Induced resistance to prevent postharvest diseases

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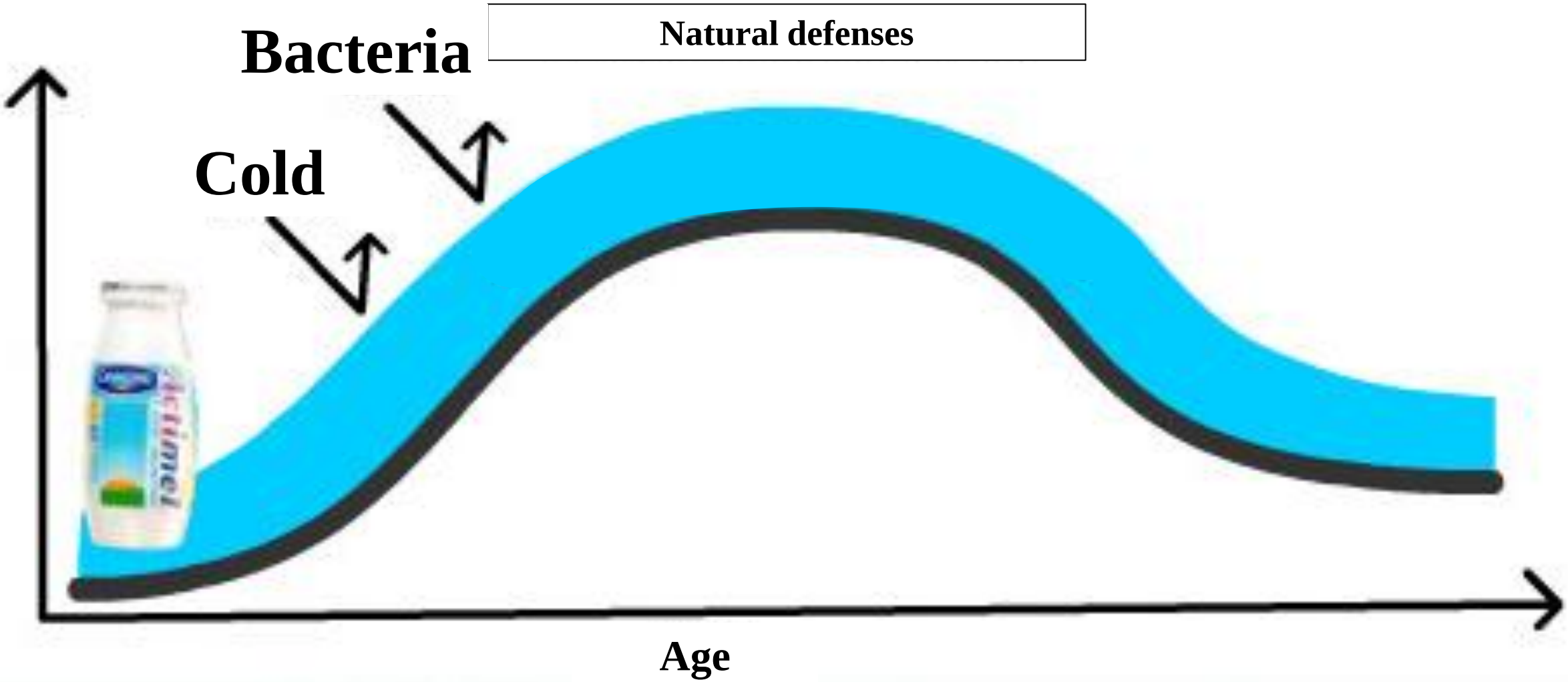
Prevention and management of pre and postharvest diseases of fresh fruit and vegetables

22-24 May 2025, Thessaloniki, Greece

The induction of resistance

How to strengthen plant defenses?



Journal of Experimental Botany
doi:10.1093/jxb/ert026

Journal of Experimental Botany
www.jxb.oxfordjournals.org

REVIEW PAPER

Controlling crop diseases using induced resistance: challenges for the future

Dale R. Walters*, Jaan Ratsep and Neil D. Havis

Crop & Soil Systems Research Group, SRUC, West Mains Road, Edinburgh EH9 3JG, UK

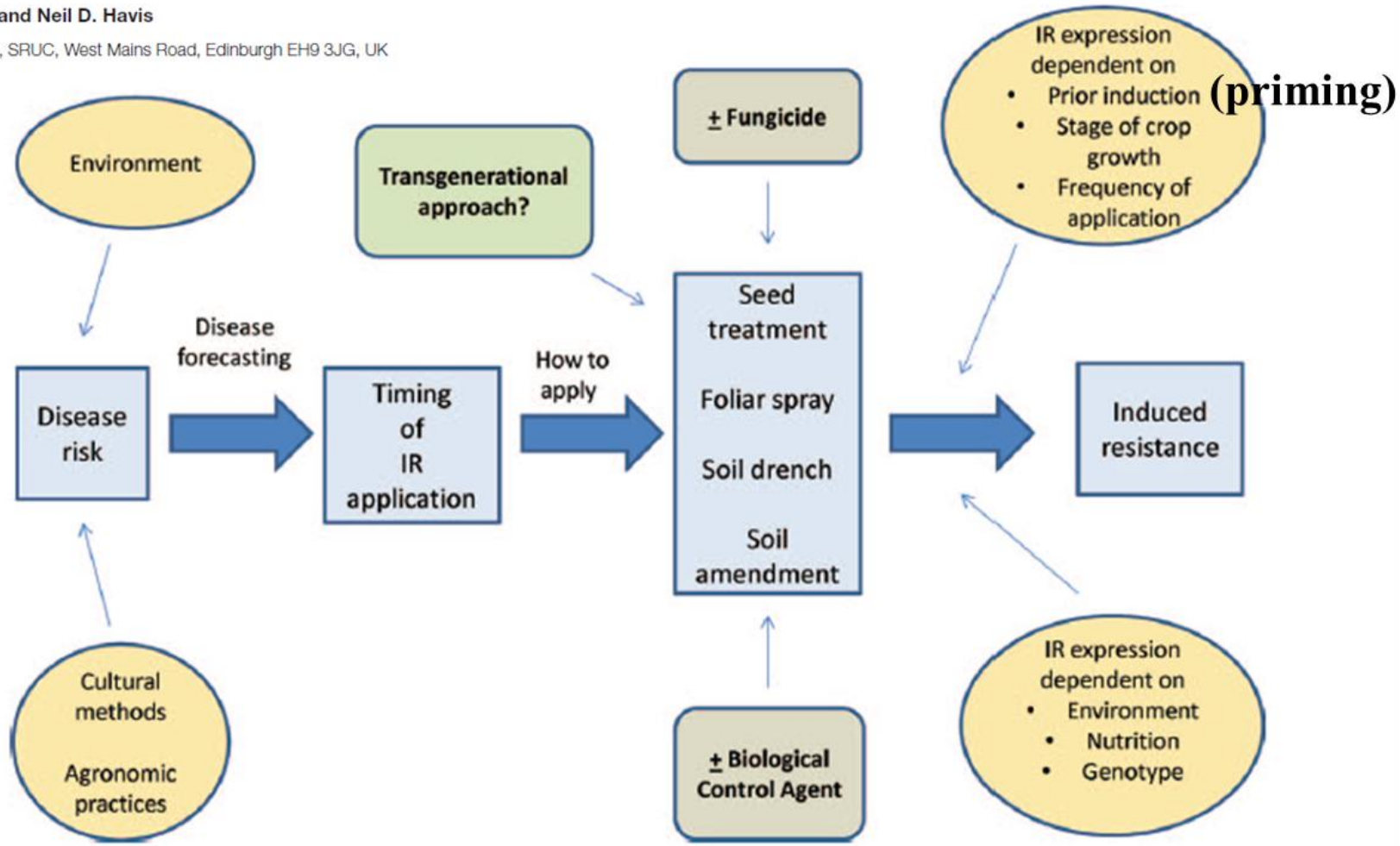
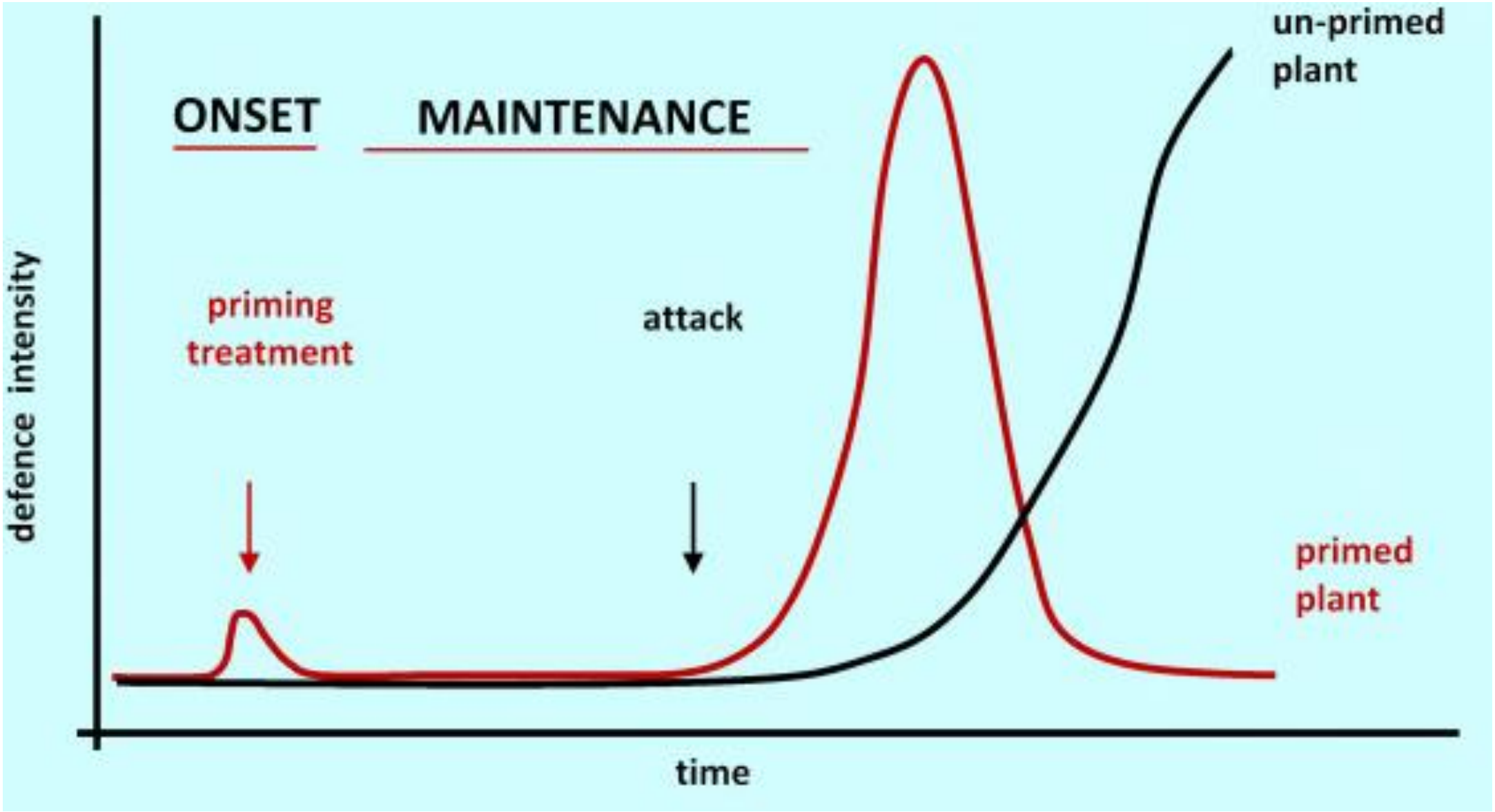


Fig. 2. Factors affecting the expression of induced resistance in practice. IR, induced resistance. Adapted from Reglinski *et al.* Integration of induced resistance in crop production. In D Walters, A Newton, G Lyon, eds, *Induced resistance for plant disease control: a sustainable approach to crop protection*. Copyright (2007), with permission from Wiley-Blackwell, Oxford, pp. 201–228.

The induction of resistance



Jurriaan Ton, Università di Sheffield

MPMI Vol. 19, No. 10, 2006, pp. 1062–1071. DOI: 10.1094/MPMI-19-1062.

REVIEW

Priming: Getting Ready for Battle

Prime-A-Plant Group: Uwe Conrath,[1] Gerold J. M. Beckers,[1] Victor Flors,[2] Pilar García-Agustín,[2] Gábor Jakab,[3] Felix Mauch,[4] Mari-Anne Newman,[5] Corné M. J. Pieterse,[6] Benoit Poinssot,[7] María J. Pozo,[8] Alain Pugin,[7] Ulrich Schaffrath,[1] Jurriaan Ton,[6] David Wendehenne,[7] Laurent Zimmerli,[9] and Brigitte Mauch-Mani[9]

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Submitted 21 May 2006. Accepted 12 June 2006.

MPMI Vol. 19, No. 10, 2006, pp. 1062–1071. DOI: 10.1094/MPMI-19-1062. © 2006 The American Phytopathological Society

REVIEW

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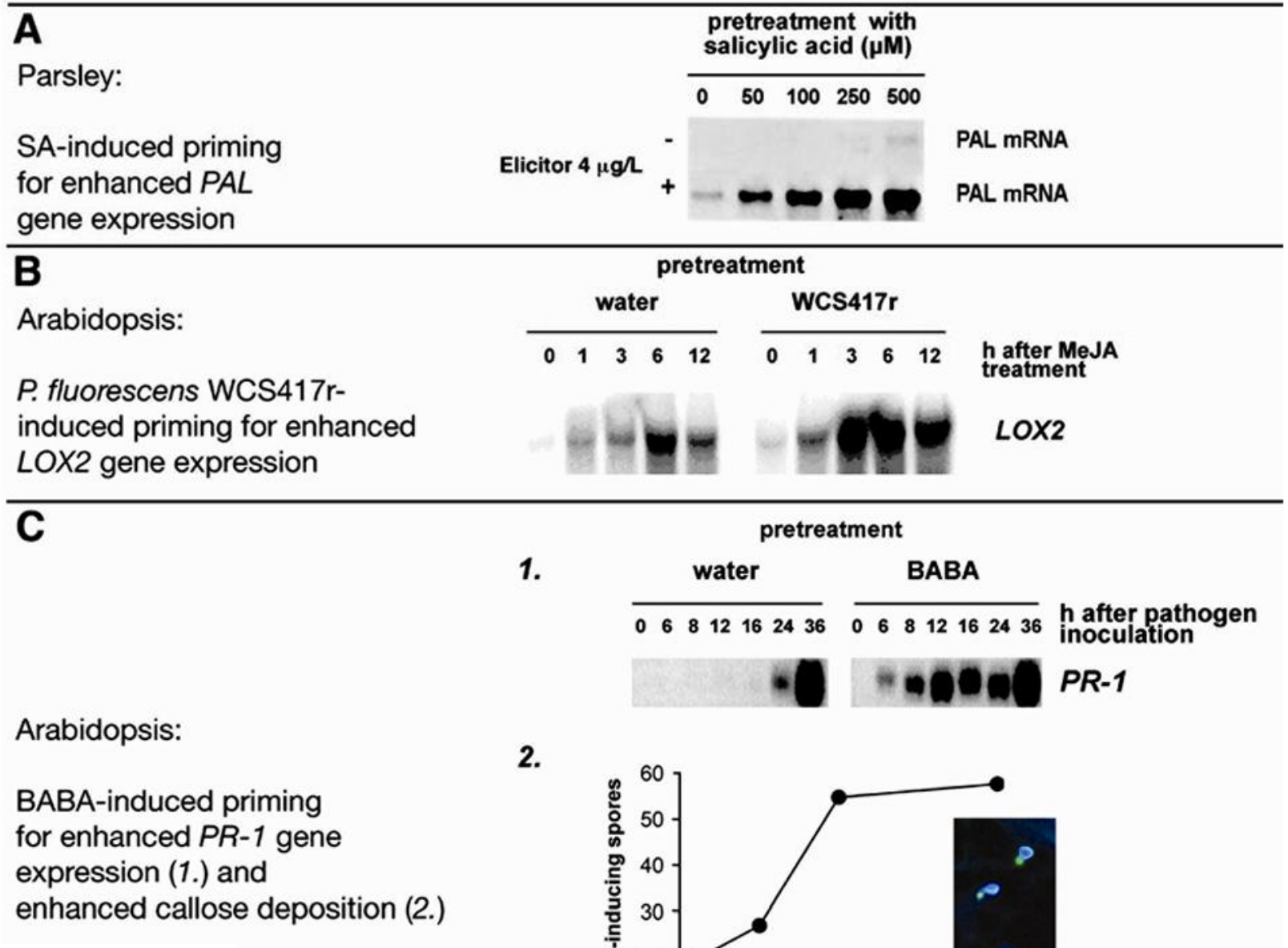

Fig. 1. Priming for enhancement of defense responses in various plant species. **A,** Salicylic acid (SA)-induced priming for augmented phenylalanine ammonia-lyase (*PAL*) gene expression in parsley cell suspensions. Pretreatment with SA results in enhanced *PAL* activation induced by subsequent treatment with an oomycete cell-wall elicitor (Thulke and Conrath 1998). **B,** *Pseudomomonas fluorescens* WCS417r–induced priming in *Arabidopsis* for enhanced induction of the *LOX2* gene upon treatment with methyl jasmonate (MeJA). **C,** β-aminobutyric acid (BABA)-induced priming in *Arabidopsis* for earlier and stronger *PR-1* gene expression upon infection by *Pseudomonas syringae* pv. *tomato* DC3000 (**1.**) and BABA-induced priming for enhanced formation of papillae at two days after infection with spores of *Hyaloperonospora parastica* WACO9 (**2.**). Inset shows a representative example of germinating *H. parasitica* spores triggering callose depositions in epidermal cells. (J. Ton, *unpublished results*). **D,** Lipopolysaccharide (LPS)-induced priming for faster production of the phenolic conjugates coumaroyl tyramine (CT) and feruloyl tyramine (FT) in pepper upon infection with *Xanthomonas campestris* pv. *campestris* (Newman et al. 2002). **E,** Volatile-induced priming for potentiated expression of the jasmonic acid–inducible *PIN* gene in maize upon treatment by wounding and caterpillar regurgitant (J. Ton and T. C. J. Turlings, *unpublished results*).

The induction of resistance

Priming for Enhanced Defense

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Caspar J.G. Langenbach, and Michal R. Jaskiewicz

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Annu. Rev. Phytopathol. 2015. 53:5.1–5.23

The *Annual Review of Phytopathology* is online at
phyto.annualreviews.org

This article's doi:
10.1146/annurev-phyto-080614-120132

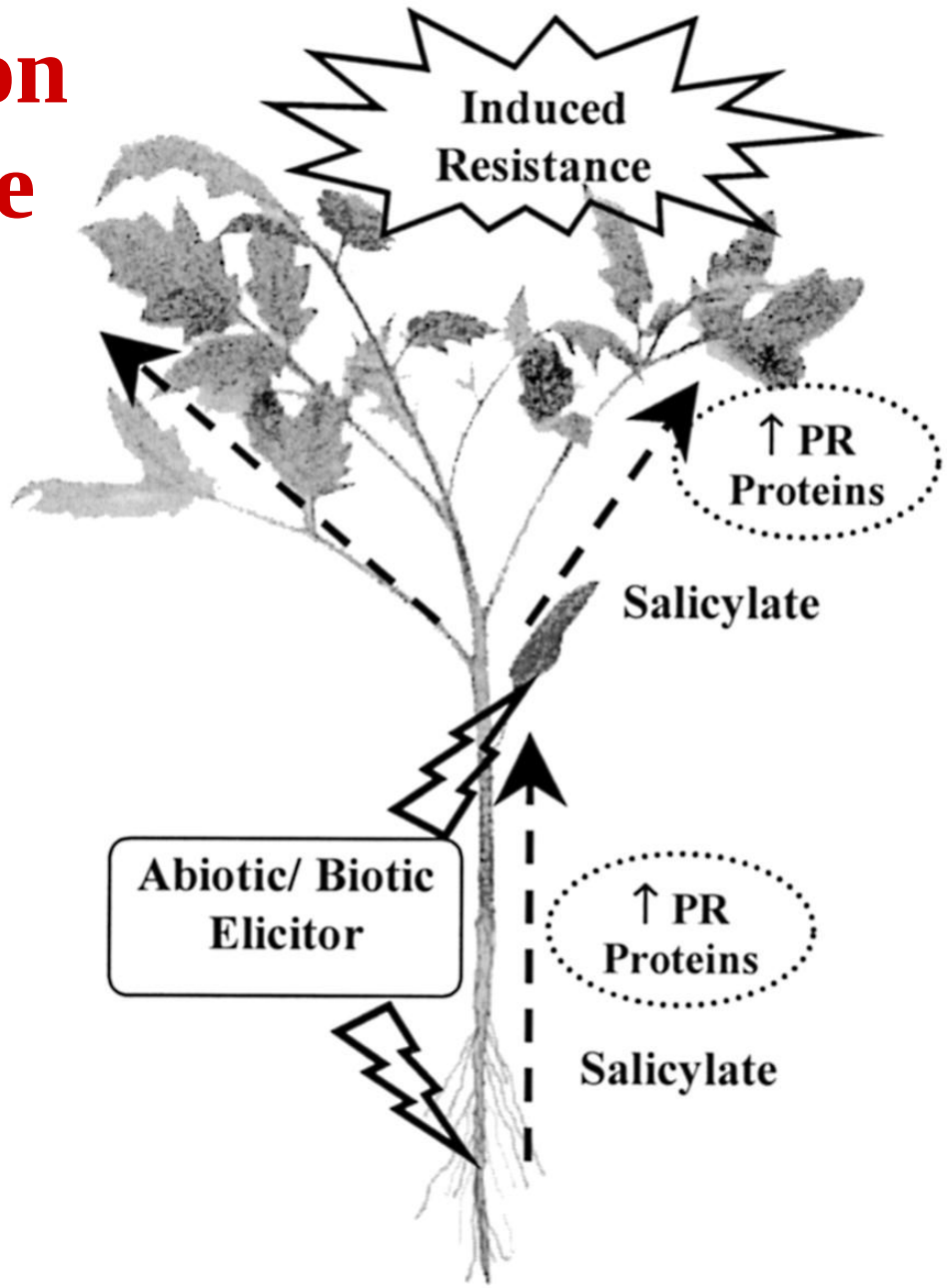
Keywords

epigenetic memory, primed immunity, signal transduction, sustainable agriculture, systemic immunity

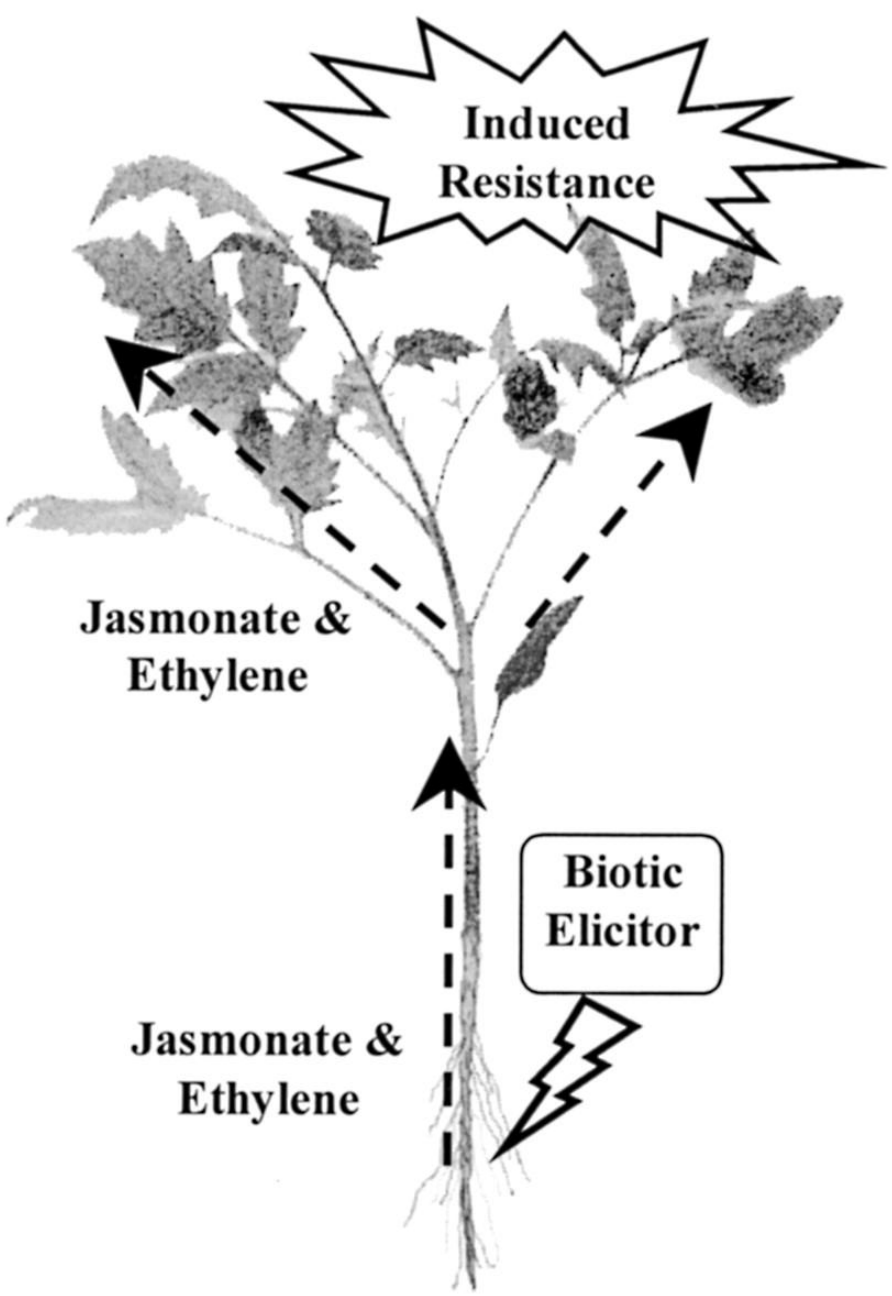
Abstract

When plants recognize potential opponents, invading pathogens, wound signals, or abiotic stress, they often switch to a primed state of enhanced defense. However, defense priming can also be induced by some natural or synthetic chemicals. In the primed state, plants respond to biotic and abiotic stress with faster and stronger activation of defense, and this is often linked to immunity and abiotic stress tolerance. This review covers recent advances in disclosing molecular mechanisms of priming. These include elevated levels of pattern-recognition receptors and dormant signaling enzymes, transcription factor HsfB1 activity, and alterations in chromatin state. They also comprise the identification of aspartyl-tRNA synthetase as a receptor of the priming activator β-aminobutyric acid. The article also illustrates the inheritance of priming, exemplifies the role of recently identified priming activators azelaic and pipecolic acid, elaborates on the similarity to defense priming in mammals, and discusses the potential of defense priming in agriculture.

The induction of resistance



Systemic Acquired Resistance (SAR)



Induced Systemic Resistance (ISR)

Vallad and Goodman, 2004 Crop Science

The induction of resistance

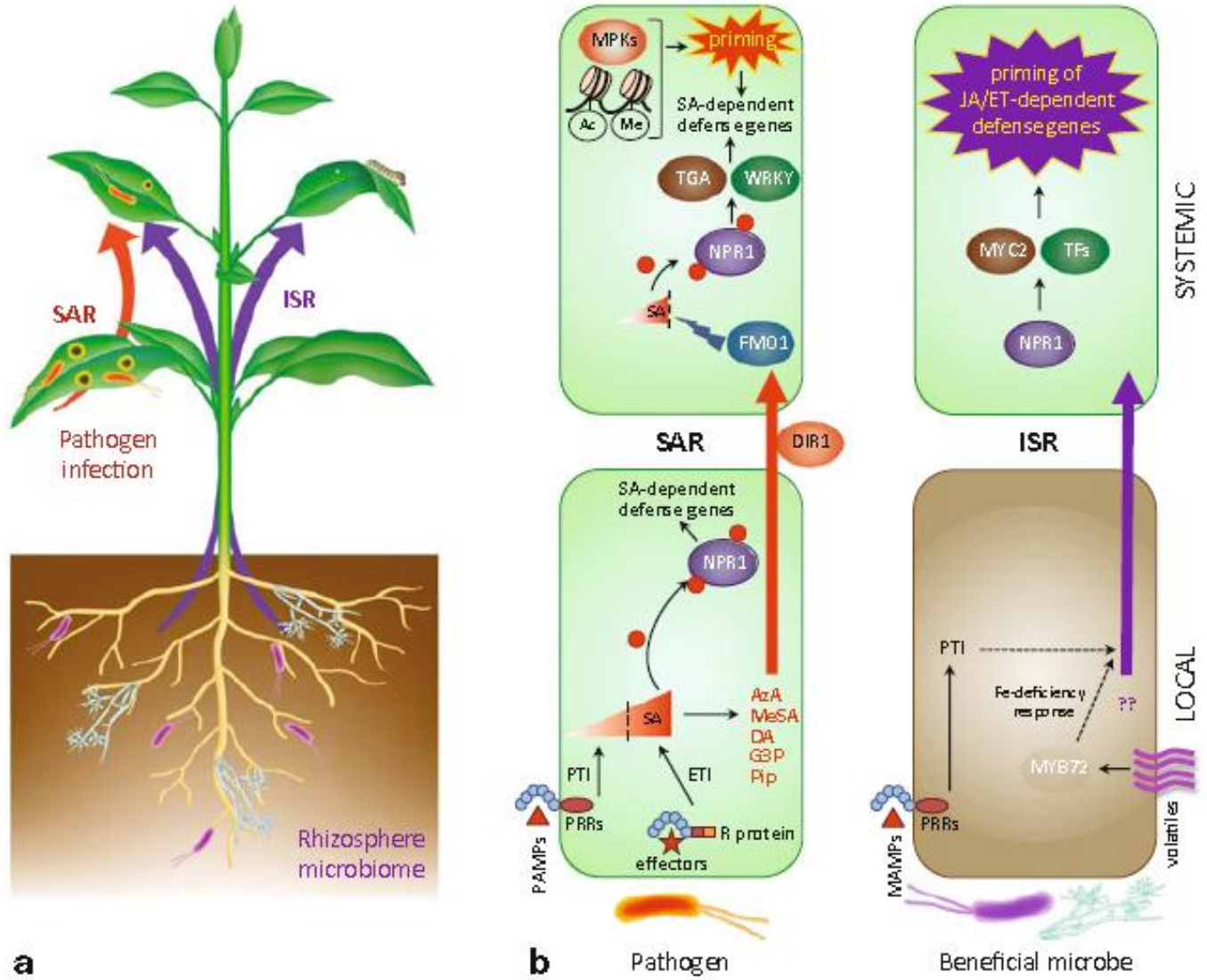
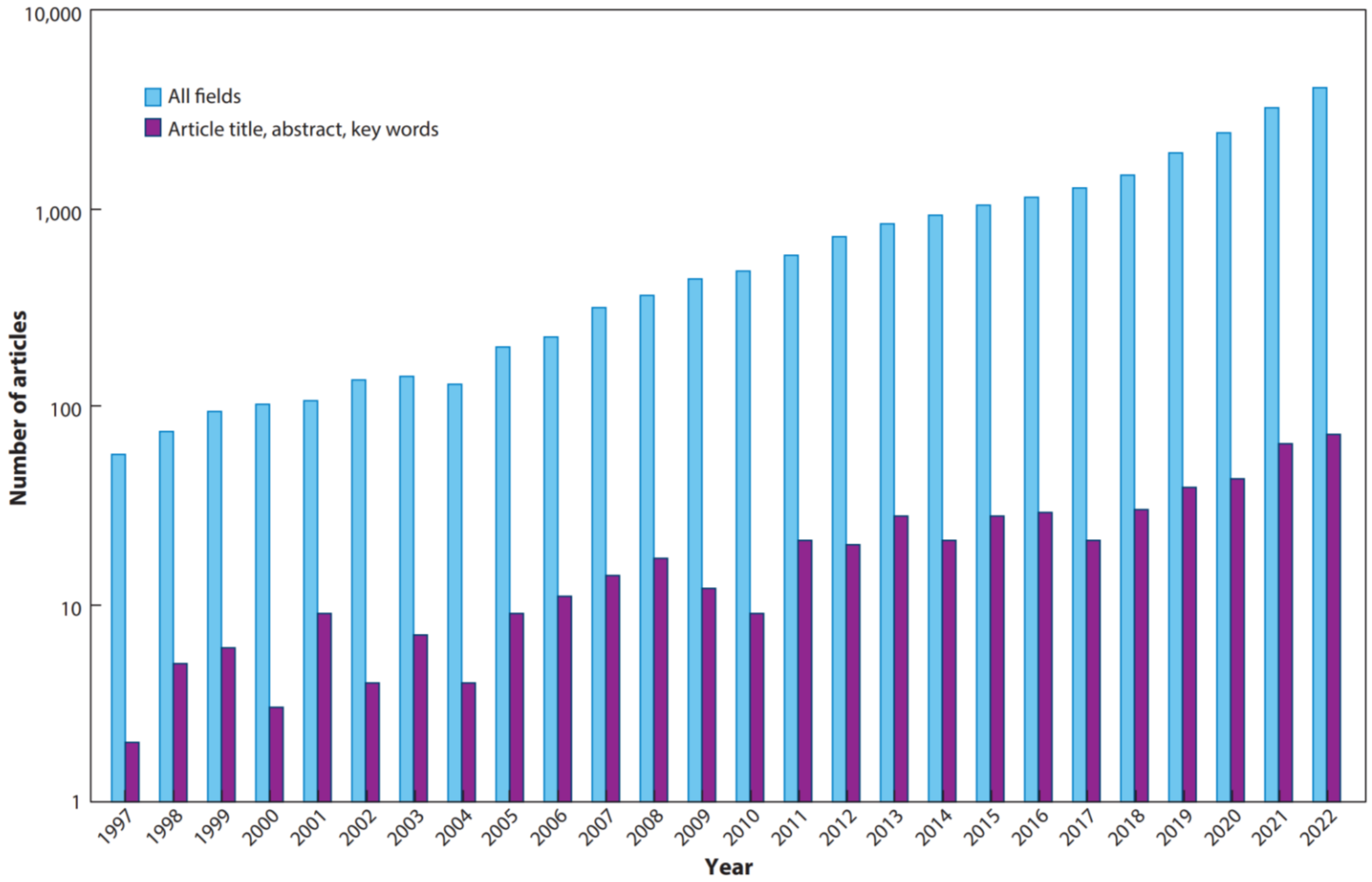


Fig. 14.1 **a** Schematic representation of biologically induced disease resistance triggered by pathogen infection (*SAR; red arrow*) and colonization of the roots by beneficial microbes (*ISR; purple arrow*). Induced resistance involves long-distance signals that are transported through the vasculature or as airborne signals, and systemically propagate an enhanced defensive capacity against a broad spectrum of attackers in still healthy plant parts. **b** Schematic representation of molecular components and mechanisms involved in pathogen-induced SAR and rhizobacteria-mediated ISR. Solid black lines indicate established interactions; dashed black lines indicate hypothetical interactions. Colored arrows indicate systemic translocation of long-distance signals (indicated in the same color at the base of the arrows). *Ac* acetylation, *ET* ethylene, *ETI* effector-triggered immunity, *Fe* iron, *ISR* induced systemic resistance, *JA* jasmonic acid, *MAMP* microbe-associated molecular pattern, *Me* methylation, *PAMP* pathogen-associated molecular pattern, *PRR* pattern-recognition receptor, *PTI PAMP*-triggered immunity, *R* protein Resistance protein, *SA* salicylic acid, *SAR* systemic acquired resistance, *TF* transcription factor

Popularity of investigations on induced resistance

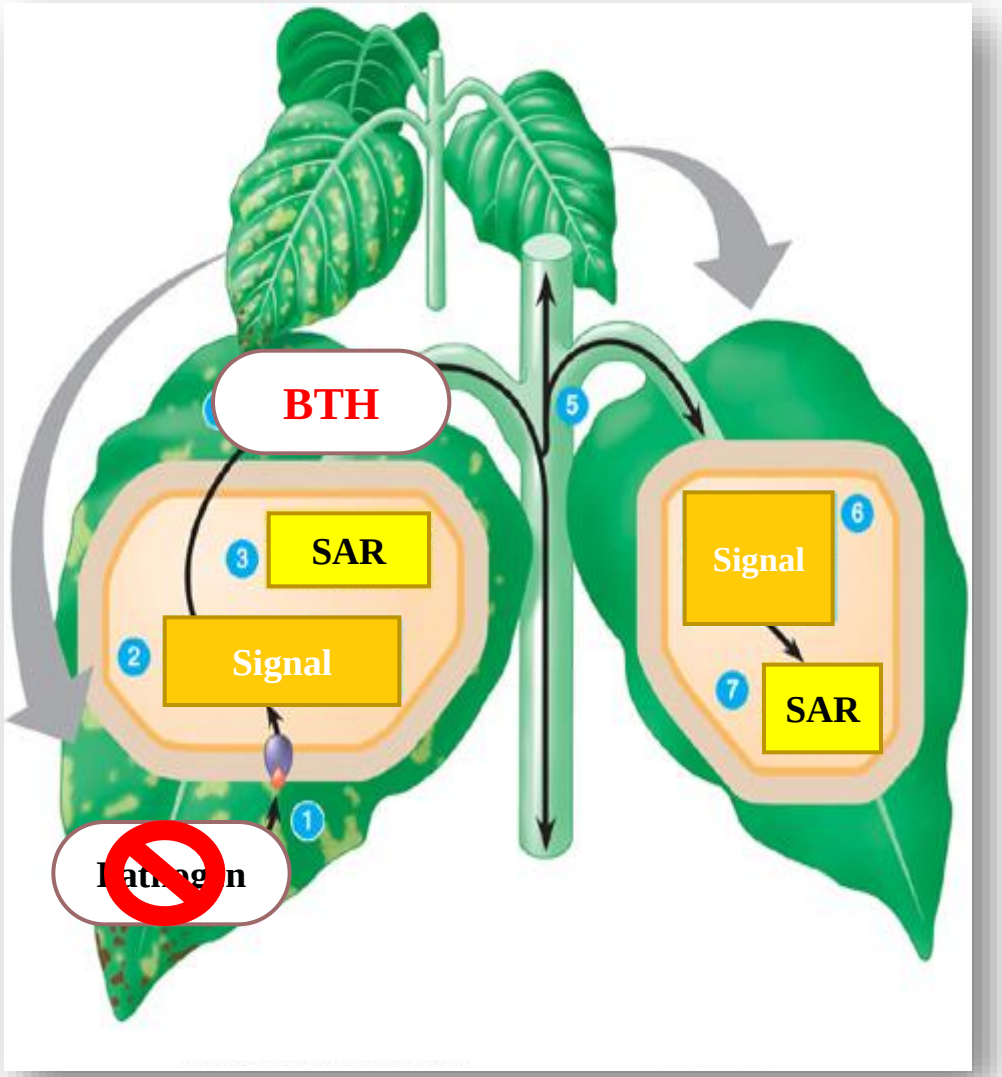


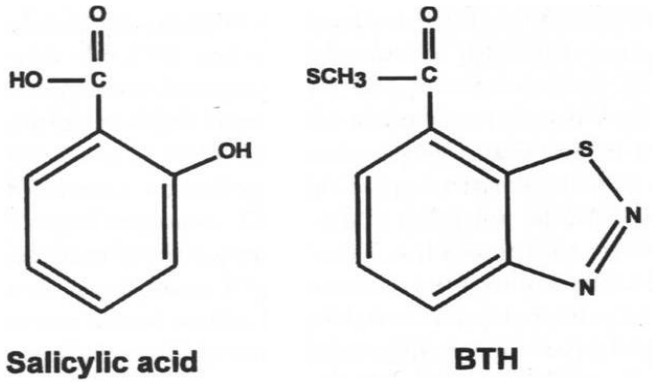
Prusky and Romanazzi, 2023 ARP

https://doi.org/10.1146/annurev-phyto-021722-035135

Benzothiadiazole (BTH)

or known as acibenzolar-*S*-methyl or
Benzo (1,2,3) thiadiazole-7 carbothionic acid *S*-methyl ester





- **Analogue of Salicylic Acid (SA), that is light sensitive**
- **BTH triggers Systemic Acquired Resistance (SAR)**

Resistance inducers

ELICITOR	TARGET					
	Chromista	Funghi	Batteri	Virus	Fitoplasmi	Insetti
Acibenzolar-S-Methyl or Benzothiadiazole (BTH)	X	X	X	X	X	X
β-aminobutyric acid (BABA)	X	X		X		
Cerevisane	X	X				
Chitosan	X	X	X	X	X	X
Glutathion + oligosaccharines	X				X	X
Isonicotinic acid (INA)	X	X	X	X		
Jasmonic acid (JA, MeJA)		X				X
Laminarin	X	X				
Phosetyl-Al	X	X	X		X	
Potassium phosphyte	X	X				
Prohexadione-Ca			X		X	
Protein hydrolysates	X	X				
Salicylic acid (SA)		X		X	X	
Yeast extracts	X	X				
Essential oils (TO,CO,OO,GO)	X	X	X	X	X	X

Romanazzi, 2014 Acta Italus Hortus

Postharvest Pathology and Mycotoxins

Antifungal Activity of Chitosan on Two Postharvest Pathogens of Strawberry Fruits

Ahmed El Ghaouth, Joseph Arul, Jean Grenier, and Alain Asselin

First and second authors: Département de science et technologie des aliments et Centre de recherche en horticulture, Université Laval, Québec, G1K 7P4, Canada; third and fourth authors: Département de phytologie, Université Laval, Québec, G1K 7P4, Canada.

This research was supported by the Conseil des recherches en pêches et agro-alimentaire (CORPAQ). We thank Jean Trudel for his collaboration and Louise Laroche for typing the manuscript.

Address correspondence to J. Arul.

Accepted for publication 5 November 1991.

ABSTRACT

El Ghaouth, A., Arul, J., Grenier, J., and Asselin, A. 1992. Antifungal activity of chitosan on two postharvest pathogens of strawberry fruits. Phytopathology 82:398-402.

Effect of chitosan coating on decay of strawberry fruits held at 13 C was investigated. Strawberry fruits were inoculated with spore suspensions of *Botrytis cinerea* or *Rhizopus stolonifer* and subsequently coated with chitosan solutions (10 or 15 mg/ml). After 14 days of storage, decay caused by *B. cinerea* or *R. stolonifer* was markedly reduced by chitosan coating. Decay was not reduced further when the concentration of chitosan coating was increased from 10 to 15 mg/ml. Coating intact strawberries with chitosan did not stimulate chitinase, chitosanase, or β-1,3-glucanase activities in the tissue as revealed by polyacrylamide gel assays. Chitosan, when applied on freshly cut strawberries, however, stimulated acidic chitinase activity. Chitosan was very effective in inhibiting spore germination, germ tube elongation, and radial growth of *B. cinerea* and *R. stolonifer* in culture. Furthermore, chitosan at a concentration greater than 1.5 mg/ml induced morphological changes in *R. stolonifer*. Mechanisms by which chitosan coating reduced the decay of strawberries appear to be related to its fungistatic property rather than to its ability to induce defense enzymes such as chitinase, chitosanase, and β-1,3-glucanase.

Additional keywords: *Fragaria* sp., glucanohydrolase, gray mold.

molecules https://doi.org/10.3390/molecules27113484

Review

Basic Substances, a Sustainable Tool to Complement and Eventually Replace Synthetic Pesticides in the Management of Pre and Postharvest Diseases: Reviewed Instructions for Users

Gianfranco Romanazzi [1,*], Yann Orçonneau [2], Marwa Moumni [1], Yann Davillerd [2] and Patrice André Marchand [2]

Citation: Romanazzi, G.; Orçonneau, Y.; Moumni, M.; Davillerd, Y.; Marchand, P.A. Basic Substances, a Sustainable Tool to Complement and Eventually Replace Synthetic Pesticides in the Management of Pre and Postharvest Diseases: Reviewed Instructions for Users. *Molecules* **2022**, *27*, 3484. https://doi.org/10.3390/molecules27113484

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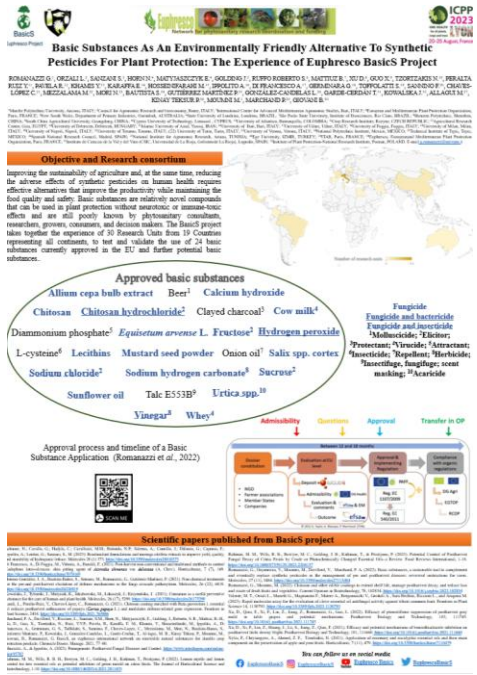
BasicS
Euphresco Project

Fungicide
Fungicide and bactericide
Fungicide and insecticide
[1]Molluscicide; [2]Elicitor; [3]Protectant; [4]Virucide; [5]Attractant; [6]Insecticide; [7]Repellent; [8]Herbicide; [9]Insectifuge, fungifuge; scent masking; [10]Acaricide



Approved basic substances

Allium cepa bulb extract Beer[1] **Calcium hydroxide**

Chitosan **Chitosan hydrochloride[2]** Clayed charcoal[3] **Cow milk[4]**

Diammonium phosphate[5] ***Equisetum arvense* L.** **Fructose[2]** **Hydrogen peroxide**

L-cysteine[6] **Lecithins** **Mustard seed powder** Onion oil[7] **Salix spp. cortex**

Sodium chloride[2] **Sodium hydrogen carbonate[8]** **Sucrose[2]**

Sunflower oil Talc E553B[9] **Urtica spp.[10]**

Vinegar[8] **Whey[4]**

EuphrescoBasicS

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euphrescobasics

Euphresco BasicS

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GRN No. (sorted Z-A)	Substance	Date of closure	FDA's Letter
997	Chitosan and *beta*-1,3-glucans from white button mushrooms (*Agaricus bisporus*)	Feb 28, 2022	FDA has no questions (in PDF) (140 kB)
991	Chitonase enzyme preparation produced by *Bacillus subtilis*		Pending
443	Shrimp-derived chitosan	Feb 11, 2013	At notifier's request, FDA ceased to evaluate the notice
397	Chitosan from *Aspergillus niger*	Dec 19, 2011	FDA has no questions
170	Shrimp-derived chitosan	Oct 31, 2005	At notifier's request, FDA ceased to evaluate the notice.
73	Shrimp-derived chitosan	Jan 31, 2002	At notifier's request, FDA ceased to evaluate the notice

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https://www.cfsanappsexternal.fda.gov/scripts/fdcc/index.cfm?set=GRASNotices&sort=GRN_No&order=DESC&startrow=1&type=basic&search=chitosan

What's chitosan?

Chitin related food science today (and two centuries ago)

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Special Highlight: Chitin/Chitosan 37 AGRO/Food Industry Hi-tech September/October 2003

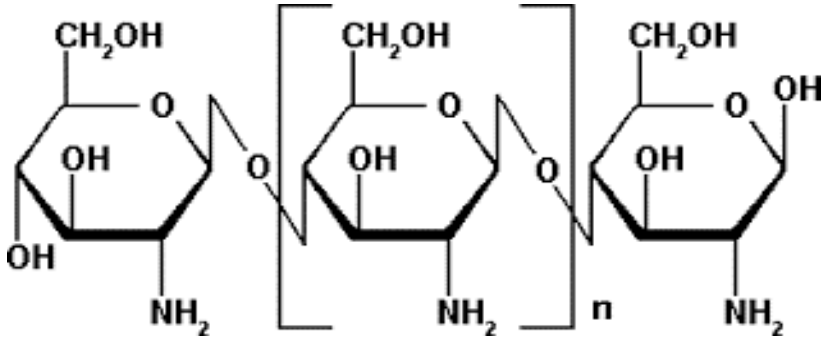
THE DISCOVERY OF CHITIN (IN A BOTANIC GARDEN).

In 1807 Henry Braconnot was appointed director of the Botanic Garden and Professor of Natural History in Nancy. The four-century old University of Nancy, as well as the University of Strasbourg, had been suppressed by the Assemblée Générale, and in Nancy the Medical School and the Academy were the only learned structures. Actually, the Garden and the Chair were part of the Medical School because of the interest in officinal plants. Those years were crucial for the connections between botany, chemistry and medicine. For example, morphine was isolated by Serturner in 1806, quinine was discovered by Pelletier and Caventon in 1823 and atropine was crystallized in 1833. The discovery of the anaesthetic action of nitrous oxide, diethyl ether and chloroform started a revolution in surgery.
Braconnot had access to very modest means for doing research, also due to the continental embargo consequent to the Napoleon's wars. Nevertheless, while taking care of the heavily damaged Garden discovered chitin in 1811 started large scale cultivation of the sugar beet and the extraction and purification of sugar with the intention of alleviating food shortage. This activity was abruptly put to an end by the changed political situation which permitted to import sugar from tropical countries. He went on, however, with his idea of extracting sugars from plants and remarkably anticipated the modern approaches by directing attention to *Heliantus tuberosus* from which inulin is extracted today.
Braconnot was interested in the definition of the nutritional value of mushrooms. Braconnot wrote that poor countrymen considered mushrooms a manna given free as a gift of providence, and eagerly waited for the mushroom seasons. Today *Agaricus bisporus* is widely cultivated.
Systematic sulfuric acid treatment of a large number of substances led him to isolate two amino acids, glycine and leucine, in 1820. This discovery brought a certain renown to him. The direction of the Garden and the relevant problems (risky use of gas for heating the hothouses, fights against military plans to build caserns inside the Garden) prevented Braconnot from exploiting his chemical discoveries. He was a precursor of Chevreul with his studies on fats, but he had no means to identify the fatty acids; he brought forward the idea of plant alkali but he could not isolate the alkaloids.
On the theoretical ground, he expressed the view that hydrogen and oxygen together with fire were the fundamental constituents of the universe, and plants can produce a number of elements from light and water.
Braconnot published 112 papers in the form of memoirs of the Academy of Sciences, Letters and Arts of Nancy, also known as Academy of Stanislas, the King of Polish origin who ruled the Lorraine region. Other publications are in *the Annales de Chimie et Physique* and *Journal de Chimie Médicale*. He was also appointed corresponding member of the national Académie des Sciences, after Wollaston.
Braconnot certainly was an eminent chemist, as D.A. Godron, his successor, wrote, but he profused many energies in botany. Actually his teaching was according to Linnée, in a time period when novel theories on cellular structure, plant sexuality and alternate generations were being brought forward, as a consequence of the studies done on enormous collections of previously unknown plants. For instance the Flinders expedition (1801) made available 4000 unknown species of plants from Australia. In 1852 the 14,100 m^2 Garden had 3452 plants species, including some from New Zealand and Reunion Island provided by Empress Joséphine. Braconnot took into account the novel views in botany, but dimmed sight forced him to refrain from teaching for several years before retirement. He left everything to the City of Nancy.
The discovery of chitin was essentially based on some reactions carried out on raw material isolated from *Agaricus volvaceus, A. acris, A. cantarellus, A. piperatus, Hydnum repandum, H. hybridum* and *Boletus viscidus*.
The existence of chitosan in nature remained unknown until 1954, when it was discovered in the yeast *Phycomyces blakesleeanus*. Chitosan occurs as the major structural component of the cell walls of certain fungi, mainly of the *Zygomycetes* species. However, to date, chitosans have been commercially produced by alkaline deacetylation of crustacean chitins.

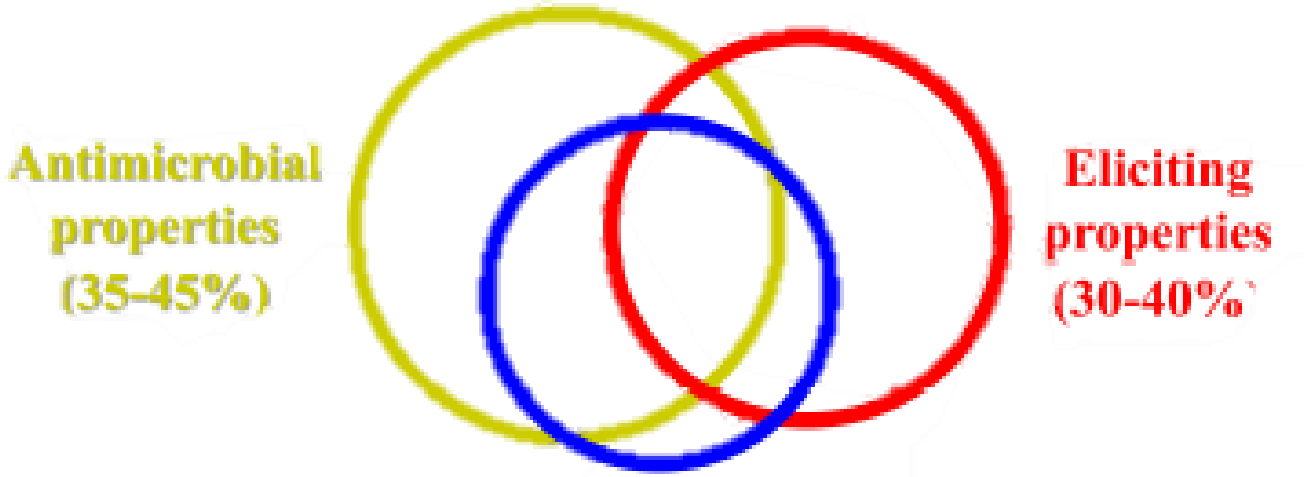
MODERN APPLICATIONS OF CHITOSAN IN FOOD SCIENCES

Antibacterial Activity

The antibacterial activity of chitosan was originally documented by Muzzarelli et al. (1990) who published electron micrographs showing the alterations produced in the bacterial cell wall and organelles. Those results were brilliantly confirmed more than a decade later by Helander et al (2001). Chemical and electrophoretic analyses of cell-free supernatants of chitosan-treated cell suspensions showed that interaction of chitosan with *E. coli* and the salmonellae involved no release of lipopolysaccharide or other membrane lipids. Highly cationic mutants of *S. typhimurium* were more resistant to chitosan than the parent strains. Electron microscopy showed that chitosan caused extensive cell surface alterations and covered the outer membrane with vesicular structures. Chitosan thus appeared to bind to the outer membrane, explaining the loss of the barrier function. This property makes chitosan useful for food protection (Helander et al., 2001). It was also found that the antibacterial activity of quaternized chitosan against *E. coli* is stronger than that of chitosan (Jia et al., 2001).
The antibacterial activity may be either bactericidal or



Chitosan is a natural biopolymer obtained from deacetylation of crab shells or extracted from fungi (e.g. *Aspergillus* sp.) with threefold activity



frontiers in Microbiology

Chitosan, a Biopolymer With Triple Action on Postharvest Decay of Fruit and Vegetables: Eliciting, Antimicrobial and Film-Forming Properties

Gianfranco Romanazzi[1], Erica Feliziani[1] and Dharini Sivakumar[2]*

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frontiers in Microbiology

Chitosan, a Biopolymer With Triple Action on Postharvest Decay of Fruit and Vegetables: Eliciting, Antimicrobial and Film-Forming Properties

Gianfranco Romanazzi[1], Erica Feliziani[1] and Dharini Sivakumar[2]*

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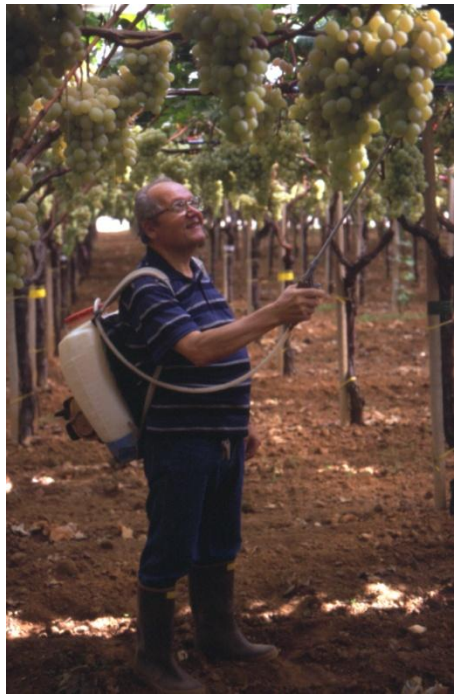
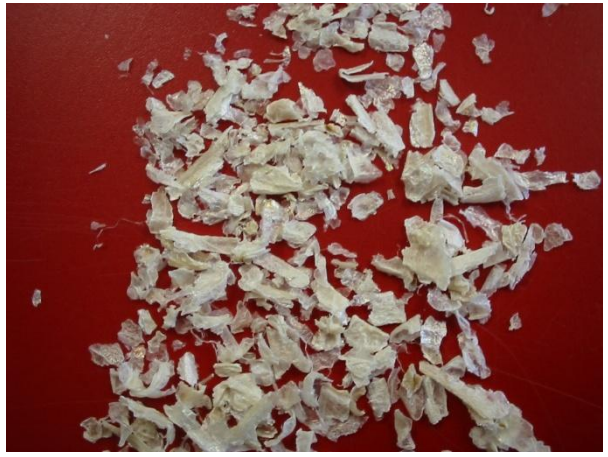
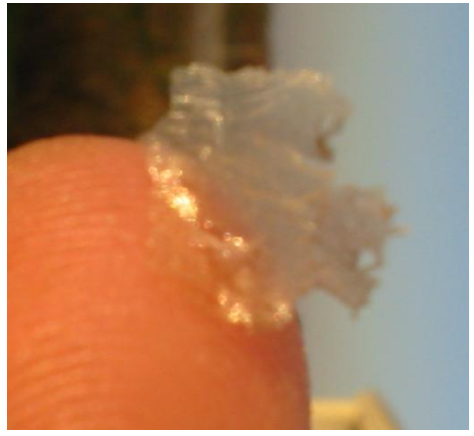
TABLE 5 | Some chitosan-based commercial products that are available for control of postharvest diseases of fruit and vegetables.

Product trade name	Company (Country)	Formulation	Active ingredient (%)
Chito plant	ChiPro GmbH (Bremen, Germany)	Powder	99.9
Chito plant	ChiPro GmbH (Bremen, Germany)	Liquid	2.5
OII-YS	Venture Innovations (Lafayette, LA, United States)	Liquid	5.8
KaitoSol	Advanced Green Nanotechnologies Sdn Bhd (Cambridge, United Kingdom)	Liquid	12.5
Armour-Zen	Botry-Zen Limited (Dunedin, New Zealand)	Liquid	14.4
Biorend	Bioagro S.A. (Chile)	Liquid	1.25
Kiforce	Alba Milagro (Milan, Italy)	Liquid	6
FreshSeal	BASF Corporation (Mount Olive, NJ, United States)	Liquid	2.5
ChitoClear	Primex ehf (Siglufjordur, Iceland)	Powder	100
Bioshield	Seafresh (Bangkok, Thailand)	Powder	100
Biochikol 020 PC	Gumitex (Lowics, Poland)	Liquid	2
Kadozan	Lytone Enterprise, Inc. (Shanghai Branch, China)	Liquid	2
Kendal cops	Valagro (Atessa, Italy)	Liquid	4
Chitosan 87%	Korea Chengcheng Chemical Company (China)	TC (Technical material)	87
Chitosan 2%	Korea Chengcheng Chemical Company (China)	SLX (Soluble concentrate)	2





Dissolved in diluted acids



Effects of Pre- and Postharvest Chitosan Treatments to Control Storage Grey Mold of Table Grapes

G. ROMANAZZI, F. NIGRO, A. IPPOLITO, D. DI VENERE, AND M. SALERNO

ABSTRACT: The effectiveness of pre- and postharvest treatments with chitosan (0.1, 0.5, and 1.0%) to control *Botrytis cinerea* on table grapes was investigated. In postharvest treatments, small bunches dipped in chitosan solutions and inoculated with the pathogen showed a reduction of incidence, severity, and nesting of grey mold, in comparison with the control. Single berries artificially wounded, treated with the polymer, and inoculated with *B. cinerea* showed a reduced percentage of infected berries and lesion dia. Higher chitosan concentrations demonstrated greater decay reduction. All preharvest treatments significantly reduced the incidence of grey mold, as compared to the control. Table grapes treated with 1.0% chitosan showed a significant increase of phenylalanine ammonia-lyase (PAL) activity. Consequently, besides a direct activity against *B. cinerea*, chitosan produces other effects contributing to reduce decay.

Keywords: *Botrytis cinerea*, postharvest decay, PAL activity, sulphur dioxide, microflora

Introduction

GREY MOLD, INDUCED BY *BOTRYTIS CINEREA* PERS., CAUSES HEAVY losses of table grapes in the field and is a major obstacle to their long-distance transport and storage. The pathogen is able to develop at low temperature, shortening the length of storage and marketing (Ippolito and others 1998). In Italy, no synthetic fungicides are licensed to control decay of table grapes after harvest; sulphur dioxide is permitted as an adjuvant and is effective in reducing grey mold development during storage. However, alternatives to SO_2 are required in view of damage to bunches due to temperature increase, of hazards for human health, and of the difficulties in using SO_2 with colored grapes (Nelson and Richardson 1967). Considerable progress has recently been made in developing alternatives to synthetic fungicides for the control of postharvest diseases of fruit and vegetables (Wilson and Wisniewski 1994; Schena and others 1999; Ippolito and Nigro 2000; Romanazzi and others 2001a). The use of a natural substance such as chitosan, a high molecular weight cationic polysaccharide present in fungal cell walls and arthropod exoskeletons, has been considered as a valid alternative. In fact, chitosan is an ideal preservative coating for fresh fruit and vegetables because of its film-forming and biochemical properties (Muzzarelli 1986); it prolongs storage life and controls decay of strawberries (El Ghaouth and others 1991; Romanazzi and others 2000a), litchi (Zhang and Quantick 1997), and apples (Du and others 1998). Chitosan reduces the growth of many phytopathogenic bacteria and fungi (Allan and Hadwiger 1979). Moreover, it elicits phytoalexin formation (Reddy and others 1999) and induces the production of antifungal hydrolases (Fajardo and others 1998; Zhang and Quantick 1998; Hirano 1999). Chitosan has generally been applied in postharvest treatments (Baldwin and others 1995; Cheah and others 1997), and there are very few examples of preharvest application (Reddy and others 2000; Romanazzi and others 2000a, 2000b).

The objective of this study was to investigate the effectiveness of pre- and postharvest chitosan treatments in controlling grey mold storage rot of table grapes. In addition, the influence of chitosan on the naturally-occurring microflora and on phenylalanine ammonia-lyase (PAL) activity of the treated berries was evaluated.

Materials and Methods

Fruits

Trials were carried out on table grapes (*Vitis vinifera* L., cv Italia) grown in commercial groves located at Rutigliano (Province of Bari), Southern Italy. Vines, cultivated according to standard cultural practices, were covered with plastic sheets in the 2nd half of August to protect bunches from rainfall and to delay the harvest.

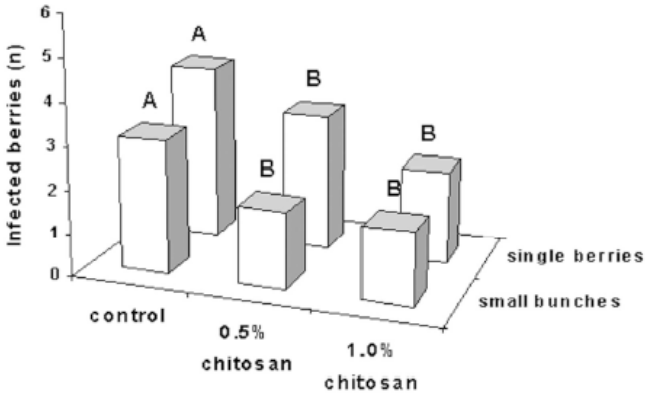
Pathogens

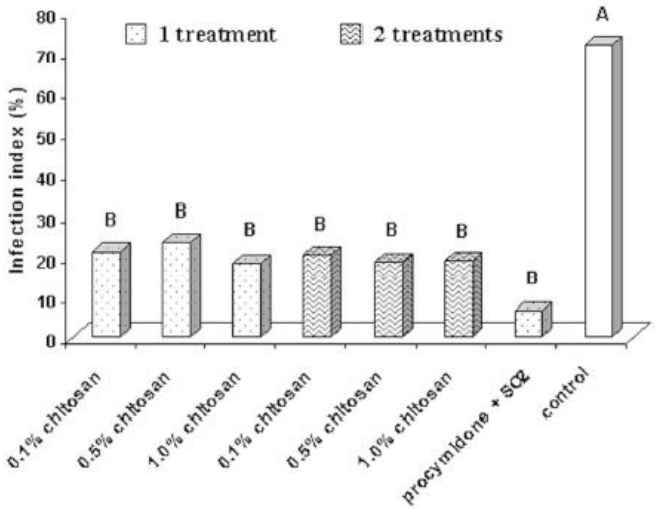
B. cinerea, strain 69, had been isolated from a cold-stored table grape berry and maintained on potato dextrose agar (PDA) slants at 5 ± 1 °C, with annual inoculation and re-isolation from berries to maintain virulence. In the drop-inoculation experiments, the inoculum consisted of aqueous spore suspension (10^4 spores ml^{-1}); in the spray-application experiments, concentrated stock suspension was added to achieve a final concentration of 10^5 spores ml^{-1}. The spore suspension was prepared by flooding a 12-d old culture of *B. cinerea*, grown at 20 ± 2 °C, with 10 ml of sterile distilled water containing 0.1% (v/v) Tween 80 (Eastman Chemical, Kingsport, Tenn., U.S.A.) gently agitated to remove the spores.

Chitosan

Crab-shell chitosan, purchased from Sigma Chemical Co. (St. Louis, Mo., U.S.A.), was ground to a fine powder (particle size smaller than 1 mm) by extensive grinding in a mortar, washed 3 times in distilled water (20 ml of water per g of chitosan), pelleted by low-speed centrifugation and air-dried at room temperature. The purified chitosan was prepared as described by Benhamou and others (1994). For experimental use the stock

Antonio Ippolito





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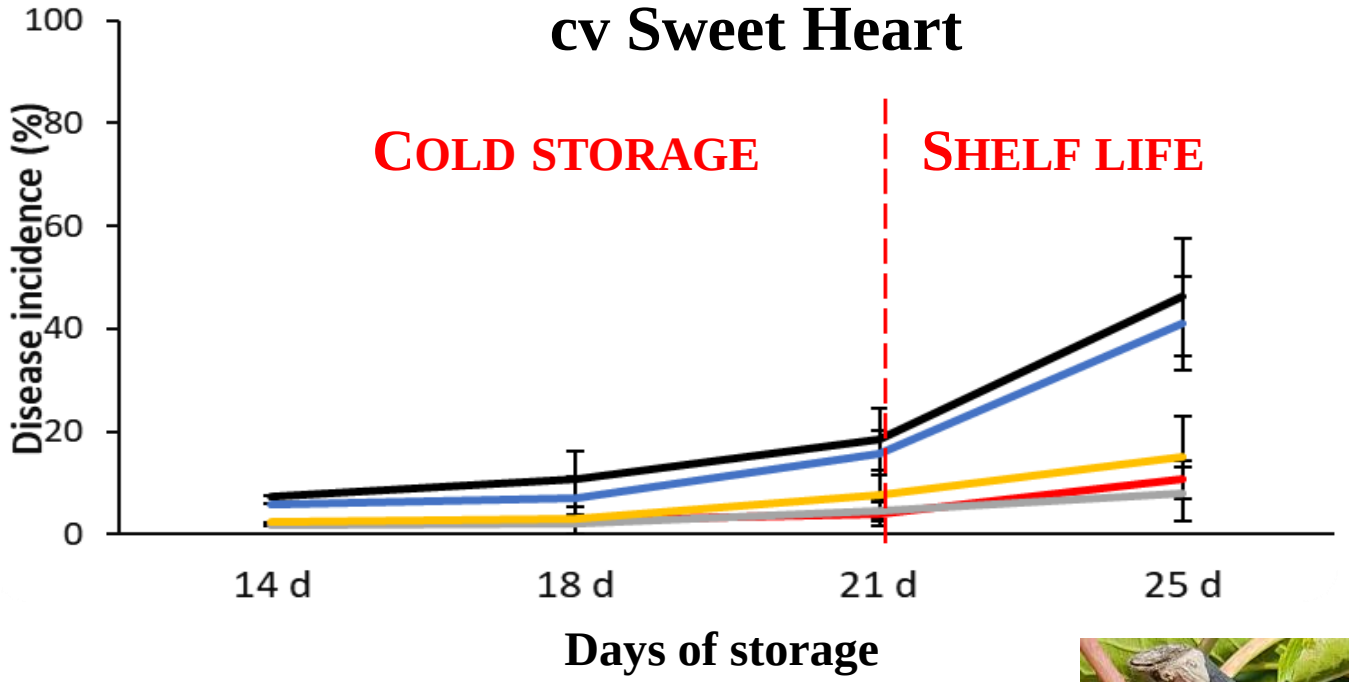
PRIMA PARTNERSHIP FOR RESEARCH AND INNOVATION IN THE MEDITERRANEAN AREA

STOP MED WASTE

Sweet cherry cultivars: **Lapins** and **Sweet Heart**
4 treatments: 3 blooming stage + 1 preharvest
Basic substances: 1. **Chitosan**
2. **Sodium bicarbonate**
21 days of **cold storage** (1± 1 °C) and **4 days** of **shelf life** (20 ± 1 °C) in **microperforated plastic bags**

***Alternaria* spp.**

Botrytis cinerea



Reduction of **disease incidence** and **severity**

Postharvest Biology and Technology 228 (2025) 113619

Contents lists available at ScienceDirect

Postharvest Biology and Technology

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Volatile organic compounds released by chitosan formulations present diverse chemical composition and produce differential effects on postharvest pathogens

Samuel Álvarez-García [a,b], Ilaria D'Isita [c], Onofrio Marco Pistillo [c], Marwa Moumni [a], Giacinto Salvatore Germinara [c], Gianfranco Romanazzi [a,*]

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Journal of Cleaner Production
Volume 451, 20 April 2024, 142131

Applications of chitosan alone, alternated or combined with copper for grapevine downy mildew management in large scale trials

Gianfranco Romanazzi [a], Simone Piancatelli [a], Roberto Potentini [b], Giuliano D'Ignazi [c], Marwa Moumni [a]

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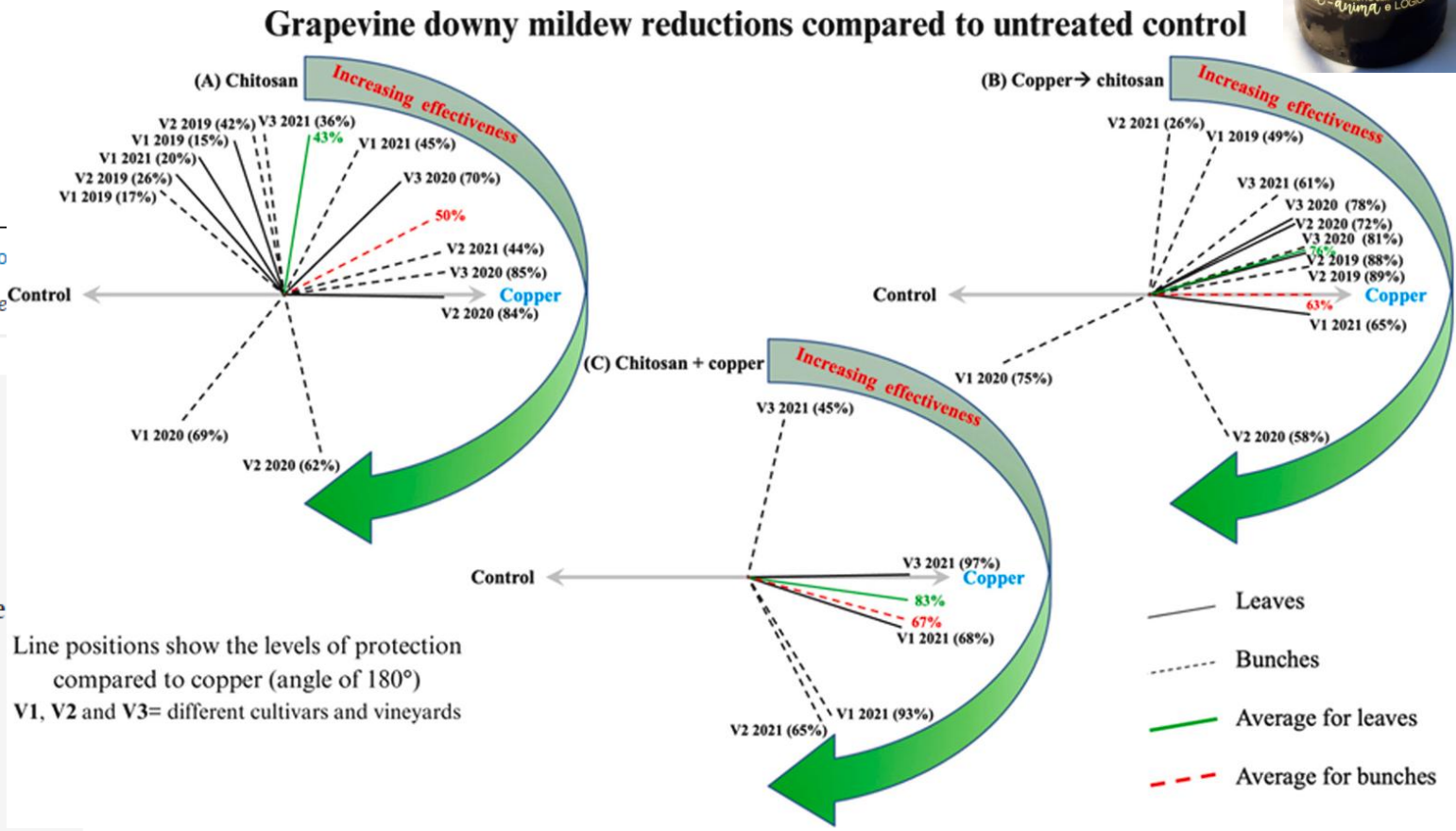
Highlights

- Chitosan treatments controlled grapevine downy mildew on leaves and bunches.
- Starting chitosan application at flowering reduced copper residues in grape juice.
- Chitosan showed a higher effectiveness in protecting bunches than leaves.
- Starting season with copper then applying chitosan was as effective as copper alone.
- Combination of low rates of chitosan and copper was more effective than copper alone.



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frontiers in Plant Science

ORIGINAL RESE
published: 24 February
doi: 10.3389/fpls.2017.

Global Transcriptome Analysis and Identification of Differentially Expressed Genes in Strawberry aft Preharvest Application of Benzothiadiazole and Chitosan

*Lucia Landi[1], Rita M. De Miccolis Angelini[2], Stefania Pollastro[2], Erica Feliziani[1], Franco Faretra[2] and Gianfranco Romanazzi[1]**

[1] Department of Agricultural, Food and Environmental Sciences, Marche Polytechnic University, Ancona, Italy, [2] Dep of Soil, Plant and Food Sciences, University of Bari 'Aldo Moro', Bari, Italy

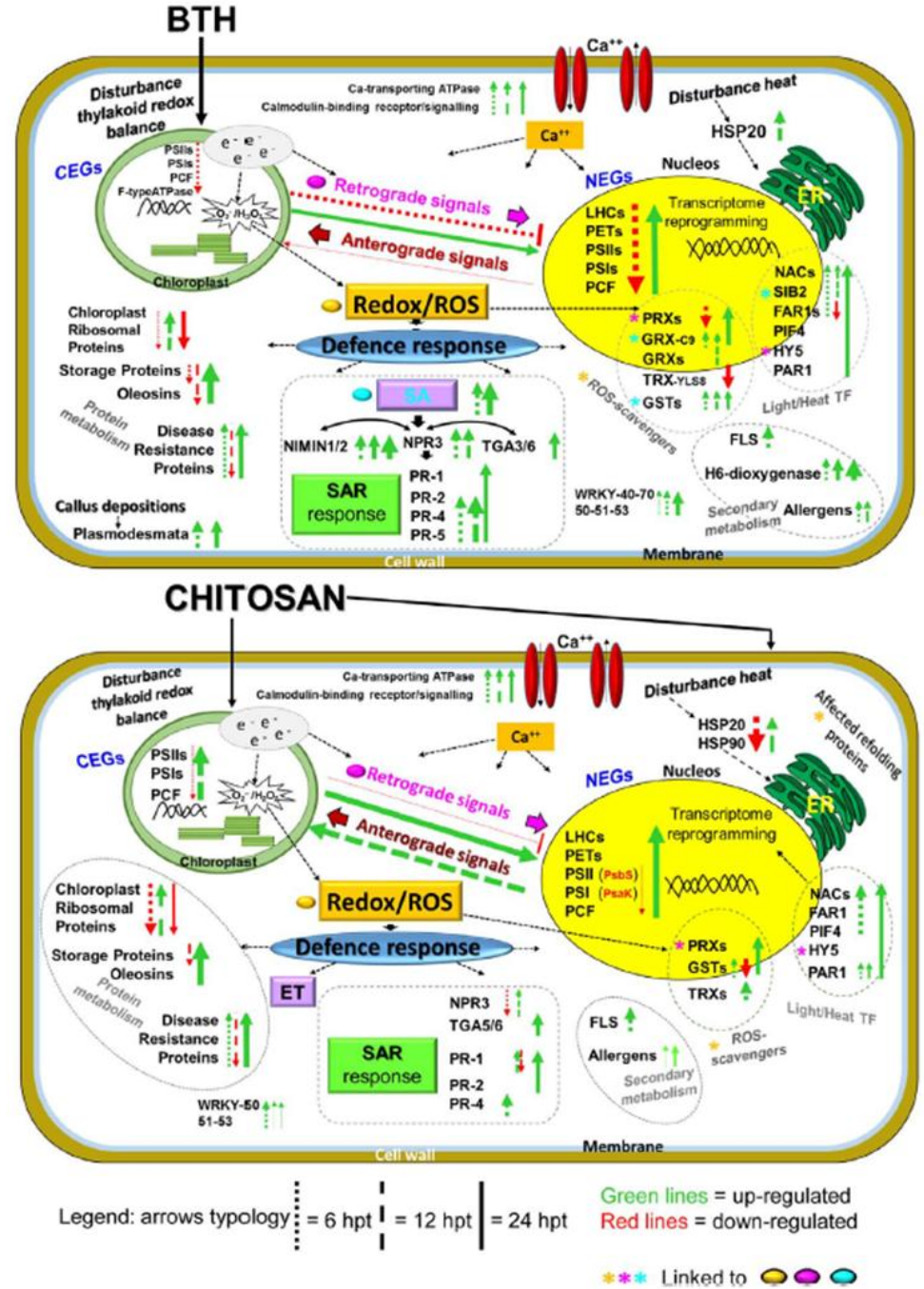


FIGURE 10 | Overview of the proposed transcriptome reprogramming model in strawberry fruit following preharvest treatment of the strawberry plants with BTH and chitosan at 6, 12, and 24 hpt, according to the major genes that were up-regulated and down-regulated. The thickness of the

Chitosan and postharvest decay of fresh fruit: Meta-analysis of disease control and antimicrobial and eliciting activities

Razieh Rajestary* | Lucia Landi* | Gianfranco Romanazzi

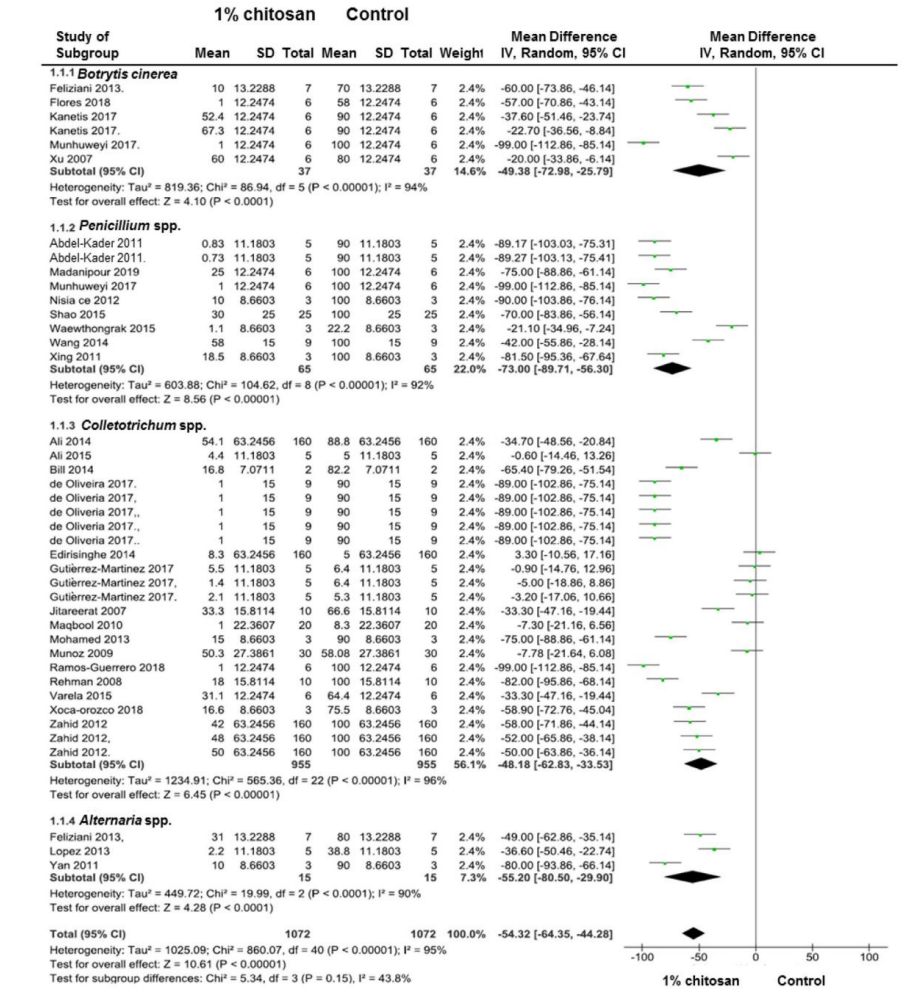


FIGURE 3 Forest plot using the RavMan 5.3 software for random effects analysis related to the effectiveness of 1% chitosan on *in vitro* mycelium growth. *Botrytis cinerea*, *Penicillium* spp., *Colletotrichum* spp. and *Alternaria* spp. were considered as subgroups. For Kanetis (2017), Kader (2011), de Oliveria (2017), Gutièrrez-Martinez (2017) and Zahid (2012), several studies were included from each article into the subgroups. IV, inverse variance; CI, confidence interval. The figure shows only the name of the first author and publication year. For complete citation see the manuscript

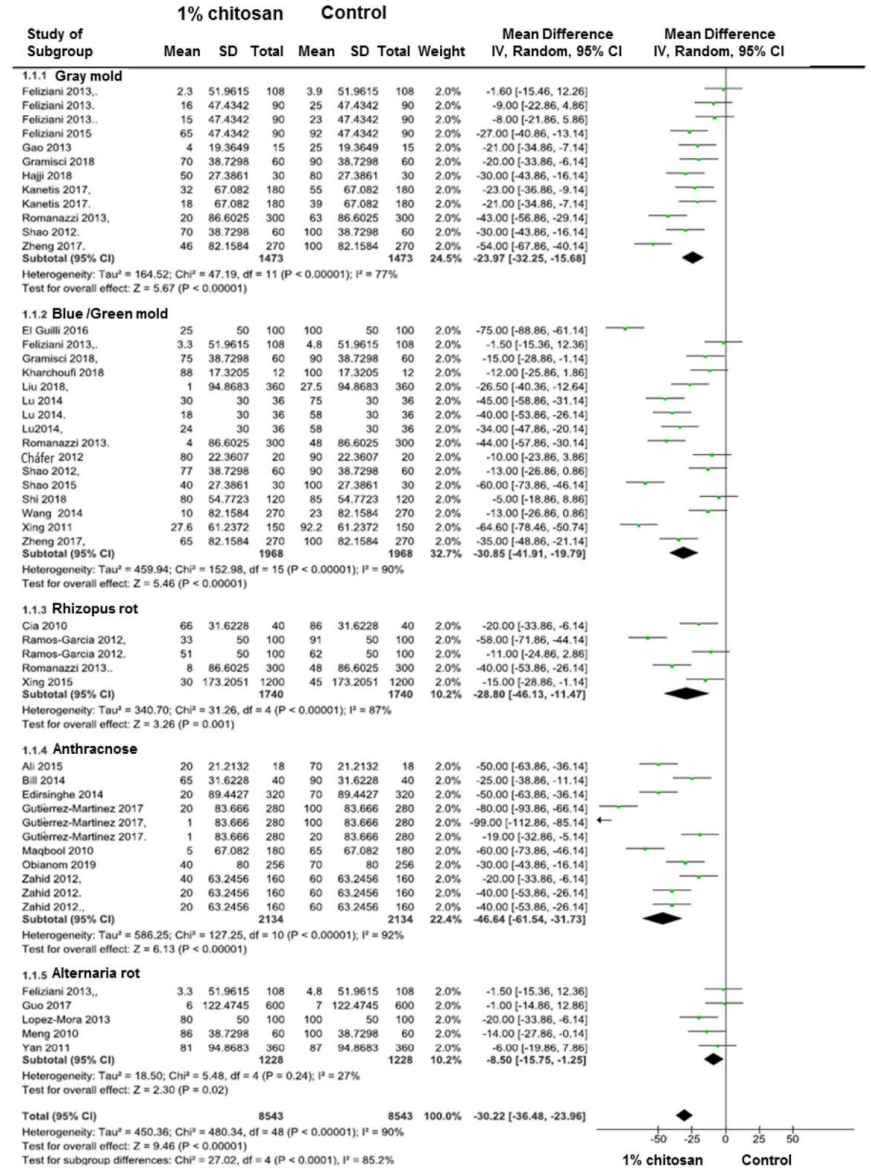


FIGURE 2 Forest plots using the RavMan 5.3 software for random effects analysis related to the effectiveness of 1% chitosan on disease incidence. Gray mold, blue/green mold, *Rhizopus* rot., anthracnose and *Alternaria* rot were considered as subgroups. For Feliziani (2013), Kanetis (2017), Lu (2014), Shao (2012), Ramos-Garcia (2012), Gutièrrez-Martinez (2017) and Zahid (2012), several studies were included from each article into the subgroups. IV, inverse variance; CI, confidence interval. The figure shows only the name of the first author and publication year. For complete citation see the manuscript

Chitosan and postharvest decay of fresh fruit: Meta-analysis of disease control and antimicrobial and eliciting activities

Razieh Rajestary* | Lucia Landi* | Gianfranco Romanazzi

Study of Subgroup	1% chitosan Mean	SD	Total	Control Mean	SD	Total	Weight	Mean Difference IV, Random, 95% CI
1.1.1 Phenylalanine ammonia-lyase								
Silva 2018	104	77.4597	240	96.15	77.4597	240	3.7%	7.85 [-6.01, 21.71]
Bill 2014	186.31	31.6228	40	12.86	31.6228	40	3.7%	173.45 [159.59, 187.31]
Jongsri 2017	96.29	19.3649	15	103.84	19.3649	15	3.7%	-7.55 [-21.41, 6.31]
Landi 2014	200	31.6228	40	50	31.6228	40	3.7%	150.00 [136.14, 163.86]
Shao 2015	61	19.3649	15	163	19.3649	15	3.7%	-102.00 [-115.86, -88.14]
Shen 2017	115.38	47.4342	90	86.66	47.4342	90	3.7%	28.72 [14.86, 42.58]
Song 2016	100	43.3013	75	100	43.3013	75	3.7%	0.00 [-13.86, 13.86]
Waewthongrak 2015	130.76	27.3861	30	76.47	27.3861	30	3.7%	54.29 [40.43, 68.15]
Zahid 2015	115.38	27.3861	30	86.6	27.3861	30	3.7%	28.78 [14.92, 42.64]
Subtotal (95% CI)			**575**			**575**	**33.3%**	**37.06 [-17.28, 91.40]**
Heterogeneity: Tau² = 6868.38; Chi² = 1106.94, df = 8 (P < 0.00001); I² = 99%								
Test for overall effect: Z = 1.34 (P = 0.18)								
1.1.2 Chitinase								
Ali 2014	222.2	38.7298	60	45	38.7298	60	3.7%	177.20 [163.34, 191.06]
Bill 2014	195.06	31.6228	40	51	31.6228	40	3.7%	144.06 [130.20, 157.92]
Feliziani 2013	123.3	47.4342	90	81.06	47.4342	90	3.7%	42.24 [28.38, 56.10]
Feliziani 2013,	124.81	47.4342	90	80.11	47.4342	90	3.7%	44.70 [30.84, 58.56]
Feliziani 2013.	113.8	47.4342	90	87.26	47.4342	90	3.7%	26.54 [12.68, 40.40]
Hewajulige 2009	173.91	27.3861	30	57.5	27.3861	30	3.7%	116.41 [102.55, 130.27]
Jongsri 2017	100	12.2474	6	100	12.2474	6	3.7%	0.00 [-13.86, 13.86]
Landi 2014	200	31.6228	40	50	31.6228	40	3.7%	150.00 [136.14, 163.86]
Shao 2015	108.23	19.3649	15	92.39	19.3649	15	3.7%	15.84 [1.98, 29.70]
Shen 2017	123.5	27.3861	30	80.95	27.3861	30	3.7%	42.55 [28.69, 56.41]
Subtotal (95% CI)			**491**			**491**	**37.0%**	**75.95 [36.18, 115.73]**
Heterogeneity: Tau² = 4068.05; Chi² = 741.25, df = 9 (P < 0.00001); I² = 99%								
Test for overall effect: Z = 3.74 (P = 0.0002)								
1.1.3 β-1,3-Glucanase								
Ali 2014	325	38.7298	60	30.76	38.7298	60	3.7%	294.24 [280.38, 308.10]
Bill 2014	228.8	31.6228	40	43.7	31.6228	40	3.7%	185.10 [171.24, 198.96]
Hewajulige 2009	250	27.3861	30	40	27.3861	30	3.7%	210.00 [196.14, 223.86]
Jongsri 2017	100	12.2474	6	100	12.2474	6	3.7%	0.00 [-13.86, 13.86]
Landi 2014	200	31.6228	40	50	31.6228	40	3.7%	150.00 [136.14, 163.86]
Shao 2015	100	19.3649	15	100	19.3649	15	3.7%	0.00 [-13.86, 13.86]
Shen 2017	108.3	27.3861	30	92.3	27.3861	30	3.7%	16.00 [2.14, 29.86]
Wang 2013	137.73	33.541	45	72.6	33.541	45	3.7%	65.13 [51.27, 78.99]
Subtotal (95% CI)			**266**			**266**	**29.6%**	**115.06 [38.24, 191.88]**
Heterogeneity: Tau² = 12239.86; Chi² = 1720.58, df = 7 (P < 0.00001); I² = 100%								
Test for overall effect: Z = 2.94 (P = 0.003)								
Total (95% CI)			**1332**			**1332**	**100.0%**	**74.58 [41.15, 108.01]**
Heterogeneity: Tau² = 7805.21; Chi² = 4084.71, df = 26 (P < 0.00001); I² = 99%								
Test for overall effect: Z = 4.37 (P < 0.0001)								
Test for subgroup differences: Chi² = 2.82, df = 2 (P = 0.24), I² = 29.1%								

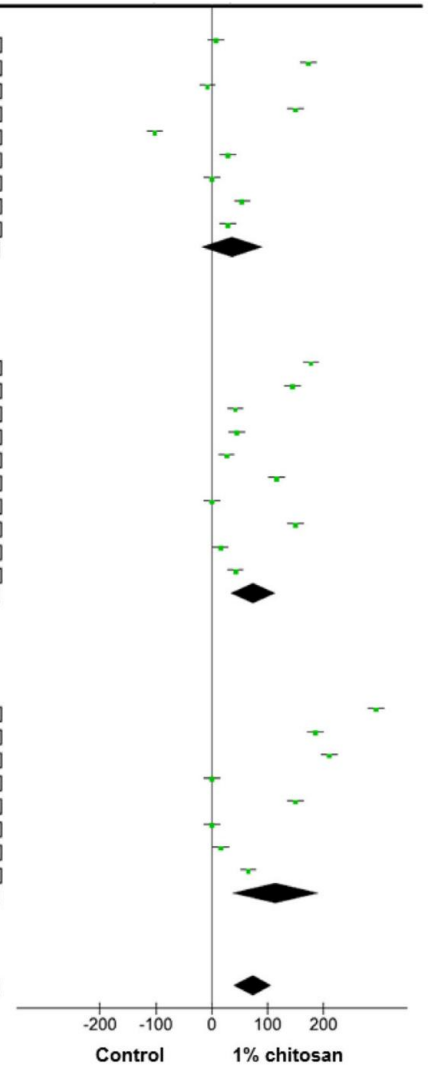


FIGURE 4 Forest plots using the RavMan 5.3 software for random effects analysis related to the effectiveness of 1% chitosan on plant defense mechanism enzyme activities. Phenylalanine ammonia-lyase (PAL), chitinase and *β*-1,3-glucanase were considerd as subgroups. For Feliziani (2013) several studies were included from each article into the subgroups. IV, inverse variance; CI, confidence interval. The figure shows only the name of the first author and publication year. For complete citation see the manuscript

Contenuto in *trans*-resveratrolo e catechina dell'epidermide di bacche trattate con chitosano e UV-C

Trattamento	Autumn Black		B36-55	
	Trans-resveratrolo	Catechina	*Trans*-resveratrolo	Catechina
Chitosano	ND*	ND	1.90 C	ND
UV-C	17.56 b	1.37 b	18.12 B	ND
Chitosano + UV-C	23.35 a	2.55 a	22.00 A	ND
Testimone	ND	ND	1.84 C	ND

*ND = Inferiore al limite di determinazione (0.2 µg/g peso fresco della buccia)

Macchine per trattamenti con UV-C

e-Xtra*

Dark Period Following UV-C Treatment Enhances Killing of *Botrytis cinerea* Conidia and Controls Gray Mold of Strawberries

Wojciech J. Janisiewicz, Fumiomi Takeda, D. Michael Glenn, Mary J. Camp, and Wayne M. Jurick II

First, second, and third authors: U.S. Department of Agriculture, Agricultural Research Service (USDA-ARS), Appalachian Fruit Research Station, 2217 Wiltshire Road, Kearneysville, WV 25430; forth author: USDA-ARS, Statistics Group, Northeast Area, Beltsville, MD 20705; and fifth author: USDA-ARS, Henry A. Wallace Beltsville Agricultural Research Center, Food Quality Laboratory, Beltsville, MD 20705.
Accepted for publication 21 December 2015.

ABSTRACT

Janisiewicz, W. J., Takeda, F., Glenn, D. M., Camp, M. J., and Jurick, W. M., II. 2016. Dark period following UV-C treatment enhances killing of *Botrytis cinerea* conidia and controls gray mold of strawberries. Phytopathology 106:386-394.

Strawberries are available throughout the year either from production in the field or from high and low tunnel culture. Diversity of production conditions results in new challenges in controlling diseases before and after harvest. Fungicides have traditionally been used to control these diseases; however, their limitations necessitate a search for new approaches. We found that UV-C irradiation of *Botrytis cinerea*, a major pathogen of strawberry, can effectively kill this fungus if a dark period follows the treatment. The inclusion of a 4-h dark period resulted in almost complete kill of *B. cinerea* conidia on agar media at a dose of 12.36 J/m^2. The UV-C dose did not cause a reduction in photosynthesis in strawberry leaves or discoloration of sepals, even after exposing plants repeatedly (twice a week) for 7 weeks. Although irradiation of dry conidia of *B. cinerea* with this dose resulted in some survival, the conidia were not infective and not able to cause decay even when inoculated onto a highly susceptible mature apple fruit. Irradiation of strawberry pollen at 12.36 J/m^2 did not affect pollen germination, tube growth and length in vitro, or germination and tube growth in the style of hand-pollinated emasculated strawberry flowers. No negative effect of the UV-C treatment was observed on fruit yield and quality in high tunnel culture. In the fruit and flower petal inoculation tests, the UV-C treatment was highly effective in reducing fruit decay and petal infection. This UV-C treatment with an exposure time of 60 s may be useful in controlling gray mold in tunnel production of strawberries and may also have the potential for use in intensive field and indoor production of other fruits and vegetables providing that a 4-h dark period follows the irradiation.

TABLE 6. Incidence of gray mold on strawberry fruit that were wounded and inoculated with either sterile tap water (STW) or suspension of *Botrytis cinerea* and irradiated with UV-C (254 nm) for various times followed by a 4-h dark incubation

Treatment	Incidence of gray mold (%)		
	3 days	5 days	7 days
STW	0.0 b[y]	0.0 b	0.0 b
STW + 60 s UV-C	0.0 b	0.0 b	0.0 b
B. cinerea	25.0 a (±16.0)[z]	75.0 a (±8.3)	100.0 a
B. cinerea + 60 s UV-C	0.0 b	41.7 ab (±16.0)	50.0 ab (±9.6)
B. cinerea + 90 s UV-C	0.0 b	0.0 b	0.0 b
B. cinerea + 120 s UV-C	0.0 b	0.0 b	0.0 b

[y] Values followed by the same letter in the same column are not significantly different according to Sidak adjusted *P* values so that the experiment-wise error was 0.05.

[z] Standard error of the mean of four replicates.

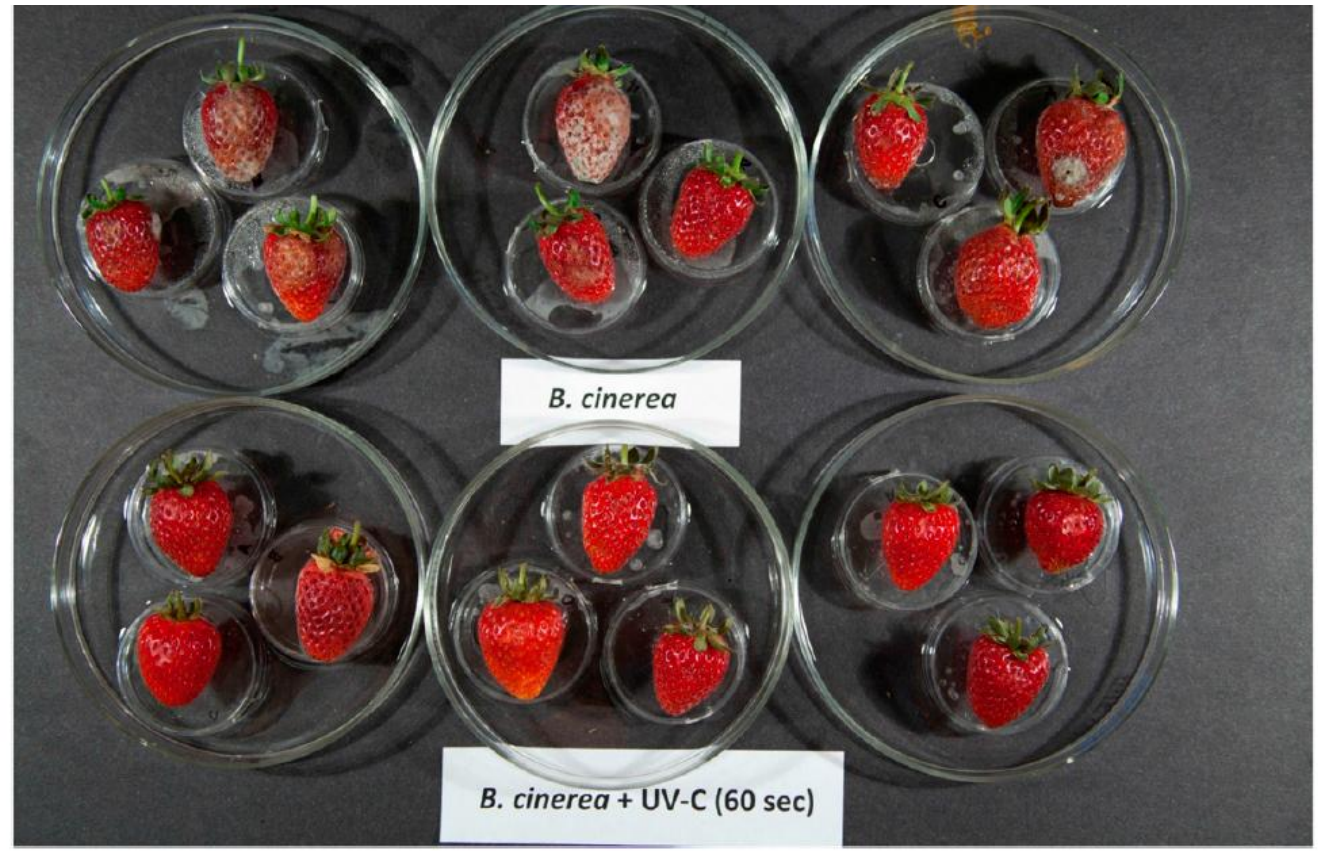
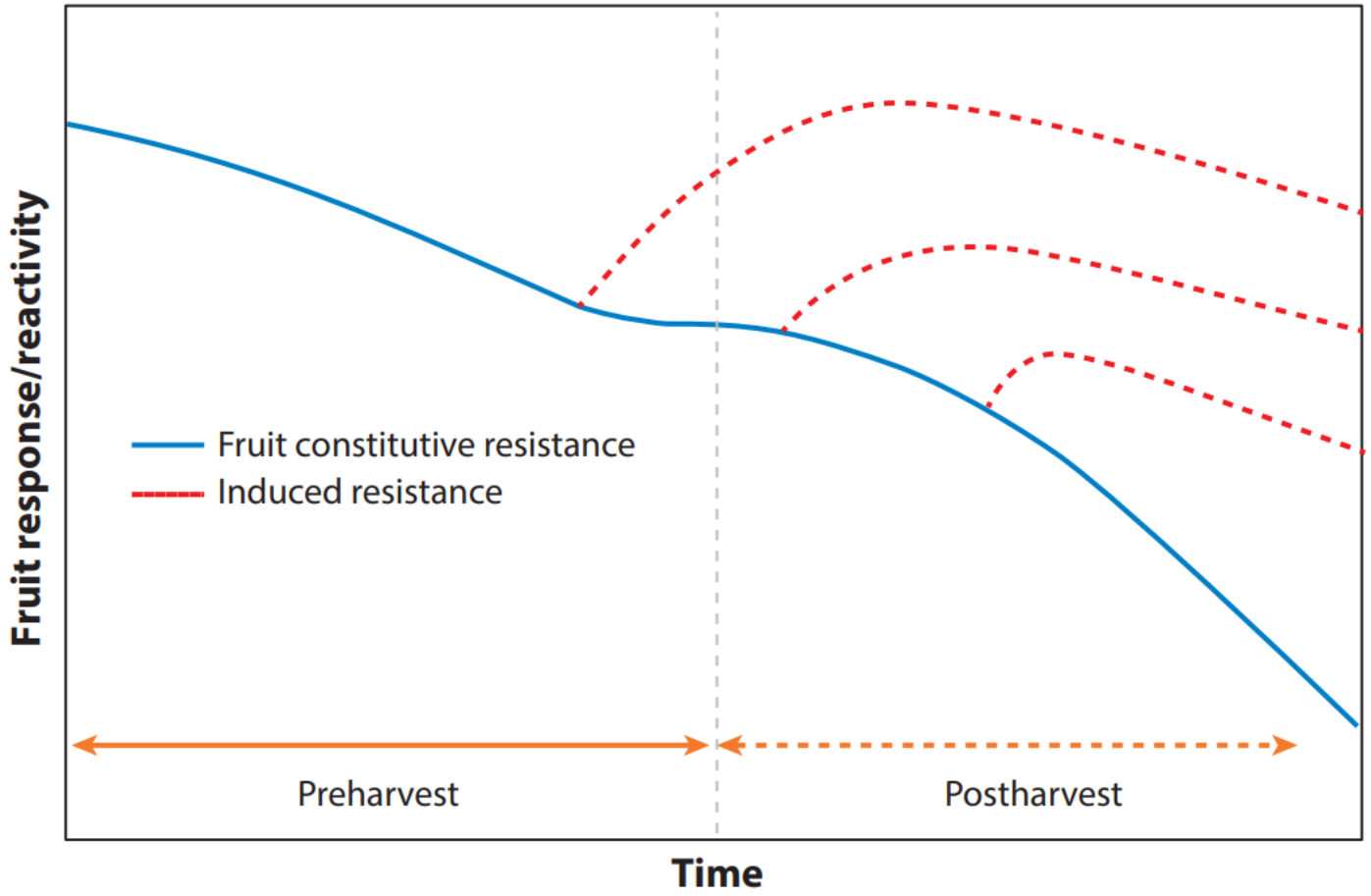


Fig. 2. Example of control of fruit decay on wounded fruit inoculated with *Botrytis cinerea* using UV-C irradiation for 60 s followed by 4 h of dark period and incubation for 5 days at 22°C.

Supplementary Figure S1. Self-propelled UV-C irradiation apparatus with four irradiation units covering four raised beds with strawberry plants in high tunnel at the USDA-ARS Appalachian Fruit Research Station in Kearneysville, WV.

Keep high and eventually increase the resistance of plant tissues

Induced resistance needs to be applied at proper time

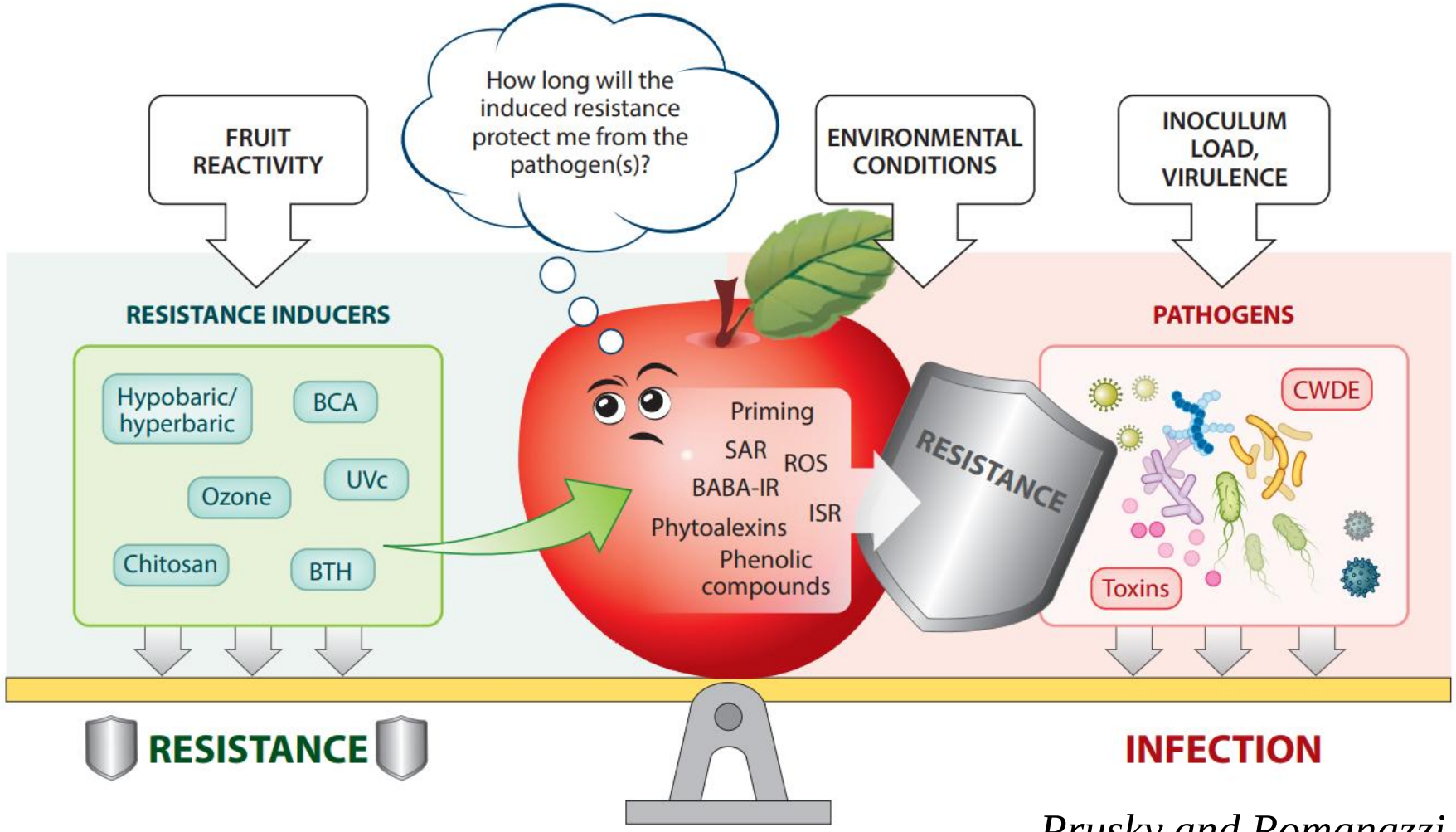


Prusky and Romanazzi, 2023 ARP

https://doi.org/10.1146/annurev-phyto-021722-035135

Keep high and eventually increase the resistance of plant tissues

Harvested fruit and vegetables are in a delicate dynamic equilibrium



Prusky and Romanazzi, 2023 ARP

https://doi.org/10.1146/annurev-phyto-021722-035135

Postharvest Biology and Technology 122 (2016) 82–94

Contents lists available at ScienceDirect

Postharvest Biology and Technology

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

Induced resistance to control postharvest decay of fruit and vegetables

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Considerations

Table 5
Aspects related to the induction of resistance to postharvest diseases of fruit and vegetables.

Negative sides	Positive sides
Complete effect is not always reproducible	Long-lasting effects
Does not provide a complete control of decay	Broad range of targets
Not easy to implement as part of farmer and packinghouse practices	Do not cause appearance of resistant isolates of the pathogen
Investigation methods are not standardized	Increasing number of biostimulants on the market
	Low side effects
	Reduction of pesticide use
	Promoted by EU Directive n. 128/2009 «Sustainable Use of Pesticides» and following National Action Plans
	Increased amounts of beneficial antioxidant compounds

Induced resistance to prevent postharvest diseases

Thanks for your attention

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Prevention and management of pre and postharvest diseases of fresh fruit and vegetables

22-24 May 2025, Thessaloniki, Greece