

# We are IntechOpen, the world's leading publisher of Open Access books Built by scientists, for scientists

6,100

Open access books available

149,000

International authors and editors

185M

Downloads

Our authors are among the

154

Countries delivered to

TOP 1%

most cited scientists

12.2%

Contributors from top 500 universities



WEB OF SCIENCE™

Selection of our books indexed in the Book Citation Index  
in Web of Science™ Core Collection (BKCI)

Interested in publishing with us?  
Contact [book.department@intechopen.com](mailto:book.department@intechopen.com)

Numbers displayed above are based on latest data collected.

For more information visit [www.intechopen.com](http://www.intechopen.com)



Chapter

# Mycorrhizal Association and Plant Disease Protection: New Perspectives

*Julio Alves Cardoso Filho*

## Abstract

Soil fungi of the phylum Glomeromycota and plants form arbuscular mycorrhizal (AM) symbiosis. The AM fungi, during the symbiosis, establish a sink for plant photosynthate by utilizing it for biomass and metabolic energy, while the AM plants obtain nutrients and water through the AMF hyphae. The benefits of AM symbiosis on plant fitness include better mineral nutrition, especially those that are immobile in soil solution (e.g., phosphorus, copper, and zinc), and higher tolerance of mycorrhizal plants to abiotic stresses, such as drought, salinity, high soil temperature, presence of heavy metals, and others abiotic factors. Recent studies have revealed that AMF can suppress pests and plant diseases by the activation of defense regulatory genes. The knowledge of the mechanisms behind the induction of resistance by mycorrhizal symbiosis (mycorrhizal-induced resistance [MIR]) remains unknown. This chapter describes the current advanced status of the role of MIR in plant disease protection.

**Keywords:** plant defense, arbuscular mycorrhizas, mycorrhizal-induced resistance

## 1. Introduction

Mycorrhizas are complex symbioses formed by several components that determine the rate of colonization, such as the incidence of propagules, and the effects and functions of symbiosis on plants and ecosystems [1]. Mycorrhizal fungi improve the host plant's resistance to environmental stresses, while the host plant provides carbon in the photosynthates form, for fungal growth and reproduction [2–4]. Arbuscular mycorrhizas (AMs) are beneficial interactions formed by plant roots and soil fungi of the phylum Glomeromycota [1]. The regulation of mycotrophism determines the response of the host plant, and biotrophism controls the degree of colonization and production of propagules, guaranteeing the survival and evolution of this group of fungi [5, 6]. AM is the most widespread form of mycorrhizal association and is of great ecological and economic importance [7–9]. AMs are compartmentalized biological systems. Thus, they suffer from the influence of the environment and numerous edaphic factors of each component that directly or indirectly control the establishment, the functioning, and the occurrence of AM [10–15]. AM symbiosis is generally inhibited under high fertility and favored by low fertility, where colonization and

sporulation are generally maximal. Phosphorus (P) fertilization in the soil optimizes plant growth and reduces colonization [16].

The protection against soil-borne pathogens has been reported in mycorrhizal plants [17–24]. The differential expression of several genes involved in plant defense against pathogen attack has been observed and may play a fundamental role in colonization [25–27]. This modulation seems to occur not only locally but also systemically [28]. This phenomenon, called “priming,” results in an induction of basal resistance mechanisms upon subsequent pathogen attack [28–31]. In symbiotic systems, microbial-associated molecular patterns (MAMPs) from AM fungi are perceived and elicit a transient defense response, which later undergoes suppressed induction at the early stages of AM [32]. The absence of a hypersensitive response (HR) after AM fungi recognition may reflect a non-activation, a low level of defense response, or suppression of the plant defense system [30, 31]. The phenylpropanoid biosynthetic pathway, widely known for the action of phytoalexins, involves a series of enzymes that can be regulated at the transcriptional level by biotic and abiotic stimuli and is influenced by mycorrhization [30, 31]. In signaling the localized induction of defense genes considered specific, two types of mechanisms may be involved: acid endochitinase PR4 and  $\beta$ 1,3-endoglycanase EG488 and the systemic suppression of the expression of genes encoding these enzymes and those involved in the phenylpropanoid metabolism [32]. The expression of genes related to the plant defense system is systemically suppressed during the establishment of AM symbiosis [33]. However, the expression of other genes is locally induced, and the modulation of these responses depends on external factors, such as the phosphate level [34, 35].

In this chapter, we want to discuss new perspectives and updates on mycorrhiza-induced resistance (MIR).

## **2. Resistance of plants to microorganisms**

The plant defense system is multi-component, acting in a dynamic and coordinated manner, at the appropriate time and place and with adequate magnitude [36–39]. Plant resistance would be its ability to delay or prevent the colonization of its tissues by a phytopathogen, characterized by its dynamic and coordinated nature in a sequence of logical events, immediately after the pathogen contacts its tissues [40]. The growing development of technologies aimed at agriculture and increases in the use of inputs, especially pesticides, have contributed to increased agricultural productivity and adverse effects on the environment and human health. New plant protection measures have been highlighted; such as the induction of resistance (IR) has been used to control pests and diseases [41–43].

### **2.1 Non-host resistance in plants**

Land plants are sessile, and despite not having an adaptive immune system similar to animals, they are resistant to most microorganisms that attack them in an attempt to invade their tissues [44]. This phenomenon characterizes resistance as a rule and susceptibility to some microorganisms. This recognition of non-adapted pathogens by non-host plants at the cellular level is called non-host resistance (NHR) [45]. Non-host resistance (NHR) is, by definition, the resistance displayed by all genotypes of a plant species to all genotypes of a pathogen species, being considered the most common and effective form of resistance to diseases that occur in nature

[46]. Several genes appear to control the NHR in a given plant species; in addition, the number of genes involved is related to the specific genotype of the analyzed plant [46]. NHR “resistance” refers to the inability of a pathogen to complete its asexual or sexual life cycle on that host plant species [47]. NHR is a tool for breeding against the induction factors of biotic and abiotic stresses, aiming at the development of durable genetic resistance [48]. NHR is an elaborate defense system that protects plants against invasion by non-pathogenic or pathogenic organisms and involves physical and biochemical mechanisms [49, 50]. These defenses include a combination of preformed and inducible mechanisms [51] that act as a physical barrier to penetration and as a toxic barrier [52]. The first line of plant defense is the structural and biochemical mechanism that is present even before the inoculum deposition, called constitutive or passive [53]. The barrier imposed by the cuticle and cell wall is considered an important factor of NHR. The cuticle is structurally variable between plant species; is composed of cutin, waxes, and hydrocarbons; and is closely associated with the cell wall of the epidermal cells [54]. Other mechanisms are activated from the recognition of the pathogen, by the host plant that is active, inducible, or post-formed, and can also be structural and biochemical [55]. Among the biochemical post-formed responses is the accumulation of reactive oxygen species (ROS), phytoalexins, pathogenesis-related (PR) proteins, and HR [56]. However, most defense mechanisms are activated in response to infection by the pathogen [57]. During initial contact with the pathogen, pathogen-associated molecular patterns (PAMPs) [58], such as chitin and glucans in fungi, flagellin, and elongation factor Tu in bacteria, are recognized by the plant through pattern recognition receptors (PRRs) [59]. Recognition of PAMPs triggers signaling events and basal resistance, called PAMP-activated immunity (PTI) [60]. Pathogens have evolved effectors that interfere with different signaling processes involved in plant defense, suppressing PTI, promoting virulence, and triggering effector-activated susceptibility (ETS) [61]. Plants, in turn, acquired resistance (R) genes that detect pathogen-specific effectors, resulting in effector-activated immunity (ETI) [62]. ETI is a version of PTI, typically involving HR, a form of programmed cell death that limits colonization by the pathogen [60]. HR is mediated by the accumulation of ROS, which, in addition to having a toxic effect on the pathogen, can act as secondary messengers for the activation of defense responses [63–67]. Mitogen-activated protein kinases (MAPKs) modulate the activity of transcriptional regulators and phytohormones [68]. Salicylic acid (SA), ethylene, and jasmonic acid are the main hormones involved in signaling. Other hormones, such as abscisic acid and cytokinins, have also emerged as participants in signaling pathways for defense [69, 70]. As a result of the recognition of the pathogen by the host and the consequent activation of signal transduction pathways, several defense mechanisms are formed to limit the infection [71–78]. All plant species are capable of constitutively biosynthesizing chemical compounds with potential defensive function, suggesting that this ability is an evolutionary trait [79]. A feature of antimicrobial compounds is that some are found on the plant surface or accumulated in cells close to the host surface, especially vacuoles or organelles in epidermal cells, and released by hydrolytic enzymes after attack by the microorganism [80].

## **2.2 Host resistance in plants**

The microorganisms that manage to overcome the mechanisms of RNH become pathogens of the plant species and need to act against the host resistance that the



plant has [81]. Plants also have a surveillance system that detects/monitors the presence or activity of effector molecules within their tissues and cells. This surveillance system has specific receptors (R proteins) encoded by the plant's R genes [82]. The typical R proteins with nucleotide-binding and leucine-rich domains (NLRs) have an ATPase-binding domain (NB—nucleotide-binding ATPase) and a TIR (toll interleukin-1 receptor) or CC (coiled-coil) domain forming the TIR-NB-LRR or CC-NB-LRR proteins, respectively [82]. The NB domain serves ATP binding and hydrolysis/signaling cascade, and the LRR domain is responsible for activation/ autoinhibition. In the LRR domain, the N-terminal activates the modulation, while the C-terminal is related to recognition specificity [83–85]. Proteins from the NLR genes in their inactive form (absence of the effector cognate) are located in the host cell cytoplasm bound to the plasma membrane, endoplasmic reticulum, or tonoplast. In the presence of the effector, the cognate can move to the nucleus, interacting with transcription factors or with other cytoplasmic proteins to start the signaling chain for the expression of defenses [86–89]. Effector detection triggers a signaling cascade that culminates in the expression of defense and HR genes to contain the pathogen's advance, resulting in race-specific resistance, the ETI immune response, also known as vertical resistance. ETI is one of the main components of host resistance [90, 91]. ETI is activated by the direct or indirect interaction between one or more effectors and one or more NLR proteins. In the Decoy model, where the NLR detects changes in a protein that mimics the target, the effector apparently does not have a defined biological function [92, 93]. In the Guard model, during infection, a modification of the target protein (monitored) occurs by the action of the effector releasing the R protein (monitor), thus allowing it to initiate the signaling cascade that leads to the induction of ETI [94]. Resistance conferred by R genes depends on the effector for virulence or adaptability of the pathogen and its evolutionary potential [95]. From the point of view of resistance durability, for resistance conferred by R genes (qualitative resistance), the evolutionary pressure on the pathogen conferred by quantitative resistance is significantly reduced, thus constituting a source of durable resistance [96]. In summary, resistance mediated by R genes is specific to certain races of the pathogen and effective against biotrophic and hemibiotrophic parasites. On the other hand, quantitative resistance provides a means for controlling biotrophic, hemibiotrophic, and necrotrophic pathogens, being effective against several races of a pathogen, providing broad-spectrum resistance, or in some specific cases, effective against several pathogens [97–103].

### **3. Plant priming for enhanced defense**

To compensate for their sessile life and face a broad range of biotic and abiotic stresses, plants have evolved survival and adaptation strategies, such as inducing some stress memory or stress imprinting [104]. In plants, the IR is frequently associated with the accumulation of antimicrobial pathogenesis-related (PR) proteins and with the so-called priming of cells [89]. Priming for enhanced defense is a cellular process in biological and chemical IR immunity, including systemic acquired resistance (SAR), induced systemic resistance (ISR), and herbivore-induced resistance [105–109]. Plants maintain immune memory through priming, in the absence of such specialized cells [110, 111].

### **3.1 Epigenetic molecular mechanism of priming**

#### *3.1.1 Memory of plant immunization*

Advances in the knowledge of epigenetic regulation in the plant multiple generation stress memory have provided new procedures and approaches for breeding crops and sustainable germplasm banks for future climate challenges [112, 113]. Plant stress memory is described under two categories: mitotic stress memory, or somatic memory, and meiotic stress memory, or transgenerational memory [114–116]. Plant stress memory associated with the inheritance of SAR is likely to be epigenetic [117, 118]. In plants, defense priming and SAR are associated with epigenetic modifications of histones, DNA methylation, increased signaling enzymes, and an accumulation of pattern recognition receptors (PRRs) at cell membranes [119, 120]. In summary, strategies exploiting epigenetic variations appear promising for crop resistance breeding [121–124].

### **4. Mycorrhiza-induced resistance: new perspectives**

The effects of AM symbiosis on plant interactions with other organisms, such as the induction of resistance against plant pathogens, seem to result from the combination of multiple mechanisms that may operate simultaneously [125]. A proposed hypothesis is that colonization of roots by AM fungi primes defense mechanisms, leading to mycorrhiza-induced resistance (MIR) [126] by the activation of MAMP-triggered immunity (MTI) [127]. MIR is a low-cost type of induced resistance that may be among the reasons to explain why root associations with AM fungi have been conserved during evolution and are widespread among species [128, 129]. MIR includes a priming of defense-related plant genes and shares more elements with the ISR induced by rhizobacteria [130, 131]. The plant can restrict AMF colonization once the plant is already mycorrhizal, a phenomenon known as autoregulation [132]. The mechanisms operating in such autoregulation may also affect plant interactions with phytopathogens [133]. However, the molecular mechanisms that regulate the formation and establishment of AM symbiosis and the modulation of plant defense responses during MIR are still not understood [134]. According to Fiorilli et al. [135], who elucidate the molecular mechanisms underlying the establishment of AM symbiosis, we need to investigate the changes in transcripts and proteins in roots and leaves during the double (plant-AM fungus) and tripartite (plant-AM fungus-pathogen) interactions [136, 137]. The recognition of friend versus foe is still incompletely understood in signaling between the host plant and the pathogen interaction [138–141]. Another critical challenge is to elucidate the biological roles of receptor-like kinases (RLK) mediated by endocytosis in the plant interaction with microbes, aiming to elucidate the molecular mechanisms by which pathogens and non-pathogen microorganisms can reprogram the RLK trafficking [142, 143]. Besides, the role of MIR against viruses and foliar phytopathogens stays in the speculative field. In some cases, the susceptibility to the foliar pathogen is related to mycorrhizal plants compared with non-mycorrhizal plants. However, it is linked with the higher amounts of plant phosphorus available to viruses for their multiplication in infected and colonized plants [144, 145]. Recent advances indicate that the beneficial effects of MIR may not be related to mycorrhizal plant nutrition [140]. Thus, knowing the

mechanisms of AM symbiosis physiology regulation under different environmental conditions is required to understand the MIR context of AM fungi-host plant dependency.

## 5. Conclusions and future prospects

MIR is a low-cost type of IR and has a positive effect from an ecological point of view. However, still, open questions require particular attention, among which is why infection by AM fungi does not elicit a defense response in roots. Besides, the role of MIR against viruses and foliar phytopathogens stays in the speculative field. Thus, knowing the mechanisms of AM symbiosis physiology regulation during MIR is required for their applications in sustainable agriculture.

## Conflicts of interest

The author declares no conflict of interest.


## Author details

Julio Alves Cardoso Filho  
Center for Engineering and Agrarian Sciences Federal University of Alagoas,  
Rio Largo, Brazil

\*Address all correspondence to: [julio.filho@ceca.ufal.br](mailto:julio.filho@ceca.ufal.br)

## IntechOpen

---

© 2022 The Author(s). Licensee IntechOpen. This chapter is distributed under the terms of the Creative Commons Attribution License (<http://creativecommons.org/licenses/by/3.0>), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. 

## References

- [1] Schüßler A, Schwarzott D, Walker C. A new fungal phylum, the Glomeromycota: evolution and phylogeny. *Mycological Research*. 2001;**105**:1413-1421. DOI: 10.1017/S0953756201005196
- [2] Smith SE, Gianinazzi-Pearson V. Physiological interactions between symbionts in vesicular-arbuscular mycorrhizal plants. *Annual Review of Plant Physiology and Plant Molecular Biology*. 1988;**39**:22124. DOI: 10.1146/annurev.pp.39.060188.001253
- [3] Smith SE, Read DJ, *Mycorrhizal Symbiosis*. 3rd ed. London: Academic Press; 2008. p. 815. ISBN: 978-0-12-370526-6
- [4] Harrison MJ. Cellular programs for arbuscular mycorrhizal symbiosis. *Current Opinion in Plant Biology*. 2012;**15**:691-698. DOI: 10.1016/j.pbi.2012.08.010
- [5] Wang B, Qiu YL. Phylogenetic distribution and evolution of mycorrhizas in land plants. *Mycorrhiza*. 2006;**16**:299-363. DOI: 10.1007/s00572-005-0033-6
- [6] Soudzilovskaia NA, van Bodegom PM, Terror C, Zelfde MV, McCallum I, Luke McCormack M, et al. Global mycorrhizal plant distribution linked to terrestrial carbon stocks. *Nature Communications*. 2019;**10**(1):5077.7. DOI: 10.1038/s41467-019-13019-2
- [7] Francis R, Read DJ. The contributions of mycorrhizal fungi to the determination of plant community structure. *Plant and Soil*. 1994;**159**:11-25. DOI: 10.1007/BF00000091
- [8] Jeffries P, Gianinazzi S, Perotto S, Turnau K, Barea JM. The contribution of arbuscular mycorrhizal fungi in sustainable maintenance of plant health and soil fertility. *Biology Fertility of Soils*. 2003;**37**:1-16. DOI: 10.1007/s00374-002-0546-5
- [9] Smith JL, De Moraes CM, Mescher MC. Jasmonate- and salicylate-mediated plant defense responses to insect herbivores, pathogens and parasitic plants. *Pest Management Science*. 2009;**65**:497-503. DOI: 10.1002/ps.1714
- [10] Redecker D, Schüßler A, Stockinger H, Stürmer SL, Morton JB, Walker C. An evidence-based consensus for the classification of arbuscular mycorrhizal fungi (Glomeromycota). *Mycorrhiza*. 2013;**23**:515-531. DOI: 10.1007/s00572-013-0486-y
- [11] Redecker D, Raab P. Phylogeny of the Glomeromycota (arbuscular mycorrhizal fungi): recent developments and new gene markers. *Mycologia*. 2006;**98**:885-895. DOI: 10.3852/mycologia.98.6.885
- [12] Oehl F, Sieverding E, Palenzuela J, Ineichen K, da Silva GA. Advances in Glomeromycota taxonomy and classification. *IMA Fungus*. 2011;**2**:191-199. DOI: 10.5598/imafungus.2011.02.02.10
- [13] Krüger M, Krüger C, Walker C, Stockinger H, Schüßler A. Phylogenetic reference data for systematics and phylotaxonomy of arbuscular mycorrhizal fungi from phylum to species level. *The New Phytologist*. 2012;**193**:970-984. DOI: 10.1111/j.1469-8137.2011.03962.x
- [14] Fitter AH. Darkness visible: reflections on underground ecology.



- Journal of Ecology. 2005;**93**:231-243.  
DOI: 10.1111/j.0022-0477.2005.00990.x
- [15] Rosendahl S. Communities, populations and individuals of arbuscular mycorrhizal fungi. *The New Phytologist*. 2008;**178**:253-266.  
DOI: 10.1111/j.1469-8137.2008.02378.x
- [16] Das D, Paries M, Hobecker K, et al. Phosphate starvation response transcription factors enable arbuscular mycorrhiza symbiosis. *Nature Communications*. 2022;**13**:477.  
DOI: 10.1038/s41467-022-27976-8
- [17] Azcon-Aguilar C, Barea JM. Arbuscular mycorrhizas and biological control of soil borne plant pathogens – an overview of the mechanisms involved. *Mycorrhiza*. 1997;**6**:457-464.  
DOI: 10.1007/s005720050147
- [18] Whipps JM. Prospects and limitations for mycorrhizas in biocontrol of root pathogens. *Canadian Journal of Botany*. 2004;**82**:1198-1227. DOI: 10.1139/b04-082
- [19] Barea JM, Pozo MJ, Azcon R, Azcon-Aguilar C. Microbial co-operation in the rhizosphere. *Journal of Experimental Botany*. 2005;**56**:1761-1778.  
DOI: 10.1093/jxb/eri197
- [20] Pozo MJ, Azcón-Aguilar C. Unraveling mycorrhiza-induced resistance. *Current Opinion in Plant Biology*. 2007;**10**:393-398. DOI: 10.1016/j.pbi.2007.05.004
- [21] Saldajeno MG, Chandanie WA, Kubota M, Hyakumachi M. Effects of interactions of arbuscular mycorrhizal fungi and beneficial saprophytic mycoflora on plant growth and disease protection. In: Siddiqui ZA, Akhtar MS, Futai K, editors. *Mycorrhizae: Sustainable Agriculture and Forestry*. Netherlands, Dordrecht: Springer; 2008. pp. 211-226.  
DOI: 10.1007/978-1-4020-8770-7\_9
- [22] Pozo MJ, Verhage A, García-Andrade J, García JM, Azcón-Aguilar C. Priming plant defenses against pathogens by arbuscular mycorrhizal fungi. In: Azcón-Aguilar C, Barea JM, Gianinazzi S, Gianinazzi-Pearson V, editors. *Mycorrhizas: Functional Processes and Ecological Impact*. Heidelberg: Springer-Verlag; 2009. pp. 137-149. DOI: 10.1007/978-3-540-87978-7\_9
- [23] Pozo MJ, Jung SC, López-Ráez JA, Azcón-Aguilar C. Impact of arbuscular mycorrhizal symbiosis on plant response to biotic stress: The role of plant defense mechanisms. In: Koltai H, Kapulnik Y, editors. *Arbuscular Mycorrhizas: Physiology and Function*. 2nd ed. Dordrecht: Springer; 2010. pp. 193-207. DOI: 10.1007/978-90-481-9489-6\_9
- [24] Dreischhoff S, Das IS, Jakobi M, Kasper K, Polle A. Local responses and systemic induced resistance mediated by ectomycorrhizal fungi. *Frontiers in Plant Science*. 2020;**14**(11):590063.  
DOI: 10.3389/fpls.2020.590063
- [25] Van Wees SC, Van der Ent S, Pieterse CMJ. Plant immune responses triggered by beneficial microbes. *Current Opinion in Plant Biology*. 2008;**11**:443-448. DOI: 10.1016/j.pbi.2008.05.005
- [26] van der Heijden MGA, Bardgett RD, van Straalen NM. The unseen majority: Soil microbes as drivers of plant diversity and productivity in terrestrial ecosystems. *Ecology Letters*. 2008;**11**:296-310. DOI: 10.1111/j.1461-0248.2007.01139.x
- [27] Jung SC, Medina-Matinez A, Lopez-Raez JA, Pozo MJ.

- Mycorrhiza-induced resistance and priming of plant defenses. *Journal of Chemical Ecology*. 2012;**38**:651-664. DOI: 10.1007/s10886-012-0134-6
- [28] Conrath U, Beckers GJ, Flors V, García-Agustín P, Jakab G, Mauch F, et al. Priming: getting ready for battle. *Molecular Plant-Microbe Interactions*. 2006;**19**:1062-1071. DOI: 10.1094/MPMI-19-1062
- [29] Ahmad S, Gordon-Weeks R, Pickett J, Ton J. Natural variation in priming of basal resistance: from evolutionary origin to agricultural exploitation. *Molecular Plant Pathology*. 2010;**11**:817-827. DOI: 10.1111/j.1364-3703.2010.00645.x
- [30] Conrath U. Molecular aspects of defense priming. *Trends in Plant Science*. 2011;**16**:524-531. DOI: 10.1016/j.tplants.2011.06.004
- [31] Pastor V, Luna E, Mauch-Mani B, Ton J, Flors V. Primed plants do not forget. *Environmental and Experimental Botany*. 2013;**94**:46-56. DOI: 10.1016/j.envexpbot.2012.02.013
- [32] Diao F, Dang Z, Xu J, Ding S, Hao B, Zhang Z, et al. Effect of arbuscular mycorrhizal symbiosis on ion homeostasis and salt tolerance-related gene expression in halophyte *Suaeda salsa* under salt treatments. *Microbiological Research*. 2021;**245**:126688. DOI: 10.1016/j.micres.2020.126688
- [33] Wang H, An T, Huang D, Liu R, Xu B, Zhang S, et al. Arbuscular mycorrhizal symbioses alleviating salt stress in maize is associated with a decline in root-to-leaf gradient of Na<sup>+</sup>/K<sup>+</sup> ratio. *BMC Plant Biology*. 2021;**21**(1):457.7. DOI: 10.1186/s12870-021-03237-6
- [34] Bahadur A, Batool A, Nasir F, Jiang S, Mingsen Q, Zhang Q, et al. Mechanistic insights into arbuscular mycorrhizal fungi-mediated drought stress tolerance in plants. *International Journal of Molecular Sciences*. 2019;**20**(17):4199.27. DOI: 10.3390/ijms20174199
- [35] Kang J-N, Lee W-H, Won SY, Chang S, Hong J-P, Oh T-J, et al. Systemic expression of genes involved in the plant defense response induced by wounding in *Senna tora*. *International Journal of Molecular Sciences*. 2021;**22**:10073. DOI: 10.3390/ijms221810073
- [36] Jones JDG, Dangl JL. The plant immune system. *Nature*. 2006;**444**:323-329. DOI: 10.1038/nature05286
- [37] Andolfo G, Ercolano MR. plant innate immunity multicomponent model. *Frontiers in Plant Science*. 2015;**13**(6):987. DOI: 10.3389/fpls.2015.00987
- [38] Mermigka G, Amprazi M, Mentzelopoulou A, Amartolou A, Sarris PF. Plant and animal innate immunity complexes: fighting different enemies with similar weapons. *Trends in Plant Science*. 2020;**25**(1):80-91. DOI: 10.1016/j.tplants.2019.09.008
- [39] Duxbury Z, Wu CH, Ding P. A comparative overview of the intracellular guardians of plants and animals: NLRs in innate immunity and beyond. *Annual Review of Plant Biology*. 2021;**17**(72):155-184. DOI: 10.1146/annurev-arplant-080620-104948
- [40] Devanna BN, Jaswal R, Singh PK, Kapoor R, Jain P, Kumar G, et al. Role of transporters in plant disease resistance. *Physiologia Plantarum*. 2021;**171**(4):849-867. DOI: 10.1111/ppl.13377
- [41] Yao T, Gai XT, Pu ZJ, Gao Y, Xuan YH. From functional characterization to the application of SWEET sugar transporters in plant resistance breeding. *Journal of*

Agricultural and Food Chemistry. 2022; **70**(17):5273-5283.4. DOI: 10.1021/acs.jafc.2c00582

[42] Gautam T, Dutta M, Jaiswal V, Zinta G, Gahlaut V, Kumar S. Emerging roles of SWEET sugar transporters in plant development and abiotic stress responses. *Cell*. 2022;**11**(8):1303.12. DOI: 10.3390/cells11081303

[43] Breia R, Conde A, Badim H, Fortes AM, Gerós H, Granell A. Plant SWEETs: from sugar transport to plant-pathogen interaction and more unexpected physiological roles. *Plant Physiology*. 2021;**186**(2):836-852.11. DOI: 10.1093/plphys/kiab127

[44] Rai A, Sivalingam PN, Senthil-Kumar M. A spotlight on non-host resistance to plant viruses. *Peer J*. 2022;**31**(10):e12996. DOI: 10.7717/peerj.12996

[45] Lee S, Whitaker VM, Hutton SF. Mini review: potential applications of non-host resistance for crop improvement. *Frontiers in Plant Science*. 2016;**11**(7):997. DOI: 10.3389/fpls.2016.00997

[46] Oh S, Choi D. Receptor-mediated nonhost resistance in plants. *Essays in Biochemistry*. 2022;**66**(5):435-445.30. DOI: 10.1042/EBC20210080

[47] Panstruga R, Moscou MJ. What is the molecular basis of nonhost resistance? *Molecular Plant-Microbe Interactions*. 2020;**33**(11):1253-1264. DOI: 10.1094/MPMI-06-20-0161-CR

[48] Sahu PK, Sao R, Choudhary DK, Thada A, Kumar V, Mondal S, et al. Advancement in the breeding, biotechnological and genomic tools towards development of durable genetic resistance against the rice blast disease.

*Plants (Basel)*. 2022;**11**(18):2386.13. DOI: 10.3390/plants11182386

[49] Gupta N, Reddy K, Bhattacharyya D, et al. Plant responses to geminivirus infection: guardians of the plant immunity. *Virology Journal*. 2021;**18**:143. DOI: 10.1186/s12985-021-01612-1

[50] Sun Y, Gao M, Kang S, Yang C, Meng H, Yang Y, et al. Molecular mechanism underlying mechanical wounding-induced flavonoid accumulation in *Dalbergia odorifera* T. Chen, an endangered tree that produces chinese rosewood. *Genes (Basel)*. 2020;**11**(5):478.28. DOI: 10.3390/genes11050478

[51] Herrera-González JA, 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**(22):6819.11. DOI: 10.3390/molecules26226819

[52] Vega-Muñoz I, Duran-Flores D, Fernández-Fernández ÁD, Heyman J, Ritter A, Stael S. Breaking bad news: dynamic molecular mechanisms of wound response in plants. *Frontiers in Plant Science*. 2020;**8**(11):610445. DOI: 10.3389/fpls.2020.610445

[53] Lee K, Seo PJ. Wound-induced systemic responses and their coordination by electrical signals. *Frontiers in Plant Science*. 2022;**18**(13):880680. DOI: 10.3389/fpls.2022.880680

[54] Wang X, Kong L, Zhi P, Chang C. Update on cuticular wax biosynthesis and its roles in plant disease resistance. *International Journal of Molecular Sciences*. 2020;**21**(15):5514.1. DOI: 10.3390/ijms21155514

- [55] García T, Gutiérrez J, Veloso J, Gago-Fuentes R, Díaz J. Wounding induces local resistance but systemic susceptibility to *Botrytis cinerea* in pepper plants. *Journal of Plant Physiology*. 2015;**15**(176):202-209. DOI: 10.1016/j.jplph.2014.12.013
- [56] Tavanti TR, Melo AAR, Moreira LDK, Sanchez DEJ, Silva RDS, Silva RMD, et al. Micronutrient fertilization enhances ROS scavenging system for alleviation of abiotic stresses in plants. *Plant Physiology and Biochemistry*. 2021;**160**:386-396. DOI: 10.1016/j.plaphy.2021.01.040
- [57] Shinya T, Yasuda S, Hyodo K, Tani R, Hojo Y, Fujiwara Y, et al. Integration of danger peptide signals with herbivore-associated molecular pattern signaling amplifies anti-herbivore defense responses in rice. *The Plant Journal*. 2018;**94**(4):626-637. DOI: 10.1111/tpj.13883
- [58] Taghavi M, Khosravi A, Mortaz E, Nikaein D, Athari SS. Role of pathogen-associated molecular patterns (PAMPS) in immune responses to fungal infections. *European Journal of Pharmacology*. 2017;**5**(808):8-13. DOI: 10.1016/j.ejphar.2016.11.013
- [59] Saijo Y, Loo EP, Yasuda S. Pattern recognition receptors and signaling in plant-microbe interactions. *The Plant Journal*. 2018;**93**(4):592-613. DOI: 10.1111/tpj.13808
- [60] Peng Y, van Wersch R, Zhang Y. Convergent and divergent signaling in PAMP-triggered immunity and effector-triggered immunity. *Molecular Plant-Microbe Interactions*. 2018;**31**(4):403-409. DOI: 10.1094/MPMI-06-17-0145-CR
- [61] Yu TY, Sun MK, Liang LK. Receptors in the induction of the plant innate immunity. *Molecular Plant-Microbe Interactions*. 2021;**34**(6):587-601. DOI: 10.1094/MPMI-07-20-0173-CR
- [62] Kothari IL, Patel M. Plant immunization. *Indian Journal of Experimental Biology* 2004;**42**(3):244-252. PMID: 15233292
- [63] Yu X, Feng B, He P, Shan L. From chaos to harmony: responses and signaling upon microbial pattern recognition. *Annual Review of Phytopathology*. 2017;**55**:109-137. DOI: 10.1146/annurev-phyto-080516-035649
- [64] Ye C, Zheng S, Jiang D, Lu J, Huang Z, Liu Z, et al. Initiation and execution of programmed cell death and regulation of reactive oxygen species in plants. *International Journal of Molecular Sciences*. 2021;**22**(23):12942.30. DOI: 10.3390/ijms222312942
- [65] Locato V, De Gara L. programmed cell death in plants: an overview. *Methods in Molecular Biology*. 1743;**2018**:1-8. DOI: 10.1007/978-1-4939-7668-3\_1
- [66] Balint-Kurti P. The plant hypersensitive response: concepts, control and consequences. *Molecular Plant Pathology*. 2019;**20**(8):1163-1178. DOI: 10.1111/mpp.12821
- [67] DeFalco TA, Zipfel C. Molecular mechanisms of early plant pattern-triggered immune signaling. *Molecular Cell*. 2021;**81**(17):3449-3467.2. DOI: 10.1016/j.molcel.2021.07.029
- [68] Xiong L, Yang Y. Disease resistance and abiotic stress tolerance in rice are inversely modulated by an abscisic acid-inducible mitogen-activated protein kinase. *The Plant Cell*. 2003;**15**(3):745-759. DOI: 10.1105/tpc.008714
- [69] Kachroo A, Kachroo P. Mobile signals in systemic acquired resistance. *Current*



Opinion in Plant Biology. 2020;58:41-47. DOI: 10.1016/j.pbi.2020.10.004

[70] Pieterse C, Van Wees S. Induced disease resistance. In: Lugtenberg B, editor. Principles of Plant-Microbe Interactions. Cham: Springer; 2015. pp. 123-133. DOI: 10.1007/978-3-319-08575-3\_14

[71] Walters DR, Ratsep J, Havis ND. Controlling crop diseases using induced resistance: challenges for the future. Journal of Experimental Botany. 2013;64:1263-1280. DOI: 10.1093/jxb/ert026

[72] Fu ZQ, Dong X. Systemic acquired resistance: turning local infection into global defense. Annual Review of Plant Biology. 2013;64:839-863. DOI: 10.1146/annurev-arplant-042811-105606

[73] Gao Q-M, Zhu S, Kachroo P, Kachroo A. Signal regulators of systemic acquired resistance. Frontiers in Plant Science. 2015;6:228. DOI: 10.3389/fpls.2015.00228

[74] Pieterse CMJ, Zamoudis C, Berendsen RL, Weller DM, Van Wees CMS, Bakker AHMP. Induced systemic resistance by beneficial microbes. Annual Review of Phytopathology. 2014;52:347-375. DOI: 10.1146/annurev-phyto-082712-102340

[75] Nguyen Q-M, Iswanto ABB, Son GH, Kim SH. Recent advances in effector-triggered immunity in plants: new pieces in the puzzle create a different paradigm. International Journal of Molecular Sciences. 2021;22:4709. DOI: 10.3390/ijms22094709

[76] Gupta B, Bhaumik U, Sengupta A, Chakraborty M, Saha J, et al. Plant immunity: an enigma during biotic and abiotic stress. Journal of Plant Biochemistry and Physiology.

2015;3:e128. DOI: 10.4172/2329-9029.1000e128

[77] Jing B, Xu S, Xu M, Li Y, Li S, Ding J, et al. Brush and spray: a high-throughput systemic acquired resistance assay suitable for large-scale genetic screening. Plant Physiology. 2011;157(3):973-980. DOI: 10.1104/pp.111.182089

[78] Zhou M, Wang W. Recent advances in synthetic chemical inducers of plant immunity. Frontiers in Plant Science. 2018;6(9):1613. DOI: 10.3389/fpls.2018.01613

[79] Delventhal R, Rajaraman J, Stefanato FL, et al. A comparative analysis of nonhost resistance across the two *Triticeae* crop species wheat and barley. BMC Plant Biology. 2017;17:232. DOI: 10.1186/s12870-017-1178-0

[80] Vivaldo G, Masi E, Taiti C, et al. The network of plants volatile organic compounds. Scientific Reports. 2017;7(1):11050. DOI: 10.1038/s41598-017-10975-x

[81] Gill US, Lee S, Mysore KS. Host versus nonhost resistance: distinct wars with similar arsenals. Phytopathology. 2015;105(5):580-587. DOI: 10.1094/PHYTO-11-14-0298-RVW

[82] Du D, Zhang C, Xing Y, Lu X, Cai L, Yun H, et al. The CC-NB-LRR OsRLR1 mediates rice disease resistance through interaction with OsWRKY19. Plant Biotechnology Journal. 2021;19(5):1052-1064. DOI: 10.1111/pbi.13530

[83] Andolfo G, Sánchez CS, Cañizares J, Pico MB, Ercolano MR. Large-scale gene gains and losses molded the NLR defense arsenal during the Cucurbita evolution. Planta. 2021;254(4):82.24. DOI: 10.1007/s00425-021-03717-x

[84] Liu Y, Zeng Z, Zhang YM, Li Q, Jiang XM, Jiang Z, et al. An angiosperm

- NLR Atlas reveals that NLR gene reduction is associated with ecological specialization and signal transduction component deletion. *Molecular Plant*. 2021;**14**(12):2015-2031.6. DOI: 10.1016/j.molp.2021.08.001
- [85] Yan J, Fang Y, Xue D. Advances in the genetic basis and molecular mechanism of lesion mimic formation in rice. *Plants (Basel)*. 2022;**11**(16):2169.21. DOI: 10.3390/plants11162169
- [86] Wu JY, Xue JY, Van de Peer Y. Evolution of *NLR* resistance genes in magnoliids: dramatic expansions of *CNLs* and multiple losses of *TNLs*. *Frontiers in Plant Science*. 2021;**21**(12):777157. DOI: 10.3389/fpls.2021.777157
- [87] Lapin D, Johannrees O, Wu Z, Li X, Parker JE. Molecular innovations in plant TIR-based immunity signaling. *Plant Cell*. 2022;**34**(5):1479-1496.26. DOI: 10.1093/plcell/koac035
- [88] Parker JE, Hessler G, Cui H. A new biochemistry connecting pathogen detection to induced defense in plants. *The New Phytologist*. 2022;**234**(3):819-826. DOI: 10.1111/nph.17924
- [89] Maruta N, Burdett H, Lim BYJ, Hu X, Desa S, Manik MK, et al. Structural basis of NLR activation and innate immune signaling in plants. *Immunogenetics*. 2022;**74**(1):5-26. DOI: 10.1007/s00251-021-01242-5
- [90] Nguyen QM, Iswanto ABB, Son GH, Kim SH. Recent advances in effector-triggered immunity in plants: new pieces in the puzzle create a different paradigm. *International Journal of Molecular Sciences*. 2021;**22**(9):4709.29. DOI: 10.3390/ijms22094709
- [91] Naveed ZA, Wei X, Chen J, Mubeen H, Ali GS. The PTI to ETI continuum in phytophthora-plant interactions. *Frontiers in Plant Science*. 2020;**11**:593905. DOI: 10.3389/fpls.2020.593905
- [92] Villegas-Vázquez EY, Xoconostle-Cázares B, Ruiz-Medrano R. An ancestry perspective of the evolution of PBS1 proteins in plants. *International Journal of Molecular Sciences*. 2021;**22**(13):6819.25. DOI: 10.3390/ijms22136819
- [93] Chakraborty J, Ghosh P, Das S. Autoimmunity in plants. *Planta*. 2018;**248**(4):751-767. DOI: 10.1007/s00425-018-2956-0
- [94] Ray SK, Macoy DM, Kim WY, Lee SY, Kim MG. Role of RIN4 in regulating PAMP-triggered immunity and effector-triggered immunity: current status and future perspectives. *Molecules and Cells*. 2019;**42**(7):503-511.31. DOI: 10.14348/molcells.2019.2433
- [95] Pilet-Nayel ML, Moury B, Caffier V, Montarry J, Kerlan MC, Fournet S, et al. Quantitative resistance to plant pathogens in pyramiding strategies for durable crop protection. *Frontiers in Plant Science*. 2017;**27**(8):1838. DOI: 10.3389/fpls.2017.01838
- [96] Veneault-Fourrey RM. Quantitative resistance linked to late effectors. *The New Phytologist*. 2021;**231**:1301-1303. DOI: 10.1111/nph.17462
- [97] Andersen EJ, Ali S, Byamukama E, Yen Y, Nepal MP. Disease resistance mechanisms in plants. *Genes (Basel)*. 2018;**9**(7):339.4. DOI: 10.3390/genes9070339
- [98] Dong OX, Ronald PC. Genetic engineering for disease resistance in plants: recent progress and future perspectives. *Plant Physiology*. 2019;**180**(1):26-38. DOI: 10.1104/pp.18.01224

- [99] Ceulemans E, Ibrahim HMM, De Coninck B, Goossens A. Pathogen effectors: exploiting the promiscuity of plant signaling hubs. *Trends in Plant Science*. 2021;**26**(8):780-795. DOI: 10.1016/j.tplants.2021.01.005
- [100] Dinglasan E, Periyannan S, Hickey LT. Harnessing adult-plant resistance genes to deploy durable disease resistance in crops. *Essays in Biochemistry*. 2022;**66**(5):571-580. DOI: 10.1042/EBC20210096
- [101] Jaswal R, Kiran K, Rajarammohan S, Dubey H, Singh PK, Sharma Y, et al. Effector biology of biotrophic plant fungal pathogens: current advances and future prospects. *Microbiological Research*. 2020;**241**:126567. DOI: 10.1016/j.micres.2020.126567
- [102] Shao D, Smith DL, Kabbage M, Roth MG. Effectors of plant necrotrophic fungi. *Frontiers in Plant Science*. 2021;**12**:687713. DOI: 10.3389/fpls.2021.687713
- [103] Mapuranga J, Zhang N, Zhang L, Chang J, Yang W. Infection strategies and pathogenicity of biotrophic plant fungal pathogens. *Frontiers in Microbiology*. 2022;**13**:799396. DOI: 10.3389/fmicb.2022.799396
- [104] Kamle M, Borah R, Bora H, Jaiswal AK, Singh RK, Kumar P. Systemic acquired resistance (SAR) and induced systemic resistance (ISR): role and mechanism of action against phytopathogens. In: Hesham AL, Upadhyay R, Sharma G, Manoharachary C, Gupta V, editors. *Fungal Biotechnology and Bioengineering. Fungal Biology*. Cham: Springer; 2020. pp. 457-470. DOI: 10.1007/978-3-030-41870-0\_20
- [105] Zhu L, Huang J, Lu X, Zhou C. Development of plant systemic resistance by beneficial rhizobacteria: Recognition, initiation, elicitation and regulation. *Frontiers in Plant Science*. 2022;**13**:952397. DOI: 10.3389/fpls.2022.952397
- [106] Tripathi D, Raikhy G, Kumar D. Chemical elicitors of systemic acquired resistance –salicylic acid and its functional analogs. *Curr. Plant Biol*. 2019;**17**:48-59. DOI: 10.1016/j.cpb.2019.03.002
- [107] Yu Y, Gui Y, Li Z, Jiang C, Guo J, Niu D. Induced systemic resistance for improving plant immunity by beneficial microbes. *Plants*. 2022;**11**(3):386.30. DOI: 10.3390/plants11030386
- [108] Yang Z, Zhi P, Chang C. Priming seeds for the future: Plant immune memory and application in crop protection. *Frontiers in Plant Science*. 2022;**29**(13):961840. DOI: 10.3389/fpls.2022.961840
- [109] Serteyn L, Quaghebeur C, Ongena M, Cabrera N, Barrera A, Molina-Montenegro MA, et al. Induced systemic resistance by a plant growth-promoting rhizobacterium impacts development and feeding behavior of aphids. *Insects*. 2020;**11**(4):234.8. DOI: 10.3390/insects11040234
- [110] Liu X, Quan W, Bartels D. Stress memory responses and seed priming correlate with drought tolerance in plants: an overview. *Planta*. 2022; **23**:255(2):45. DOI: 10.1007/s00425-022-03828-z
- [111] Galviz Y, Souza GM, Lüttge U. The biological concept of stress revisited: relations of stress and memory of plants as a matter of space–time. *Theory of Experiment Plant Physiology*. 2022;**34**:239-264. DOI: 10.1007/s40626-022-00245-1



- [112] Liu H, Able AJ, Able JA. Priming crops for the future: rewiring stress memory. *Trends in Plant Science*. 2022;**27**(7):699-716. DOI: 10.1016/j.tplants.2021.11.015
- [113] Zhang H, Lang Z, Zhu JK. Dynamics and function of DNA methylation in plants. *Nature Reviews. Molecular Cell Biology*. 2018;**19**(8):489-506. DOI: 10.1038/s41580-018-0016-z
- [114] Varotto S, Krugman T, Aiese Cigliano R, Kashkush K, Kondić-Špika A, Aravanopoulos FA, et al. Exploitation of epigenetic variation of crop wild relatives for crop improvement and agrobiodiversity preservation. *Theoretical and Applied Genetics*. 2022;**9**. DOI: 10.1007/s00122-022-04122-y
- [115] Preite V, Oplaat C, Biere A, Kirschner J, van der Putten WH, Verhoeven KJF. Increased transgenerational epigenetic variation, but not predictable epigenetic variants, after environmental exposure in two apomictic dandelion lineages. *Ecology and Evolution*. 2018; **19**;8(5):3047-3059. DOI: 10.1002/ece3.3871
- [116] Liu J, He Z. Small DNA methylation big player in plant abiotic stress responses and memory. *Frontiers in Plant Science*. 2020;**11**:595603. DOI: 10.3389/fpls.2020.595603
- [117] Zhi P, Chang C. Exploiting epigenetic variations for crop disease resistance improvement. *Frontiers in Plant Science*. 2021;**12**:692328. DOI: 10.3389/fpls.2021.692328
- [118] Leonetti P, Molinari S. Epigenetic and metabolic changes in root-knot nematode-plant interactions. *International Journal of Molecular Sciences*. 2020;**21**(20):7759.20. DOI: 10.3390/ijms21207759
- [119] Dalakouras A, Ganopoulos I. Induction of promoter DNA methylation upon high-pressure spraying of double-stranded RNA in plants. *Agronomy*. 2021;**11**:789. DOI: 10.3390/agronomy11040789
- [120] He Y, Li Z. Epigenetic environmental memories in plants: establishment, maintenance, and reprogramming. *Trends in Genetics*. 2018;**34**:856-866. DOI: 10.1016/j.tig.2018.07.006
- [121] Dalakouras A, Papadopoulou KK. Epigenetic modifications: an unexplored facet of exogenous RNA application in plants. *Plants*. 2020;**9**:673. DOI: 10.3390/plants9060673
- [122] Cohen SP, Leach JE. High temperature-induced plant disease susceptibility: more than the sum of its parts. *Current Opinion in Plant Biology*. 2020;**56**:235-241. DOI: 10.1016/j.pbi.2020.02.008
- [123] Alonso C, Ramos-Cruz D, Becker C. The role of plant epigenetics in biotic interactions. *The New Phytologist*. 2019;**221**:731-737. DOI: 10.1111/nph.1540
- [124] Annacondia ML, Markovic D, Reig-Valiente JL, Scaltsoyiannes V, Pieterse CMJ, Ninkovic V, et al. Aphid feeding induces the relaxation of epigenetic control and the associated regulation of the defense response in *Arabidopsis*. *The New Phytologist*. 2021;**230**(3):1185-1200. DOI: 10.1111/nph.17226
- [125] Schoenherr AP, Rizzo E, Jackson N, Manosalva P, Gomez SK. Mycorrhiza-induced resistance in potato involves priming of defense responses against cabbage looper (Noctuidae: Lepidoptera). *Environmental Entomology*. 2019;**48**(2):370-381.3. DOI: 10.1093/ee/nvy195



- [126] Dutilloy E, Oni FE, Esmaeel Q, Clément C, Barka EA. Plant beneficial bacteria as bioprotectants against wheat and barley diseases. *Journal of Fungi*. 2022;;8(6):632-14. DOI: 10.3390/jof8060632
- [127] McDowell JM. Focus on activation, regulation, and evolution of MTI and ETI. *Molecular Plant-Microbe Interactions*. 2019;32(1):5. DOI: 10.1094/MPMI-11-18-0307-FI
- [128] Filho JAC, Pascholati SF, Sabrinho RR. Mycorrhizal association and their role in plant disease protection. In: Hakee K, Akhtar M, editors. *Plant. Cham: Soil and Microbes*. Springer; 2016. pp. 95-143. DOI: 10.1007/978-3-319-29573-2\_6
- [129] Sanmartín N, Pastor V, Pastor-Fernández J, Flors V, Pozo MJ, Sánchez-Bel P. Role and mechanisms of callose priming in mycorrhiza-induced resistance. *Journal of Experimental Botany*. 2020;71(9):2769-2781. DOI: 10.1093/jxb/eraa030
- [130] Vishwakarma K, Kumar N, Shandilya C, Mohapatra S, Bhayana S, Varma A. Revisiting plant-microbe interactions and microbial consortia application for enhancing sustainable agriculture: a review. *Frontiers in Microbiology*. 2020;11:560406. DOI: 10.3389/fmicb.2020.560406
- [131] Wei Z, Friman VP, Pommier T, Geisen S, Jousset A, Shen Q. Rhizosphere immunity: targeting the underground for sustainable plant health management. *Frontiers of Agricultural Science and Engineering*. 2020;7(3):317-328. DOI: 10.15302/J-FASE-2020346
- [132] Pons S, Fournier S, Chervin C, Bécard G, Rochange S, Frei Dit Frey N, et al. Phytohormone production by the arbuscular mycorrhizal fungus *Rhizophagus irregularis*. *PLoS One*. 2020;15(10):e0240886. DOI: 10.1371/journal.pone.0240886
- [133] López Sánchez A, Pascual-Pardo D, Furci L, Roberts MR, Ton J. Costs and Benefits of Transgenerational Induced Resistance in *Arabidopsis*. *Frontiers in Plant Science*. 2021;26(12):644999. DOI: 10.3389/fpls.2021.644999
- [134] Nishad R, Ahmed T, Rahman VJ, Kareem A. Modulation of Plant Defense System in Response to Microbial Interactions. *Frontiers in Microbiology*. 2020;11:1298. DOI: 10.3389/fmicb.2020.01298
- [135] Fiorilli V, Vannini C, Ortolani F, et al. Omics approaches revealed how arbuscular mycorrhizal symbiosis enhances yield and resistance to leaf pathogen in wheat. *Scientific Reports*. 2018;8:9625. DOI: 10.1038/s41598-018-27622-8
- [136] Mac Lean AM, Bravo A, Harrison MJ. Plant signaling and metabolic pathways enabling arbuscular mycorrhizal symbiosis. *The Plant Cell*. 2017;29(10):2319-2335. DOI: 10.1105/tpc.17.00555
- [137] Benjamin G, Pandharikar G, Frendo P. Salicylic acid in plant symbioses: beyond plant pathogen interactions. *Biology (Basel)*. 2022;11(6):861. DOI: 10.3390/biology11060861
- [138] Antolín-Llovera M, Petutsching EK, Ried MK, Lipka V, Nürnberger T, Robatzek S, et al. Knowing your friends and foes--plant receptor-like kinases as initiators of symbiosis or defense. *The New Phytologist*. 2014;204(4):791-802. DOI: 10.1111/nph.13117
- [139] Balint-Kurti P. The plant hypersensitive response: concepts,

control and consequences. *Molecular Plant Pathology*. 2019;**20**(8):1163-1178.  
DOI: 10.1111/mpp.12821

[140] Pozo de la Hoz J, Rivero J, Azcón-Aguilar C, Urrestarazu M, Pozo MJ. Mycorrhiza-induced resistance against foliar pathogens is uncoupled of nutritional effects under different light intensities. *Journal of Fungi*. 2021;**7**:402.  
DOI: 10.3390/jof7060402

[141] Wang H, Hao Z, Zhang X, Xie W, Chen B. Arbuscular mycorrhizal fungi induced plant resistance against fusarium wilt in jasmonate biosynthesis defective mutant and wild type of tomato. *Journal of Fungi*. 2022;**8**(5):422.20.  
DOI: 10.3390/jof8050422

[142] Dora S, Terrett OM, Sánchez-Rodríguez C. Plant-microbe interactions in the apoplast: Communication at the plant cell wall. *The Plant Cell*. 2022;**34**(5):1532-1550. DOI: 10.1093/plcell/koac040

[143] Pruitt RN, Gust AA, Nürnberger T. Plant immunity unified. *Nature Plants*. 2021;**7**(4):382-383. DOI: 10.1038/s41477-021-00903-3

[144] Kadam SB, Pable AA, Barvkar VT. Mycorrhiza induced resistance (MIR): a defense developed through synergistic engagement of phytohormones, metabolites and rhizosphere. *Functional Plant Biology*. 2020;**47**(10):880-890.  
DOI: 10.1071/FP20035

[145] Aguilera P, Ortiz N, Becerra N, Turrini A, Gaínza-Cortés F, Silva-Flores P, et al. Application of arbuscular mycorrhizal fungi in vineyards: water and biotic stress under a climate change scenario: new challenge for chilean grapevine crop. *Frontiers in Microbiology*. 2022;**3**(13):826571.  
DOI: 10.3389/fmicb.2022.826571