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# Plant Lectins with Insecticidal and Insectistatic Activities

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Additional information is available at the end of the chapter

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## Abstract

Lectins are an important group of proteins which are spread in all kingdoms of life. Their most lighted characteristic is associated to their specific carbohydrate binding, although function has been not even identified. According to their carbohydrate specificity, several biological activities have been assessed, finding that lectins can be used as mitogenic agents, biomarkers, and cytotoxic and insecticide proteins. Lectins have been classified according to several features such as structure, source, and carbohydrate recognition. The Protein Research Group (PRG) has worked on Colombian seeds from the family of Fabaceae and Lamiaceae plants, isolating and characterizing their lectins, and found more than one lectin in some plants, indicating that according to its specificity, different lectins can have different biological activities. In the case of legume domain lectins, they have shown the biggest potential as insecticide or insectistatic agents due to the glycosylation pattern in insect midgut cells. This review attempts to identify the characteristics of plant legume lectin domains that determine their insecticidal and insectistatic activities.

**Keywords:** lectin, insecticide, insectistatic, legume

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## 1. Introduction

Lectins are glycoproteins of nonimmune origin that recognize and bind carbohydrates. These proteins are found in a wide variety of species (viruses, bacteria, fungi, seaweed, animals, and plants). This review is mainly based on information of plant lectins that have been found as important new agents in biological control. Plant lectins have been widely studied,

and in this group, the legume lectins have been related to insecticidal and insectistatic activities. In addition, *Phaseolus vulgaris* (PHA), *Glechoma hederacea* (Gleheda), *Canavalia ensiformis* (ConA), *Griffonia simplicifolia* (GSII), and *Pisum sativum* (PSA) lectins and other legume and Lamiaceae lectins have been studied by the Protein Research Group (PRG) in Colombia. It was evidenced that plant legume lectin domains have structural features characterized by a high percentage of  $\beta$ -sheet structures associated with dimeric or tetrameric assembly, presenting several specific sugar recognition sites, including mannose. In addition to these features, these lectins can interact with the digestive system of insect pests and produce a decrease in intestinal absorption capacity.

## 2. Definition, classification, and general features of lectins

Lectins are proteins or glycoproteins of the nonimmune origin with specific binding affinity for the carbohydrate moiety of glycoconjugates [1]. Lectins comprise a structurally diverse class of proteins characterized by their ability to selectively bind carbohydrate moieties of the glycoproteins of the cell surface. Lectins may be obtained from plant, microbial, or animal sources and may be soluble or membrane bound [2]. In nature, lectins play a role in biological recognition phenomena involving cells and proteins and thereby protect plants against external pathogens such as fungi and other organisms. The ability to bind and agglutinate red blood cells is well known and used for blood typing; hence, the lectins are commonly called hemagglutinins [3].

The term lectin is derived from the Latin word *legere* meaning “to choose” or “select” and has been generalized to encompass all nonimmune carbohydrate-specific agglutinins regardless of blood type specificity or source. Lectins were initially found and described in plants, but in subsequent years, multiple lectins were isolated from microorganisms and also from animals [4]. Interestingly, plant and animal lectins show no primary structural homology, but they demonstrate similar preferential binding to carbohydrates [5]. This suggests that animal and plant lectin genes may have coevolved, thus highlighting the importance of lectin-carbohydrate interactions in living systems [6].

Based on the amino acid sequences of available lectins, it is deduced that the carbohydrate-binding property of most lectins resides in a polypeptide sequence, which is termed as “carbohydrate-recognition domain” [7]. The binding with simple or complex carbohydrate conjugates is reversible and non-covalent. The specificity of lectins toward carbohydrates can be defined on the basis of “hapten inhibition test,” in which various sugars or saccharides are tested for their capacity to inhibit the property of hemagglutination of erythrocytes [8].

Lectins have been classified according to different features such as source (animal, vegetal, fungal, viral), carbohydrate affinity (mannose, glucose, galactose, fucose, sialic acid), number, and specificity of carbohydrate recognition domains (merolectins, hololectins, chimerlectins, and superlectins) [9]. However, current classification is based on 3D structure and is related to 48 families (**Table 1**) [10].

Distribution								
No.	Family	Fold	Assembly	Animal	Plant	Fungi	Bacteria	Virus
1	L-type	Jelly roll	Dimer	x	x	x		
	L-type-like	Jelly roll	Monomer	x	x	x		
2	Galectin	Jelly roll	Monomer, dimer	x		x		x
3	Pentaxim	Jelly roll	Pentamer	x				
4	I-type	Ig-like $\beta$ -sandwich	Linked to different domains	x				
5	C-type	$\alpha/\beta$ -fold	Linked to different domains	x				
6	Hyaladherin	$\alpha/\beta$ -fold	Linked to different domains	x				
7	Chitinase-like	$(\beta/\alpha)_8$ -Barrel	Monomer	x	x	x	x	x
8	M-type	$(\alpha/\alpha)_7$ -Barrel	Monomer	x	x	x	x	
9	R-type	$\beta$ -Trefoil	Linked to enzyme	x	x	x	x	
	R-type-like	$\beta$ -Trefoil	Linked to different domains			x	x	
10	ACA-like	$\beta$ -Trefoil	Dimer		x			
11	Botulinum neurotoxin-like	$\beta$ -Trefoil	Linked to different domains				x	
12	F-box	Jelly roll	Linked to different domains	x				
13	F-type	Jelly roll	Linked to different domains	x	x	x	x	
14	PA-LL-like	Jelly roll	Dimer				x	
15	P-type	$\alpha/\beta$ -fold	Dimer	x				
16	Ficolins	Fibrinogen-like	Trimer	x				
17	Malectin	Jelly roll	Monomer	x				
18	Calnexin	Jelly roll	Monomer	x				
19	Tachylectin-2-like	5-Bladed $\beta$ -propeller	Monomer	x				
20	Tachycitin-like	$\beta$ -sheet-cysteine fold	Monomer	x				
21	Hevein	Cystine-knot motif	Dimer	x	x			
22	Jacalin-related	$\beta$ -Prism I	Tetramer	x	x			
23	SUEL-related	$\alpha/\beta$ -fold	Linked to different domains	x				

Distribution								
No.	Family	Fold	Assembly	Animal	Plant	Fungi	Bacteria	Virus
24	H-type	Six-stranded antiparallel $\beta$ -sandwich	Hexamer	x	x			
25	Cystine-knot	Cystine-knot motif		X				
26	TgMIC4	$\alpha/\beta$ -fold	Tandem repeat	x				
27	TgMIC1	Sialic acid binding protein	Linked to different domains	x				
28	LysM	$\beta\alpha\alpha\beta$ -Motif	Triple repeat	x	x	x	x	
29	LNP-type	$\alpha/\beta$ -fold	Monomer	x	x		x	
30	Monocot	$\beta$ -Prism II	Monomer, dimer, tetramer		x		x	
31	ABL-like	$\alpha/\beta$ -sandwich	Dimer, tetramer		x	x		
32	CV-N	Three-stranded $\beta$ -sheet and $\beta$ -hairpins	Monomer		x	x	x	
33	PVL-like	Seven-bladed $\beta$ -propeller	Monomer			x		
34	AAL-like	Six-bladed $\beta$ -propeller	Monomer			x	x	
35	Flocculins	$\beta$ -Sandwich	Monomer			x	x	
36	PCL-like	Jelly roll	Tandem repeat			x		
37	BC2LCN	Jellyroll	Trimer				x	
38	Staphylococcal toxin	$\beta$ -Barrel	Monomer				x	
39	AB5 toxin	$\alpha/\beta$ -fold	AB5				x	
40	PA-IIL-like	$\beta$ -Sandwich	Dimer				x	
41	MVL	$\alpha/\beta$ -fold	Dimer				x	
42	PapG	$\beta$ -Sandwich	Linked to different domains				x	
43	FimH	$\beta$ -Sandwich	Linked to different domains				x	
44	F17-G	$\beta$ -Sandwich	Linked to different domains				x	
45	Hemagglutinin	Jelly roll	Trimer					x
46	RotavirusVP4	Jelly roll	Virus capsid					x
47	Viral proteins	$\beta$ -Sandwich	Virus capsid					x
48	Knob domain	Jelly roll	Virus capsid					x

Folding, assembly, and source of each family is shown.

**Table 1.** Lectin families in nature.

### 3. Structure and biological activities of plant lectins

Lectins are mainly present in seeds of plants [4, 8, 9], but they are also identified in vegetative tissues such as bulbs, tubers, rhizomes, roots, bark, stems, fruits, and leaves [11].

As previously mentioned, based on their number domains and their characteristics, plant lectins can be divided into four classes [9]:

- **Merolectins** are lectins that possess a single carbohydrate-binding domain. As a result, the merolectins do not present agglutinating activity.
- **Hololectins** contain two or multivalent carbohydrate-binding sites.
- **Chimerolectins** possess a carbohydrate-binding domain and an additional domain that confers other biological activities.
- **Superlectins** are lectins with two or multivalent carbohydrate domains that are able to recognize structurally unrelated sugars.

However, since 1998, five novel lectin domains have been identified in plants. At present, plant lectins are classified into 12 different families, with distinct carbohydrate-binding domains. The families are *Agaricus bisporus* agglutinin homologs, amaranthines, class V chitinase homologs, *Euonymus europaeus* agglutinin family, *Galanthus nivalis* agglutinin family, proteins with hevein domains, jacalins, proteins with legume lectin domains, LysM domain proteins, the *Nicotiana tabacum* agglutinin family, and the ricin B family [12].

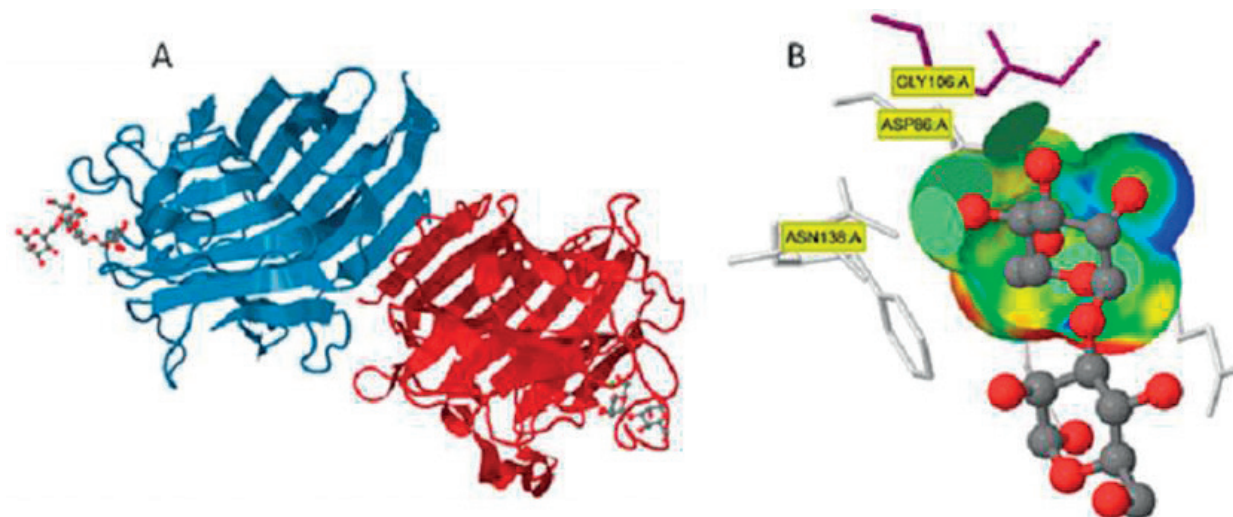
In general, the three-dimensional structure of lectins is composed of a high content of  $\beta$ -sheets with little contribution from  $\alpha$ -helices. The  $\beta$ -sheets are connected by loops forming antiparallel chains. The stability of dimers and tetramers is conferred by hydrophobic interactions, hydrogen bonds, and salt links [13]. Three regions are formed in carbohydrate-binding site [12–14]:

- The central region is constituted by a conserved core in which residues interact with metallic ions ( $Mg^{2+}$ ,  $Mn^{2+}$ , and  $Ca^{2+}$ ), required for carbohydrate interactions. This core provides necessary binding energy, but it is not important to the lectin's carbohydrate specificity.
- Some aromatic residues surround the core and occupy variable positions in a horseshoe shape. This region is fully involved in the lectin's monosaccharide specificity.
- Finally, residues with higher variability are located in the outer zone and are involved in interactions with larger oligosaccharide ligands.

The structural features of plant lectins are shown in **Figure 1**, which is possible to see the high content of  $\beta$ -sheets (**Figure 1A**) and the structure of a typical carbohydrate recognition domain (**Figure 1B**).

However, the kind of expressed lectins can have some differences according to the specific tissue or the moment in which the plant is expressing it. A lot of plant lectins are constitutively expressed in high amounts in seeds and vegetative storage tissues where





**Figure 1.** Structural conformation of plant lectins. (A) *Pterocarpus angolensis* homodimer lectin (PDB code (2PHF)). The  $\beta$ -sheet conformation is the most usual in plant lectins ( $\beta$ -sandwich). (B) The carbohydrate recognition domain (CRD) is highly conserved in plant lectins, according to its specificity.

they have been shown to play a role in plant defense [15]. But, plants also express minute amounts of specific lectins as particular responses toward environmental stresses and pathogen attack. In the absence of plant stress, the inducible lectins are not expressed at detectable levels [16]. According that, a central question which has often been asked but up to now not yet been answered definitively is that on the biological function(s) of plant lectins. Several functions have been mentioned, but there is not a final decision about that. However, because of its carbohydrate interactions, lectins have been tested for several biological functions, getting interesting results in some of them. Biological activities are related to immunomodulatory and antitumor [17–19], antifungal [20–23], antiparasitic [24–26], antiproliferative [27–30], healing process [31–33], drug delivery [34–36], as histochemical markers [37–39], biosensors [40, 41], insecticide [42–46], etc.

#### 4. Fabaceae (legume) and Lamiaceae (mint) lectins

The specific carbohydrate recognition shown by lectins makes them important tools in glycobiology, and, although their physiological role remains unknown, they appear to mediate protein-cell and cell-cell interactions. Lectins are widespread in nature, and most of them have been isolated and characterized from Fabaceae, Gramineae, and Lamiaceae families, among others [47, 48]. Those lectins have been related to insect defense mechanisms, storage proteins, carbohydrate transport, mechanisms of physiological regulation, and mitogenic stimulation processes [49–55]. The ability of the nitrogen-fixing bacteria rhizobia to form a symbiotic relationship with legumes, in which plant root lectins are involved, is well known. The plant-associated bacteria have important effects on plant health and productivity [56–59]. Thus biofilm formation on plants is associated with symbiotic and pathogenic responses, and some root lectins promote this process [60]. The lectins could be a good biotechnological alternative in the control of bacterial biofilms for different purposes, for example, clinical

applications [61]. In general, plant lectins have been widely used for studying carbohydrates on cell surface, for typing blood groups, isolating glycoconjugates, and detecting changes in normal oligosaccharide synthesis in tumoral disorders and other pathologies [62–66].

Lectins from Fabaceae have been extensively studied and have a broad specificity for any carbohydrate moieties regardless of having highly conserved amino acid sequences between different species. These proteins have been for a long time a paradigm in the research of interaction protein-carbohydrate and their relationship structure-function [67, 68]. Available sequences (RCSB PDB, UniProtKB/Swiss-Prot) show 20% similarity and 20% of identical amino acids, and conserved amino acids are in the “binding site” and coordinate metal ions [9]. These proteins generally have two or four identical subunits with a molecular weight around 25 kDa; each one contains a binding site for metal ions. A typical example of dimeric lectins belongs to the Viceae tribe. The tetrameric lectins are present in species of the tribe Diocleae, specific by glucose/mannose. In these tribes, many lectins have been isolated and characterized with some biochemical differences and molecular similarities [47]. Recently, subtribe Diocleinae in the Millettoid legumes have been taxonomically tangled together with the large heterogeneous tribe Phaseoleae; however, a comprehensive molecular phylogenetic analysis based on nuclear and chloroplast markers includes all genera ever referred to Diocleae except for the monospecific Philippine *Luzonia*, resolving several key generic relationships within the Millettoid legumes and considered classification of Diocleinae subtribe as a tribe with three main clades: *Canavalia*, *Dioclea*, and *Galactia*. *Canavalia* clade has species gender *Canavalia*; *Dioclea* clade includes *Dioclea*, *Cymbosema*, *Cleobulia* and *Macropsyчанthus*; and *Galactia* clade gender has *Galactia*, *Neorudolphia*, *Rhodopsis*, *Bionia*, *Cratyliа*, *Lackeya*, *Camptosema*, and *Collaea* [69].

This tribe is widely distributed throughout the neotropics, and several species from the genus *Dioclea* have been shown to possess a lectin closely related to ConA (lectin type I). The better characterized lectins have been those from *D. grandiflora* [70, 71], *D. lehmanni* Diels [72], and *D. sericea* Kunth [73], among others, all of them belong to the Man/Glc group; their physicochemical properties and structural features are very similar [74].

Studies carried out in the PRG have allowed us to find other lectins having distinct structural and functional properties (named lectin type II) from *Diocleae lehmanni* (DLL), *Dioclea sericea* (DSL), *Dioclea grandiflora* (DGL), *Canavalia ensiformis* (CEL), and *Galactia lindenii* (GLL) [73, 75–77]. These lectins are localized in the same cellular compartment as happens in *D. lehmanni* seeds [78] and have different physicochemical properties; this allow us to question about the physiological role of these proteins. Lectin type II has high affinity toward H type 2 blood group ( $\alpha$ -L-Fuc (1–2)- $\beta$ -D-Gal (1–4)- $\beta$ -D-GlcNAc-O-R), and the N-terminal region presents a unique sequence hitherto found in some Diocleinae lectins and suggests a functional similarity among this type of lectin which possesses distinctive characteristics differentiating them from “classical” mannose/glucose (Man/Glc) lectins. Taking subunit MW into account, it has been demonstrated that tetrameric forms prevailed in type I lectins, being in fast equilibrium with dimers and monomers whose amount depended upon pH or solution ionic strength [79], while some lectins from type II prevalence dimeric forms (**Table 2**). Despite their high similarity, these ConA-like (type II) lectins could induce different responses in biological assays; for example, when tested for stimulation of human lymphocyte proliferation in vitro, ConBr had a higher proliferation index than ConA, possibly due to minor changes in binding specificities [80].



Type	Species	Specificity	Monosaccharide inhibitor	Erythroagglutination	Native (kDa)	Subunits (kDa)	pI	References
I	<i>D. grandiflora</i>	Man/Glc	Man, Glc, Fru	Rabbit	100	$\alpha$ :25- $\alpha$ :26; $\beta$ :13- $\beta$ :14; $\gamma$ :8- $\gamma$ :9	8.6-9	[70, 71]
	<i>D. lehmanni</i>		Man, Glc, Fru, L-sorbose, Me- $\alpha$ -D-Man, Me- $\alpha$ -D-Glc, trehalose	Rabbit, A+, O+, B+		$\alpha$ :25.3; $\beta$ :14; $\gamma$ :N.D	8.0-8.4	[72]
	<i>D. sericea</i>		Man, Glc	A+, O+, B+	57.7	$\alpha$ :29.9; $\beta$ :16.5; $\gamma$ : 13.4	6.6-6.9	[73]
	<i>D. altissima</i>		Man, Glc, Fru	Rabbit	100	$\alpha$ :26.3; $\beta$ :14; $\gamma$ : 9	8.6-9.0	[131]
	<i>D. violaceae</i>		Man, Glc, Fru, maltose	Rabbit		$\alpha$ :29.5; $\beta$ :15.8; $\gamma$ : 11.7		[132]
	<i>D. rostrata</i>		Man, Glc, Fru	Rabbit, O+ and B+		$\alpha$ :30.9; $\beta$ :15.8; $\gamma$ : 11.7		[67]
	<i>D. lasiophylla</i>		Man, Me- $\alpha$ -D-Man, ovalbumin, fetuin	Rabbit		$\alpha$ :25,569; $\beta$ :12,998; $\gamma$ : 12,588		[133]
	<i>D. sclerocarpa</i>		Glc; Gal	Rabbit	102	$\alpha$ : 25,606; $\beta$ :12,832; $\gamma$ :12,752		[134]
	<i>C. ensiformis</i>		Man, Me- $\alpha$ -fructofuranoside	Rabbit	96	$\alpha$ :25.5; $\beta$ :14; $\gamma$ :12.5	7.1	[67]
	<i>C. mollis</i>		Glc, Me- $\alpha$ -D-Man	Rabbit > A+, O+, B+		$\alpha$ :30; $\beta$ :16; $\gamma$ : 14	8.5-8.6	[135]
	<i>C. roseum</i>		Man	Rabbit		$\alpha$ :30; $\beta$ :18; $\gamma$ : 12		[136]
	<i>G. lindenii</i>		p-Nitrophenyl- $\beta$ -D-mannopyranoside, Man	A+, O+	100	29; 60	6,5	[77]

Type	Species	Specificity	Monosaccharide inhibitor	Erythroagglutination	Native (kDa)	Subunits (kDa)	pI	References
II	<i>C. ensiformis</i>	H-Type II	Sucrose, melezitose, lactose	A+, O+, B+	57.5	29–30	5.2–5.4	[76]
	<i>D. grandiflora</i>		Sucrose, melezitose, lactose	A+, O+, B+	58.9	29–30	5.1–5.4	[76]
	<i>D. lehmanni</i>		Sucrose, melezitose, lactose	A+, O+, B+ > rabbit	58.4	29–30	6.5–6.6	[75]
	<i>D. sericea</i>		Lactose, sucrose, melibiose	A+, O+, B+	57.27	26.58–30	5.3–5.7	[73]
	<i>G. lindenii</i>		GalNAc, Me-β-Gal, Lactose	B+, O+ > A+	104,256	26,064	8.3	[137]
	<i>C. roseum</i>		GalNAc and N-acetyl-α-D-lactosamine	Rabbit	65	29	–	[138]
	<i>Captosemin</i>		N-acetyl-α-D-galactosamine	A+, O+, B+	104	26	–	[139]

Abbreviations: kDa, kilodalton; pI, isoelectric point; H-type II, antigen ( $\alpha$ -L-Fuc(1-2)- $\beta$ -D-Gal(1-4)- $\beta$ -D-GlcNAc-O-R); Man, mannose; Glc, glucose; Me, methyl; Gal, galactose; Fru, fructose; GalNAc, N-acetyl- $\alpha$ -D-galactosamine.

**Table 2.** Physicochemical properties of lectins of Diocleae tribe.

Lamiaceae lectins have been little studied despite preliminary reports on their ability to recognize the Tn/T antigens [81], normally a cryptic structure in the peptide core of O-glycoproteins and which is widely expressed in several tumors and other disorders such as Tn syndrome and IgA nephropathy [82–85]. The importance of Thomsen-Friedenreich antigen (TF or T, galactose (Gal)  $\beta$ 1,3 GalNAc $\alpha$ -O-serine (Ser)/threonine (Thr)) as well as to its precursor, the Tn antigen, and its sialylated forms (sTn) has been reviewed recently [86–91]; according to the above, it is important to have alternatives to study these structures such as the lectins and antibodies. However, a word of caution should be given as accumulating evidence, which has shown that mAbs and lectins do not interact with Tn-containing structures in an identical manner. The observed differences have been ascribed to different Tn-density requirements for the interaction to occur [92].

Detailed studies have been carried out on a very few Lamiaceae species from the Northern hemisphere's temperate zone until now [93–97], and the lectin from *Salvia sclarea* L. seeds (SSL) was the first to be isolated and partially characterized [94]. By contrast, species from the Neotropical *Salvia* subgenus Calosphace Benth have been little explored despite their great diversity. A systematic survey has been conducted on species belonging to the Neotropical Calosphace Benth subgenus [98], and certain species naturalized in the New World have also been investigated [99], some having commercial value. Given the abundance of Lamiaceae species in Colombia and the potential biotechnological applications, our group undertook a systematic search for the identification, isolation, and characterization of lectins from selected species with the determination of their biological activities. The lectins from *S. palifolia* Kunth and *Hyptis mutabilis* (Rich.) Briq. [100] have been partially characterized, and a detailed work has been done with *S. bogotensis* Benth and *Lepechinia bullata* (Kunth) Epling [101, 102].

The importance of these proteins as tools in a variety of biological studies and detection, isolation, structural, and functional properties has been studied, and more recently, T/Tn-specific lectins have been found in the families Amaranthaceae, Fabaceae, Moraceae, and Orchidaceae, among others. The lectins themselves belong to five families of structurally and evolutionarily related proteins (amaranthines, legume lectins, jacalin-related lectins, type 2 ribosome-inactivating proteins, and GNA-related lectins) [103].

Interestingly, a lectin type I was found in *S. bogotensis* Benth. (SBoL-I) and *Lepechinia bullata* (Kunth) Epling (LBL-I) (such as those found in the tribe Diocleae type I), which recognizes mannose/glucose residues; this fact, together with the molecular properties and highly similar N-terminal regions, led us to propose that lectins type I and type II are two good differentiated groups with structural features proper of legume lectins family, particularly from Diocleae tribe, *Salvia*, and *Lepechinia* genders (**Table 3**) [104]. For these lectins, SDS-PAGE profile was similar to other mannose lectins, a band around 30 kDa with an isoelectric point near to 6.5, and they were able to agglutinate human RBCs from A, B, and O donors. This means that specificity by mannose/glucose moieties or mannose-rich glycan is not a unique feature of any family; conversely, species such as *Galanthus nivalis* (tribe Galantheae) [105] and *Centrolobium microchaete* (tribe Dalbergieae) [106], among others, even species from other families such as Moraceae have mannose/glucose lectins [107].

Molecular properties	GLL-I <sup>1</sup>	DLL-I <sup>2</sup>	CRL-I <sup>3</sup>	CEL-I <sup>4</sup>	SBoL-I <sup>5</sup>	LBL-I <sup>6</sup>
M <sub>r</sub> subunit (kDa) <sup>7</sup>	29	25, 14	ND	26.5	30–33	30–34
M <sub>r</sub> protein (kDa) <sup>8</sup>	100	ND	ND	106	ND	ND
SDS-page (kDa)	29, 60	25, 14	30, 18, 12	26, 14, 12.5	30, 60	30, 60
Glycosylation	Si	ND	ND	No	Si	Si
Neutral Sugars (%)	ND	1.7–1.9	ND	ND	ND	ND
Isoelectric point (PI)	6.15	8.0; 8.13 8.3; 8.42	ND	7.1	6.5	6.5
Mannose inhibition (mM)	150	50	19.5	ND	ND	ND
Sequence N-terminal	ND	ADTIVAVELD SYPNTDIGDPSYPH	ADTIVAVELD SYPNTDIGDPSYPH	ADTIVAVELD TYPNTDIGDPSYPH	ADTIVAVELD	ADTIVAVELD

<sup>1</sup>*Galactia lindenii* lectin type -I (GLL-I) [77].

<sup>2</sup>*Dioclea lehmanni* lectin type I (DLL-I) [72].

<sup>3</sup>*Cymbosema roseum* lectin type I (CRL-I) [136].

<sup>4</sup>*Canavalia ensiformis* concanavalin A (CEL-I) [67].

<sup>5</sup>*Salvia bogotensis* lectin type I (SBoL-I) [104].

<sup>6</sup>*Lepechinia bullata* lectin type I (LBL-I) [104].

<sup>7</sup>Reduced conditions.

<sup>8</sup>Non-reduced conditions without heat.

ND, non-determined.

**Table 3.** Molecular properties of lectins type I from Fabaceae and Lamiaceae families.

## 5. Insecticide and insectistatic activity of plant lectins

There are several evidences for the defensive role of vegetal lectins in protecting plants against insect pests [108–110], and lectins are currently receiving a significant interest as insecticidal agents against sap-sucking insects including aphids and leaf and plant hoppers, with no effect on human metabolism [111, 112]. Lectins act on insects by binding to glycoproteins present in insect gut epithelium, eventually causing death of insect by inhibiting absorption of nutrients. It was believed that N-linked glycans in insects were exclusively of the high mannose type; therefore, there are great interests, especially in mannose-specific plant lectins, as possible insecticidal or insect-detering molecules for the new pest management strategies [113, 114]. Nevertheless, the lectins possess different sugar specificities and, considering the variety of glycan structures in the bodies of insects, have many different possible targets. Advances have been made in the knowledge related to glycan diversity and function(s) of protein glycosylation in insects, N-glycosylation, and O-glycosylation, and it postulated that the interference in insect glycosylation appears to be a promising strategy for pest insect control [115]. Therefore, it is difficult to predict the exact mode of action of each lectin and even more difficult to understand the variability in insect toxicity upon exposure to different plant lectins. The use of initial bioassays employing artificial diets has led to the most recent advances, such as plant breeding and the construction of fusion proteins, using lectins for targeting the delivery of toxins and to potentiate expected insecticide effects [116–118].

The first lectin known for insecticidal activity was *Galanthus nivalis* agglutinin, which belongs to a superfamily of alpha-D-mannose-specific plant bulb lectins [105, 119]. The mannose-binding lectins have shown strong insecticidal activity against chewing and sap-sucking insects and particularly in controlling aphids [120–124]. Lectin isolated from bulbs of *Phycella australis* presented a strong insecticidal activity against the pea aphid and green peach aphid, affecting the survival, feeding behavior, and fecundity of aphids, where *Acyrtosiphon pisum* proved to be particularly sensitive [125].

No considerable mortality effect of ASA lectins (native or recombinant lectins) was shown on larvae of potato moths (*Tecia solanivora*); however, recombinant ASAI lectin had an effect on the pupa mortality, which was bigger than the native lectin effect. The effect of lectins on the weight and fertility of adults showed that both lectins had a big effect on fertility when the lectin is used in a low concentration (lower than 0.003 mg/mL), and, in some cases, lectins produced malformations in female adults [126]. Fitches et al. found toxic effects on *Acyrtosiphon pisum* using both recombinant lectins; however, ASA II was more toxic than ASA I, at the same dose [127].

Lectins from legume family have shown insectistatic and insecticidal activity [52] (Table 4). The lectins from seeds of *Canavalia brasiliensis*, *Dioclea grandiflora*, *Dioclea rostrata*, *Cratylia floribunda*, and *Phaseolus vulgaris* have shown to protect seeds against the beetle *Callosobruchus maculatus*. In general, the plant lectins are the most potent agents against insect pests of a variety of crops including wheat, rice, tobacco, and potatoes [128]. *Canavalia* lectins exhibited a range of different toxicities toward *Artemia nauplii* and bound to a similar area in the digestive tract; differences in spatial arrangement and volume of CRD (carbohydrate recognition domain) may explain the variation of the toxicity showed by each lectin despite the high structural similarity [129]. The sensitivity of different insect species to the insecticidal effects

of lectin ingestion is variable, and the binding of a lectin to the gut does not necessarily imply toxicity. Other studies signal that lectins affect various insect hydrolytic enzymes such as glucosidases, phosphatases, and proteases which are involved in digestion, development, growth, and detoxification. To date a great number of studies have shown lectin toxicity in insects belonging to different orders, including Lepidoptera, Coleoptera, and Hemiptera. However, the exact mode of action of lectins in providing resistance against insects remains unclear. The most relevant property of lectin's anti-insect activity can be related to its interactions with different glycoproteins or glycan structures in insects, which may interfere with a number of physiological processes in these organisms. Lectins possess at least one carbohydrate-binding domain and different sugar specificities, possible targets for lectin binding are numerous, and several mechanisms can be associated (**Figure 2**).

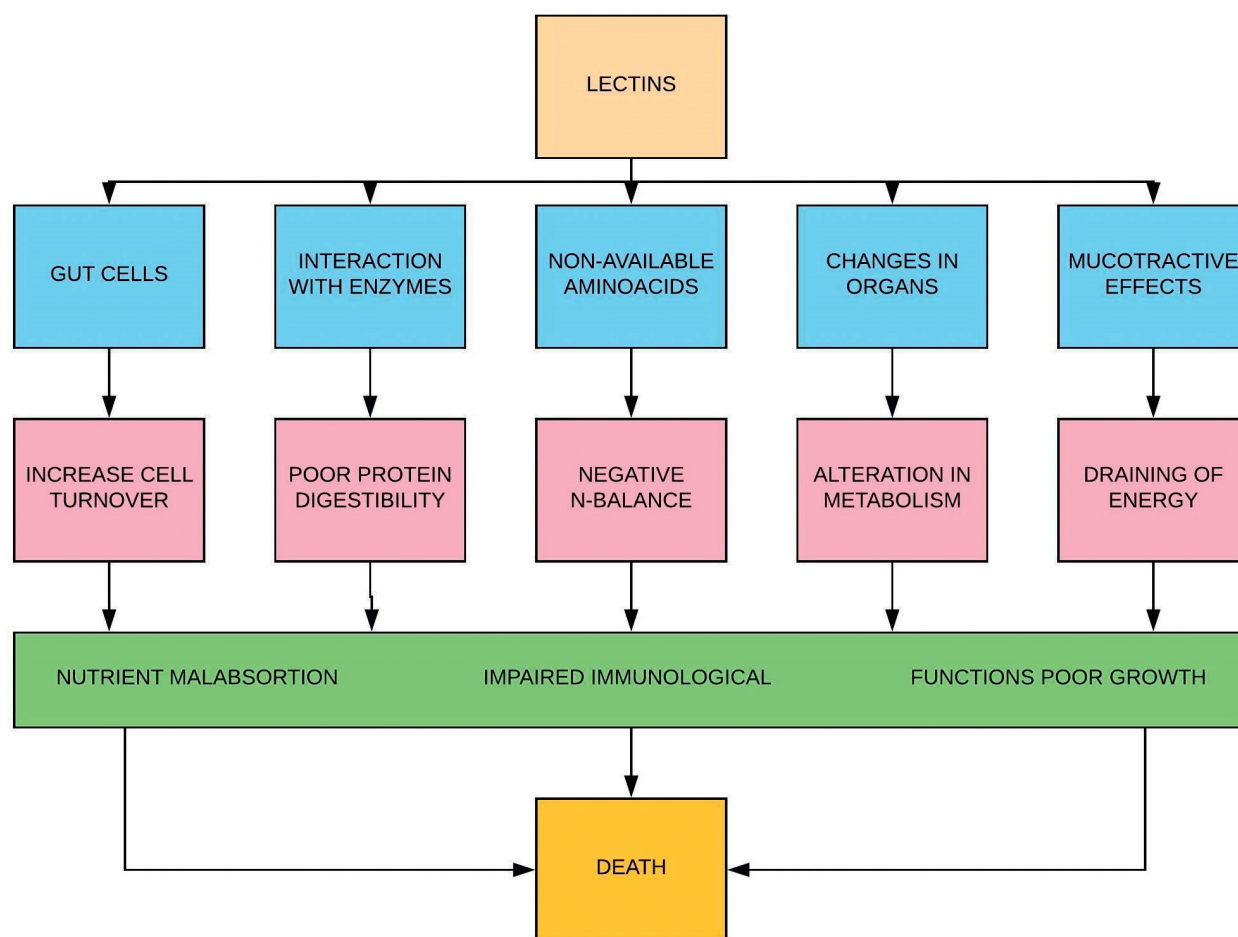
Preliminary evidence of Gleheda's insecticidal activity against Colorado potato beetle larvae (*Leptinotarsa decemlineata*) has been obtained using a single dose of lectin [130]; it would have been very interesting to carry out dose-response experiments and to assay several insect pests to elucidate whether the lectin was insect specific. Nevertheless, Gleheda's insecticidal activity stresses the importance of this unusual lectin, begging the question of whether such activity is shared by other Lamiaceae lectins. To date Lamiaceae lectin is unique with known insecticidal activity. The importance of lectins due to their insecticidal properties, isolation of native lectins, and lectin genes could be agronomically important tools for crop plants for developing resistance against insect pests mainly for sap-sucking

Lectin	Insect pests	Activity	References
PSA	<i>Meligethes aeneus</i>	Insecticidal, insectistatic	[140]
ConA	<i>Tarophagous proserpina</i>	Insectistatic	[141]
Gleheda	<i>Leptinotarsa decemlineata</i>	Insectistatic	[130]
ConA	<i>Callosobruchus maculatus</i>	Insectistatic	[142]
ConA	<i>Helicoverpa armigera</i>	Insectistatic	[143]
GS-II	<i>Callosobruchus maculatus</i>	Insectistatic	[144]
PHA	<i>Callosobruchus maculatus</i>	Insecticidal	[145]
PHA-E	<i>Empoasca fabae</i>	Insecticidal	[146]
Bmoll	<i>Anagasta kuehniella</i>	Insecticidal	[147]
	<i>Zabrotes subfasciatus</i>		
	<i>Callosobruchus maculatus</i>		
	<i>Callosobruchus maculatus</i>		
DGL	<i>C. maculatus</i>		[108]
DRL			
CFL			

*Pisum sativum* (PSA), *Canavalia ensiformis* (concanavalin A (ConA)), *Glechoma hederacea* (Gleheda), GS-II: *Griffonia simplicifolia* agglutinina, *Phaseolus vulgaris* (PHA), *Bauhinia monandra* leaf lectin (bmoll), *Dioclea grandiflora* (DGL), *D. rostrata* (DRL), *Cratylia floribunda* (CFL). Taking from Calvacante et al. [60] and modified.

**Table 4.** Legume lectins domain with insectistatic and insecticidal activity.





**Figure 2.** Possible targets and associated mechanisms of lectin anti-insect activity. Lectins have antinutritional properties by which they interact with several targets in digestive tract and other organs.

insect. These proteins are very interesting, and its molecular properties have been well described; however, there is still a long way to study and learn about the mechanisms of these molecules at a physiological and molecular level.

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### References

[1] Goldstein IJ, Hughes RC, Monsigny M, Osawa T, Sharon N. What should be called a lectin? *Nature*. 1980;285:66

- [2] Kumar KK, Lalith Prakash CK, Sumanthi J, Reddy GS, Shekar PC, Reddy B. Biological role of lectins: A review. *Journal of Orofacial Sciences*. 2012;**4**:20-25
- [3] Liu B, Bian HJ, Bao JK. Plant lectins: Potential antineoplastic drugs from bench to clinic. *Cancer Letters*. 2010;**287**:1-12
- [4] Sharon N, Lis H. Lectins as cell recognition molecules. *Science*. 1989;**246**:227-234
- [5] Ghazarian H, Idoni B, Oppenheimer SB. A glycobiology review: carbohydrates, lectins, and implications in cancer therapeutics. *Acta Histochemica*. 2011;**113**(3):236-247. DOI: 10.1016/j.acthis.2010.02.004
- [6] Gorelik E, Galili U, Raz A. On the role of cell surface carbohydrates and their binding proteins (lectins) in tumor metastasis. *Cancer Metastasis Reviews*. 2001;**20**:245-277
- [7] Drickamer K. Two distinct classes of carbohydrate recognition domains in animal lectins. *The Journal of Biological Chemistry*. 1988;**263**:9557-9560
- [8] Singh H, Sarathi SP. Insight of lectins – A review. *Journal of Scientific and Engineering Research*. 2012;**3**:4
- [9] Van Damme EJM, Peumans WJ, Barre A, Rouge P. Plant lectins: A composite of several distinct families of structurally and evolutionary related proteins with diverse biological roles. *Critical Reviews in Plant Sciences*. 1998;**17**:575-692
- [10] Fujimoto Z, Tateno H, Hirabayashi J. Lectin structures: Classification based on the 3-D structures. *Lectins: Methods and Protocols*. 2014:579-606
- [11] Van Damme EJ, Lannoo N, Fouquaert E, Peumans WJ. The identification of inducible cytoplasmic/nuclear carbohydrate-binding proteins urges to develop novel concepts about the role of plant lectins. *Glycoconjugate Journal*. 2003;**20**:449-460
- [12] Macedo MLR, Oliveira CF, Oliveira CT. Insecticidal activity of plant lectins and potential application in crop protection. *Molecules*. 2015;**20**(2):2014-2033
- [13] Sharon N, Lis H. Legume lectins—A large family of homologous proteins. *The FASEB Journal*. 1990;**4**:3198-3208
- [14] Young NM, Oomen RP. Analysis of sequence variation among legume lectins: A ring of hypervariable residues forms the perimeter of the carbohydrate-binding site. *Journal of Molecular Biology*. 1992;**228**:924-934
- [15] Peumans WJ, Van Damme EJM. Lectins as plant defense proteins. *Plant Physiology*. 1995;**109**:347-352. DOI: 10.1104/pp.109.2.347
- [16] Lannoo N, Van Damme EJ. Lectin domains at the frontiers of plant defense. *Frontiers in Plant Science*. 2014;**5**:1-16
- [17] Wang H, Liu W, Ng T, Ooi V, Chang S. The immunomodulatory and antitumor activities of lectins from the mushroom *Tricholoma mongolicum*. *Immunopharmacology*. 1996;**31**(3):205-211
- [18] Majee S, Biswas G. Exploring plant lectins in diagnosis, prophylaxis and therapy. *Journal of Medicinal Plants Research*. 2013;**7**(47):3444-3451

- [19] Ashraf M, Khan R. Mitogenic lectins. *Medical Science Monitor*. 2003;**9**(11):RA265-RA269
- [20] He X, Ji N, Xiang X, Luo P, Bao J. Purification, characterization, and molecular cloning of a novel antifungal lectin from the roots of *Ophioglossum pedunculatum*. *Applied Biochemistry and Biotechnology*. 2011;**165**(7):1458-1472
- [21] De Albuquerque L, De S'a Santana G, Napoleao T, Coelho L, Da Silva M, Paiva P. Antifungal activity of *Microgramma vacciniifolia* rhizome lectin on genetically distinct *Fusarium oxysporum* f. sp. *Lycopersiciraces*. *Applied Biochemistry and Biotechnology*. 2014;**172**(2):1098-1105
- [22] Yao Q, Wu C, Luo P. A new chitin-binding lectin from rhizome of *Setcreasea purpurea* with antifungal, antiviral and apoptosis-inducing activities. *Process Biochemistry*. 2010;**45**(9):1477-1485
- [23] Trindade M, Lopes J, Soares-Costa A. Structural characterization of novel chitin-binding lectins from the genus *Artocarpus* and their antifungal activity. *Biochimica et Biophysica Acta—Proteins and Proteomics*. 2006;**1764**(1):146-152
- [24] Afonso-Cardoso S, Silva C, Ferreira M, Souza M. Effect of the *Synadenium carinatum* latex lectin (ScLL) on *Leishmania (Leishmania) amazonensis* infection in murine macrophages. *Experimental Parasitology*. 2011;**128**(1):61-67
- [25] Albuquerque L, Pontual E, Santana G. Toxic effects of *Microgramma vacciniifolia* rhizome lectin on *Artemia salina*, human cells, and the schistosomiasis vector *Biomphalaria glabrata*. *Acta Tropica*. 2014;**138**:23-27
- [26] Santos A, Cavada B, Rocha B, Nascimento K, SantAna A. Toxicity of some glucose/mannose-binding lectins to *Biomphalaria glabrata* and *Artemia salina*. *Bioresource Technology*. 2010;**101**(2):794-798
- [27] Batterbury M, Tebbs C, Rhodes J, Grierson I. *Agaricus bisporus* (edible mushroom lectin) inhibits ocular fibroblast proliferation and collagen lattice contraction. *Experimental Eye Research*. 2002;**74**(3):361-370
- [28] Yu L, Fernig D, Smith J, Milton J, Rhodes J. Reversible inhibition of proliferation of epithelial cell lines by *agaricus bisporus* (edible mushroom) lectin. *Cancer Research*. 1993;**53**(19):4627-4632
- [29] Pereira P, Del Aguila E, VerIcimo M, Zingali R, Paschoalin M, Silva J. Purification and characterization of the lectin from taro (*Colocasia esculenta*) and its effect on mouse splenocyte proliferation in vitro and in vivo. *Protein Journal*. 2014;**33**(1):92-99
- [30] da Silva L, Filho C, De Paula R, Coelho L, Da Silva M, Correia M. *Cratylia mollis* lectin: A versatile tool for biomedical studies. *Current Bioactive Compounds*. 2014;**10**(1):44-54
- [31] Jacinto A, Cordeiro J. The role of transcription independent damage signals in the initiation of epithelial wound healing. *Nature Reviews Molecular Cell Biology*. 2013;**14**(4):249-262
- [32] Velnar T, Bailey T, Smrkolj V. The wound healing process: An overview of the cellular and molecular mechanisms. *Journal of International Medical Research*. 2009;**37**(5):1528-1542

- [33] Coriolano M, De Melo C, Silva F. Parkia pendula seed lectin: Potential use to treat cutaneous wounds in healthy and immunocompromised mice. Applied Biochemistry and Biotechnology. 2014;**172**(5):2682-2693
- [34] Sheng Y, He H, Zou H. Poly(lactic acid) nanoparticles coated with combined WGA and water-soluble chitosan for mucosal delivery of  $\beta$ -galactosidase. Drug Delivery. 2014;**21**(5):370-378
- [35] Jain S, Gupta M, Sahoo A, Pandey A, Jain A. Lectin conjugated gastro-retentive microspheres of amoxicillin for effective treatment of helicobacter pylori. Current Science. 2014;**106**(2):267-276
- [36] Adebisi A, Conway B. Lectin-conjugated microspheres for eradication of *Helicobacter pylori* infection and interaction with mucus. International Journal of Pharmaceutics. 2014;**470**(1):28-40
- [37] Schnegelsberg B, Schumacher U, Valentiner U. Lectin histochemistry of metastasizing and non-metastasizing breast and colon cancer cells. Anticancer Research. 2011;**31**(5):1589-1597
- [38] Beltrao E, Medeiros P, Rodrigues O. Parkia pendula lectin as histochemistry marker for meningothelial tumour. European Journal of Histochemistry. 2003;**47**(2):139-142
- [39] Chandler K, Goldman R. Glycoprotein disease markers and single protein-omics. Molecular and Cellular Proteomics. 2013;**12**(4):836-845
- [40] Li F, Feng Y, Yang L, Li L, Tang C, Tang B. A selective novel non-enzyme glucose amperometric biosensor based on lectin-sugar binding on thionine modified electrode. Biosensors and Bioelectronics. 2011;**26**(5):2489-2494
- [41] Luna D, Oliveira M, Nogueira M, Andrade C. Biosensor based on lectin and lipid membranes for detection of serum glycoproteins in infected patients with dengue. Chemistry and Physics of Lipids. 2014;**180**:7-14
- [42] De Oliveira A, Silva L, Lima T. Biotechnological value of Moringa oleifera seed cake as source of insecticidal lectin against Aedes aegypti. Process Biochemistry. 2016;**51**(10):1683-1690
- [43] Williams C, Collier C, Nemacheck J, Liang C, Cambron S. A lectin-like wheat gene responds systemically to attempted feeding by avirulent first-instar hessian fly larvae. Journal of Chemical Ecology. 2002;**28**:1411-1428
- [44] Puthoff DP, Sardesai N, Subramanyam S, Nemacheck JA, Williams CE. Hfr-2, a wheat cytolytic toxin-like gene, is up-regulated by virulent hessian fly larval feeding. Molecular Plant Pathology. 2005;**6**:411-423
- [45] Pyati P, Chellamuthu A, Gatehouse AMR, Fitches E, Gatehouse JA. Insecticidal activity of wheat hessian fly responsive proteins HFR-1 and HFR-3 towards a non-target wheat pest, cereal aphid (*Sitobion avenae* F.). Journal of Insect Physiology. 2012;**58**:991-999
- [46] Vandenborre G, Groten K, Smaghe G, Lannoo N, Baldwin IT, van Damme EJM. Nicotiana tabacum agglutinin is active against Lepidopteran pest insects. Journal of Experimental Botany. 2010;**61**:1003-1014

- [47] Sharon N, Lis H. Lectins. Netherlands: Springer Science; 2007
- [48] Rüdiger H, Gabius H. The history of lectinology. In: Gabius HJ, editor. The Sugar Code. Fundamentals of Glycosciences. Weinheim, Germany: Wiley; 2009. pp. 261-268
- [49] De Schutter K, Van Damme EJM. Protein-carbohydrate interactions as part of plant Defense and animal immunity. *Molecules*. 2015;**20**:9029-9053
- [50] Dang L, Van Damme EJM. Review toxic proteins in plants. *Phytochemistry*. 2015;**117**: 51-64
- [51] Lima TE, Sartori ALB, Rodrigues MLM. Plant antiherbivore defenses in Fabaceae species of the Chaco. *Brazilian Journal of Biology*. 2017;**77**(2):299-303. DOI: 10.1590/1519-6984.12815
- [52] Casas ZY, Reyes-Montaña EA, Vega NA. Lectinas con dominio de Leguminosa: Características estructurales y utilidad como agentes insectistáticos e insecticidas. *Chilean Journal of Agricultural and Animal Sciences (ex Agro-Ciencia)*. 2016;**32**(2):157-169
- [53] Gabius HJ, André S, Kaltner H, Siebert HC. The sugar code: Functional lectinomics. *Biochimica et Biophysica Acta (BBA) – General Subjects*. 2002;**1572**(2-3):165-177
- [54] Maciel EVM, Araújo-Filho VS, Nakazawa M, Gomes YM, Coelho LCBB, Correia MTS. Mitogenic activity of *Cratylia mollis* lectin on human lymphocytes. *Biologicals*. 2004;**32**:57-60
- [55] Dan X, Ng TB. Two legume defense proteins suppress the mobility of nasopharyngeal carcinoma cells. *Journal of Enzyme Inhibition and Medicinal Chemistry*. 2016;**31**(6):1328-1334
- [56] Rodríguez-Navarro DN, Dardanelli MS, Ruiz-Sainz JE. Attachment of bacteria to the roots of higher plants. *FEMS Microbiology Letters*. 2007;**272**:127-136. DOI: 10.1111/j.1574-6968.2007.00761.x
- [57] Albareda M, Dardanelli M, Sousa C, megias M, Temprano F, Rodriguwz-Navarro D. Factors affecting the attachment of rhizospheric bacteria to bean and soybean roots. *FEMS Microbiology Letters*. 2006;**259**(1):67-73 <https://doi.org/10.1111/j.1574-6968.2006.00244.x>
- [58] Brewina N, more KIS. Legume lectins and nodulation by *Rhizobium*. *Trends in Plant Science*. 1997;**2**(3):92-98. DOI: 10.1016/S1360-1385(96)10058-3
- [59] De HoV P, Brill L, Hirsch A. Plant lectins: The ties that bind in root symbiosis and plant defense. *Molecular Genetics and Genomics*. 2009;**282**:1-15. DOI: 10.1007/s00438-009-0460-8
- [60] Calvacante T, Firmino N, Solon F, de Andrade C, Albuquerque R. Plant lectins as alternative tools against bacterial biofilms. *American Journal of Microbiological Research*. 2014;**8**(27):2555-2564. DOI:105897/AJMR2014.6710
- [61] Vasconcelos M, Vassiliepe F, Alves V, Colares H,1 Santiago Nascimento K, Holanda A, Cavada B, Holanda E, Henriques M and Pereira M. Effect of algae and plant lectins on planktonic growth and biofilm formation in clinically relevant bacteria and yeasts. *BioMed Research International*. 2014:1-9. Article ID: 365272. DOI: 10.1155/2014/365272



- [62] Syed P, Gidwani K, Kekki H, Leivo J, Pettersson K, Lamminmaki U. Role of lectin microarrays in cancer diagnosis. *Proteomics*. 2016;**16**(8):1257-1265
- [63] Gorakshakar AC, Ghosh K. Use of lectins in immunohematology. *Asian Journal of Transfusion Science*. 2016;**10**(1):12-21
- [64] Coulibaly F, Youan B. Current status of lectin-based cancer diagnosis and therapy. *AIMS Molecular Science*. 2017;**4**(1):1-27. DOI: 10.3934/molsci.2017.1.1
- [65] Lagarda-Diaz I, Guzman-Partida A, Vazquez-Moreno L. Review legume lectins: Proteins with diverse applications. *International Journal of Molecular Sciences*. 2017;**18**:1242. DOI: 10.3390/ijms18061242
- [66] Poiroux G, Barre A, Van Damme E, Benoist H, Rougé P. Review plant lectins targeting O-glycans at the cell surface as tools for cancer diagnosis, prognosis and therapy. *International Journal of Molecular Sciences*. 2017;**18**(6):1232. DOI: 10.3390/ijms18061232
- [67] Goldstein IJ, Poretz RD., Isolation physicochemical characterization and carbohydrate-binding specificity of lectins. In: Liener IE, Sharon N, Goldstein IJ, editors. *The Lectins Properties, Functions and Applications in Biology and Medicine*. Elsevier; 1986. pp. 233-247
- [68] Loris R. Principles of structures of animal and plant lectins. *Biochimica et Biophysica Acta*. 2002;**1572**(2-3):198-208
- [69] De Queiroz LP, Pastore JFB, Cardoso D, Snak C de C, Lima AL de C, Gagnon E, Vatanparast M, Holland AE, Egan AN. A multilocus phylogenetic analysis reveals the monophyly of a recircumscribed papilionoid legume tribe Diocleae with well-supported generic relationships. *Molecular Phylogenetics and Evolution*. 2015;**90**:1-19
- [70] Moreira RA, Barros ACH, Stewart JC, Pusztai A. Isolation and characterization of a lectin from the seeds of *Dioclea grandiflora* (Mart.). *Planta (Heidelh.)*. 1983;**158**:63-69
- [71] Richardson M, Campos FDAP, Moreira RA, Ainouz IL, Begbie R, Watt WB, Pusztai A. The complete amino acid sequence of the major alpha subunit of the lectin from the seeds of *Dioclea grandiflora* (Mart). *European Journal of Biochemistry*. 1984;**144**:101-111
- [72] Pérez G, Hernández M, Mora E. A lectin from the seeds of *Dioclea lehmanni*. *Phytochemistry*. 1990;**29**:1745-1749
- [73] Sierra AY, Pérez GE. purificación y caracterización de dos lectinas en semillas de *Dioclea sericea*. *Revista de la Academia Colombiana de Ciencias*. 1999;**23**(88):445-454
- [74] Van Damme EJM, Peumans WJ, Pusztai A, Bardocz S. *Handbook of Plant Lectins: Properties and Biomedical Applications*. Chichester, UK: John Wiley; 1998
- [75] Pérez G. Isolation and characterization of a novel lectin from *Dioclea lehmanni* (Fabaceae) seeds. *The International Journal of Biochemistry & Cell Biology*. 1998;**30**:843-853
- [76] Melgarejo LM, Vega N, Pérez G. Isolation and characterization of novel lectins from *Canavalia ensiformis* DC and *Dioclea grandiflora* Mart. Ex Benth. seeds. *Brazilian Journal of Plant Physiology*. 2005;**17**(3):315-324



- [77] Quintero M. Elucidación parcial de la estructura primaria de la lectina LGL-P2 y purificación y caracterización parcial de la lectina LGL-P4 presentes en semillas de *Galactia lindenii*. Trabajo de grado de Maestría, Departamento de Química: Universidad Nacional de Colombia; 2014
- [78] Melgarejo LM, Pérez G. Immunolocalization of the lectins p2 Y p4 from *Dioclea lehmanni* seeds. *Plant & Cell Physiology*. 1997;**38**(4):480-483
- [79] Nagano C, Calvete J, Baretino D, Perez A, Cavada B, Sanz L. Insights into the structural basis of the pH-dependent dimer–tetramer equilibrium through crystallographic analysis of recombinant *Diocleinae* lectins. *The Biochemical Journal*. 2008;**409**:417-428. DOI: 10.1042/BJ20070942
- [80] Cavada B, Barbosa T, Arruda S, Grangeiro T, Barral-Netto M. Revisiting proteus: Do minor changes in lectin structure matter in biological activity? Lessons from and potential biotechnological uses of the *Diocleinae* Subtribu lectins. *Current Protein & Peptide Science*. 2001;**2**:123-135
- [81] Pérez G, Vega N. Lamiaceae lectins. *Functional Plant Science and Biotechnology* 2007;**1**(2):288-299
- [82] Springer GF. T and Tn, general carcinoma autoantigens. *Science*. 1984;**224**(4654):1198-1206
- [83] Lisowska E. Tn Antigens and their significance in oncology. *Acta Biochimica Polonica*. 1995;**42**(1):11-17
- [84] Berger EG. Tn-syndrome. *Biochimica et Biophysica Acta (BBA) – Molecular Basis of Disease*. 1999;**1455**(2-3):255-268
- [85] Ju T, Wang Y, Aryal RP, Lehoux SD, Ding X, Kudelka MR, Cutler C, Zeng J, Wang J, Sun X, Heimburg-Molinari J, Smith DF, Cummings RD. Tn and sialyl-Tn antigens, aberrant O-glycomics as human disease markers. *Proteomics. Clinical Applications*. 2013;**7**(9-10):618-631. DOI: 10.1002/prca.201300024
- [86] Ju T, Otto VI, Cummings RD. The Tn antigen-structural simplicity and biological complexity. *Angewandte Chemie International Edition in English*. 2011;**50**:1770-1791
- [87] Li Q, Anver M, Butcher D, Gildersleeve J. Resolving conflicting data on expression of the Tn antigen and implications for clinical trials with cancer vaccines. *Molecular Cancer Therapeutics*. 2009;**8**(4):971-979. DOI: 10.1158/1535-7163.MCT-08-0934
- [88] Cazet A, Julien S, Bobowski M, Burchell J, Delannoy P. Tumour-associated carbohydrate antigens in breast cancer. *Breast Cancer Research*. 2010;**12**:204
- [89] Ju T, Aryal RP, Kudelka MR, Wang Y, Cummings RD. The Cosmc connection to the Tn antigen in cancer. *Cancer Biomarkers*. 2014;**14**(1):63-81. DOI: 10.3233/CBM-130375
- [90] Fu C, Zhao H, Wang Y, Cai H, Xiao Y, Zeng Y, Chen H. Tumor-associated antigens: Tn antigen, sTn antigen, and T antigen. *HLA Journal*. 2016;**88**(6):275-286. DOI: 10.1111/tan.12900
- [91] Review MJ. The role of Sialyl-Tn en cancer. *International Journal of Molecular Sciences*. 2016;**17**(3):275

- [92] Osinaga E, Bay S, Tello D, Babino A, Pritsch O, Assemat CD, Nakada H, Alazari P. Analysis of the fine specificity of Tn-binding proteins using synthetic glycopeptide epitopes and a biosensor based on surface plasmon resonance spectroscopy. *FEBS Letters*. 2000;**469**:24-28
- [93] Kitagaki-Ogawa H, Matsumoto I, Seno N, Takahashi N, Endo S, Arata Y. Characterization of the carbohydrate moiety of *Clerodendron trichotomum* lectins: Its structure and reactivity toward plant lectins. *European Journal of Biochemistry*. 1986;**161**:779-785
- [94] Medeiros A, Bianchi S, Calvete JJ, Balter H, Bay S, Robles A, et al. Biochemical and functional characterization of the Tn-specific lectin from *Salvia sclarea* seeds. *European Journal of Biochemistry*. 2000;**267**:1434-1434
- [95] Lis H, Latter H, Adar R, Sharon N. Isolation of two blood type A and N specific isoelectins from *Moluccella laevis* seeds. *FEBS Letters*. 1988;**233**:191-195
- [96] Wang W, Peumans WJ, Rougé P, Rossi C, Proost P, Chen J, et al. Leaves of the Lamiaceae species *Glechoma hederacea* (ground ivy) contain a lectin that is structurally and evolutionary related to the legume lectins. *The Plant Journal*. 2003;**33**:239-304
- [97] Wenping H, Limin H, Zhezhi W. Molecular cloning and expression of a novel gene related to legume lectin from *Salvia miltiorrhiza* Bunge. *African Journal of Biotechnology*. 2015;**14**(28):2234-2243
- [98] Pérez G, Vega N, Fernández-Alonso JL. Prospección de lectinas en especies de labiadas colombianas. Un enfoque sistemático-ecológico-II. *Caldasia*. 2006;**28**:179-195
- [99] Fernández-Alonso JL, Vega N, Pérez G. Lectin prospecting in Colombian Labiatae. A systematic ecological approach – III. Mainly exotic species (cultivated or naturalised). *Caldasia*. 2009;**31**:227-245
- [100] Filgueira-Duarte JJ, Pérez G. Producción de lectinas Tn-específicas obtenidas de *Salvia palifolia* y *Hyptis mutabilis* por variación somaclonal celular. *Revista Facultad De Ciencias Básicas, Universidad Militar Nueva Granada*. 2013;**9**:134-141
- [101] Vega N, Pérez G. Isolation and characterisation of a *Salvia bogotensis* seed lectin specific for the Tn antigen. *Phytochemistry*. 2006;**67**(4):347-355
- [102] Wilches-Torres A, Rojas-Caraballo J, Sanabria E, Reyes-Montaña E, Fernández-Alonso JL, Varrot A, Imberty A, Vega N. Purification and biochemical characterization of a T/Tn specific lectin from *Lepechinia bullata* Seeds (*Lamiaceae*). *International Journal of Pharmacy and Pharmaceutical Sciences*. 2017;**9**(11):165-174
- [103] Rougé P, Peumans WJ, Van Damme EJM, Barre A, Singh T, Wu JH, Wu AM. Structure-function relationships of plant lectins that specifically recognize T and Tn antigens. In: Wu AM, editor. *The Molecular Immunology of Complex Carbohydrates*. 3rd ed. Springer; 2011. pp. 157-170
- [104] Wilches A. Aproximación a la estructura primaria de lectinas específicas Para el antígeno Tn e identificación de nuevas lectinas específicas Para glucosa/manosa en

Semillas de *Salvia bogotensis* y *Lepechinia bullata*. Approach primary structure of Tn antigen specific lectins and identification of new glucose/mannose specific lectins in *Salvia bogotensis* and *Lepechinia bullata* seeds [doctoral dissertation]. Sciences Faculty National University from Colombia. 2017

- [105] Van Damme EJM, Allen AK, Peumans WJ. Isolation and characterization of a lectin with exclusive specificity towards mannose from snowdrop (*Galanthus nivalis*) bulbs. *FEBS Letters*. 1987;**215**:140-114
- [106] De Vasconcelos MA, Alves AC, Carneiro RF, Sampaio Dias AH, Viana Martins FW, Batista Cajazeiras J, Nagano CS, Holanda Teixeira E, do Nascimento KS, Cavada BS. Purification and primary structure of a novel mannose-specific lectin from *Centrolobium microchaete* Mart seeds. *International Journal of Biological Macromolecules*. 2015;**81**:600-607
- [107] Barre A, Bourne Y, Van Damme EJ. Mannose-binding plant lectins: Different structural scaffolds for a common sugar-recognition process. *Biochimie*. 2001;**83**(7):645-651
- [108] Gatehouse AMR, Powell KS, Peumans WJ, Van Damme EJM, Gatehouse JA. Insecticidal properties of plant lectins: Their potential in plant protection. In: Pusztai A, Bardocz S, editors. *Lectins: Biomedical Perspectives*. London: Taylor & Francis; 1995. pp. 35-58
- [109] Vandenberghe G, Smagghe G, Van Damme EJ. Plant lectins as defense proteins against phytophagous insects. *Phytochemistry*. 2011;**72**(13):1538-1550
- [110] Jaber K, Haubruge E, Francis F. Development of entomotoxic molecules as control agents: Illustration of some protein potential uses and limits of lectins. *Biotechnologie, Agronomie, Société et Environnement*. 2010;**14**(1):225-241
- [111] Karimi J, Allahyari M, Bandani AR. Lectins and their roles in pests control. In: Bandani AR, editor. *New Perspectives in Plant Protection*. InTech; 2012. DOI: 10.5772/39377
- [112] Michiels K, Van Damme EJM, Smagghe G. Plant-insect interactions: What can we learn from plant lectins? *Archives of Insect Biochemistry and Physiology*. 2010;**73**:193-221. DOI: 10.1002/arch.20351
- [113] Vandenberghe G, Smagghe G, Ghesquière B, Menschaert G, Nagender Rao R, Gevaert K, Van Damme EJM. Diversity in protein glycosylation among insect species. *PLoS One*. 2011;**6**(2):e16682. DOI: 10.1371/journal.pone.0016682
- [114] Hamshou M, Van Damme EJM, Vandenberghe G, Ghesquiere B, Trooskens G, Gevaert K, Smagghe G. GalNAc/Gal-binding *Rhizoctonia solani* Agglutinin has antiproliferative activity in *Drosophila melanogaster* S2 cells via MAPK and JAK/STAT signaling. *PLoS One*. 2012;**7**(4):e33680. DOI: 10.1371/journal.pone.0033680
- [115] Walski T, De Schutter K, Van Damme E, Smagghe G. Diversity and functions of protein glycosylation in insects. *Insect Biochemistry and Molecular Biology*. 2017;**83**:21-34
- [116] Fitches EC, Pyati P, King GF, Gatehouse JA. Fusion to snowdrop Lectin magnifies the oral activity of insecticidal v-Hexatoxin-Hv1a peptide by enabling its delivery to the central nervous system. *PLoS One*. 2012;**7**(6):e39389. DOI: 10.1371/journal.pone.0039389

- [117] Yang S, Pyati P, Fitches E, Gatehouse J. A recombinant fusion protein containing a spider toxin specific for the insect voltage-gated sodium ion channel shows oral toxicity towards insects of different orders. *Insect Biochemistry and Molecular Biology*. 2014;**47**(100):1-11. DOI: 10.1016/j.ibmb.2014.01.007
- [118] Rani S, Sharma V, Hada A, Bhattacharya RC, Koundal KR. Fusion gene construct preparation with lectin and protease inhibitor genes against aphids and efficient genetic transformation of *Brassica juncea* using cotyledons explants. *Acta Physiologiae Plantarum*. 2017;**39**(5):1-13
- [119] Stoger E, Williams S, Christou P, Down R, Gatehouse J. Expression of the insecticidal lectin from snowdrop (*Galanthus nivalis* agglutinin; GNA) in transgenic wheat plants: Effects on predation by the grain aphid *Sitobion avenae*. *Molecular Breeding*. 1999;**5**(1):65-73
- [120] Sauvion N, Nardon C, Febvay G, Gatehouse AM, Rahbe Y. Binding of the insecticidal lectin Concanavalin A in pea aphid, *Acyrtosiphon pisum* (Harris) and induced effects on the structure of midgut epithelial cells. *Journal of Insect Physiology*. 2004;**50**(12):1137-1150
- [121] Sadeghi A, Van Damme EJM, Michiels K, Kabera A, Smagghe G. Acute and chronic insecticidal activity of a new mannose-binding lectin from *Allium porrum* against *Acyrtosiphon pisum* via an artificial diet. *The Canadian Entomologist*. 2009;**141**:95-101
- [122] Das A, Roy A, Hess D, Das S. Characterization of a highly potent insecticidal lectin from *Colocasia esculenta* tuber and cloning of its coding sequence. *American Journal of Plant Sciences*. 2013;**4**:408-416 <http://dx.doi.org/10.4236/ajps.2013.42A053>
- [123] Roy A, Das S. Molecular mechanism underlying the entomotoxic effect of *Colocasia esculenta* tuber agglutinin against *Dysdercus cingulatus*. *Insects*. 2015;**6**:827-846. DOI: 10.3390/insects6040827
- [124] Sprawka I, Goławska S, Parzych T, Sytykiewicz H, Czerniewicz P. Apoptosis induction by Concanavalin A in gut cells of grain aphid. *Arthropod-Plant Interactions*. 2015;**9**:133-140. DOI: 10.1007/s11829-015-9356-1
- [125] Zapata N, Van Damme EJM, Vargas M, Devotto L, Smagghe G. Insecticidal activity of a protein extracted from bulbs of *Phycella australis* Ravenna against the aphids *Acyrtosiphon pisum* Harris and *Myzus persicae* Sulzer. *Chilean Journal of Agricultural Research*. 2016;**76**(2):188-194
- [126] Carreño N. Evaluación preliminar de actividad insecticida de lectina ASA II a partir de ajo (*Allium sativum*), sobre *Tecia solanivora*. Preliminary evaluation of the insecticidal activity of lectin ASA II on *tecia solanivora* [Master dissertation]. Sciences Faculty. National University from Colombia. 2013
- [127] Fitches E, Wiles D, Douglas A, Hinchliffe G, Audsley N, Gatehouse J. The insecticidal activity of recombinant garlic lectins toward aphids. *Insect Biochemistry and Molecular Biology*. 2008;**38**:905-915
- [128] Sousa Arruda F, Alves Melo A, Alves Vasconcelos M, Farias Carneiro R, Barroso-Neto I, Silva S, Nascimento Pereira Jr F, Shiniti Nagano C, Santiago Nascimento K,



- Holanda Teixeira E, Saker-Sampaio S, Sousa Cavada B, Holanda Sampaio A. Toxicity and binding profile of lectins from the genus *Canavalia* on brine shrimp. *BioMed Research International*. 2013;1-7. Article ID: 154542. DOI: 10.1155/2013/154542
- [129] Sprawka I, Goławska S, Goławski A, Chrzanowski G, Czerniewicz P, Sytykiewicz H. Entomotoxic action of jackbean lectin (Con A) in bird cherry-oat aphid through the effect on insect enzymes, *Journal of Plant Interactions*. 2014;**9**(1):425-433. DOI: 10.1080/17429145.2013.848947
- [130] Wang W, Hause B, Peumans WJ, Smagghe G, Mackie A, Fraser R, Van Damme EJM. The Tn antigen-specific lectin from ground ivy is an insecticidal protein with an unusual physiology. *Plant Physiology*. 2003;**132**(3):1322-1334
- [131] Moreira R, Monteiro A, Oliveira J, Sousa-Cavada B. Isolation and characterization of *Dioclea altissima* var. *megacarpa* seed lectin. *Phytochemistry*. 1997;**46**:139-144
- [132] Moreira RA, Cordeiro EF, Ramos MV, Grangeiro TB, Martins JL, Oliveira JTA, et al. Isolation and partial characterization of a lectin from seeds of *Dioclea violacea*. *Revista Brasileira de Fisiologia Vegetal*. 1996;**8**:23-29
- [133] Pinto Jr VR, Queiroz de Santiago M, da Silva Osterne VJ, Almeida Correia JL, Nascimento Pereira JF, Batista Cajazeiras J, de Vasconcelos MA, Teixeira EH, do Nascimento AS, Miguel TB, Miguel Ede C, Sampaio AH, do Nascimento KS, Nagano CS, Cavada BS. Purification, partial characterization and immobilization of a mannose-specific lectin from seeds of *Dioclea lasiophylla* Mart. *Molecules*. 2013;**18**(9):10857-10869. DOI: 10.3390/molecules180910857
- [134] Correia JLA, Nascimento ASF, Cajazeiras JB, Gondim ACS, Pereira RI, Sousa BL, Silva ALC, Garcia W, Teixeira EH, Nascimento KS, Rocha BAM, Nagano CS, Sampaio AH, Cavada BS. Molecular characterization and tandem mass spectrometry of the lectin extracted from the seeds of *Dioclea sclerocarpa* Ducke. *Molecules*. 2011;**16**:9077-9089
- [135] De Souza GA, Oliveira PSL, Trapani S, Santos ACO, Rosa JC, Laure HJ, Faça VM, Correia MT, Tavares GA, Oliva G, Coelho LC, Greene LJ. Amino acid sequence and tertiary structure of *Cratylia mollis* seed lectin. *Glycobiol*. 2003;**13**:961-972
- [136] Cavada BS, Marinho E, Souza E, Benevides R, Delatorre P, Souza L, Nascimento KS, Sampaio A, Moreno F, Rustigel J, Canduri F, Azevedo W, Debray H. Purification, partial characterization and preliminary X-ray diffraction analysis of a mannose-specific lectin from *Cymbosema roseum* seeds. *Acta Cryst*. 2006;**F62**:235-237
- [137] Almanza AM, Vega NA, Pérez G. Isolation and characterization of a lectin from *Galactia lindenii* seeds that recognizes blood group H determinants. *Archives of Biochemistry and Biophysics*. 2004;**492**:180-190
- [138] Rocha B, Moreno F, Delatorre P, Souza E, Marinho E, Benevides R, Rodrigues J, Souza L, Nagano C, Debray H, Sampaio A, De Azevedo W, Cavada B. Purification, characterization, and preliminary X-ray diffraction analysis of a lactose-specific lectin from *Cymbosema roseum* seeds. *Applied Biochemistry and Biotechnology*. 2009;**152**:383-393

- [139] Batista FAH, Goto LS, Garcia W, de Moraes DI, de Oliveira Neto M, Polikarpov I, Cominetti MR, Selistre-de-Araújo HS, Beltramini LM, Ulian Araújo AP.. Camptosemin, a tetrameric lectin of *Camptosema ellipticum*: structural and functional analysis. *European Biophysics Journal*. 2010;**39**(8):1193 (205)
- [140] Melander M, Ahman I, Kamnert I, Stromdahl AC. Pea lectin expressed transgenically in oilseed rape reduces growth rate of pollen beetle larvae. *Transgenic Research*. 2003;**12**(5):555-567
- [141] Powell KS. Antimetabolic effects of plant lectins towards nymphal stages of the planthoppers *Tarophagous proserpina* and *Nilaparvata lugens*. *Entomologia Experimentalis et Applicata*. 2001;**99**(1):71-78
- [142] Sadeghi A, Van Damme EJ, Peumans WJ, Smagghe G. Deterrent activity of plant lectins on cowpea weevil *Callosobruchus maculatus* (F.) oviposition. *Phytochemistry*. 2006;**67**(18):2078-2084
- [143] Shukla SA, Arora R, Sharma HC. Biological activity of soybean trypsin inhibitor and plant lectins against cotton bollworm/legume pod borer, *Helicoverpa armigera* Plant Biotechnology. 2005;**22**(1):1-6
- [144] Zhu K, Huesing JE, Shade RE, Bressan RA, Hasegawa PM, Murdock LL. An insecticidal N-acetylglucosamine-specific lectin gene from *Griffonia simplicifolia* (Leguminosae). *Plant Physiology*. 1996;**110**(1):195-202
- [145] Gatehouse AMR, Dewey FM, Dove J, Fenton KA, Pusztai A. Effect of seed lectins from *Phaseolus vulgaris* on the development of larvae of *Callosobruchus maculatus*; mechanism of toxicity. *Journal of the Science of Food and Agriculture*. 1984;**35**(4):373-380
- [146] Habibi J, Backus EA, Huesing JE. Effects of phytohemagglutinin (PHA) on the structure of midgut epithelial cells and localization of its binding sites in western tarnished plant bug, *Lygus hesperus* Knight. *Journal of Insect Physiology*. 2000;**46**(5):611-619
- [147] Macedo MLR, das Graças Machado Freire, M, da Silva MBR, Coelho LCBB. Insecticidal action of *Bauhinia monandra* leaf lectin (bmoll) against *Anagasta kuehniella* (Lepidoptera: Pyralidae), *Zabrotes subfasciatus* and *Callosobruchus maculatus* (Coleoptera: Bruchidae). *Comparative Biochemistry and Physiology. Part A, Molecular & Integrative Physiology*. 2007;**146**:486-498



