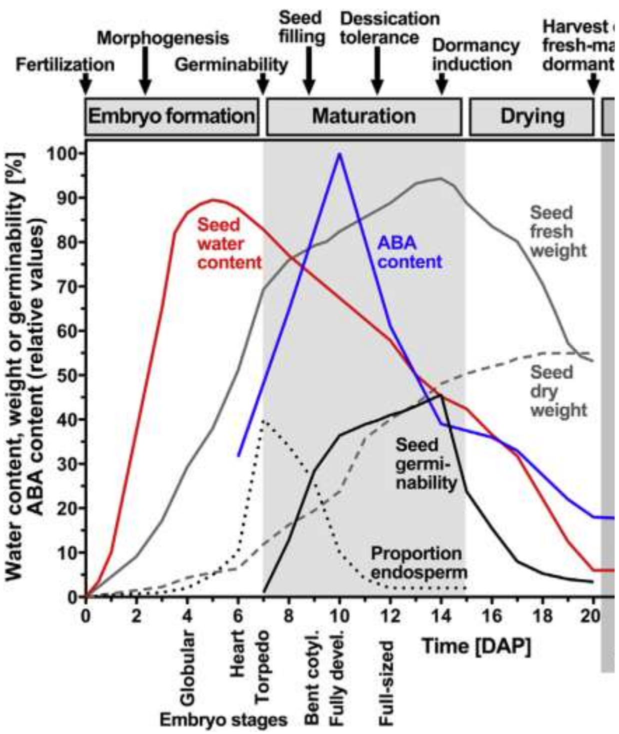
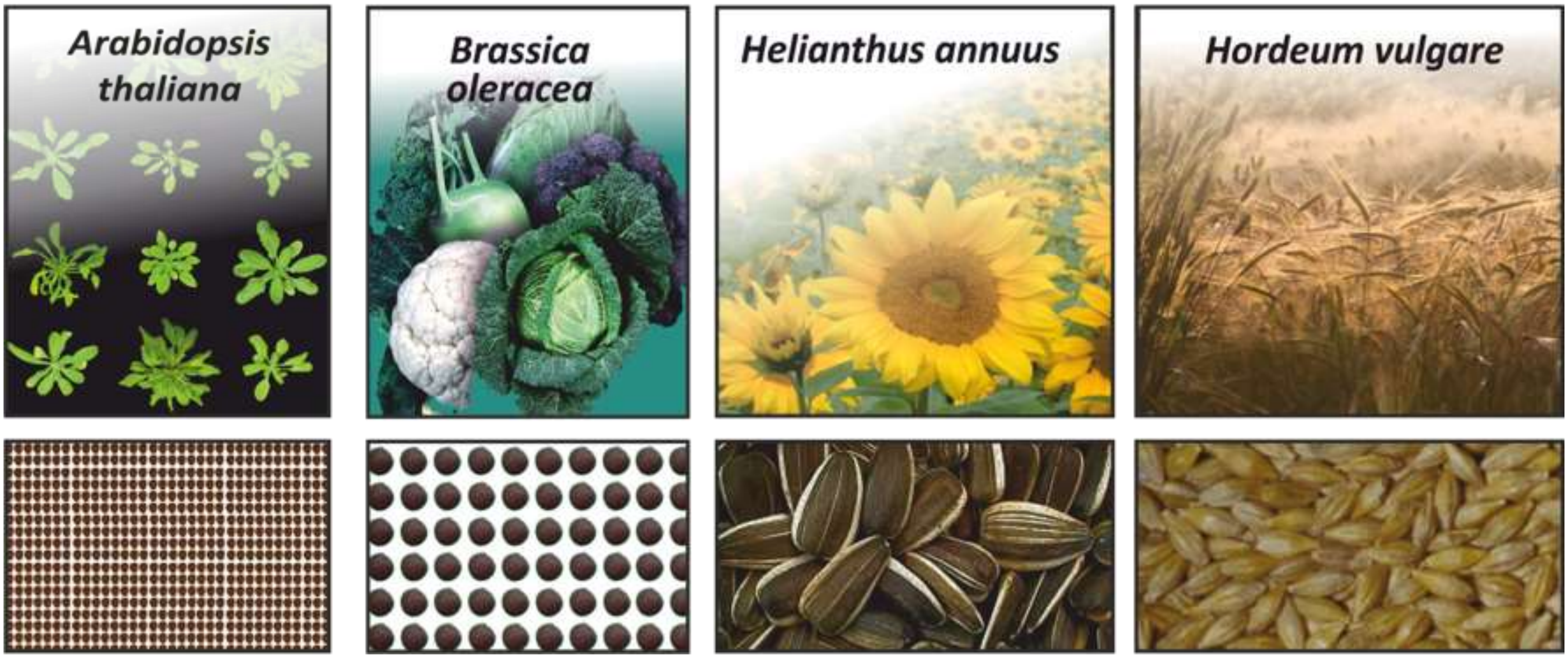
Environmental effects on seed development



European Project **EcoSeed**

Impacts of **E**nvironmental **co**nditions on **Seed** Quality



Dedicated to unravelling the effects on seed quality of the stresses predicted to occur more frequently due to climate change:

ELEVATED TEMPERATURE AND DROUGHT

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Effect of temperature regime on Arabidopsis thaliana seeds

Arabidopsis mother plant treatments: temperature

Standard conditions: plants were grown at **18/22 °C** (8 h night / 16 h day)

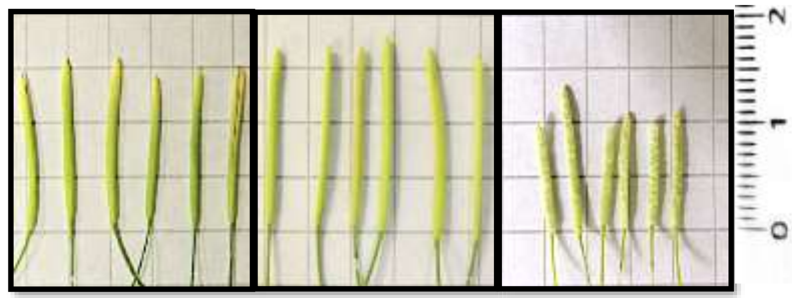
✧ **Elevated/lower temperature:** plants were grown at 18/22 °C (8 h night / 16 h day) until flowering, then the temperature regimes were changed to lower or higher temperatures than the controls (**14/16** or **25/28**°C)

Effect of temperature regime on Arabidopsis thaliana seeds

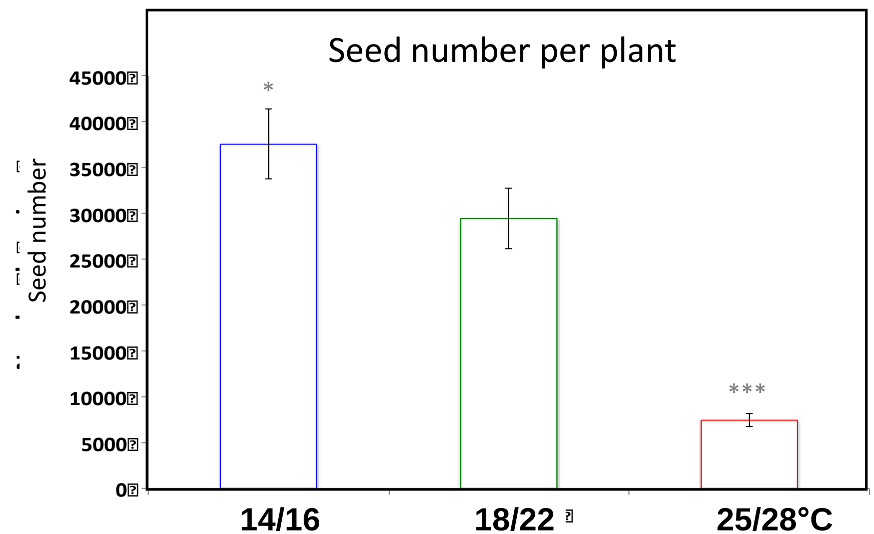
- Plant stature, silique size and seed yield decrease with increasing temperature

WT Col-0

14/16 18/22 25/28 °C



14/16 18/22 25/28 °C



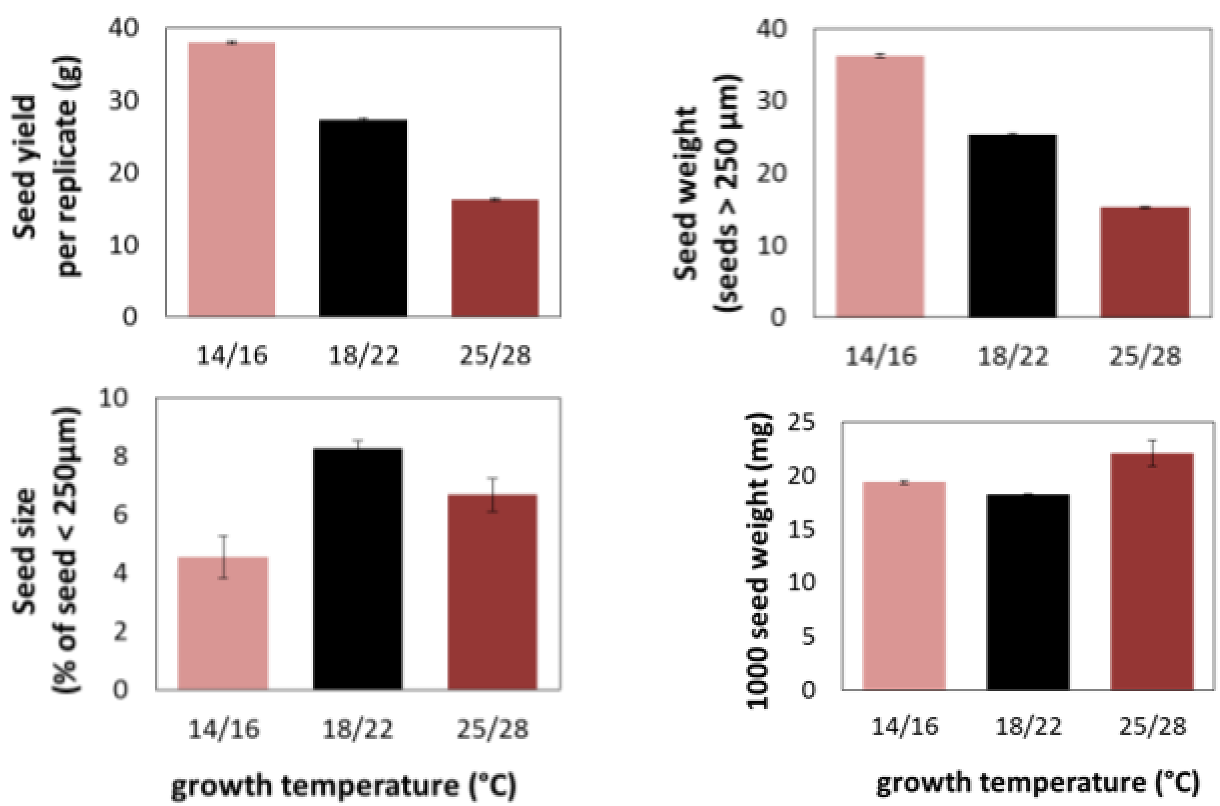
*** <0.001, ** <0.01, * <0.05

SCIENCES SORBONNE UNIVERSITÉ

Effect of temperature regime on Arabidopsis thaliana seeds

Effects of increasing temperature on seed quality

- With increasing temperature: (less seeds per silique), lower yield, fewer useable seeds (seeds < 250 mm produced at 25/28 °C were misshapen and not viable)
- At the highest temperature, less but larger seeds were produced



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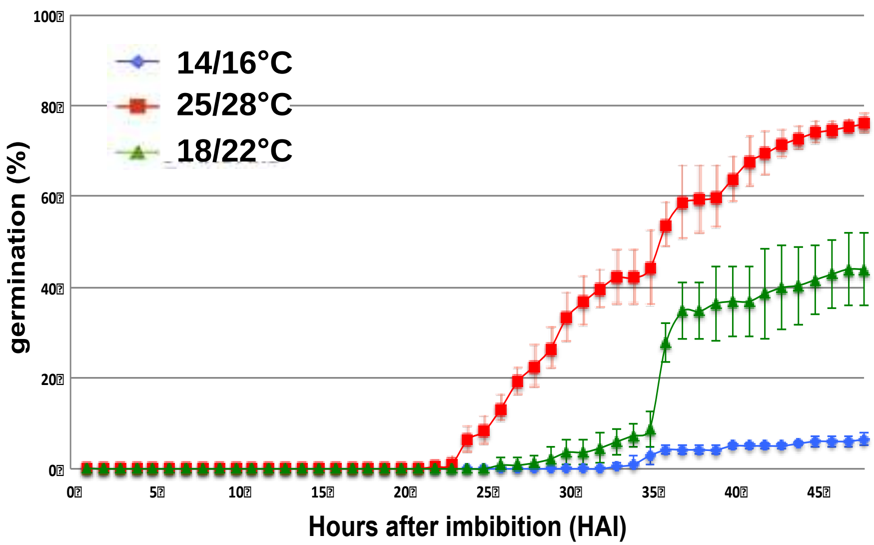
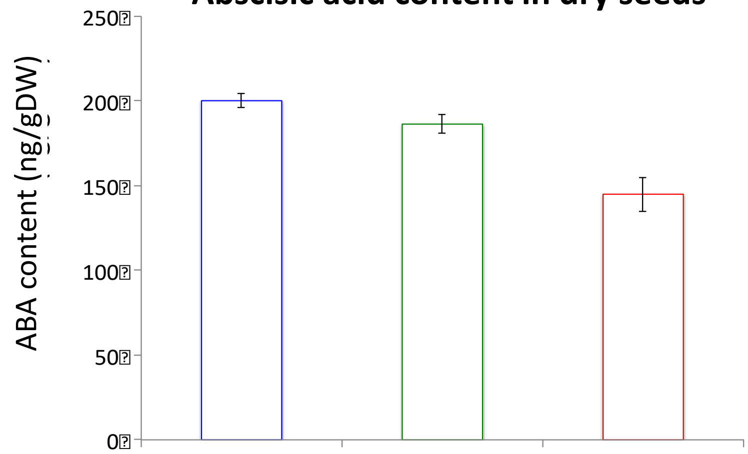
Temperature effect on germination and hormone contents

WT Col-0

Germination at 25°C of freshly harvested seeds



Abscisic acid content in dry seeds



*** <0.001, ** <0.01, * <0.05

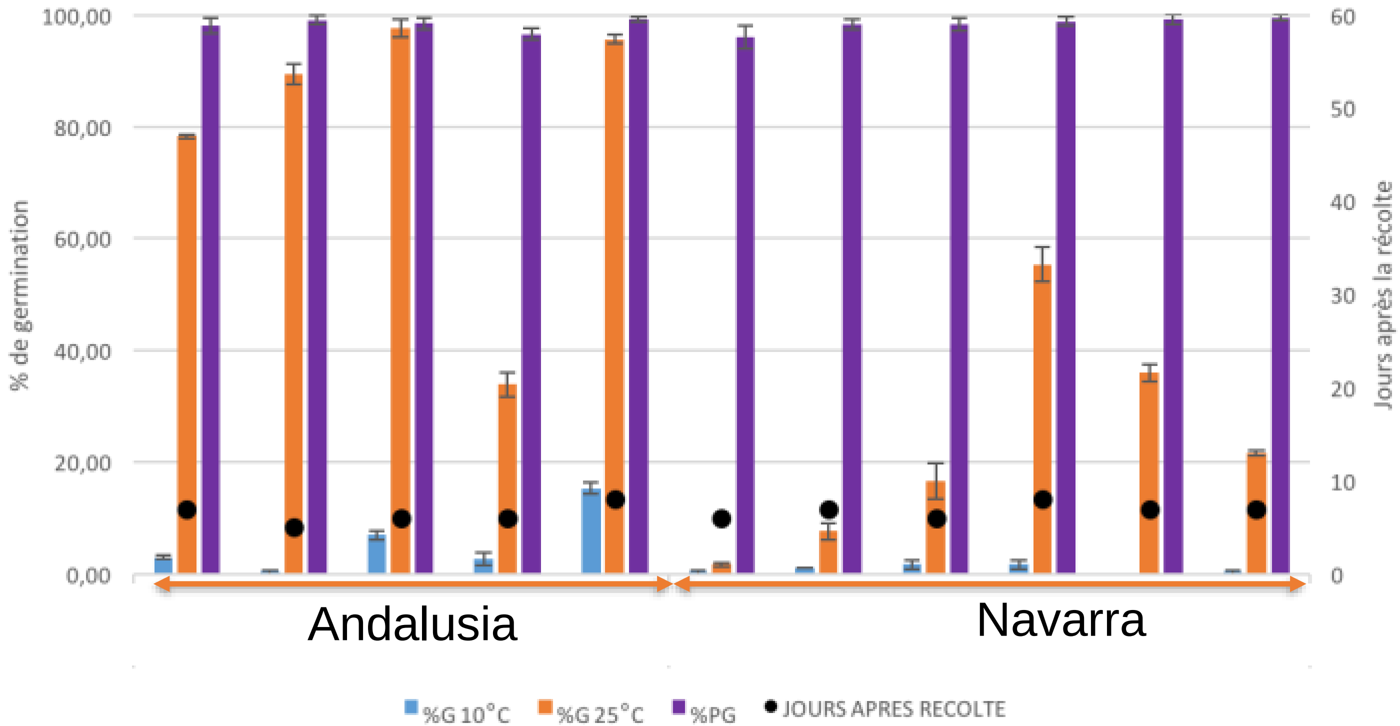
With increasing temperature:

✧ Reduction of seed dormancy

✧ Reduction of ABA contents in dry seed

Environmental effect on sunflower seed dormancy
A study in two spanish areas

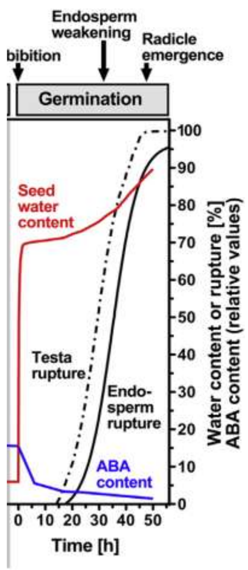
One genetics, several batches, two locations



For the same genetics, lower dormancy in Andalusia

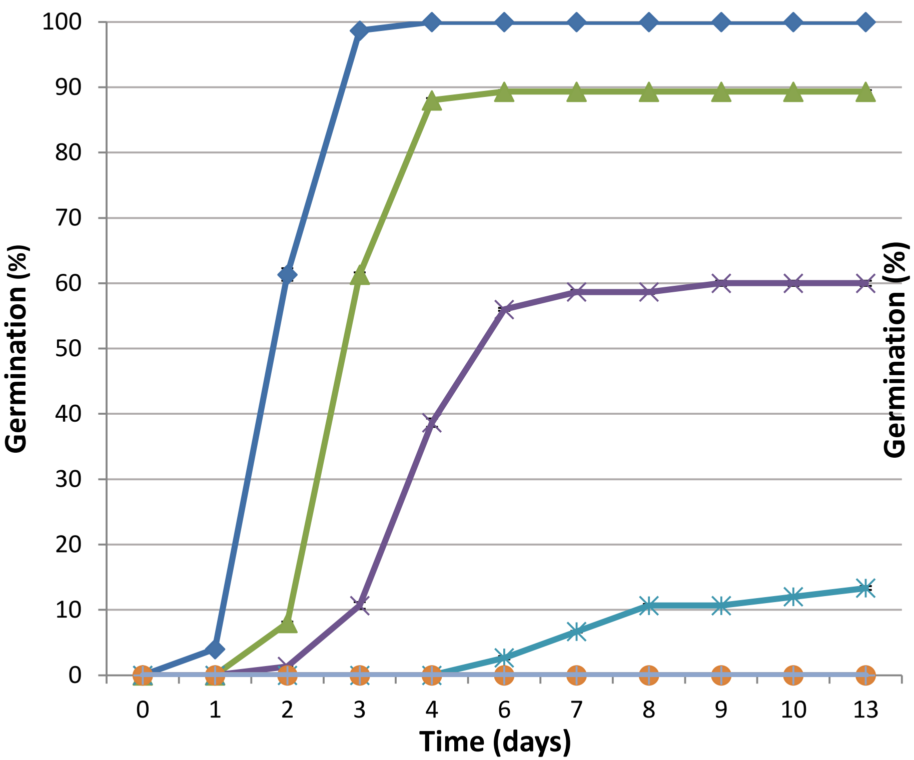
SunDOR

Environmental effects on seed germination

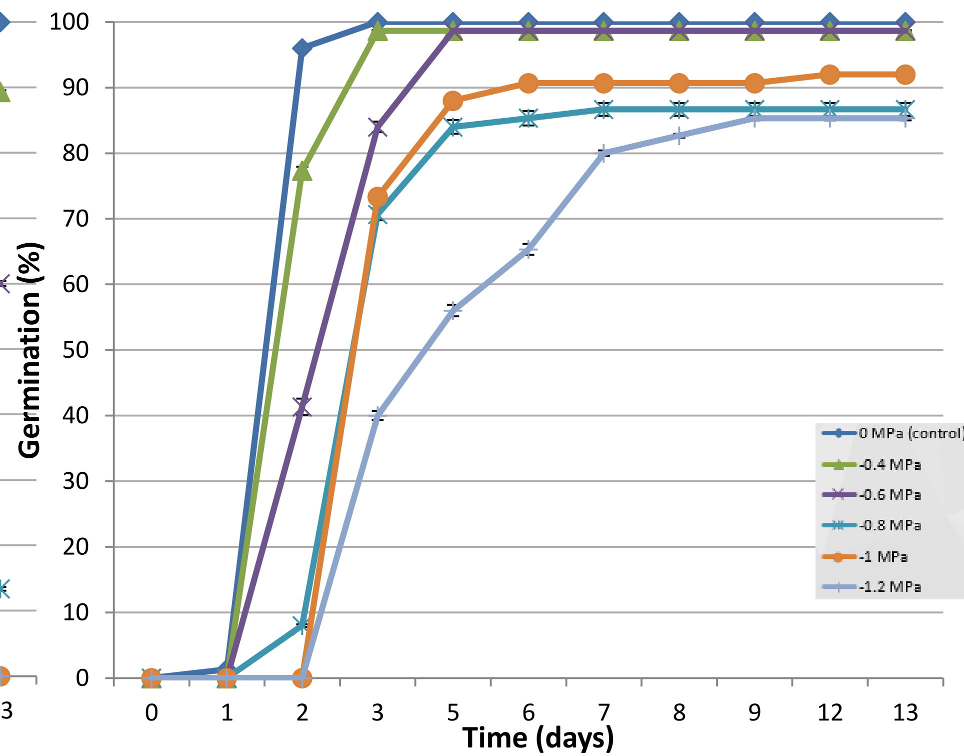


Effect of water stress on seed germination

conditions: 20˚ C 0; -0.4; -0.6; -0.8; -1 and -1.2 MPa (polyethylene glycol)

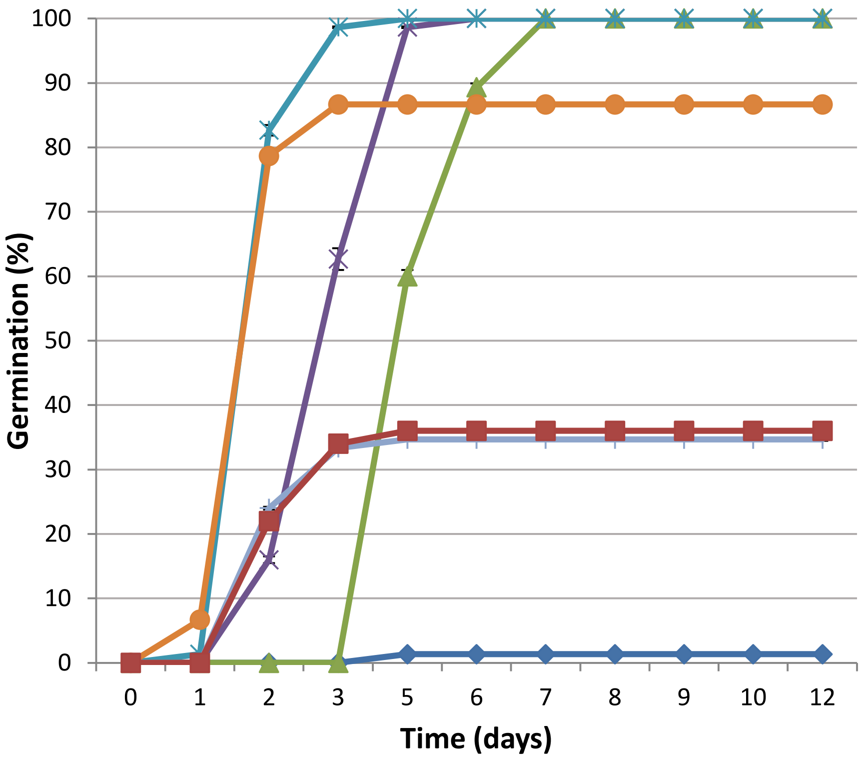


Sensitive genotype

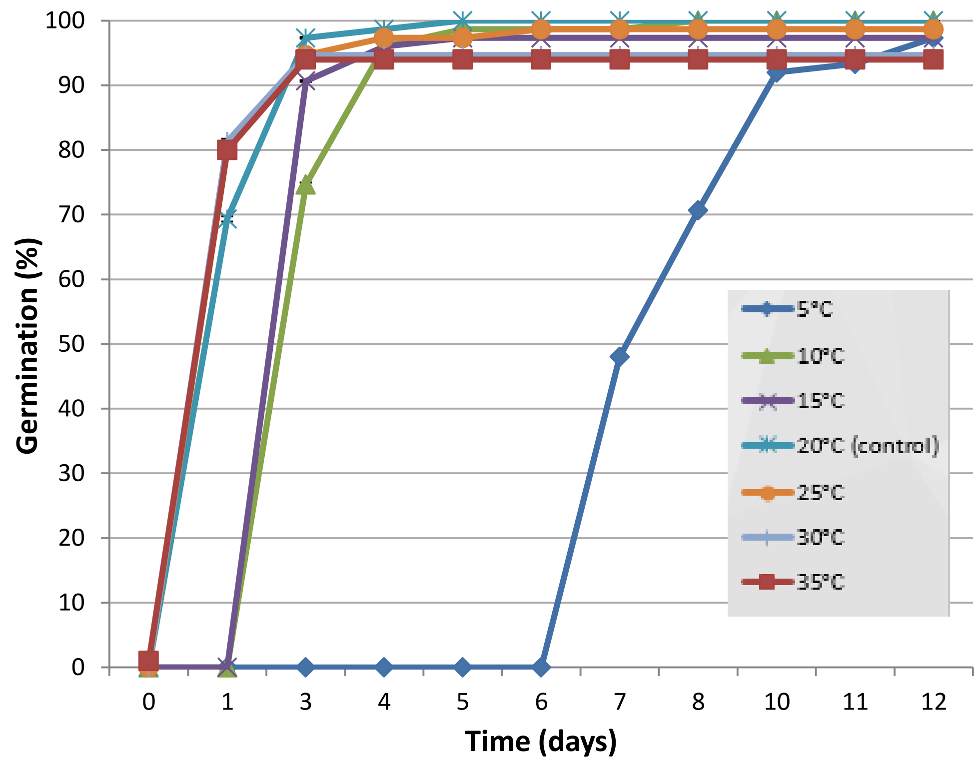


Tolerant genotype

Effect of thermal (cold) stress on seed germination



sensitive



tolerant

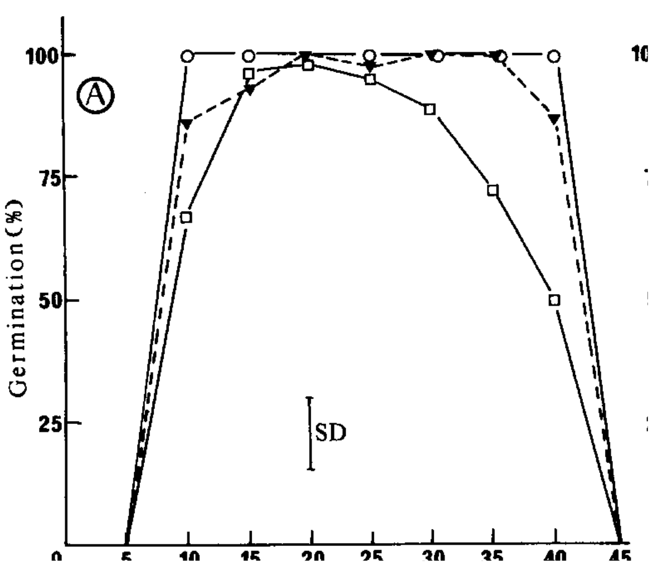
There is a strong genetic component in seed response to water and thermal stress

Effect of hypoxia (flooding) on seed germination

Achene

10 %

GERMINATION AND SEEDLIN(



Seedling

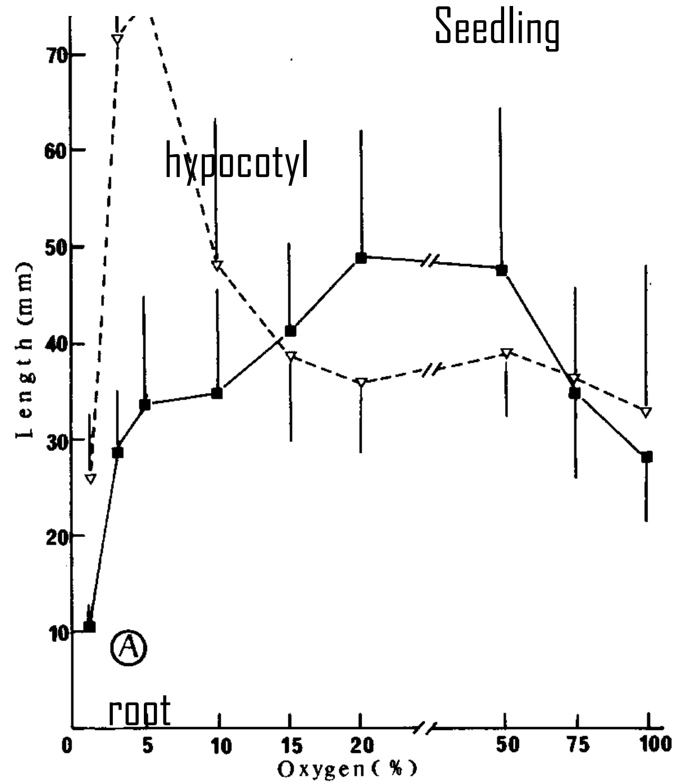


FIG. 6. The effect of oxygen concentration on root an
as in l

hypocotyl to oxygen is illustrated by the root

Gay et al., 1991

Environmental factors altered by climate change are the ones that regulate germination

Expected: poor stand establishment, low yields

How to address negative effects of environmental changes on seed germination?

Genetics: identify the responsible genetic factors or underlying genes associated to seed dormancy and germination under adverse environmental conditions

Table 1 List of genes and molecular markers associated with abiotic stress identified in field crops

Field crop	Desired trait	Associated gene/QTL	Gene description	Conditions/ Comments
Wheat	Tolerance to drought	*TraesCS5A02G022100*, *TraesCS5B02G014200* and *TraesCS5D02G563900*	GATA transcription factor (TF), RING/ U-box superfamily protein and Glutathione S-transferase (GST)	Putative candidate genes associated to QTL involved in the drought tolerance at the germination stage
	Preharvest sprouting	*MKK3*	MAP kinase activity protein	Putative gene of seed dormancy in QTL *Phy1*
		Ta-*MFT*	Phosphatidylethanolamine-binding protein	Gene resides in the seed dormancy QTL *QPhs.ocs-3A.1*
Barley	Preharvest sprouting	*AlaAT*	Alanine aminotransferase protein	Causal gene of seed dormancy in QTLs *Qsd1*
		MKK3	MAP kinase activity protein	Causal gene of seed dormancy in QTLs *Qsd2-AK*
	Tolerance to drought	*HORVU6Hr1G008640*, *HORVU6Hr1G008730*, *HORVU6Hr1G008880 and HORVU6Hr1G008880*	Catalase 1, Catalase 3, heat shock 70 kDa protein C and AP2-like ethylene-responsive TF	QTL at chromosome 6H associated with germination percentage related traits

Impact of climate perturbations on seeds and seed quality for global agriculture

Christophe Bailly and Maria Victoria Gomez Roldan

Changes to production methods : date of sowing , shift of crops northward

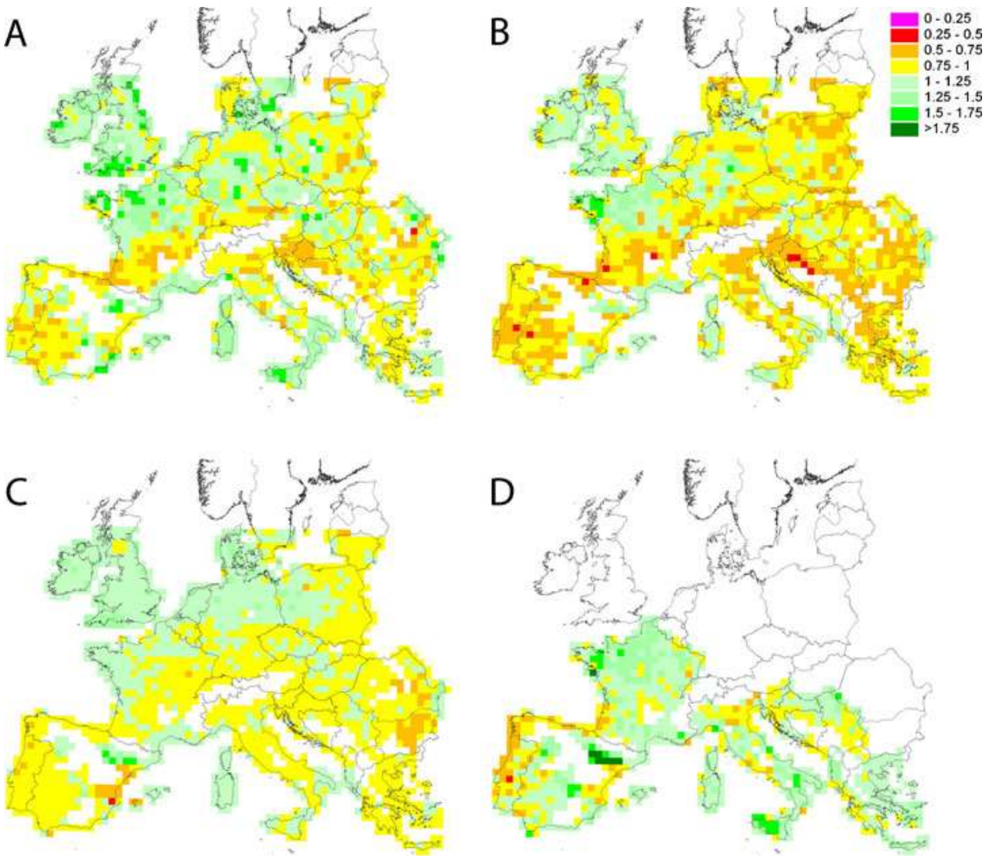


Fig. 6 Relative change in crop yield of sunflower (subfigure **a**), soybean (subfigure **b**), Spring wheat (subfigure **c**) and durum wheat (subfigure **d**) in a +2°C scenario with respect to the present period, not considering adaptation strategies

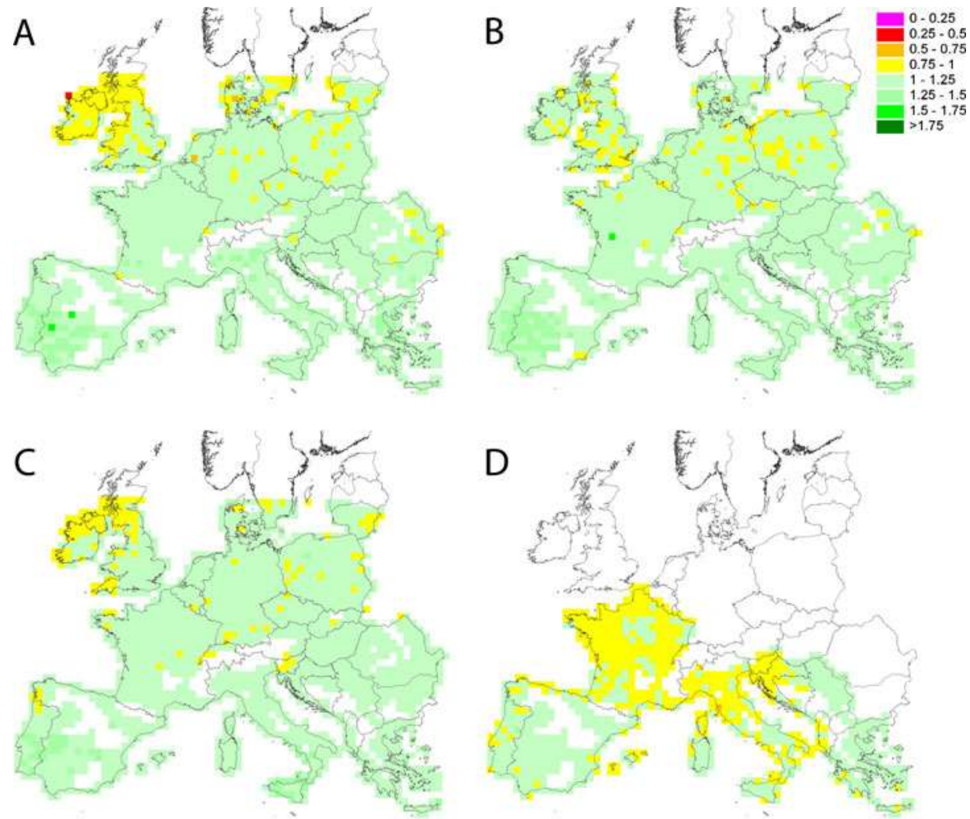


Fig. 7 Relative change in crop yield of sunflower (subfigure **a**), soybean (subfigure **b**), Spring wheat (subfigure **c**) and durum wheat (subfigure **d**) in a +2°C scenario considering an advanced sowing with respect to the present period. The relative change is calculated with respect to the same +2°C scenario without adaptation

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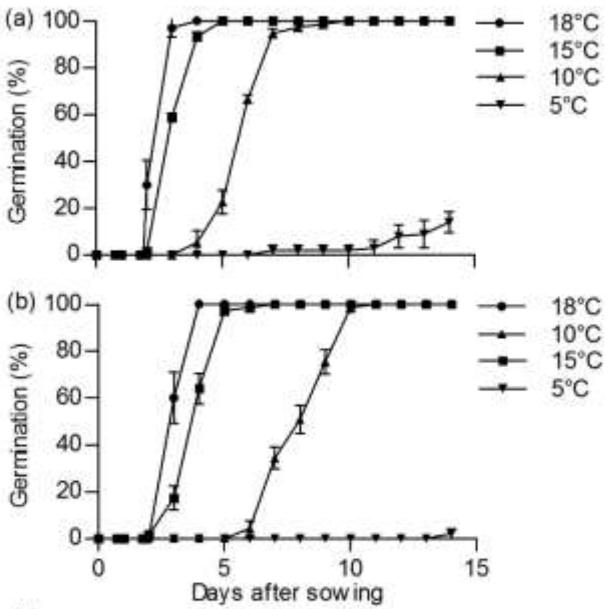
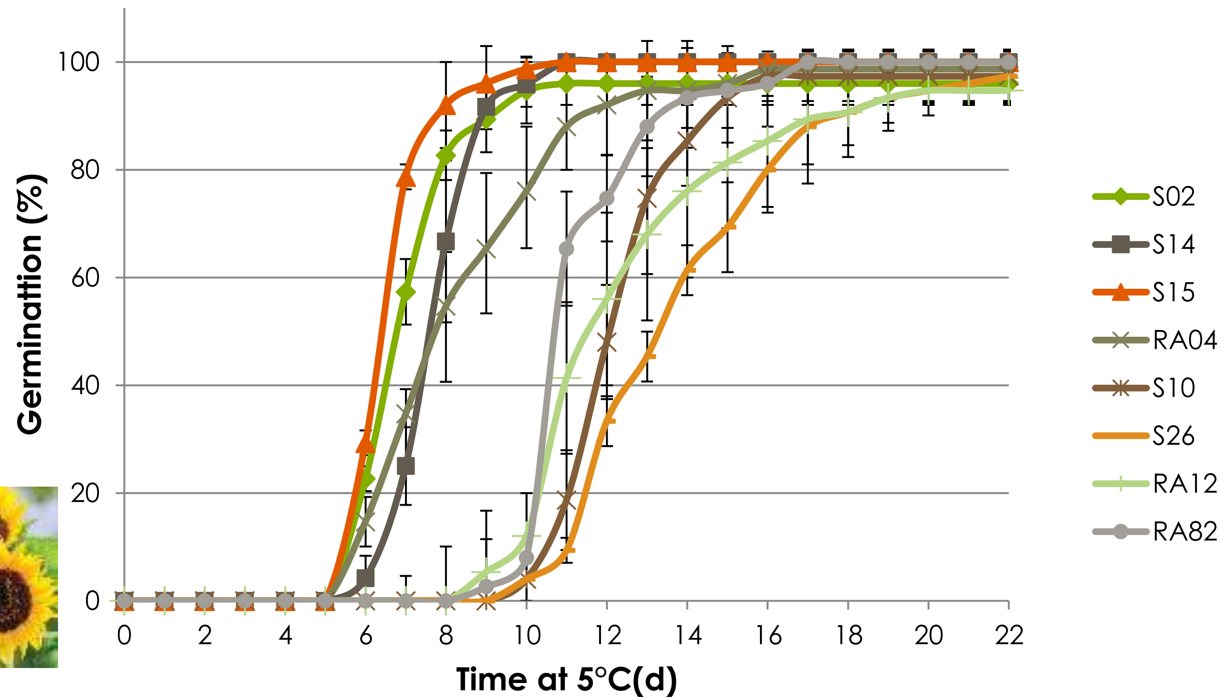


(c)

Hybrid	T50 (h)			Thermal Time (50 %) (°C.h)
	18°C	15°C	10°C	
A	52.2	71.3	134.1	691
B	69.5	89.2	184.7	888

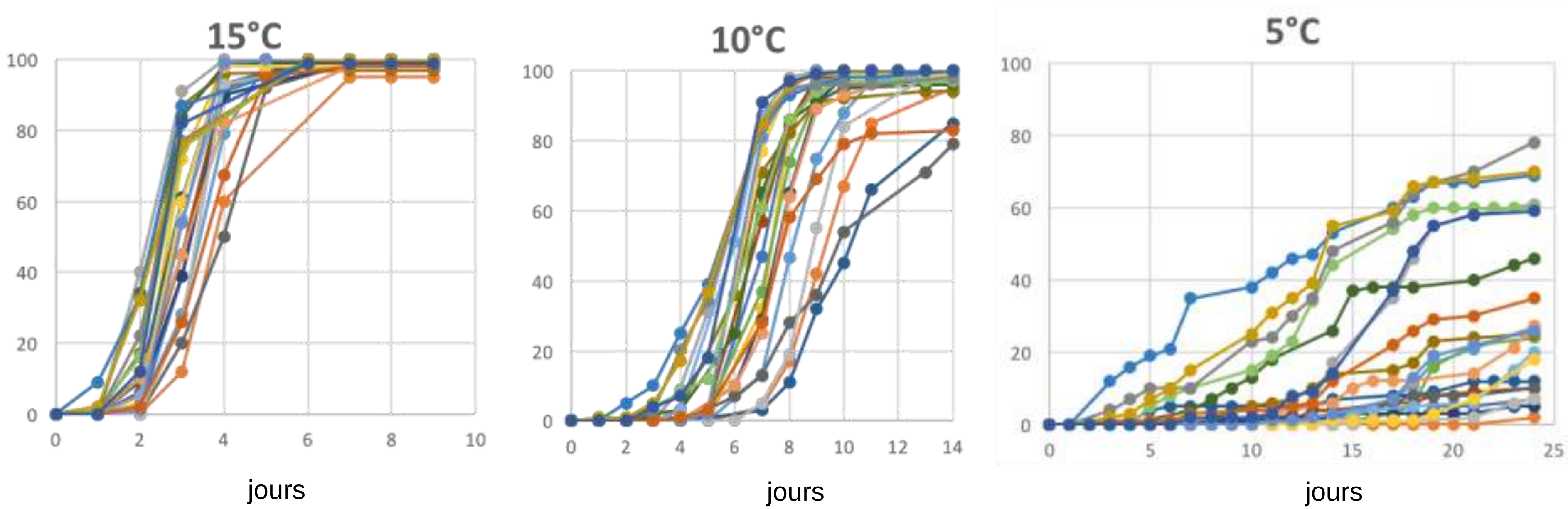
Noblet et al. Scientific Report 2017



How to address this issue ?
An example of strategy to stimulate maize seed germination in cold conditions

Identification of markers of tolerance/sensivity of maize seeds to cold conditions at the germination stage

23 hybrids / 3 qualities (Q1, Q2, Q3) : a genetic component in seed tolerance to cold



vigour

	V8.Q1	V14.Q1	V11.Q1	V12.Q3	V9.Q1	V13.Q1	V1.Q1	V7.Q1	V10.Q1	V19.Q1
φ(T)(50%) (°h)	988	893	872	814	740	694	664	637	635	573

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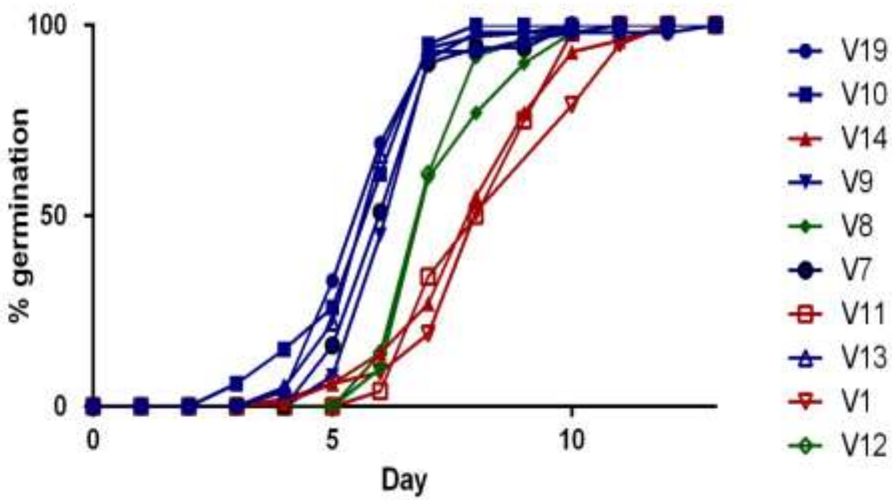
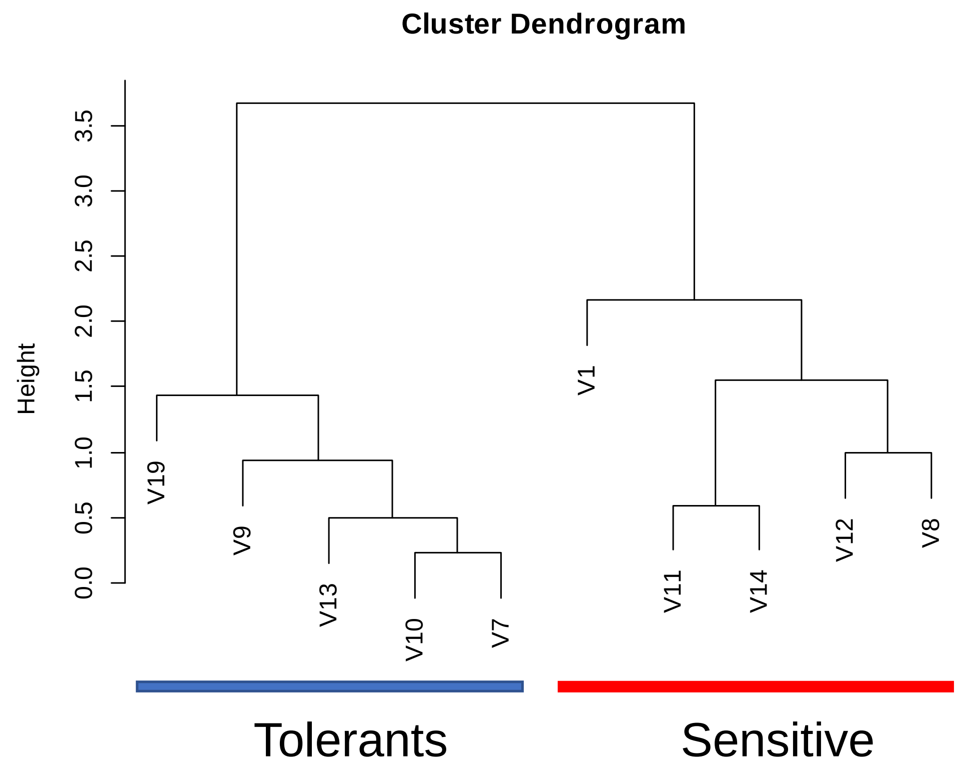
Metabolomics

Germination at 10°C





Changes to production methods : irrigation

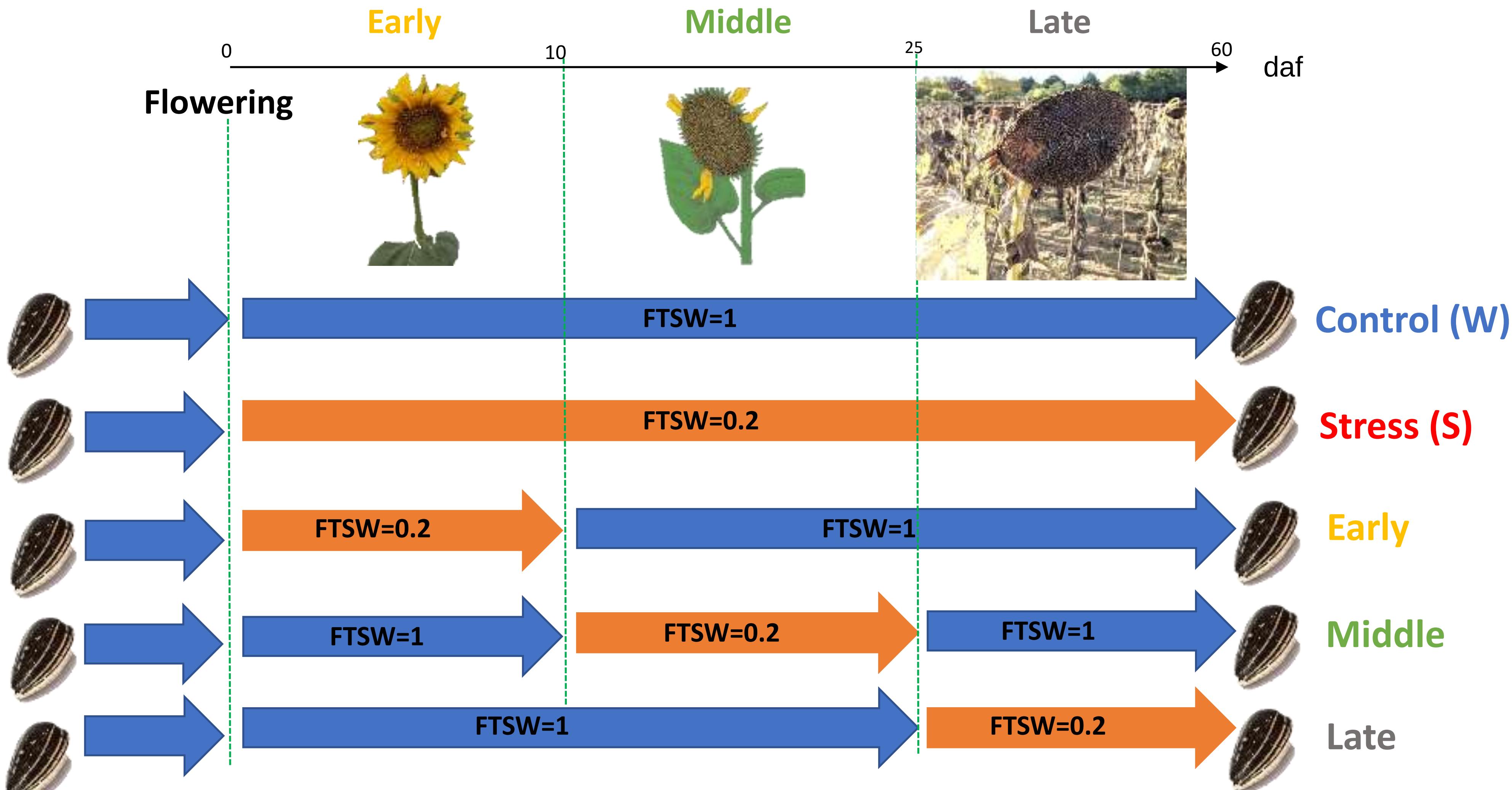
Sunflower seed vigour: SUNRISE project

Context: Sunflower a strategic crop in France and Europe
Climate change: - 20 % yield in 2100 in France
SUNRISE: effect of drought stress on sunflower

Our objectives: Investigate the effects of drought stress during sunflower seed development on seed vigour of the progeny

Seeds produced on Heliaphen (INRAe Toulouse)

Experimental design



FSTW = fraction of transpirable soil water

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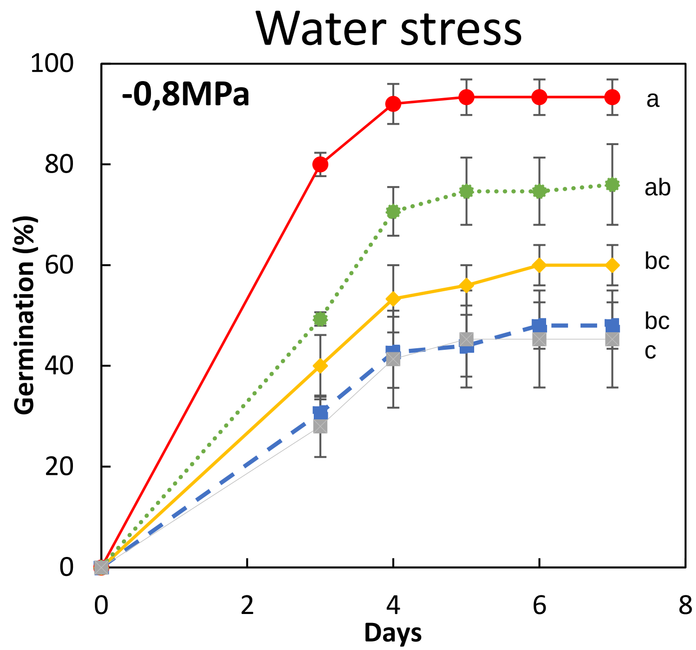
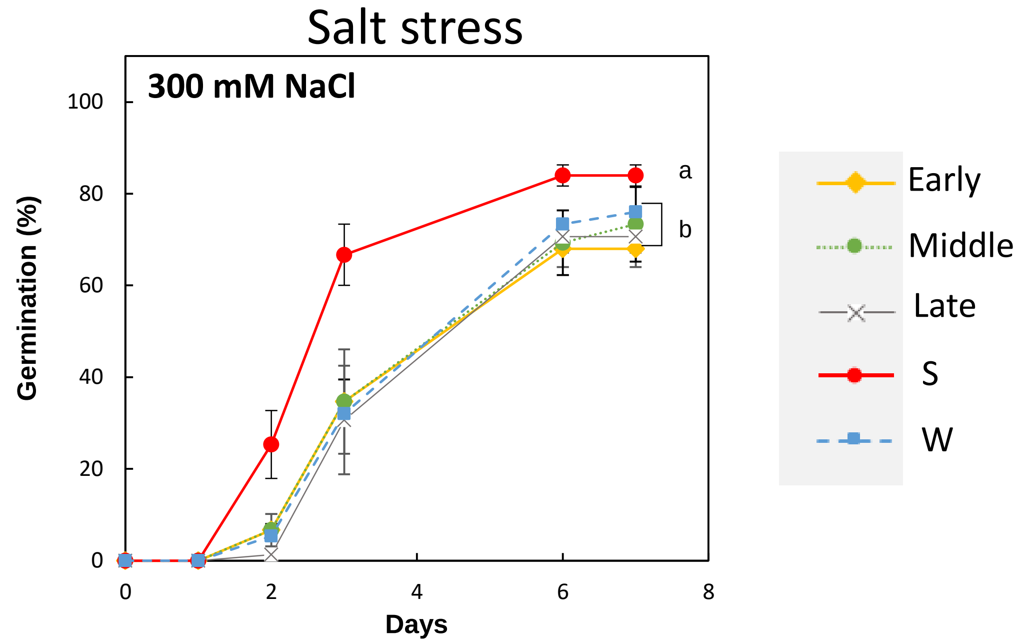
Vancostenoble et al (2022) Env Exp Bot

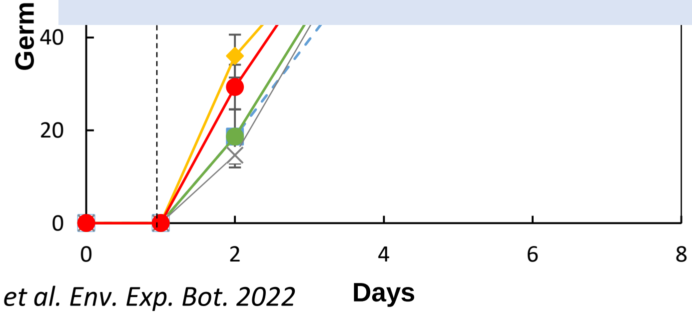


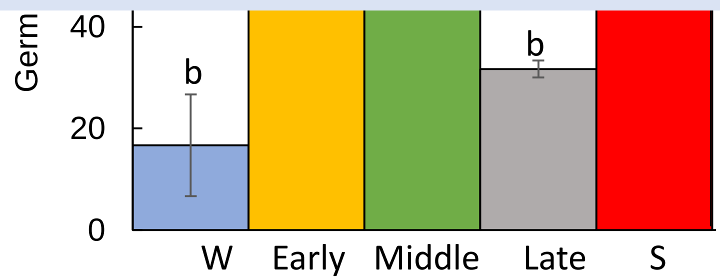


Controlled drought stress on the mother plant can induce higher seed vigour

A key role of the developmental stage for the transmission of seed vigour traits

Induction of stress memory by priming





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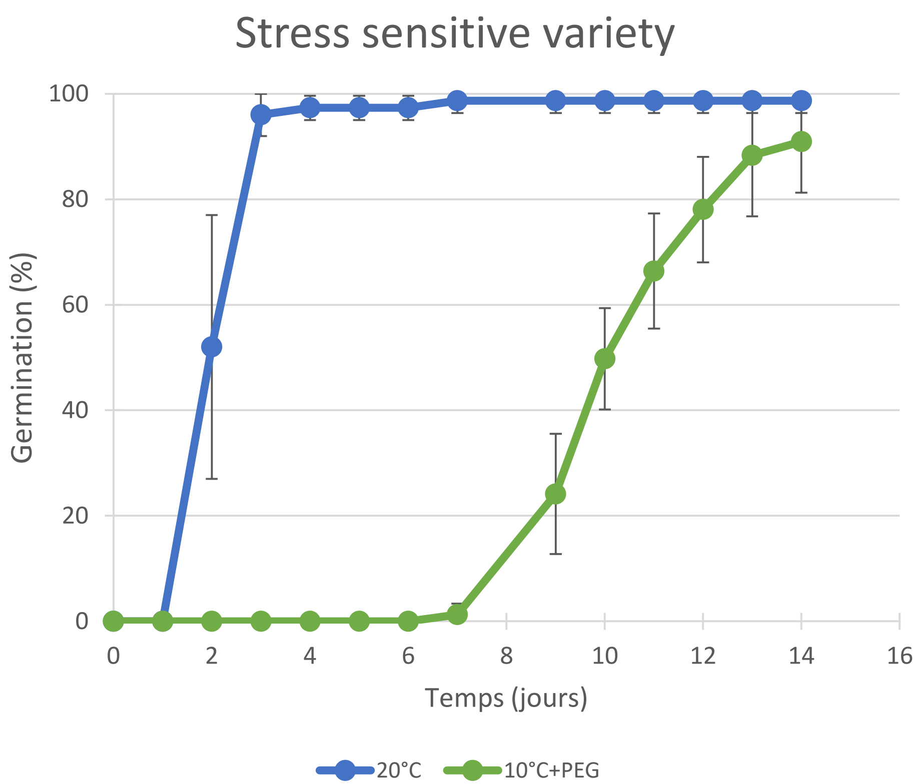
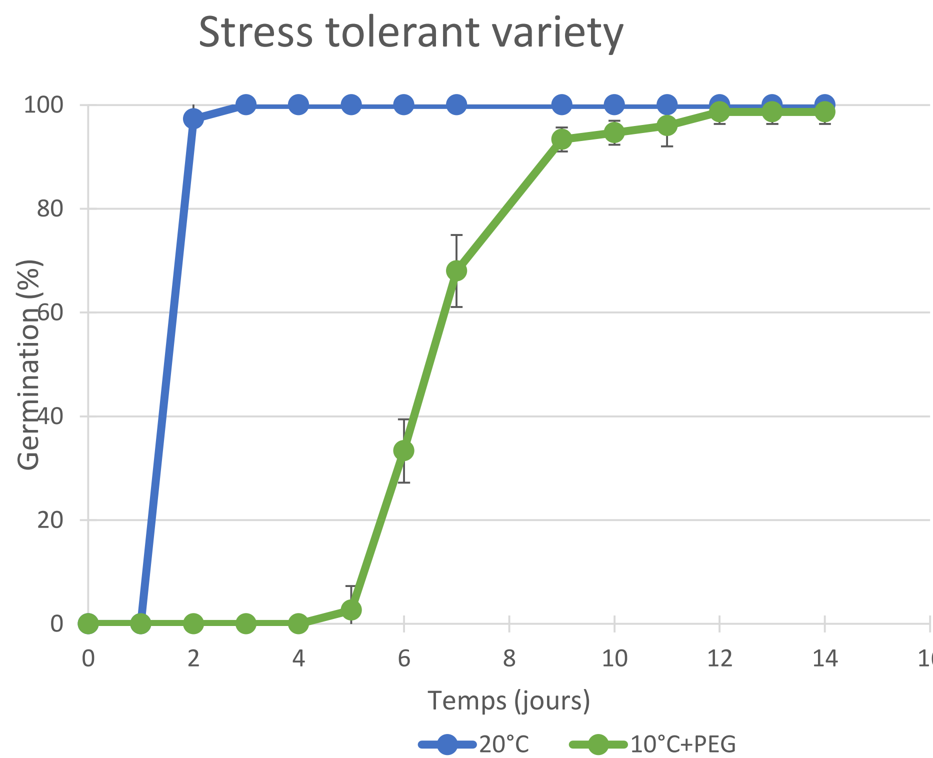
Biostimulants of seed germination to improve stand establishment in adverse conditions

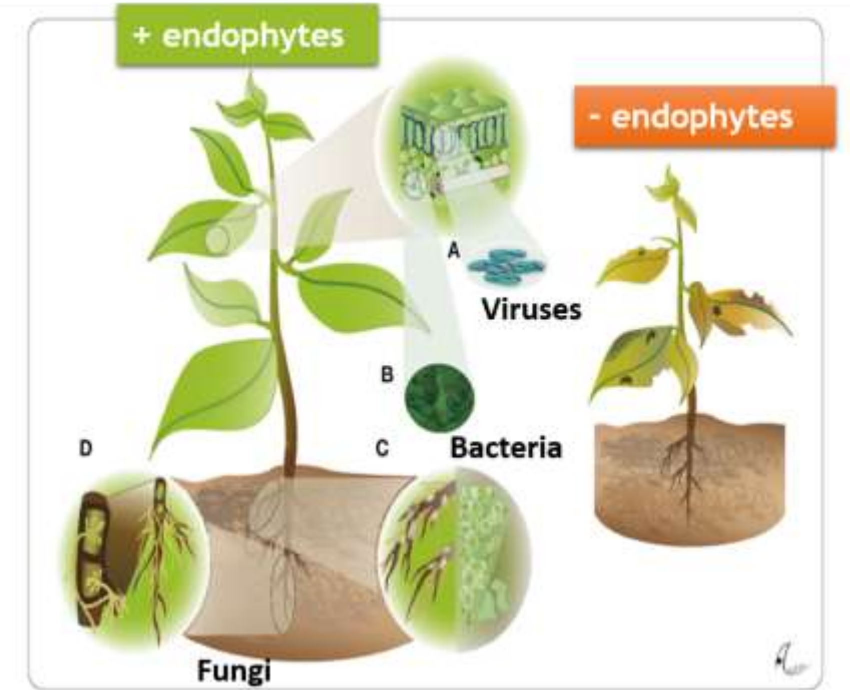
Ex: sunflower, germination under cold and water stress





Endophytes as sources of novel biostimulants

Microorganisms (fungi, bacteria) living in tissus of the host plant without causing apparent damages
(≠ epiphytes, pathogens)



Positive effects on plant fitness

- Plant growth promotion
- Enhanced tolerance to diseases
- Mitigation of abiotic stresses

Chemical mediation (bioactive metabolites)

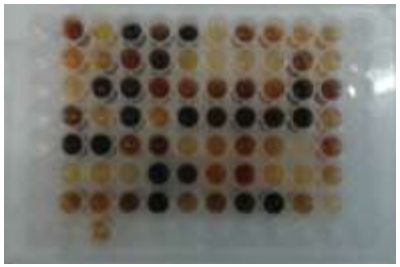
- Exploitation of new biologically-active molecules
- Identification of new modes of action

Promising and currently under-explored sources for innovative solutions in agriculture

Investigating the potential of fungal endophyte and their derived for seed trait improvement

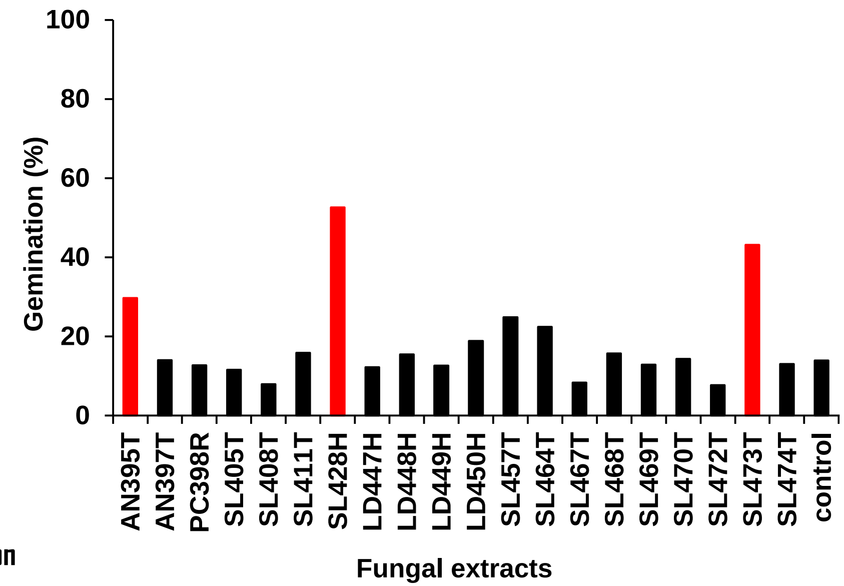
Identifiying fungal endophyte bioactive chemicals impacting seed germination

Fungal endophyte extract (FEEs) collections



Arabidopsis thaliana as a model (dicot weed/rapeseed relative)

Search for FEEs improving or inhibiting of seed germination



- 72 FEEs analyzed
- 15 exhibit stimulatory activity
- 4 exhibit inhibitory activity

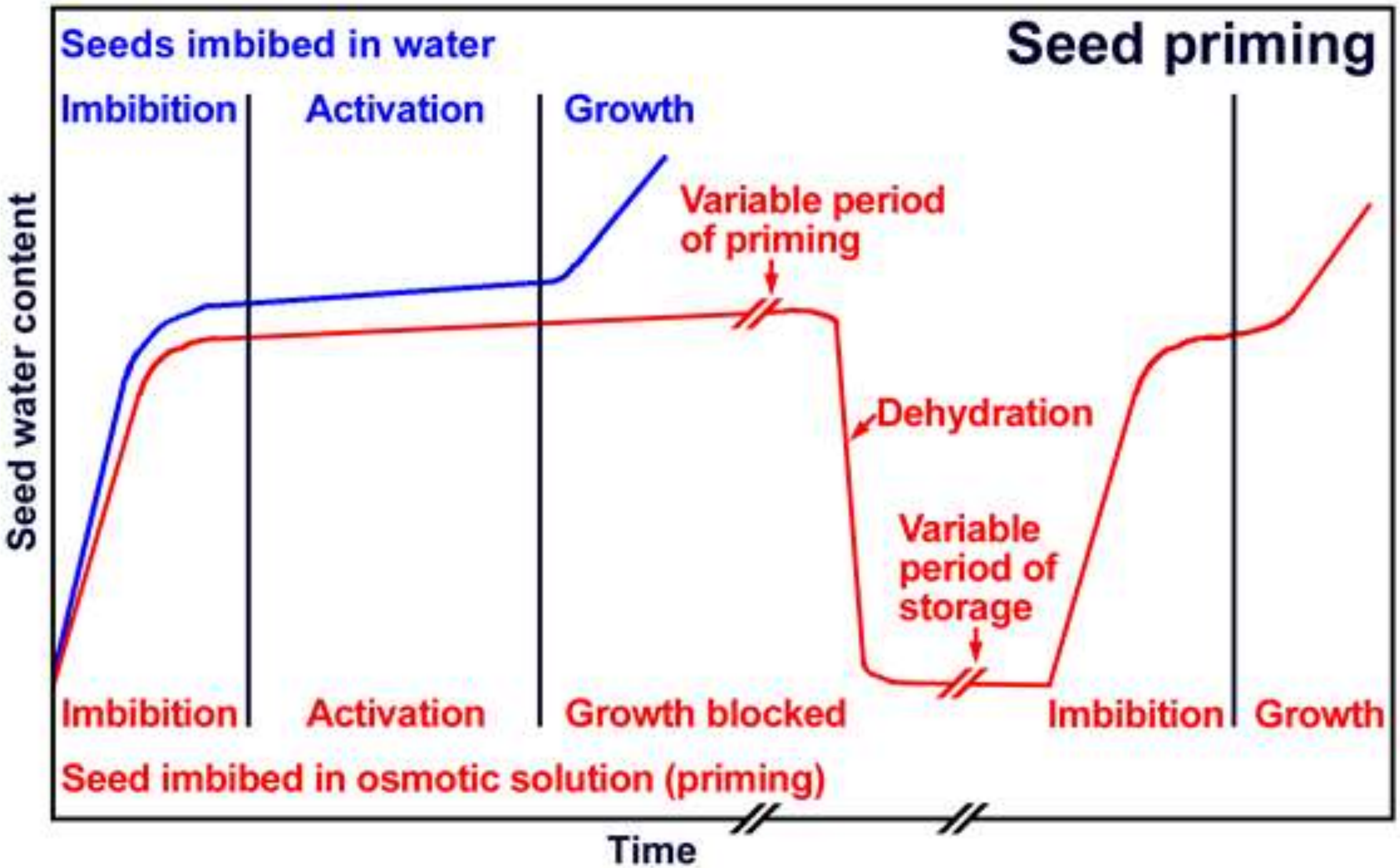
➢ Effect on crop or weed seed germination
➢ Effect on germination under penalizing conditions

Collaboration
Pr S. Prado
MNHN, Paris

Seed fungal endophytes as biostimulants and biocontrol agents to improve seed performance

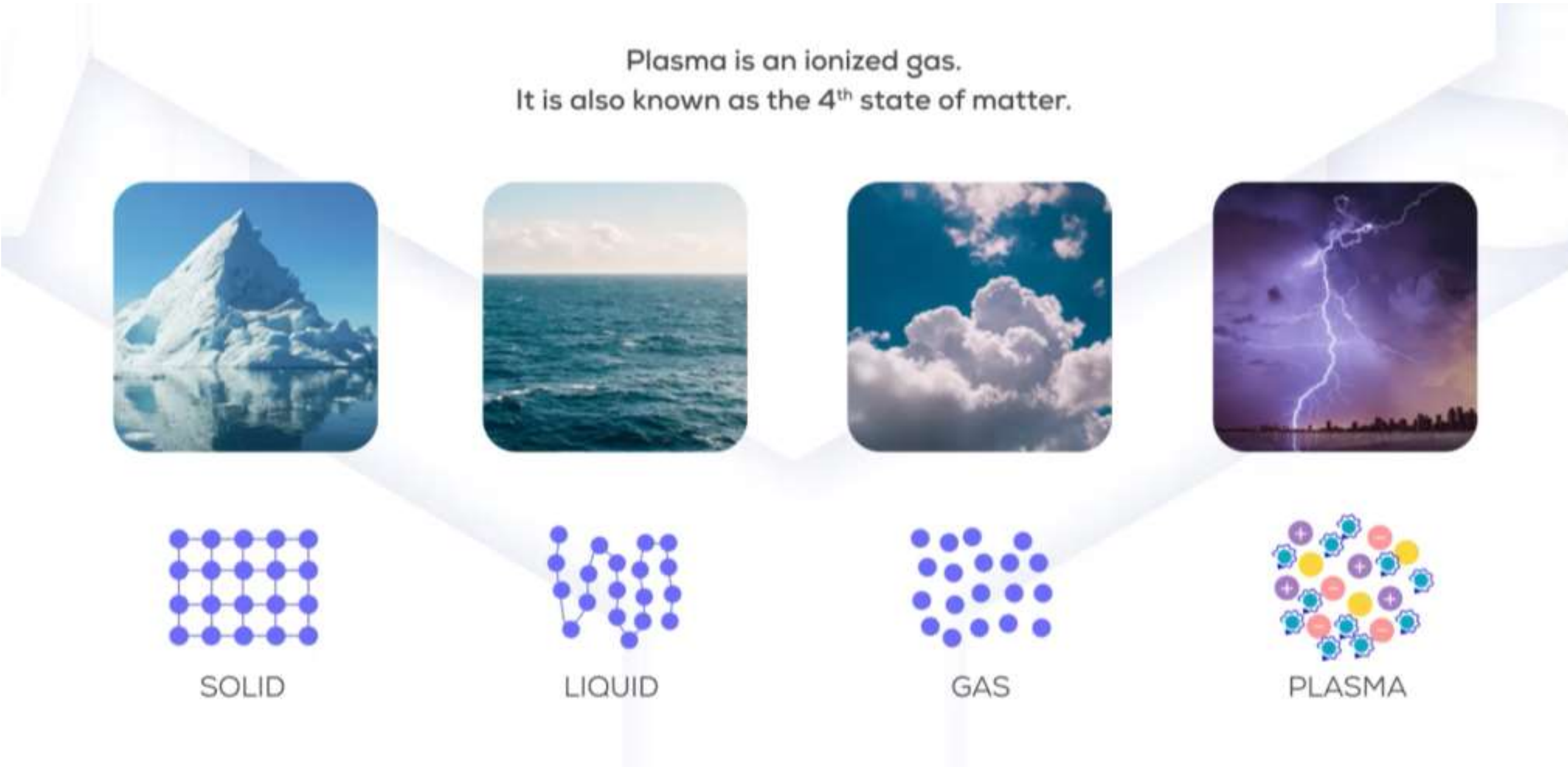
Félix Rétif, Caroline Kunz, Kevin Calabro, Clémence Duval, Soizic Prado, Christophe Bailly and Emmanuel Baudouin

Seed technology: seed priming



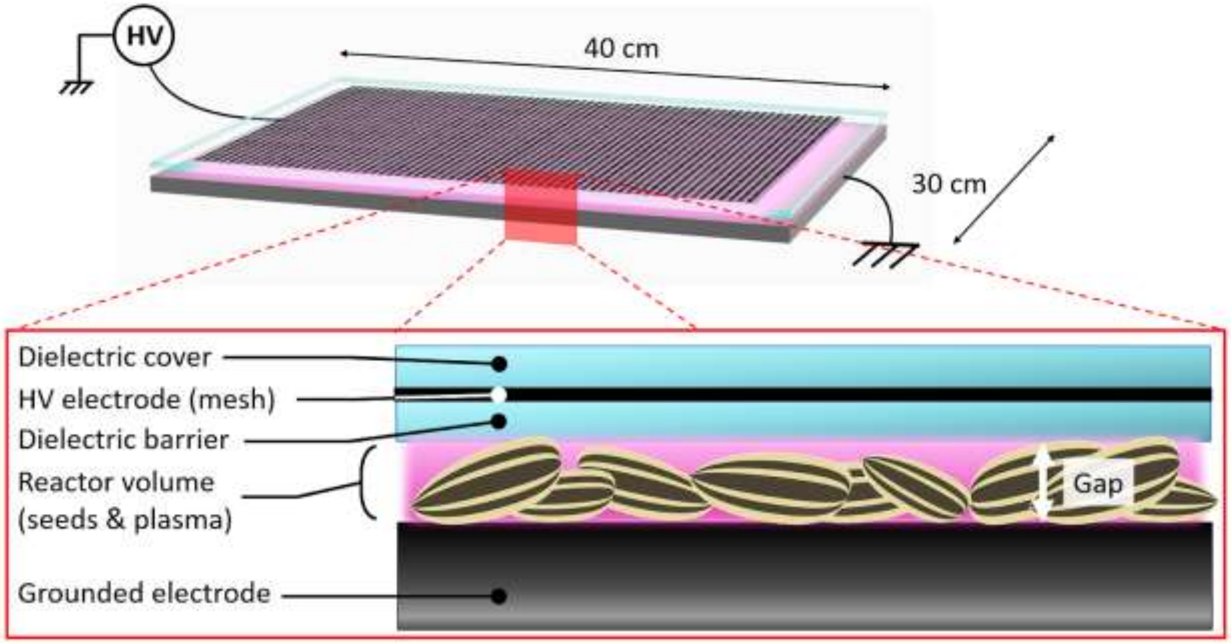
Bradford KJ, Bewley JD (2002). Seeds: Biology, Technology and Role in Agriculture. Chapter 9, pp. 210-239. In: Plants, Genes and Crop Biotechnology (eds Chrispeels MJ, Sadava DE), Jones and Bartlett, Boston.

Novel methods for improving seed germination: use of cold-plasmas in seed biology



Cold atmospheric plasma (CAP), "dry" approach

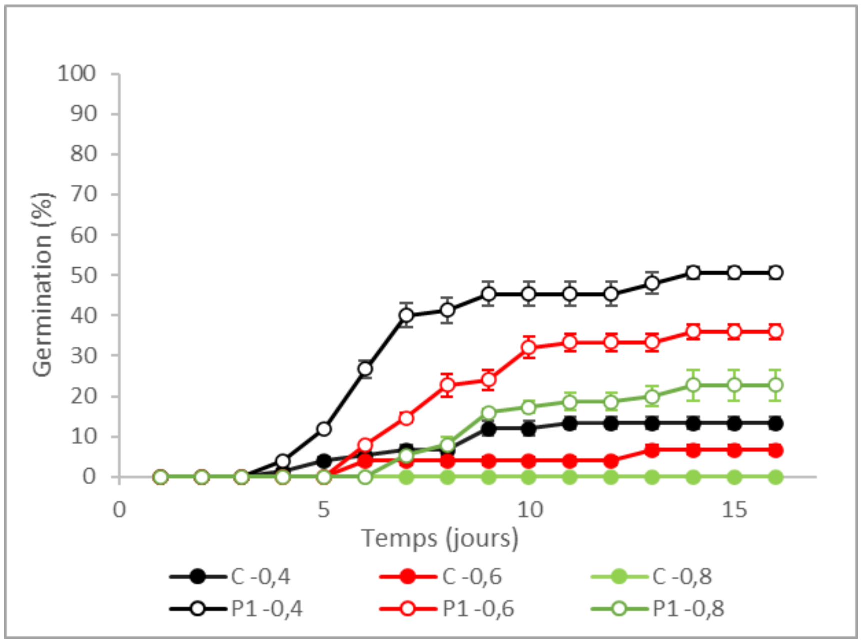
Thierry Dufour
Physics of Plasma Lab

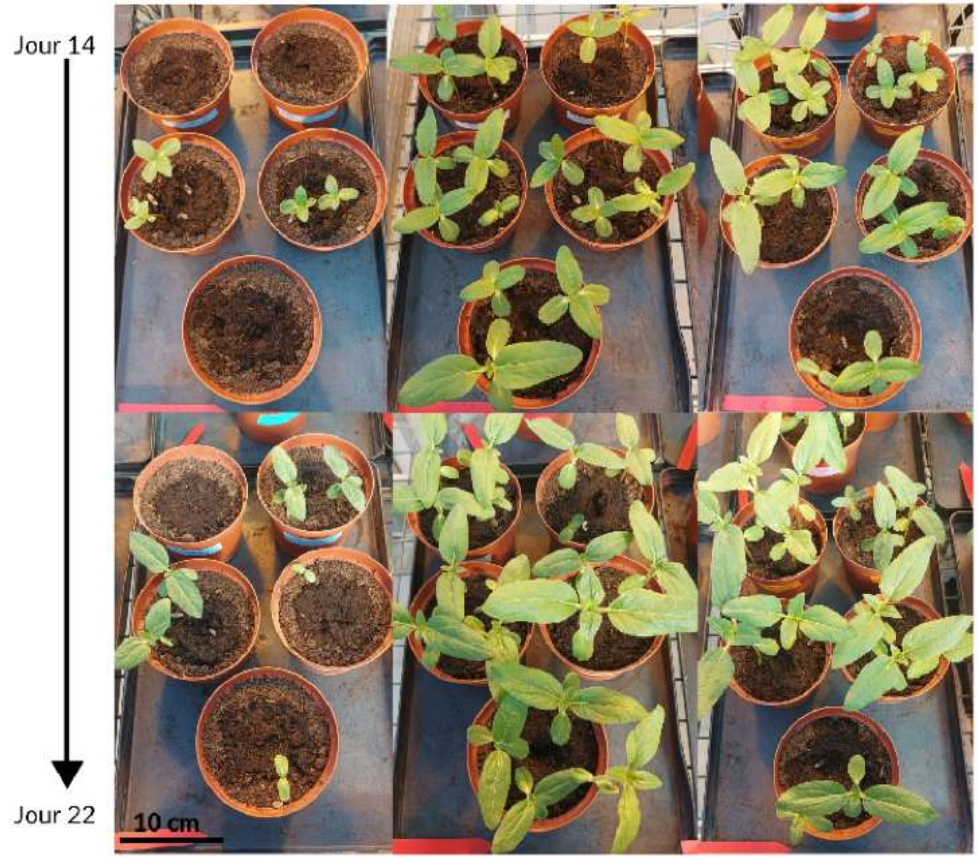


Duration the treatment: 15 min, dry seeds
Peak amplitude of the voltage : 7kV at 145 Hz
Power 11.6 W

Patented, 2022

CAP treatment stimulates seed vigour





control plasmas

22 d after sowing in water stress conditions
(30 % field capacity, greenhouse)

Léna Taras, PhD

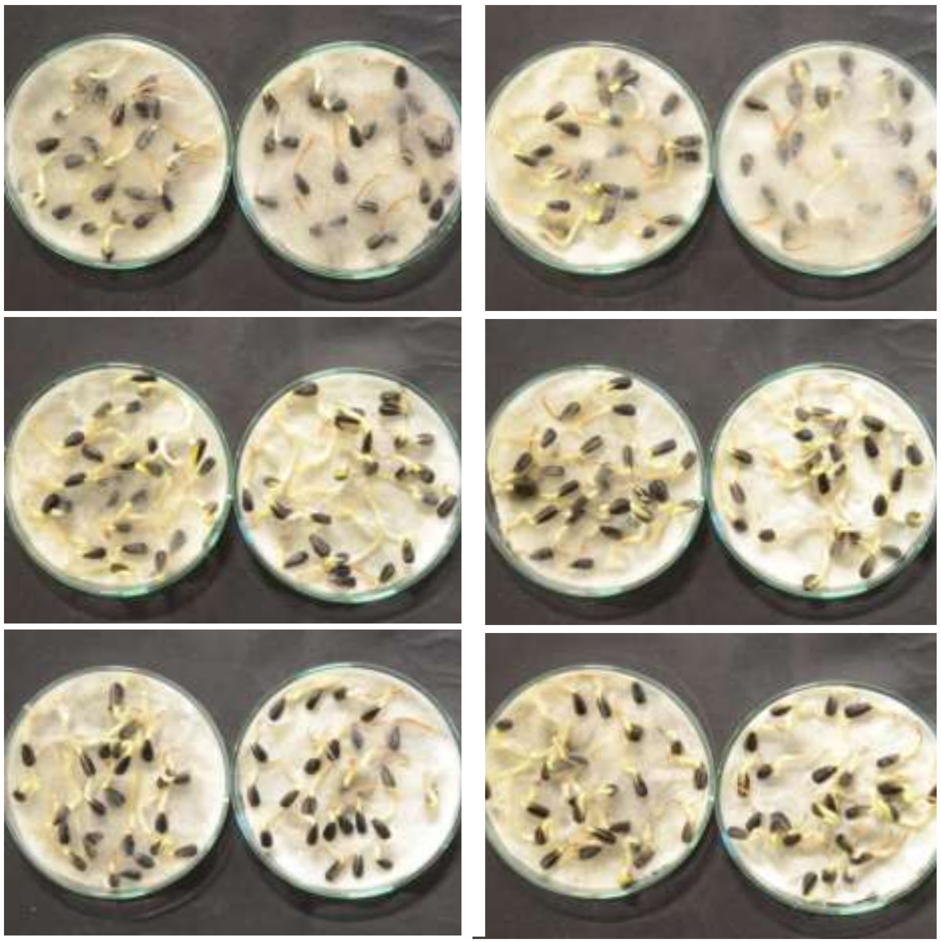
Additionnaly Plasmas eliminate seed pathogens and are an alternative to chemicals

Sunflower

Control (t= 0 min)

Plasma 15 min

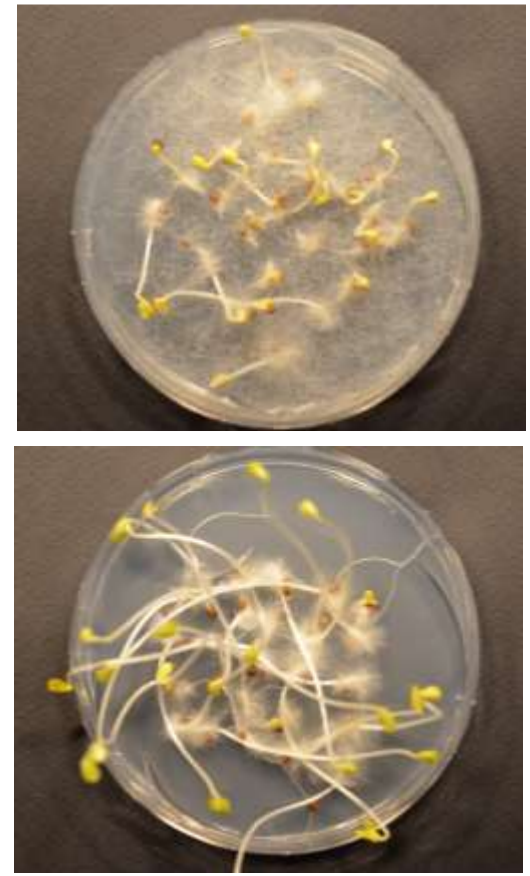
Plasma 30 min



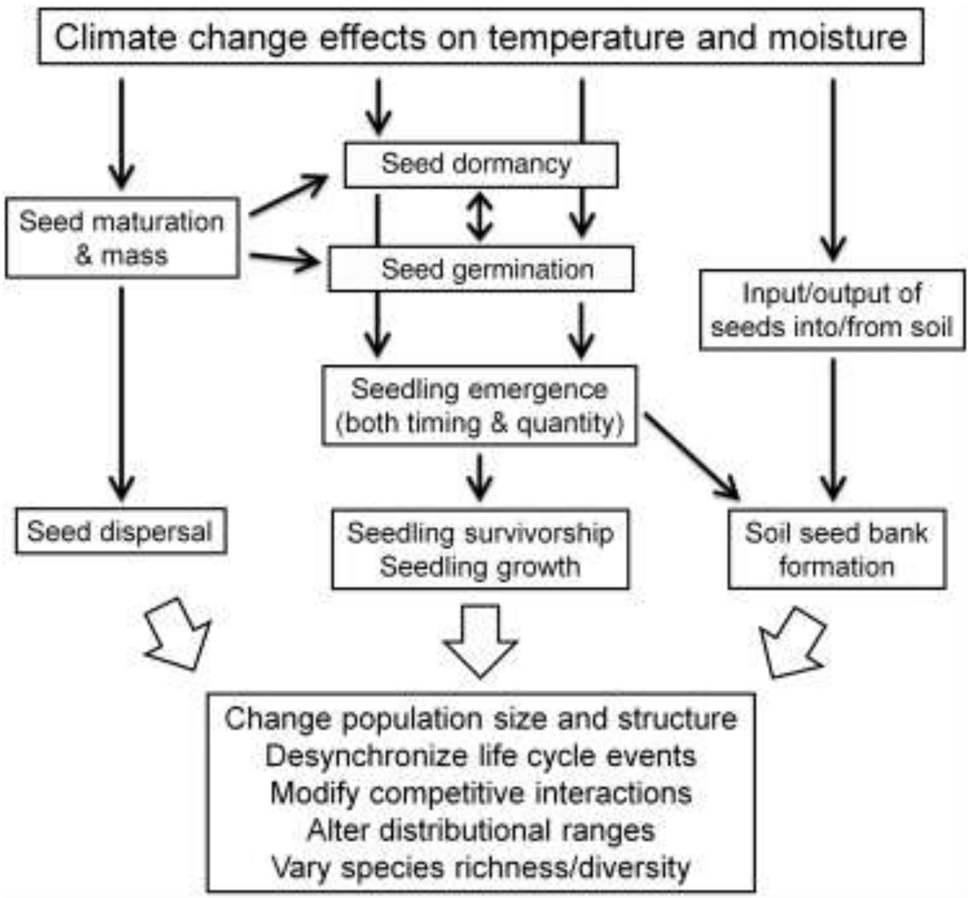
White cabbage

Control (t= 0 min)

Plasma 15 min



Expected consequences of climate change on seed physiology



Climate change and plant regeneration from seed

JEFFREY L. WALCK*, SITI N. HIDAYATI*, KINGSLEY W. DIXON†‡, KEN THOMPSON§ and PETER POSCHLOD¶

- Alteration of dormancy at harvest
- Changes in kinetics of dormancy release
- Poor stand establishment
- Modification of soil seed bank dynamics (weeds)

A better understanding of seed biology is required to insure crop productivity and dynamics of plants populations in ecosystems under a changing climate

Seed Biology Group

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