

# A Review on Polyamines and Biotic Stresses in Plants

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**ABSTRACT**— *The biotic stresses are one of the main causes to the loss of crops, and their development, growth and productivity in the environment. Polyamines are positively charge compounds that have active potential power to DNA, RNA and protein (negative charge compounds), are exist in all living life for their low molecular weight and smallness. Naturally occurring polyamines are involved biotic stress response especially different plants disease and contribute the survival of plant in environment. They contribute a lot of different biological functions, such as controlling the cell cycle, protecting the cell, involve in gene expression, cell signaling replication, transcription, translation and membrane stabilization. This article specially highlights the recent advancement of polyamines in modern plant science research their impact of biotic stress specially the diseases caused by different microorganisms (bacteria, fungus) and creature systems.*

**Keywords**— Plants, polyamines, biotic stresses, PR proteins, MAPKs.

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## 1. INTRODUCTION

Polyamines are low molecular weight aliphatic cations that are ubiquitous present in all life organisms. Their first invention was made as early 1678, when crystals forms from human semen were first described [60] where, two polyamines (Spd and Spm) among three are responsible for the odor of semen. Naturally occurring two polyamines, Put (butane-1, 4-diamine) and cadaverine (pentane-1, 5-diamine), are formed by the decomposition of bacteria which are volatile materials [7]. In plants, there are present three types of major polyamines are putrescine, spermidine, and spermine. But another type of polyamine, cadaverine is present in legumes plant. Polyamines in plants have been mentioned to play important roles in growth, leaf senescence, embryogenesis, organ development, and abiotic and biotic stress response [26, 61, 30, 6, 29, 1, 8, and 27]. Polyamines are positive charge molecules; these compounds have high strong binding affinity to different cellular compounds, including DNA, RNA, chromatin and proteins. Thus, they have been maintain a lot of cellular processes, including regulation of gene expression, replication, transcription, translation, cell proliferation, modulation of cell signaling, and membrane stabilization [50, 8, and 21]. Polyamines can responsible for the regulation of cell death [54, 49]. Polyamines in plants are also contributing for agro-economical importance, including phytonutrient content, fruit quality, and vine life [35, 34 and 62]. Polyamines have defense response against the pathogen attack and reduce diseases [5]. Polyamines metabolism in plant cells create a suitable environment for the interacting the pathogens, such as fungal [4, 16], viral pathogens [55] and mycorrhizae [62]. Thus, a lot of experiments have been acquired regarding on polyamines and diseases of plant. For example, spermine (Spm) not only plays a role as a mediator in defense signaling against pathogen [51] but is also important for resistance to virus infection [65]. In this review, we summarize plant polyamines metabolism and their functions, with specific feature on biotic responses.

## 2. BIOSYNTHESIS AND METABOLISM OF POLYAMINES IN PLANT

The biosynthesis and metabolism of PAs in plants have been showed in figure 1. At the beginning step in the biosynthesis of polyamines that are catalyzed arginine- ornithine decarboxylases (ADC, ODC) from decarboxylation of arginine or ornithine to putrescine. Putrescine is synthesized from ADC pathway that is catalyzed three enzymes including ADC, N-carbamoylputrescine amidohydrolase (CPA) and agmatine iminohydrolase (AIH). Putrescine is synthesized from arginine by three enzymatic steps that are catalyzed by ADC, AIM and CPA. Higher molecular weight polyamine spermine is synthesized from spermidine that is catalyzed by SPM synthase and spermidine is synthesized by the enzyme SPM synthase from putrescine. The enzyme SAM decarboxylase catalyzes S-adenosylmethionine and produce aminopropyl groups. SAM is the main points for the production ethylene. Thus, encoding the genes sequences for all enzymatic activities, only ODC is exceptional in Arabidopsis plant. This plant has no ODC activity [19] and

putrescine is produced from arginine pathway [24, 42]. There are also two genes responsible for SPD synthase (SPDS1 and SPDS2), two for SPM synthase (SPMS and ACL5) [20, 41] and four genes responsible for SAM decarboxylase (SAMDC1, 2, 3 and 4) [59]. The enzyme diamine oxidases (DAOs) is responsible for the catalyze Put is converted into  $\Delta^1$ -pyrroline and as a byproducts are produces ammonia and  $H_2O_2$ . Diamine oxidases (DAO) are found in cell walls of plant, and hydrogen peroxide is produced by the catabolism of Put under salinity conditions. Put is converted in  $\Delta^1$ -pyrroline, is converted  $\gamma$ -aminobutyric acid (GABA), which is converted into succinic acid is a oxidative reactions that is occurred in Krebs cycle [14]. Polyamines have two important functions in plants, the first is ROS scavengers and the second is regulator of redox homeostasis [23]. The production of  $H_2O_2$  in apoplasts or per-oxisomes due to the result of polyamines catabolism and anabolism by the enzymes of DAO and PAO [43].  $H_2O_2$  is a signal molecule and maintains a lot of processes, such as ion channel, salinity response process [40].  $H_2O_2$  maintains the signal in transcription levels [3] and role the adaptation of plant under unfavorable environments through the mediator of polyamines.

### 3. PLANT-PATHOGEN INTERACTION

Polyamines have a defense mechanism against biotic stress specially pathogens [64]. Hypersensitive response is one of the powerful defense mechanism against tobacco mosaic virus when entry into the cells of *Nicotiana tabacum* carrying the resistance gene and activates the cell death [55, 31]. It was noted that spermine located in the apoplast which express pathogen related protein-genes [65]. Spermine enhanced mitogen activated protein kinases or expressed hypersensitive genes when exogenously applied spermine to tobacco leaves and defense response against TMV and cell death [51, 57 and 37]. It is reported that mitochondria is inactivated when produce ROS (reactive oxygen species) in the cells are prerequisite [51] (Fig. 2). Mitochondria involves against pathogen (biotic stress) and PCD (programmed cell death) [2, 27]. Plant polyamines catabolism is linked with cells development, growth and function [9]. Yoda et al. [69, 68] reported that TMV infection to the tobacco leaves and cell death due to the catabolism of polyamines and produce  $H_2O_2$ . Thus, it is clear that plants polyamine catabolized to  $H_2O_2$  and  $H_2O_2$  is a defensive tool against biotic stresses [9, 63]. The overexpression of *ZFT1* gene in tobacco plant prevent against tobacco mosaic virus [57, 58]. Overexpression of *CaPFI* gene in pine plants are more salinity and drought tolerance [52, 47]. It was noted that *CaPFI* transgenic pine linked with polyamines biosynthesis and increased biotic tolerance [53].

Tun et al. [56] suggested that Spm (spermine) and Spd (spermidine) produce nitric oxide (NO) in *Arabidopsis*, but putrescine and arginine are not [11, 10]. NO is a most important inhibitor to inhibits plant mitochondrial oxidative phosphorylation [67] and has a significant role in plant pathogen interactions [46, 45]; thus, it is needed more research for the production of NO through the mediator of polyamines are justified [66].

### 4. PLANT-MYCORRHIZA INTERACTION

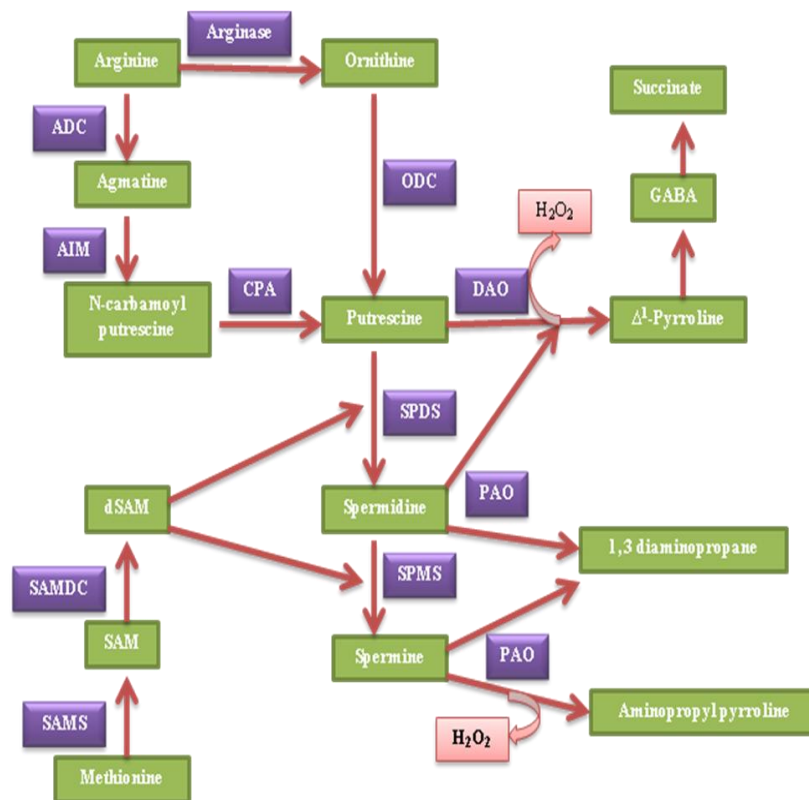
Plants root development, their functions or the interaction between biotic components in soil (microorganisms) and the root tissues. Kytoviita and Sarjala [28] indicated that the symbiosis of mycorrhizae result to increased putrescine in scot pine roots. It is reported that exogenous applied Put in arbuscular mycorrhizae that results to increase the colony in the roots of pea [12, 13]. The function of PAs in arbuscular mycorrhizal infection was, therefore, postulated. Thus, it has been shown that the relationships between symbiotic and non-symbiotic roots have different polyamines level and reported that PA could create a suitable carbon sink environment for symbionts, as a result to fascination of photoassimilates [40]. Later, it was detected high amount of free PAs in mycorrhiza and *Lotus glaber* plants that compared with non-mycorrhiza plants [17, 48]. The association induced resists host defense mechanism. It was also increased PAs level in plants and mycorrhiza. Moreover, the interactions between plants and mycorrhizae, and the role of PAs in symbiotic relationships are less studied [28].

### 5. PLANT VIRUS INTERACTION

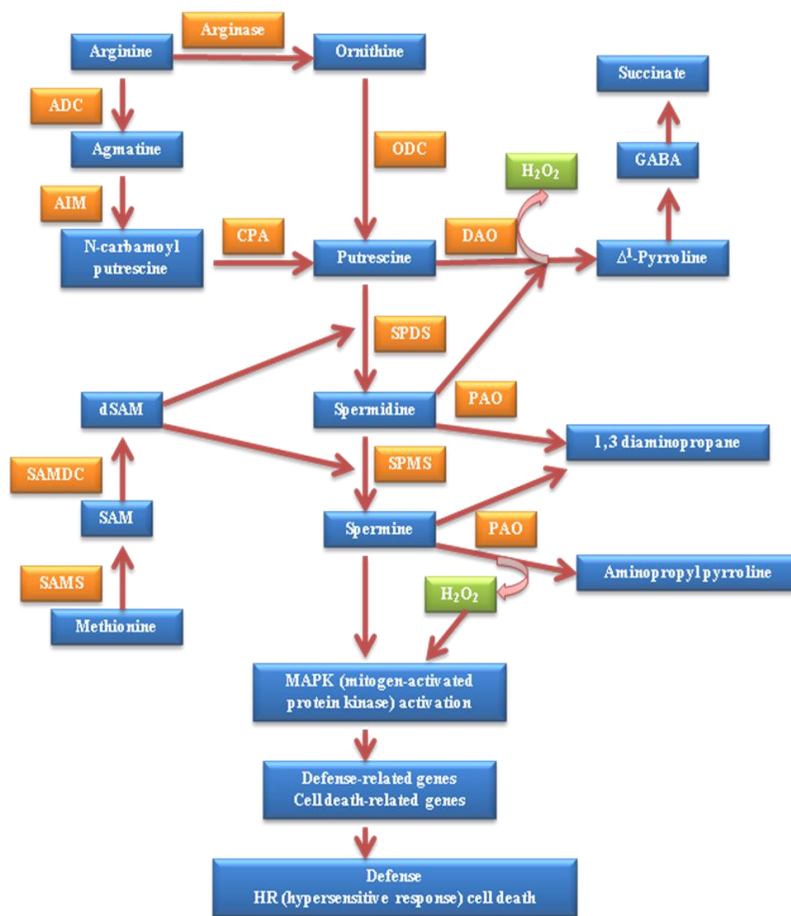
Polyamines metabolism changes in HR of *Nicotiana tabacum* during the infection of tobacco mosaic virus (TMV). Negrel et al. [39] indicated that ornithine decarboxylase (ODC) was increased in *Nicotiana tabacum* leaves during the infection of TMV and accumulated high amounts of HCAAs (hydroxycinnamic acid amides), such as feruloylputrescine and feruloyltyramine [32, 22]. Study of tobacco cv Samsun NN showed that polyamines level changes in tobacco plants by the infection of tobacco mosaic virus and it was showed that high concentrations of putrescine and spermidine accumulated in the necrotic area of leaves and lesion formation [55, 25]. It was suggested that high amounts of polyamines are needed for the evolvment of necrotic lesion of leaves. Reduce 90% lesion formation in tobacco leaf discs by inoculation of TMV. This is indicated that HCAAs have active role in TMV resistance. Thus, PAs and HCAAs play an important role in hypersensitive response to TMV that protect viral replication [33].

## 6. DEFENSE OF PLANT

The external and internal environments of plants and their balance are equally maintained by plant organelles. It was reported that exogenously applied Spm (spermine) in *Nicotiana tabacum* leaves that leads to malfunction of mitochondria, increased marker gene (HR, hypersensitive response), mitogen activated protein kinases (MAPKs) and programmed cell death (PCD) [57, 37 and 36] and pathogen related proteins (PRPs) are induced by lesion formation in tobacco leaves when high amount of Spm are accumulated in cells and resistance against tobacco mosaic virus. Finally, it was identified that Spm activates two protein kinases including salicylic acid induced protein kinase and wound induced protein kinase and the expression of genes which involved to defense mechanism and they protect the plant [15, 51].



**Figure 1:** Common channel for the metabolism and synthesis of PAs in plant. ADC: Arginine decarboxylase, ODC: Ornithine decarboxylase, SPDS: Spermidine synthase, SPMS: Spermamine synthase, AIM: Agmatine iminohydrolase, CPA: N-Carbamoyl putrescine amidohydrolase, DAO: Diamine oxidase, PAO: Polyamine oxidase, SAMDC: S-adenosylmethionine decarboxylase, SAM: S-adenosyl methionine, GABA:  $\gamma$ -aminobutyric acid.



**Figure 2:** The hypothetical role of PAs in plant survival against pathogens.

## 7. CONCLUSIONS AND FUTURE PROSPECTS

Different food/vegetable crops in the worlds that are differently affected by biotic stresses and their productivity is decreasing every year. Thus, it is very necessary to improvement diseases resistant plant variety. Polyamines have physiological and cellular functions in biotic stress tolerance. To perceive the function of polyamines in growth and differentiation, the version of plant ‘PAs modulation’ has been elucidated. To find out the defense mechanisms or ion channels of polyamines that plays a defensive role in biotic stresses. Therefore, a lot of recent biological techniques required specially molecular biology and genetic engineering techniques (microarray, transcriptomics, metabolomics, proteomics, reverse genetics approaches) for the improvement of PAs transgenic plant to diseases resistant and their functions will be implicate in plant sciences.

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