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Beneficial microorganisms: the best partner to improve plant adaptative capacity

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Abstract:

Currently, the world is facing a high population increase as well as climate change involving global warming, water shortage which limits agronomic productivity, necessary to achieve food security for the growing population. As sessile organisms unable to run away from danger, plants are endowed with sophisticated mechanisms to overcome all stressing situations for survival, involving an enormous amount of chemical molecules, specific for each situation. In addition, they establish intimate relationships with beneficial microorganisms creating the plant microbiome. Within this microbiome are beneficial bacteria, known as Plant Growth Promoting Rhizobacteria (PGPR), which represent a great tool to boost plant fitness in different aspects, as they are able to trigger multiple targets simultaneously.

The present work describes the physiological mechanisms involved in plant adaptation to water stress, nutrient absorption, and adaptative responses to biotic stress and how bioeffectors are able to modulate these responses, focusing on the mechanisms involved in plant adaptation to water stress (salinity and water shortage), plant innate immunity and general mechanisms involved in plant protection to pathogen outbreaks. A few examples in *Solanum lycopersicum*, *Olea europea* and *Rubus* sp illustrate effects of PGPR increasing plant adaptative capacity

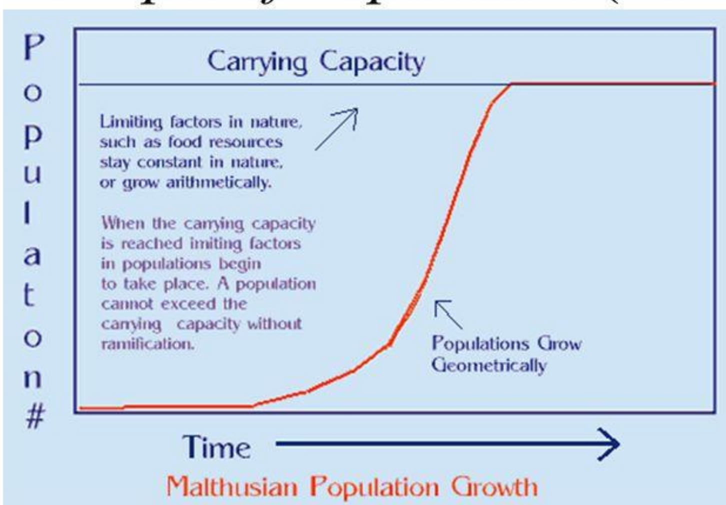
Keywords: beneficial bacteria, adaptation, water stress, food security

IECPS 2020

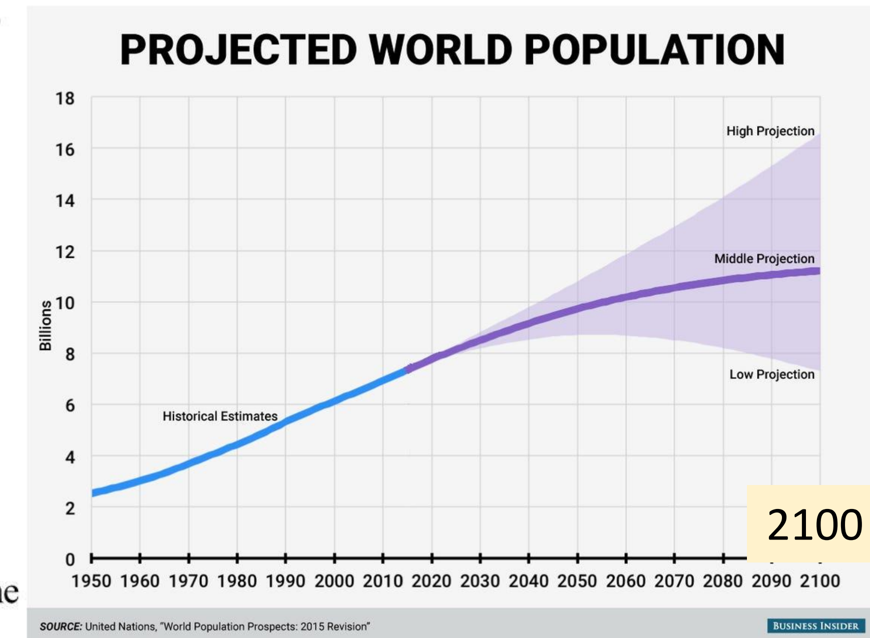
THE SCENARIO

The world population is expected to triple between 1950 (2.5 billion) and 2050 (10 billion)

Thomas Malthus, *Essay on the Principle of Population* (1798)



The rate of human population growth is greater than the rate of increase of food supply --> will lead to famine



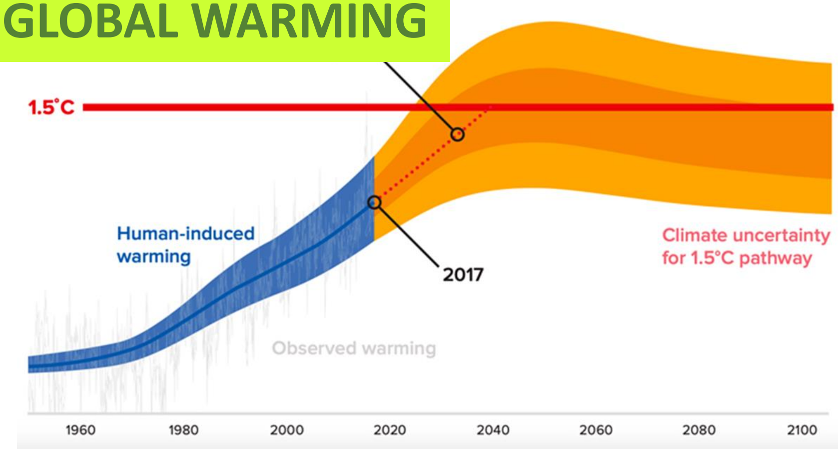
https://www.google.es/search?hl=es&authuser=0&biw=965&bih=575&tbm=isch&sa=1&ei=5otZW_jwLtGPlwSF_7voDg&q=human+population+through+time&oq=human+population&gs_l=img.1.1.0l4j0i30k1l6.13399.16365.0.19489.16.10.0.6.6.0.101.719.9j1.10.0....0...1c.1.64.img..0.16.757...35i39k1j0i67k1.0.ided1OddXEo#imgrc=KlQ2z6QbkeEoYM:

Globally, more than one billion people per year are chronically hungry

Image courtesy CDC/ Dr. Lyle Conrad (number 6901) Image courtesy CDC (number 6903)

More than *two* billion people per year are chronically anemic due to iron deficiency

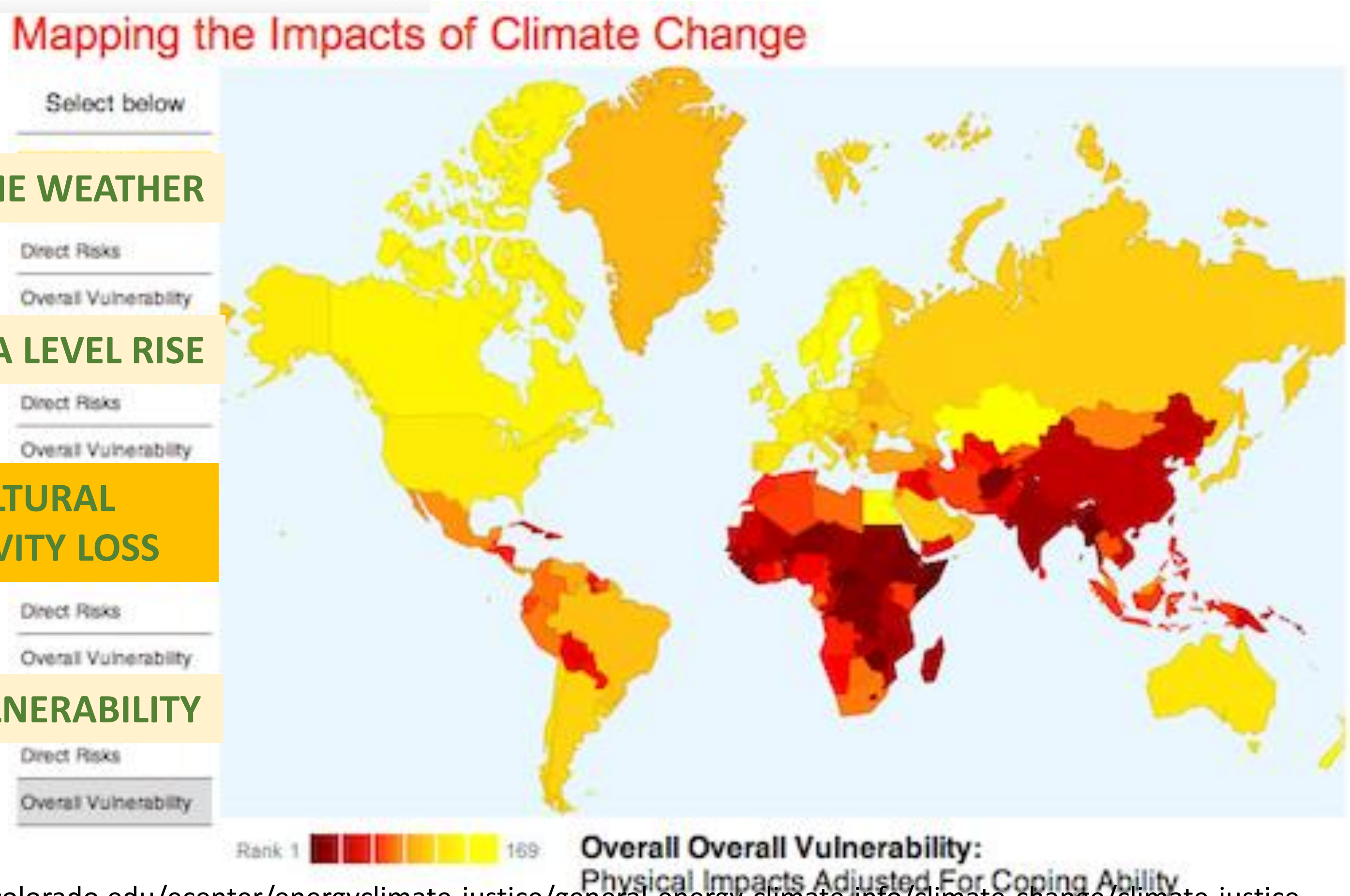
Scarcity of foods is not the only problem…..



GLOBAL WARMING

CLIMATE CHANGE

WATER AVAILABILITY LIMITED
SALINITY
ARID SOILS



EXTREME WEATHER

SEA LEVEL RISE

AGRICULTURAL PRODUCTIVITY LOSS

OVERALL VULNERABILITY

https://www.colorado.edu/ecenter/energyclimate-justice/general-energy-climate-info/climate-change/climate-justice

THE CHALLENGE

Food security

SUSTAINABILITY

Food security exists when all people, at all times, have physical and economic access to sufficient, safe and **nutritious** food to meet their dietary needs and food preferences for an active and **healthy** life. (FAO)

A major objective of plant science is to increase food production; current estimates indicate that we need to increase production by 70% in the next 40 years.

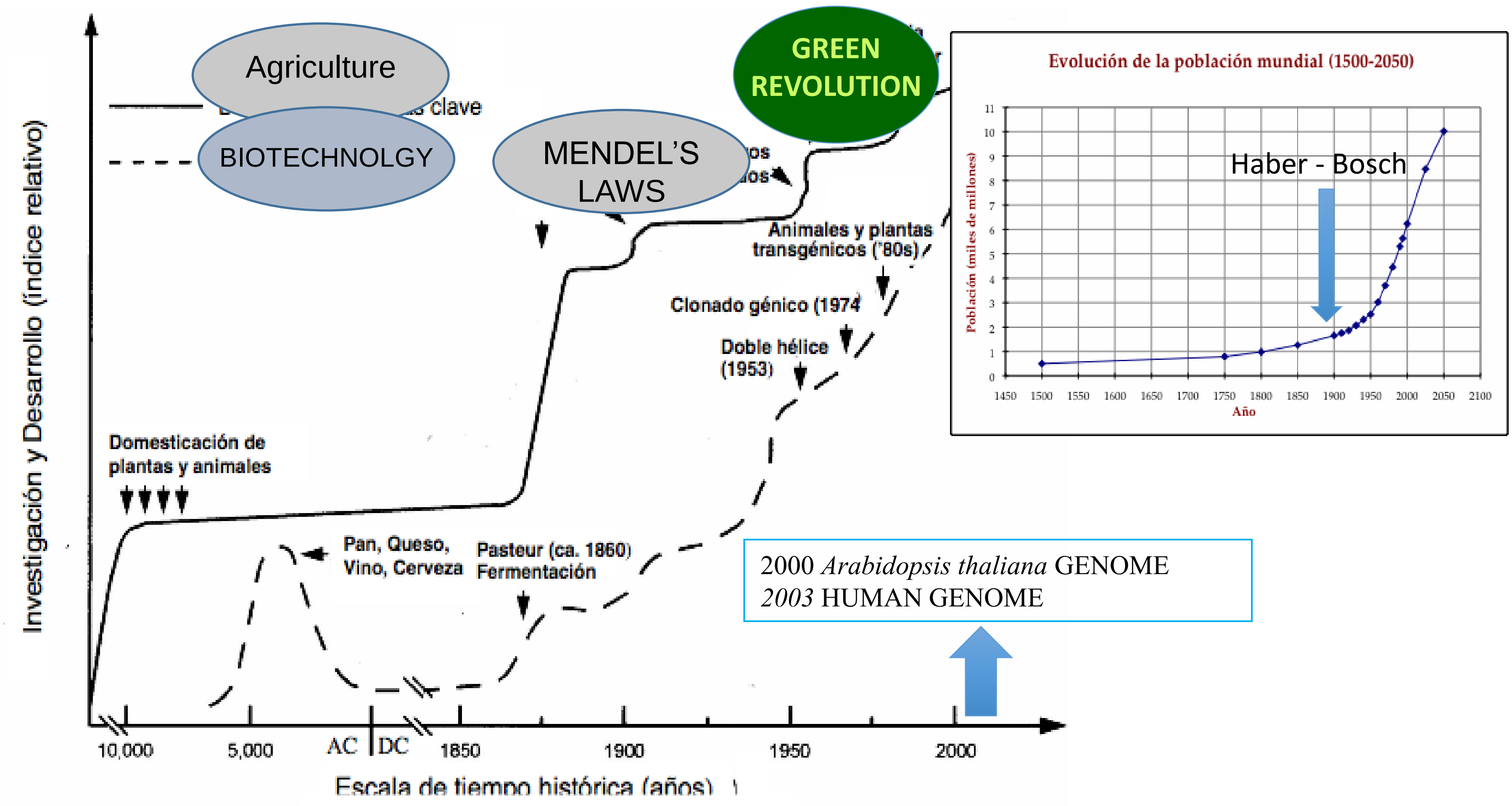
ENOUGH

HEALTHY
NUTRITIOUS

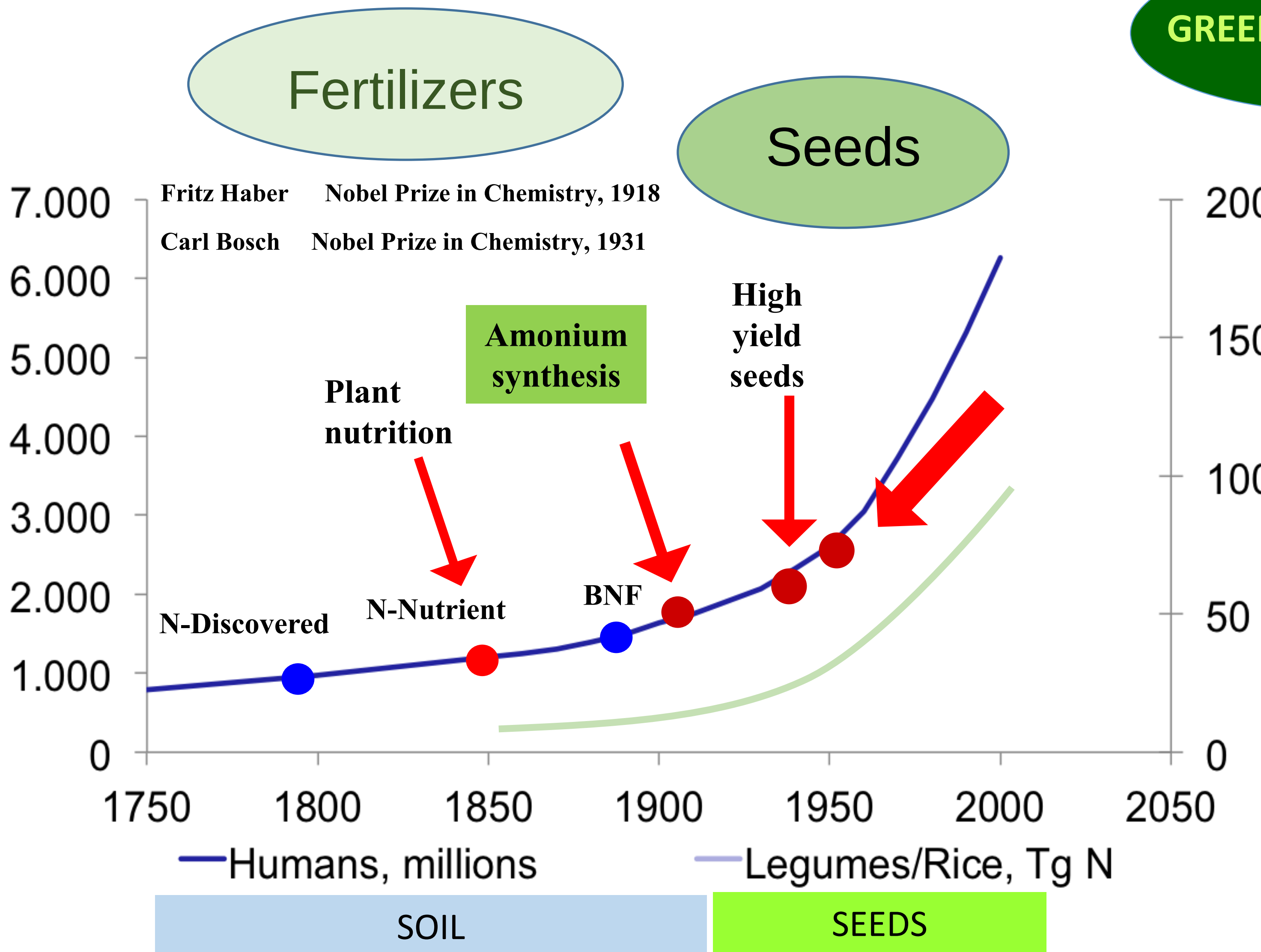
LESS DEVELOPED COUNTRIES

MILESTONES IN BIOTECNOLOGY ENABLING POPULATION GROWTH

INCREASES IN GLOBAL POPULATION ALWAYS ASSOCIATED TO AN INCREASED CAPACITY TO PRODUCE FOOD



GREEN REVOLUTION



After a long period of strict abiotic concept of agriculture ....

WHAT'S NEXT?

WHAT'S NEXT?

MICROORGANISMS

THE BIOTIC COMPONENT ON THE MOVE:

PLANT MICROBIOME

SOIL IS A COMPLEX SYSTEM, AN ECOSYSTEM

HOLDS AN ENORMOUS DIVERSITY OF ORGANISMS

MICROORGANISMS ESTABLISH COMPLEX INTERACTIONS AMONG THEM

AND

WITH THE PLANTS THAT LIVE THEREIN

DIFFERENT SOILS, DIFFERENT PROBLEMS, DIFFERENT MICROBIOMES

- **Microbial density: above 10^{11} per gram of soil.**
- **Highest diveristy: more than 10^{4} diferent species per gram of soil**

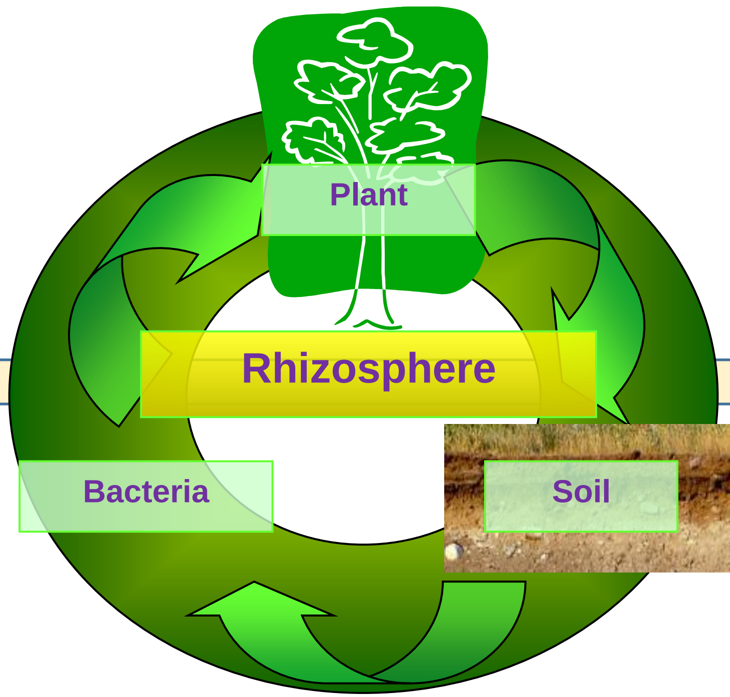
A MILESTONE IN THE BIOTIC COMPONENT OF THE SOIL

THE PLANT-MICROBE INTERACTION

THE RIZOSPHERE

Lorentz Hiltner (**1904**)

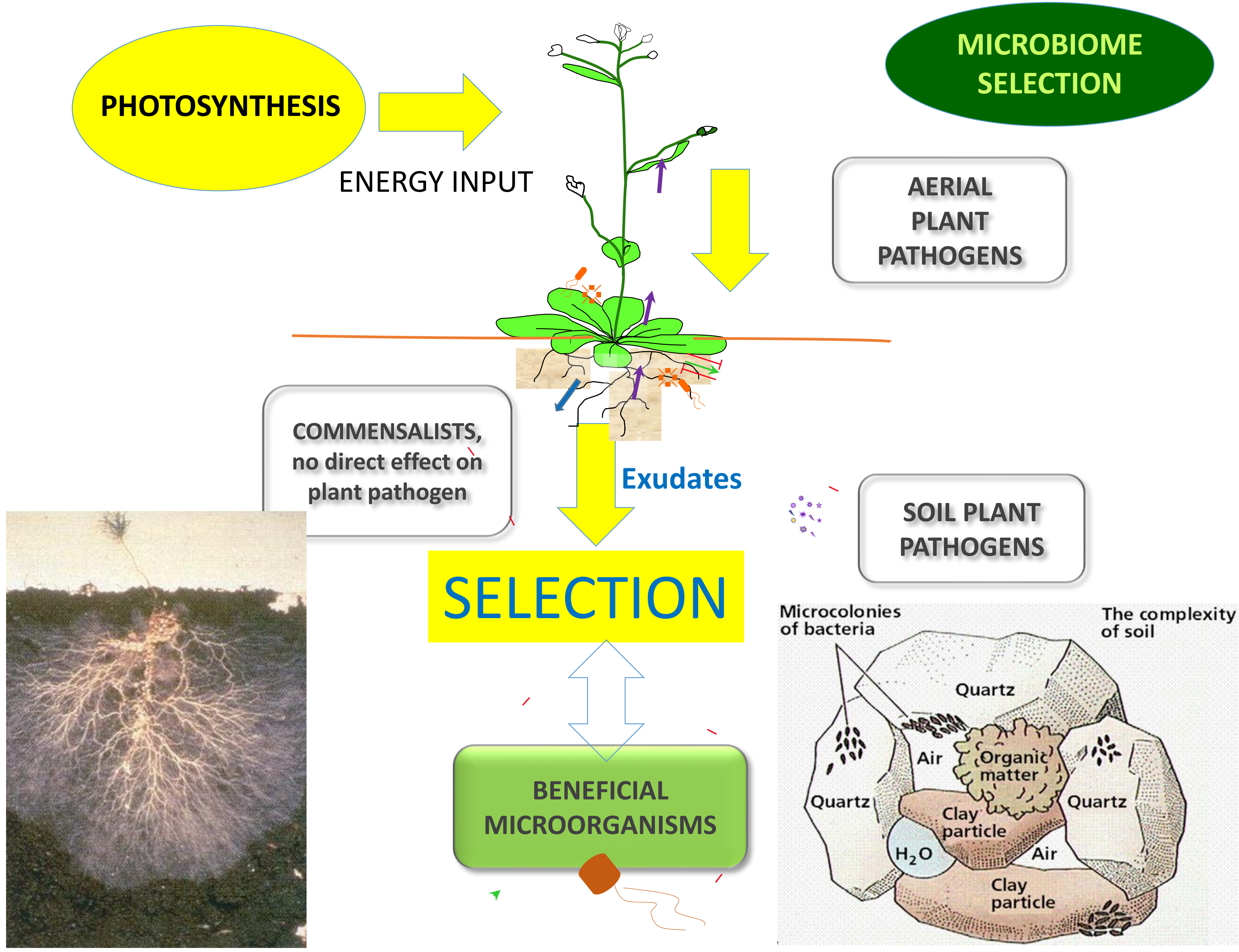
EFFECT



ECOSYSTEM

Lynch (**1990**)

MICROORGANISMS | SOIL | PLANTS



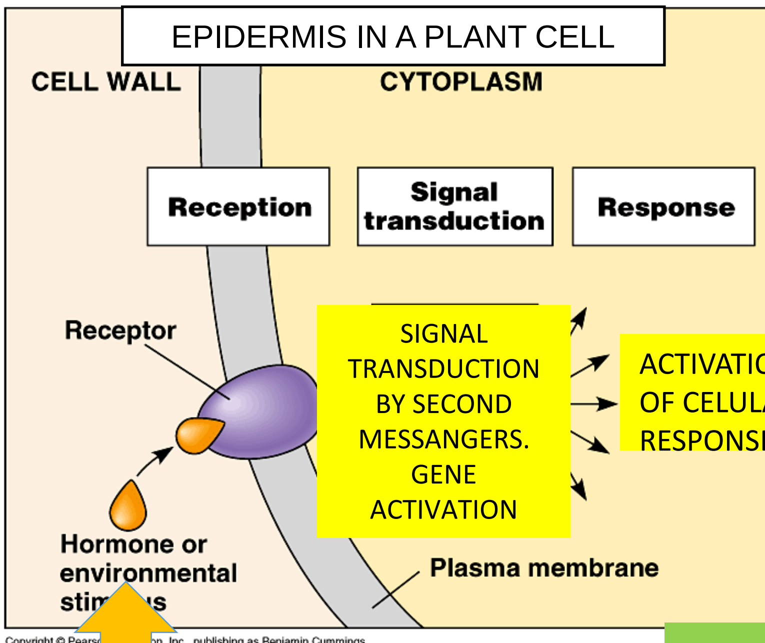
PHOTOSYNTHESIS
ENERGY INPUT
MICROBIOME SELECTION
AERIAL PLANT PATHOGENS
COMMENSALISTS, no direct effect on plant pathogen
Exudates
SOIL PLANT PATHOGENS
SELECTION
BENEFICIAL MICROORGANISMS
Microcolonies of bacteria
The complexity of soil
Quartz
Air
Organic matter
Quartz
Quartz
Clay particle
H_2O
Air
Clay particle

HOW DO MICROBES IMPROVE PLANT FITNESS?

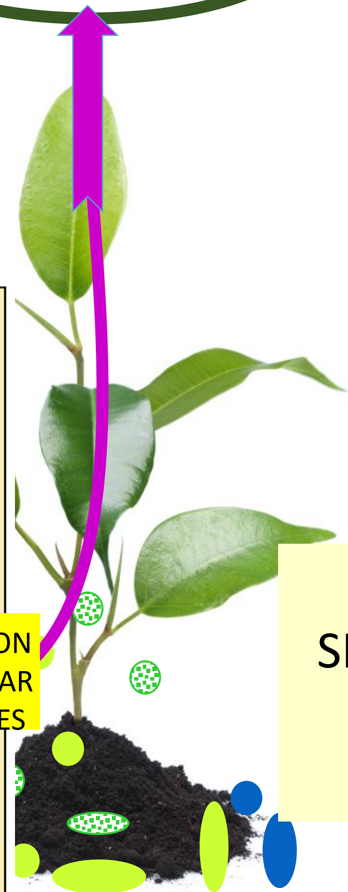
A) INVOLVING PLANT METABOLISM

Metabolic changes are triggered in roots and appear in leaves
SYSTEMIC RESPONSE

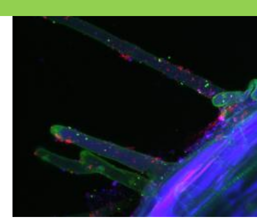
SECONDARY METABOLISM



ELICITOR: A MOLECULE RELEASED BY BACTERIA



MICROBIOME



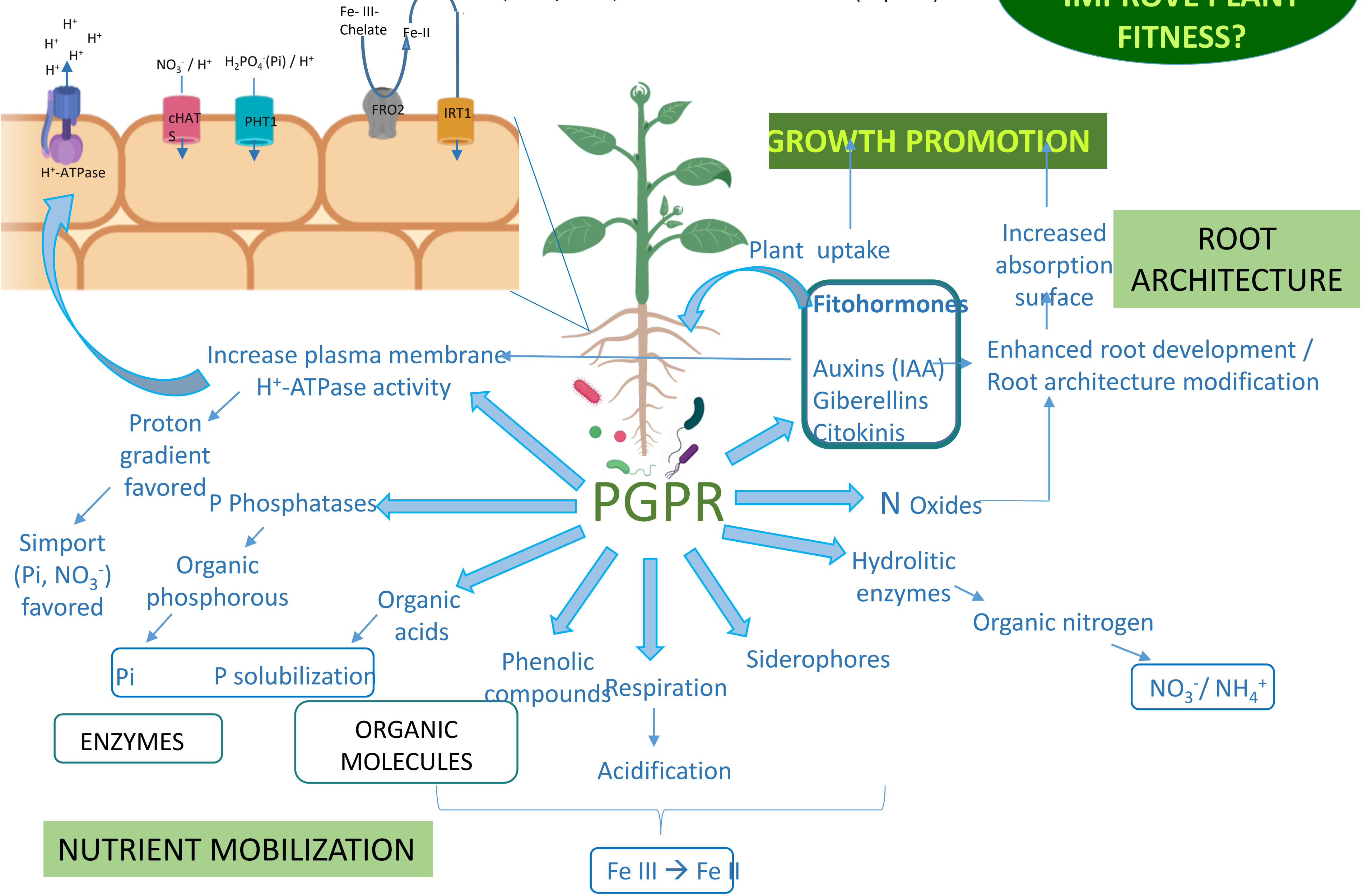
B) AFFECTING EXTERNAL FACTORS:

Nutrient mobilization
Control of other microorganisms….

MULTIPLE MECHANISMS SIMULTANEOUSLY TRIGGERED BY BENEFICIAL MICROORGANISMS

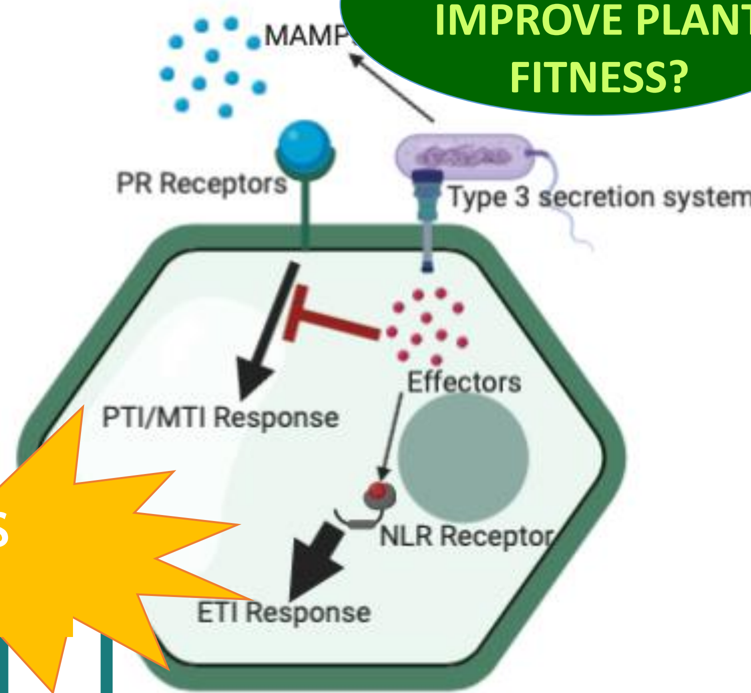
Ilangumaran, G. and D.L. Smith. 2017. Plant Growth Promoting Rhizobacteria in Amelioration of Salinity Stress: A Systems Biology Perspective. Front. Plant Sci., 23 https://doi.org/10.3389/fpls.2017.01768

Biotechnological Applications of Bioeffectors Derived From The Plant Microbiome to Improve Plant's Physiological Response for a Better Adaptation to Biotic and Abiotic Stress. Fundamentals and Case Studies. García-Villaraco, et al, 2021, in TAYLOR AND FRANCIS (in press)



PLANT DEFENSE BIOTIC STRESS

HOW DO MICROBES IMPROVE PLANT FITNESS?



ROS

Intracellular Signal molecules (SA, JA/Et)

Genetic expression changes

Defense Molecules (PRs, PDFs, Phytoalexins)

Systemic Signal molecules (MeSA, PiP, etc.)

SYSTEMIC RESPONSE

PTI: PATHOGEN TRIGGERED IMMUNITY

ETI: EFFECTOR TRIGGERED IMMUNITY

BEYOND PLANT DEFENSE

HOW DO MICROBES IMPROVE PLANT FITNESS?

PRIMING PHASE

POST CHALLENGED PRIMING STATE

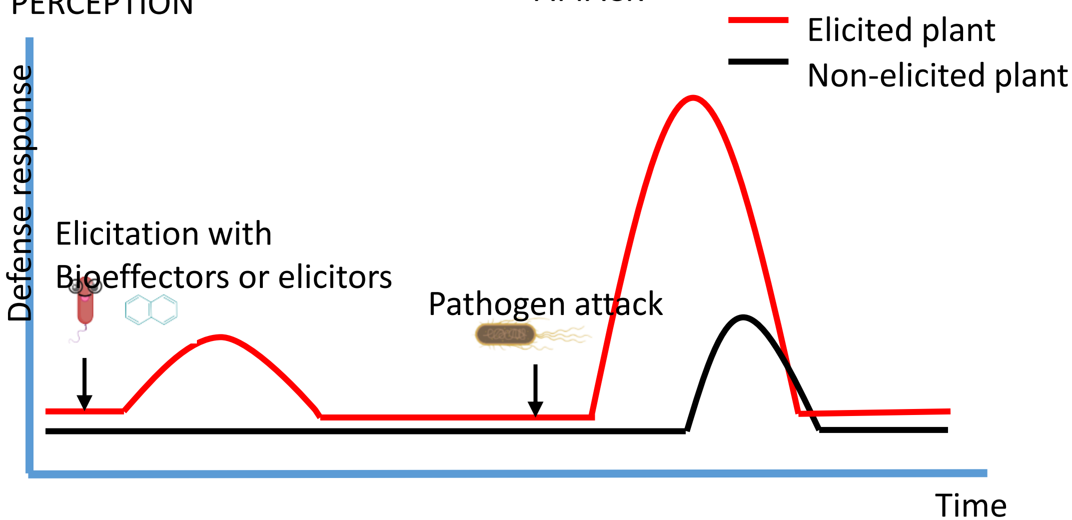
ROS /gene activation/others

Phytoalexin synthesis/PR proteins/other

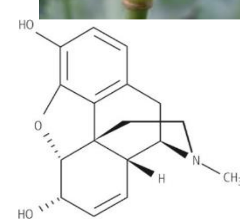
MORE ROBUST DEFENSE

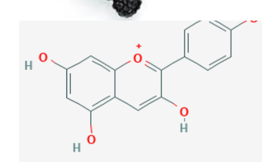
STIMULI PERCEPTION

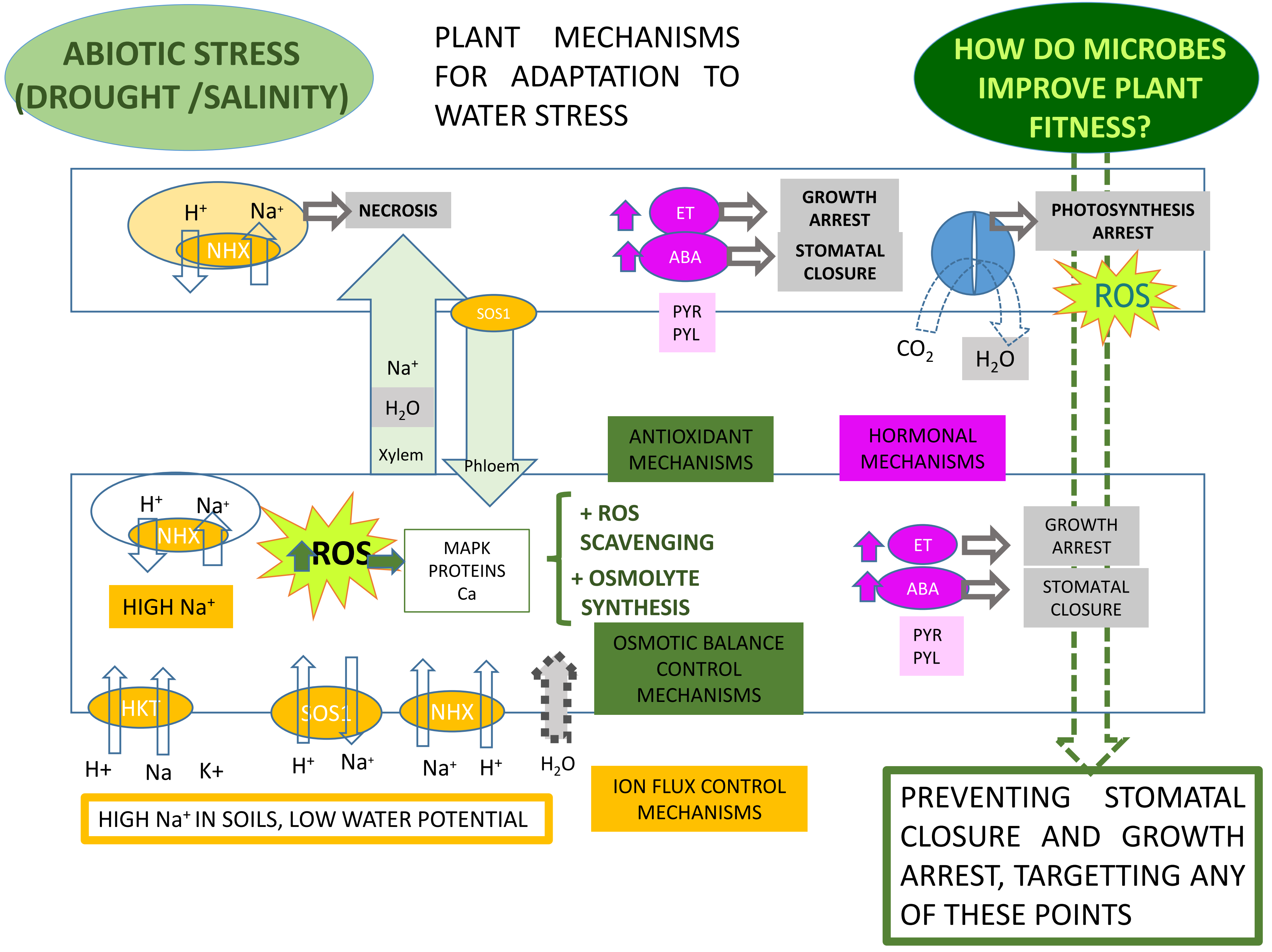
TRIGGERING ATTACK

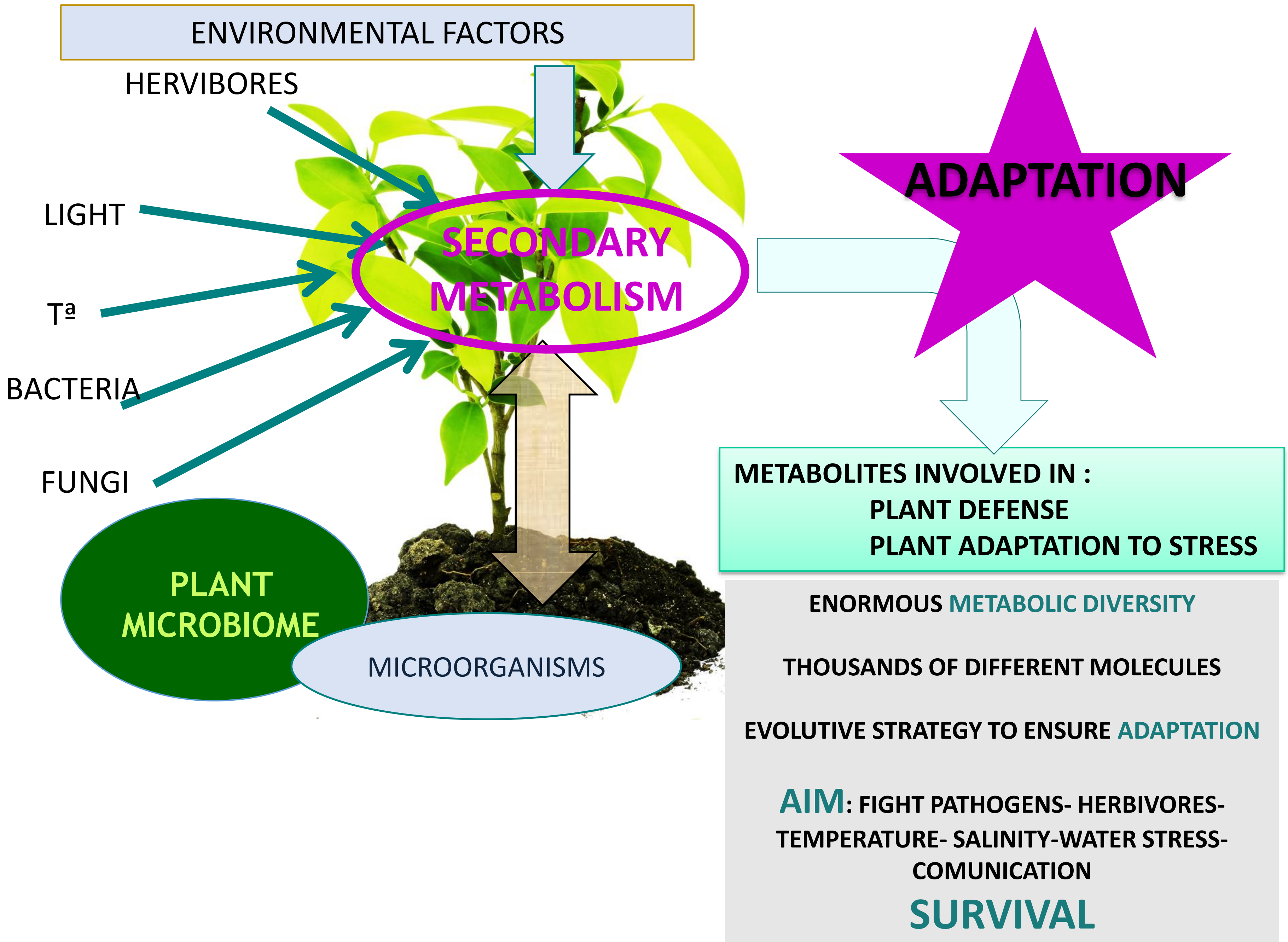


HIGHER QUALITY OF PLANT FOODS DUE TO MORE BIOACTIVES (SECONDARY METABOLISM)






ABIOTIC STRESS (DROUGHT /SALINITY)
PLANT MECHANISMS FOR ADAPTATION TO WATER STRESS
HOW DO MICROBES IMPROVE PLANT FITNESS?
H+ Na+
NHX
NECROSIS
ET
ABA
GROWTH ARREST
STOMATAL CLOSURE
PYR PYL
PHOTOSYNTHESIS ARREST
ROS
CO2
H2O
SOS1
Na+
H2O
Xylem
Phloem
ANTIOXIDANT MECHANISMS
HORMONAL MECHANISMS
H+ Na+
NHX
ROS
MAPK PROTEINS Ca
HIGH Na+
+ ROS SCAVENGING
+ OSMOLYTE SYNTHESIS
ET
ABA
GROWTH ARREST
STOMATAL CLOSURE
PYR PYL
OSMOTIC BALANCE CONTROL MECHANISMS
HKT
SOS1
NHX
H+ Na K+
H+ Na+
Na+ H+
H2O
ION FLUX CONTROL MECHANISMS
HIGH Na+ IN SOILS, LOW WATER POTENTIAL
PREVENTING STOMATAL CLOSURE AND GROWTH ARREST, TARGETTING ANY OF THESE POINTS


ENVIRONMENTAL FACTORS
HERVIBORES
LIGHT
Tª
BACTERIA
FUNGI
SECONDARY METABOLISM
ADAPTATION
PLANT MICROBIOME
MICROORGANISMS
METABOLITES INVOLVED IN :
PLANT DEFENSE
PLANT ADAPTATION TO STRESS
ENORMOUS METABOLIC DIVERSITY
THOUSANDS OF DIFFERENT MOLECULES
EVOLUTIVE STRATEGY TO ENSURE ADAPTATION
AIM: FIGHT PATHOGENS- HERBIVORES- TEMPERATURE- SALINITY-WATER STRESS- COMUNICATION
SURVIVAL

AGRONOMIC GOALS

HOW DO MICROBES IMPROVE PLANT FITNESS?

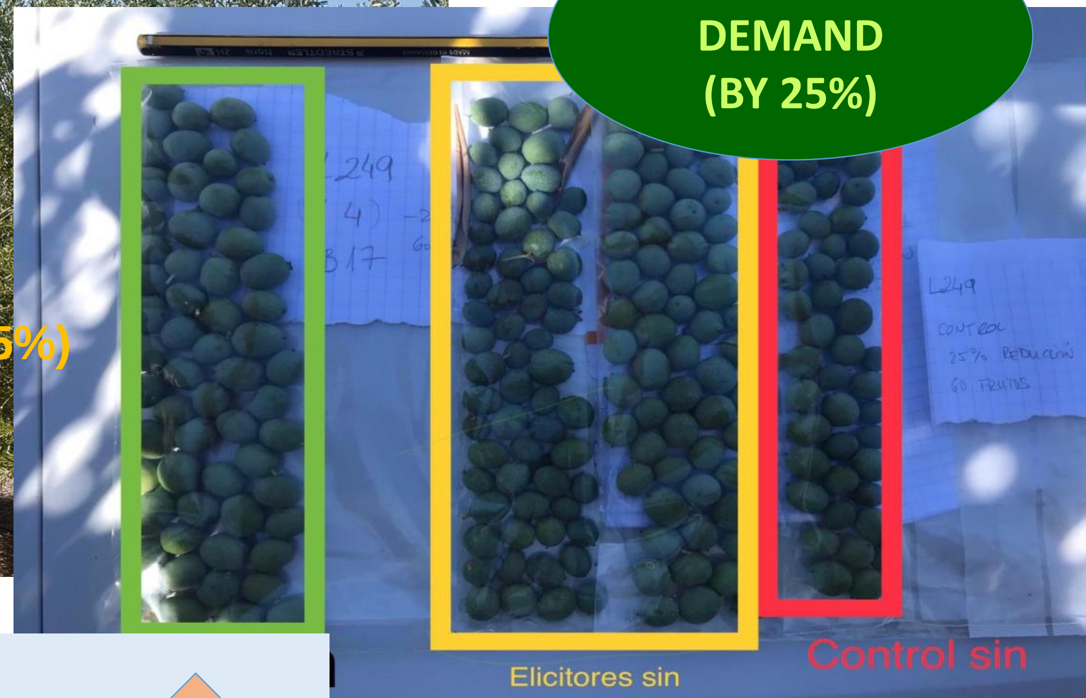
MANIPULATING PLANT PHYSIOLOGY TO

- Lower water and fertilizer demand
- Improve nutrient content
- Improve drought tolerance
- Improve tolerance to other stresses
- Enhance pathogen resistance

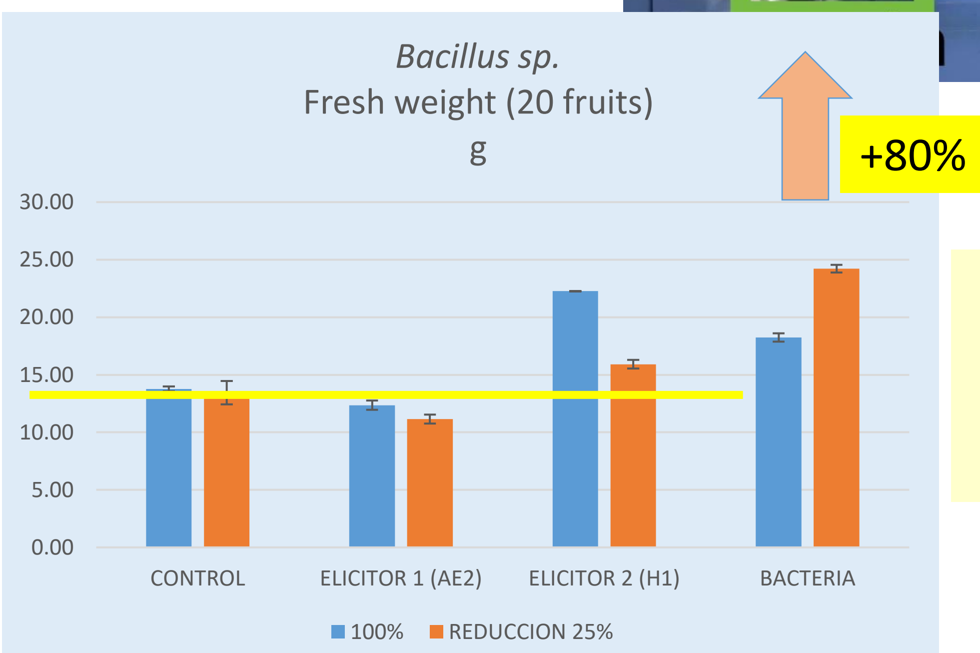
A) GENETIC MANIPULATION
SINGLE TARGETS

B) BENEFICIAL MICROORGANISMS : MULTIPLE TARGETS

Ilangumaran, G. and D.L. Smith. 2017. Plant Growth Promoting Rhizobacteria in Amelioration of Salinity Stress: A Systems Biology Perspective. Front. Plant Sci., 23 https://doi.org/10.3389/fpls.2017.01768



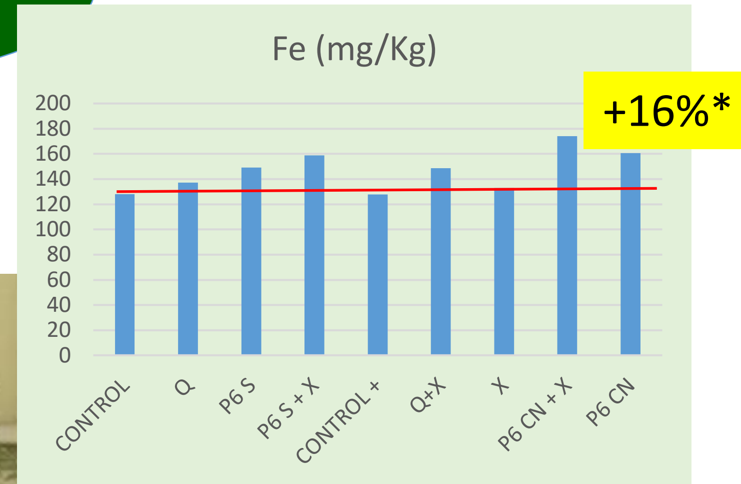
LOWER WATER DEMAND (BY 25%)

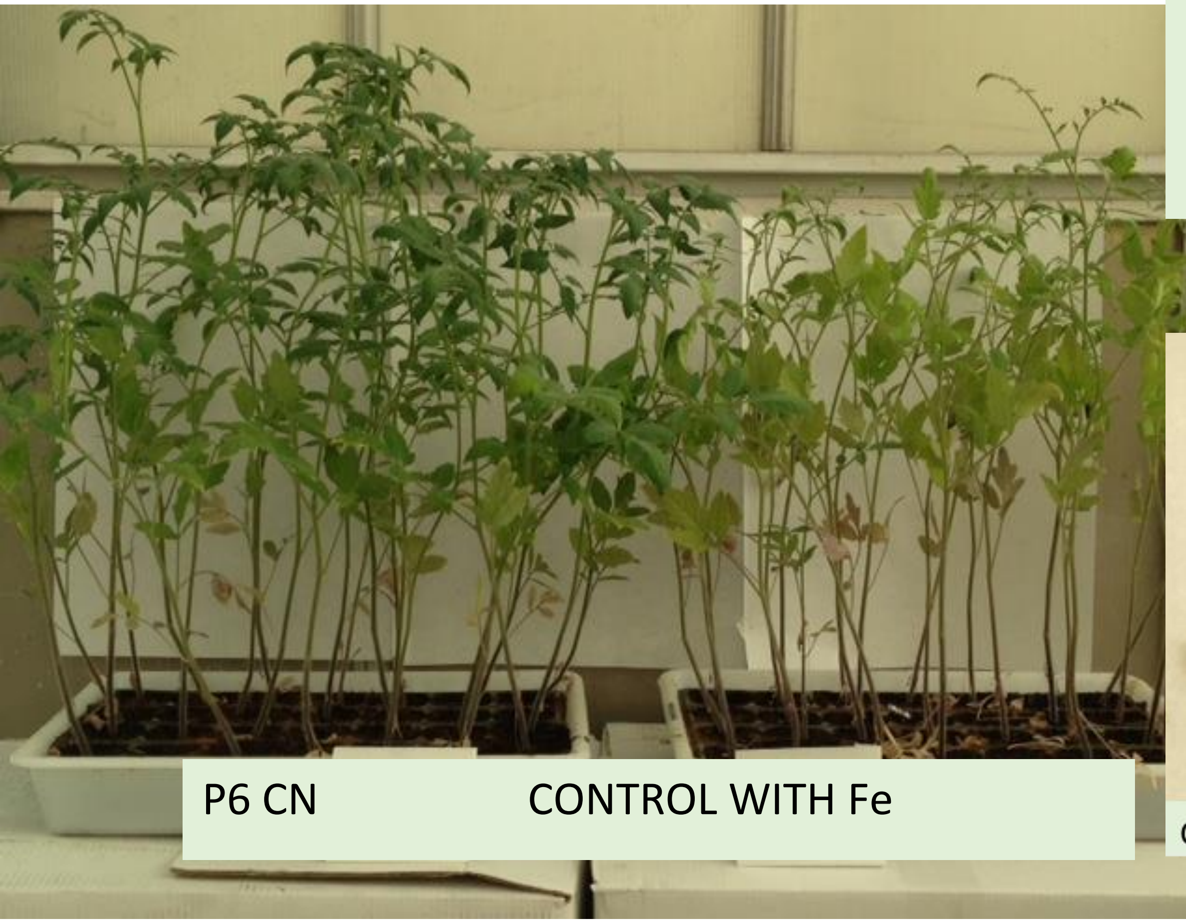


INCREASED HARVEST YIELD UP TO 20% ON WATER LIMITED PLANTS

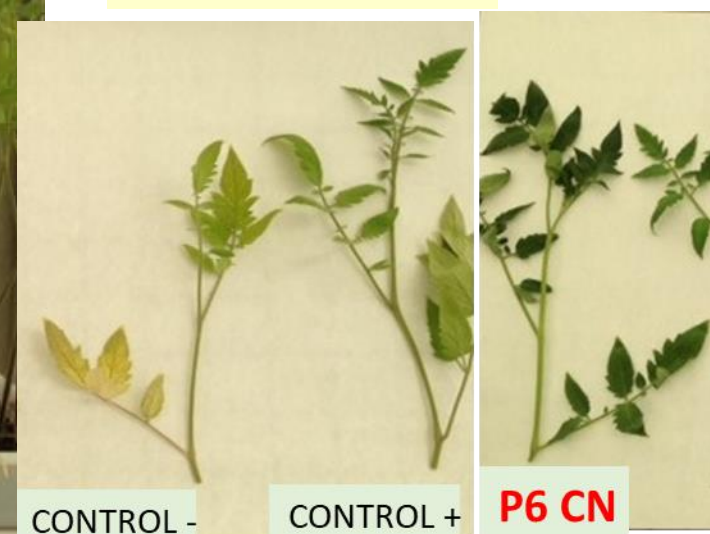
ENHANCED C FIXATION

LOWERING CHEMICAL INPUTS
IMPROVING NUTRIENT CONTENTS IN TOMATO (Fe)





Pseudomonas sp.



DIFFERENT STRATEGIES TO IMPROVE PLANT ADAPTATION TO HIGH ABIOTIC STRESS (DROUGHT AND TEMPERATURE):

- PHOTOSYNTHETIC PIGMENTS
- ANTIOXIDANTS (ENZYME AND NON ENZYME)

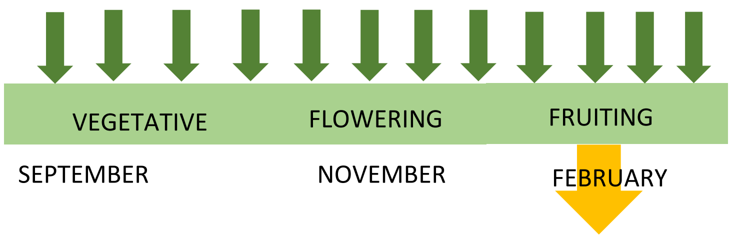
IMPROVE DROUGHT TOLERANCE & RESISTANCE TO OTHER STRESSES

CONTROL ROS BALANCE

ANTIOXIDANTS / PIGMENTS	(5 strains)		(5 strains)	
	↑ APX ↑Flavonols	↑ APX ↓Flavonols	↓ APX ↑Flavonols	↓ APX ↓Flavonols
No pigment variation (2 strains)	K8	H47	—	—
Lower pigment contents (8 strains)	G7	L44	—	L24

F3H (Flavonol-3-hydroxylase) PLAYS A PIVOTAL ROLE ON FLAVONOID METABOLISM IMPROVING ADAPTATION TO BIOTIC STRESS IN BLACKBERRY https://doi.org/10.1371/journal.pone.0232626

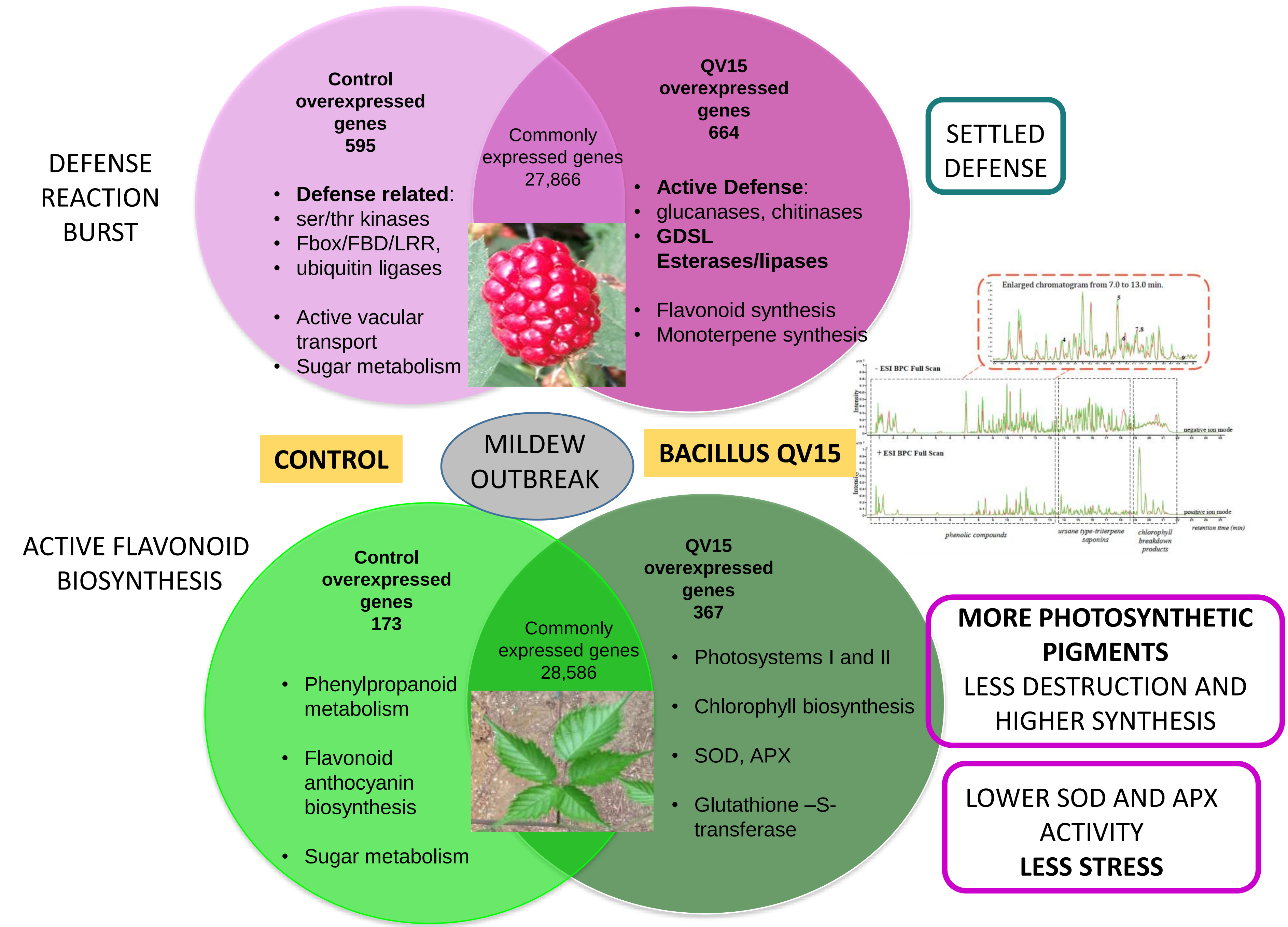
MILDEW OUTBREAK



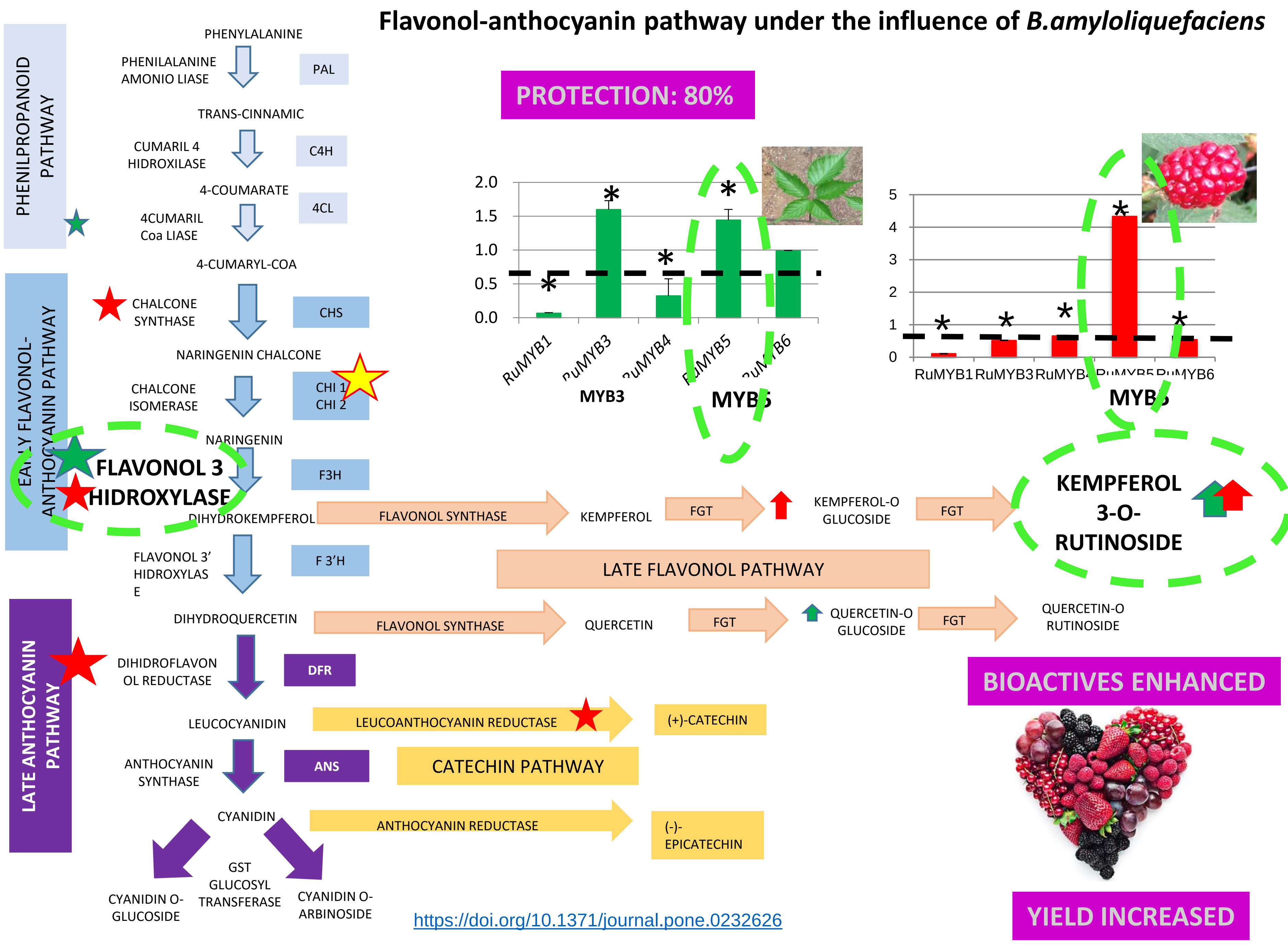
TRANSCRIPTOME
qPCR
TARGETED METABOLOMICS

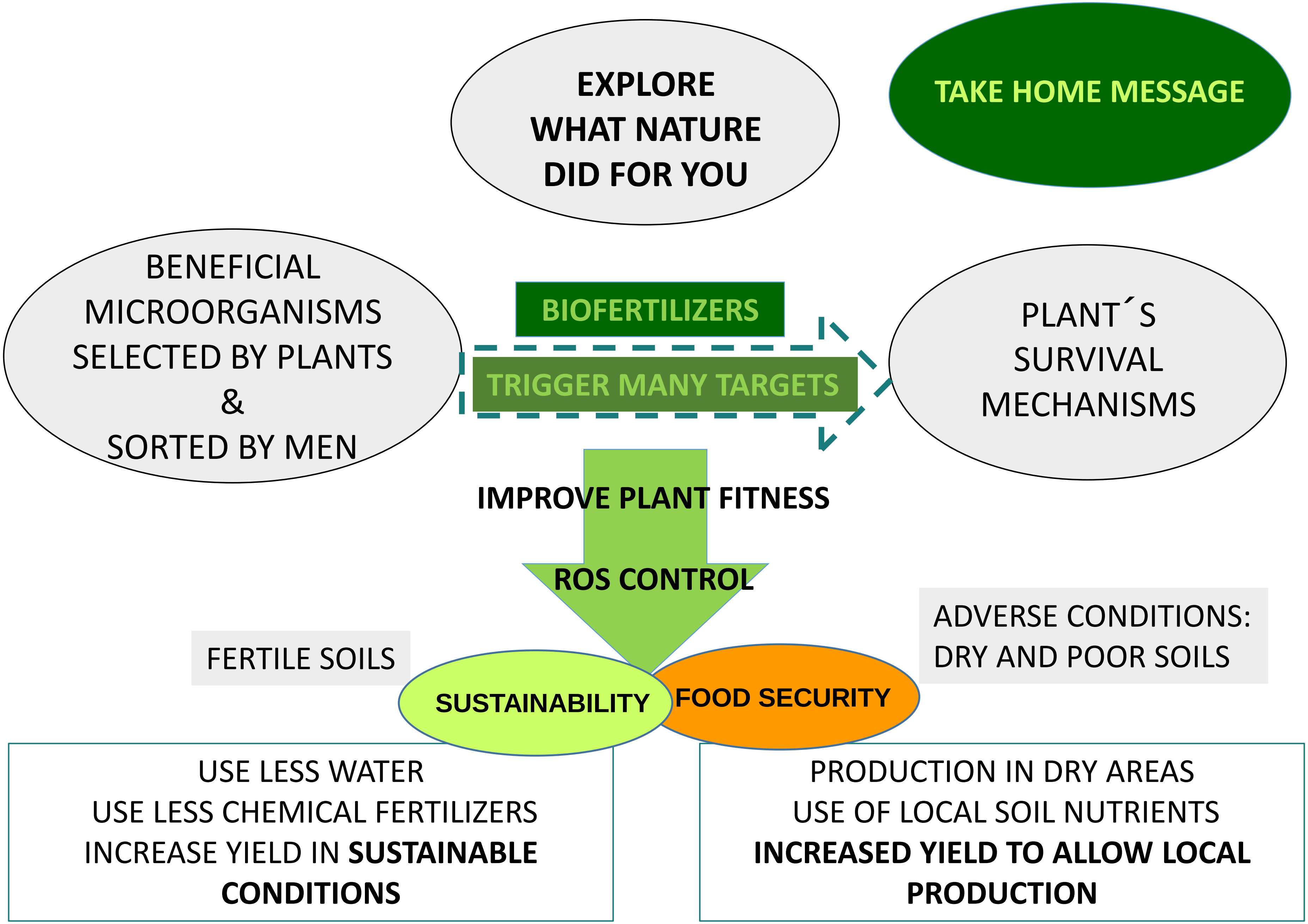
	Flowers/m2	Production (Kg /plant)	Evolution of disease (%affected surface average)	Relative disease index (%)
Control	237.95 ± 2.28 (a)	6.2 ± 0.22 (a)	15% (b)	100 ± 1.05 (b)
QV15	323.5 ± 1.77 (b)	6.4 ± 0.09 (a)	5% (a)	12.02 ± 0.36 (a)

Bacillus amyloliquefaciens
PATENT P201730818



DEFENSE REACTION BURST
Control overexpressed genes 595
• Defense related:
• ser/thr kinases
• Fbox/FBD/LRR,
• ubiquitin ligases
• Active vacular transport
• Sugar metabolism
Commonly expressed genes 27,866
QV15 overexpressed genes 664
• Active Defense:
• glucanases, chitinases
• GDSL Esterases/lipases
• Flavonoid synthesis
• Monoterpene synthesis
SETTLED DEFENSE
Enlarged chromatogram from 7.0 to 13.0 min.
- ESI BPC Full Scan
negative ion mode
+ ESI BPC Full Scan
positive ion mode
Intensity
retention time (min)
phenolic compounds
ursane type-triterpene saponins
chlorophyll breakdown products
CONTROL
MILDEW OUTBREAK
BACILLUS QV15
ACTIVE FLAVONOID BIOSYNTHESIS
Control overexpressed genes 173
• Phenylpropanoid metabolism
• Flavonoid anthocyanin biosynthesis
• Sugar metabolism
Commonly expressed genes 28,586
QV15 overexpressed genes 367
• Photosystems I and II
• Chlorophyll biosynthesis
• SOD, APX
• Glutathione –S-transferase
MORE PHOTOSYNTHETIC PIGMENTS
LESS DESTRUCTION AND HIGHER SYNTHESIS
LOWER SOD AND APX ACTIVITY
LESS STRESS


Flavonol-anthocyanin pathway under the influence of B.amyloliquefaciens
PHENILPROPANOID PATHWAY
PHENYLALANINE
PHENILALANINE AMONIO LIASE
PAL
TRANS-CINNAMIC
CUMARIL 4 HIDROXILASE
C4H
4-COUMARATE
4CUMARIL Coa LIASE
4CL
4-CUMARYL-COA
EARLY FLAVONOL-ANTHOCYANIN PATHWAY
CHALCONE SYNTHASE
CHS
NARINGENIN CHALCONE
CHALCONE ISOMERASE
CHI 1
CHI 2
NARINGENIN
FLAVONOL 3 HIDROXYLASE
F3H
DIHYDROKEMPFEROL
FLAVONOL SYNTHASE
KEMPFEROL
FGT
KEMPFEROL-O GLUCOSIDE
FGT
KEMPFEROL 3-O-RUTINOSIDE
LATE FLAVONOL PATHWAY
FLAVONOL 3' HIDROXYLAS E
F 3'H
DIHYDROQUERCETIN
FLAVONOL SYNTHASE
QUERCETIN
FGT
QUERCETIN-O GLUCOSIDE
FGT
QUERCETIN-O RUTINOSIDE
LATE ANTHOCYANIN PATHWAY
DIHIDROFLAVON OL REDUCTASE
DFR
LEUCOCYANIDIN
LEUCOANTHOCYANIN REDUCTASE
(+)-CATECHIN
ANTHOCYANIN SYNTHASE
ANS
CATECHIN PATHWAY
CYANIDIN
ANTHOCYANIN REDUCTASE
(-)-EPICATECHIN
GST GLUCOSYL TRANSFERASE
CYANIDIN O-GLUCOSIDE
CYANIDIN O-ARBINOSIDE
PROTECTION: 80%
2.0
1.5
1.0
0.5
0.0
RuMYB1
RuMYB3
RuMYB4
RuMYB5
MYB3
MYB5
5
4
3
2
1
0
RuMYB1
RuMYB3
RuMYB6
MYB5
BIOACTIVES ENHANCED
YIELD INCREASED
https://doi.org/10.1371/journal.pone.0232626


EXPLORE
WHAT NATURE
DID FOR YOU
TAKE HOME MESSAGE
BENEFICIAL
MICROORGANISMS
SELECTED BY PLANTS
&
SORTED BY MEN
BIOFERTILIZERS
TRIGGER MANY TARGETS
PLANT´S
SURVIVAL
MECHANISMS
IMPROVE PLANT FITNESS
ROS CONTROL
FERTILE SOILS
ADVERSE CONDITIONS:
DRY AND POOR SOILS
SUSTAINABILITY
FOOD SECURITY
USE LESS WATER
USE LESS CHEMICAL FERTILIZERS
INCREASE YIELD IN SUSTAINABLE CONDITIONS
PRODUCTION IN DRY AREAS
USE OF LOCAL SOIL NUTRIENTS
INCREASED YIELD TO ALLOW LOCAL PRODUCTION

Acknowledgments

Project founded by Ministerio de Economía y competitividad:
Projects of I+D+I, government research program, innovation and development orientated to society challenges. Reference: AGL-2013-45189-R
Founding, Ministerio de Economía y Competitividad: BES-2014-069990

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https://www.biotecnologia-vegetal-microbioma-ceu.es/

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