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Review article

Resistance induction in crop plants against insect herbivores and pathogens by elicitors

Hamdy A. Eldoksch[1] and Abdel-Khalik H. El-Sebae[2]
[1]Central Agric. Pesticide Laboratory, Agricultural Research Center, Dokki, Giza, Egypt, E-mail (hamdyarc@yahoo.com)
[2]Pesticide Chemistry Dept., Fac. of Agric., Alexandria University, El-Shatby, Alexandria, Egypt, E-mail (El_Sebae@hotmail.com)

Abstract

Crop plants, during their life cycle, can protect themselves against the attack of arthropod herbivores and pathogens with various resistance mechanisms. The jasmonate and salicylate signaling pathways are two inducible defense responses that can protect plants against these multiple pests by the production and synthesis of a number of phytochemicals and defensive proteins such as proteinase inhibitor proteins, polyphenol oxidase and steroid glycoalkaloids as well as pathogenesis-related proteins (PR-proteins) and phytoalexins that target physiological processes in the attacking organisms. Secondary metabolites produced by plants in response to induction by biotic or abiotic elicitors also include volatile organic compounds that attract natural enemies of insect herbivores. Research efforts in the area of inducible plant resistance is now being developed concerning the use of induced plant genes for insect herbivory and pathogen resistance and the potential of using induced resistance (IR) or systemic acquired resistance (SAR) as environmentally safe methods of insect and disease pest control, respectively. This paper views this research as a body to fully utilize the information in formulating future development of plant protection products and farming practices that can assist growers in controlling arthropod herbivores and pathogen attack on high cash value plant crops. The integration of induced host plant resistance and semiochemical approaches with other methods of pest management would be accepted as compatible with integrated pest management system in conventional agriculture as well as with organic farming practices.

Keywords: Induced resistance, salicylate and jasmonate pathways, elicitors, secondary metabolites, tritrophic interactions, integrated pest management.

1. Introduction

Crop plants during their life cycle are susceptible to a broad range of herbivore insects and pathogenic fungi and bacteria which if uncontrolled can cause high infestation rates and great crop loose. Control of plant diseases and herbivores is primarily dependent on application of synthetic fungicides and insecticides within integrated pest management programs. Although effective, their repeated use led to the appearance of many resistant strains of these pests and increasing tolerance of these strains to applied pesticides. Besides, these chemicals also have undesirable side effects on non-target organisms including natural enemies and pollinators and cause environmental and human health hazards (National Research Council, 1986). The withdrawal of many pesticides from agricultural use has stimulated the search for more acceptable and safe alternatives which are needed for economically viable and environmentally safe crop protection. One such possible alternative to pesticides is host plant resistance. Host plant resistance can be manipulated through breeding programs or through phenotypic manipulations of plant resistance (induced resistance) using natural elicitors such as jasmonic acid or salicylic acid. Recently, much research efforts have been focused on the interaction between host plants, insect herbivores and plant pathogens. These researches have exhibited many vital and important responses that are used by plants to protect themselves from the damage that can occur from insect feeding and pathogen infection (Turlings and Ton, 2006; Karban and Chen, 2007).

The jasmonate and salicylate signaling pathways are two inducible defense responses that can protect plants against multiple pests. Inducible resistance mechanisms such as systemic acquired resistance (SAR) are wide-spectrum plant defense responses that can be induced biologically by challenging a plant with a weaker strain of a specific pathogen or exposing a plant to natural or synthetic chemical elicitors. SAR has been studied for the past 100 years as a means of increase resistance to fungal, bacterial and viral pathogens in crop plants such as potato, tomato, wheat and rice (Agrios, 1997). The term "induced resistance" (IR) is used to describe plant defenses that are induced by insect damage and that render plants more resistance to subsequent attack by a broad range of herbivores (Karban and Baldwin, 1997). Induced resistance has been demonstrated in tomato, cotton, corn and many other plant species.

The signaling events which mediate different resistance responses in plants are important from an agricultural perspective. So, an understanding of the interactions between the different defense pathways targeted towards different pests and pathogens is essential for the improvement of crop protection programs. Thus, inducible plant defenses could potentially be utilized to develop much-needed alternative pest management strategies for insect herbivory and plant diseases. This review article is oriented towards the factors which influence the activation of inducible plant resistance mechanisms with special reference to the molecular bases of plant defense responses against insect herbivores and pathogens which lead to better understanding of the complex interaction between plants, insects and pathogens that can assist in controlling herbivore and pathogen attack in high cash value plant crops.

2. Production and accumulation of defensive compounds and inducible plant responses

In the natural eco-systems, plants protect themselves against the attack of arthropod herbivores and pathogens with various defense biochemical mechanisms. These defensive mechanisms are carried out throughout the production and synthesis of defensive compounds within secondary plant metabolism. These phytochemical compounds are accumulated and stored for using when the plant is under attack. There are two resistance mechanisms in plants can be classified into constitutive or pre-existent resistance that accumulated from natural selection and inducible resistance in which plants can synthesize and produce defensive compounds in response to insect or pathogen attack. Bradley *et al.*(1992) reported that after insect feeding on plants, they release many different molecules which could act either as elicitors of defense responses in neighbouring plant cells or as defensive toxins. Also, plants form a physical barriers containing lignin to protect themselves from pathogen invasion by the strengthening of the cell wall and the physical isolation of infected cells from their neighbours. Cell wall strengthening is caused via rapid oxidation of cell wall proteins which takes place minutes after wounding. Chemical defenses against invading herbivores and pathogens are also produced in response to leaf infestation, both in the wounded leaf and at systemic sites. These chemical defenses can be separated into two major categories; secondary metabolites and proteins. Ryan (2000) classified the genes encoding newly synthesized proteins after wounding to three groups; antinutritional proteins or defense genes, signal pathway genes and proteinases. He described the events in the insect resistance response in tomato. In this species, the major insecticidal gene products in induced resistance are proteinase inhibitors (PIs) and polyphenol oxidase (PPO) (Fig. 1), both of which are interfering with insect digestion and then nutrient uptake. Some secondary metabolites with defensive functions are present constitutively in plants and the majority are induced by insect wounding, or infection by pathogens. These metabolites include terpenoids, alkaloids and phenolics and are known as phytoalexins. Defensive molecules and insect antifeedant compounds (El-Sebae, 1987; Eldoksch and El-Sebae, 2005) and also lignin are produced via the phenylpropanoid biosynthetic pathway.

The inducible resistance mechanisms to pathogens such as *Botrytis cinerea* and *Palsmopara viticola* in grapevines are the accumulation of antimicrobial phytoalexins and the production of pathogenesis-related protein (PR proteins). The major phytoalexins produced in grapevines are resveratrol (Fig. 2) and its derivatives piceid, pterostilbene and ε-viniferin (Jeandet *et al.*, 2002). Furthermore, a commercial product Synermix (Laboratories Göemar) contains seaweed extract and $AlCl_3$, has been exhibited to activate resveratrol accumulation in grape leaves and increased resistance to pathogens (Elmer and Reglinski, 2006). It has been shown that the application of low concentrations of jasmonic acid or methyl jasmonate to plants induce proteinase inhibitors, proline-rich cell wall protein and several enzymes involved in plant defense responses.

3. IR and SAR chemical pathways and interaction effects

Plants growing under natural conditions face simultaneous challenges from different external stresses, so that different signaling pathways for defense responses have evolved (Walling, 2000). Plants respond to pathogen and insect attack requiring the initiation of inducible defense reactions with a complex array of signaling events that ultimately result in the activation of sets of defense genes. Salicylic acid (SA) has an important role in the signaling pathway leading to the induction of systemic acquired resistance (SAR) against pathogens attack. After infection, endogenous levels of SA increase locally and systemically and SA levels increase leading to the production of pathogenesis-related (PR) proteins and phytoalexins. Insect feeding cause local elicitation as well as systemic responses in many plant species. These responses may function as direct resistance with morphological and biochemical traits that act directly against subsequent attack or reduce herbivore performance or as indirect resistance that assist in the attraction of natural enemies of herbivores. Jasmonic acid (JA) is the central signaling molecule in induced responses against insect herbivores. In response to insect feeding or injury, linolenic acid is released from membrane lipids and then converted to JA by several enzymatic reactions (Fig. 1).

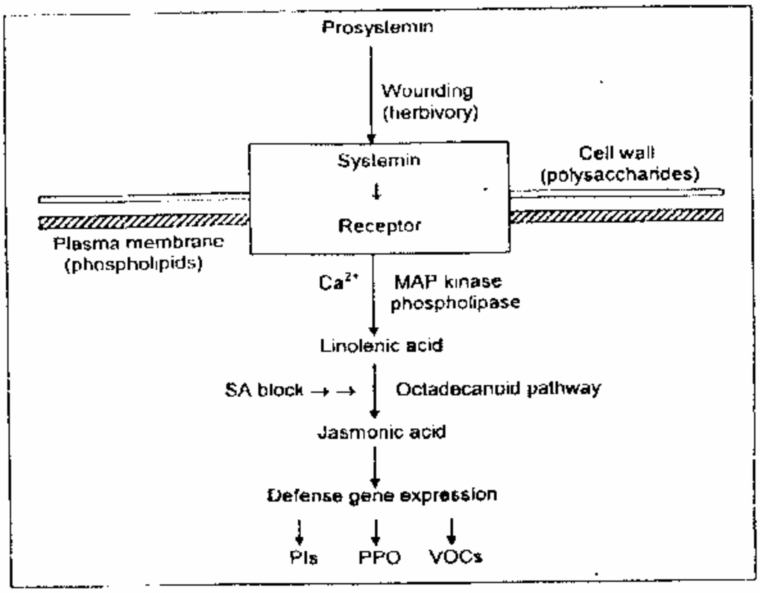

Fig. 1. Schematic diagram of the signaling pathway necessary for local and systemic synthesis and accumulation of the insect antifeeding proteins proteinase inhibitor (PI) and polyphenol oxidase (PPO) in the wounding response in tomato as well as the release of volatile organic compounds (VOCs) that attract natural enemies of insect herbivores. Also showing the point of inhibition by salicylic acid (SA) in the pathway. Adapted from Ryan (2000).

JA then facilitates the induction of plant defensive genes encoding proteinase inhibitors (PIs) and of enzymes involved in the production of volatile compounds, or secondary metabolites such as nicotine, glycoalkaloids, phenolic and terpenoid compounds (Reymond and Farmer, 1998). Moyen *et al.* (1998) reported that, after the application of biotic or abiotic elicitors on plants, there is a series of ion fluxes at the plasma membrane that play a causal role in defense gene activation.

Several research studies indicated a requirement for calcium in elicitor induced gene expression. Application of elicitors on plants caused rapid increases in cytoplasmic Ca^{2+} concentrations and the production of reactive oxygen species (ROS) that include H_2O_2. H_2O_2 activates protein phosphorylation cascades which in turn regulate defense gene expression. Research efforts in this area could potentially lead to enhancement in plants of IR and SAR in a vaccine form (vaccination). Prohexadione-calcium (Regalis 10 WG) is a new elicitor of plant resistance recently registered in Poland as an agent regulating an apple shoot growth and fruit setting. This product increases resistance of apple trees to fire blight, apple scab, powdery mildew and spot disease as well as several insect pests (Sobiczewski and Buban, 2004).

3.1. Cross-Resistance and Trade-Offs

IR and SAR signaling pathways can interact either synergistically or antagonistically (Walling, 2000). The evidence for both "cross-resistance" and "trade-offs" between induced resistance against herbivores and induced resistance to pathogens is mixed. Several studies have shown that elicitation of a particular defense pathway by one particular pathogen or insect negatively affects resistance to other groups of pathogens or insects. Felton *et al.* (1999) reported that transgenic tobacco plants with reduced SA levels as a result of deficient of the phenyl alanine ammomia-lyase (PAL) gene gave reduced SAR against tomato moazaic virus (TMV) but activated herbivore induced resistance to *Heliothis virescens* larvae. The over expression of PAL gene in tobacco plants exhibited a significant reduction in induced resistance against insect herbivores, while TMV-induced SAR was activated. Treatment of tomato plants by the SAR inducer acibenzolar-S-methyl (BTH) negatively affected insect resistance. BTH induced resistance against *Pseudomonas syringae* on tomato, but improved palatability of plant leaves for feeding by the corn earworm, *Heliothis zea*. Thaler (1999a) indicated that tomato plants treated with BTH reduced resistance to the beet armyworm, *Spodoptera exigua*. In contrast, Thaler (1999b) showed that JA, when exogenously applied to tomato, not only induced plant resistance to beet armyworm damage, but also doubled the incidence of parasitism of the endoparasitic wasp *Hyposoter exigua* on the armyworm. Iverson *et al.* (2001) tested the role of salicylic acid (SA) and jasmonic acid (JA) in altering the tomato plant's defense against herbivory by tobacco hornworm. They indicated that JA, endogenously or exogenously applied, is necessary for defense against insect herbivory and SA disrupts JA biosynthesis leading to little resistance to the feeding caterpillars. The phenomenon of reduced insect resistance in SAR-expressing plants is potentially attributed to the increased SA levels or inhibition of JA biosynthesis and production (Fig. 1). On the other hand, Zehnder *et al.* (1997) found a cross-protection against both cucumber beetles and wilt disease after the treatment by the elicitor plant growth-promoting rhizobacteria (PGPR). Understanding the ways in which local and systemic defense pathways are coordinated individually and jointly with other environmental stresses is an important objective in the application of these results for improvement of crop protection programs.

4. Enhancing plant resistance by elicitors

Elicitors are natural or synthetic compounds that activate the plant defensive systems and can induce biochemical changes that enable the plant to reduce disease incidence and insect herbivores infestation.

4.1. Chemical elicitors (SA and JA)

Plant pathogenesis related (PR) proteins are induced as a result of pathogen infections and some other herbivore attacks or due to the exogenous application of salicylic acid (SA) and related analogues such as 2,6-dichloroisonicotinic acid (INA) and benzothiadiazole (BTH), which have been shown to induce resistance to viral, fungal and bacterial pathogens in plants. PR proteins such as chitinases and glucanases can degrade the cell walls of some phytopathogens and consequently may play a part in the host plant's defensive system. Induced resistance may be elicited by herbivory or by application of plant-derived products such as jasmonic acid. JA is an endogenous plant growth regulator widely distributed in higher plants. In response to injury, a plant may produce JA, which induces the expression of defensive compounds such as insect proteinase inhibitors and polyphenol oxidase. Jasmonic acid may also be systematically distributed through the plant and create volatile gases, which in turn may induce neighbouring plants to increase their defense allocations as well as attract parasitic wasps to attack the infesting herbivores. The bio-synthesis of jasmonic acid takes place via the octadecanoid pathway (Fig. 1). JA induces broad-spectrum resistance in many crop plants. Thaler (1999) reported that plants can be treated with natural plant elicitors to induce resistance to herbivores. He found that foliar jasmonic acid application on tomato plants increased levels of polyphenol oxidase, an oxidative enzyme implicated in resistance against several insect herbivores. Omer *et al.* (2000) indicated that foliar jasmonic acid application on grapevines induced resistance in plants against the Pacific spider mite, *Tetranychus pacificus* Mc Gregor as well as the root-feeding grape phylloxera, *Daktulosphaira vitifoliae* (Fitch). Hassanien and Eldoksch (1997) demonstrated that complete protection of squash fruits against infection by *Agrobacterium tumefaciens* was achieved when caraway and chenopodium extracts or carvone (Fig. 2) were applied to fruits 30 min before inoculation, showing no sign of bacterial development over the test period up to 10 days after inoculation.

Treatment of clusters of grapevine, *Vitis vinifera* with methyl jasmonate significantly increased berry resveratrol and α-viniferin which have antimicrobial activity (Vezzulli *et al.*, 2007). Resveratrol, a phytoalexin in grapevine plants (Fig. 2) has also proven to enhance the resistance of vine plants to *Plasmopara viticola* fungus. In addition, Heijari *et al.* (2008) indicated that the long term exposure of Scots pine (*Pinus sylvestris* L.) trees to exogenous methyl jasmonate application increased needle chemical defense compounds including monoterpene, limonene and sesquiterpenes leading to poorer pine sawfly performance. More recently, in greenhouse experiments, foliar application of flax oil with 70% linolenic acid, the precursor of jasmonic acid as well as caraway oil (24% carvone , 57% limonene) on lima bean seedlings increased the resistance of the plants, leading to increased insect antifeeding activity and lower caterpillars growth rate (Eldoksch and El-Sebae –unpublished data).

4.2. Microbial inducers

Some microorganisms have been reported to enhance plant disease and insect resistance through the activation of host defenses. Eldoksch *et al.* (2001) found that wheat treatment with Plant guard (*Trichoderma harizianum*) and Rhizo-N (*Bacillus subtillis*) one week before inoculation by brown leaf rust induced antifungal activity with significant reduction in rust severity of about 50% and 25%, respectively. Zehnder *et al.* (1997) showed that treatment of cucumber with plant growth-promoting rhizobacteria (PGPR) induced cucumber resistance against both wilt disease and cucumber beetles and this was associated with reduced concentrations of cucurbitacin , a secondary plant metabolite and cucumber beetle feeding stimulant. Djonovic *et al.* (2007) reported that the beneficial fungus *Trichoderma virens* secrets a highly effective elicitor Sm1 that induces systemic disease resistance in cotton and maize and this protection was associated with induction of jasmonic acid and green leaf volatiles biosynthetic genes.

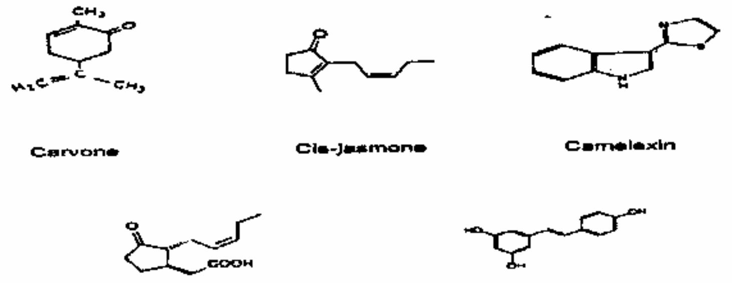

Fig. 2. Chemical structures of some compounds contribute in plant defense reactions.

4.3. Abiotic elicitors

It has been shown that several abiotic agents have the ability to induce plant resistance to insects and pathogens. Coulomb *et al.* (1998) reported that copper hydroxide has the ability to elicit the level of peroxidase, phenol, resveratrol and anthocyanins in grapevines. Calcium is considered to play an important role in plant defense against pathogens and insects. The treatment of grapes with calcium or potassium silicate resulted in strengthening of the cell walls in grape leaves leading to increased resistance to *B. cinerea*. Besides, NPK fertilizers have the ability not only to stimulate growth but also induce systemic resistance in cucumber and maize and also exhibited efficacy for the control of powdery meldew in grape plants (Reuveni and Reuveni, 1998). Gomez *et al.* (2005) indicated that silicon fertilization induced wheat plant resistance to the greenbug *Schizaphis graminum* (Rondani). Also, Cherif *et al.* (1994) reported that cucumber plants fertilized by silicon showed an increase in the production of the defense enzymes peroxidase, polyphenoloxidase, β-1,3-glucanase and chitinase, as a response to infection by pathogens. Additionally, corn plants fertilized by sodium silicate were not preferred by the corn leaf aphid, *Rhopalosiphum maidis* (Fitch).

4.4. Aphids and whiteflies as elicitors

There are clear ecological and physiological links exist between herbivorous insects and plant pathogens, in both primary plant metabolism (nutrition and resource allocation) and defense (Moran *et al.*, 2002). The feeding, growth and reproduction of insects that feed on the phloem sap of plants, such as aphids and whiteflies are often affected by plant pathogen infections which lead to changes in the nutritive and physical properties of tissues. Phloem feeding by aphids can in turn affect the distributions of both plant pathogens (via vectoring) and subsequent infestation by aphids. The activities of aphid salivary oxidative enzymes and the presence of aromatic compounds in the saliva could lead to oxidative reactions in the phloem which lead to the formation of reactive oxygen species (Walling, 2000). These molecules participate in the induction of plant defenses following pathogen infection and injury.

5. Herbivores-induced emission of volatile organic compounds

5.1. Indirect plant defenses

Plant responses to insect herbivory can be classified to direct and indirect defenses. Direct defenses can be preformed or constitutive, including structural barriers and the storage of toxic compounds and inducible defenses such as the synthesis and elicitation of defensive proteins and metabolites. Indirect defenses include the synthesis and release of some volatile compounds which serve signals between plants and as attractants of natural enemies of attacking herbivores. Indirect defenses that involve interactions between plants, herbivores and their natural enemies identified as "tritrophic interactions" (Paré and Tumlinson, 1999; Walling, 2000; Wratten et al., 2002 and Wackers and Bezemer, 2003). Plant leaves in natural ecosystems release small quantities of volatile chemicals that include monoterpenes, sesquiterpenes and aromatic compounds and also green-leaf volatiles which are synthesized via the lipoxygenase pathway (Metcalf, 1997). When plant leaves are injured by herbivore insects many more volatile compounds are produced and released. Several hours after the initial herbivore attack volatile compounds are produced and released locally at the site of injury and systemically. The predators and parasitoid wasps are able to use these volatile chemicals as a long distance signal of the presence of a potential host. Many studies indicated that the volatiles released from leaves after insect feeding act as attractants to parasitoids and predators (Turlings *et al.*, 1995; De Moraes *et al.*, 1998 and D'Alessandro *et al.*, 2005).

5.2. Volicitin and β-glucosidase as elicitors

Volicitin is an elicitor isolated from the saliva of the beat armyworm, *Spodoptera exigua* (Alborn *et al.*, 1997). Application of volicitin to maize plants induced a volatile blend that attracted *Cotesia marginiventris*, a parasitic wasp that normally attracted by *S. exigua* feeding. The host plant is able to recognize and respond to volicitin by triggering the synthesis of defensive volatile chemicals. β-glucosidase is the second volatile elicitor isolated from insect oral secretions of caterpillar, *Pieris brassicae* (Mattiacci *et al.*, 1995). β-glucosidase was able to induce the same volatile compounds when applied to cabbage leaves as that got following *P. brassicae* feeding which resulting in the attraction of parasitic wasps. JA is a key regulator of volatiles biosynthesis in plants. The application of JA to plants gave volatile blends with nearly the same of those obtained after insect feeding. Corn (*Zea mays* L.) has been used as the plant model in several studies of tritrophic systems using parasitic wasps as the third level (Turlings *et al.*, 1998). It has been demonstrated that the wasp attractive ingredients in the volatile blend released by corn plant as the result of feeding damage by beat armyworm (BAW) are a mixture of terpenoids and an indole. The plant produces this mixture when it is exposed to volicitin present in the BAW caterpillar saliva. Volicitin activates a jasmonate pathway in the plant to produce the blend of volatile compounds.

5.3. Efficacy of airborne chemicals on plant immunity and tritrophic interactions

Plants are sensitive to the airborne chemicals (Farmer and Ryan, 1990). A potential new approach to immunization against herbivorous and pathogens may be to continually expose plants to methyl jasmonate vapor. The intercropping flowering plants within a glasshouse or small-scale field crop was found to assist in reducing insect pests and pathogens incidence as the flowering plants attracted many of beneficial insects for pollination. Farmer and Ryan (1990) and Heijari *et al.* (2008) indicated that methyl jasmonate can act as a volatile signal that induces the accumulation of protein inhibitor proteins and phytoalexins to higher levels than can be induced by wounding, leading to increase plant resistance to several insects and pathogens. The presence of Me JA from sagebrush leaves can induce proteinase inhibitor accumulation in leaves of nearby tomato plants through the atmosphere. Larronde *et al.* (2003) and Vezzulli *et al.* (2007) found that airborne methyl jasmonate induced stilbene accumulation in leaves and berries of grapevine plants. Aerial treatment of Arabidopsis seedlings with E-2-hexenal, methyl salicylate and methyl jasmonate induce several genes known to be involved in the plant's defense response including phenyl propanoid related genes as well as genes of the lipoxygenase (LOX) pathway. Cis-jasmone (Fig. 2) is a compound of plant volatiles and its release can be induced by damage during insect herbivory (Birkett *et al.*, 2000). The lettuce aphid avoided plants emitted this compound. It was found to be repellent in laboratory and field tests against cereal aphids. Also, when Cis-jasmone applied to bean plants induced the production of volatile compounds including (E)-β-ocimene which affect plant indirect defense by stimulating the activity of parasitic insects. Induced lettuce was more attractive to the seven-spot ladybird, an aphid parasitoid.

In southern Australia, herbaceous mite *Halotydeus destructor* that feed on subterranean clover cotyledons can cause severe damage. The mites live on the soil surface and move up onto plants to feed. Several green leaf volatiles are involved in the plant-mite interaction. After feeding starts, 2-E-hexenol is released that at low concentrations is attractive to mites, causing the feeding aggregations (Ridsdill-Smith *et al.*, 2002), while at high concentrations act as deterrents to mites. The distinct role of jasmonate and aldehydes in plant-defense responses was studied by Chehab *et al.* (2008). They demonstrated that jasmonates are indispensable metabolites in mediating the activation of direct plant-defense responses that help in the production of camalexin (Fig. 2) the main phytoalexin in Arabidopsis which exhibited fungicidal activity against *Botrytis cinerea*. Furthermore, hexenyl acetate an acetylated C_6-aldehyde was found to be the predominant wound-inducible volatile signal that mediates indirect defense responses by directing tritrophic interactions.

6. CONCLUSION

The use of elicitors of plant resistance in pest control is considered an important potential component of integrated pest management (IPM) programs, leading to activation in plants of IR and SAR in a vaccine form.

Semiochemicals emitted naturally by plants or after inducement can be used to influence beneficial insects. They can be applied to maximize the impact of parasitic organisms that attack pest populations. Extracts of natural products provide semiochemicals that by acting as signals can direct interactions between plants, insects and their natural enemies. These semiochemicals when applied alone they give insufficient pest control, but they have the potential to give good results when used with other components in integrated control such as host plant resistance as well as biological control agents. Enhancing plant diversity in agricultural crop fields is essential to improve the chances of beneficial insects to survive and locate their insect hosts and subsequently improve the success rate of biological control (Wratten *et al.*, 2002; Feeby *et al.*, 2004; Zehnder *et al.*, 2007 and Nicholls *et al.*, 2008). Furthermore, the decrease in growth and development of herbivores due to direct resistance will result in increase exposure to natural enemies leading to increased rate of predation or parasitism of pests. So, induction of direct and indirect resistance in plants at suitable times could have beneficial effects in suppression of harmful pests (herbivores and pathogens). The integration of induced host plant resistance and biological control agents is necessary to improve pest management programs that would be benefit and compatible with integrated pest management system in conventional agriculture as well as with organic farming practices.

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تنشيط المقاومة فى نباتات المحاصيل ضد آكلات العشب الحشرية ومسببات الأمراض بإستخدام المحفزات

حمدى على الدكش[1] ، عبدالخالق حامد السباعى[2]
[1]المعمل المركزى للمبيدات، مركز البحوث الزراعية، وزارة الزراعة، الدقى، جيزة
[2]قسم مبيدات الآفات ، كلية الزراعة - جامعة الأسكندرية

إن نباتات المحاصيل خلال دورة حياتها تستطيع أن تحمى نفسها ضد هجوم آكلات العشب من المفصليات ومسببات الأمراض النباتية بأساليب مقاومة مختلفة. إن المسار الميتابولزمى فى تخليق كل من الجاسمونات والساليسيلات يظهرا إستجابات دفاعية قابلة للتحفيز والتنشيط والذى بواسطته يستطيع النبات أن يحمى نفسه ضد الآفات المختلفة عن طريق إنتاج وتخليق عدد من الكيماويات النباتية والبروتينات الدفاعية مثل البروتينات المثبطة لإنزيم البروتيناز، إنزيم البولى فينول أكسيداز والمواد الجليكوقلويدية الاستيرويدية وأيضاً إنتاج وتخليق البروتينات ذات العلاقة بمسببات الأمراض النباتية والفيتوألكسين والتى تؤثر على العمليات الفسيولوجية فى الكائنات المهاجمة للنبات.

إن مواد النبات الثانوية التى ينتجها النبات كإستجابة للتحفيز الخارجى بواسطة المحفزات الحيوية وغير الحيوية تشمل أيضاً مركبات عضوية متطايرة والتى تعمل على جذب الأعداء الطبيعية للحشرات الضارة المختلفة.

إن الجهود البحثية فى مجال المقاومة القابلة للتحفيز تتقدم الأن بسرعة فى إتجاه إستخدام جينات النبات المحفزة لإحداث المقاومة فى النباتات ضد الأمراض والحشرات.

هذا البحث يوضح الجهود العلمية والبحثية فى مجال تنشيط المقاومة الذاتية للنبات ضد الحشرات ومسببات الأمراض النباتية وإعطاء صورة عن مجالات التطور المستقبلى فى منتجات وقاية النبات والعمليات الزراعية المطلوبة والتى قد تساعد المزارعين والمنتجين فى مكافحة مسببات الأمراض والحشرات المختلفة على المحاصيل الإقتصادية والتى تفيد فى مجال كل من الزراعة التقليدية والزراعة العضوية.