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Entomotoxic Potential of Plant Lectins as an Environment Friendly Tool to Control Insect Pests

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Abstract

A large number of insect pests infest crops at various stages including, pre- and post-harvest periods. Since immemorial times, agriculturists have applied numerous protective strategies to control insect infestation viz. variable cultural practices, crop rotation etc. and in modern times the application of chemical pesticides. Chemical pesticides impart environmental (soil, water) toxicity leading to health hazards and also have a negative impact on non-target species, thereby, disrupting natural biological control along with the development of resistance among target pests. Plant lectins combine specifically with the carbohydrate components of glycoproteins, glycolipids and other glycoconjugates in the pest and interfere with insect metabolism. Due to this property plant lectins can be utilised as defence proteins against phytophagous pests. Some of the plant lectins have been tested for their promising entomotoxic potential. This review demonstrates the entomotoxic potential of some candidate lectins and their impact on insect pests.

Keywords: Lectins; Insect; Pest; Entomotoxic; Crop

Introduction

Insect pests affect and destroy almost one-fifth of the world's total agricultural produce annually. Insect predation in agriculture has challenged researchers to explore newer eco-friendly natural insecticides (Paul & Das, 2021). Insect pests result in around US$ 17.7 billion in annual crop losses worldwide (Oliveira et al., 2014). The use of pesticides is indispensable in modern agriculture. Nowadays, pesticides are regarded as one of the major causes of environmental contamination. Pesticides not only pollute land and water resources but also destroy useful micro-ecosystems (Schulz, 2004). Recently, the research community has focused its attention towards environment-friendly alternatives to pesticides. One such strategy is to utilise the plant's natural inbuilt defences. The plant defence mechanisms against insect pests are dynamic and diverse (War et al., 2012). Plants respond to insect attacks by producing defence proteins and toxins that target insect physiology (Mithofer and Boland, 2012). Plant lectins comprise a heterogeneous group of glycoproteins that have the capability to recognize and bind to specific carbohydrate molecules. Lectins interact with glycans in insects, interfere with the insect physiology and affect fecundity, growth, and development (Shahidi-Noghabi et al., 2009). Plant lectins are toxic to insect pests and, therefore, possess potential insecticidal properties. The current manuscript aims to uncover the plant lectins for their entomotoxic activity and to give them wide recognition as well as general acceptance as natural insecticides to be used upon crops for plant protection.

Plant lectins

Lectins are non-immune in origin and can specifically agglutinate cells. Lectins are carbohydrate-binding proteins (glycoproteins) that are ubiquitous in nature and have been thoroughly investigated from various biological sources (Cavada et al., 2019) including plants, animals and microorganisms (Chandra et al., 2006). Plant lectins are found to have carbohydrate binding specificity for glycoconjugates ranging from animals to microbes i.e. phytophagous insects, fungi, microorganisms and viruses (Vandenborre et al., 2011). Based upon the structural resemblance in their carbohydrate-binding domains that are revealed by modern genomic and transcriptomic studies, the lectins isolated from plant sources are classified into 12 different families (Van Damme et al., 2008). In plants, the family Leguminosae is the most studied one for lectins and observed to be similar in their sequence as well as structure (Grandhi et al., 2015) showing their common ancestry and divergent evolution. To date, numerous legume lectins that have been investigated show the presence of characteristic carbohydrate-binding domains (Procopio et al., 2017). Previously, GNA, Legume and Hevein family of lectins were assumed to predominate in seeds or vegetative storage tissues but nowadays, plant lectins are classified into twelve distinct families based upon evolutionary and structurally related different carbohydrate-binding lectin domains (Van Damme et al., 2008)

Entomotoxic activity of Lectins

Various plant lectins have been reported to show entomotoxic (insectistatic and insecticidal) activities eg. *Galanthus nivalis* agglutinin (GNA)-related lectins, *Nicotiana tabacum* agglutinin (NICTABA)-related lectins, hevein-related lectins, ricin related lectins, amaranthins, legume lectins and jacalins are found to exhibit insect toxicity (Van Damme et al., 2008). A number of plant lectins possessing toxic effects against insect pests have been extensively studied. The artificial lectin feeding assays reveal that the adverse impacts of lectins on the growth as well as the fecundity of the insect pest (Vandenborre et al., 2011) depend upon the lectin family as well as the insect species. Insect pests belonging to orders Coleoptera, Lepidoptera, Hemiptera or Diptera are found to be affected mostly by plant lectins (Michiels et al., 2010).

Mechanism of action

Inside the insect midgut, carbohydrate-binding domains of lectin bind with the glycoconjugates in the epithelial cell lining leading to the disruption of epithelial cell lining and in turn increased membrane permeability towards harmful substances that enter haemolymph (Sprawka et al., 2015). Moreover, the lectins that pass through the epithelial layer move to the haemolymph and bind to various enzymes viz. α-amylases, ATP synthase, β-glucosidases, NADH oxidoreductase etc. (Macedo et al., 2015) and induce apoptotic pathway leading to fatalities among insects (Tang et al., 2020).

GNA-related lectins

Sourced from snowdrop bulbs (*Galanthus nivalis*), the GNA shows insecticidal properties against a wide range of insect pests, with Hemipterans being the most sensitive ones. Insect glycoprotein rich in terminal mannose residues are the specific binding site of snowdrop GNA lectin (Schachter, 2009). Powel was the first to demonstrate the insecticidal activity of mannose-specific GNA lectin from snowdrop plant (*Galanthus nivalis*) against aphids (Powell et al., 1993). GNA lectins are less toxic to mammals than PHA or WGA lectins and are engineered into several crops to test their impact (Powell, 2001). Some important lectins such as *Allium sativum* agglutinin (ASAL), *Allium cepa* agglutinin (ACA), and GNA-related lectins have been tested and confirmed for their entomotoxic effects as mentioned in Table 1.

Legume lectins

Lectins mostly isolated from the seeds of legume plants are called legumes. These lectins have an affinity for N-glycans having terminal sialic acid and galactose, Mannose/Glucose-N-acetyl complex residues. Despite having common sugar binding specificity, the lectins sourced from different legume plants are selective in their insecticidal activity like ConA shows high selectivity towards the *Tarophagous proserpina* (tara plant hopper) with a higher mortality rate than PSA (Powell, 2001). Both GNA and ConA target aminopeptidase enzyme in the insect midgut (Cristofoletti et al., 2006). ConA accumulates in the hemolymph, fat tissue and Malpighian tubules (Fitches et al., 2001). Legume lectins viz. ConA, Gleheda, PSA and GS-II are reported to be toxic against *Acyrthosiphon pisum and Tarophagous proserpina*, *Leptinotarsa decemlineata*, *Meligethes aeneus* and *Callosobruchus maculatus* as in Table 2.

Table 1. Entomotoxicity of GNA-related lectins

Lectin	Pest insect	Action	References
ASAL (*Allium sativum* agglutinin) garlic leaf lectin	*Sogatella furcifera* (white-backed Planthopper)	Nymphicidal	Yarasi et al. (2008)
	Nilaparvata lugens (brown leafhopper)	Nymphicidal	Yarasi et al. (2008)
GNA-related lectins	*Spodoptera littoralis* (cotton leafworm)	Restricted larval weight gain	Sadeghi et al. (2008, 2009)
	Eoreuma loftini (Mexican rice borer)	Restricted larval weight gain	Sétamou et al. (2002)
	Lacanobia oleracea (tomato moth)	Toxic to larval growth	Gatehouse et al. (1997)
ACA (*Allium cepa* agglutinin) onion lectin	*Nephotettix virescens* (green leafhopper)	Toxic to larval growth	Saha et al. (2006)
	Lipaphis erysimi (mustard aphid)	Nymphicidal	Hossain et al. (2006)
GNA	*Rhopalosiphum maidis* (corn leaf aphid)	Enhanced resistance	Wang et al. (2005)
	Sitobion avenae (grain aphid)	Entomotoxic	Stoger et al. (1999)

Table 2. Entomotoxicity of Legume lectins

Lectin	Pest insect	Action	References
ConA (concanavalin A) Jackbean	*Acyrthosiphon pisum* (Hemipteran pea aphid)	Toxic	Sauvion et al. (2004)
	Tarophagous proserpina (Tara planthopper)	Insecticidal	Sauvion et al. (2004)
Gleheda (*Glechoma hederacea*) Ground ivy	*Leptinotarsa decemlineata* (Colorado potato beetle)	Larvicidal	Wang et al. (2003)
PSA (*Pisum sativum* agglutinin) Pea	*Meligethes aeneus* (pollen Beetle)	Restricted larval weight gain	Melander et al. (2003)
GS-II (*Griffonia simplicifolia*)	*Callosobruchus maculatus* (cowpea weevil)	Sensitive	Zhu et al. (1996)

Hevein-related lectins

Lectin isolated from the latex of *Hevea brasiliensis*, a rubber tree is called 'hevein' (Girdol et al., 1994) and is mannose and N-glycans binding lectin. Hevein-related plant lectins exhibit specific binding affinity for chitin polymer in fungi, nematodes and arthropods (Merzendorfer, 2006), and show more toxicity towards Lepidopterans than Hemipteran insects. These lectins are the safest ones for mammals. WGA (wheat germ agglutinin) are reported to be Toxic towards *Callosobruchus maculatus*, *Diabrotica undecimpunctata* and *Ostrinia nubilalia* insect larvae as given in Table 3. Hevein-related lectins have no target in mammals and, therefore can be utilised safely to genetically modify plants.

Table 3. Entomotoxicity of Hevein-related lectins

Lectin	Pest insect	Action	References
WGA (wheat germ agglutinin)	*Ostrinia nubilalia* (European corn borer)	Lepidopteran neonatal larvae Toxicity	Hopkins and Harper (2001)
	Diabrotica undecimpunctata (southern corn rootworm)	Larval growth inhibitor	Czapla and Lang (1990)
	Callosobruchus maculatus (cowpea weevil)	Toxic to Larvae	Murdock et al. (1990)

Tobacco leaf lectin

NICTABA lectins (Tobacco leaf lectin) are reported to be synthesized in the leaves of tobacco (*Nicotiana tabacum*) in response to insect attack, therefore, have a major role in the plant defence response (Chen et al., 2002). *Nicotiana tabacum* agglutinin domain has an affinity for mannose-N-glycans and Glucose-N-acetyl oligomers, NICTABA-related lectins have been tested and reported to larval growth restrictors for two Lepidopteran larvae *Spodoptera littoralis* & *Manduca sexta*, *Acyrthosiphon pisum* and *Myzus persicae* resp. as given in Table 4.

Table 4. Entomotoxicity of Tobacco leaf lectins

Lectin	Pest insect	Action	References
NICTABA	*Spodoptera littoralis* (cotton leafworm)	Restricted larval growth	Vandenborre et al. (2010)
	Manduca sexta (tobacco hornworm)	Detrimental for larvae	Vandenborre et al. (2010)
PP2 (phloem protein 2)	*Acyrthosiphon pisum* (pea Aphids)	Restricted nymphal weight gain	Beneteau et al. (2010)
	Myzus persicae (green peach aphid)	Restricted nymphal weight gain	Beneteau et al. (2010)

Ricin-related lectins

Lectins having the Ricin-B domain are called Ricin-related lectins and were first isolated from castor bean (*Ricinus communis*) and have an affinity for Galactose / N-acetyl Galactose, Sialic residues. These are also called type-2 ribosome inactivating proteins (RIP) i.e. SNA-I', cinnamomin, Maize RIP are reported as toxic towards *Spodoptera exigua*, *Helicoverpa armigera* & *Culex pipiens pallens*, *Helicoverpa zea* & *Lasioderma serricorne* as given in table 5.

Table 5. Entomotoxicity of Ricin-related lectins

Lectin	Pest insect	Action	References
Type-2 RIP SNA-I' from (*Sambucus nigra*) elderberry bark	*Spodoptera exigua* (beet armyworm)	Larvicidal	Shahidi-Noghabi et al. (2009)
RIP (*Zea mays*) maize	*Helicoverpa zea* (corn earworm)	Larvicidal	Dowd et al. (2003)
	Lasioderma serricorne (cigarette beetle)	Larvicidal	Dowd et al. (2003)
Cinnamomin (*Cinnamomum camphora*) camphor tree seeds	*Culex pipiens pallens* (common mosquito)	Toxic	Zhou et al. (1999)
	Helicoverpa armigera (bollworm)	Toxic	Zhou et al. (1999)

Jacalin-related lectins

Jacalins are mannose-binding lectins produced in response to feeding by Hessian fly therefore called Hessian fly responsive proteins containing an Amaranthus domain (Giovanini et al., 2007) and specific affinity for Galactose and Man, N-glycans. Entomotoxic activities of Heltuba and HFR-1 Jacalin-related lectins are mentioned in Table 6.

Table 6. Entomotoxic activities of Jacalin-related lectins

Lectin	Pest insect	Action	References
Heltuba (*Helianthus tuberosus*) Jerusalem artichoke	*Myzus persicae* (peach-potato aphid)	reduced development and decreased fecundity	Chang et al. (2003)
HFR-1 (Mayetiola destructor Say) Hessian fly responsive protein	*Drosophila melanogaster*	Larvicidal	Subramanyam et al. (2008)

Conclusion

Lectins from plant sources have shown their potential as natural insecticides for crops which can replace harmful synthetic chemicals. But plant sources producing lectins having entomotoxic activity are still largely unexplored. Recent Arabidopsis, rice and soybean genome sequencing revealed the presence of hundreds of lectin superfamilies putative lectin genes (Jiang et al., 2010). Nowadays, commercial transgenic plants are engineered to express Bt toxins derived from *Bacillus thuringiensis* bacterium, which is ineffective to phloem sucking pests. Plant lectins can be promising entomotoxic candidate acting on sucking insect pests like aphids. Isolation and purification of the plant lectins by applying biochemical techniques can revolutionize the lectin industry for use as natural insecticides. Moreover, by applying genetic engineering tools, the lectin encoding genes from lectin-producing plants can be engineered for non-lectin-producing crop plants for protection from insect pests.

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