Induced Resistance in Harvested Fruit and Vegetables: A host physiological response limiting postharvest disease development

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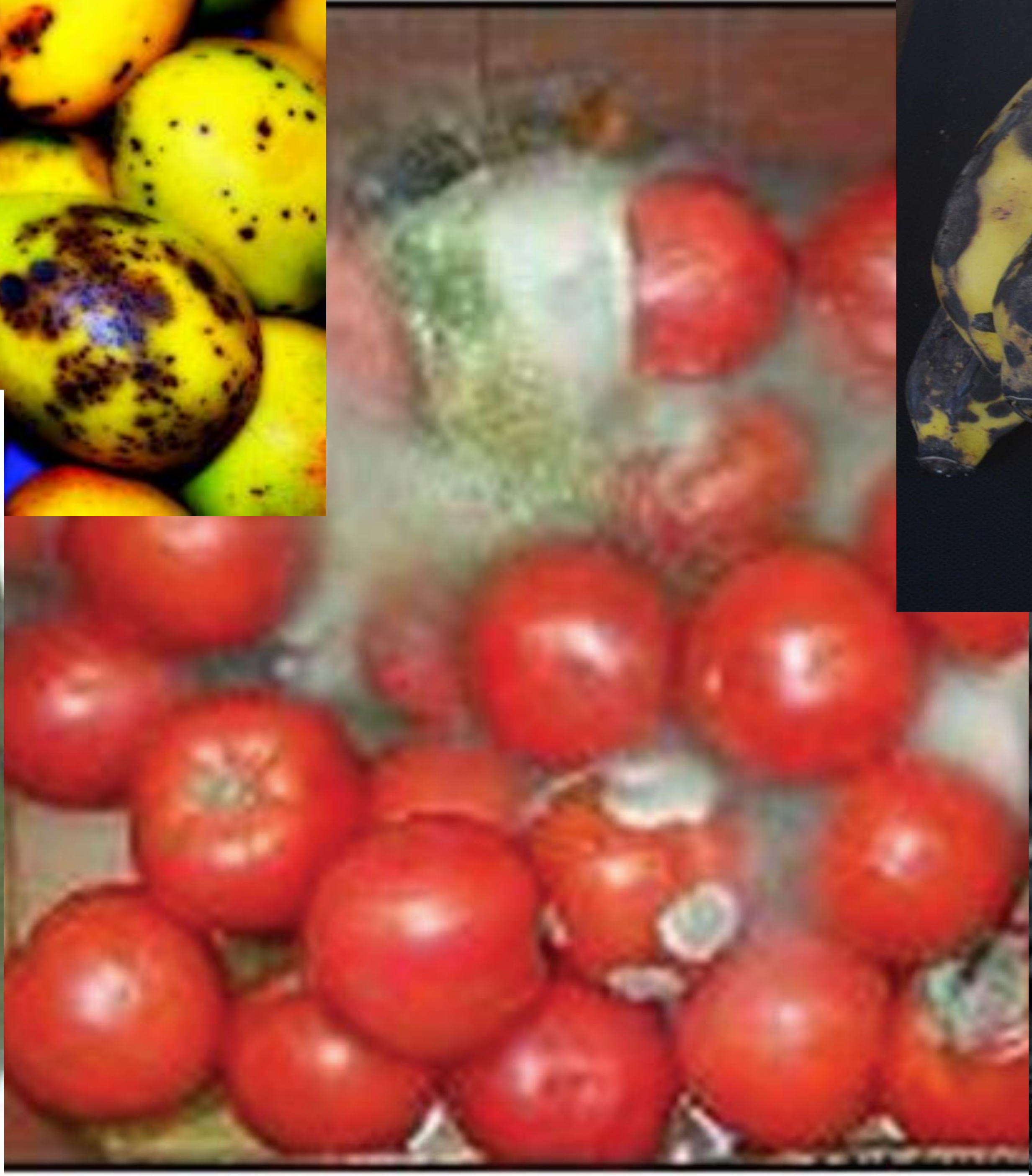
Prevention of diseases development:

- Pre-harvest treatments with fungicides
- Post-harvest treatments with fungicides
- Pre and postharvest induced resistance treatments





Prevention of diseases development:

- Pre-harvest treatments with fungicides
- Post-harvest treatments with fungicides
- Pre and postharvest induced resistance treatments

Induce resistance in host fruit and vegetables

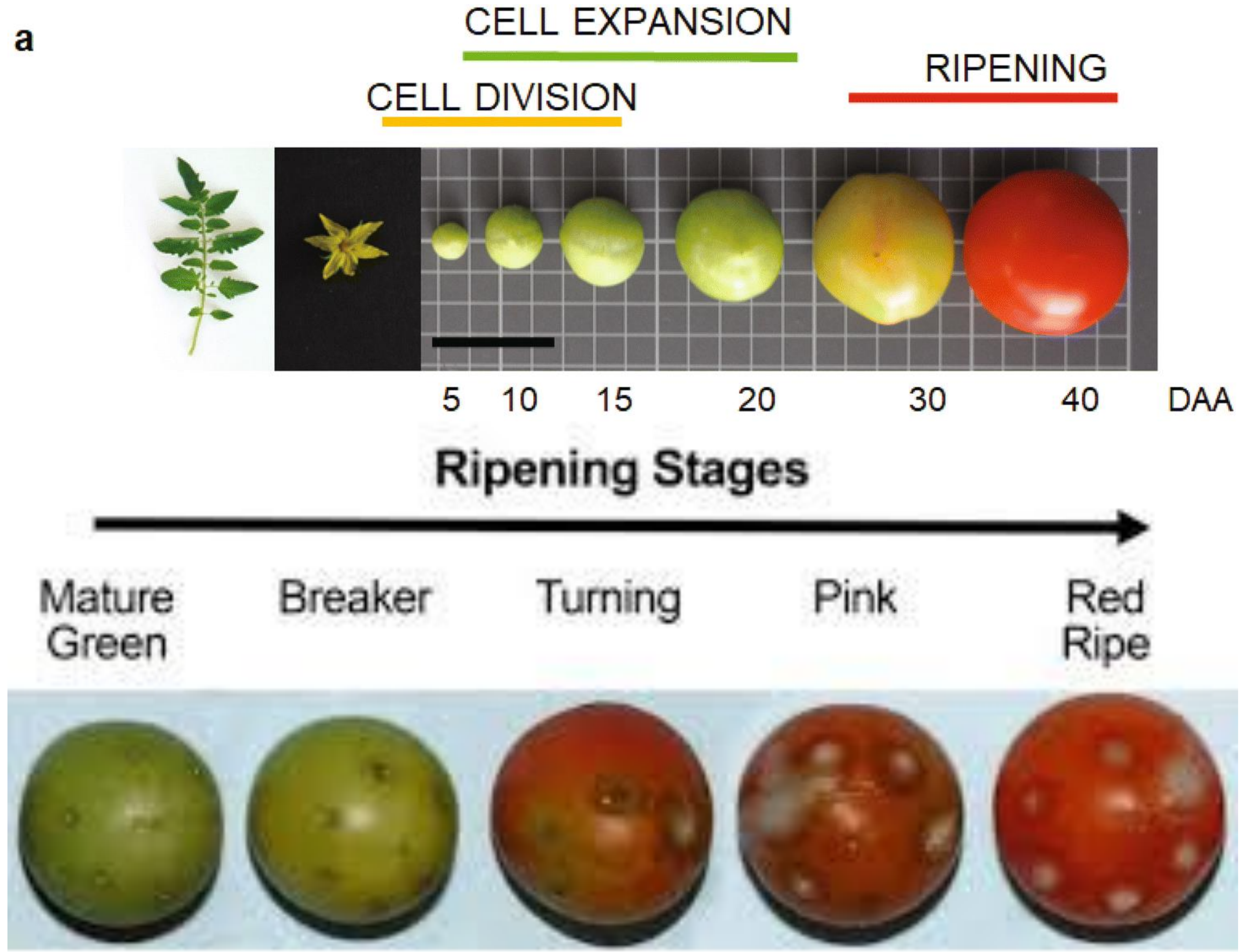
Include all the different abiotic and biotic treatments that **enhance defensive capacity developed by the plant that confer long-lasting protection** during storage and shelf life.

The questions that we try to understand are:

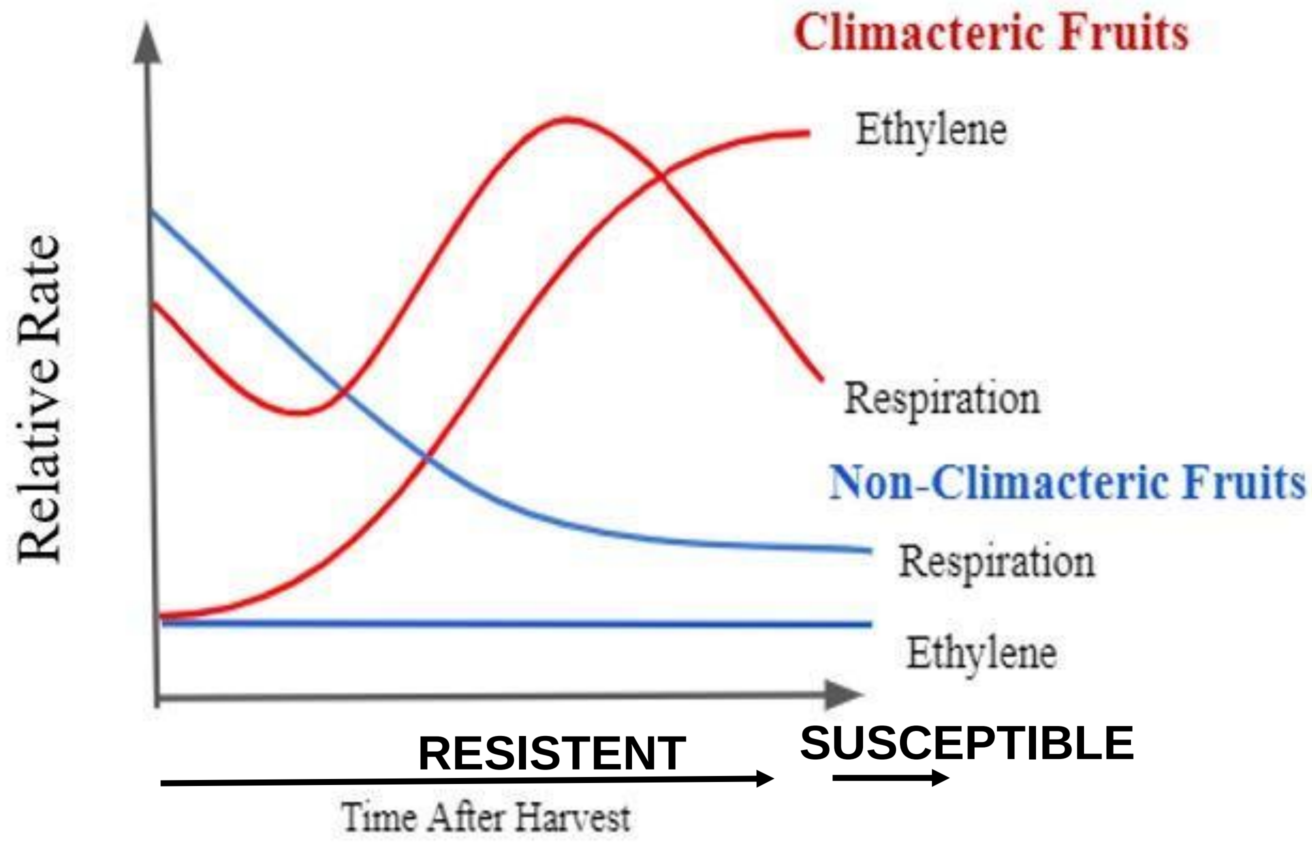
1. **What are the natural mechanism of resistance in fruits**

2. **Are the same mechanism activated by induce resistance?**

3. **Why there is no induced resistance in ripe fruits?**


a
CELL EXPANSION
RIPENING
CELL DIVISION
5
10
15
20
30
40
DAA
Ripening Stages
Mature Green
Breaker
Turning
Pink
Red Ripe

One question is whether climacteric ripening directly triggers increased susceptibility to disease and fungal invasion



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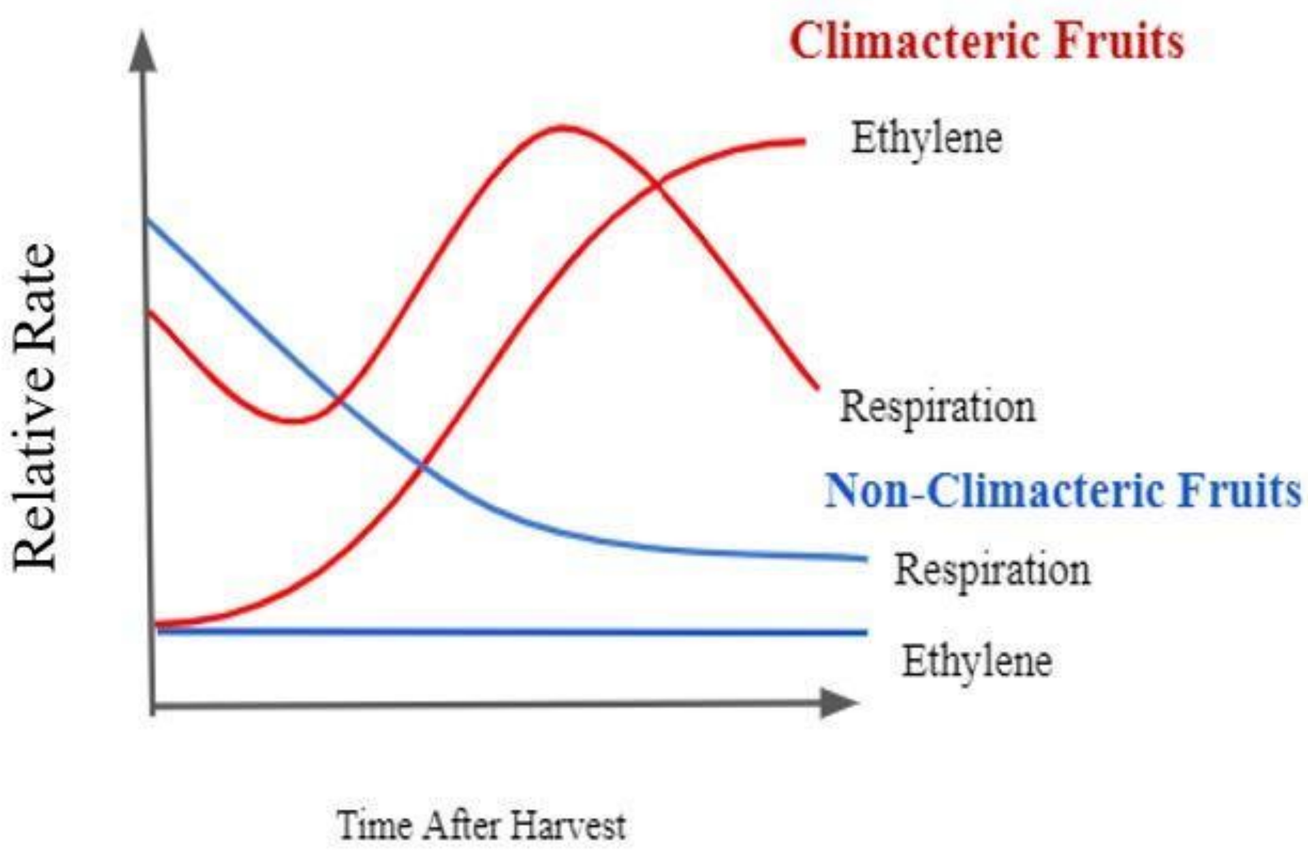
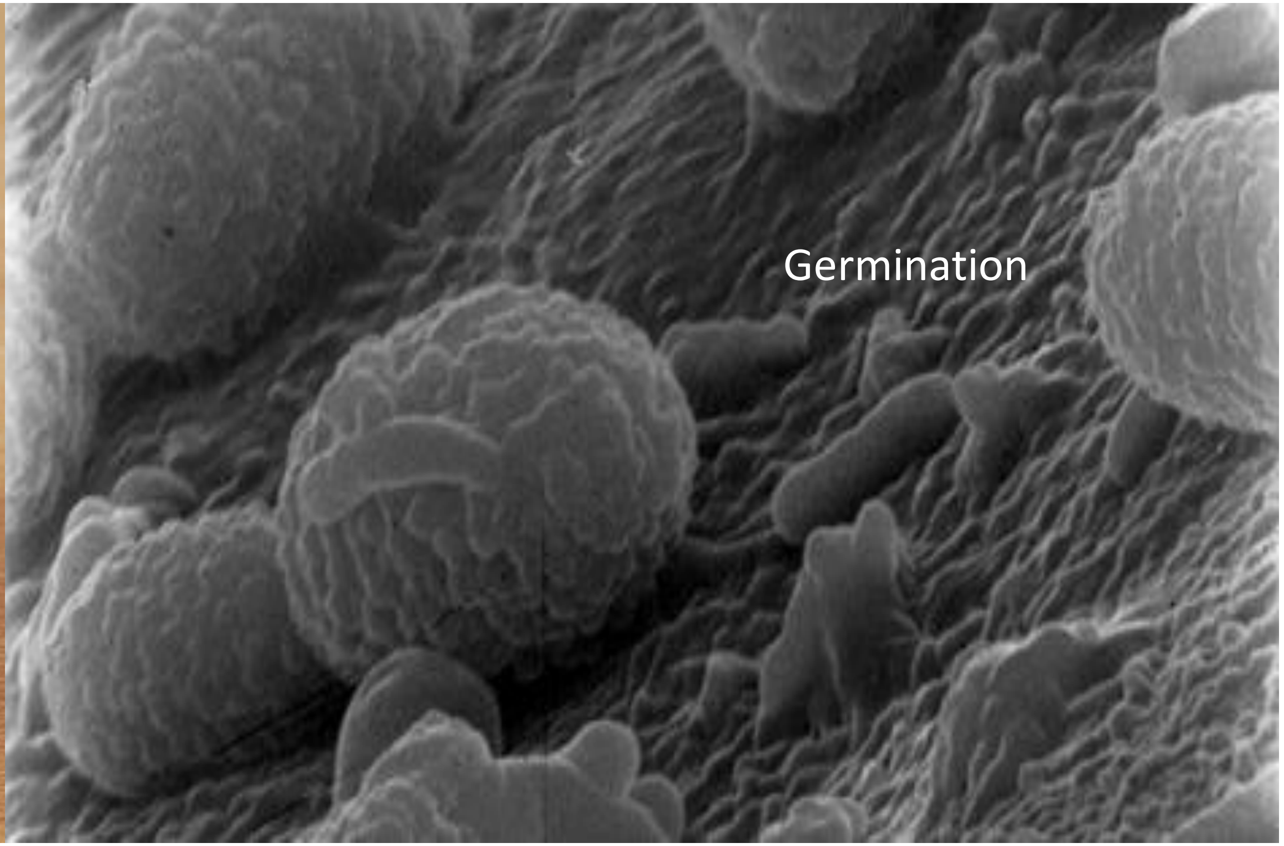


Probably not, because susceptibility to fungal pathogens is also observed in non-climacteric senescing fruit

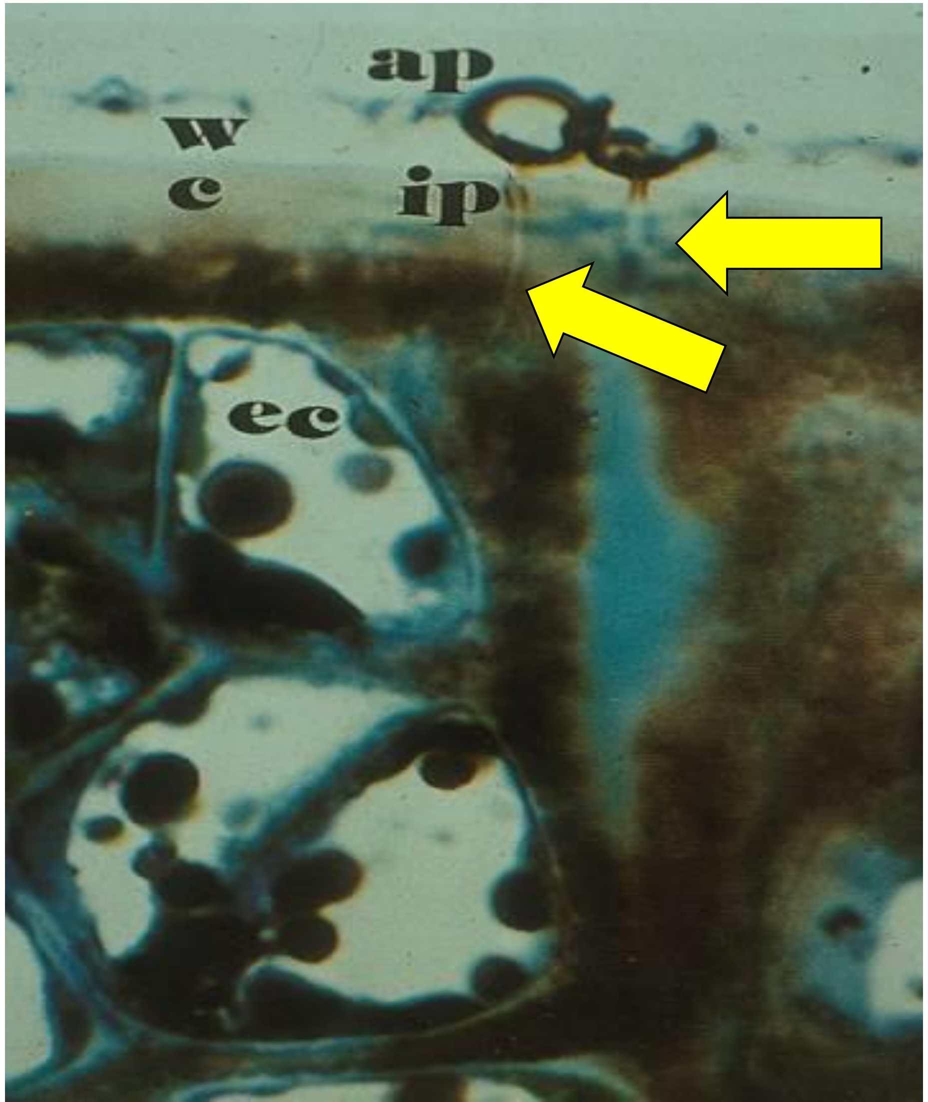

CLIMACTERIC
NO CLIMACTERIC

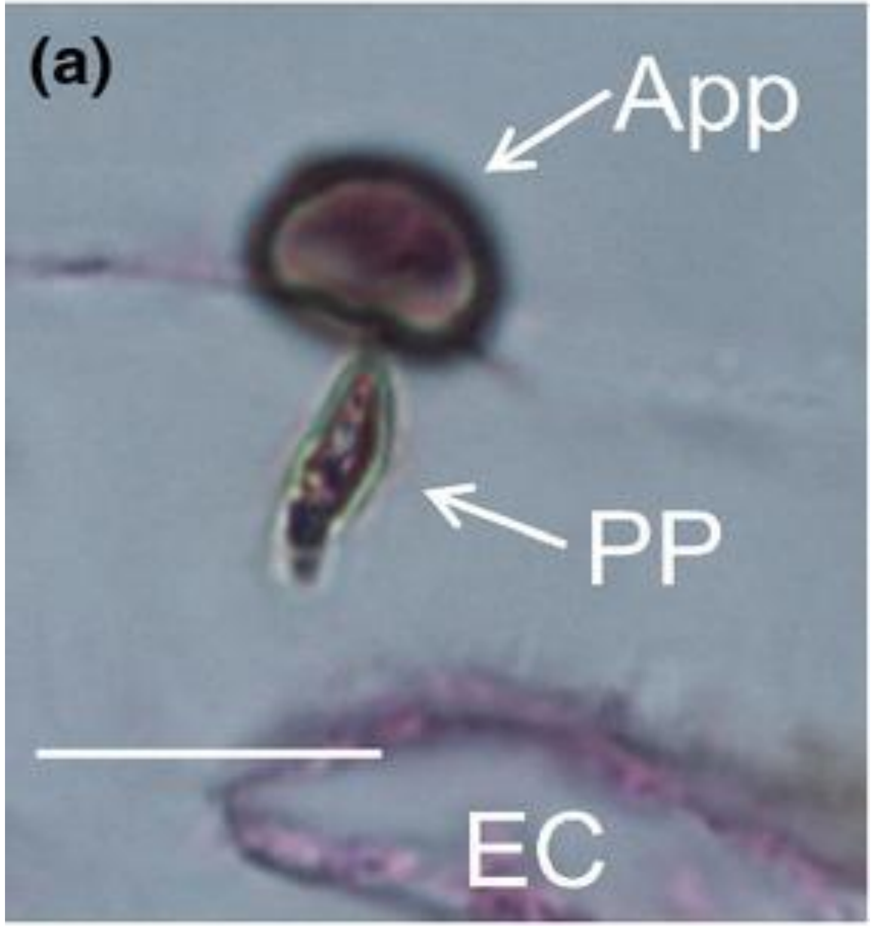
What is the relation between fruit maturation/ripening and disease

One of the systems of resistance studies was: *Colletotrichum gloeosporioides* in avocado



Appressoria penetration and quiescence by Colletotrichum for several months until ripening





During quiescence of *C. gloeosporioides*, 7903 fungal genes were expressed as compared with 10450 and 11446 in the appressoria and necrotrophic stages, respectively. Of these, 178 genes could

be defined as quiescent-specific

Preformed antifungal compounds in unripe avocado fruit

TRI-ENE

(1999)

(-cis- cis, trans)-1-acetoxy-2-hydroxy-4-oxo-heneicosa-5,12,15-triene

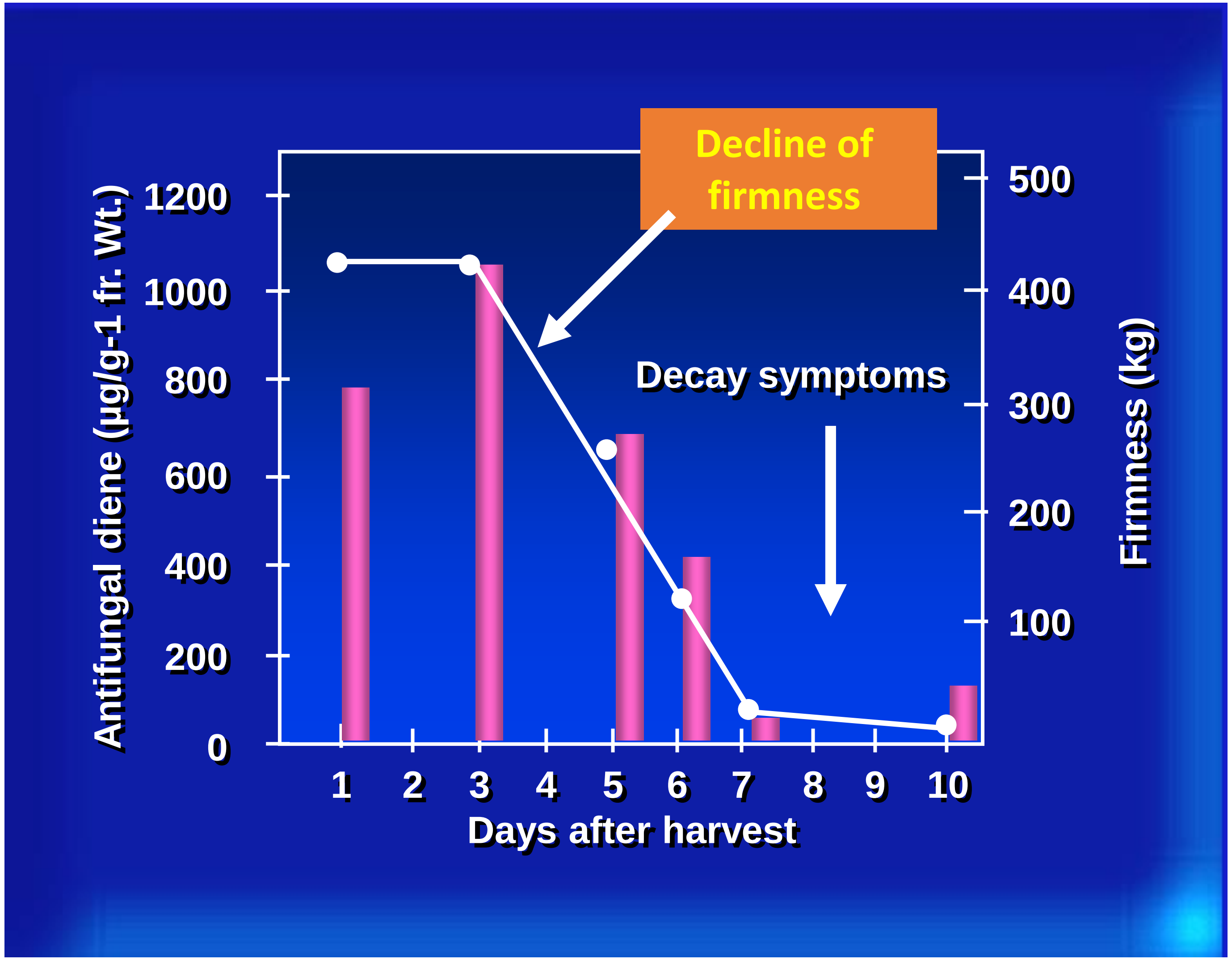
DI-ENE

(cis, cis)-1-acetoxy-2-hydroxy-4-oxo-heneicosa-12,15-diene (1981)

MONO-ENE

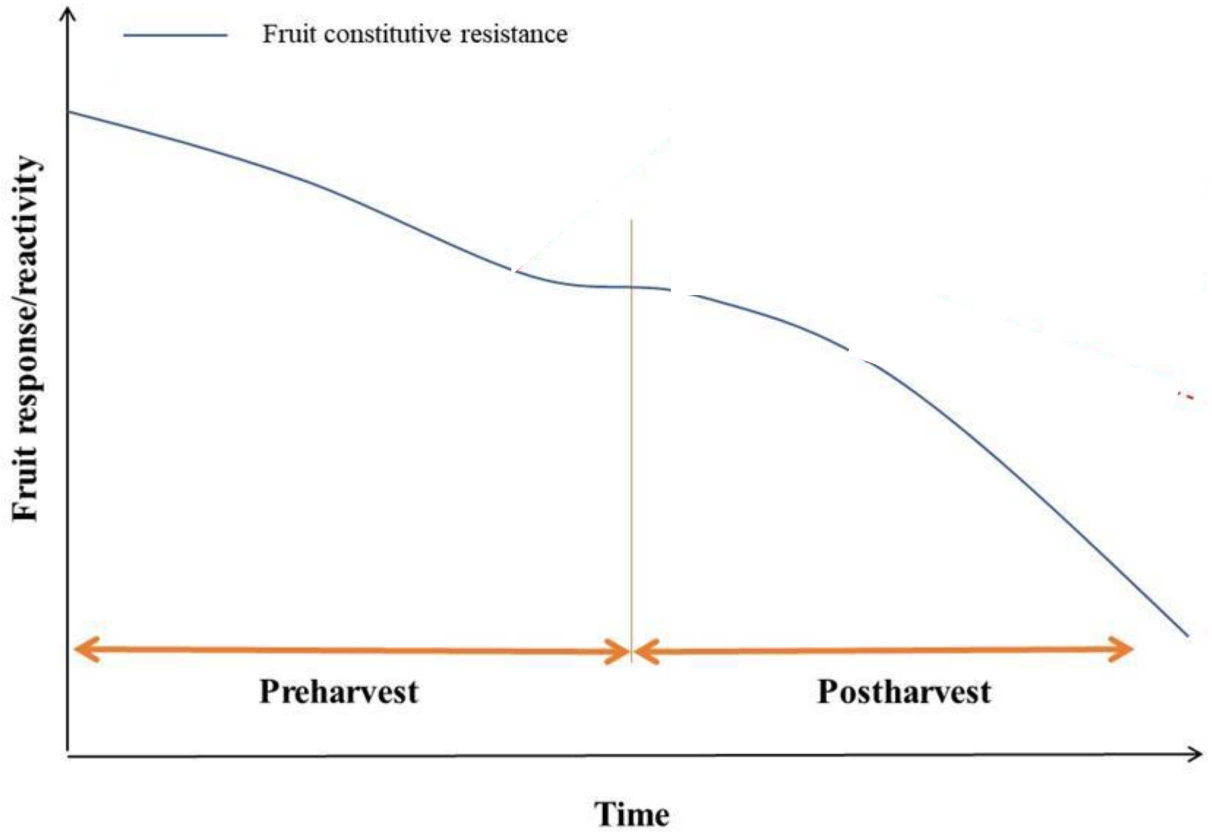
1-acetoxy-2,4-dihydroxy-n-heptadeca-16-ene (1986)

Decline of antifungal compounds during fruit ripening in the peel of avocado fruit



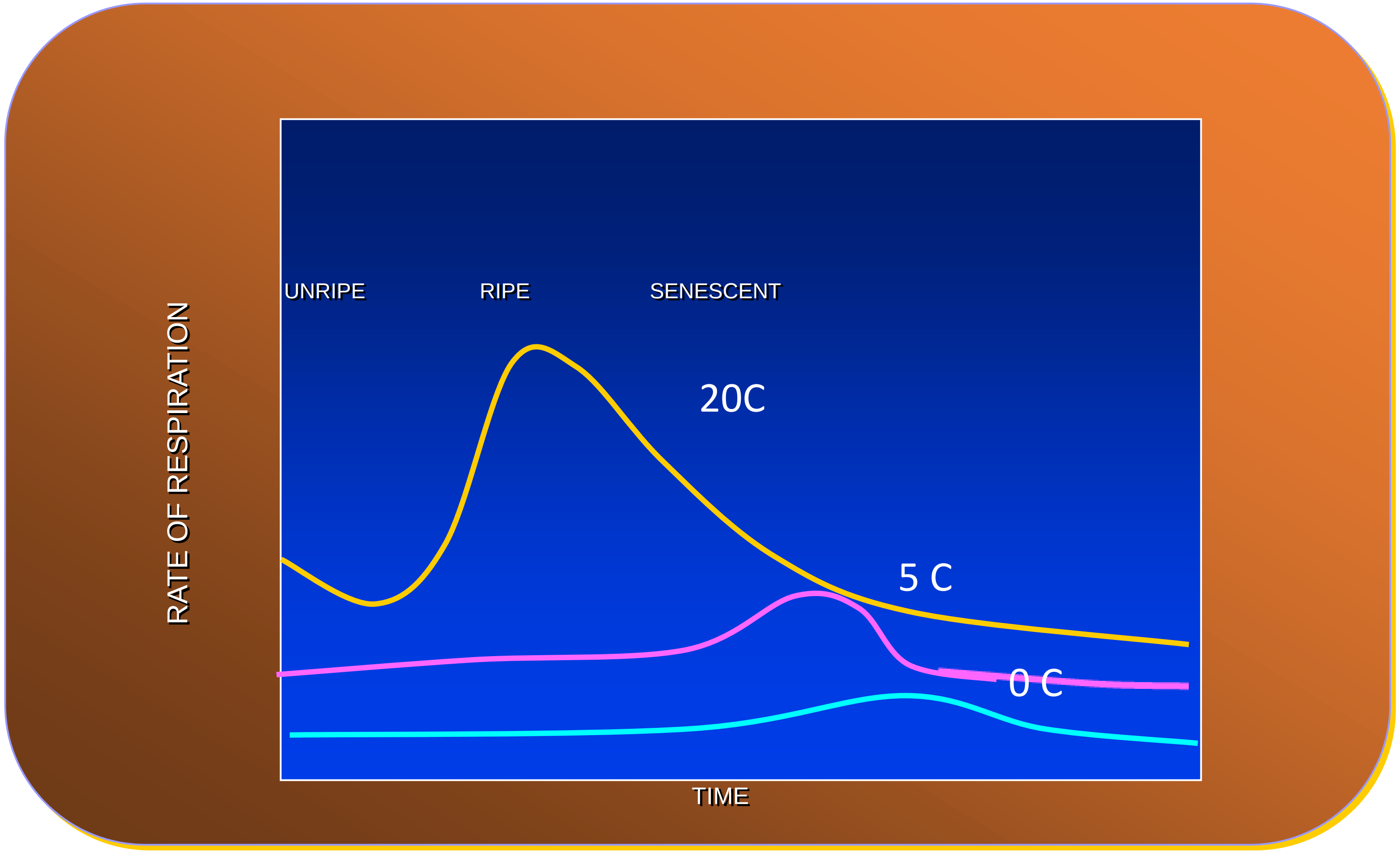
Colletotrichum (Anthracnose) in ripe avocado

Evolution of the resistance of the fruit at different ripening stage

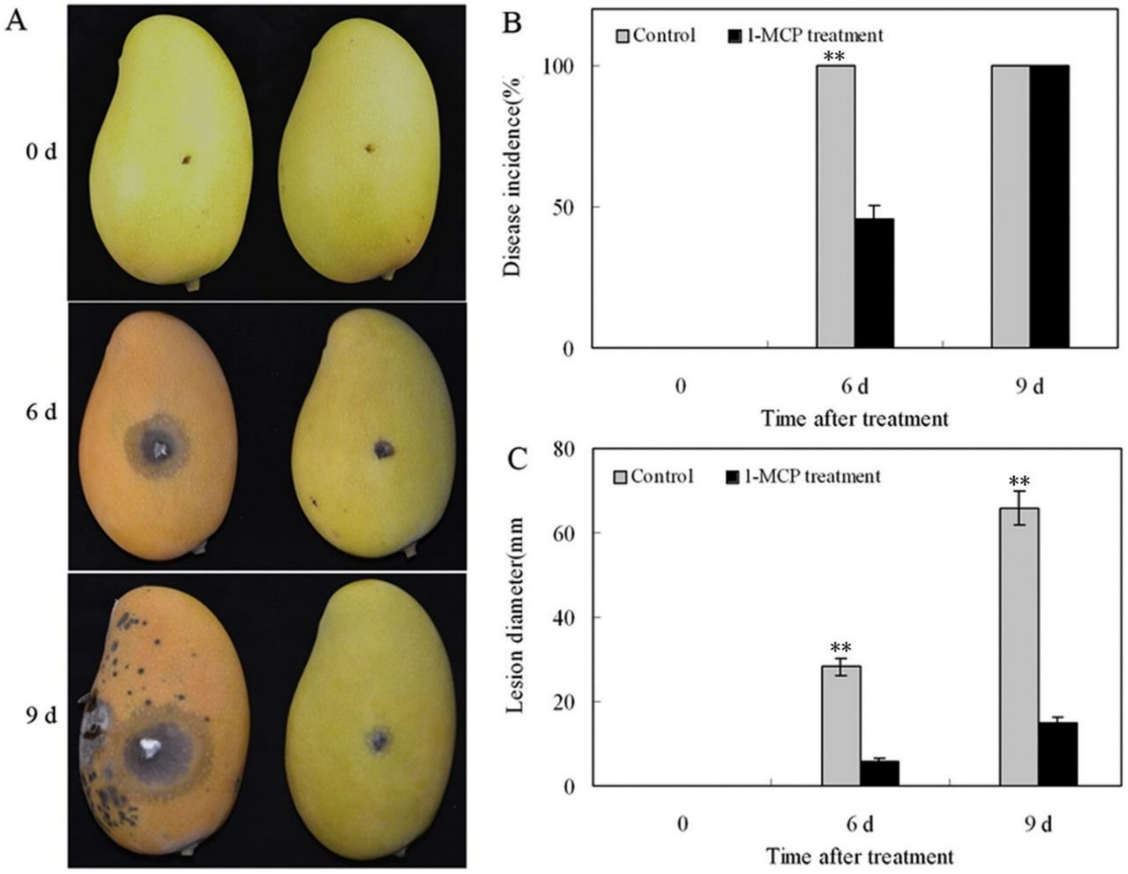


What happens if we delay ripening?

Delay of ripening by low temperature, delay respiration and delay disease development



Delay ripening by the use of the ethylene inhibitor 1-MCP affect decay development



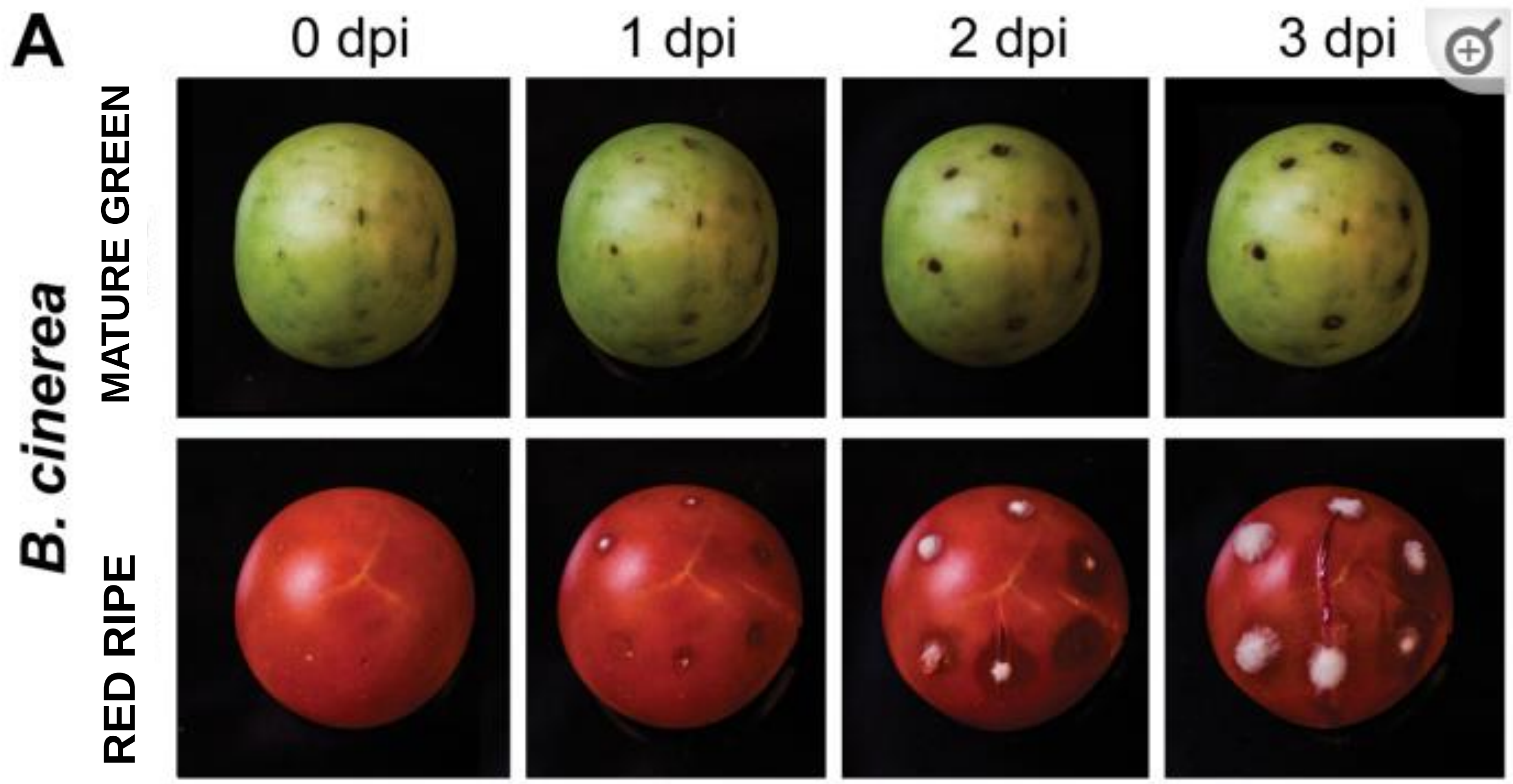
Induce resistance or delay ripening ???

We are interested in a delay ripening and maturation and then induce resistance

1st Conclusion: is that disease development is dependent on fruit ripening

What is the basis for the resistance in unripe fruits

Tomato fruit responses to *B. cinerea*.
Disease progression in inoculated mature green and red ripe fruit each day up to 3 d post-inoculation (dpi).



J

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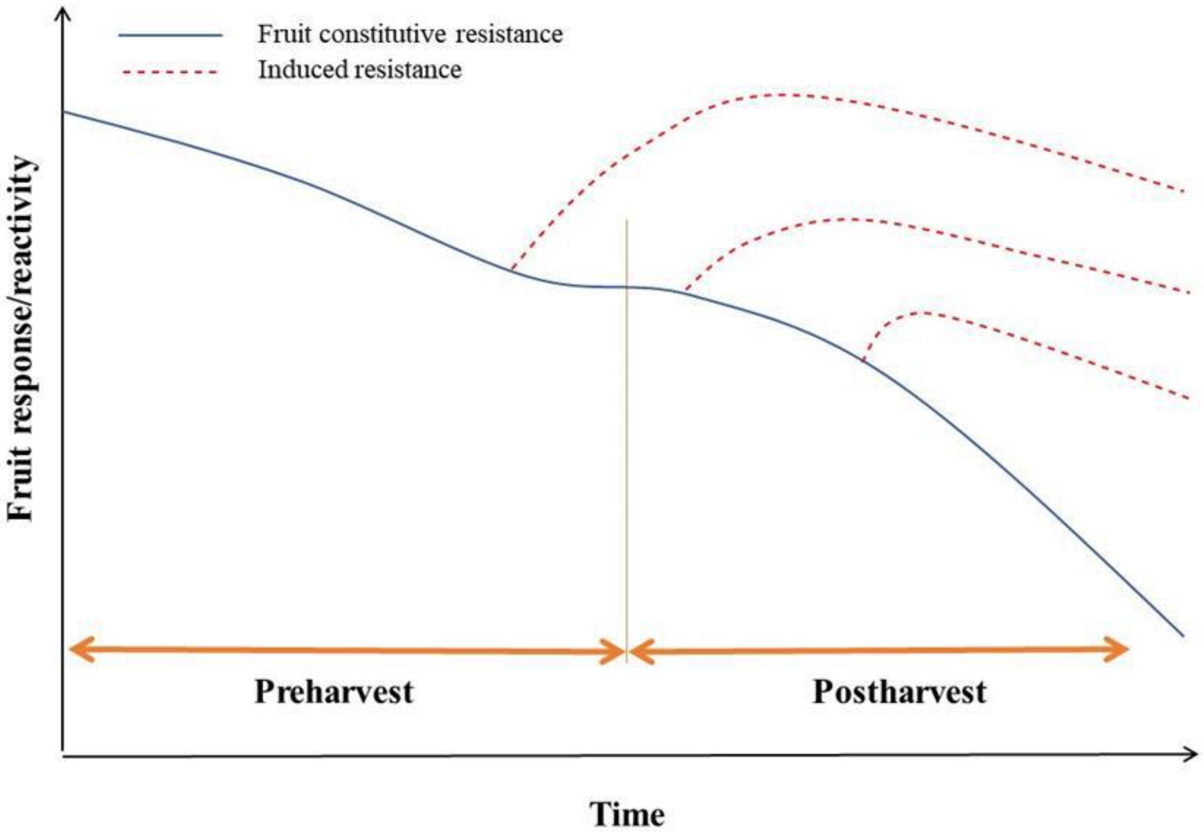
The common profiles between resistant and susceptible

- Receptor-like kinases, the leucine-rich repeat subclass,
- Transcription factors WRKY (repressors and activators of plant processes),
- Ethylene transcription factors including Ethylene Response Factors (ERF)
- Developmental and stress responses including SA and the ET/JA pathways
- Some genes that appear in both the resistant and susceptible profile include the JA biosynthesis, expression of *LoxD*, the subtilisin-like protease SBT3, the peroxidase CEVI-1, and the chitinases CHI9.
- The conclusion was that responses in resistant and susceptible interactions are similar but still show differential levels of profile expression levels during fungal attack

Thus, the ability to induce an immune response does not appear compromised in the susceptible-fruit stage

If so why does the ripening mature fruit NOT show resistance and/or induce resistance

Evolution of the resistance of fruit and vegetables following induced resistance before and after harvest at different ripening stage



Fruit resistance and induced process are dependent on the magnitude of the reactivity of the fruit

- Is highest before and soon after harvest

  whereas

- The reactivity (or response) of the fruit declines with the progress of ripening.

What happens during maturation and ripening

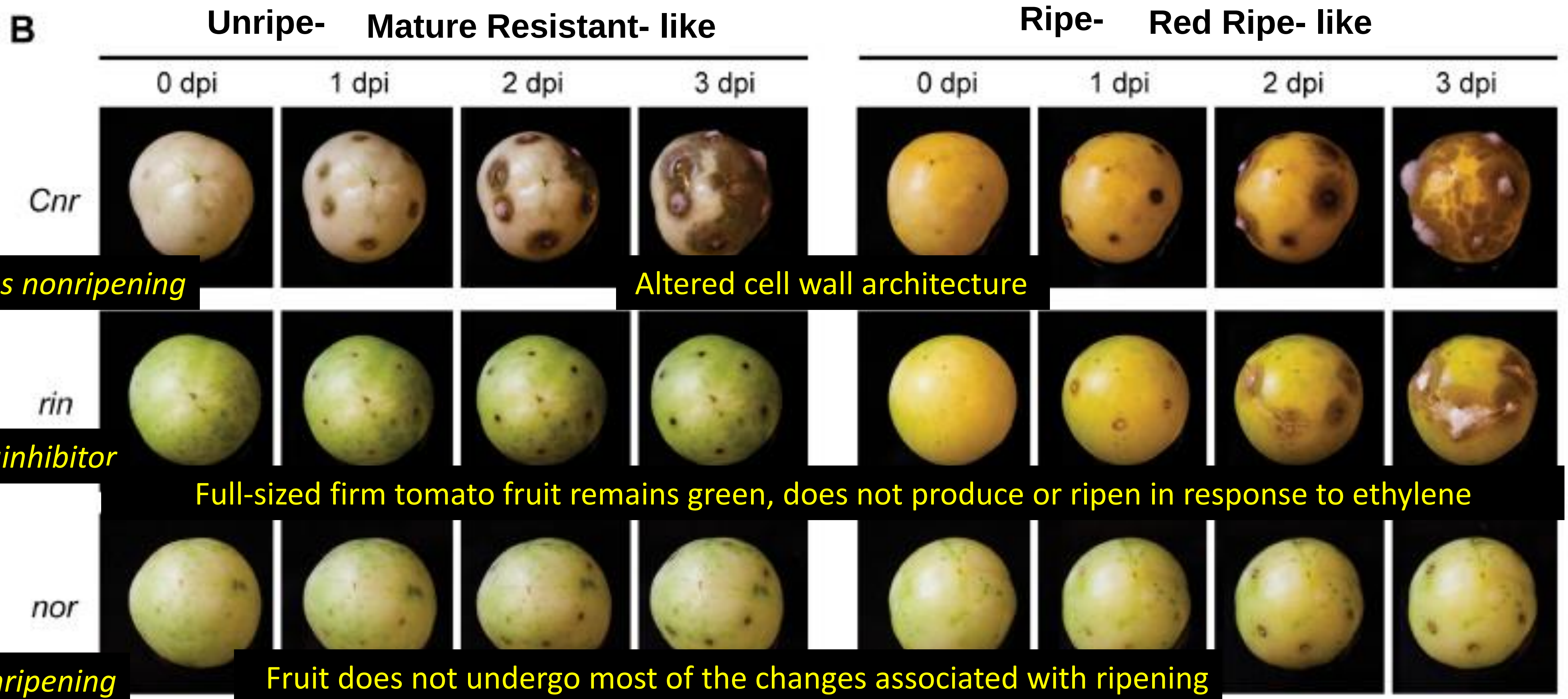
- Components of the plant immune system gradually lose either their effectiveness or the ability to activate resistance processes
- The fruit shows reduction of defense hormone production
- A reduction of signaling and downstream transcriptional responses
- Ripening processes lead to cell wall breakdown
- Simple sugar accumulation
- Changes in pH and secondary metabolite composition and
- Increased production and sensitivity to ethylene (ET)

.

Thus, there are changes occurring during ripening that contribute to the induce susceptibility in mature ripe fruit

Is this true??

Susceptibility of the non-ripening mutants *Cnr*, *rin*, and *nor* to *B. cinerea*-inoculated mature green-like and red ripe-like fruit



Colorless nonripening

Altered cell wall architecture

ripeninginhibitor

Full-sized firm tomato fruit remains green, does not produce or ripen in response to ethylene

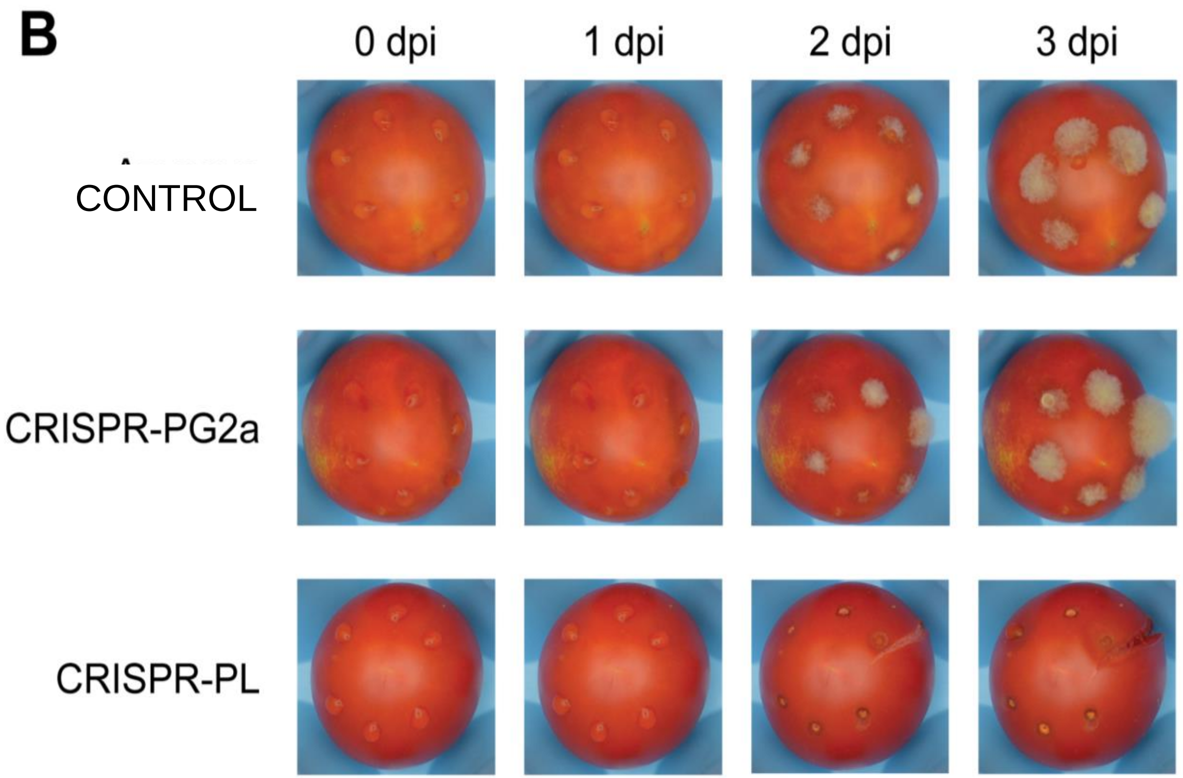
nonripening

Fruit does not undergo most of the changes associated with ripening

2nd conclusion is that:

Not all the factors occurring during ripening are involved in susceptibility

Inoculations of CRISPR lines of tomato with *Botrytis cinerea*. Disease incidence measurements at 1, 2, and 3 dpi.



Knock out of the PL gene that show increase activity during ripening, result in an increase of resistance and kept Botrytis in a quiescent stage

J Exp Bot, Volume 72, Issue 7, 29 March 2021, Pages 2696–2709, https://doi.org/10.1093/jxb/eraa601

2^{nd} conclusion is that:

Not all the factors occurring during ripening are involved in susceptibility

We can summarize that

Fruit colonization is promoted by a decrease in preformed defenses and an increase in susceptibility factors during ripening

Induce resistance in host fruit and vegetables

Abiotic and biotic treatments that **enhance defensive capacity developed by the plant that confer long-lasting protection** during storage and shelf life.

Examples of different genes expression or enzyme activities in response application of natural and synthetic chemicals inducing resistance

	Genes and/or enzymes							
Treatment	**SOD**	**CAT**	**POD**	**APX**	**CHT**	**PAL**	**GLU**	**PPO**
Salicylic acid		-	++	-	+	++	+	
Methyl salicylic acid	+	++	++	+				
BTH-benzothiadiazole	+	+	++		+	+	++	
β-aminobutyric ac.			+		+			
Riboflavin			++			+		+
1-MCP	+	+						
Harpin			+++		+++			
Oligandrin			+			+		+
Chitosan			+	++	++	+++	+++	
Yeast saccharide			++		+	+++	+++	
Silicon			+++		+++			
Sodium carbonate			++		-	++	++	

SOD, superoxide dismutase
CAT, catalase,
POD, peroxidase
APX, ascorbate peroxidase
CHT, chitinases
GLU, β-1,3-glucanase
PAL, phenylalanine ammonia lyases;
PPO, polyphenol oxidase

The question is:

Are all those treatments modulating?

- A specific limitation of fungal growth

or

- A wide response of the whole fruit?

Some amino acid contributing to induce resistance

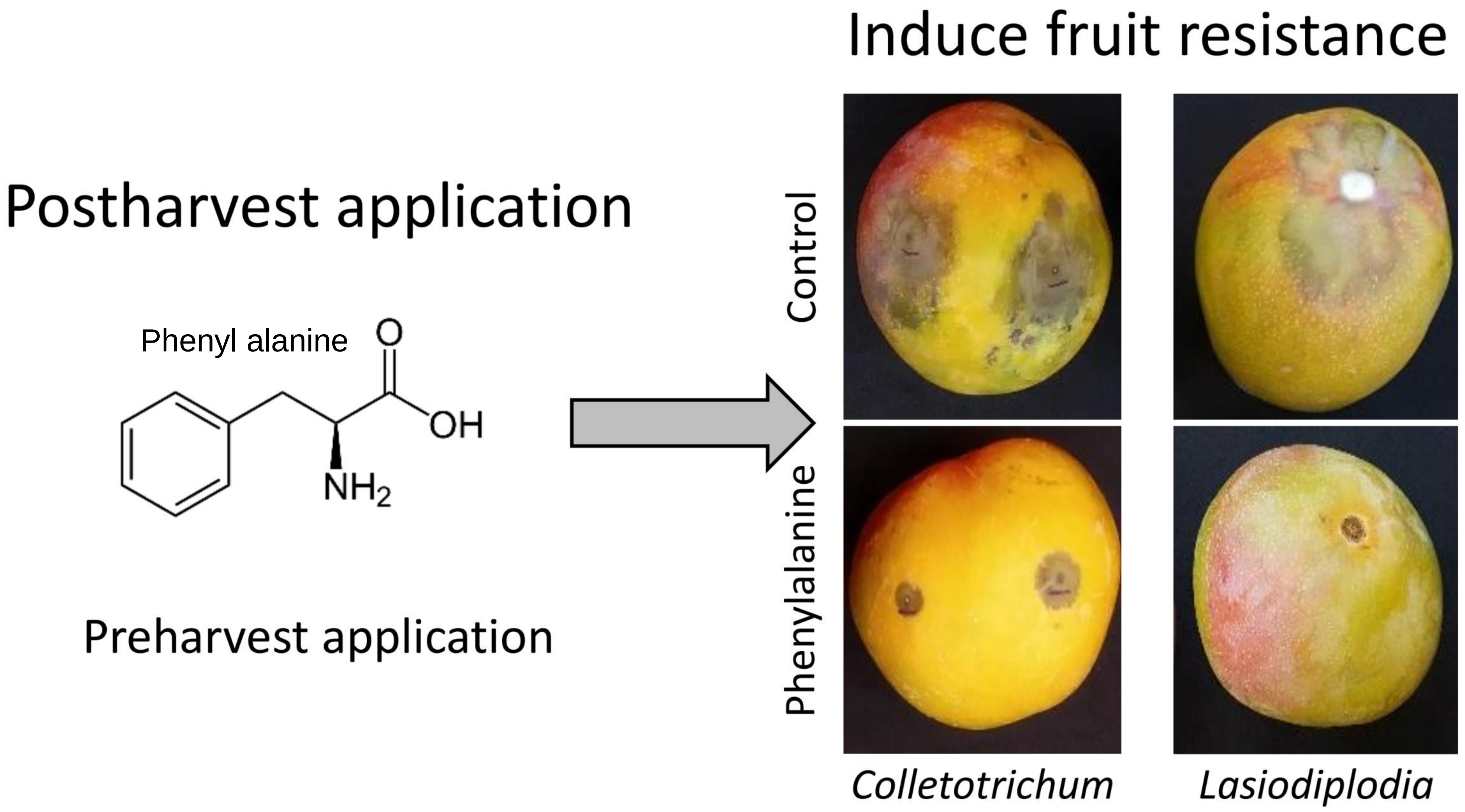
ϵ-poly-L-lysine induce disease resistance against *Penicillium expansum* in apple fruit

control

25 μL L^{-1} PL

50μL L^{-1} PL

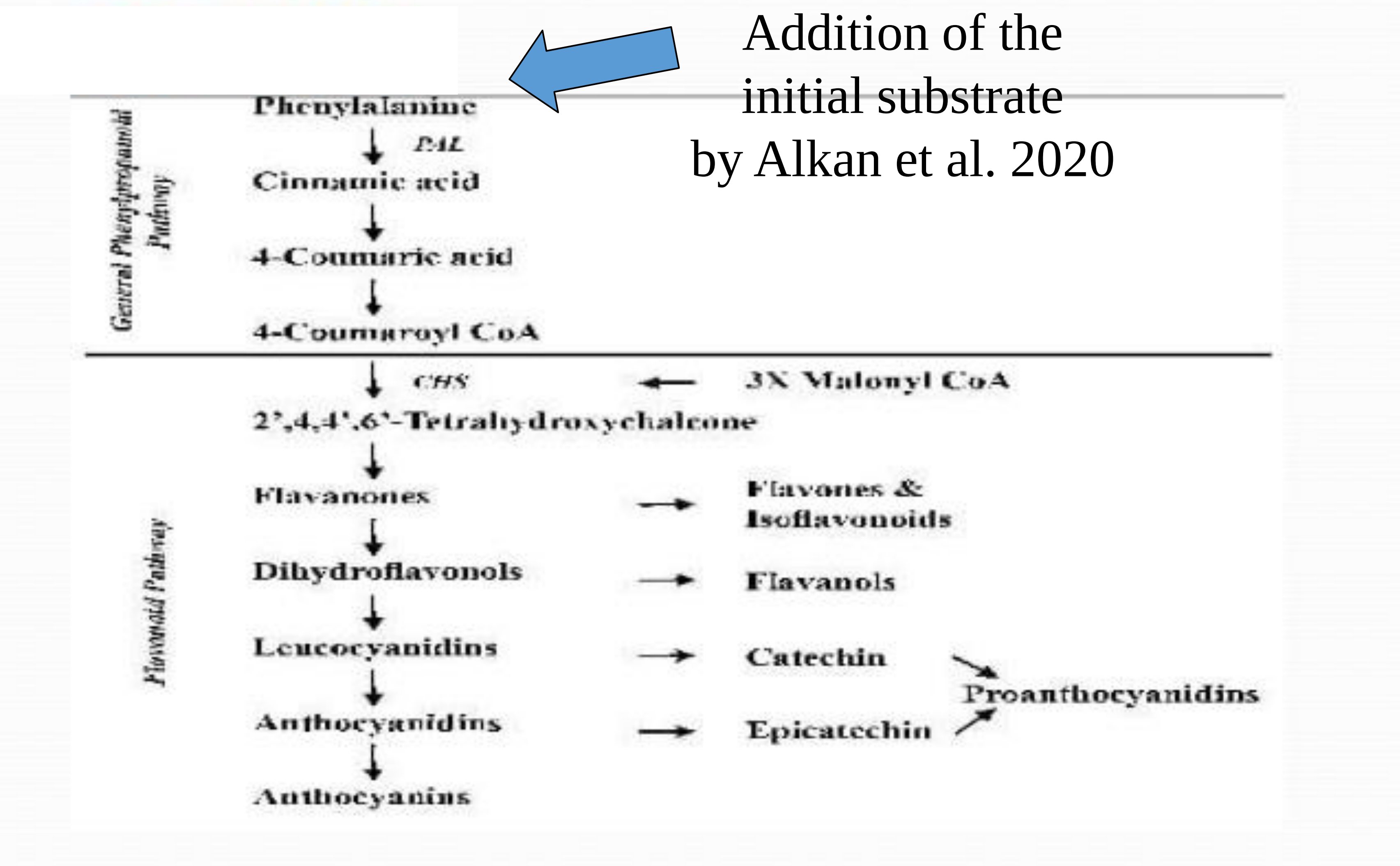
100μL L^{-1} PL



Induce fruit resistance
Postharvest application
Phenyl alanine
O
OH
NH2
Preharvest application
Control
Phenylalanine
Colletotrichum
Lasiodiplodia

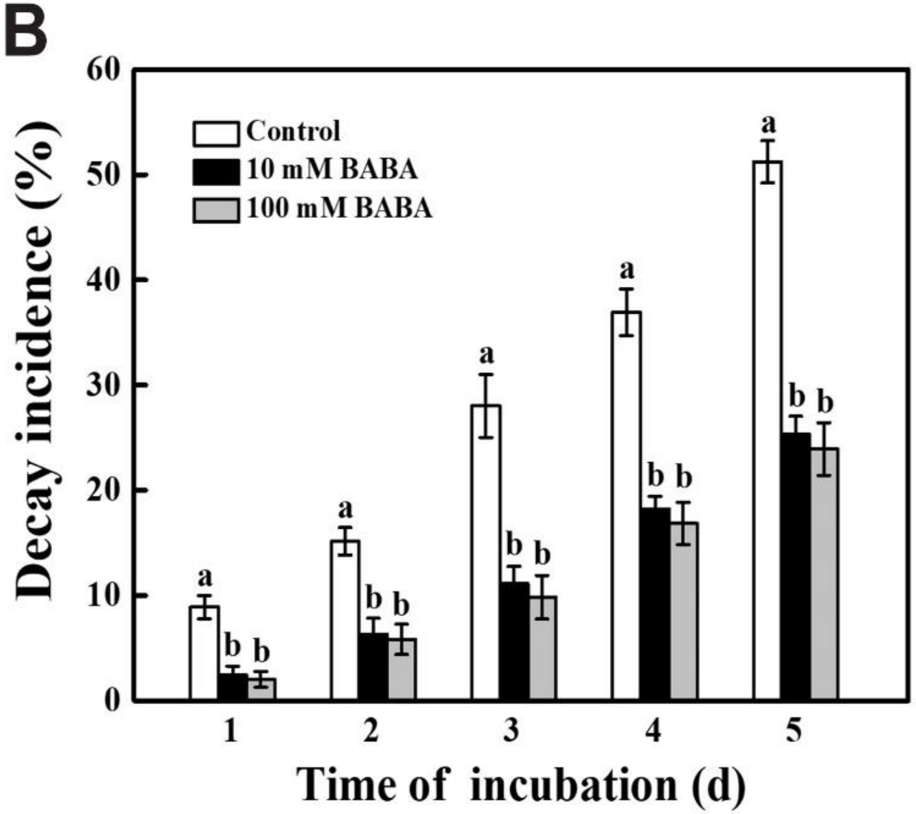
The Phenyl Propanoid pathway

Addition of the
initial substrate
by Alkan et al. 2020



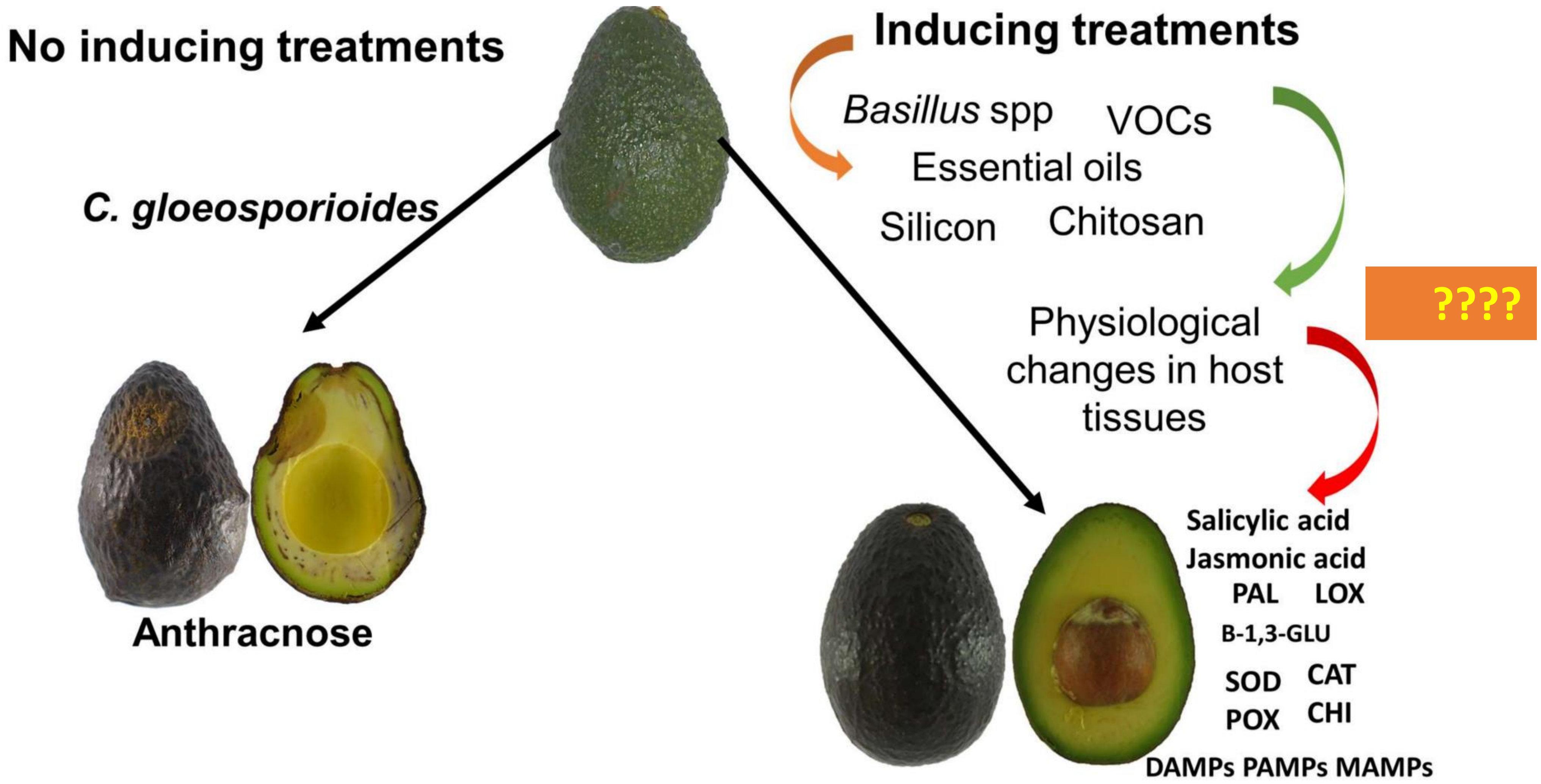
β-aminobutyric acid (BABA)

, A.**Changes in disease phenotype of Botrytis, B, decay incidence**



Published in: Chunhong Li; Kaituo Wang; Changyi Lei; Shifeng Cao; Yixiao Huang; Nana Ji; Feng Xu; Yonghua Zheng;
MPMI 2021, 34, 1250-1266.

Anthracnose infection processes following inducing treatments, and mechanisms of action of natural compounds in the fruit



Herrera-González, J.A.; Bautista-Baños, S.; Serrano, M.; Romanazzi, G.; Gutiérrez-Martínez, P. Non-Chemical Treatments for the Pre- and Post-Harvest Elicitation of Defense Mechanisms in the Fungi–Avocado Pathosystem. *Molecules* **2021**, *26*, 6819.

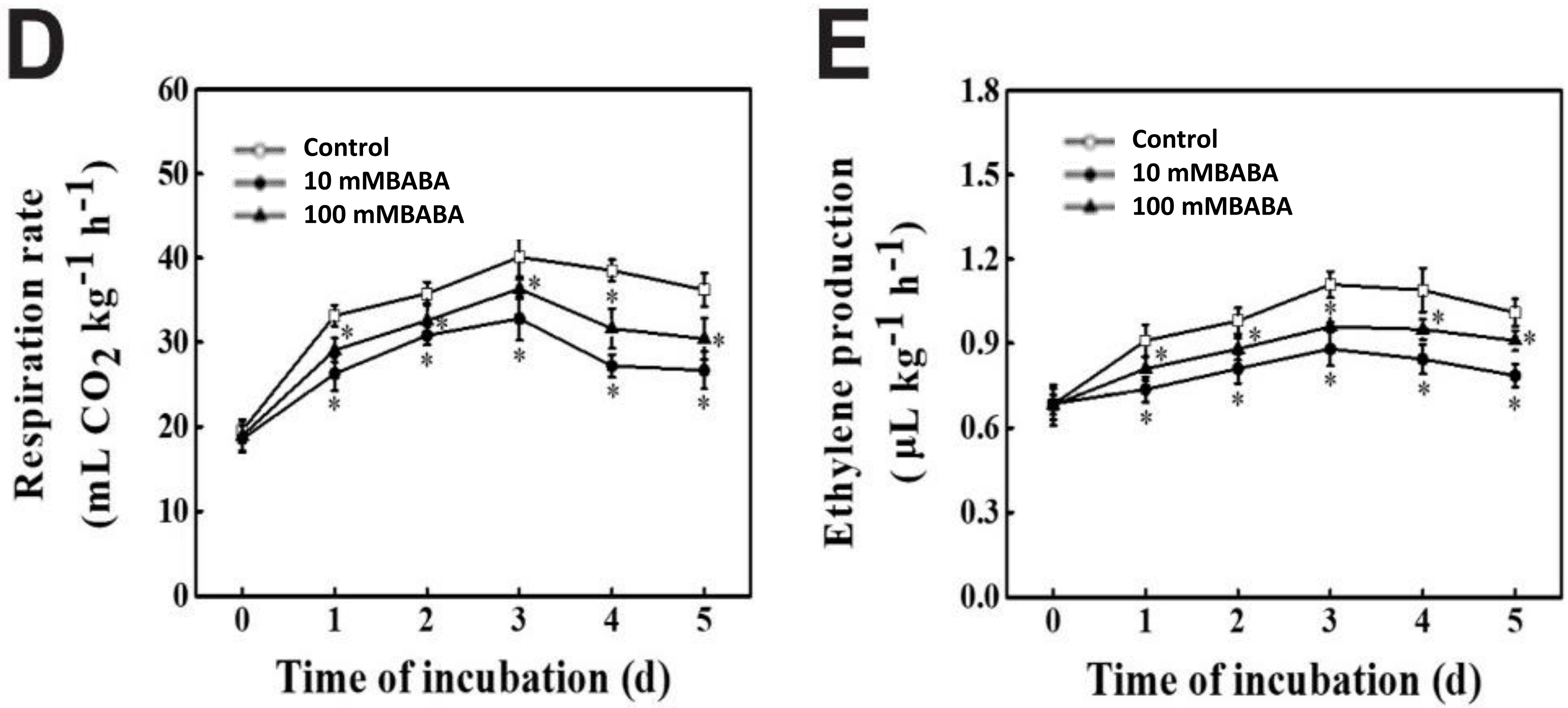
Defense responses elicited by chitosan and its derivatives

Biochemical defenses
Deposition of callose
Lignin
Formation of Tyloses
HR/programmed cell death
SAR
Pathogenesis related proteins
Metabolites production, ascorbate, glutathione, flavonoids, putrescine and spermidine
Phenols

Romanazzi G, Moumni M. Chitosan and other edible coatings to extend shelf life, manage postharvest decay, and reduce loss and waste of fresh fruits and vegetables. Curr Opin Biotechnol. 2022 Dec;78:102834. doi: 10.1016/j.copbio.2022.102834. Epub 2022 Nov 4. PMID: 36343563.

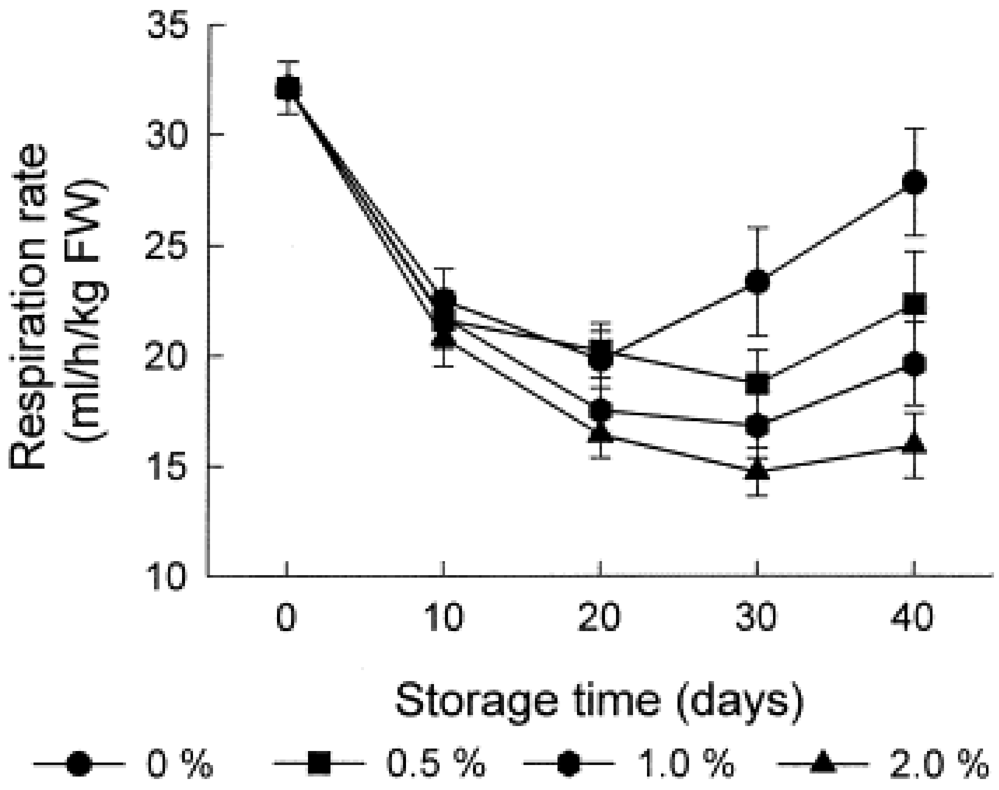
However !!!

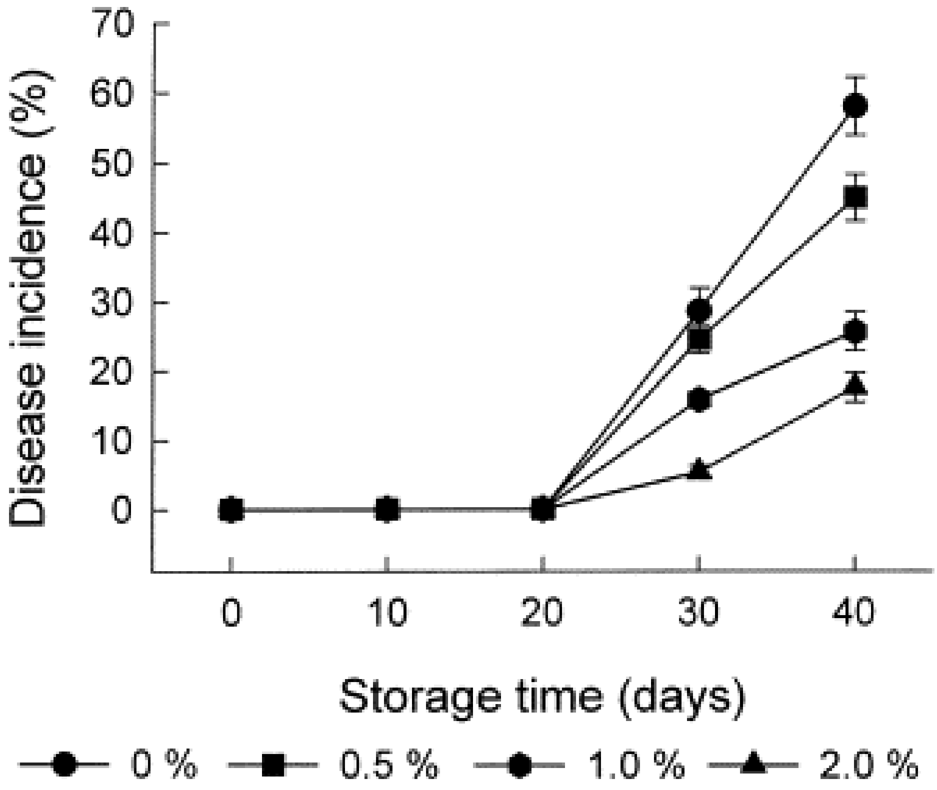
Changes in, Respiration rate, and Ethylene production content in grapes under β-aminobutyric acid (BABA) treatments at 0, 10, and 100 mM during incubation at 20°C for 5 days.



The effect of the compound seems to differentially modulate the physiological aspect of the fruit

Chitosan treatment reduces respiration and disease development in longan fruit during storage at 2C





Yueming Jiang, Yuebiao Li, 2001, Effects of chitosan coating on postharvest life and quality of longan fruit, Food Chemistry, Volume 73, Issue 2,

Induce resistance treatments:

1. Triggers physiological host responses, inducing accumulation of defense compounds that limit fungal growth,

2. **But should be delaying at the same time fruit senescence, and preserving the physiological response capability of fruit for longer periods**

3. This will enhance a better plant’s ability to defend itself from invading pathogens

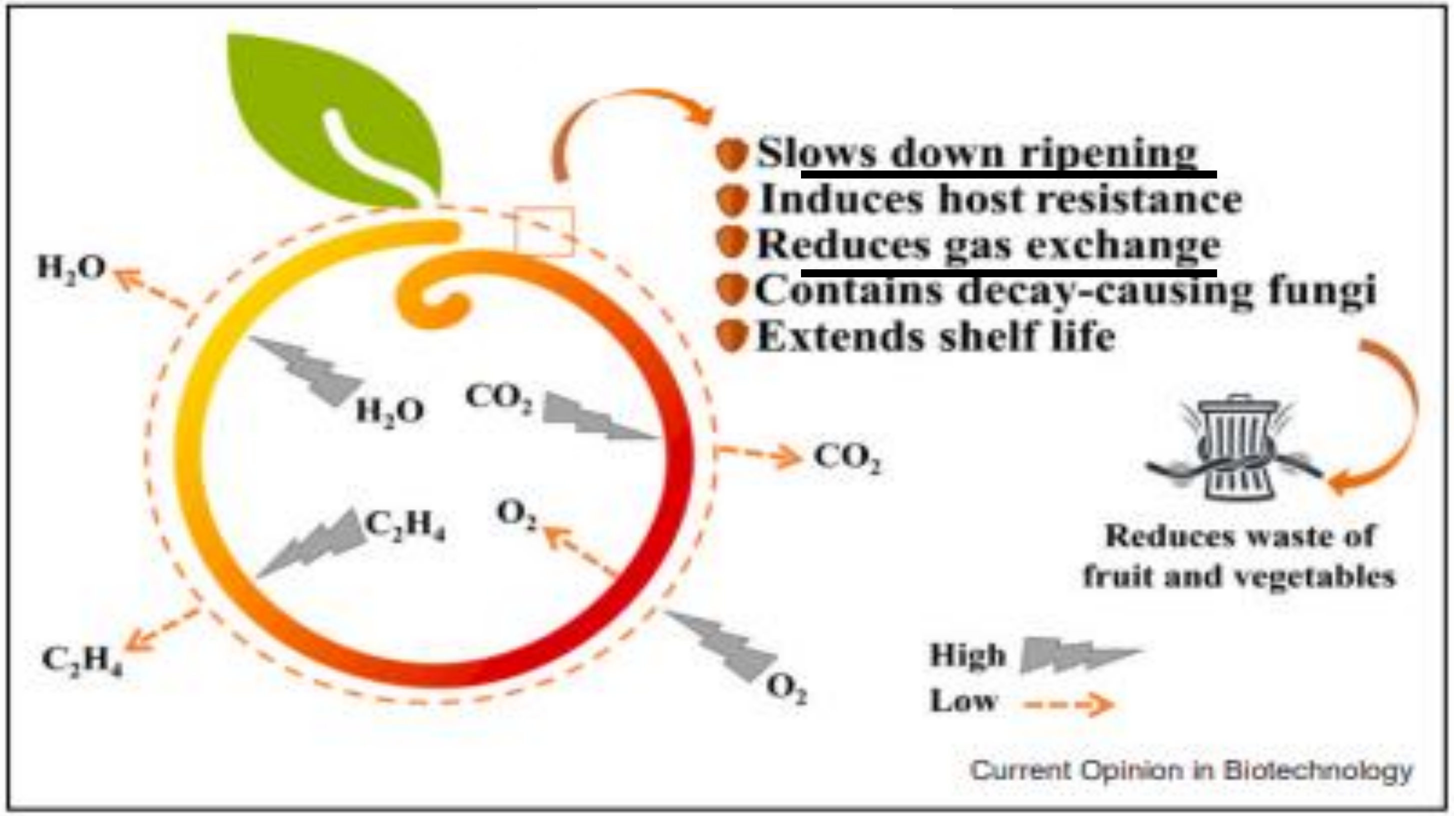
General concept

Most of the published reports showing the limitation of decay development by biotic and abiotic treatments need to report in parallel the effect of the delay ripening and senescence that was not consider of importance by the authors

The evolution of induce resistance of the fruit should handle

Research on delay fruit maturation, where induce resistance can also modify the host physiology and ripening

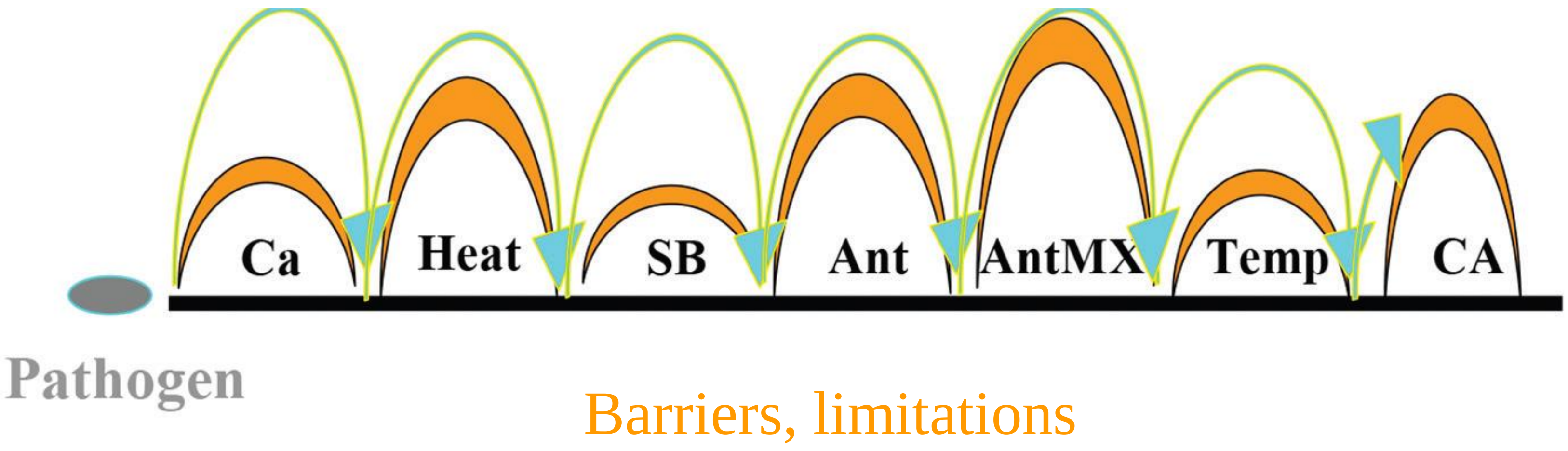
The future directions for preservation should include



Main proprieties of edible coatings applied on fruits and vegetables, affecting the permeability to ethylene (C_2H_4), water (H_2O), oxygen (O_2), and carbon dioxide (CO_2).

Take home message

Multi-barrier concept for managing postharvest diseases



Ca = calcium, Heat = 38°C for 4 d, SB = sodium bicarbonate, Ant = antagonist, AntMX = antagonist mixture, Temp = low storage temperature, CA = controlled atmosphere storage

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Dov Prusky and Gianfranco Romanazzi
Annual Review of Phytopathology, 2023