Trends in
Parasitology

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Spotlight

# Autophagy and jasmonate fight nematode blight

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**Plant-parasitic nematodes (PPNs) pose a serious threat to world crop production and global food security. However, our understanding of the molecular mechanisms underlying plant defense against PPNs remains very limited. Recently, Zou *et al.* reported that the interplay between autophagy and jasmonate pathways mediates plant immunity against root-knot nematodes.**

PPNs are common in agricultural soils, causing widespread damage to crops. There are over 4100 species of PPN, and they cost the agricultural industry over $157 billion dollars in crop losses every year [1]. It is estimated that PPNs lead to around a 10–25% loss of crop yields globally [2]. PPNs typically feed by piercing and killing root cells using their stylets, resulting in poor plant growth and yield performance.

Some economically damaging nematodes, like root-knot nematodes (RKNs), establish permanent feeding sites within roots without killing surrounding cells (Figure 1). RKNs pose an especially significant threat to the agricultural industry, costing billions of dollars per year in damage to crops [3]. RKNs infest over 2000 plant species globally. They invade plant roots as larvae, causing the formation of galls or 'knots'. RKNs mature in roots, then mate and lay eggs, thereby perpetuating infestation. Knots block nutrient and water transport, while also allowing for entry of harmful organisms such as fungal, viral, and bacterial pathogens, leading plants to become weak and diseased, eventually withering or perishing [4]. Above-ground symptoms may not always be obvious, thus masking the infections until populations reach economic thresholds [3].

Plants have developed intricate, multilayered immune systems to shield themselves from harmful assaults such as nematode infestations. A major aspect of these sophisticated immune systems involves the phytohormone jasmonates (JAs) [2]. JAs are lipid-based compounds which are crucial in regulating transcriptional reprogramming during plant growth and development as well as defense responses [5]. This signaling pathway plays an essential role in both pathogen-associated molecular pattern (PAMP)-triggered immunity (PTI) and effector-triggered immunity (ETI) responses against nematodes and necrotrophic plant pathogens [6]. Conversely, autophagy functions to degrade damaged proteins and components, clearing the path for new, unspoiled proteins to replace the old [7]. This process is vital for maintaining cellular stability and defending against pathogens. While autophagy can degrade virulence proteins to combat certain infections, it can also negatively regulate plant resistance to pathogens, as well as regulate hormones and cellular signaling pathways. However, autophagy's relationship with JAs and its role in plant defense against PPNs have not been previously explored. Zou *et al.* made great strides in investigating the plant's defense systems against RKNs (*Meloidogyne incognita*) and determining the importance of autophagy and JA when tomato plants fight against RKN infection [6] .

There are two main types of autophagy: selective and nonselective autophagy. Nonselective autophagy, also known as bulk autophagy, is a broader process that transfers nonspecific cargo, targeting random and general areas for housekeeping within cells to help maintain homeostasis [8]. The type of autophagy focused on in this study was selective autophagy - a highly regulated process that targets and eliminates damaged or unwanted matter within a cell – such as bacteria, viruses, pathogens, or damaged cellular components. Selective autophagy has specific targets and will seek out targeted cargo to degrade and eliminate unwanted matter within cells. It is a form of cellular quality control that keeps cellular systems running cleanly and efficiently.

RKN infection appeared to induce the expression of numerous *ATG* genes as well as the accumulation of autophagosomes, which was crucial for defense against RKNs (Figure 1) [6]. According to Zou *et al.*, jasmonate-associated MYC2-like proteins (JAMs), which function as negative regulators of JA signaling, interact with autophagy-related 8a (ATG8a) through two conserved ATG8-interacting motifs (AIMs) positioned at their N terminus (AIM1) and C terminus (AIM2). JAM1 was identified as a substrate of selective autophagy in tomato plants during RKN infestation, resulting in enhanced resistance [5]. Consistent with these observations, tomato *jam1, jam2* single, and *jam1 jam2* double-mutants all exhibited enhanced resistance to RKNs [6].

Autophagy's interactions with the JA signaling pathway were also investigated. The transcriptional factor, ethylene response factor 1 (ERF1), plays a key role in JA signaling [9]. Its ability to aid in RKN resistance, as well as its interactions with Mediator 25 (MED25), were analyzed by the authors. JAM1 has been shown to disrupt the interactions between ERF1 and MED25 to suppress transcriptional activities of ERF1 (Figure 1) [6]. Zou *et al.* found autophagy degrades the negative regulator JAM1, which prevents formation of the ERF1 and MED25 transcription activation complex, to activate the JA pathway. The authors found that ERF1 and MED25 positively regulate tomato's resistance to RKNs, as knockout mutants of these

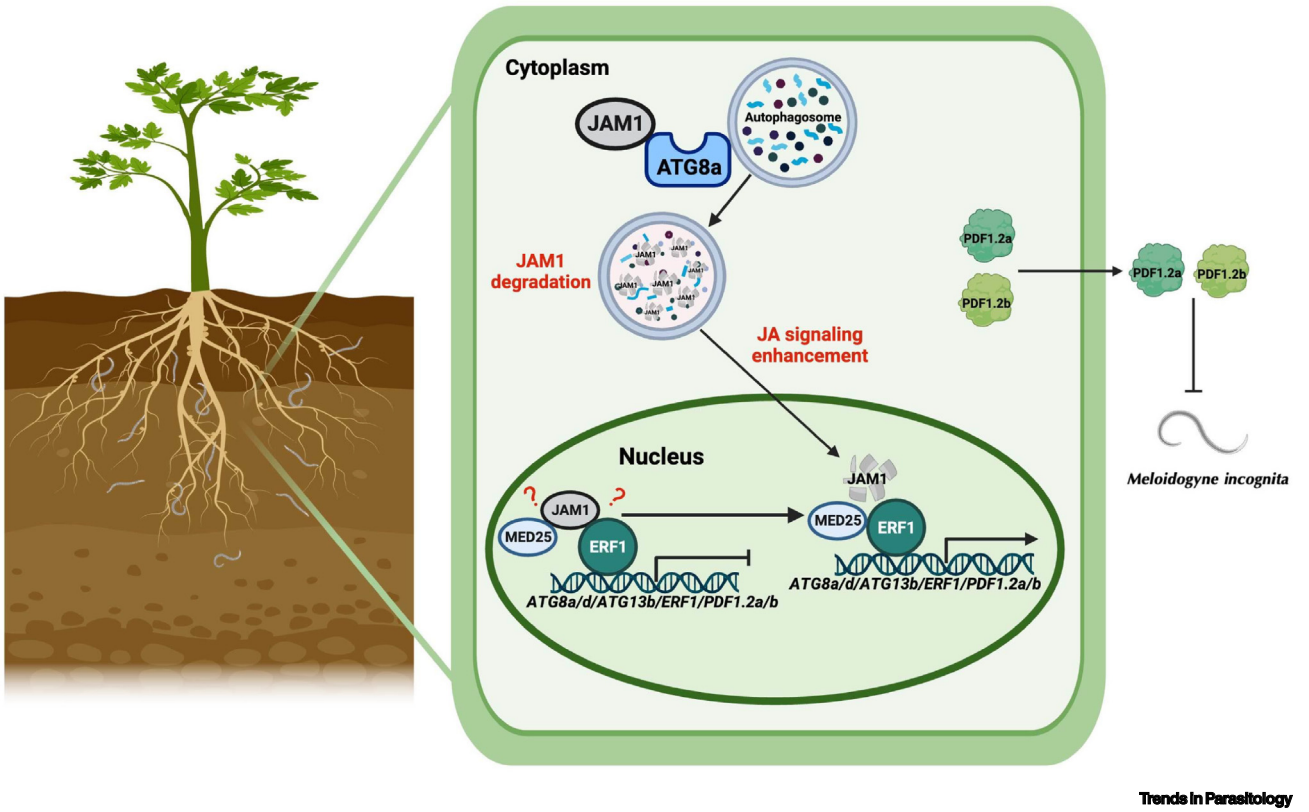


Figure 1. A simplified model for the roles of mutual potentiation of autophagy and jasmonate pathways in plant defense against root-knot nematodes. In the absence of root-knot nematode (RKN: *Meloidogyne incognita*) infection, JAM proteins, such as JAM1, block the interaction between ERF1 and MED25 to dampen the expression of genes involved in anti-RKN defense including *ERF1*, *ATG8a/b*, *ATG13,* and *PDF1.2a/b*. When tomato plants are infected by RKNs, expression of autophagy related genes and formation of autophagosomes are increased, which renders the degradation of JAM1 and possibly JAM2 and JAM3 via their interaction with ATG8a. The reduction of JAM1, and possibly JAM2 and JAM3, enhances the interaction between ERF1 and MED25, with the resulting ERF1-MED25 transcriptional complex binding to the promoters of *ATG8a/b*, *ATG13,* and *PDF1.2a/b* as well as to that of *ERF1*. This probably creates a positive feedback loop to amplify the expression of the antinematode PDF1.2a and PDF1.2b defensin peptides, which will likely be secreted to the extracellular space to confer resistance against RKNs in tomato plants. The figure was created with BioRender. The question marks denote the need to further investigate whether JAM1 interacts with MED25 and/or ERF1 directly or indirectly. Abbreviations: ATG8a, autophagy-related 8a; ERF1, ethylene response factor 1; JA, jasmonate; JAMs, jasmonate-associated MYC2-like proteins; MED25, Mediator 25.

genes showed increased sensitivity to RKN infection. Overall, findings suggest that MED25 acts as a coactivator for ERF1 in regulating JA-related defense genes, with JAM1 obstructing ERF1's transcriptional activity by inhibiting the interaction between MED25 and ERF1.

Furthermore, the authors demonstrated that ERF1 can bind to the promoters of *ERF1*, *PDF1.2a*, *PDF1.2b*, and *ATG* genes *ATG8a*, *ATG8d*, and *ATG13b* and promotes the expression of these genes (Figure 1) [6]. The PDF1.2a and PDF1.2b defensin peptides will likely be secreted into plant apoplasts to confer resistance to RKNs [4]. These findings indicate that ERF1 plays a positive regulatory role in the expression of antinematode genes, making it an essential regulator in the process of tomato defense against RKN infection. Notably, the ERF1 upregulated by RKN infection could bind to its own promoter to promote self-transcription, thus creating a positive feedback loop to amplify the expression of the genes functioning in RKN defense [6].

In summation, autophagy and jasmonate pathways potentiate each other to deliver a stronger defense against RKNs. This discovery could be beneficial to the agricultural industry as it may be employed to develop RKN-resistant tomato plants. For instance, CRISPR-mediated genome editing can now be used to create knockout mutants of *JAM* genes or to enhance the expression of *ERF1* or *ATG* genes for engineering RKN resistant crops.

Future studies could investigate whether and how autophagy is involved in important immune processes against RKNs, such as PTI and ETI, through positively regulating the JA signaling pathway. As

demonstrated in this study, JAM1 protein interferes with the interaction between MED25 and ERF1 to reduce the expression of ERF1 target genes (Figure 1). It is not clear whether JAM1 prevents their interaction through direct or indirect physical association with these two proteins (Figure 1). Besides RKNs, other PPNs, such as cyst nematodes and root lesion nematodes, and the burrowing nematode, also cause severe crop losses [10]. Therefore, it will be of great interest to find out whether autophagy and JA may cooperate with each other to promote plant defense against a wider spectrum of economically important PPNs.

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## Declaration of interests

The authors declare no competing interests.

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## References

1. Singh, S. *et al.* (2015) Nematodes: a threat to sustainability of agriculture. *Procedia Environ. Sci.* 29, 215–216
2. Desmedt, W. *et al.* (2020) A phytochemical perspective on plant defense against nematodes. *Front. Plant Sci.* 11, 602079
3. Castagnone-Sereno, P. *et al.* (2013) Diversity and evolution of root-knot nematodes, genus *Meloidogyne*: new insights from the genomic era. *Annu. Rev. Phytopathol.* 51, 203–220
4. Watanabe, S. *et al.* (2013) Pathogen infection trial increases the secretion of proteins localized in the endoplasmic reticulum body of Arabidopsis. *Plant Physiol.* 163, 659–664
5. Sasaki-Sekimoto, Y. *et al.* (2013) Basic helix-loop-helix transcription factors JASMONATE-ASSOCIATED MYC2-LIKE1 (JAM1), JAM2, and JAM3 are negative regulators of jasmonate responses in *Arabidopsis*. *Plant Physiol.* 163, 291–304
6. Zou, J. *et al.* (2023) Autophagy promotes jasmonate-mediated defense against nematodes. *Nat. Commun.* 14, 4769
7. Bu, F. *et al.* (2020) Multiple functions of ATG8 family proteins in plant autophagy. *Front. Cell Dev. Biol.* 8, 466
8. Jin, M. *et al.* (2013) SnapShot: selective autophagy. *Cell* 152, 368–368.e362
9. Lorenzo, O. *et al.* (2003) ETHYLENE RESPONSE FACTOR1 integrates signals from ethylene and jasmonate pathways in plant defense. *Plant Cell* 15, 165–178
10. Jones, J.T. *et al.* (2013) Top 10 plant-parasitic nematodes in molecular plant pathology. *Mol. Plant Pathol.* 14, 946–961