Phytohormones as Botanicals in Integrated Pest Management: A Sustainable Approach for Crop Protection

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***Abstract*—The global agriculture industry faces significant losses due to insect pests. Pesticides have traditionally served as a crucial tool in pest control, but their widespread use has led to environmental pollution and harmful effects on both animals and humans, disrupting the natural ecosystem. In light of these challenges, natural alternatives to chemical pesticides are gaining attention, and botanical-derived insecticides offer a promising solution. Among them, phytohormones, or plant growth regulators (PGRs), have shown potential in enhancing plant quality, regulating growth rate, and ultimately increasing crop yield. However, the use of PGRs also raises concerns about their impact on non-target organisms, particularly insects. This review article provides a comprehensive overview of the utilization of phytohormones in insect pest management as a sustainable and eco-friendly approach to crop protection. While PGRs like gibberellic acid (GA3) and Indole-3-acetic acid (IAA) have shown positive effects on plant growth, they have also been found to influence insect's developmental time, longevity, reproductive potential, and hemolymph metabolites. Studies have demonstrated the ability of PGRs to interfere with insect fertility, life cycle parameters, and immune systems, making them potential candidates for eco-friendly insect pest control in Integrated Pest Management (IPM).**

***Index Terms*—Phytohormone, indole-3-acetic acid, gibberellic acid, abscisic acid, biopesticides, insect pest management, crop protection.**

I. INTRODUCTION

Major loss of agricultural crops is caused by insect pests worldwide. In habitats that have been artificially altered by humans and in which crops have been chosen for their size, productivity, and nutritional value as well as their concentration in small spaces are extremely adaptable to insect pests. In the course of agricultural growth, pesticides have developed into a crucial instrument for plant protection and crop improvement (Sharma et al., 2019). Pesticides are compounds (natural or synthetic) used in a variety of agronomic techniques to control insects, weeds, and illnesses that affect plants. Pesticides include herbicides, insecticides, fungicides, rodenticides, nematicides and other pesticides (Dhaliwal et al., 2015). According to a study, pathogens and pests are to blame for losses in the worldwide wheat crop of 10% to 28%, losses in the rice crop of 25% to 41%, losses in the maize crop of 20% to 41%, losses in the potato crop of 8% to 21%, and losses in the soybean crop of 11% to 32% (Savary et al., 2019). In India, insecticides make up more than half of pesticides applied. The average annual consumption of chemical pesticides was roughly 55000 tonnes from 2014 to 2018, but the average annual consumption of biopesticides was 3500 tonnes from 2014 to 2019. Both the Indian states of Maharashtra and Uttar Pradesh account for 40% of the global pesticide market (Nayak & Solanki, 2021).

Although pesticides are thought of as a quick, simple, and affordable way to get rid of insect pests, they have polluted practically every site and their residues may be found in soil, air, and water all over the world. The natural operation of an ecosystem may be affected by pesticides sprayed into the environment either permanently or only temporarily (Stoytcheva, 2011). Regular and indiscriminate use of pesticides has harmed not only the environment and agriculture, but also the health and development of both animals and humans by introducing them into our food chain. Synthetic pesticides, which are crucial for pest control,

kill economically significant insect pests as well as their beneficial natural enemies and other organisms (Aktar et al., 2009).

Botanicals are naturally occurring chemicals extracted from plants. Natural insecticides are available as an alternative to chemical pesticides. More than 3500 compounds in 400 plant families have been described to have toxic insect effects (García-Lara & Saldivar, 2016).

Phytohormones (PHs) or Plant Growth Regulators (PGRs) are a group of natural chemical compounds produced by plants. These are used to increase plant product quality, regulate plant growth rate, and thus increase crop yield. Indole-3-acetic acid (IAA) is one of the most important natural auxins (Davies, 2010), which affect plant growth and development. However, it has also adverse impacts on non-target organisms such as insects by altering developmental time, longevity, reproductive potential and hemolymph metabolites (Kaur & Rup, 2002; Rup et al., 2000; Uçkan et al., 2020). According to reports, PGRs can block or activate immunological potential enzymes in rat spleen and lung tissue, as well as the antioxidative defense system (Celik & Tuluce, 2007). Evidently, the addition of PGRs to insects has also altered their fertility, longevity, and egg viability (Visscher, 1980). Other studies also revealed that PGRs have the potential to negatively affect insect growth, reproduction, life table parameters, hemocyte biochemistry and immunology. According to this background, current review article aims to give a comprehensive overview of the use of Phytohormones in insect pest management in the replacement of chemical pesticides for sustainable crop protection.

II. DIFERRENT PHYTOHORMONES AND THEIR EFFECT ON INSECTS

A. Inole-3-acetic acid (IAA)

Auxins are endogenous plant growth regulators, mainly involved in root/shoot formation and relative growth (Sachs, 2005). Studies have shown that auxins work together with CKs in various cellular or physiological processes such as cell cycle progression, cell expansion, apical dominance, leaf development, and embryonic development during seed maturation (Jurado et al., 2011; Tromas et al., 2009).

Effect on Biochemical composition

A study found that IAA affects amount of biochemical composition of hemolymph when different concentrations (2, 5, 10, 50, 100, 200, 500, and 1,000ppm) of IAA were added to the synthetic diet of *Achoria grisella*. Any dose of IAA, with the exception of 10 ppm, enhanced the protein content in the hemolymph. IAA administration increased the level of sugar at 100 and 200 ppm, although a decrease in lipid was seen in the larvae at doses of 5, 10, 200, and 1,000 ppm (Uçkan et al., 2014).

Effect on Gonads

Statistically analyzed data revealed that when newly emerged *Dacus dorsalis* Hendel (Diptera; Tephritidae) flies were treated topically with different concentrations (0.3, 0.5, 2 and 5%) of IAA, the size of gonads were decreased effectively. The germinal regions of the gonads were the most severely affected parts. Treated testes were shown to have significantly fewer sperm bundles. Data evaluated that in treated flies, the ovarian size decreased during 8–12 days, peak time of ovarian development (Thakur & Mann, 1982).

Effect on Hemocyte count

The cytotoxic effect of IAA was seen on hemocytes of *Achoria grisella* (Lepidoptera: Pyralidae) larvae, at different doses of IAA. The findings showed that the total hemocyte counts increased at all levels examined when IAA (2 to 1,000 ppm) was added to the diet of A. grisella larvae. The proportion of granulocytes increased at 2, 5, 100, 200, and 1,000 ppm whereas the proportion of plasmatocytes declined (Çelik et al., 2017). In a study *Galleria mellonella* L. (Lepidoptera: Pyralidae) was used as a model insect to study the dietary effect of indole-3 acetic acid (IAA), a well-known member plant growth regulator auxin on hemocyte counts and behavior. When different doses (50, 500, 1000, 5000 and 10000 ppm) of IAA was administered to *G. mellonella*, the total hemocyte counts increased (Çelik et al., 2017).

Acridine orange-ethidium bromide double staining revealed that none of the IAA doses changed the proportion of mitotic to apoptotic cells ratio in living organisms, while in vitro tests in *G. mellonella* revealed a reduction in the number of late apoptotic cells at 1000 and 5000 ppm. No significant changes were seen in the encapsulation rate of Sephadex A-25 beads while non-melanized hemocyte concentrations

increased by 5000 ppm at the 4th hour. Additionally, a significant reduction in melanization at 50 ppm and an increase in the number of non-melanized beads after 24 h at 50 and 1000 ppm were noted (Kaya et al., 2021).

Effect on Antioxidant system

Different dietary IAA doses (50–10,000 ppm) increased the amount of lipid peroxidation (LPO) in the host hemolymph, *G. mellonella* (L.). Higher doses of dietary IAA decreased catalase (CAT), superoxide dismutase (SOD) and glutathione transferase (GST) enzymes' activities in *G. mellonella*. These results suggest that including IAA in the food of model host *G. mellonella* larvae causes oxidative stress and adversely affects *G. mellonella* survival (Özyılmaz et al., 2019).

Effect on Larval mortality

When the third instar larvae of *G. mellonella* were force-fed, an artificial meal enriched with six concentrations of IAA, namely 100, 10.0, 1.0, 0.1, 0.01 & 0.001ppm. At 1.00 ppm of IAA, all emerging adults perished; however, adult mortality was not seen at the three lower doses. The LC50 value was determined to be 0.24 ppm. IAA only at the two higher concentrations showed a retarding effect on pupation. A considerable and dose-dependent prolongation of the larval and pupal periods was observed (Abo Elsoud et al., 2021).

B. Gibberellic acid (GA3)

The natural plant growth regulator gibberellic acid, a pentacyclic diterpene acid also known as gibberellin A3, GA, and GA3, is utilized in agriculture all over the world. It plays a fundamental role in regulating the growth of plants. An increase in the heights of several crop plants is reported, including tomatoes, after application of GA3 (Nibhavanti et al., 2006). Additionally, GA3 increases the yield per hectare, fruit set yield per plant, yield per plot, and number of fruits per cluster (Akand et al., 2015; Gelmesa et al., 2012). In addition to being beneficial for a plant, GA3 therapy is harmful to the insects that live and breed on such plants. Evidence suggests that this substance has an impact on food intake, growth, development, and survival as well as fecundity and fertility are all influenced by GA3.

Effect on Antifeedant and cytotoxic activity

The rates of diet consumption and the effectiveness of converting food consumption by *H. armigera* larvae are demonstrated to be significantly reduced by the addition of GA3 (800 μg g−1 diet) to an artificial diet. As the concentration rises, the relative growth rate declines. After consuming four concentrations of GA3, there is a considerable reduction in the relative α-amylase activity in *H. armigera* sixth-instar larvae. At the maximum concentration, the alanine and aspartate aminotransferase activity declines. However, compared to the control, the activity of acid phosphatase, alkaline phosphatase, γ-glutamyl transferase, and lactate dehydrogenase increases considerably.

Epithelial cell degradation was seen in histological analysis of the midgut of GA3-treated larvae (800 μg g−1 diet). The alanine and aspartate aminotransferase activity decreases at the highest concentration. However, acid phosphatase, alkaline phosphatase, γ-glutamyl transferase and lactate dehydrogenase activity increase significantly compared with the control. The findings unequivocally showed that GA3 harms H. armigera by interfering with its nutritional physiology and metabolism (Shayegan, Jalali Sendi, et al., 2019).

Biochemical changes

GA3 a plant growth regulator (PGR) was shown to exhibit hazardous symptoms in a dose-dependent way. It was also discovered that GA3 disturbs the moulting processes. The treated insects were unable to reject the old integuments, which results in mortality in the 5th instar larvae. This study's data also demonstrated that GA3 caused a sizable quantitative variance in haemolymph metabolites. As a result of these modifications, the total concentrations of proteins and carbohydrates are markedly reduced, while the total concentration of haemolymph lipids is increased (Abdellaoui et al., 2013).

Effect on Oxidative stress

In *Galleria mellonella*, it was discovered that treatment with GA3 in diet led to a notable increase in SOD and GST activities at lower GA3 doses (50–1,000 ppm). This research demonstrated that GA3 is effective at triggering the antioxidant defense system of insects as a source of free radical and can be toxic for larvae in a dose-dependent manner (Altunta, 2015).

Effect on Fecundity and fertility

It has been discovered that GA3 dramatically lowers fecundity and fertility in *Locusta migratoria*. Additionally, hemolymph metabolites (proteins, carbohydrates, and lipids) are irregularly incorporated into the oocyte as a result of gibberellic acid, which significantly lowers their concentrations in the ovaries (Abdellaoui et al., 2015).

Effect on Antifeedant and repellent property

It has been shown that GA3 significantly and dose-dependently decreased the fresh weight of food consumption in fifth instar nymphs of *L. migratoria migratoria*, resulting in weight loss in the nymphs. The findings showed that GA3 greatly reduced the ability of *L. migratoria migratoria* fifth instar nymphs to absorb food. Varied GA3 concentrations resulted in markedly different consumption indices (Abdellaoui, Halima-Kamel, & Ben, 2009)

Effect on Immunological and Antioxidant response

Gibberellic acid (GA3) treatment has noticeable effects on the growth, reproduction, and survival of *Helicoverpa armigera*, especially at higher concentrations (800 mg GA3/kg diet) of GA3 tested. This was revealed by data from a study on the influence of gibberellic acid on life table parameters of *H. armigera* in laboratory conditions (Shayegan, Sendi, et al., 2019).

Physiological effect on reproductive potential

The highest decrease in fecundity and fertility rates was seen with a greater dose of GA3 (6125µg/ml) in a study on the physiological effects of gibberellic acid (GA3) on the reproductive ability of *Locusta migratoria migratoria* (Abdellaoui et al., 2009).

Insecticidal activity

Larvae of *S. littoralis* (Lepidoptera, Noctuidae) and *L. migratoria migratoria* (Orthoptera, Acrididae) were used to test the oral toxicity of gibberellic acid (GA3), a plant growth regulator. The insects were fed diets containing varied amounts of GA3 (125, 625 and 3125 ppm). The food consumption of both insect species was dramatically decreased by GA3 treatment, which resulted in weight loss in the larvae. Some larval mortality due to exuviation issues was also evidence of GA3 toxicity. Malformations of various kinds were seen as a result of problems with nymphal integument rejection. Additionally, it was noted that digestive tract of *L. migratoria migratoria* was mushy. An examination of histology of the foregut and gastric caeca later revealed that GA3 had cytotoxic effects. In fact, it has been shown that the cellular structure of these organs has completely disorganized and lost its epithelial cells (Abdellaoui, Halima-Kamel, & Ben Hamouda, 2009a).

C. Abscisic acid

Abscisic acid (ABA), commonly referred to as phytohormones, performs crucial roles in controlling plant growth and development, seed development and bud dormancy, cell division, abscission, and leaf senescence. Additionally, it mediates the reactions of plants to stressors like infections, salt, wounds, temperature and dehydration (Bassaganya-Riera et al., 2010; Li et al., 2011). Numerous studies have demonstrated that plants increase ABA synthesis in response to insect damage, which suggests that ABA serves as a defense against herbivore attack (Peña-Cortés & Willmitzer, 1995; Thaler & Bostock, 2004).

Toxicity of ABA

When last instars of *G. mellonella* were injected with different concentration of ABA (10, 20, and 50 mg/ml), the mortality was dose-dependent and LD50 was 49.124 mg/ml (Er & Keskin, 2015).

Effect on Vitellogenesis

A study revealed that ABA inhibited the total protein concentration of the haemolymph and particularly that of vitellogenin in the carnivorous dipteran *Sarcophaga bullata* (De Man et al., 1981).

Effects on Development

The duration of the larval stage was significantly lengthened by treatment with ABA in a dose-dependent manner. Larval duration was considerably longer in ABA-treated animals than in control groups. Regardless of concentration, the time until adults began to emerge in ABA-treated individual was considerably longer than in controls. On the other hand, pupation rates dramatically dropped in a dose-dependent way for all ABA doses. Similarly, at exposure of all doses of ABA reduced the adult emergence ratio as compared to the control.

Effects on Longevity and Fecundity of Adults

In comparison to control and other doses, the lifespan of adult *G. mellonella* treated with ABA at 20 mg/ml fell dramatically. At all doses, ABA treatment significantly reduced the number of eggs laid. On the other hand, in contrast to the control, the differences were only statistically significant at 20 and 50 mg/ml. Adults had a >45% decrease in fecundity as compared to controls (Er & Keskin, 2015).

Effects on Total Hemocyte Count (THC) of *G. mellonella*

At 4, 24, and 48 hours after ABA injections, the number of circulating hemocytes had significantly decreased. The lowest cell count per ml was seen at 48 hours after ABA injection at the highest dose of 50 mg/ml, whereas the highest cell count per ml was seen at the lowest dose of 10 mg/ml. Based on the type of treatment, the time, and their interaction, one way ANOVA analysis showed that all significantly affect the THC of *G. mellonella* larvae following an ABA injection (Er & Keskin, 2015).

D. Cytokinin (CK)

A class of phytohormone called Cytokinins (CKs) is involved in the control of plant development, physiological processes, and yield (Werner et al., 2003). In addition, Cytokinins are essential for responding to abiotic stressors such drought, salt, and extreme heat or cold (Argueso et al., 2009; O'Brien & Benková, 2013).

Effect on biochemical

According to an experimental data of Rup et al., the efficacy of Cytokinin against second instar nymphs (48 hours old) of *Lipaphis erysimi*, was observed by using both leaf dipping and leaf surface coating method of treatment. Result from this study showed that Cytokinin did not induce any derogatory influence on carbohydrate content at 1024ppm concentration for two-time intervals i.e. 48 and 96 hours (Rup et al., 2000).

Table 1. Different plant growth regulators and their effect on different insects.

S. No.	Plant Growth Regulators (PGRs)	Affected Insect	Stage	Reference
1.	Auxin (IAA)	*Dacus dorsalis* (Diptera: Trypetidae)	Adult	(Thakur & Mann, 1982)
		Galleria mellonella (Lepidoptera: Pyralidae)	3rd instar larvae, Adult	(Kaya et al., 2021)
		Achoria grisella (Lepidoptera: Pyralidae)	Nymph	(Çelik et al., 2017)
2.	Auxin (IBA)	*Lipaphis erysimi* (Hemiptera: Aphididae)	3rd instar Nymph	(Rup et al., 2000)
3.	Gibberellic acid (GA3)	*Spodoptera littoralis* (Lepidoptera: Noctuidae)	Larvae	(Abdellaoui et al., 2009)
		Galleria mellonella (Lepidoptera: Pyralidae)	Adult	(Altuntas, 2015)
		Helicoverpa armigera (Lepidoptera: Noctuidae)	6th instar larvae	(Shayegan, et al., 2019)
		Locusta migratoria (Orthoptera: Acrididae	5th instar nymph	(Abdellaoui et al., 2009)
4.	Abscisic acid (ABA)	*Galleria mellonella* (Lepidoptera: Pyralidae)	Adult	(Er & Keskin, 2015)
		Sarcophaga bullata (Diptera: Sarcophagidae)	Adult	(De Man et al., 1981)
5.	Cytokinin (CK)	*Lipaphis erysimi* (Hemiptera: Aphididae)	Nymph	(Rup et al., 2000)

III CONCLUSIONS

In conclusion, phytohormones hold tremendous potential as an eco-friendly and sustainable alternative to chemical pesticides in insect pest management. However, further research and practical application are necessary to develop effective and safe pest control strategies, considering both their positive impacts on crop protection and their potential effects on non-target organisms and ecosystems. The review advocates for a holistic and integrated approach to pest management that combines the advantages of phytohormones with other biocontrol methods, fostering sustainable agriculture and environmental conservation.

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