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APPLICATIONS OF PLANT LECTINS IN BIOTECHNOLOGY AND THERAPEUTICS

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ABSTRACT

Lectins are carbohydrate-binding proteins broadly used in various therapeutic and biomedical applications. The variable affinity of lectins towards variety of carbohydrates has raised attention for the biologist to explore functional aspects of lectins. Lectins express specificity to simple carbohydrates for example mannose, lactose, sialic acid, complex glycan, and glycoproteins. Lectins are classified based on their sugar specificity and are used as a tool to study protein-carbohydrate interactions. Lectins are ubiquitous in nature and identified from all sources such as bacteria, fungi, algae, and animals. Plants are the most abundant source of lectins, and till now, more than three hundred lectins were characterized from plants. These are distributed to various parts of a plant according to their requirements and function. The physiological role of lectins in a plant is still not well understood. The overabundant presence of lectins in plant seeds and storage tissues indicated their role in plant development. Plant lectins shows a broad range of activities like antibacterial, antifungal, insecticidal, anticancerous, antileishmanial, antiviral, and anticoagulants. In this review, we aim to highlight the plant lectins classification and their application in various biological aspects.

Keywords: Lectins, Plant lectins, Sugar specificity, Therapeutic aspect

INTRODUCTION

Lectins are glycoprotein with a divers function capable to bind specific carbohydrates without modifying them **(Gemeiner *et al.*, 2009)**. Lectins are non-immune origin differ from antibody in many aspects. Antibodies are structurally similar exclusively present in animals whereas lectins are structurally different from each other and also present in plants and bacteria where no immunological system present **(Sharon, 2008)**. In the late 18th century Peter Hermann Stillmark observed that the protein from plants can agglutinate erythrocytes and it was named Phytohemagglutinin {(Phyto (plant)+ Hemagglutinin (red blood cells agglutinate)}**(Sharon *et al.*, 2004)**. These observations led to the discovery of the first phytohemagglutinin from seeds of the castor plant which was named ricin **(Polito *et al.*, 2019)**. In 1954 Boyd and Shapleigh recognized that phytohemagglutinins were selectively agglutinate different human blood groups ABO, because of its sugar specificity. The selective nature of phytohemagglutinin named as lectin from the Latin verb that's means "to select" proposed by Boyd and Shapleigh **(Hou *et al.*, 2003)**. Lectins are isolated and characterized by almost all five kingdoms (Monera, Protista, Fungi, Plantae, and Animalia) **(Naik *et al.*, 2017)**. In case of plants, the source of lectins are roots, bulbs, pulps, tubers, rhizome, latex, barks, stems, leaves, flowers, fruits, and seeds (Table 1). Lectins are extracted from different parts of the plants have a wide range of applications in biochemistry, plant biology, agriculture, cell biology, immunology, virology, and biomedical field. The physiological role of lectins in plants remains unclear or controversial. Differences in structural and sugar specificity indicates lectins unlikely to have similar functions inside the plant. Insecticidal, antibacterial effect of plant lectins demonstrated that lectins play crucial role in plant defense system. More in detail lectins show potential role as antibacterial, antifungal, anti-HIV, antitumor, cytotoxic, insecticidal, immunomodulatory, vasorelaxant, histochemical, tumor detection marker, and pathology. This review is mainly on specificity, classification and application of plant lectins.

Table 1 Source of plant lectins

S.No.	Plants	Source
1	*Pinellia ternata*	Tubers
2	*Acacia farnesiana*	Seeds
3	*Sambucus ebulus L*	shoot
4	*mulberry*	leaf
5	*Microgramma vacciniifolia*	rhizome
6	*Euphorbia trigona*	latex
7	*Hyacinth*	bulbs
8	*Punica granatum*	fruits
9	*Moringa oleifera*	Seed cake
10	*Sophora flavescens*	roots
11	*Alpinia purpurata*	inflorescences
12	*Crataeva tapia*	bark
13	*Cucumis sativus*	phloem exudate

Specificity and Classification of Plant lectin

In recent years mannose-specific lectins were extensively characterized from monocot plants. Sugar specific hemagglutination inhibition assay ensured the specificity of lectins. *Lonchocarpus campestris* lectin **(De Freitas Pires *et al.*, 2019)**, *Diocleinae* lectin **(Leal *et al.*, 2018)**, and *Sauromatum* guttatum lectin **(Thakur *et al.*, 2017)** inhibited by mannose (Table 2).
Structure studies showed Phe, Trp or Tyr mainly formed interaction with mannose. Entadin lectin **(Naik *et al.*, 2020)** and *Genipa americana* bark lectin **(Costa *et al.*, 2018)** were inhibited by lactose sugar. Simple sugar needs higher concentration to inhibits agglutination activity of lectin whereas complex sugar or carbohydrates need lesser concentration **(Siritapetawee *et al.*, 2018).** Hemagglutination assay is a benchmark to identify lectin from any source and the use of erythrocytes in this assay indicates lectins are specific for different erythrocytes. The lectins from *Sambucus ebulus* L **(Jiménez *et al.*, 2013)**, *Morus alba* (white mulberry) **(Deepa, *et al.*, 2012)**, and *Tinospora tomentosa* **(Saha *et al.*, 2014)** agglutinate human erythrocytes whereas lectins from, *Lonchocarpus campestris* seed **(De Freitas Pires *et al.*, 2018)**, *Genipa americana* bark **(Costa *et al.*, 2018)**, and *Coccinia indica* fruits **(Bobbili *et al.*, 2018)** agglutinate rabbit erythrocytes. Lectins from *Praecitrullus fistulosus* fruit **(Shivamadhu *et al.*, 2017)**, *Moringa oleifera* seed **(Asaduzzaman *et al.*, 2018),** *Kaempferia rotunda* tuberous rhizome **(Ahmed *et***

***al*., 2017)** and *Crotalaria retusa* seeds **(Aragão *et al*., 2017)** agglutinate human as well as rabbit erythrocytes. Due to diversity of lectin in respect to function and origin its classification is still not completely evolved. Based on the overall structure and carbohydrate-binding site lectin can be divided into four types i. Merolectins: They are low molecular weight proteins consist of only one carbohydrate domain example Hevein, chitin-binding protein from the latex of the rubber tree (*Hevea brasiliensis*) ii. Hololectins: They contain more than two carbohydrate-binding sites. Hololectins are divalent or multivalent which help to agglutinate cells. Most of the plant lectins belong to this category. iii. Chimerolectins: They are chimeric proteins composed of carbohydrate-binding domain and catalytic activity domain. Depending upon binding sites they behave as merolectin or hololectin. iv. Superlectins: superlectin can also be considered as chimerolectins consist exclusively of at least two carbohydrate-binding sites, which recognize structurally two unrelated sugars. During the last three decades, advanced biotechnology techniques help to understand the structure and function of various forms of lectin. Based on structural and functional aspects plant lectins are classified into seven different categories (Table 3).

Table 2 Sugar specificity of plant lectin

S.No.	Sugar specificity	Lectin
1	Mannose	*Lonchocarpus campestris, Diocleinae, Sauromatum guttatum, Pinellia ternata,* wheat, *Allium sativum, Microgramma vaccinifolia, Colocasia esculenta, Dioclea lasiophylla mart, Centrolobium microchaete Mart, Machaerium acutifolium*
2	Lactose	*Genipa americana, Spatholobus Parviflorus, Tinospora tomentosa,* Soybean, *Trichosanthes anguina, Abrus fruticulosus, Genipa Americana*
3	Galactose	*Nicotiana benthamiana, Bauhinia ungulata L., Lotus corniculatus, Champedak, Euphorbia trigona Miller, Clathrotropis nitida, Dioclea grandiflora, Morus alba* L., *Phaseolus lunatus billb, Euphorbia tirucalli, Euphorbia antiquorum, Artocarpus hypargyreus hance*
4	Glucose and mannose	*Canavalia brasiliensis, Pisum sativum, Dolichos lablab,* litchi, *Crataeva tapia, Microgramma vacciniifolia, Parkia platycephala*
5	n-Acetyl glucosamine	*Praecitrullus fistulosus, Apuleia leiocarpa,* White kidney bean, *Bauhinia forficate, Alpinia purpurata, Remusatia vivipara,*
6	Glycoproteins	*Colocasia esculenta, Solanum tuberosum, Lagenaria siceraria, Dypsis decaryi*
7	Arabinose	*Anacardium occidentale*
8	D-galactosamine	*Phaseolus lunatus L., cicer aritium*
9	Chitin	*Cucumis sativus, Moringa oleifera, Praecitrullus fistulosus*
10	Fructose	*Moringa oleifera*

Table 3 Properties and classifications of plant lectins

S.No.	Types of lectin	First discovered	Molecular weight range	Plant source	Sugar specificity	Application
1	Legume	*Robinia pseudoacacia*	20-42 kDa	*Acacia farnesiana, Abrus precatorius, Canavalia ensiformis, Canavalia Brasiliensis, Canavalia grandiflora, Canavalia maritime, Canavalia virosa, Centrolobium microchaete , Clathrotropis nitida, Cratylia argentea, Calliandra surinamensis, Dolichos lablab, Dioclea grandiflora, Dioclea sclerocarpa, Dioclea violacea, Dioclea reflexa, Dioclea lasiocarpa, Vatairea guianensis, Phaseolus vulgaris, Phaseolus acutifolius, Phaseolus lunatus* L., *Parkia biglobosa, Parkia platycephala, Platypodium elegans, Cratylia mollis, Cratylia argentea, Centrolobium tomentosum, Bauhinia ungulata L., Bauhinia forficate, Bauhinia monandra, Bauhinia variegate, Bauhinia Purpurea, Spatholobus Parviflorus, Cicer arietinum,* Lotus, *pisum sativum, Dioclea lasiophylla,*	D-Galactose, Lactose, Methyl α-D-galactopyranoside, mannose, glucose,	Antibacterial, Anticancer, Plant defense, Vasorelaxant, Nimeticidal, Seed germination, Antifungal, Amaylase inhibitor, Anti-inflamatory,
2	Chitin-binding	*Solanum tuberosum*	4-70 kDa	*Bauhinia forficate, Microgramma vaccinifolia, Apuleia leiocarpa , Punica granatum, Moringa oleifera, Praecitrullus fistulosus*	Glycoprotein, Mannose, Chitin	Anticancer, Anticoagulant, Insecticidal, Antibacterial,
3	Type-2 RIP	*Ricinus communis*	22-38 kDa	*Sambucus ebulus L, Abrus fruticulosus,*		Toxic,
4	Monocot mannose specific	*Allium sativum*	12-30 kDa	*Pinellia ternate, Triticum aestivum, Hippeastrum, Allium sativum, Allium chinense, Allium cepa, Colocasia esculenta, Dioscorea bulbifera*	mannose	Anticancer, Antibacterial, Insecticidal, Antifungal,
5	Jacalin-related	*Maclura pomifera*	Subunits of 2-14 kDa	Jack fruit	Galagtose/mannose	Anticancer
6	Amaranthin	Amaranthus caudatus	33 kDa	*Amaranth*	Not reported	Anticancer,
7	Cucurbitaceae	*Cucurbita maxima*	Subunits of 30-35 kDa	*Cucumis sativus, Cucurbita maxima, Trichosanthes anguina, Cucumis sativus, Lagenaria siceraria, Praecitrullus fistulosus, Coccinia indica,*	Lactose,	Plant defence

i**. Chitin Binding lectins**: All the proteins in this category contain one hevein domain for the consideration of chitin-binding lectin. ii. Cucurbitaceae phloem lectins: These lectins are found in phloem exudates of *Cucurbita, Citrullus, Cucumis, Sechium, Luffa,* and *Coccinia* species. iii. **Monocot mannose-binding lectins**: Monocot mannose-binding lectins are extracted and charcterised from monocotyledonous plants. Tuhe first monocot mannose binding lectin was characterized by a snowdrop bulb. iv. **Legume lectins**: These lectins are isolated from a large family of Leguminosae (Fabaceae). Till now more than 100 lectins are isolated from this family and most of the lectins are purified from seeds (Table 2). v. **Type 2 RIP and related lectins:** Ribosome-inactivating proteins (RIP) are inhibiting or inactivate eukaryotic ribosomes. RIP is divided in to two category RIP-I and RIP-II. RIP-II consists of two chain A and B and that having carbohydrate binding sites with lectin activity (Table 2). vi**. Jacalin-related lectins:** Jacalin is a plant seed tetrameric protein specific to either mannose or galactose sugars. Lectins structurally (Similar domain or fold) and evolutionary related considered as jacalin related lectins. vii**. Amaranthin lectin family:** Amaranthin lectin was isolated purified from seed of Amaranthus caudate. Amaranthins lectins are homodimeric proteins composed of subunits of approximately 33 kDa, which are not glycosylate (Table 3).

Lectin Applications in Biotechnology

Antibacterial Activity

Since 2012, many of the lectins show inhibitory action against different bacteria, lectin from wheat (*Triticum aestivum*) was able to increase resistance to the infection of *Pseudomonas syringae* **(Ma *et al.*, 2013)**. *Acacia farnesiana* seeds lectin was able to inhibit *Xanthomonas axonopodis pv. passiflorae* (Gram-negative) and *Clavibacter michiganensis* (Gram-positive) **(Santi-Gadelha *et al.*, 2012)**. Lectins isolated from stem *Tinospora tomentosa* showed antibacterial propeties against *Salmonella* **(Saha *et al.*, 2014)**. *Apuleia leiocarpa* seeds lectins showed antibacterial activity effects on the gram-positive bacteria *B. subtilis, B. cereus, E. faecalis, M. luteus, S. pyogenes,* and *S. aureus* with the smallest MIC (45.12 µg/ml). This lectin also showed inhibition against X.*campestris pv. campestris, X. campestris pv. viticola, X. campestrispv. malvacearum, Klebsiella pneumoniae, E. coli, P. aeruginosa,* and *S. enteritidis* with the lowest minimal inhibition concentration (11.2 µg/ml) against *X. campestris pv. Apuleia leiocarpa* lectin was bactericidal (Minimal bactericide concentration of 22.5 µg/ml) only against the three varieties of *X. campestris* **(Carvalho *et al.*, 2015)**. Over expression of lectin from *Arabidopsis* shows less disease symptoms after infection with *Pseudomonas syringae* when it's compare to the wild type of *Arabidopsis* **(Van Hove *et al.*, 2015)**. Lectin from *Bauhinia variegate* showed inhibition against oral bacteria facultatively anaerobic, gram-positive *Streptococcus* mutans and *Streptococcus sanguinis* **(Klafke *et al.*, 2016)**. Lectins from *Canavalia brasiliensis* and *Cratylia argentea* enhanced the antimicrobial immunity of macrophages experimentally infected with *S. typhimurium* **(Silva *et al.*, 2016; Batista *et al.*, 2017)**. Chitin binding lectin from juicy sarcotesta of *Punica granatum* showed antibacterial activity against *Micrococcus luteus,Serratia marcescens, Streptococcus mutans, Aeromonas* sp., *Enterococcus faecalis, Escherichia coli, Klebsiella* sp., *Salmonella enterica serovar. enteritidis, Staphylococcus aureus, Staphylococcus epidermidis* and *Staphylococcus saprophyticus*. It was observed that bacteria treated (*Aeromonas* sp., *S. aureus, S. marcescens* and *S. enterica)* with *Punica granatum* lectin having reduced adhesion and invasion abilities to HeLa cells were reduced when these bacteria were previously treated with **(Silva *et al.*, 2016)**. Lectin purified and characterized from leaves of *Calliandra surinamens* showed growth inhibition against *Staphylococcus saprophyticus*, *Staphylococcus aureus* (nonresistant) and the *Staphylococcus aureus* (Oxacillin resistant) whereas against *E.coli* no inhibition was observed **(Figueiredo *et al.*, 2017)**. Lectin isolated from the latex of *Euphorbia tirucalli* was able to inhibit the growth of Gram-negative bacteria *Escherichia coli* **(Palharini *et al.*, 2017)**. The lectin from inflorescence of *Alpinia purpurata* showed bacteriostatic activity against non-resistant *Staphylococcus aureus* with minimal inhibitory concentrations (MIC50) of 50 µg/mL and Oxacillin resistant *Staphylococcus aureus* with minimal inhibitory concentrations (MIC50) of 400 µg/mL. It also showed bactericidal effect on the non-resistant *Staphylococcus aureus* with minimal bactericidal concentrations (MBC50) of 200 µg/mL **(Ferreira *et al.*, 2018)**. The lectin isolated from the crude latex of *Euphorbia antiquorum* L. can inhibits the growth of Gram-positive bacteria such as *Staphylococcus aureus* and *Staphylococcus epidermidis*, without killing them with a minimum inhibitory concentration (MIC) of 2000 µg/ml, *Propionibacterium acnes* (human skin commensal) with MIC of 125 µg/ml and *Streptococcus agalactiae* with MIC of 250 µg/ml. Whereas in case of gram negative bacteria *Samonella typhimurium* which inhibits with a MIC of 1000 µg/ml. **(Siritapetawee *et al.*, 2018)** (Table 4).

Table 4 Antibacterial activity of plant lectins

Plants	Source	Against Bacteria
Triticum aestivum	Seed	*Pseudomonas syringae*
Acacia farnesiana	Seed	*Xanthomonas axonopodis pv. passiflorae* and *Clavibacter michiganensis*
Tinospora tomentosa	Stem	*Salmonella*
Apuleia leiocarpa	Seed	*B. subtilis, B. cereus, E. faecalis, M. luteus, S. pyogenes,* and *S. aureus, X. campestris* pv. *campestris, X. campestris pv. viticola, X. campestris pv. malvacearum, Klebsiella pneumoniae, E. coli, P. aeruginosa,* and *S. enteritidis*
Bauhinia variegate	Seed	*Streptococcus mutans* and *Streptococcus sanguinis*
Canavalia brasiliensis	Seed	*S. typhimurium*
Cratylia argentea	Seed	*S. typhimurium*
Punica granatum	Fruit	*Micrococcus luteus, Serratia marcescens, Streptococcus, Aeromonas* sp., *Enterococcus faecalis, Escherichia coli, Klebsiella* sp., *Salmonella enterica serovar. Enteritidis, Staphylococcus aureus, Staphylococcus epidermidis* and *Staphylococcus saprophyticus.*
Calliandra surinamensis	Leaf	*Staphylococcus saprophyticus, Staphylococcus aureus* and *the Staphylococcus aureus*
Euphorbia tirucalli	Latex	*Escherichia coli*
Alpinia purpurata	Inflorescence	*Staphylococcus aureus*
Euphorbia antiquorum L.	Latex	*Staphylococcus aureus* and *Staphylococcus epidermidis*

Anti-Bio-Film Activity

A Lectin from litchi (*Litchi chinensis*) seeds showed antibiofilm activity against *Pseudomonus aeruginosa* **(Bose *et al.*, 2016)**. Lectin isolated from the leaves of *Calliandra surinamensis* is an effective inhibitor of oral multispecies biofilms formed by bacteria from supragingival plaque **(Figueiredo *et al.*, 2017)**. Chitin binding lectin isolation and purified from pomegranate (*Punica granatum*) sarcotesta showed significant antibiofilm activity on *Candida albicans* (pathogenic yeast) at inhibitory concentrations of 0.195 and 0.39 µg/mL **(Da Silva *et al.*, 2018)**. The lectin remarkably inhibited biofilm formation by non-resistant *Staphylococcus aureus* isolate and *Candida albicans* from inflorescence of *Alpinia purpurata* at sub-inhibitory concentrations **(Ferreira *et al.*, 2018)**. *Bauhinia variegata* lectin showed anti-biofilm formation against *Streptococcus mutans* and *S. sanguinis* **(Klafke *et al.*, 2016)**.

Antifungal Activity

Chitin binding lectins are predominant in plants that bind to fungal cell wall which is made of chitin a complex polysaccharide. CBL lectins bind to chitin and stop the growth of fungus. Galctose binding lectin isolated from seeds of *Bauhinia ungulata* L. (*Caesalpinoideae*) showed antifungal activity against *Fusarium solani, Fusarium moniliforme, Fusarium oxysporum, Colletotrichm lindemuthianum* and *Aspergillus niger* **(Silva *et al.*, 2014)**. Lectin isolated and characterized from seed of *Spatholobus parviflorus* showed anti-fungal activity against *Aspergillus niger* and *Fusarium* sp. *Aspergillus niger* hyphal growth inhibition was seen at low concentration approx. 0.04 mg/mL of lectin. Whereas *Fusarium* sp. was inhibited at much higher lectin concentration **(Geethanandan *et al.*, 2013)**. The lectin from *Phaseolus vulgaris* cv. Chinese pinto bean showed antifungal activity against mycelial growth in *Valsa mali* a destructive fungus of apple, by 30.6 % at 30 µM **(Ang *et al.*, 2014)**. The crude plant lectin isolated from the stem of *Tinospora tomentosa* shows fungal growth inhibition of *Aspergillus niger* and showed a clear inhibition of the growth of another fungal strains *saccharomyces cerevasecis* **(Saha *et al.*, 2014)**. Lectin isolated from leaf *Allium sativum* showed antifungal activity its gene was further expressed in an *elite indica* rice cv. IR64 by employing *Agrobacterium tumefaciens*-mediated transformation to engineer rice plants conferring resistance to sheath blight which mainly caused by *Rhizoctonia solan* (plant pathogenic fungus) **(Ghosh *et al.*, 2016)**. Lectin isolated from *Phaseolus lunatus* billb seeds inhbited the fungal growth of *Sclerotium rolfsii, Fusarium solani, Fusarium oxysporum,* and *Botrytis cinerea* **(Wu *et al.*, 2016)**. *Calliandra surinamensis* leaf lectin was assessed against four *Candida species* but only *Candida krusei* was sensitive to this lectin with MIC 125 µg/mL and MFC of 250 µg/mL **(Figueiredo *et al.*, 2017)**. The lectin from Sunflower seeds (*Helianthus annuus* L.*)* affects the viability of sunflower phytopathogenic fungus *Sclerotinia sclerotiorum* **(Del Rio *et al*., 2018)**. The pomegranate (*Punica granatum*) sarcotesta contains a chitin-binding lectin showed antifungal activity against *Candida albicans* and *Candida kruse* with MIC50 of 25.0 and 12.5 µg/mL respectively **(Da Silva *et al.*, 2018)**. The lectin from inflorescence of *Alpinia purpurata* showed fungistatic activity against *Candida albicans* and *Candida parapsilosis* **(Ferreira *et al.*, 2018)**. Antifungal protein from *Cicer arietinum* seeds showed antifungal activity against *Candida parapsilosis*, *Candida krusei*, and *Candida tropicalis* **(Kumar *et al.*, 2014)** (Table 5)**.**

Table 5 Antifungal activity of plant lectins

Plants	Source	Against fungus
Bauhinia ungulata L	Seed	*Fusarium solani, Fusarium moniliforme, Fusarium oxysporum, Colletotrichm lindemuthianum* and *Aspergillus niger*
Spatholobus parviflorus	Seed	*Aspergillus niger* and *Fusarium* sp.
Phaseolus vulgaris cv	Seed	*Valsa mali*
Tinospora tomentosa	Stem	*Aspergillus niger* and *Accharomyces cerevasecis*
Allium sativum	Leaf	*Rhizoctonia solani*
Phaseolus lunatus billb	Seed	*Sclerotium rolfsii, Fusarium solani, Fusarium oxysporum*, and *Botrytis cinerea*
Calliandra surinamensis	Leaf	*Candida krusei*
Helianthus annuus L.	Seed	*Sclerotinia sclerotiorum*
Punica granatum	Fruit	*Candida albicans* and *Candida kruse*
Alpinia purpurata	Inflorescence	*Candida albicans* and *Candida parapsilosis*
Cicer arietinum	Seed	*Candida parapsilosis*, *Candida krusei*, and *Candida tropicalis*

Insecticidal Activity

Hippeastrum hybrid (*Amaryllis*) ornamental plant bulb lectin showed insecticidal activity against the larvae of the cotton leaf worm (*Spodoptera littoralis*) **(Caccia *et al.*, 2012)**. Tubers of *Colocasia esculenta* having lectin which is toxic against *Aphis gossypii* (Cowpea aphid), *Dysdercus cingulatus* (Red cotton bug) and *Aphis craccivora* (Cowpea aphid) with the lectin concentration of 9.98 ± 0.239 µg/mL, 16.95 ± 0.279 µg/mL and 15.21 ± 0.274 µg/mL respectively **(Das *et al.*, 2013)**. *Microgramma vaccinifolia* rhizome lectin showed toxicity against *Nasutitermes corniger* (termite) workers and soldiers and acts as termiticidal lectin **(Albuquerque *et al*., 2014)**. The lectin of *Myracrodruon urundeuva* and its leaf extract showed insecticidal properties against *Sitophilus zeamais* (maize weevil) which is a major pest of maize **(Camaroti *et al.*, 2013)**. The effects of *Dioclea violacea* lectin (DVL) on larval development in flour moth or mill moth (*Anagasta kuehniella)*. DVL interfered with larval growth, retarding development and decreasing larval mass without affecting survival **(Oliveira *et al.*, 2015)**. Lectin with insecticidal property against the stored product pest, *Callosobruchus maculatus* was successfully isolated from the seeds of *Canavalia virosa* **(Shanmugavel *et al.*, 2016)**. *Moringa oleifera* seed cake lectin exerted deleterious effects on larvae (LC50: 0.89 mg/mL) and eggs (EC50: 0.14 mg/mL) of *Aedes aegypti* (Yellow fever mosquito) and served as an oviposition-stimulant at the concentration of 0.1 mg/mL **(De Oliveira *et al.*, 2016)**. The chitin-binding lectin from *Moringa oleifera* seeds showed insecticidal activity against *Anagasta kuehniella* (flour moth) **(Fernando *et al.*, 2017)**. Later the same chitin-binding lectin from *Moringa oleifera* seeds were investigated on gamma irradiation a low dose of gamma irradiation (10 mGy) can be used to improve the deleterious effects of moringa seed lectin on *Aedes aegypti* larvae and eggs **(Santos *et al*., 2018)**. Lectin from *Abelmoschus esculentus* seeds Kunitz-type serine/cysteine protease inhibitor reported its toxic effects on the Mediterranean fruit fly *Ceratitis capitata* **(De Lacerda *et al.*, 2017)**. Lectin extracted from *Polygonum persicaria* L. is able to decrease damages of lepidopterous pests mainly *H. armigera* and *P. brassicae* on agricultural field **(Rahimi *et al.*, 2018)**. The lectin isolated from the leaves of *Schinus terebinthifolius* showed insecticidal activity against maize weevil (*Sitophilus zeamais*). The lectin doses of 100, 200, and 250 mg/g showed mortality rates of 32%, 40%, and 51% respectively on 7th day of treatments. On 12th day, the percentage of dead insects were increased to 94% to 97%. On 20th day of treatment all the insects were died, Whereas in control groups all the insects were survived even on 34th day **(Camaroti *et al.*, 2018) (**Table 6).

Table 6 Insecticidal activity of plant lectins

Plants	Source	Against insects
Hippeastrum hybrid	Bulb	Cotton leaf worm
Colocasia esculenta	Tuber	Cowpea aphid and Red cotton bug
Microgramma vaccinifolia	Rhizome	Termite
Myracrodruon urundeuva	Leaf	Maize weevil
Dioclea violacea	Seed	Flour moth
Canavalia virosa	Seed	Cowpea weevil
Moringa oleifera	Seed	Yellow fever mosquito and flour moth
Abelmoschus esculentus	Seed	Mediterranean fruit fly
Polygonum persicaria L.	Fruit	Cotton bollworm
Schinus terebinthifolius	Leaf	Maize weevil

Anti-HIV Activity

Dioscorea bulbifera bulbils lectin showed anti-HIV activity and inhibits the HIV-1 reverse transcriptase activity in a dose dependent manner with IC50 of 1.3 µg **(Sharma *et al.*, 2017)**.Sauromatum guttatum (*Sauromatum venosum*) plant tuber lectinglycan array analysis and in-silico studies of the coding sequence proposed biological property as a putative anti-HIV agent **(Thakur *et al*., 2017)**.

Antileishmanial Activity

Lectinn isolated from *Abrus fruticulosus* seeds that has type 2 ribosome-inactivating properties showed antileishmanial activity against the promastigote form of *Leishmania* **(Vasconcelos *et al.*, 2018)**.

Nematicidal Activity

The lectin from white kidney beans (*Phaseolus vulgaris*) showed nematicidal effect against *Teladorsagia circumcincta* and *Trichostrongylus colubriformis* which are the parasites of sheep and goats **(Ríos-de Álvarez *et al.*, 2012)**. Seeds of *Dioclea lasiophylla* having lectin which shows less toxicity against *Artemia* sp. *nauplii* **(Pinto *et al.*, 2013)**. Lectin isolated from *Moringa oleifer*a seed was evaluated for the inhibition of nematodes *Strongyloides* genera, *Oesophagostomum*, *Haemonchus* and *Trichostrongylus in vitro* effect of WSMoL (water soluble *Moringa oleifer*a lectin) on hatching of eggs and the development of early-stage larvae of gastrointestinal nematodes from naturally infected goats **(De Medeiros *et al.*, 2018)**. Lectin from *Abelmoschus esculentus* seeds Kunitz-type serine/cysteine protease inhibitor reported its toxic effects on the root-knot nematodes *Meloidogyne incognita* and *Meloidogyne javanica* **(De Lacerda *et al.*, 2017)**. Eutirucallin: lectin isolated from latex of *Euphorbia tirucalli* was shows to be effective when tested directly against *Toxoplasma gondii* infection in vitro **(Palharini *et al.*, 2017)**. *Canavalia brasiliensis* lectin inhibits *Haemonchus contortus* also known as the barber's pole worm, in vitro, and through the *in silico* studies suggested that the inhibition of development is directly related to the recognition of the core trimannoside present in the N-glycans of these parasites **(Batista *et al.*, 2018)**.

Lectin application in the therapeutic aspect

Anticancerous Activity

Canavalia ensiformis (ConA) and *Canavalia brasiliensis* (ConBr) lectins showed antiproliferative activity with the IC50 values of approximately 3 µg/mL and 20 µg/mL using human leukemia MOLT-4 and HL-60 after 72 hrs of incubation with the lectins. The lectin was not toxic against normal human peripheral blood lymphocytes even with 200 µg/mL concentration of lectins **(Faheina-Martins *et al.*, 2012)**. Hog plum (*Ximenia Americana*) fruit kernels is having a lectin known as Riproximin is specifically bind to two types of glycostructures, the N-linked NA2/NA3{Galβ1-4GlcNAcβ1-2Manα1-6[Galb1-4GlcNAcb1-2Manα1-3]Manβ1-4GlcNAcBSA/Galβ1-4GlcNAcβ1-2Manα1-6[Galb1-4GlcNAcb1-2(Galb1-4GlcNAcb1-2)Manα1-3]Manβ1-4GlcNAc –BSA} and the O-linked clustered Tn tumor-specific antigen which found in tumor cells **(Bayer *et al.*, 2012).** Lectin isolated and characterized from mulberry leaf induced apoptosis in human breast cancer cell line (MCF-7) and colon cancer cell line (HCT-15). Lectin required with the concentration of 8.5 µg/mL for MCF-7 and 16 µg/mL for HCT-15 to get 50% inhibition of cell growth after 24 hrs induced with lectin **((Deepa and Priya, 2012; Deepa *et al.*, 2012)**. Lectin isolated from *Bauhinia ungulata* L. seeds showed in vitro antiproliferative activity against the HT-29 cell line of human colon adenocarcinoma in a dose-dependent manner, which require 160 µg/mL concentration of lectin to inhibit 80% of cell growth after 24 hrs of incubation **(Silva *et al.*, 2014).** Lectin from pods of Lotus *corniculatus* showed antiproliferative activity towards human leukemic (THP-1) cancer cells and lung cancer (HOP62) cells and colon cancer cells (HCT116) with an IC50 of 39 µg/mL and 50 µg/mL and 60 µg/mL respectively after 24 hrs of lectin dose **(Rafiq *et al.*, 2013)**. Pea *(Pisum sativum* L.) seeds lectin was able to inhibit 84% of Ehrlich ascites carcinoma (EAC) cells after 24 hrs of incubation with the concentration of 120 µg/mL of pea lectin **(Kabir *et al.*, 2013)**. The seeds of *Phaseolus vulgaris* cv. Chinese pinto bean showed anti proliferative activity against nasopharyngeal carcinoma HONE-1cells with an IC50 of 1mg/mL after 24 hrs of incubation with lectin **(Ang *et al.*, 2014).** Monocot mannose-binding lectin from tubers of *Pinellia ternata* showed anti-proliferative effects on human liver tumor cell line Bel-7404 **(Zhou *et al.*, 2014)**. Lectin from the bulbs of *Allium chinense* inhibited 50% of the human hepatoma Hep-3B cells after 48 hrs with the doses of 60 µg/mL of allium lectin **(Xiao *et al.*, 2015)**. Lectin extracted from the seeds of *Canavalia brasiliensis* (ConBr) as a therapeutic agent for melanoma because it inhibit the growth of murine melanoma B16F10 cells **(Silva *et al.*, 2014)**. *Bauhinia forficata* seeds lectin was treated against the breast cancer cells MCF-7, MDA-MB-231, MDA-MB-468 and MCF-10A among of all these cells *Bauhinia forficate* lectin was effective against MCF-7 cells **(Silva *et al.*, 2014).** Antiproliferative lectin from *Cicer arietinum* seeds was toxic against human oral carcinoma cells (KB) at the concentration of 37.5 µg/mL (IC50) after 48 hrs of incubation and at the same time it was not toxic for normal human peripheral blood mononuclear cells (PBMCs) **(Kumar *et al.*, 2014)**. Toxic effects of *Microgramma vacciniifolia* rhizome lectin on lung mucoepidermoid carcinoma (NCI-H292) cells at IC50 concentration of 25.23 µg/mL, It did not affect the viability of chronic myelocytic leukaemia K562 and larynx epidermoid carcinoma Hep-2 tumour cells, as well as PBMCs normal cells **(Albuquerque *et al.*, 2014)**. Mannose-binding *Polygonatum odoratum* lectin showed anti-proliferative effect on MCF-7 cell growth with IC50 concentration of 10 µg/mL after 24 hrs of inhibition **(Ouyang *et al.*, 2014)**. Lectin isolated from soybean seed showed invitro antitumor effect on HeLa (cervical cancer), Hep2 (oral cancer), HepG2 (liver cancer), MDAMB 231(breast cancer), U373 MG (glioblastoma) with the IC50 concentration of 60, 20, 40, 40, 51 µg/mL, respectively and it did not affect the HaCaT (human keratinocyte). It also showed invivo antitumor effect on Dalton's lymphoma (DL) bearing mice; There was 74% and 82% reduction in cancer cell survival on the 10^{th} day for the 1 and 2 mg/kg body weight doses, respectively **(Panda *et al.*, 2014)**. *Amaranthus mantegazzianus* seed lectin and commercial *Amaranthus caudatus* lectin were capable of inhibiting UMR106 rat osteosarcoma-derived cell proliferation with an IC50 of 0.1 mg/mL and 0.08 mg/mL respectively after 24 hrs of incubation **(Quiroga *et al.*, 2015)**. *Typhonium flagelliforme* (Lodd.) blume having lectin in tuber reported as antiproliferation activity against human breast cancer cell MCF-7 with LC50 of 90.78 ppm and the same tuber was isolated from other region showing LC50 of 130.93 ppm **(Biosci *et al.*, 2015)**. Ribosome-inactivating protein; three types of lectin ETRI1, ETRI2 and ETRI3 from the latex of *Euphorbia trigona* miller showed cytotoxicity against tumoral cell lines HeLa (IC50-11nM, 12nM, 10nM respectively), A549 (IC50-32nM, 32nM, 38nM respectively), H116 (IC50-40nM, 18nM, 21nM respectively), HL-60 (IC50-75nM, 44nM, 44nM respectively), HT-29 (no inhibition) and non-tumoral cell line NIH-3T3 (IC50-875nM, 480nM, 480nM respectively) analyzed by flowcytometry **(Villanueva *et al.*, 2015)**. High-mannose-type glycans of *Maackia Amurensis* lectin was purchased which is known to interact with the α2,3-sialic acid moiety expressed on the MCF-7 human breast cancer cell line. The researcher groups have deglycosylated the lectin by using PNGase F for the removal of the high-Man-type N-linked glycans which leaving the two paucimannosidic type glycans in place on deglycosylated lectin, structural analysis of both the lectin releave the information that there was no difference in both the structure and both the lectin were active. They found that the presence of a single GlcNAc attached to Asn 61 is sufficient for the lectin activity **(Kim *et al.*, 2015)**. *Polygonatum odoratum* lectin induce apoptosis and autophagy in lung cancer A549 cells. They found that the lectin down-regulated the expression of micro RNA (miR-1290) and at the same time upregulated the expression of micro RNA (miR-15a-3p), which leads to the apoptosis and autophagy of A549 cells by ROS-p53 mediated pathway **(Wu *et al.*, 2016).** White kidney bean (*Phaseolus vulgaris cv*.) seeds lectin showed anti-proliferative activity on HONE1 cells, HepG2 cells, MCF7 cells and WRL68 cells with IC50 values of 18.8 µM, 19.7 µM, 26.9 µM, and >80 µM respectively for a 48 hrs treatment with lectin **(Chan *et al.*, 2016)**. Brazilian lima bean variety (*Phaseolus lunatus* L. var. *cascavel*) seeds having lectin with anti-tumor activity against melanoma derived cells (A375) at doses of 100, 50 and 25µg/mL, reducing tumor cells after 48 hrs of incubation number of cells was reduced by 73, 41, and 7%, and after 72 hrs of incubation it was reduced by 83, 53, and 0%, respectively **(Lacerda *et al.*, 2016).** Lectin from *Canavalia virosa* seeds having cytoxicity activity against rat glioma cells (C6). The researcher group found that 100 µg/mL of lectin can able to decrease the cell viability by 25% and 50% after 24 and 48 hrs of treatment with lectin, respectively **(Osterne *et al.*, 2017)**. Lectin from the latex of mulberry (*Morus indica*) showed toxicity against an epithelial cell line MDCK and a breast cancer cell line MCF-7 cell line at the concentration of 0.625 µM of lectin for 72 hrs of treatment the viability for both cell lines reached ~35% and at the concentration of 1.25 µM it reached 17% in case of MDCK cells and 26% in case of MCF-7 **(Datta *et al.*, 2016)**. Lectin from latex of *Lagenaria siceraria* showed invitro cell cytotoxicity against MCF-7, A549, Dalton's lymphoma ascites (DLA), and Ehrlich ascites carcinoma (EAC) with IC50 value of 17.4 µg/mL, 20.4 µg/mL, 12 µg/mL, and 19.5 µg/mL, after 48 hrs of lectin doses but in case of non- cancerous cells NIH-3T3 was not showed toxicity at 50 µg/mL. It also showed invivo antitumor activity in ascites tumor model, Six dose of lectin with the concentration of 25 mg/kg was administered to tumor bearing mice on every alternative days and the found that there were reduction in the size of tumor **(Vigneshwaran *et al.*, 2016).** *Phaseolus lunatus* billb seed lectin strongly inhibit the prolif-eration of K562 leukemia cells with an IC50 of 13.7 µM, whereas HeLa and HepG2 cells were only weakly affected after 48 hrs of incubation with the lectin **(Wu *et al.*, 2016).** *Calliandra surinamensis* leaf lectin was evaluated for cell cytotoxicity on the cancer cell lines K562 (chronic myelogenous leukemia) and T47D (breast cancer) and noncancerous cells human peripheral blood mononuclear (PBMCs) after the treatment of lectin for 72 hrs the IC50 observed with the concentration of 67.04 ± 5.78 and 58.75 ± 2.5µg/mL for cancerous cells respectively. Lectin did not affect non-cancerous cells at concentrations lower than 100 µg/mL **(Figueiredo *et al.*, 2017)**. The concanavalin A (Con A) and jacalin lectins on colonic adenocarcinoma cells (SW480) evaluated for antiproliferation of cells with pre-incubated lectins with dairy propionibacteria (*Propionibacterium acidipropionici* CRL 1198) as well as post-incubated lectins with the *P. acidipropionici* CRL 1198. They found that there were decreased in the antiproliferation activity of SW480 cells after incubating lectins with *P. acidipropionici* CRL 1198 as compare to the lectins activity before incubating the lectins with *P. acidipropionici* CRL 1198 **(Zarate, 2017)**. Lectin from *Dioscorea bulbifera* bulbils inhibit the cell growth of HT 29, SW 620 and HepG2 cells with IC50 of 110 µg, 9.8 µg, 40 µg respectively after 72 hrs of interaction with lectin **(Sharma *et al.*, 2017)**. The seeds of *Canavalia bonariensis* lectin showed antitumor activity against rat C6 glioma cells with the lectin concentration of 50 and 100 mg/mL decrease cell viability at 40% and 50%, respectively, after 24 hrs treatment where as in case of 48 hrs of treatment with lectin concentration of 30 and 100 mg/mL cell viability decreased upto 30% and 50% respectively **(Cavada *et al.*, 2018)**. Native as well as recombinant lectin of *Cratylia mollis* seed showed toxicity against human prostate adenocarcinoma (PC-3) cells after 24 hrs exposure to the lectin along with the Concanavalin A. They observed that there were more than 10% decreased in the cell viability at 100 µg/mL and 300 µg/mL of lectin concentration in case of both the native as well as recombinant *Cratylia mollis* seed lectin; IC50 were 29.91 µg/mL and 39.69 µg/mL for recombinant and native *Cratylia mollis* seed lectin respectively. But there were no significant decrease in the cell viability in case of Concanavalin A with the concentration of 30 to 300 µg/mL **(Figueirôa *et al.*, 2017)**. Lectins isolated from the seeds of *Canavalia brasiliensis, Canavalia maritima, Dioclea lasiocarpa* and *Dioclea sclerocarpa* showed anti-proliferative activity against Human ovarian carcinoma (A2780), human Caucasian lung carcinoma (A549), human prostate carcinoma (PC3) and human breast carcinoma (MCF-7), with IC50 values ranging from 52 to 529 nM. Out of the four different lectins, *Dioclea lasiocarpa* lectin showed highly active against A2780 with IC50 value of 52 ± 2 nM. Whereas with MCF-7 IC50 value was 275 nM **(Gondim *et al.*, 2017)**. Later on the same group of researcher worked on the same lectin (*Dioclea lasiocarpa* lectin) showed decrease in the cell viability of rat glioma cells (C6) but decrease in the cell viability starts at the low concentration 10 µg/mL both after 24 hrs and 48 hrs on incubation **(Nascimento *et al.*, 2017)**. Methyl-β-d-galactopyranoside specific lectin from *Kaempferia rotunda* showed 43.7% cell growth inhibition in vitro against EAC cells at 160 µg/mL at the same time it was not inhibited the growth of U87 cell line and in-vivo antitumor effect of the lectin was observed in EAC bearing Swiss albino mice at the doses of 3.0 and 6.0 mg/kg/day for five consecutive days and found that there were decrease in cell growth of EAC by 41 and 59% respectively **(Ahmed *et al.*, 2017)**. The crude lectin from the latex of *Euphorbia tirucalli* showed toxicity against non-tumor cell lines such as peritoneal macrophages, murine bone-marrow-derived macrophages and fibroblasts after 18 hrs of incubation but purified lectin did not showed toxicity against these non-tumor cells. Where as in case of tumor cell lines HeLa: Human cervical cancer cell line, PC-3: Human prostate cancer cell line, MDA-MB-231: Human breast cancer cell line, MCF-7: Human breast adenocarcinoma cell line the crude and purified lectin showed anti-proliferative activity; at concentration of 25 and 50 µg/mL, HeLa and PC3 were more susceptible to the harmful effects of purified lectin. MDA-MB-231 and MCF-7 were more susceptible to the harmful effects of crude lectin. There was same effect even at higher concentration. Breast cancer cell lines (MDA-MD-231 and MCF-7) were more sensitive to crude extract (47.9 and 56.9% death rates) than to the purified lectin (25.5 and 32.5%) death rates. Meanwhile, purified lectin killed more PC3 cells (27.5% death rate) than crude extract (19.6% death rate). There was no difference in cytotoxicity in HeLa cells between crude extract and purified lectin. In-vivo antitumor activities of both the crude and purified lectin were evaluated on intraperitoneal administered 100 Ehrlich ascites carcinomas (EAC) on mice. They found that the mice treated with crude and purified lectin were survived and there were no significant difference between the survival rates **(Palharini *et al.*, 2017)**. In vitro cytotoxic effects of *Moringa oleifera* seeds lectin on (B16-F10) melanoma cells; concentration of lectin ranging from 1.5–16 µM was evaluated for the reduction of the cells. The IC50 value was found at 9.72 µM. They determine that the reduction of the number of cells is due to the activation of caspases 3, 8 and 9 **(Luz *et al.*, 2017)**. Lectin from the same *Moringa oleifera* seeds inhibit the growth of Ehrlich ascites carcinoma (EAC) cell in-vitro with a concentration of lectin ranging from 25–200 µg/mL; at 200 µg/mL and 12.5 µg/mL the inhibitory effect was 71.08% and 15.27% respectively. In-vivo antitumor effect of the *Moringa oleifera* lectin on Ehrlich ascites carcinoma (EAC) on mice was observed at a concentration of lectin dose of 2.0 mg/kg/day there were 25.38% of EAC cell growth inhibition but when the concentration was increased to 4.0 mg/kg/day, the growth inhibition was increased to 55% **(Asaduzzaman *et al.*, 2018)**. Lectin from the phloem exudates/sap of fruit of *Praecitrullus fistulosus* showed invitro antiproliferative effects on cell lines HT29 (colon cancer), HeLa (cervical cancer), MCF7 (breast cancer) and K562 (leukemia) with an IC50 value of 43.80 µg, 45.17 µg, 62.80 µg and 76.23 µg respectively. The lectin did not showed cytotoxicity against normal cell line, peripheral blood mononuclear cells (PBMCs) even at a higher concentration of 1 mg/mL. In-vivo anticancerous activity was observed on EAC model 10 mg/kg injection for every alternate day (3 doses on day 7, 9 & 11). When compare it to the control i.e., without injection of lectin; the mice after receiving the first dose itself on day 7 there were gradual decrease in the body weight. After receiving the 3rd dose mice reduced tumor cell proliferation up to 75% **(Shivamadhu *et al.*, 2017).** High mannose N-glycan binding lectin from *Remusatia vivipara* tubers showed anticancerous activity against the human breast cancer cell lines MDA-MB-468, MCF-7 and MCF-10A. After 48 hrs of treatment of lectin; 67.07% and 34.23% of cell viability was decreased in MDA-MB-468 and MCF-7 cells at 10 µg/mL dose of lectin. Whereas at 100 µg/mL concentration the cell viability decrease was 80.8% and 50.6% respectively. In case of non-tumorigenic MCF-10A cells derived from human fibrocystic mammary tissue, lectin exerted only marginal effect with 18.2% decrease in cell viability at 40 µg/mL concentration of lectin **(Sindhura *et al.*, 2017)**. Lectin from *Dioclea lasiophylla* Mart. Ex Benth seeds showed toxicity against C6 glioma cells at a concentration of 50 and 100 µg/mL of lectin decreased cell viability after 24 hrs of incubation and at 30–100 µg/mL after 48 hrs incubation **(Leal *et al.*, 2018)**. *Canavalia ensiformis* (ConA) and *Dioclea violacea* (DVL) lectins showed antiglioma effect on rat glioma cells (C6). *Dioclea violacea* lectin at concentration of 30 µg/mL decreased cell viability around 30% after 24 hrs of incubation, whereas after 48 hrs of incubation there were 66% of decrease in cell viability. *Canavalia ensiformis* lectin at concentration of 30 µg/mL the decrease in the cell viability was observed only after 24 hrs of incubation, there were only 30% decrease in the cell viability after 48 hrs of incubation **(Nascimento *et al.*, 2018)**. *Pisum sativum* seeds lectin showed inhibition of 17, 35 and 63% in SW480 cells at concentration of 0.25, 0.5 and 1.0 mg/mL after 3 days of treatment. Similarly, 18, 36 and 62% cell growth inhibition were noted in SW48 cells at concentration of 0.25, 0.5 and 1.0 mg/mL **(Islam *et al.*, 2018)**. The purified lectin from soya bean seeds displayed minor inhibition with 30% cell growth inhibition of B16F1 melanoma cells at a concentration of 35 µg/mL **(Roy *et al.*, 2018)**.

Anti-inflammatory and Antinociceptive Activity

Lectin from *Abelmoschus esculentus* seeds showed activity in reducing zymosan-induced temporomandibular joint (TMJ) inflammatory hypernociception in rats along with the mechanism of action like reduced leukocyte influx along with MPO activity as well as lectin reduced TNF-α and IL-1β levels in temporomandibular joint inflammatory tissue and trigeminal ganglion, Which showed lectin exerts anti-inflammatory activity **(Freitas *et al.*, 2016)**. Later lectin from the same plant *Abelmoschus esculentus* significantly reduced formalin-induced TMJ inflammatory hypernociception and decreased Evans blue extravasation. It decreased TNF-α levels in the TMJ tissue, trigeminal ganglion, and subnucleus caudalis. The lectin did not show antinociceptive effects in the presence of naltrindole or nor-binaltorphimine **(Alves *et al.*, 2018)**. *Bauhinia monandra* leaf lectin showed anti- inflammatory activity of 64% on paw edema induced by carrageenan as well as it also exert antinociceptive activity on mice **(Campos *et al.*, 2016)**. Lectins from *Parkia platycephala* showed antinociceptive activity in the mouse model of acetic acid induced and also demonstrated anti-inflammatory effect causing inhibition of leukocyte migration induced by both direct and indirect chemo attractants **(Umaro *et al.*, 2016)**. *Crotalaria retusa L.* seeds lectin inhibited the mice paw edema and neutrophil migration into the peritoneal cavity induced by carrageenan **(Aragão *et al.*, 2017)**. Lectin from *Lonchocarpus campestris* seeds inhibited paw edema and hyperalgesia induced by carrageenan as well as it showed antinociceptive activity in the behavioural tests of Formalin and Writhing ***(*Pires *et al.*, 2018)**.

Anti-coagulant Activity

Lectin purified from *Bauhinia forficata* seeds showed anticoagulant and antiplatelet properties. Coagulation time was increases in presence of *Bauhinia forficata* lectin and this consequence is not due to inhibition of human plasma kallikrein or human factor Xa. Dose dependent manner this lectin inhibits ADP and epinephrine-induced platelet aggregation. It was observed that at 3.0 µM concentration this lectin completely inhibits the platelet aggregation **(Silva *et al.*, 2012)**. *Moringa oleifera* seed lectin showed anticoagulant protein on in-vitro blood coagulation parameters and at least on activated partial thromboplastin by more than 300 Second and prothrombin times at a concentration ranging from 3 to 60 µg/mL **(Luz *et al.*, 2013)**. *Phthirusa pyrifolia* leaves lectin showed anticoagulant activity. It was showed through coagulation times like activated partial thromboplastin time (APTT) and thrombin time (TT) extrinsic pathway **(Costa *et al.*, 2017)**.

Immune Response Activity

Lectin from banana was cloned and expressed after that it was injected in Balb/c (albino). This experiment showed increased IgG and IgM concentrations in dose-dependent manners **(Dimitrijevic *et al.*, 2012)**. In the year 2016 same group showed banana lectin could be able to increase the concentration of IgA and IgG production in a dose-dependent manner**(Marinković *et al.*, 2016)**. One more recombinant banana lectin binds to murine peritoneal macrophages and affects their functional aspects. Lectin raised the production of IL-10, TGFβ, IL-4 and enhancement of arginase activity with reduction of NO IL-12 formation **(Marinkovic *et al.*, 2017)**. Again, another lectin from the fruit pulp of banana, when orally administered to the mice, they found that there were, no significant differences were found in the lymphocytes of mouse peripheral blood, although an increase of CD4+ and decrease of CD8+ T-cells were observed in the thymus. However, they found that there were decrease in IL-6 and IFNγ and increase of IL-10, IL-17A and TNFα production in the peripheral blood of mice **(Sansone *et al.*, 2016)**. B-chain of *Korean mistletoe* seeds lectin did not induce apoptosis in bone marrow-derived dendritic cells ($BMDC_s$). Whereas the treatment of lectin on $BMDC_s$ increases the expressions of co-stimulatory molecules (CD40, CD80, CD86, and MHC II) and the secretions of cytokines (IL-1β, IL-6, IL-12p70, and TNF-α). The lectin induced naïve CD4+ T cell differentiation toward Th1 cells directly and indirectly **(Kim *et al.*, 2014)**. Lectin from the Onion (*Allium cepa*) plant bulb increase the production of NO (nitric oxide) up to 6–8-fold in macrophage cell line, RAW264.7 and rat peritoneal macrophages. It stimulated the production of cytokines (TNF-α, IL-12, IFN-γ and IL-2)) and furthermore enhanced the proliferation of murine thymocytes **(Prasanna *et al.*, 2015)**. Another onion lectin showed immune-protective properties by promoting the development of lymphoid cells count (WBC and lymphocytes count) and immune response in cyclophosphamide induced immune suppressed Wistar rats. Furthermore, it also depressed proinflammatory molecules like COX-2 and NO, and expression levels of immune regulatory molecule TNF-α, and suppressed the Th2-type type cytokine, i.e., serum IL-10 **(Kumar *et al.*, 2016)**. Lectin from the inflorescence of *Alpinia purpurata* induced the release of cytokines belonging to Th1 (IFN-γ, TNF-α, and IL-6) and Th17 (IL-17A) profiles as well as of nitric oxide. It stimulated the production of IL-10 as well as activate both T CD8+ and CD^{4+} subsets of lymphocytes **(Brito *et al.*, 2017)**. *Microgramma vacciniifolia* fronds lectin induced immunomodulatory properties on human peripheral blood mononuclear cells (PBMCs) by increasing TNFα, IFNγ, IL-6, IL-10, and nitric oxide production. It also stimulates T lymphocytes from PBMCs to differentiate into CD8+ cells **(Leite *et al.*, 2017)**. Lectin from the leaf pinnulae of *Calliandra surinamensis* activates immune cells in BALB/c mice splenocytes. They found that there were changes in in cytosolic calcium concentration ($[Ca^{2+}]$cyt), mitochondrial membrane potential (ΔΨm), and reactive oxygen species (ROS) levels associated with cell viability, proliferation, cytokine and nitric oxide production. It also promotes the production of IL-2 and TNF-α **(Procópio *et al.*, 2018).**

Mitogenic Activity

In the case of Red Kidney Bean (*Phaseolus vulgaris* L.), wild-type lectin and irradiated (γ-radiation) form lectins showed the mitogenic effect on lymphocyte proliferation. Authors found that the lectin after irradiation at 1kGy showed a decrease in mitogenic activity approx 70%, Whereas at 10kGy showed complete mitogenic activity **(Mallikarjunan *et al.*, 2014).**

Glycoconjugates Research

Anacardium occidentale bark lectin was Immobilization on CNBr-Activated (cynogen bromide) Sepharose CL-4B. Bound feutin to this column demonstrated that lectin matrix could be used for glycoconjugates research **(MacIel *et al.*, 2012).** The use of matrices (Sepharose CL-4B) containing *Cratylia mollis* lectins used for isolation of glycoproteins from fetal bovine serum, human colostrum, hen egg white, and human blood plasma **(Santos-Filho *et al.*, 2013)**. Lectin isolated from *Platypodium elegans* seeds when immobilized on CNBr-activated Sepharose 4B and showed feutin binding properties in solution, demonstrated that this lectin active and capable of binding carbohydrates **(Alencar *et al.*, 2017).** Lectin extracted from *Cratylia mollis* seeds was immobilized on the surface of titanium dioxide nanotubes and found that increase in osteoblast-like cell adhesion on the TNTs-LbL-Cramoll (titanium dioxide nanotubes-layer by layer- *Cratylia mollis* seeds lectin) system when compared to the bare TNTs surfaces **(Oliveira *et al.*, 2018)**.

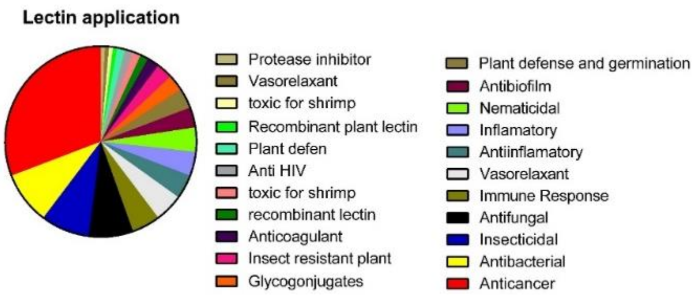

Figure 1 Application of lectins

CONCLUSION

Plant lectins are complex and carbohydrates binding proteins. The physiological role of lectins in the plant is not clear. Although plant lectins differ in their amino acids sequences, structural aspect as well evolutionary origin but most of lectins exhibits similar type of function such as antibacterial, antifungal, insecticidal, anti-inflammatory (Figure 1). Due to easy availability and requirements simple purification system plants lectins will one of the best tools to study protein-carbohydrates interaction or useful disease biology.

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