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Plants Signaling Pathways against Biotic and Abiotic Stresses in Challenging Environment

Mustansar Mubeen[1], Yasir Iftikhar[1*], Qaiser Shakeel[2] and Muhammad Ahmad Zeshan[1]

[1]Department of Plant Pathology, College of Agriculture, University of Sargodha, Sargodha, Pakistan; [2]Cholistan Institute of Desert Studies, Faculty of Agriculture and Environment, The Islamia University of Bahawalpur, Bahawalpur, Pakistan
*Corresponding author's e-mail: yasir.iftikhar@uos.edu.pk

Sessile plants confront the fluctuating harsh environmental conditions and react to alterations in biotic and abiotic components of environments by symbiotic association between plant and biosphere. The origins of stresses are the vicinal environment, which is composed of biotic and abiotic agents. A wide range of molecular mechanisms are opted by the plants for their self-defense. The plant faces harsh conditions due to its molecular battery. Signaling molecules engineer the plants to tolerate the stresses. Transposable elements become active due to living and nonliving agents. Physical and chemical agents cause induction in mutation. These changes are the first driving step in the evolution of plants. During evolution, environmental changes force the plants to adapt or succumb to stress. The plants respond to the ecological conditions by modulating the gene programmer.

Keywords: Signaling pathways, Crosstalk, Defense, Challenges, UPS, Evolution.

INTRODUCTION

Natural and anthropogenic factors are the main events to cope with the biotic and abiotic challenges (Minakshi *et al.*, 2011). Natural disasters, including extreme rainfall events, floods, cold waves, heat waves, and cyclones, are severe threats to economic losses. The alterations in climate patterns can influence the spread of pathogens and it can also affect the plant's response to biotic stresses (Nicol, 2011; Russell *et al.*, 2004). The enhancement in pathogen infestation is a major constraint in crop production (Minakshi *et al.*, 2011). The effects of stress may vary depending on time, nature severity, and prevailing environmental conditions (Gupta *et al.*, 2016; Sharma and Dubey, 2005). Stress factors hijack the plant system in a combination or interactive way (Niinemets, 2010). In interactive mode, the initial stress factor alters the plant behavior for the attack of another stress (Mittler, 2002). The damages caused by stress are more severe when more than one-factor attacks synergism. Plants respond to the environment in specific and non-specific ways (Newton *et al.*, 2011). There are many common threats and damages in signaling pathways of specific and general responses to stresses (Miller *et al.*, 2010). The plant faces a wide array of biotic and abiotic challenges, *e.g.*, insects, herbivores, fungal, bacterial, and viral attacks by specific, general, or overlapping defense mechanisms. Biotic agents interfere with the plant-water relationship to increase the pathogenesis. Plants remodel their anatomy, morphology, physiologies, biomolecules and gene expressions due to environmental stress conditions (Wang *et al.*, 2001; Shao *et al.*, 2009). Biotic stresses also stimulate the plant protoplast, chloroplast and peroxisomes to raise the reactive oxygen species (ROS) level (Bolwell, 1999). The changes in ubiquitous/proteome (UPS) help the plant to survive under harsh biotic and abiotic conditions, e.g., *Arabidopsis*, cereals and French beans. Both factors impose severe pressure on our global agents. The central theme behind this title is to find the targets of crop plants and how they tolerate environmental stress.

***Ways of defense mechanism*:** Avirulence factor (Avr) and plant defense protein (R-resistance) become susceptible if they lack cognate R gene in response to particular Avr. The plant produces SAR (Systematic Acquired Resistance) when a pathogen attack (Durrant and Dong, 2004). Plants fend off future attacks from fungi and bacteria when customized by colonizing non-pathogenic bacteria (Durrant and Dong, 2004). There are the following types of defense mechanisms:

1. Basal Defense: In this, the plant recognizes and responds to a wide range of non-host pathogens by PAMPs (pathogen-associated molecular Patterns).
2. Gene-for-Gene

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3. R-mediated Resistance

types of defense mechanism biochemical defense mechanism: Biotic and abiotic agents are coordinated via cross-talk and signaling pathways (Fig.1). The critical components of this cross-talk are transcription factor, HSF (Heat shock factor), ROS, and mitogen-activated protein kinase (MAPK) to minimize the damages by conserving valuable resources (Nicky and Peter, 2012; Rizhsky *et al.*, 2004). When the NADPH level falls, the uptake of oxygen increases in plants (Bolwell, 1996). The DPI (Diphenyleneiodonium Chloride) is the inhibitor of NADPH-oxidase, which facilitates the alleviation of the effects of ROS (Bolwell *et al.*, 1998). ROS are produced in response to both biotic and abiotic stresses (Anjum *et al.*, 2011). The crop plants either mutated transgenically (transcription factor-TF) or conventional breeding (Maize) and embryogenesis abundant (EA) in potatoes, bananas, and rice are the best defenders against stresses (Newton *et al.*, 2011; Anderson *et al.*, 2004).

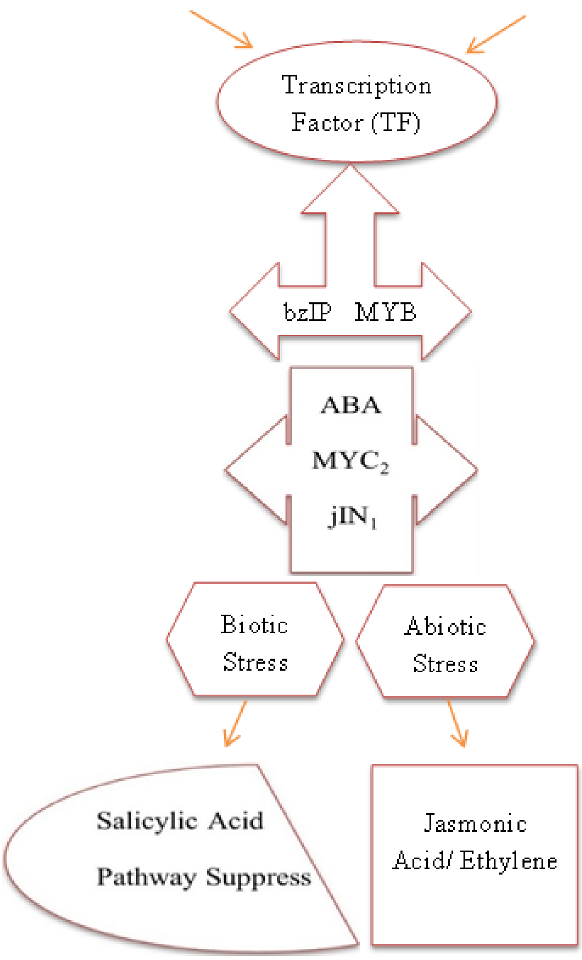

Figure 1. Combine TF and Phytohormones to deal with biotic and abiotic stresses.

***Phytohormonal/Regulator Roles in Defense Mechanism*:** Endogenous phytohormones are LMW molecules that regulate the protective mechanism in plants in a synergistic or antagonistic manner (Figure 2) (Abe *et al.*, 2012). The ABA, Ethylene, Gibberelline and Auxin facilitate the plant in alteration of UPS, transcriptional and post-transcriptional changes in response pathway (Kate and Judy, 2007). The ABA produced in response to biotic and abiotic factors strongly interacts with the ET in an intricate defense mechanism (Jonathan *et al.*, 2004). ABA causes drought stress. It is exaggerated by climatic, edaphic and agronomic factors. The unavailability of water induces the change in stomatal aperture due to ion transport, growth, yield, membrane integrity, pigment content, osmotic adjustment water relations, photosynthetic activity and reduction in turgor pressure (Figure 3) (Roelfsema, 2004; Praba *et al.*, 2009). It weakened germination and poor stand establishment (Harris *et al.*, 2002). The plants become more susceptible to disease pathogens when drought occurs in Sorghum, Beans and Date palms (Suleman *et al.*, 2001). Drought and heat stress cause the opening of chromatin conformation). Jasmonic acid and ethylene act synergistically and antagonistically during the biotic stresses. The ethylene is produced primarily in biotic and abiotic stresses (Van *et al.*, 2015). UPS programs are important against pathogens and favor the plant defense systems because several pathogens hijack the UPS components (Zheng *et al.*, 2006). This component plays an essential role in many plant processes (Imaizumi *et al.*, 2005; Van *et al.*, 2015). It helps in identification by different bioinformatics tools (Moon *et al.*, 2004).

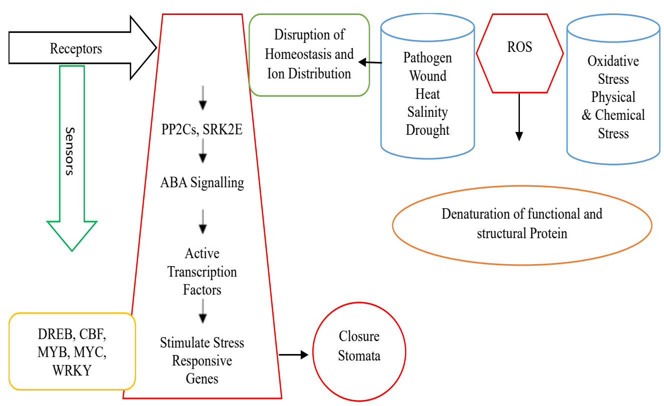

Figure 2. Drought, Heat and ABA defense mechanism

***Bioagents Role in plant protection against stress*:**
Microorganisms are the primary strategy to cope with abiotic and biotic stresses. They play a crucial role in plant growth promotion, nutrient management and disease control by colonizing the rhizosphere/endo-rhizosphere of plants (Saxena *et al.*, 2005). PGPR including *Rhizobium*, *Bradyrhizobium*, *Azotobacter*, *Azospirillum*, *Pseudomonas*

and *Bacillus, Pantoea, Paenibacillus, Burkholderia, Achromobacter, Microbacterium, Methylobacterium, variovorax, Enterobacter* Upadhyay *et al.,* (2009) have been reviewed recently to tolerate abiotic stresses.

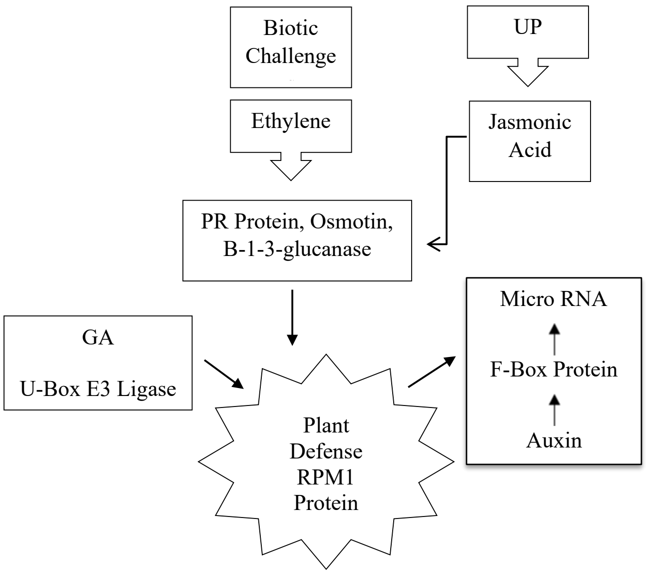

Figure 3. Crosstalk between UPS and Hormones to activate the Plant Defense System.

The viral infection protects the plants from drought in tobacco, beet, and rice. Drought, heat and salinity cause severe threats to 50% of arable land. Rhizobacterial-treated plants resist the attack of drought and bacteria (Timmusk and Wagner, 1999). Nematode ameliorates drought stress (Smith *et al.,* 2007). Different types of signaling have been discussed in the latest supporting literature to confront the environmental challenges (Table 1 and Figure 4). Stress-targeted or exposed areas of the plants are dwelling sites of rhizobacteria (Lifshitz *et al.,* 1986).

1. Thermomicrophiles and halomicrophiles can optimize metabolic activities (enzymatic activities, membrane stability) (Madigen, 1999).
2. Cytoplasmic osmolarity is modulated by the rhizobacteria for the production of osmoprotectants (Blanco, 1994).
3. Oligosaccharides of these bio-agents sustain the turgor pressure (Sandhya *et al.,* 2009a, b).
4. Exopolysaccharides can hold water holding and nutrients cementing.
5. Keeps the *Pseudomonas* hydric stress (Roberson and Firestone, 1992).
6. *Pseudomonas aeruginosa* strain AMK-P6 formulate the chaperons (heat shock (HSPs/thermoprotective proteins) and few bacteria (*Serratia marscescens* strain SRM and *Pantoea dispersa*) release cryoprotective protein (cold shock proteins-CSP) (Koda *et al.,* 2001; Castiglioni *et al.,* 2008), which prevent the denaturation of proteins and proteases during extreme temperature (Ali *et al.,* 2009).
7. Root length and number of tips increased by indole acetic acid, gibberellins and some PGPR in drought stress (Egamberdieva and Kucharova, 2009), *Paenibacillus polymyxa* in *Azospirillum thaliana* (Timmusk and Wagner, 1999) and *A. brasilense* Sp245 in *Triticum aestivum*.
8. Salinity tolerance in tomato, pepper, canola, bean and lettuce by the cooperation of PGPB (Barassi *et al.,* 2006).
9. Production of trehalose metabolism in rhizobia enhances the abiotic stress signaling pathway of leguminous plants (Suarez *et al.,* 2008).
10. Plant physiology and the expression of plant genes become improved by arbuscular mycorrhizal (AM) during water deficiency and drought stress (Ruiz-Lozano and Azcon, 2000).
11. Drought and heat stress in alpine and arid grassland habitats increase by the endophytic symbionts of dark septate fungi (DSF) (Porras-Alfaro *et al.,* 2008).
12. Brassinosteroids cause pleiotropic effects on plant development (Bishop, 2002).

***Plant Modifications to Confront the Varietal Stresses*:**

1. Stomata open in heat stress and closed in cold and water stress (Beattie, 2011). The closed stomata also prevent microbial invasion (Melotto *et al.,* 2006) by induction of ABA (Rizhsky *et al.,* 2004).
2. Callose deposition starts on the cell wall during fungal attack.
3. Transcription factors and effectors proteins (Dubos *et al.,* 2010) increased to overcome the damages caused by heat, salt and heavy metals (Miller *et al.,* 2010).
4. Production of proline to tolerate heat, salt and osmotic stress. Proline and soluble sugar levels elevate during cold stress (Gilmour *et al.,* 2000).
5. Production of secondary metabolites (Osmoprotectants, antioxidants, anthocyanin) to mound the array of stresses (Atkinson *et al.,* 2011).
6. Antioxidants scavenge ROS.
7. Regulation of phytohormonal signal to overcome or interaction (Asselbergs *et al.,* 2007).
8. The plant attracts AMF by secreting strigolactones in its microenvironment, which produces antioxidants (Catalase, superoxide dismutase, Ascorbate peroxidase, glutathione reductase, carotenoids, alpha-tocopherol, proline oxidase, r-glutanyl kinase) osmolytes (Jitender, 2011).
9. Genetical changes help in stress tolerance among crop plants (Swindell, 2006).
10. Heat Shock protein (HSP)-a chaperon, protects the plants from oxidative stress (Rizhsky *et al.,* 2004).
11. Anti-stress plants produce small non-coding RNA to overcome cold stress (Sunkar *et al.,* 2007).

Table 1. Different types of mechanism signaling to ameliorate the stresses via bioagents.

Bio-Agent	Crop	Targeted Stress	Mechanism	References
Bacillus subtilis	*A. thaliana*	Drought	Proline accumulation	Chen *et al.*, (2007)
Rhizobium and Pseudomonas	Zea mays	salinity	Proline accumulation	Bano and Fatima, (2009)
Rhizobium tropici, P. polymyxa	*Phaseolus vulgaris* L.	Drought	Overexpressing trehalose-6-phosphate synthase gene	Figueiredo *et al.*, (2008)
Pseudomonas chlororaphis	*Arabidopsis thaliana*	Drought	Volatile metabolite, 2R, 3R-butanediol, salicylic acid (SA), ethylene and jasmonic acid-signalling pathways	Cho *et al.*, (2008)
Burkholderia phytofirmans PsJN	Grapevine tissue	Cold/ chilling stress	Epiphytic and endophytic colonization of grapevine tissue and organs	Compant *et al.*, (2005)
Glomus versiforme	Citrus	Drought	Osmotic adjustment of the plant under drought stress through enhanced levels of non-structural carbohydrates, K, Ca and Mg.	Wu and Xia, (2006)
Glomus intraradices and Glomus sp. strain	Lavender	Water Deficiency	Overproduction of glutathione and ascorbate	Marulanda *et al.*, (2007)
Gigaspora margarita .	Sorghum	Drought on salt Stressed Soil (Dual)	Promoted stomatal conductance	Minakshi *et al.*, (2011)
Glomus spp.	Maize/ mung bean/ clover	Salt Stress	proline accumulation	Ben Khaled *et al.*, (2003)
Glomus intraradices	*Pterocarpus officinalis*	Flood Stress	Limited the overproduction of acetaldehyde (causing agent of flood injury)	Fougnies *et al.*, (2007)
AM fungi and Bradyrhizobium	*Casuarina equisetifolia*	Flood	Development of adv. roots, aerenchyma and hypertrophied lenticels	Rutto *et al.*, (2002)
Pseudomonas putida, Enterobacter cloacae, P. putida	Tomato	Flood	Synthesis of ACC-deaminase	Grichko and Glick (2001)
PGPR	Chickpea	Metal toxicity	Sequestration of metal ions	Gupta *et al.*, (2004)
Scytonema	Rice	Coastal Salinity	Gibberellic acid and extracellular products	Rodriguez *et al.*, (2006)
Piriformaspora indica (DSF)	*Arabidopsis thaliana, P. indica*	Diverse Set of Stress	upregulation of the message levels for phospholipase Ddelta, calcineurin B-like proteins (CBL 1) and histone acetyltransferase (HAT)	Sheramati *et al.*, (2008)
Paraphaeosphaeria quadriseptata	*Arabidopsis thaliana*	Heat Stress	induction of HSP101 and HSP70	McLellan *et al.*, (2007)
Endophytic fungi Cuvularia spp.	*Dichanthelium lanuginosum*	Heat Stress	Curvularia thermotolerance virus (CatahTV).	Redman *et al.*, (2002)

12. SiRNA regulates both bio and abiotic stresses (Ruiz, 2009).
13. NT26 keeps away pathogens during the cold period of the year (Zhang *et al.*, 2009).
14. Transgenes are successful candidates in plants during tolerance (Wei *et al.*, 2011).
15. SnRK1 is an array sensor that maintains photosynthesis and yields plants (Bartels and Sunkar, 2005).
16. Hydrated amorphous silica in the epidermis of various tissues facilitates the plant to tolerate biotic and abiotic stress (Jian, 2004).
17. Production of stress protein and compatible solutes (Bohnert and Shen, 2000), HSP, late embryogenesis abundant (LEA) protein (Mathur *et al.*, 2008), and osmoprotectants.
18. Three types of compatible solutes improved stress tolerance.
19. For nutrient balance, plants uptake proton as a coupling ion in an ion transport system (Lorenzo *et al.*, 2004).
20. The chemical composition of lignin is changed during the stress.
21. Jasmonate is a defense during the reproductive stages of plants to promote resistance against insects and pathogens (Creelman and Johne, 1995).
22. Fungal chitin and bacterial flagellin show callose deposition and oxidative burst (Flexas *et al.*, 2004) through pathogenesis in many plants (Kim *et al.*, 2006).
23. **23.** Plants produce specific proteins in hypersensitive response (HR) to encounter pathogenicity.

24. Heavy metals, nitric acid and Ca signaling play a vital role in plant immunity response.

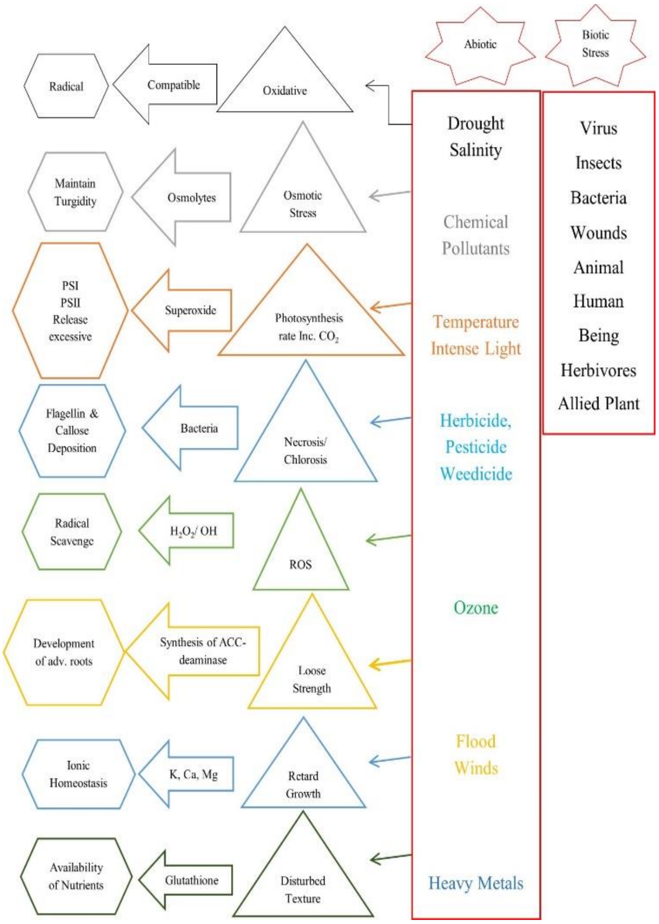

Figure 4. Biotic and abiotic stresses and prevention action

***Conclusion and Future Perspectives*:** Experimental conditions to check the tolerance in plants must be homogenous to natural conditions. It is possible to induce a broad spectrum of changes in crop plants. A significant body of research suggests that there is still a need to determine the mastermind that can play the cross-talk between abiotic and biotic stress. Taking the available current leads, future research is still needed in this area, particularly on field evaluation and application of potential organisms.

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