Jasmonic acid and Salicylic acid Mediated stress alleviation

Dr. B. D. Ranjitha Kumari
Professor and Head
Department of Botany


Auxins
Salicylic acid
Gibberellins
Abscisic acid
Plant hormones
Cytokinins
Zeatin
Jasmonates
Ethylene
Brassinosteroids

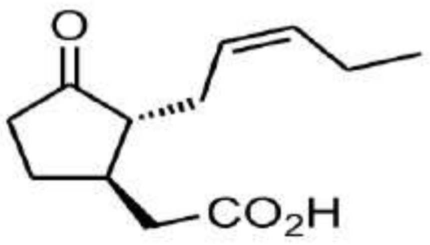
JASMONIC ACID

- Jasmonates are cyclopentanone compound or plant hormones derived from α-linolenic acid.
- It includes group of oxygenated fatty acids collectively called oxylipins and Jasmonic Acid is main precursor to different compounds to this group.
- Methyl jasmonate was first isolated from the essential oil of *Jasminum grandiflorum*

Demole *et. al.*,(1962).Helv. Chim.Acta.45:675-695

- They are ubiquitous in plant kingdom and are also produced by certain fungi.
- First isolated in culture filtrate of fungi *Lasiodiplodia theobromae*.

Aldridge *et. al.*,(1971).J.Chem.Soc.Chem. Comm. 1623-1627



A

A. Jasmonic acid

B. *Jasminum grandiflorum* plant

BIOSYNTHESIS OF JASMONATES

Conversion of linolenic acid to jasmonic acid

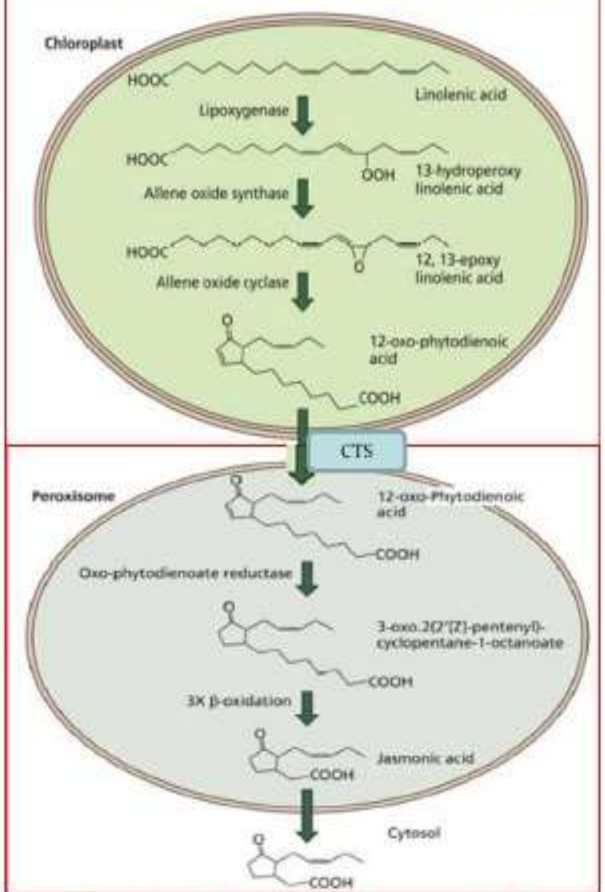


Fig : Biosynthetic Pathway of Jasmonic Acid

Source: Wasternack *et .al.*,(2002).PNARMB.72:165-221

➢Jasmonic acid synthesized from fatty acid(α-linolenic acid)

➢Lipoxygenase (LOX), AOS , AOC are key enzymes of JA biosynthesis in Chloroplast, and they form OPDA.

➢OPDA is transported to peroxisome through ABC transporter COMATOSE(CTS)

➢Reduction of cyclopentanone ring of OPDA is catalyzed by peroxisomal OPR enzyme

➢Three cycles of β-oxidation occurs to give finally Jasmonic Acid. Enzymes involved are:

- ACX1 (Acyl-CoA oxidase in tomato)
- MFP (Multifunctional Protein)
- KAT (L-3-ketoacyl CoA thiolase)

➢ The JA and its metabolic derivatives are collectively called **JASMONATES**

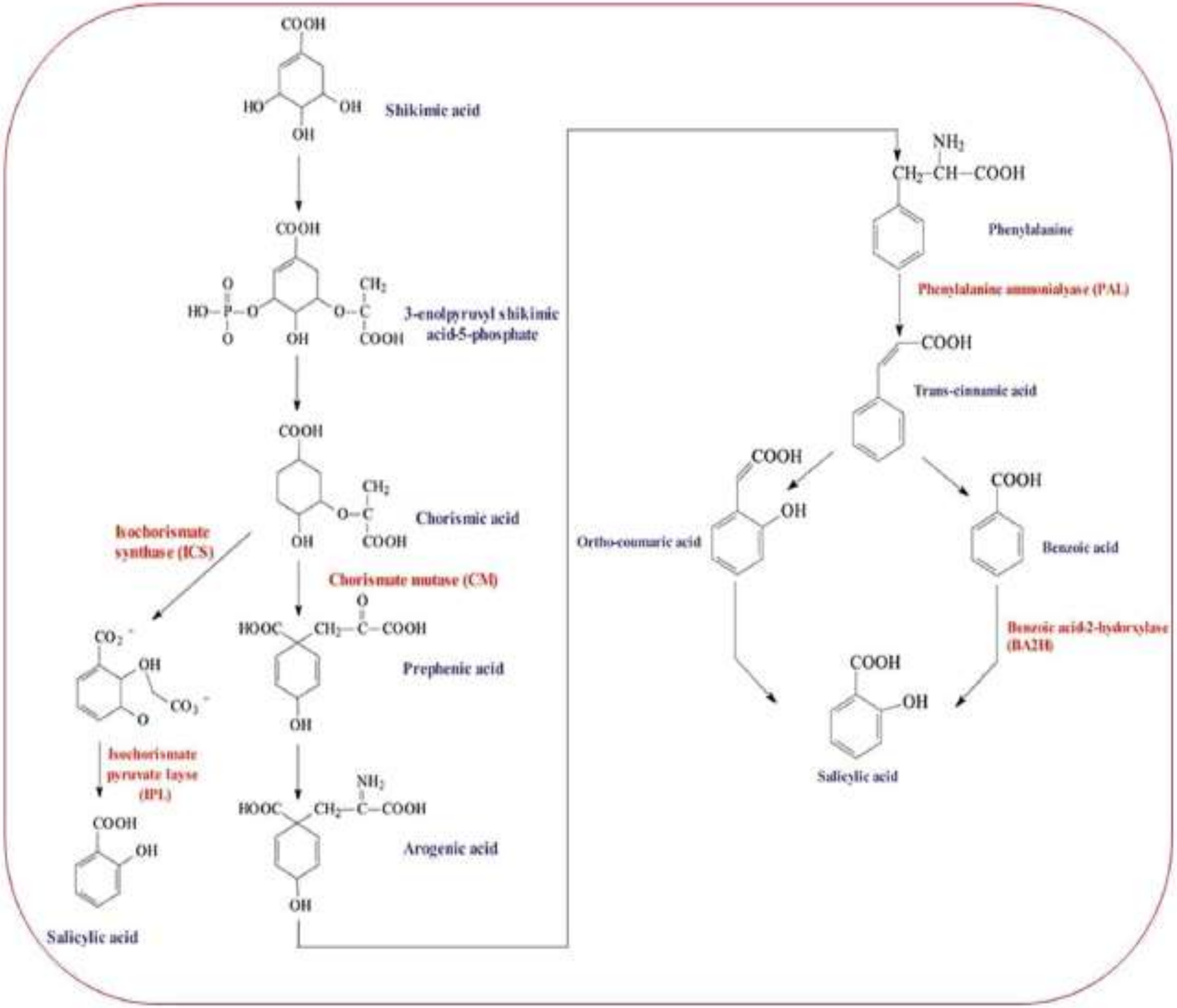


FIGURE 1 | A model of salicylic acid (SA) biosynthesis pathway starting from Shikmic acid and accomplished by three different pathways.

Derivatives of Jasmonic acid – THE JASMONATES

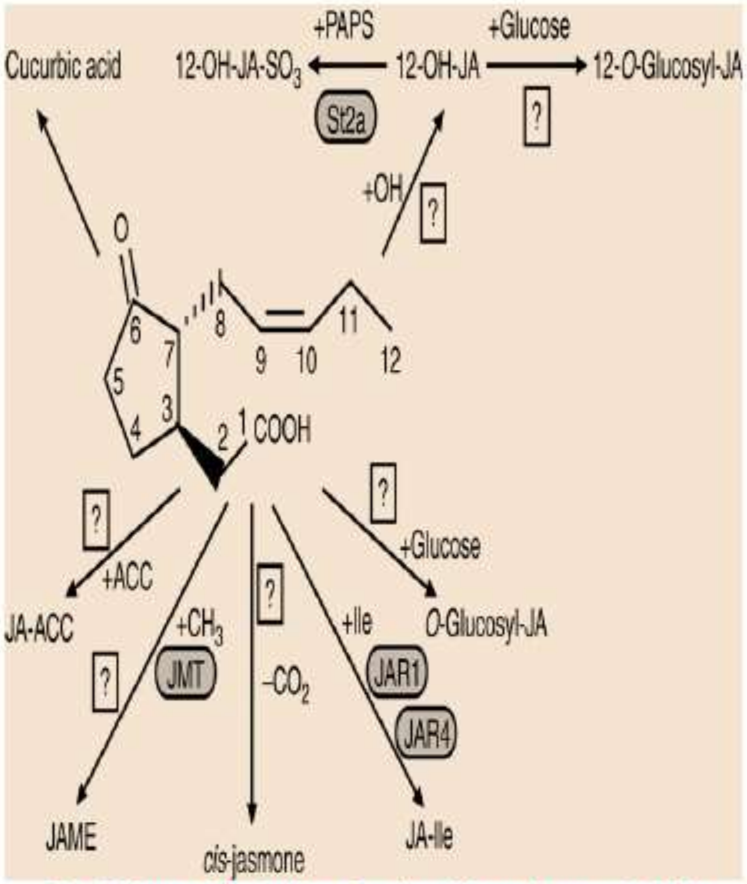


Fig : Different Metabolites Produced from Jasmonic Acid

Source: Wasternack, C. ,(2007).Annals of Botany.100:681-697

- Carboxylic acid side chain conjugated to ACC(1-amino cyclopropane-1-carboxylic acid)
- Methylated form by JA methyltransferase
- Decarboxylated to cis-jasmone
- Conjugated to AA such as Ile by JA amino acid synthase
- Reduction of keto group of pentanone ring to cucurbic acid
- Pentenyl side chain hydroxylated in position C-11 and C-12

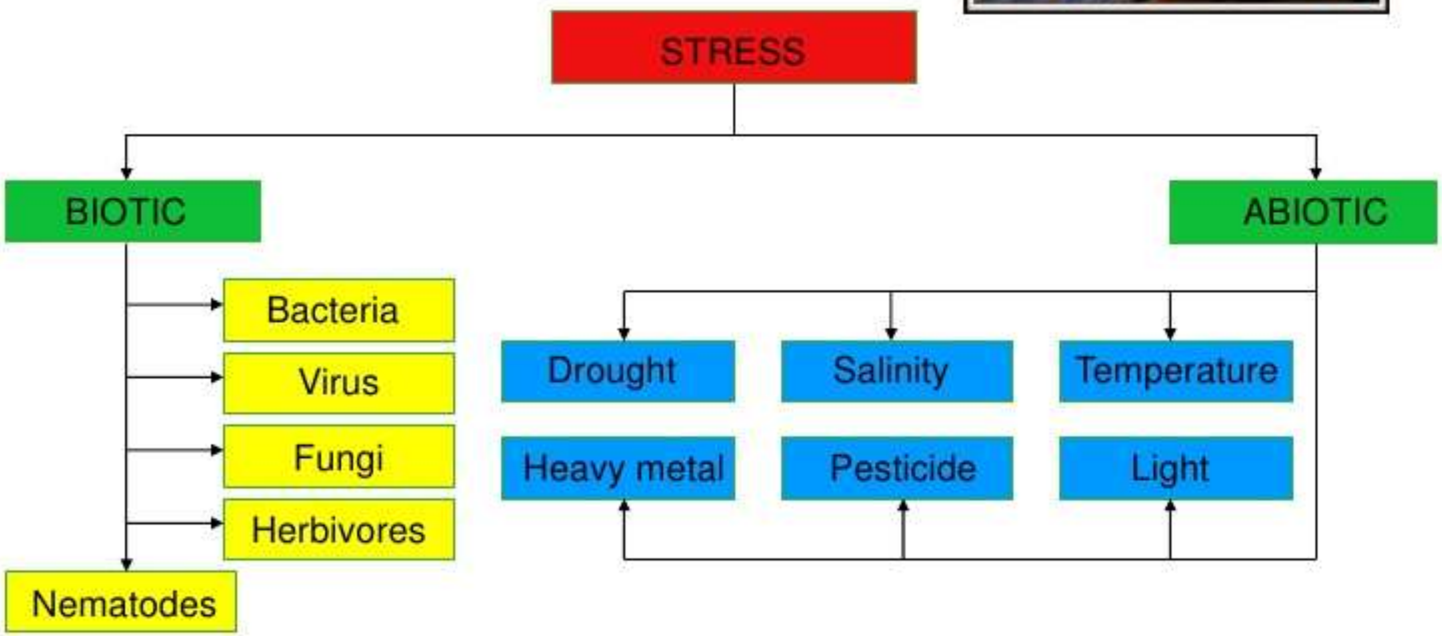
DIFFERENT PHYSIOLOGICAL ROLES OF JA

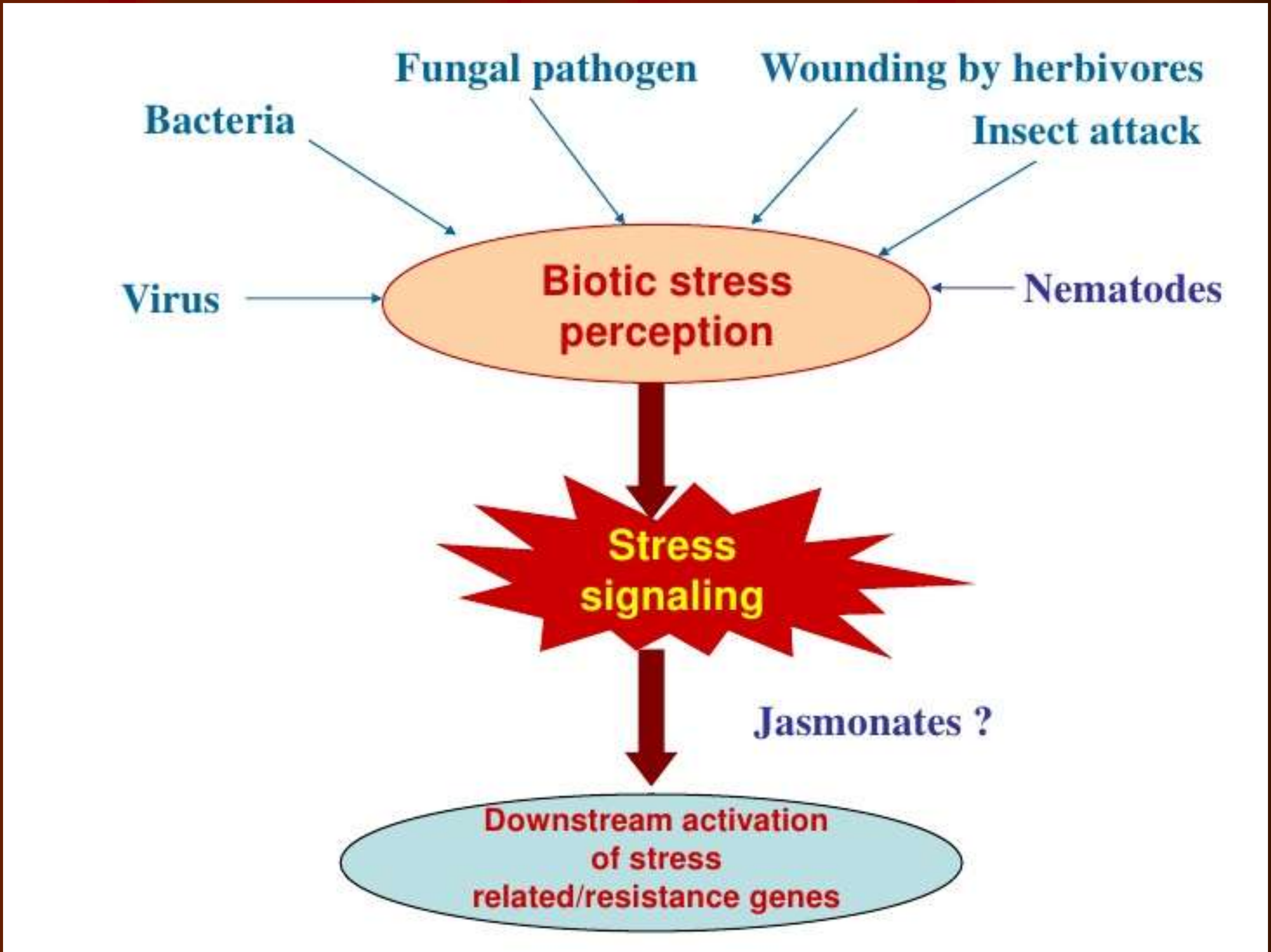
S. No	Process	Putative Signals	Alteration/Species
1	Root Growth	JA,JA-Ile	Inhibition
2	Seed Germination	JA	Inhibition
3	Tuber Formation	JA-OH,JA	Induction/Potato
4	Tendril Coiling	OPDA	Stimulation/*Bryonia*
5	Nyctinasty	JA	Stimulation/*Albizzia*
6	Trichome formation	JA	Induction/Tomato
7	Senescence	JA	Stimulation
8	Flower Development Anther Development and dehiscence Female Organ Development Filament elongation	JA	Induction/*Arabidopsis* Induction/Tomato Induction/*Arabidopsis*
12	Biotic Stress	JA, JME,OPDA	Resistance/Ubiqutitous

Source: Wasternack, C. (2007).Annals of Botany.100:681-697

STRESS AND ITS TYPES

Stress is any change in the environmental condition that may adversely affect the plant's growth, development and adaptability




Fungal pathogen
Wounding by herbivores
Bacteria
Insect attack
Virus
Biotic stress perception
Nematodes
Stress signaling
Jasmonates ?
Downstream activation of stress related/resistance genes

CERTAIN FACTS TO PONDER OVER

- In India, fungal diseases are rated either the most important or second most important factor contributing to yield loss

  Grover A. *et al.*, 2003. Current science 84:330-340

- Global loss because of pathogens is estimated to be 12% of potential crop production

  Shah D.M. *et al.*, 1997. Current Opinion in Biotechnology B:208-214

- The highest losses, estimated at more than $42 billion per year, occur in vegetables, fruits and rice

  Shah D.M. *et al.*, 1997. Current Opinion in Biotechnology B:208-214

FUNGAL DISEASES AND ECONOMIC LOSSES

Crop	Pathogen	Disease	Total yield loss(%)
Rice	*Paricularia oryzae*	Blast	21
Wheat	*Puccinia recondita*	Brown leaf rust	30
Maize	*Helminthosporium maydis*	Leaf blight	30
Sorghum	*Sphacelotheca reiliaria*	Grain mould	18
Pigeonpea	*Fusarium udum*	Wilt	24
Chickpea	*Fusarium oxysorium*	Wilt	23
Brassica	*Alternaria brassiceae*	Blight	30
Soyabeen	*Phakospora packyrhizi*	Rust	23
Potato	*Phytopthora infestans*	Late blight	31

Source: Current science, vol.84, No. 3, 10 Feb. 2003

ROLE OF JA IN RESISTANCE

- Increased endogenous level of JA on treatment of Arabidopsis with necrotrophic fungus *A. brassicola* Penninckx *et al.*(1996).Plant Cell.8:2309-2323
- Biosynthetic and Signaling Arabidopsis mutants were more sensitive to attack by necrotrophic fungal pathogen *Phytium* (*jar1,coi1* and *fad3-2fad7-1fad8* mutants) and necrotrophic bacteria *Erwinia carotovora* (*coi1* mutants)

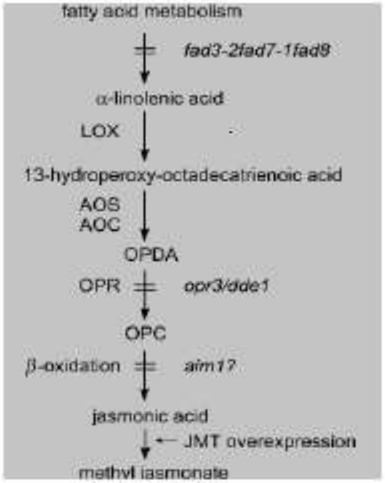
  Staswick *et al.,(1998)*.Plant Journal 15:747-754

  Vijayan *et al.*,(1998).PNAS USA 95:7209-7214
- Transgenic plants overexpressing JMT and thus higher levels of methyl jasmonate more resistant to necrotrophic pathogen *Botrytis cinera*

  Walling (2000). Journal of Plant Growth Regulators 19: 195-216
- The *fad3-2fad7-1fad8* mutant more sensitive to attack by fungal gnat *Bradysia* and *coi1 is* more sensitive to Diamond –back moth

  McConn *et al.*,(1997). PNAS USA.94:5473-5477;

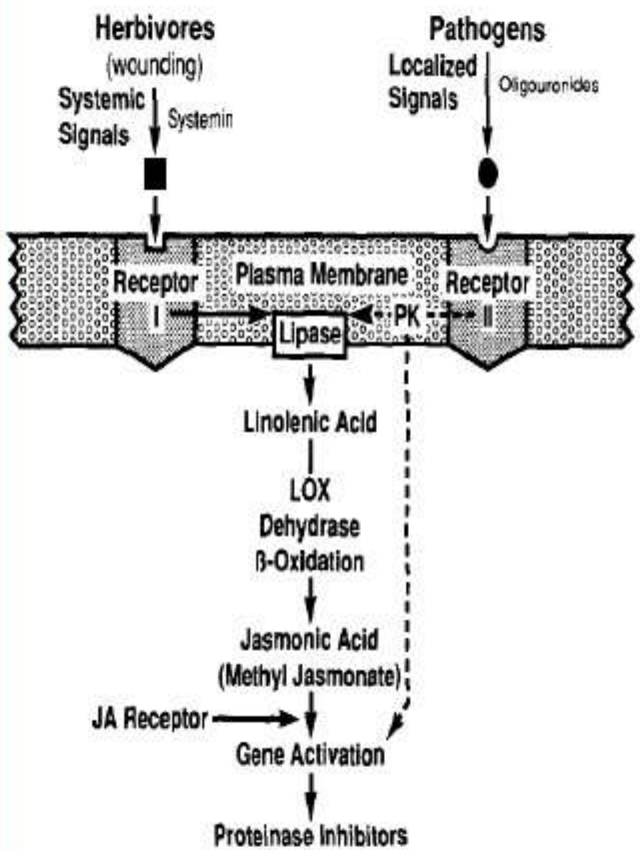
  Xie *et al* (1998). Science 280: 1091-1094



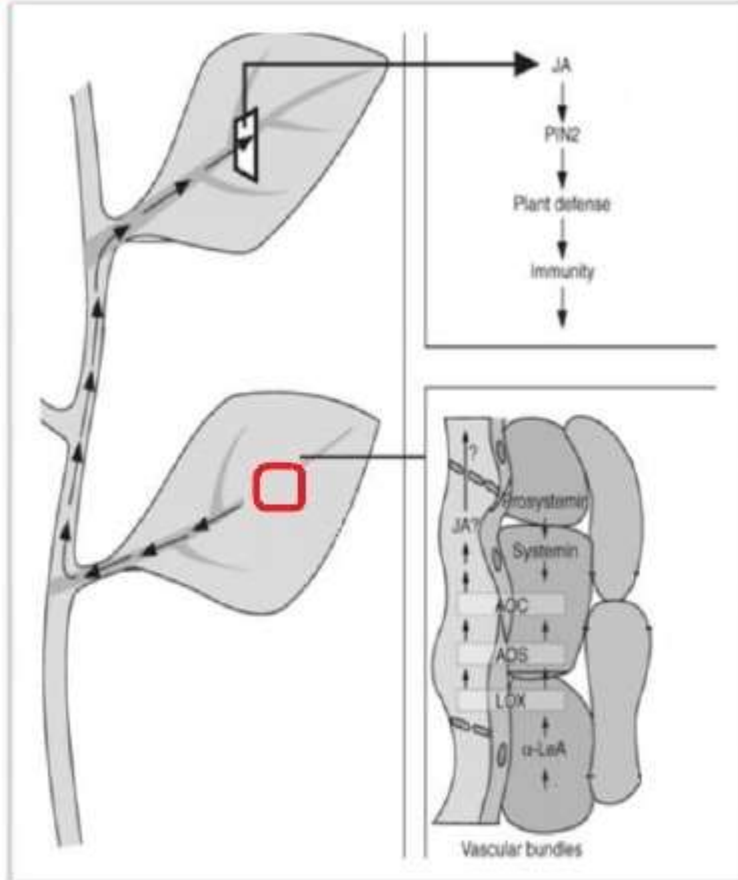
Source: Berger,(2002).Planta 214:497-504

Mutant	Biochemical Significance	Role of Mutant	Expression of JA responsive genes	Effects
coi	Coronatine insensitive	JA Signaling	Reduced	Sensitivity to insect and necrotrophic pathogens increased
fad	Defective Fatty Acid Desaturase	JA Biosynthetic	Reduced	Sensitivity to insect and necrotrophic pathogens increased
cev	Constitutive Expression of VSP	JA Signaling	Increased	Increased sensitivity to biographic pathogens
jar	JA Resistant	JA Signaling	Reduced	Increased sensitivity to necrotrophic pathogens
opr	Defective OPDA Reductase	JA Biosynthetic	Reduced	Increased sensitivity to insects
jin	JA Insensitive	JA Signaling	Reduced	Increased sensitivity to pathogens

Mechanism of action of JAs in biotic stress



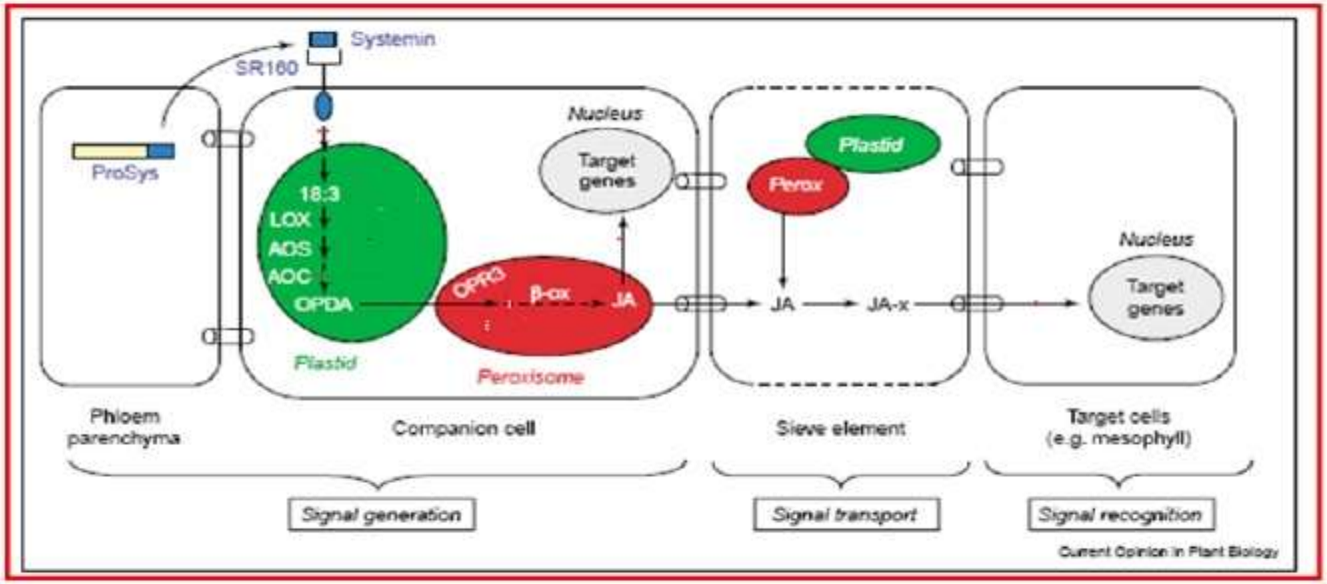
Source:Farmer and Ryan(1992).The Plant Cell.4:129-134



Source:Wasternack (2007).Annals of Botany.100:681-697

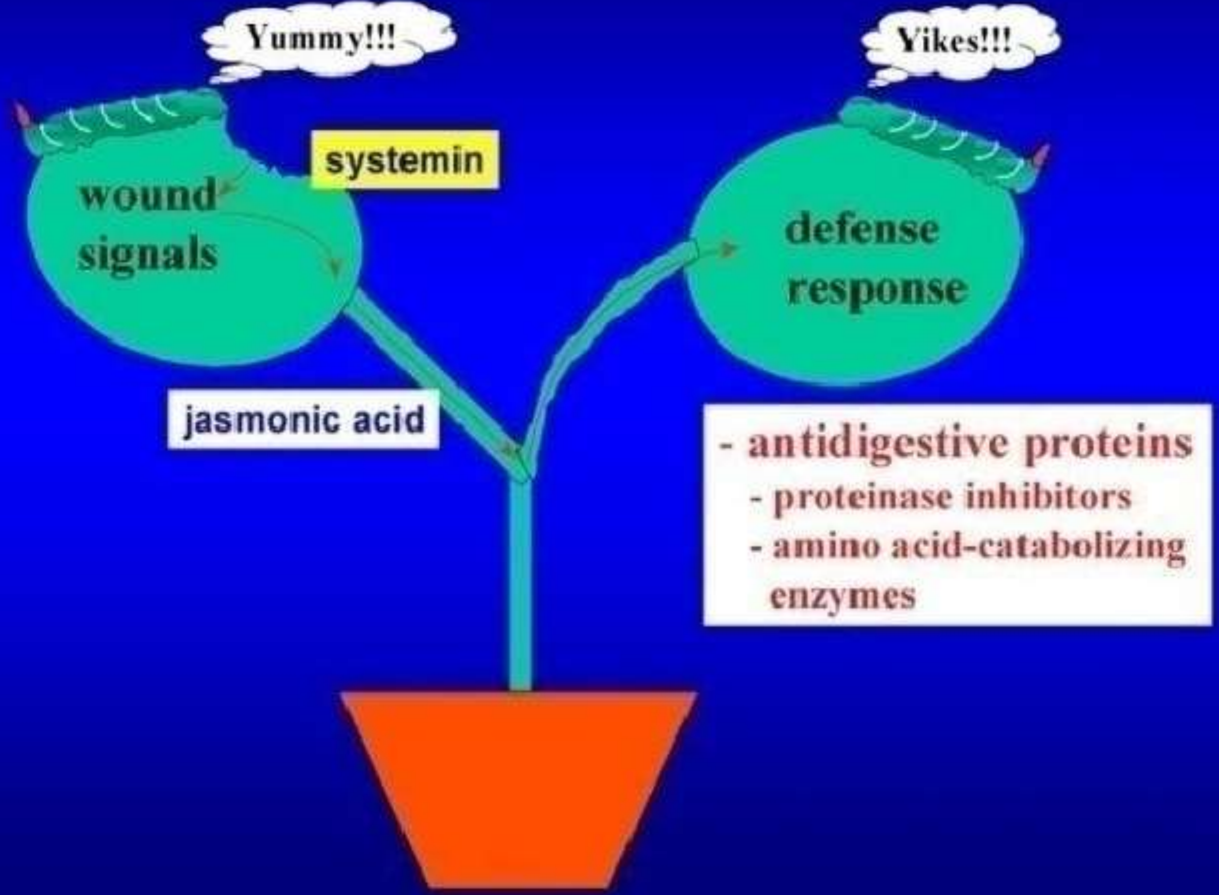
OVERALL MECHANISM OF SYSTEMIC RESPONSE

- **Wounded leaves produce an 18-amino acid peptide called systemin from carboxyl terminal of prosystemin (200 AA precursor) in PP and it elicits production of JA in companion cell-sieve element complex.**
- **JA moves throughout the plant in the phloem. Covalently modified JA (JA-x) play important role in systemic signaling.**
- **signal is recognized at the target cell e.g. mesophyll (leaf)**
- **Jasmonic acid turns on defense related genes (genes for proteinase inhibitor etc.) in target cells.**



Source: Schilmiller and Howe (2005). Current Opinion in Plant Biology . 8:369-377

Systemic Wound Response



AMPLIFICATION OF SYSTEMIN SIGNAL

- Amplification of wound signaling is a major event in systemic defense
- Systemin activates AOC which in turn activates Prosystemin through OPDA/JA. OPDA/JA again activates back the AOC.
- In systemic response once JA is synthesized, its cyclic production of JA can occur by positive feedback mechanism
- JA is a systemic signal that leads to systemic expression of genes encoding Proteinase inhibitors(PINs)
- The plant may develop some resistance against subsequent herbivore attack.
- Thus JA signaling is necessary in systemic response in leaf.

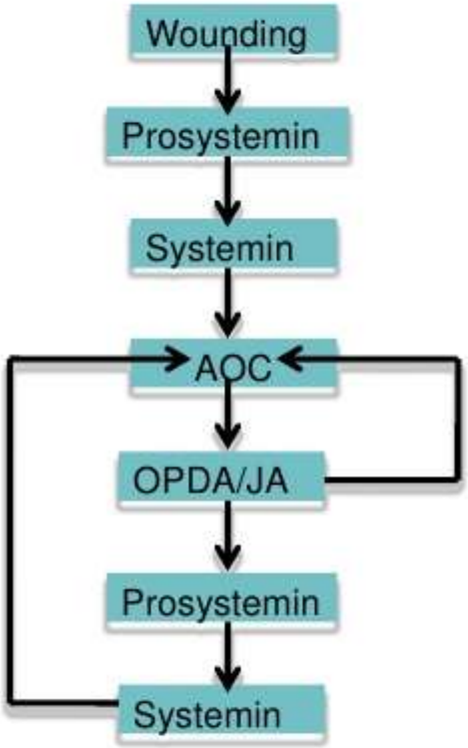


Fig: Amplification of wound signaling of tomato

Source:Wasternack *et al*(2006).163: 297-306

SYSTEMIC RESISTANCE AND ROLE OF JAs

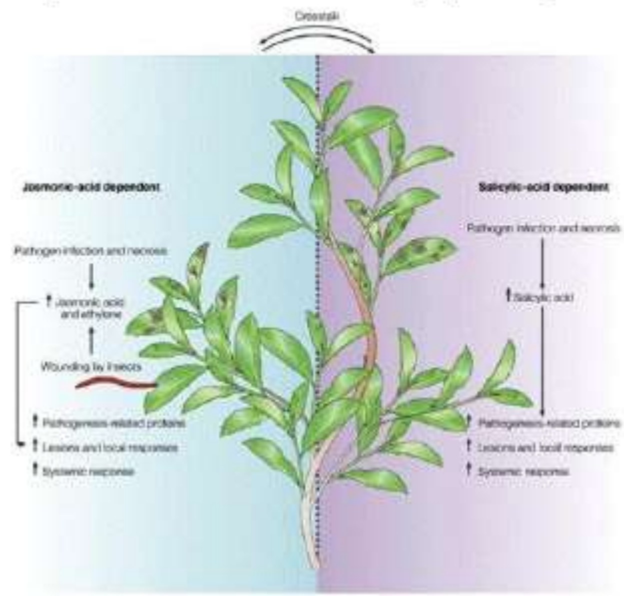
Systemic resistance in plants → Systemic Acquired Resistance (SAR)
Systemic resistance in plants → Induced Systemic Resistance (ISR)

SAR:

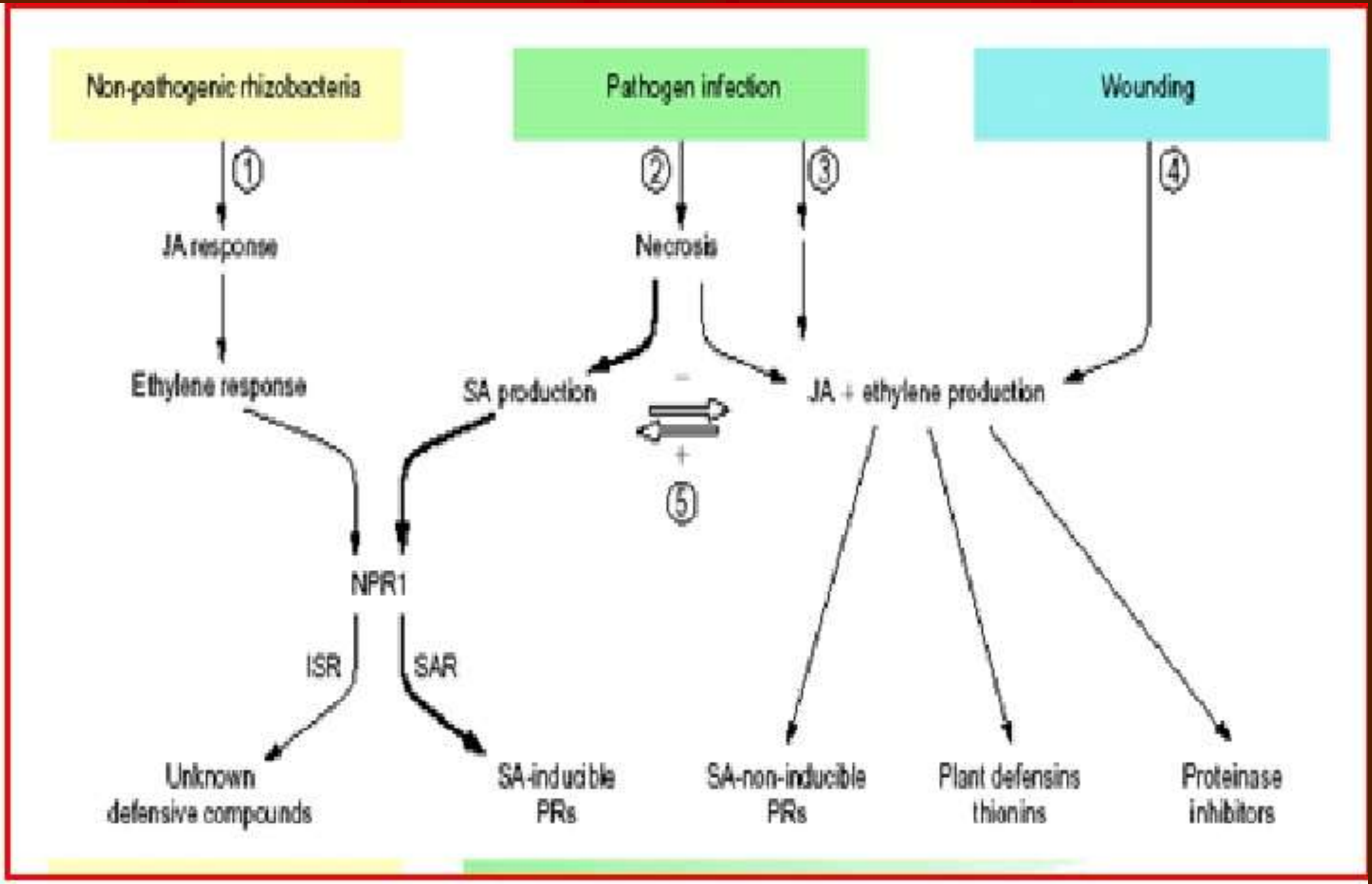
- Initial infection result in formation of necrotic lesions
- SA concentrations increase and methyl-SA is released in distal plant tissue
- PR proteins in the non-invaded parts of the plants are synthesised resulting in reduction in disease symptoms after subsequent infection of many pathogenic species.

ISR:

- Non pathogenic root colonizing rhizobacteria e.g. *P. fluorescens* or wounding initiates ISR
- ISR does not depend on SA and PR protein
- ISR requires both JA and ethylene signalling
- SAR regulatory protein NPRI is required
- Systemin is involved in ISR which is absent in SAR.



Source:Harman *et. al.*(2004) .Nature Reviews Microbiology. 2:43-56



Overall Mechanism of Defence mediated by different signaling compounds
Source: Piertse *et.al.*(2009).Nature Chemical Biology.5:308-316

TRANSCRIPTIONAL REGULATION OF JA

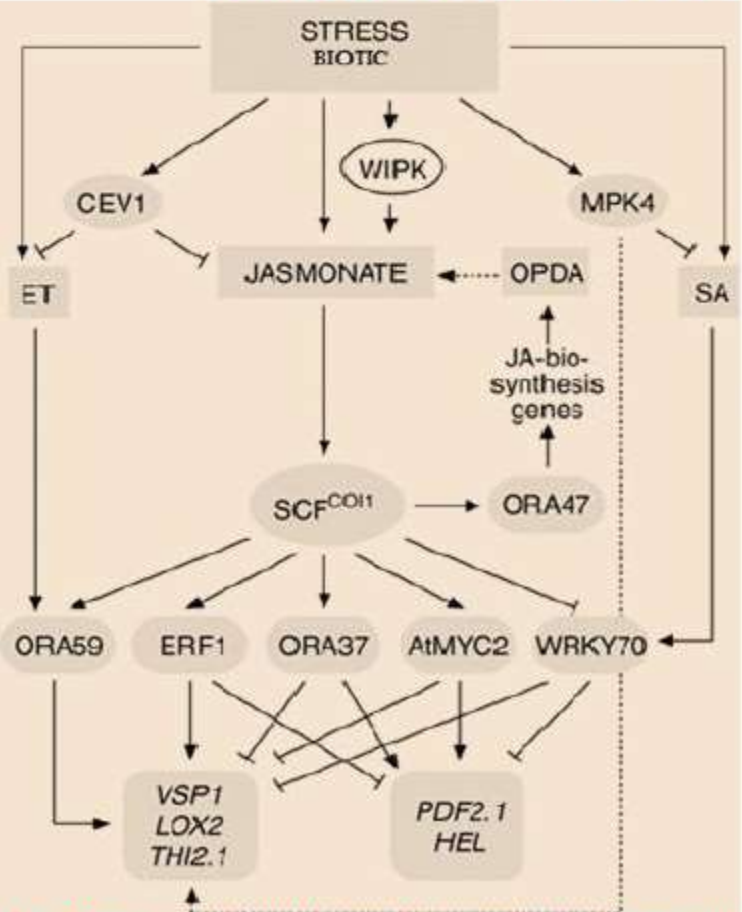


Fig: Transcription factors involved in signalling pathways of JA

Four major of interacting players of:

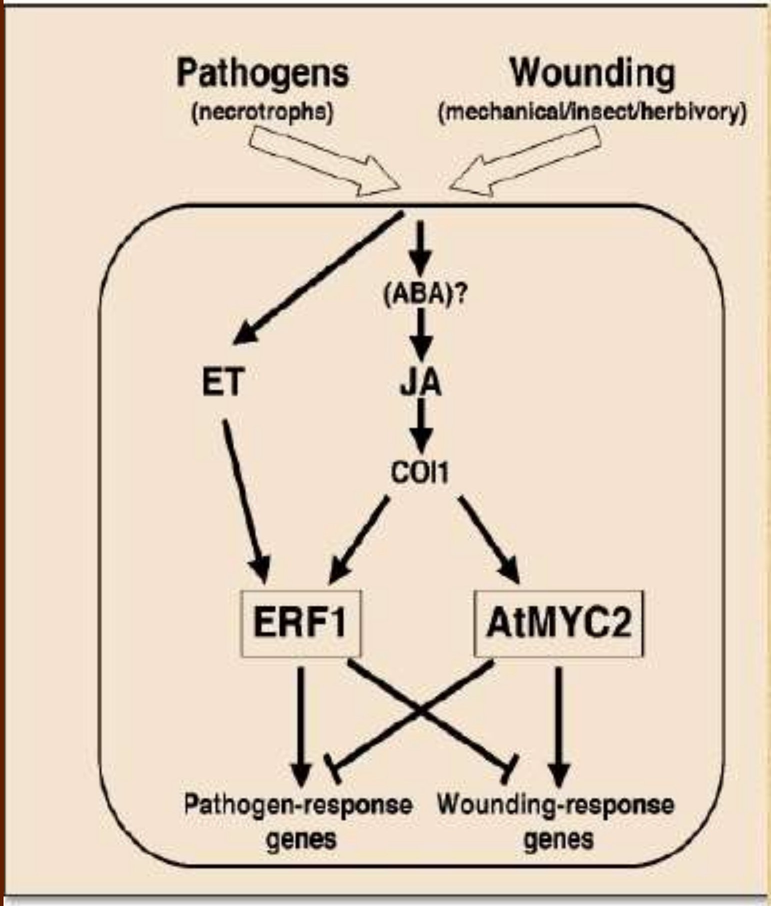
1. a JA signal
2. the SCF-type E3 ubiquitin ligase SCF^{COI1}
3. Jasmonate ZIM-domain (JAZ) repressor proteins that are targeted by SCFCOI1 for degradation by the ubiquitin/26S proteasome pathway ,and
4. transcription factors (TFs)

Howe *et. al.*(2008)Current Opinion in Plant Biology 11:428-235

Transcriptional regulation mechanism:

1. **Expression of regulatory TFs for JAs**
2. **Cross talk with the TFs responsible for expression of other hormones.**

Source: Wasternack(2007). Annals of Botany100:681-697



Cross Talk with Ethylene and JA

- The antagonistic action of MYC2 and ERF1 may cause independence between wound signaling and pathogen defence signaling
  Lorenzo *et al* (2004)Plant Cell 16:1938-1950)
- JA alone induce the expression of AtMYC2 responsible for the activation of wound response genes and for the repression of pathogen response genes.
- The cooperation of ET and JA signals through the induction of ERF1 leads activation of PR genes and to the repression of WR genes
- Therefore, the interplay between ERF1 and AtMYC2 allows the plant selection of the correct set of genes in response to these two stresses

Schematic Representation TF in response to Pathogens and Wounding

Source: Wasternack(2007). Annals of Botany100:681-697

Relevance of JAs studies

Plant lack an immune system like in animals but posses mechanism that recognizes potential pathogens and initiate defense responses. During their biochemical evolution, the plants are devised with certain magic molecules of defense (secondary metabolites) like JAs.

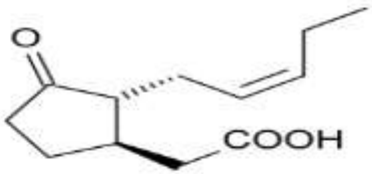
Recent insights into the JAs mediated plant defense cascade and knowledge of key regulators of this will help us to design future crops with increased biotic stress resistance and better adaptability.

Higher crop yields might be achieved by increasing the pathogen/insect resistance which can be achieved by manipulating the expression of the key genes involved in JAs biosynthesis and signaling cascades.

Feeding the ever increasing human population is biggest social problem/challenge after all.

INTRODUCTION

- Novel plant immune hormone derived from **α- linolenic acid**.
- Methyl Jasmonate was first time isolated from the essential oil of ***Jasminum grandiflorum.***
- Ubiquitous in plant kingdom and also produced by certain fungi (***Lasiodiplodia theobromae***).



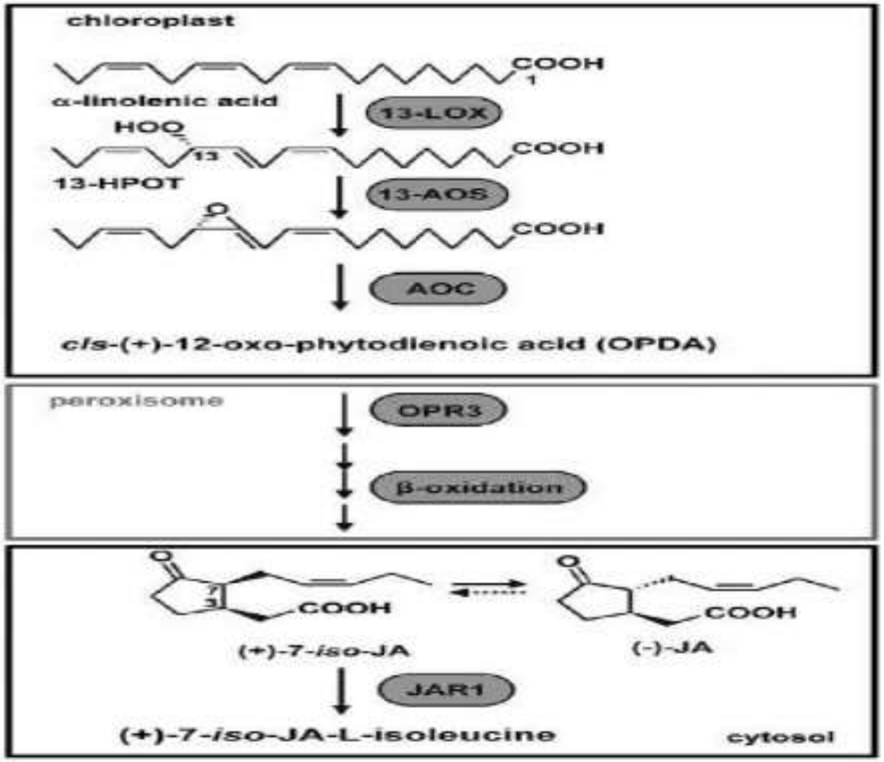
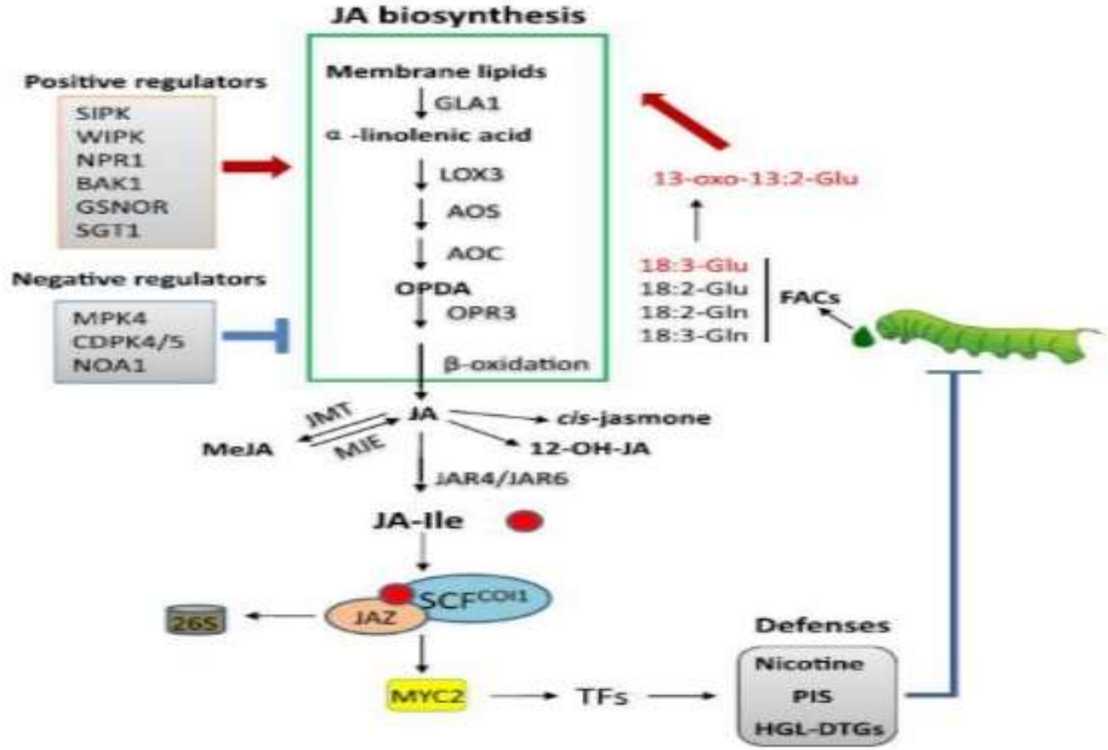


Figure 2. Biosynthesis of jasmonic acid (JA) and (+)-7-iso-JA-L-isoleucine.



Wang and Wu, 2013

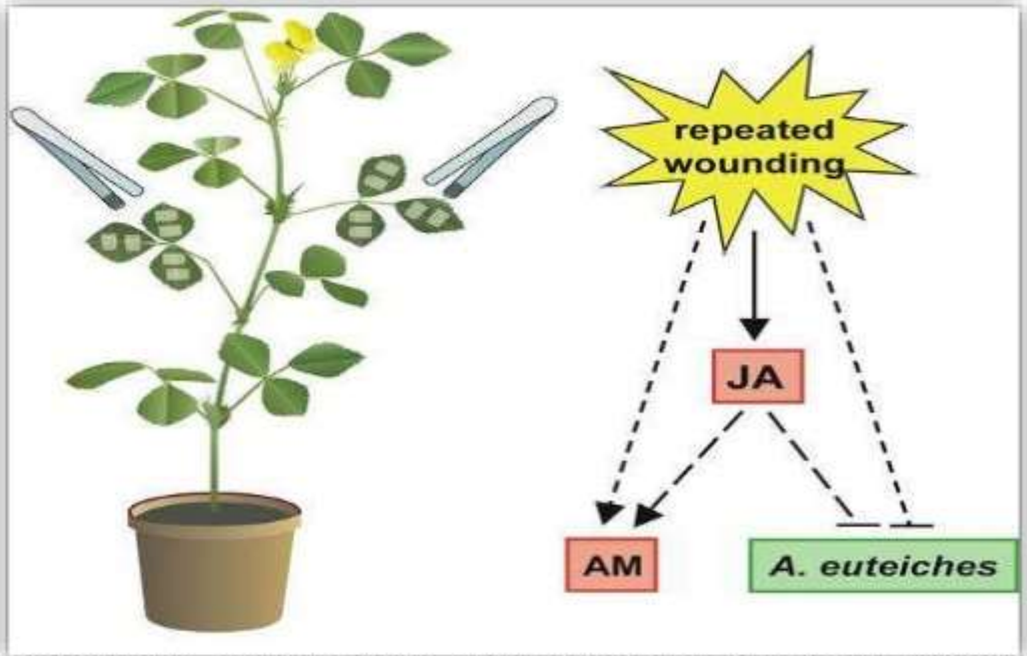


Fig. 4: Schematic overview of the effect of leaf wounding on the interaction of *Medicago truncatula* with root-colonizing microorganisms. The arbuscular mycorrhiza (AM) with *G. intraradices* was found to be promoted by repeated leaf wounding, whereas the colonization with the pathogenic oomycete *Aphanomyces euteiches* was reduced. Both effects might be triggered by the increased levels of jasmonic acid (JA).

Wasternack and Hause 2013.

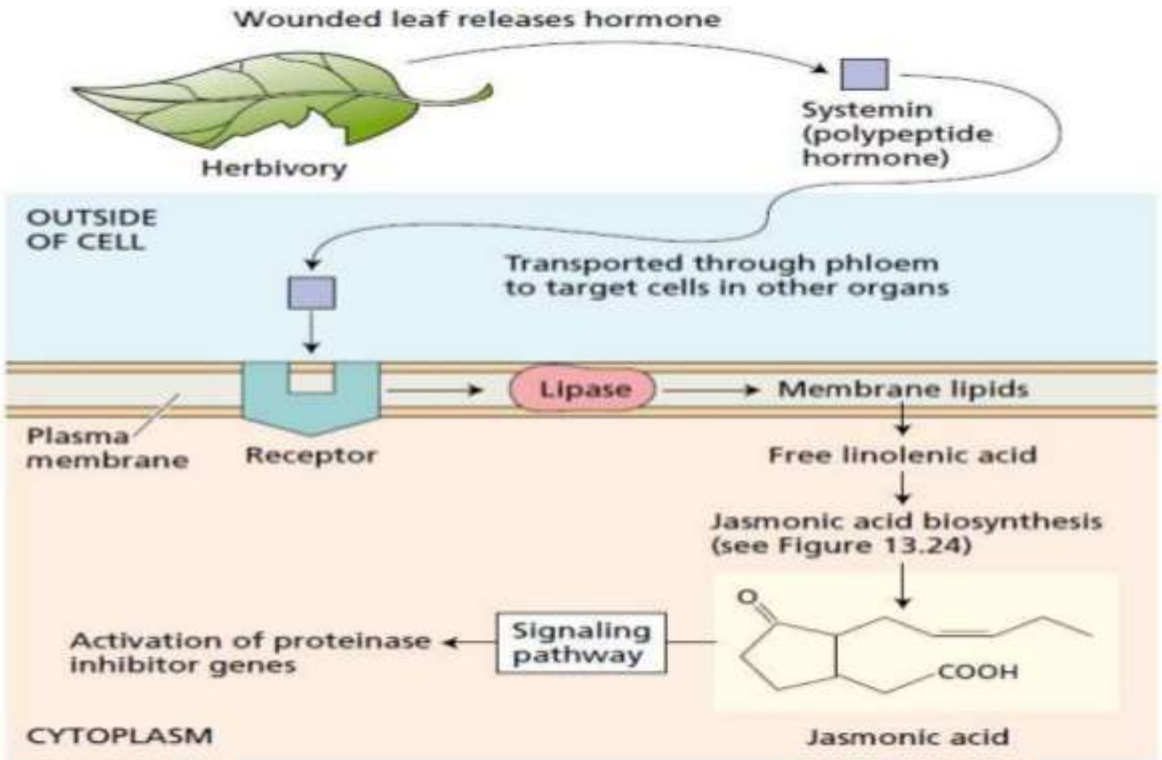


Figure 5: Schematic presentation of mechanism of JA in response to Insect attack

Taiz and Zeiger 3rd ed.

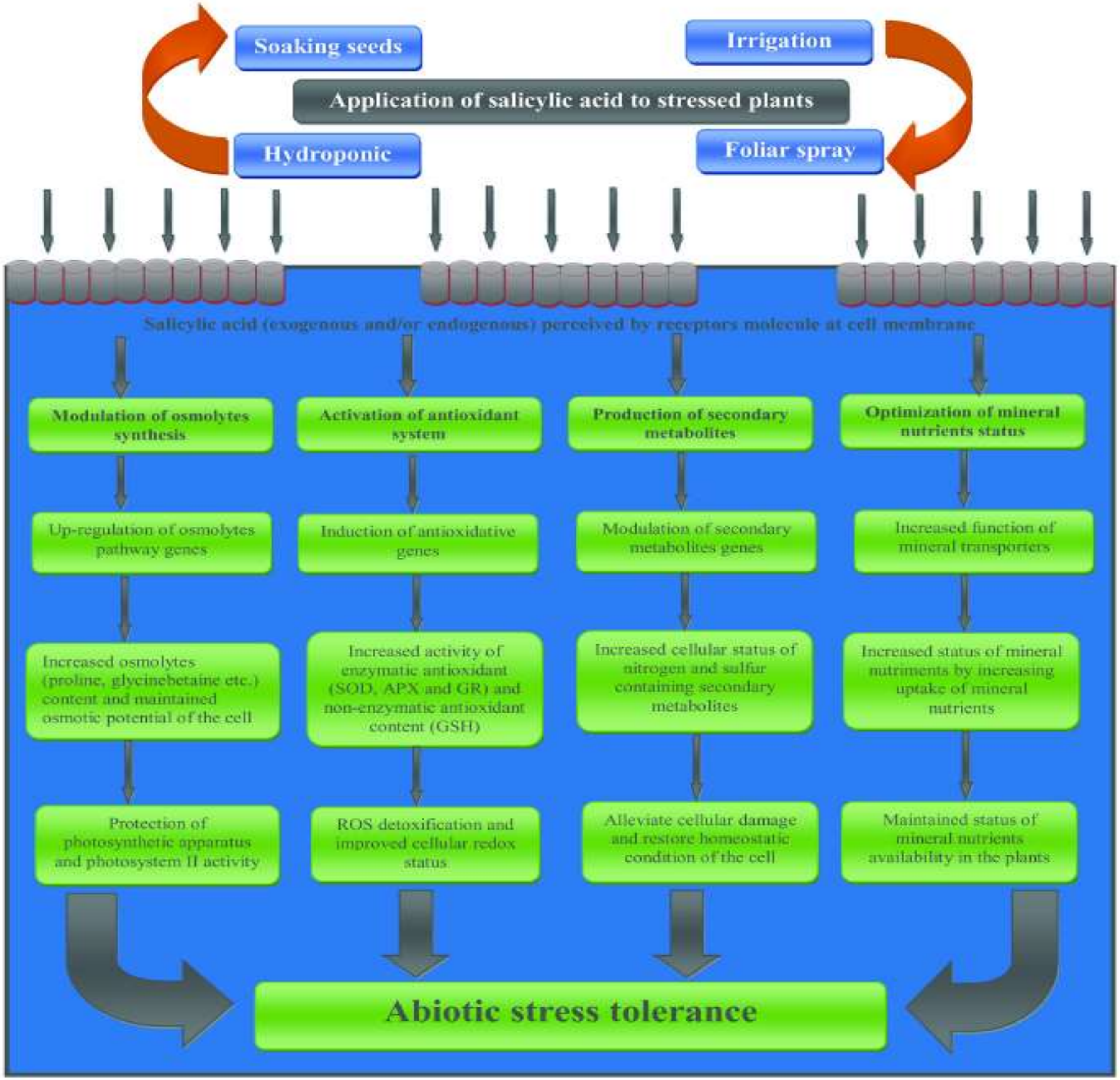


FIGURE 2 | Simplified schemes representing potential mechanisms underlying SA-mediated plant abiotic stress tolerance.

References

1. Plant Physiology by Taiz and Zeiger. 2010. 5th edition. Sinauer Associates, Inc.;

2. https://www.slideshare.net/medipesh/jasmonates-and-biotic-stress

3. https://en.wikipedia.org/wiki/Jasmonate

4. https://en.wikipedia.org/wiki/Salicylic_acid