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RELATIONSHIP BETWEEN JASMONATES AND ETHYLENE IN REGULATION OF SOME PHYSIOLOGICAL PROCESSES IN PLANTS UNDER STRESS CONDITIONS

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Introduction

Jasmonic acid (JA), methyl jasmonate (JA-Me) and their related compounds which are designated as jasmonates, are widely distributed in the plant kingdom and show various important biological activities in the regulation of plant growth and development, resulting in a consideration that they are putative new plant hormones [UEDA, KATO 1980; KODA 1992; SEMBDNER, PARTHIER 1993; CREELMAN, MULLET 1995, 1997; MUROFUSHI et al. 1999; SANIEWSKI, CZAPSKI 1999]. Endogenous levels of jasmonates, mainly JA, increase rapidly and transiently in plants or their organs under both abiotic stress conditions, such as mechanical wounding, osmotic stress, water deficit, dessication stress, heavy metals (Cu^{++}, Cd^{++}, Ag^{+}) and touching, as well as biotic stress ones, such as pathogen infection and an insect attack, and by different natural elicitors-systemin, oligogalacturonide fragments of pectic polysaccharides (i.e. cell wall of yeast or pathogens), chitosan and chitin [CREELMAN, MULLET 1995; SANIEWSKI 1997]. Jasmonates also consist of an integral part of the signal transduction chain between stress signal(s) and stress response(s). Cooperative cross-talk among jasmonates and various hormonal signals, especially ethylene occurs in regulation of growth and development and in defense responses against a wide variety of abiotic and biotic agents. In this paper, we focused on and reviewed interactions of jasmonates with ethylene under stress conditions.

Possible role of jasmonates in ethylene biosynthesis in intact plants

Jasmonates have been reported to control ethylene biosynthesis in intact plants and their organs by stimulating activities of ACC synthase and ACC oxidase [SANIEWSKI 1995, 1997; SANIEWSKI et al. 1995]. Exogenously applied JA-Me stimulates ethylene production in tomatoes at different stages of ripening and in preclimacteric apples. FAN et al. [1998] suggested that jasmonates together with

ethylene are involved in regulating ripening at an early growth stage of climacteric fruits such as tomatoes and apples.

Treatment of JA-Me at the concentration of 1 mM to broccoli (*Brassica oleracea* L. cv. Italica) florets significantly promoted ethylene production and ACC oxidase activity during senescence. These results suggest that jasmonates are substantially associated with promoting senescence by enhancing ethylene production [WATANABE et al. 2000]. GARCIA-PINEDA and LOZOYA-GLORIA [1999] showed that JA-Me induced gene expression of 1-aminocyclopropane-1-carboxylic acid (ACC) oxidase in pepper (*Capsicum annuum*).

On the other hand, we have recently suggested that ethylene exogenously applied affects endogenous levels of jasmonates and/or their sensitivities in plant tissues [SANIEWSKI et al. 1999]. As shown in Fig. 1, similar considerations have been reported in relation to gene expressions after pathogen infection. We would like to described the details in what follows.

Jasmonates and ethylene biosynthesis, as well as reactive oxygen species (ROS) generation under stress conditions

Plants are always exposed to biotic and abiotic environmental stresses that influence their growth and productivity.

Mechanical wounding and other abiotic and biotic stresses (pathogen infection and insect invasion) are well known to be common factors inducing biosynthesis of ethylene and jasmonates in plants. It is still open question what is a role of JA in controlling ethylene biosynthesis in mechanically wounded tissues, and plants infected and attacked by pathogens and insects, respectively [SANIEWSKI 1997].

Adaptation to abiotic and biotic stresses is crucial for growth and survival of plants. Reactive oxygen species (ROS) generation, including singlet oxygen, superoxide anion radical ($O_2^{\cdot -}$), hydrogen peroxide and hydroxyl radical, is usually a rapid plant response to pathogen infection and/or herbivore attack and to other abiotic and environmental stresses as well. Recent evidence indicates two very distinct roles for ROS during pathogen attacks and abiotic stresses: they can either serve as destructive molecules or as defensive factors [KUŹNIAK, URBANEK 2000; DAT et al. 2000; OROZCO-CÁRDENAS et al. 2001].

ROS are unavoidable, transient products of normal cellular metabolisms. Under normal environmental conditions they are rapidly metabolized. However, when plants are subjected to environmental stresses, excess ROS are generated. Unless these ROS are efficiently metabolized, they oxidize and damage membrane lipids, proteins and nucleic acids. That leads to cellular disfunction and can ultimately cause cell death. So, their generation is frequently considered deleterious and harmful. To protect themselves against toxic ROS, plants employ the antioxidant enzymes and metabolites that catalyze scavenging ROS, in which superoxide dismutase, catalase, ascorbate peroxidase, glutathione peroxidase, ascorbate, glutathione and tocopherols are involved.

On the other hand, recent studies have demonstrated that ROS may be implicated in plant defense systems. Evidence for defensive roles of ROS comes from the observation: 1) Different environmental stress factors such as herbi-

vores, pathogens, ozone, cold, high light intensity, mechanical wounding, salinity, drought and UV radiation stimulate the production of ROS; 2) Several factors stimulating oxidative burst and ROS generation induce gene expressions of the same defense proteins such as glutathione transferase, glutathione peroxidase, ascorbate peroxidase and some PR-proteins induced by $O_2^{\cdot -}$ or H_2O_2 treatment alone as well. As defensive factors, they can directly inhibit pathogen growth, limit the spread of pathogen infection by strengthening plant cell wall, activate defense genes acting as signaling molecules and be involved in hypersensitive response (HR) [HEATH 2000]. The HR, a well-known resistance mechanism, is characterized by rapid, localized cell death around the site of infection and so it can play efficacious role in limiting the spread of pathogen. HR also has been suggested to release signals that activate variety of defense-related genes and systemic resistance. Some data suggest that HR may function more by releasing signaling molecules involved in the induction of defense genes than as a direct defense mechanism. KENTON et al. [1999] documented the accumulation of JA in hypersensitive response tissues of tobacco plants. ROS have been implicated as a part of the signal systems responsible for inducing the responses of plants to both biotic and abiotic stresses. Especially H_2O_2 and $O_2^{\cdot -}$ have been suggested to be diffusible signals that activate genes in local and systemic acquired resistance.

The defensive role of ROS requires their cellular concentration to be carefully controlled. Preventing the high, lethal concentration of ROS generated in response to stress is a promoting way to counteract their damaging action. To avoid deleterious accumulation of ROS, they are kept under control by various antioxidant enzymes and metabolites.

Evidence coming from various observations shows that JA and JA-Me are believed to play an important role in influencing plant resistance to biotic and abiotic stresses [REYMOND, FARMER 1998]. Environmental stresses increase endogenous levels of JA, and exogenous application of JA stimulates the expression of defensive responses. A burst of ROS generation may be involved in membrane depolarization which activates octadecanoid pathway, leading to JA biosynthesis. Generated or applied JA further enhances ROS accumulation in various plant species. There is evidence that H_2O_2 production in wound responses requires a functional JA-mediated signaling pathway.

Under various stresses jasmonates as signaling molecules have been reported to induce genes encoding antimicrobial secondary metabolites – phytoalexin, terpenoids, phenylpropanoids, alkaloids; antimicrobial proteins – thionins, defensins, osmotin; proteinase inhibitors; antioxidant enzymes – glutathione transferase, ascorbate peroxidase, chalcone synthase, phenylalanine ammonia lyase and other PR-proteins [RAKWAL et al. 1999; OROZCO-CÁRDENAS et al. 2001].

Jasmonates have also been implicated as intermediate signals in elicitor-induced secondary metabolite accumulation and other defense reactions against pathogen infections and insect attacks. Exogenously applied JA enhances elicitor-induced accumulation of proteins related to pathogenesis [MEMELINK et al. 2001]. Colonization of the roots of several plant species by selected strains of nonpathogenic *Pseudomonas fluorescens*, similarly to elicitors treatment, has been demonstrated to induce resistance in uninfected plant parts towards a broad spectrum of pathogens [VAN WEES et al. 2000]. Systemic resistance induced by this kind of colonization requires JA and is based on the enhance of sensitivity to JA rather

than on an increase of its production.

In studies of the responses of higher plants to wounding, the relationships among gene expression of wound-inducible ACC synthase, the effects of JA and the roles of ROS have not been clarified yet.

Gene expression of wound-inducible ACC synthase (*CM-ACS1*) in *Cucurbita maxima* induced by wounding and the accumulation of the *CM-ACS1* transcript enhanced by wounding have been shown. Initially these were induced by ROS generating in disks upon wounding. Cooperative mechanisms by ROS and JA were then introduced, in which the level of JA increased at a later time after wounding [WATANABE, SAKAI 1998; WATANABE et al. 2001a].

Recently, WATANABE et al. [2001b] isolated further two new cDNA fragments (*CM-ACS3* and *CM-ACS4*) that encode ACC synthases from mesocarp tissue of *Cucurbita maxima* fruit. The accumulation of specific transcripts for *CM-ACS1*, *CM-ACS3* and *CM-ACS4* in tissue disks of *C. maxima* was induced by mechanical wounding. They also demonstrated that the expression of the three ACC synthase genes in wounded mesocarp tissue of *C. maxima* are differentially regulated by ethylene and JA, and ROS stimulates the accumulation of all three transcripts (Table 1).

Table 1; Tabela 1

The effect of jasmonic acid (JA), ethylene and an inhibitor of the generation of ROS, on the expression of three genes for wound-inducible 1-aminocyclopropane-1-carboxylate (ACC) synthase in winter squash (*Cucurbita maxima*)
(Table prepared on the basis of data of WATANABE et al. [2001b])

Wpływ kwasu jasmonowego (JA), etylenu i inhibitora wytwarzania wolnych rodników (ROS), na ekspresję trzech genów syntazy kwasu 1-aminocyklopropano-1-karboksylowego, indukowanych po uszkodzeniu *Cucurbita maxima*
(tabela opracowana na podstawie danych z pracy WATANABE i in. [2001b])

Gene encoded ACC synthase Geny kodujące syntazę ACC	Gene expression; Ekspresja genów			
	wounding uszkodzenie	wounding +JA uszkodzenie + JA	wounding + ethylene uszkodzenie + etylen	wounding + DPI* uszkodzenie + DPI
CM-ACS1	induction indukcja	stimulation stymulacja	inhibition hamowanie	inhibition hamowanie
CM-ACS3	induction indukcja	without effect bez wpływu	stimulation stymulacja	inhibition hamowanie
CM-ACS4	induction indukcja	inhibition hamowanie	without effect bez wpływu	inhibition hamowanie

* DPI, diphenylene iodonium – an inhibitor of the generation of ROS by NAD(P)H oxidase; inhibitor wytwarzania wolnych rodników (ROS) przez oksydazę NAD(P)H

On the other hand, the important role of ROS and JA as mediators in early responses to wounding or attack by pathogens has also been reviewed by LOW and MERIDA [1996], WASTERNACK and PARTHIER [1997] and KUŹNIAK and URBANEK [2000].

Among various air pollutants, the tropospheric ozone causes the greatest damage to both natural and cultivated plants [RAO et al. 2000; SCHRAUDNER et al.

1997]. Damage symptoms in plants range from inhibition of photosynthesis and associated growth inhibition, and yield loss to premature senescence and tissue necrosis. Ozone enters the leaves via stomata, diffuses through intercellular air spaces, and in apoplast it may react with water or some cell wall constituents and is immediately converted to ROS. Then O_3 or ROS alters the physicochemical properties of plasmalemma by its depolarization and initiate lipid peroxidation. The plasmalemma depolarization activates octadecanoid pathways leading to jasmonate biosynthesis. These signaling molecules, in turn, enhance production of ROS, induce cell death and influence expression of defense genes. The phytotoxicity of O_3 is likely a result of deleterious actions associated with ROS. Active ROS production during O_3 exposure has been detected [RAO et al. 2000]. Plant antioxidant systems are thought to be potential factors in ozone tolerance. Correlations between higher activities of antixidant enzymes and tolerance to ozone were established.

It has been demonstrated that ozone exposure activates HR-like cell death pathways in plants. A potential role of JA as a central molecule modulating stress responses is shown by the observation that its application prior to O_3 exposure reduces O_3-induced concentration of H_2O_2 and abolishes O_3-induced cell death in tobacco [ORVAR et al. 1997], poplar [OVERMYER et al. 2000] and high O_3-sensitive *Arabidopsis* ecotype [RAO et al. 2000]. Additional evidence implicating the role of JA in modulating the magnitude of O_3 induced reactions is connected to harpin, a proteinaceous elicitor of defense gene expression, isolated from different pathogenic bacteria. It has been reported that the JA-Me pretreatment inhibits the harpin induced defense responses such as H_2O_2 generation, HR and gene expression encoding phenylalanine ammonia lyase in tobacco cell suspension cultures [ANDI et al. 2001]. It is possible that jasmonates as key signal molecules controlling defense responses moderate the range of plant reactions to stresses depending on physiological situation of plant tissues exposed to detrimental factors.

A recent survey of various plant species indicated a relationship between O_3 sensitivity and O_3-induced stress ethylene production. O_3-induced ethylene biosynthesis is believed to induce premature senescence and/or react with ethylene to form damaging ROS [RAO et al. 2000]. It is well known that inhibition of ethylene biosynthesis reduced O_3-induced damage in tomato [TUOMAINEN et al. 1997] and treatment of plants with norbornadiene, an inhibitor of ethylene perception, blocked O_3-induced cell death [BAE et al. 1996]. Preliminary results indicate that ethylene is a major regulator of O_3-induced defense responses and cell death and that ethylene signaling pathways interact with both salicylic acid and JA-dependent signaling pathways [RAO et al. 2000].

Interaction of jasmonates with ethylene in regulation of some physiological processes in plants under stress conditions

a) Synergistic interaction

Jasmonates have been well known to induce strongly gene expressions of wound- or defence-related ones when plants have some stresses from mechanical injury and pathogen infection or insect invasion, resulting in the accumulation of

proteinase inhibitors (PI) and other pathogenesis-related proteins [O'DONNELL et al. 1996; KOIWA et al. 1977; SEO et al. 1997]. The interaction of jasmonates with ethylene has been reported, in which these compounds acted together to regulate PI gene expression during wound response. Gene expressions of these proteins were inhibited by inhibitors of JA and ethylene biosynthesis [O'DONNELL et al. 1996]. Wounding has also been reported to be responsible for the regulation of a wide variety of other genes: cathepsin D inhibitor, chloramphenicol acetyltransferase, vegetative storage protein, lipoxygenase, chalcone synthase and hydroperoxide lyase. Jasmonates have been reported to increase an accumulation of mRNA encoding these enzymes [DE WALD et al. 1994; ROJO et al. 1998].

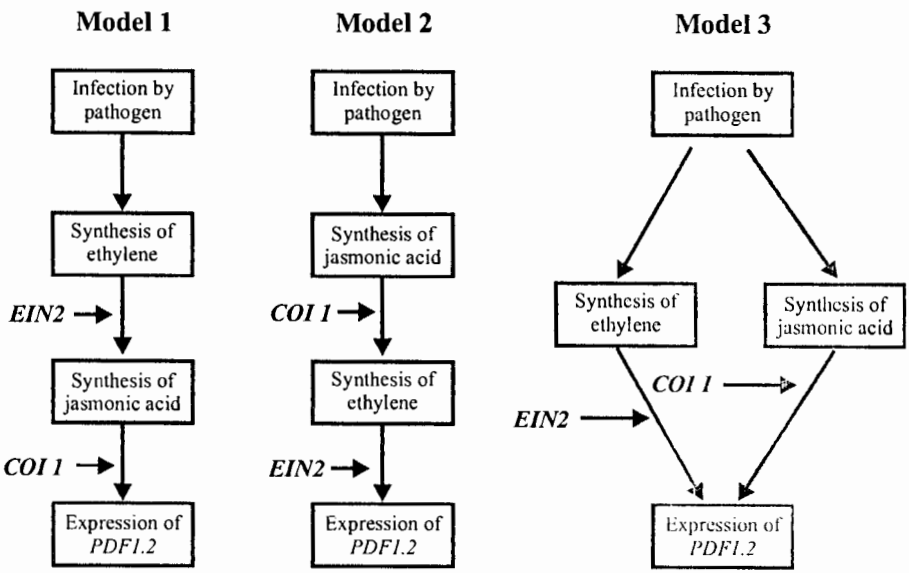
Combinations of jasmonates and ethylene caused synergistic induction of pathogenesis-related gene expression osmotin mRNA in tobacco seedlings [XU et al. 1994]. It remains to be demonstrated whether ethylene acts upstream or downstream in concert with jasmonates.

There was documented synergy between jasmonates and ethylene for the induction of the plant defense gene of *PDF1.2* in *Arabidopsis thaliana* infected by *Alternaria brassicicola* [PENNINCKX et al. 1998]. Conceptually, three different models for the interaction between JA and ethylene are suggested by PENNINCKX et al. [1998] (Scheme 1).

Scheme 1; Schemat 1

Three models for the interaction between ethylene and jasmonate signals during activation of the *PDF1.2* gene in pathogen-challenged *Arabidopsis* plants [PENNINCKX et al. 1998]

Trzy modele interakcji między etylenem i kwasem jasmonowym w czasie aktywacji genu *PDF1.2* u *Arabidopsis* w wyniku infekcji przez patogena [PENNINCKX i in. 1998]



EIN2 – a component of the ethylene signal transduction pathway; czynnik transdukcji sygnału w szlaku etylenowym

COI1 – a component of the jasmonate signal transduction pathway; czynnik transdukcji sygnału w szlaku kwasu jasmonowego

Model 1 implies that pathogen infection initially stimulates production of ethylene, which subsequently stimulates production of jasmonates, which in turn activates *PDF1.2*. Model 2 implies that pathogen infection initially leads to enhanced production of jasmonates, which subsequently triggers elevated production of ethylene, which in turn controls *PDF1.2* expression. Model 3 predicts that pathogen infection results in simultaneous production of ethylene and jasmonates, which are both required for induction of *PDF1.2*.

As described above, one of the most rapid events observed during plant-pathogen interactions is the production of ROS, which are initially in the form of superoxide anion, by NADPH oxidase complex [MEHDY 1994; LAMB, DIXON 1997]. Activation of *PDF1.2* by superoxide anion-generating paraquat (subherbicidal level) has been shown to require functional ethylene and jasmonates response pathways [PENNINCKX et al. 1998].

Gum induction is the first example for an important interaction of jasmonates and ethylene under stress conditions. Gums are a secretion mainly consisting of polysaccharides exuded onto surface of the fruits or the shoots when some plants have several kind of stresses including physical injury, insect attack and pathogen infection. Gum formation in tulip bulbs or stone fruit trees is induced by ethylene and ethylene-releasing compound, ethephon. It has been shown that jasmonates have a promoting effect on the induction and/or production of gums in stone fruit trees and tulips. It has been found that JA-Me causes a strong induction of gum formation in the bulb, stem and basal part of the leaf in tulips. It should be mentioned that ethylene did not induce gums in stem and leaves of tulips. It has been shown, however, that the simultaneous application of ACC (1-aminocyclopropane-1-carboxylic acid) with JA-Me greatly accelerates gum formation in bulbs, stems and leaves of tulip in comparison with JA-Me treatment alone [SANIEWSKI et al. 1999; SANIEWSKI et al. 2000].

Disease resistance is associated with a plant defense response that involves an integrated set of signal transduction pathways. SCHENK et al. [2000] examined changes in the expression patterns of 2375 selected genes by cDNA microarray analysis in *Arabidopsis thaliana* after inoculation with incompatible fungal pathogen *Alternaria brassicicola* or treatment with defense-related signaling molecules: JA-Me, ethylene and salicylic acid (SA). In leaves inoculated with *A. brassicicola*, the transcript levels of 168 genes were increased whereas those of 39 genes were decreased. Similarly, the transcript abundance of 221 genes for JA-Me, 55 genes for ethylene, and 192 for SA was increased as a result of treatment with these signal molecules. In contrast, transcript abundance of 96, 16 and 131 genes was reduced after treatment with JA-Me, ethylene and SA, respectively. Of 168 genes that were significantly induced by fungal inoculation, 33, 4 and 21 genes (50 genes in total) were also induced by JA-Me, ethylene and salicylic acid, respectively. JA-Me and ethylene jointly regulate transcription of 36 of 2375 genes tested. In addition, 50% genes induced by ethylene treatment were also induced by JA-Me treatment. These results indicated the existence of a substantial network of regulatory interactions and coordination occurring during plant defense among the different defense signaling pathways [SCHENK et al. 2000].

Synergistic interaction between jasmonates and ethylene was documented in induction of basic chitinase [NORMAN-SETTERBLAD et al. 2000].

Jasmonates are required, alone or in combination with ethylene, for defense against insects and necrotrophic pathogens [MCCONN et al. 1997; VIJAYAN

et al. 1998; THOMMA et al. 2000].

Interaction of JA-Me and ethylene and binding models for elicited biosynthetic steps of paclitaxel in suspension cultures of *Taxus cuspidata* and *T. Canadensis* were elaborated by MIRJALILI and LINDEN [1996], PHISALAPHONG and LINDEN [1999].

HUNG and KAO [1996] suggest that jasmonate-promoted senescence is mediated through an increase in ethylene sensitivity in detached maize leaves.

b) Ethylene suppresses processes induced by jasmonates

There are many reports that ethylene substantially suppresses some physiological processes induced by jasmonates. In *Nicotiana* species, jasmonates act as a signal molecule for the herbivore- and wound-induced accumulation of nicotine, an important defense compound in these plants [BALDWIN 1999]. It was documented that ethylene suppresses jasmonate-induced gene expression in nicotine biosynthesis [IMANISHI et al. 1998; SHOJI et al. 2000]. It is significant that feeding experiment using hawkmoth (*Manduca sexta*) results in a rise in ethylene biosynthesis that reduces JA-induced nicotine biosynthesis in *Nicotiana attenuata*, thus diminishing plant defenses [KAHL et al. 2000]. In ethylene-insensitive mutants, gene expression of the JA-responsive vegetative storage proteins (*VSP*) is also reported to increase, suggesting that the signal pathway represses the induction of *VSP* [ROJO et al. 1999; NORMAN-SETTERBLAND et al. 2000]. Antagonistic interactions between JA and ethylene are also reported to regulate the antifeedant plant lectin *GS-II* in locally wounded leaves of *Griffonia simplicifolia* [ZHU-SALZMAN et al. 1998]. When *Arabidopsis* leaves were damaged, several jasmonate-inducible genes were repressed in locally wounded tissue through the production and perception of ethylene [ROJO et al. 1999].

c) Jasmonates suppresses processes induced by ethylene

Contrary to this it has been shown that jasmonates substantially suppress the formation of apical hook induced by ethylene in *Arabidopsis thaliana* [ELLIS, TURNER 2001].

JA carboxyl methyltransferase – a key enzyme for jasmonate-regulated plant responses

SEO et al. [2001] suggested that the S-adenosyl-L-methionine: JA carboxyl methyltransferase (JMT) is a key enzyme for jasmonate-regulated plant responses. Activation of JMT expression leads to production of JA-Me. JMT was expressed differentially in different organs at particular developmental stages and induced by wounding, and was activated when *Arabidopsis* tissues were treated with exogenous JA-Me. Thus, JA-Me can amplify JMT expression induced at the developmental stages and by external stimuli including wounding. JA-Me can act as an intracellular regulator, a diffusible intercellular signal transducer, or an airborne signal mediating intra- and interplant communications. Some signals generated during an early event of developmental processes or defense responses may activate JMT that can self-amplify, stimulate, or regulate its own expression,

propagating the JA-Me-mediated cellular responses throughout whole plants [SEO et al. 2001].

It is interesting that ethylene inhibited JMT expression [SEO et al. 2001]. The result suggests that the synergistic effect exerted by ethylene on the activation of *PDF1.2* is not by the enhancement of JA-Me synthesis but rather by a cross-talk between the independent signaling pathways derived from them.

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Key words: ethylene, jasmonates, physiological processes, stress conditions, regulation, reactive oxygen species

Summary

A relationship between jasmonates and ethylene in regulation of some physiological processes in plants under stress conditions is presented. Jasmonates are naturally occurring plant hormones showing various important biological activities in the regulation of plant growth development and in defense responses against a wide variety of abiotic and biotic agents. Jasmonates have been reported to control ethylene biosynthesis in intact plants and their organs. Mechanical wounding and other abiotic (osmotic stress, water deficit, dessication stress, heavy metals, touch, ozone) and biotic stresses (pathogen infection and insect invasion) are well known to be common factors inducing ethylene and jasmonates biosynthesis, and reactive oxygen species generation (ROS). Jasmonates have been well known to interact with ethylene in regulation of different processes; various kinds of interactions were documented: 1) synergistic interaction (i.e gene expression of proteinase inhibitors, osmotin, defensin), 2) ethylene suppresses processes induced by jasmonates (i.e. biosynthesis of nicotine, vegetative storage proteins and lectins), 3) jasmonates suppress processes induced by ethylene (i.e. ethylene-induced apical hook). Jasmonic acid carboxyl methyltransferase (JMT) is a key enzyme for jasmonate-regulated plant responses. Activation of JMT expression leads to production of methyl jasmonate (JA-Me). JA-Me can act as an intracellular regulator, a diffusible intercellular signal transducer, or an airborne signal mediating intra- and interplant communications. Jasmonates represent an integral part of the signal transduction chain between stress signal(s) and stress responses(s), in most cases of the induction of gene expression and the accumulation of defense specific proteins and secondary metabolites.

ZALEŻNOŚCI MIĘDZY JASMONIANAMI A ETYLENEM W REGULACJI NIEKTÓRYCH PROCESÓW FIZJOLOGICZNYCH U ROŚLIN W WARUNKACH STRESOWYCH

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Słowa kluczowe: etylen, jasmoniany, procesy fizjologiczne, warunki stresowe, regulacja, reaktywne formy tlenu

Streszczenie

Zależności między jasmonianami i etylenem w regulacji niektórych procesów fizjologicznych u roślin w warunkach stresowych są przedmiotem tego przeglądu. Jasmoniany są naturalną grupą hormonów roślinnych i wykazują wiele ważnych funkcji fizjologicznych w regulacji wzrostu i rozwoju roślin i w reakcjach obronnych przeciwko różnym czynnikom abiotycznym i biotycznym.

Wykazano, że jasmoniany odgrywają ważną rolę w regulacji biosyntezy etylenu w roślinach nienaruszonych i ich organach. Mechaniczne uszkodzenie i inne czynniki abiotyczne (stres osmotyczny, deficyt wodny, stres desykacyjny, metale ciężkie, dotyk, ozon) i czynniki biotyczne (infekcja przez patogeny i żerowanie owadów) powodują wzmożoną biosyntezę etylenu i jasmonianów oraz generowanie reaktywnych form tlenu (ROS). Jasmoniany współdziałają z etylenem w regulacji różnych procesów, a interakcje te mają różny charakter: 1) synergistyczne współdziałanie (np. ekspresja genów inhibitorów proteinaz, osmotyny, defenzyny), 2) etylen hamuje procesy indukowane przez jasmoniany (np. biosynteza nikotyny, wegetatywnych białek zapasowych, lektyn), 3) jasmoniany hamują procesy indukowane przez etylen (np. wygięcia części wierzchołkowych powodowane przez etylen). Metylotransferaza karboksylowa kwasu jasmonowego (JMT) jest kluczowym enzymem w procesach regulowanych przez jasmoniany w roślinach. Aktywacja ekspresji JMT doprowadza do powstawania jasmonianu metylu (JA-Me) z kwasu jasmonowego. JA-Me może działać jako regulator w obrębie komórki i jako międzykomórkowy sygnał transdukcyjny, a jako lotna substancja stanowi przekaźnik informacji między roślinami. Sugeruje się, że endogenne jasmoniany stanowią przekaźnik informacji między sygnałem stresowym a reakcją stresową, polegającą głównie na indukcji ekspresji genowej i biosyntezie specyficznych białek i metabolitów wtórnych.

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