

Exploring the Biocontrol Potential of Plant Lectins: Emerging Trends and Future Perspectives

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Conflict of interest

All authors declare no conflict of interest.

Received Date: 10 June 2024

Accepted Date: 25 June 2024

Published Date: 01 July 2024

Citation:

M. Balakrishnan. Exploring the Biocontrol Potential of Plant Lectins: Emerging Trends and Future Perspectives. Journal of Bioscience & Bioengineering 2024.

1. Abstract

In today's scenario, agriculture is ravaged by a multitude of maladies which are accelerated due to climate change and overdependence on chemical fertilisers leads to damaging consequences. Despite having different molecular structures, lectins are proteins that can recognize and bind to carbohydrate structures selectively and reversibly without altering the carbohydrate moiety. They are one of the most widely studied molecules in glycobiology as they perform a wide range of activities. In the era of global warming and climate change, lectins act as a 'trojan horse' modulating the immune response (both innate and acquired) and physiological stress adaptations in plants. A selective bio curated list of rice lectin genes encompassing their related genes, sub-cellular location, gene ontology and their 3D structures are succinctly tabulated to reinforce their ubiquitous presence. At the molecular level, there is an interplay between plant hormones and lectins proving their mitogenic/proliferative activity. Their carbohydrate specificity, selectivity and entomotoxic potential renders them as staunch proponents in pest management. The biocontrol potential of oryza, a rice lectin is exemplary that sets open new vistas of research. Its docking with chitin oligomers revealed the interaction profile and contact residues to substantiate its insecticidal activity. Computational resources such as databases, tools and portals advancing lectin research are congregated for the sake of posterity. Due to their biological origin,

they foster sustainable agriculture and organic farming practices. Recent advances in high-throughput techniques are an incentive to the growth of glycomics and lectome which will eventually influence the development of transgenic lines, and pest-resistant and abiotic stress-resistant crops.

2. Keywords:

Glycobiology, glycomics, Integrated Pest Management, carbohydrate binding, agriculture and crops

3. Introduction

The Latin verb *legere*, which means to choose, read, or gather, is where the word «lectin» originates [1]. These proteins are incredibly stereospecific and can distinguish between diverse sugar compounds leading to the formation of glyco-conjugate complexes by establishing reversible bonds [2]. They are ubiquitously found in cells, membranes, and secretomes of organisms from all kingdoms of life, and harbour a level of heterogeneity in binding-pocket sequences for ligand specificity comparable to immunoglobins [3]. Carbohydrate recognition occurs in a diverse array of biological scenarios. Therefore, lectins are an exceptionally distinct class of proteins consisting of many varying protein families [4]. They show evolutionary expansion that has distinct clade-specific signatures and the function(s) of many plant lectin family genes are unknown [5]. The synthesis of insecticidal proteins is one of the plants' most significant direct defence mechanisms against the onslaught of phytophagous insects. Lectins are a chief component of entomotoxic proteins found in many plant species [6]. Plants produce lectins in reaction to unfavourable environmental factors including heat, drought, pathogen invasion, etc. Recent research has suggested that Arabidopsis EULS3 lectin, additionally referred to as ArathEULS3, encoded by At2g39050 was produced in response to drought stress [7]. The plant lectin ArtinM acts as an agonist of toll-like receptors (TLRs) thereby targeting of TLRs by lectins creates a new opportunity to therapeutically influence the immune system's sensitivity [8]. Numerous plant lectins have cytotoxic effects on animals, mostly by triggering autophagic and apoptotic pathways in cancerous cells. They exhibit varying binding patterns to malignant tissues depending on the degree of glycosylation, and as a result, they could be employed as agents for both diagnosis and treatment [9,10,11]. Dietary lectins originating from plants have been implicated in the aetiology of multiple inflammatory disorders, such as rheumatoid arthritis, diabetes, celiac disease, and inflammatory bowel disease. It has been suggested that dietary lectins may aid in the promotion of diet-induced inflammatory disorders by activating the NLRP3 inflammasome through the function of plant lectins as an external «danger signal» [12]. Some lectins facilitate the recognition of exogenous danger signals or play a role in endogenous signalling pathways, while others are considered storage proteins or

involved in symbiotic relationships [13]. Improved knowledge of the structure and function of lectins is anticipated to contribute to increased agricultural output by controlling metabolic pathways with the use of plant growth regulators or by modifying potential genes for the breeding of climate-resilient crops [5]. In this review, we briefly outline the insights from 130+ years of lectin research, their applications in crop protection and crop improvement, and their relevance in integrated pest management. The functional landscape of lectins showcasing a panoramic view of their biological potential is depicted in (Fig 1). A docking experiment was performed between oryza lectin and chitin oligomers to interpret the contact residues to substantiate its role in biological control. The various resources for lectin-glycan research are enumerated signalling the involvement of lectins in myriad biological processes with an emphasis on glycomics and glycobiology.

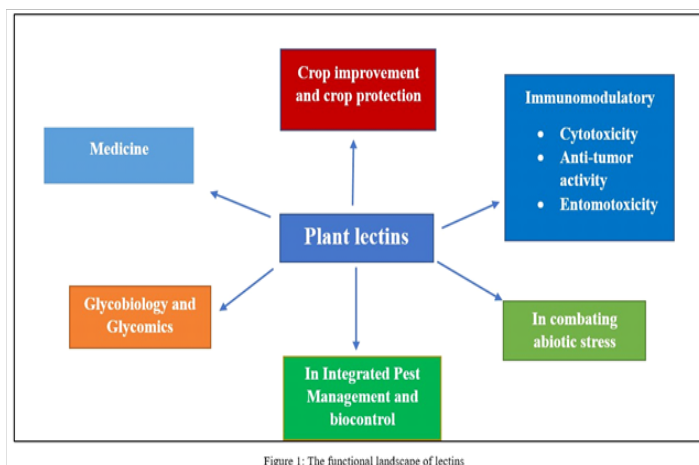


Figure 1: The functional landscape of lectins

4. Historical Overview

In his 1888 PhD thesis, Peter Hermann Stillmark provided the University of Dorpat with the first description of a lectin. He isolated ricin, an extremely toxic hemagglutinin derived from the castor plant's seeds (*Ricinus communis*) which marked the beginning of lectinology [14]. Following Stillmark's discovery, in 1891, Paul Ehrlich utilized ricin and other similar toxins as model antigens for his immunological research cementing the central role of lectins. In 1907, Karl Landsteiner model antigens for his immune studies, firmly establishing the pivotal function of lectins [15]. Karl Landsteiner identified the human A, B, and O blood groups in 1907 by observing the specificity of various seed extracts' hemagglutinating activity on erythrocytes from various animals and comparing it with antibodies of animal blood serum [2]. In 1919, Sumner isolated lectin from jack bean seeds (*Canavalia ensiformis*) and purified it for the first time in crystalline form. This was named as Concanavalin A [16]. Subsequently, in 1936, they also established that Concanavalin A precipitates glycogen and mucoproteins and agglutinates not only erythrocytes of certain animal species but also fat emulsions, starch granules, yeast cells, and

certain bacteria [17]. The 1940s saw the discovery by William C. Boyd at Boston University and by Karl O. Renkonen at the University of Helsinki, Finland, of the human blood group (or blood type) degree of hemagglutinin specificity [18]. The discovery in 1952 that lectins' ability to agglutinate is linked to their ability to bind to certain sugars [19] provided for the first time a biochemical explanation for an until then elusive biological activity [20]. In the 1960s, Peter C. Nowell found that the lectin of the red kidney bean (*Phaseolus vulgaris*), known as phytohemagglutinin (PHA), is mitogenic, that is, it possesses the ability to stimulate lymphocytes to undergo mitosis and Joseph C. Aub at found that wheat germ agglutinin (WGA) can preferentially agglutinate malignant cells. In 1974, Gilbert Ashwell together with Anatol G. Morell isolated the first mammalian lectin, the galactose-specific hepatic asialoglycoprotein receptor. Since the beginning of the 1980s, the number of purified animal lectins also started to grow quickly, largely thanks to the advent of recombinant techniques. The discovery and advancement of novel methodologies, including glycan arrays, frontal affinity chromatography, and plasmon resonance, facilitated the identification of lectin motifs and the comparative analysis of plant genomes [18]. GlyGen Portal (<https://www.glygen.org>), provides a user-friendly interface that facilitates exploration of glycoscience data [21]. An online resource to investigate glycan recognition with lectins in diverse biotechnology and clinical applications, addressing key questions regarding binding specificity called BiotechLec (<https://www.unilectin.eu/biotechlec>) [22]. A bird's eye view of the major milestones achieved in the timeline of lectin research is illustrated in (Fig 2).

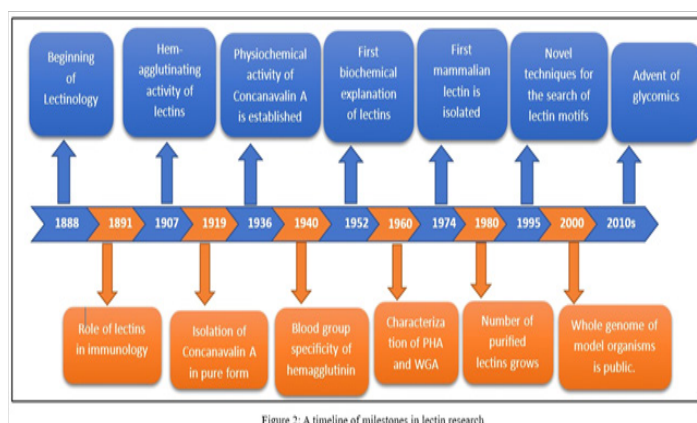


Figure 2: A timeline of milestones in lectin research

4.1. Functional characterisation of rice lectin gene family

We have examined, in detail, the published literature and the data available in various public databases, including UniProt [23] (<https://www.uniprot.org/>), and InterPro [24] (<https://www.ebi.ac.uk/interpro/>) to gather information about the rice lectin gene family. Only the entries that are reviewed or biocurated by Swiss-Prot and their sub-cellular location, gene ontology (cellular component, biological process and molecular function) are displayed in (Table 1).

Table 1: Rice lectin genes

| S. No | Gene | Name | Sub-cellular location | Gene Ontology |
|-------|--|--|---|---|
| 1. | LECRKS7, | L-type lectin-domain containing receptor kinase S.7 | Cell membrane, cytosol | Pollen aperture, ATP binding, carbohydrate binding, protein serine/threonine kinase activity, defence response |
| | DAF1, | | | |
| | Os02g0459600, LOC_Os02g26160 | | | |
| 2. | SIT1, | L-type lectin-domain containing receptor kinase SIT1 | Cell membrane | ATP binding, carbohydrate binding, protein serine/threonine kinase activity, transmembrane receptor serine/threonine kinase activity, defence response to bacterium |
| | Os02g0640500, LOC_Os02g42780, P0010C01.40 | | | |
| 3. | SIT2, Os04g0531400, LOC_Os04g44900, OsJ_15568, OSJNBa0081C01.16 | L-type lectin-domain containing receptor kinase SIT2 | Cell membrane | ATP binding, carbohydrate binding, protein serine/threonine kinase activity, transmembrane receptor serine/threonine kinase activity, defence response to bacterium |
| 4 | CRO1, pp56Os07g0246200, LOC_Os07g14270, OJ1058_C08.34-1, OJ1058_C08.34-2, OSJNBa0003K21.18-1, OSJNBa0003K21.18-2 | Calreticulin | Endoplasmic reticulum lumen | Calcium ion binding, carbohydrate binding, unfolded protein binding, protein folding, ubiquitin-dependent |
| 5. | LECRK1, Os04g0201900 LOC_Os04g12540, OsJ_13804, OSJNBb0005B05.5 | G-type lectin S-receptor-like serine/threonine-protein kinase LECRK1 | Membrane | ATP binding, carbohydrate binding, protein serine/threonine kinase activity, transmembrane receptor serine/threonine kinase activity, defence response to bacterium |
| 6. | LECRK2, Os04g0202300, LOC_Os04g12560, OsJ_13805, OSJNBb0005B05.6 | G-type lectin S-receptor-like serine/threonine-protein kinase LECRK2 | Membrane | ATP binding, carbohydrate binding, protein serine/threonine kinase activity, transmembrane receptor serine/threonine kinase activity, defence response to bacterium |
| 7. | LECRK3, | G-type lectin S-receptor-like serine/threonine-protein kinase LECRK3 | Membrane | ATP binding, carbohydrate binding, protein serine/threonine kinase activity, transmembrane receptor serine/threonine kinase activity, defence response to bacterium |
| | Os04g0202500, LOC_Os04g12580, OSJNBb0005B05.7 | | | |
| 8. | LECRK4, Os04g0202800, LOC_Os04g12600, OsJ_13808, OS-JNBb0005B05.8 | G-type lectin S-receptor-like serine/threonine-protein kinase LECRK4 | Membrane | ATP binding, carbohydrate binding, protein serine/threonine kinase activity, transmembrane receptor serine/threonine kinase activity, defence response to bacterium |
| 9. | Os01g0533400, LOC_Os01g34920, OJ1029_F04.5, OJ1619_F12.26 | Beta-galactosidase 1 (Lactase 1) | Secreted, extracellular space, apoplast | Beta-galactosidase activity, carbohydrate binding, carbohydrate metabolic process |
| 10. | Os01g0580200, LOC_Os01g39830, P0672C09.21 | Beta-galactosidase 2 (Lactase 2) | Secreted, extracellular space, apoplast | Beta-galactosidase activity, carbohydrate binding, carbohydrate metabolic process |
| 11. | Os06g0628500, LOC_Os06g42310, OSJNBa0023122.22, P0530H05.37 | Beta-galactosidase 3 (Lactase 3) | Secreted, extracellular space, apoplast | Beta-galactosidase activity, carbohydrate binding, carbohydrate metabolic process |
| 12. | Os03g0165400, LOC_Os03g06940, OJ1123F12.1 | Beta-galactosidase 5 (Lactase 5) | Secreted, extracellular space, apoplast | Beta-galactosidase activity, carbohydrate binding, carbohydrate metabolic process |
| 13. | Os03g0255100, LOC_Os03g15020 | Beta-galactosidase 6 (Lactase 6) | Secreted, extracellular space, apoplast | Beta-galactosidase activity, carbohydrate binding, carbohydrate metabolic process |
| 14. | Os05g0428100, LOC_Os05g35360, OsJ_017861, OSJNBa0044P19.21, P0636F09.15 | Beta-galactosidase 7 (Lactase 7) | Secreted, extracellular space, apoplast | Beta-galactosidase activity, carbohydrate binding, carbohydrate metabolic process |

| | | | | |
|-----|--|--|---|---|
| 15. | Os08g0549200, LOC_Os08g43570, OJ1479_B11.10 | Beta-galactosidase 11 (Lactase 11) | Secreted, extracellular space, apoplast | Beta-galactosidase activity, carbohydrate binding, carbohydrate metabolic process |
| 16. | Os09g0539200, LOC_Os09g36810, OsJ_028990 | Beta-galactosidase 12 (Lactase 12) | Secreted, extracellular space, apoplast | Beta-galactosidase activity, carbohydrate binding, carbohydrate metabolic process |
| 17. | Os10g0330600, LOC_Os10g18400, OsJ_029894, OSJNAb0008A05.15, OSJNBb0008A05.25 | Beta-galactosidase 13 (Lactase 13) | Secreted, extracellular space, apoplast | Beta-galactosidase activity, carbohydrate binding, carbohydrate metabolic process |
| 18. | Os10g0340600, LOC_Os10g19960, OsJ_029934, OSJNBa0050M22.9 | Beta-galactosidase 14 (Lactase 14) | Secreted, extracellular space, apoplast | Beta-galactosidase activity, carbohydrate binding, carbohydrate metabolic process |
| 19. | Os12g0429200, LOC_Os12g24170 | Beta-galactosidase 15 (Lactase 15) - Galactose binding lectin domain containing protein | Secreted, extracellular space, apoplast | Beta-galactosidase activity, carbohydrate binding, carbohydrate metabolic process |
| 20. | SALT ML Os01g0348900, LOC_Os01g24710, B1051E10.18, P0440D10.39 | Salt stress-induced protein (Protein mannose-binding lectin) | Cytoplasm | Carbohydrate binding |
| 21. | ADF4, Os03g0820600 LOC_Os03g60590, OJ1754_E06.22 | Actin-depolymerizing factor 4 (ADF-4) | Cytoplasm, cytoskeleton | Beta-galactosidase activity, carbohydrate binding, carbohydrate metabolic process |
| 22. | OSJNBa0032G08.3, OsJ_24359, OsJ_18437, OsJ_09233 | Malectin-like domain-containing protein | Membrane | Transmembrane receptor protein tyrosine kinase activity |
| 23. | OSJNBb0015I02.1, OSJNBa0087C10.3, OsJ_12185, OSJNBb0101N11.17, OJ1715_A07.11-1, LOC_Os12g41956, LOC_Os03g58920, LOC_Os03g58900, LOC_Os03g48610 | Galactosyltransferase | Golgi apparatus membrane | Carbohydrate binding, galactosyl transferase activity, protein glycosylation |
| 24. | OsJ_35926 | SUEL-type lectin domain-containing protein | Extracellular space, apoplast | Beta-galactosidase activity, carbohydrate binding, carbohydrate metabolic process |
| 25. | LOC_Os03g20940 | QXW lectin repeat family protein | Membrane | Carbohydrate binding |

The FASTA sequence of the individual lectins was downloaded from UniProt and using the SWISS-MODEL-server[25] the structures were generated. The following protein structures of rice lectins were derived using template-based modelling protocol. They are as illustrated in (Figs3-16).

4.2. Role in crop protection and crop improvement

One of the most important plant lectins possess characteristics that align with their putative defensive role, such as their exceptionally robust resistance to proteolysis and stability across a wide pH range, even in environments that are not indigenous to them [26].

Fig. 3: L-type lectin-domain containing receptor kinase S.7

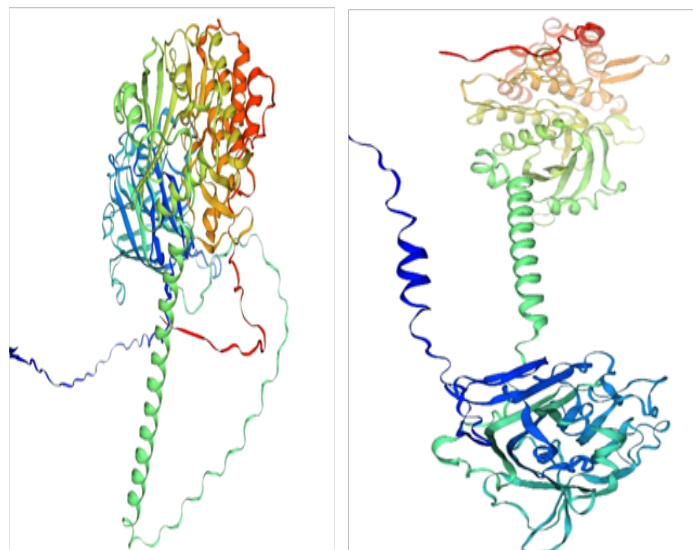


Fig. 4: L-type lectin-domain containing receptor kinase SIT1

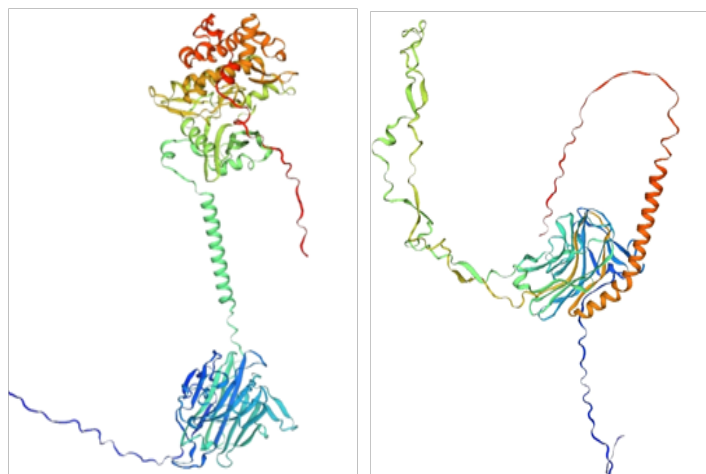


Fig. 5: L-type lectin-domain containing receptor kinase SIT2

Fig. 6: Calreticulin

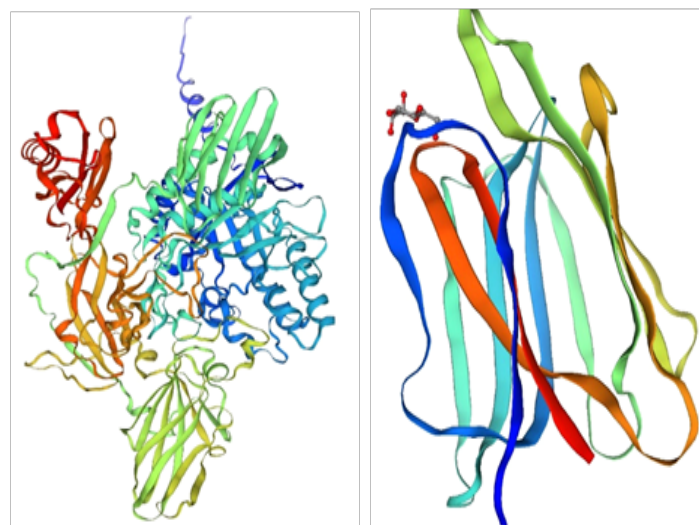


Fig. 11: Beta galactosidase

Fig.12: Salt stress-induced protein (Protein mannose-binding lectin)

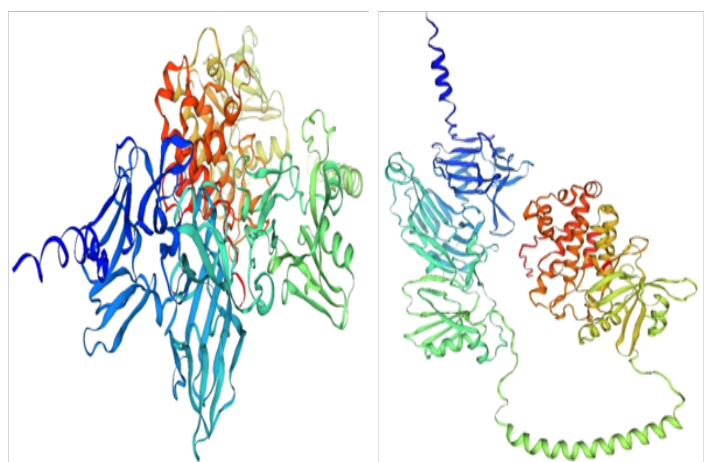


Fig. 7, Fig 8: G-type lectin S-receptor-like serine/threonine-protein kinase LECRK1, LECRK2

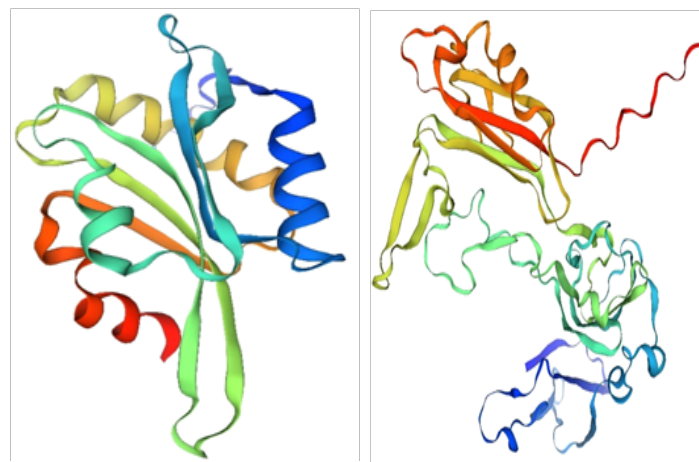


Fig. 13: Actin-depolymerizing factor 4 (ADF-4)

Fig. 14: Beta-galactosidase 15 (Galactose binding lectin domain containing protein)

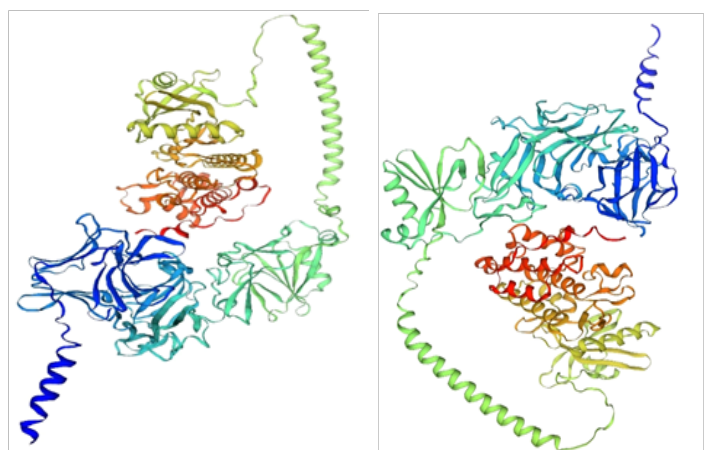


Fig. 9, Fig 10: G-type lectin S-receptor-like serine/threonine-protein kinase LECRK3, LECRK4

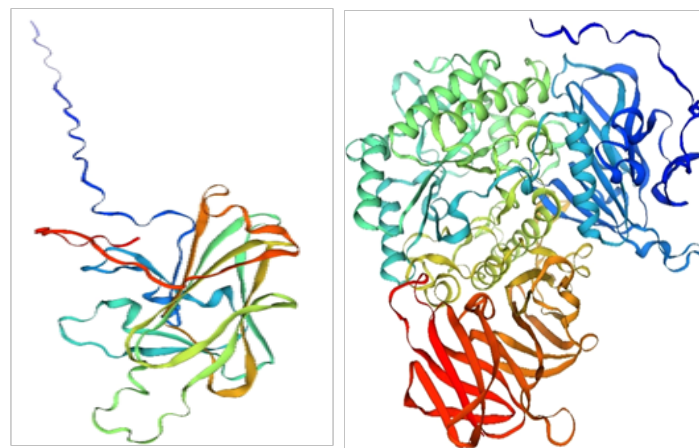


Fig. 15: Malectin-like domain-containing protein

Fig. 16: Galactosyltransferase containing protein

4.3. In crop protection

Lectins have high potential in pest control strategies and biotechnological strategies suggesting that lectin products are interesting tools for integrated pest management in important agriculture crops. Colocasia esculenta agglutinin (CEA), a lectin from Colocasia esculenta (L.) Schott corm affected normal growth and development and presented stress to the larvae, activating their detoxification and antioxidant systems. Thus, lectin seems to be a useful candidate for the control measures of *B. cucurbitae* under the integrated pest management (IPM) system [26]. Lectins from the family Araceae, namely from *Arisaema intermedium* Blume and *Arisaema wallichianum* Hook f., have been examined in relation to the development of melon fruit fly larvae in their second instar, demonstrating promising anti-insect potential. Therefore, it is possible to clone lectin gene(s) from either of these species and then use the result to create transgenics that will selectively control melon fruit flies and other insect pests [27]. When compared to larvae given a diet lacking lectin, the tuber lectin from blume demonstrated a considerable drop in acid phosphatase and alkaline phosphatase activity and a marked rise in esterase activity. The tuber lectin possesses both anti-insect and anti-proliferative characteristics [28]. The soybean cysteine [29] protease inhibitor soyacystatin N (scN) and *Griffonia simplicifolia* lectin II (rGSII) have defence functions against the coleopteran cowpea bruchid beetle *Callosobruchus maculatus* [30]. Lectin products inhibited the activity of total proteases, α -amylase, GST, and total esterases in cotton leafworm *Spodoptera littoralis* [31]. The activities of hydrolytic enzymes in the larvae of *Eldana saccharina* reared on a diet containing a lethal dose of lectin from the tuber of *Dioscorea mangelotiana* were significantly affected as compared to those fed on the diet without the lectin [32]. Zhao, et al developed a novel pest management strategy, which uses endophytes to express anti-pest plant lectins to control sap-sucking insect pests. Mannose-binding lectins purified from three different monocotyledonous plants (*Allium sativum*, *Colocasia esculenta*, and *Diffenbachia sequina*) had a detrimental effect on the growth and development of the red cotton bug [33]. A diagrammatic representation of the effect is displayed in (Fig 17).

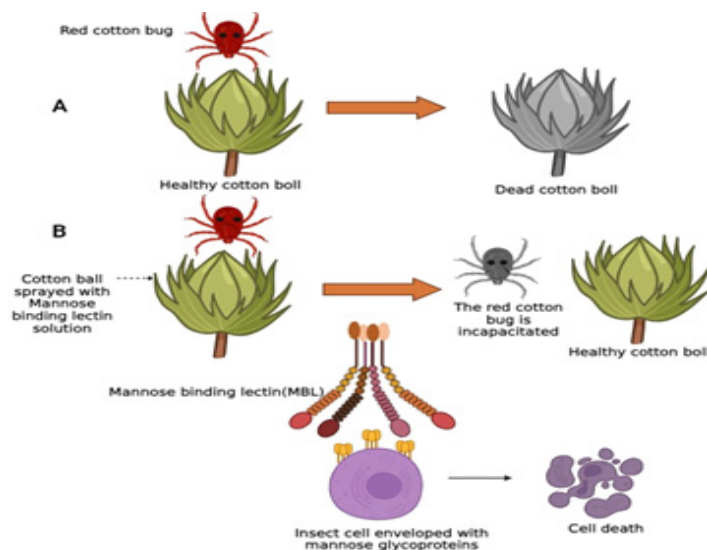


Fig. 17: (A)-Red cotton bug (*Dysdercus cingulatus*) affecting a healthy cotton boll leading to death. (B)- The cotton boll is sprayed with mannose binding lectin purified from three different species *Allium sativum*, *Colocasia esculenta*, and *Diffenbachia sequina*. After ingesting, it enters into the insect's cells and produces a cascading immune response finally leading to cell death (Created with BioRender.com).

Lectin isolated from the ornamental monocot, *Caladium bicolor* Vent significantly prolonged the development period of second instar larvae of melon fruit fly, *Bactrocera cucurbitae* (Coquillett), reduced the percentage pupation and emergence besides affecting the activity of esterases [34]. Two lectin proteins purified from the corms of *Pinellia ternata* and *Lycoris radiata* have a toxic effect on the pinewood nematode that affects its survival in vitro [35]. *Bauhinia monandra* leaf lectin (BmoLL) is bound to the midgut proteins of the insect *C. maculatus* and caused a 40 % decrease in weight [36]. Recombinant BPLP (*B. hispida* Phloem Lectin-like Protein) showed both chitin-binding lectin activity and growth-inhibitory activity against *S. ricini* larvae [37]. *Listera ovata* agglutinin (LOA) (Orchidaceae) and *Galanthus nivalis* (Amaryllidaceae) agglutinin caused larval mortality and feeding inhibition in the legume pod-borer *Maruca vitrata* (Fabricius) [38]. *Talisia esculenta* lectin (TEL) caused the mortality of *C. maculatus* and *Zabrotes subfasciatus* larvae [39]. Sprawka et al., reported the effects of dietary ingestion of the glucose-mannose binding lectin Concanavaline A (Con A) on bird cherry-oat aphid (*Rhopalosiphum padi* L.) enzymes involved in protein digestion [aminopeptidase N and cathepsin L (CatL)], sugar (α - and β -glucosidases), and phosphorus (alkaline and acid phosphatase) metabolism [40]. Gleheda, a lectin present in the leaves of ground ivy (*Glechoma hederacea*) has potent insecticidal activity against the Colorado potato beetle (*Leptinotarsa decemlineata*) which is linked to the carbohydrate-binding specificity of the lectin [41]. Reduced pupation and adult emergence of legume pod borer, *Helicoverpa armigera* was observed in response to treatment of lectins from field bean (*Phaseolus vulgaris*), pigeon pea (*Cajanus cajan*), chickpea (*Cicer arietinum*), garlic (*Allium sativum*) [42] and nowdrop (*Galanthus nivalis*) [43].

4.4. In crop improvement

Lectins modulate genes involved in stress-response pathways, symbiosis, and immunity. The multifariousness in the role of lectins may open new prospects for their biotechnological uses in multiple fields including crop improvement [44]. To enhance the resistance to pests, transgenic maize (*Zea mays* L.) containing the gene encoding snowdrop lectin (*Galanthus nivalis* L. agglutinin; GNA) under the control of a phloem-specific promoter was generated through the *Agrobacterium tumefaciens*- mediated method [45]. The high-affinity binding of (*Dolichos lablab*) galactose-specific lectin, DLL-II to kinetin and indole acetic acid, the key hormones that regulate root development and its vascular differentiation [46]. A novel potential lectin gene (*ppa*) was cloned from *Pinellia pedatisecta* that could express in transgenic lines, and conferred aphid-resistance indoors and in field conditions. Therefore, *ppa* could be a strong biotechnological candidate for producing aphid-resistant wheat [47]. Transgenic oilseed rape (*Brassica napus*) has been produced wherein the pea lectin gene

expression is driven by a pollen-specific promoter to confer resistance against pollen beetle (*Meligethes aeneus*) [48]. The new soybean lectin (SBL) retarded the development of *Spodoptera exigua* larvae, their metamorphosis, and resistance to the infection of *Phytophthora nicotianae* when the corresponding encoding gene *lec-s* was introduced into tobacco plants via *Agrobacterium*-mediated transformation [49,50].

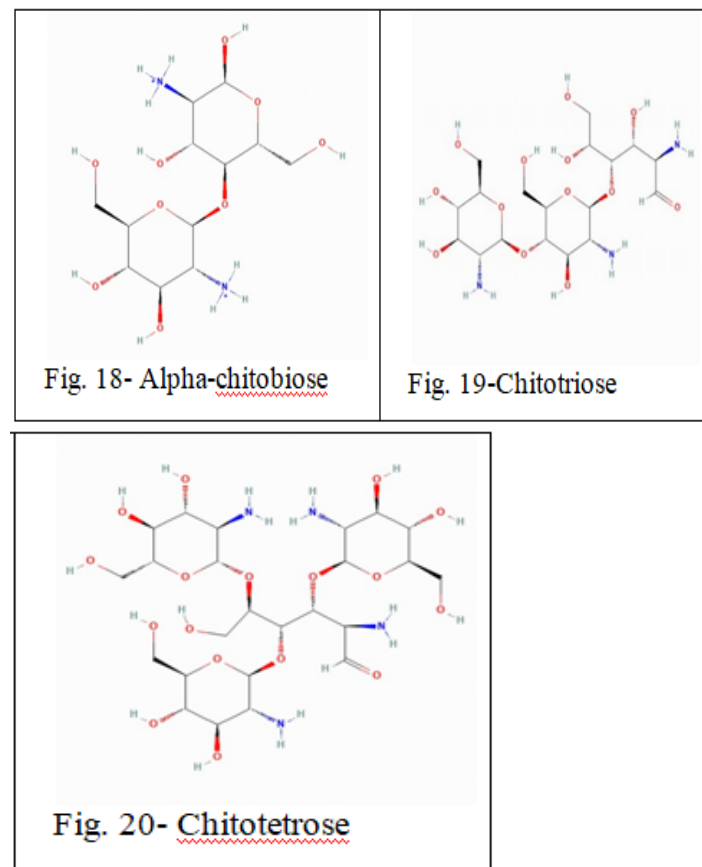
4.5. In Integrated Pest Management (IPM)

The combined consequences of climate change and the increase in insect populations provide a serious threat to the agricultural sector and global food security. Lectins are an important class of Plant Incorporated Protectants (PIP's) for insect resistance [51]. Lectins have deleterious effects against larvae, developing stages and mature forms of insects from orders Coleoptera, Diptera, Hemiptera, Homoptera, Hymenoptera, Isoptera, Lepidoptera and Neuroptera. The particular mechanisms of insecticidal action of lectins remain mysterious, though it has been suggested that this entomotoxic activity seems to depend upon the carbohydrate recognition property they exhibit [52]. Insecticidal lectins are useful tools that can contribute to the development of integrated pest management strategies with minimal effect(s) on non-target organisms. They have high potential in pest control strategies based on their activity towards the cotton leafworm, *S. littoralis* suggesting that lectin products are interesting tools for integrated pest management in important agriculture crops [53]. Besides their direct toxic effect, biotechnology has been able to utilize the capacity of lectins in successfully delivering other insecticidal proteins that normally cannot pass the midgut epithelium into the haemocoel [54]. Based on their homologous mannose binding domains, ability to agglutinate rabbit erythrocytes, and insecticidal efficacies, phylogenetic research revealed a strong similarity between AMTL (*Amorphophallus paeonifolius* Tuber Agglutinin) and GNA (*Galanthus nivalis* agglutinin). Therefore, AMTL appears to be an effective strategy for reducing crop loss brought on by hemipteran insect infestation [55]. Kidney bean and soybean lectins inhibited the activity of total proteases, α -amylase. Additionally, they reduced the average number of eggs laid / female (fecundity) and % egg hatch (fertility) significantly compared to control. Thus, suggesting that kidney bean and soybean lectins can be used as suitable alternatives for *B. thuringiensis* in integrated management programs of pink bollworm [56]. Lectin extracted from *Polygonum persicaria* L. (PPA) causes digestive disorders, leads to oxidative stress in Rice weevil, *Sitophilus oryzae* L. The usage of PPA with a food attractant carob extract in bait traps can be recommended as a new biorational formulation in *S. oryzae* management [57].

4.6. In-silico interaction analysis of *Oryzata* lectin with chitin oligomers through docking

Oryzata, a lectin from rice with mannose specificity, belonging to the family of jacalin-related lectins [58]. It was previously reported to induce cell aggregation, mimicking the immune process of encapsulation in insect cells [59]. Owing to its strong insecticidal activity it can be considered as a valuable candidate to be used as a control agent against both biting-chewing and piercing-sucking pest insects [60]. Important for

the structure of an insect's exoskeleton, chitin has also been found to play a major role in the immunological responses to fungus and other chitin-containing parasites in plants, both triggering and inhibiting them [61]. In order to understand the interactions between *oryzata* and chitin oligomers, a docking experiment was performed using CB-DOCK2 [62,63]. Chitin oligomers namely alpha chitobiose, chitotriose and chitotetrose were downloaded from PUBCHEM (<https://pubchem.ncbi.nlm.nih.gov/>) in sdf format. The 2D structures of the ligands selected is displayed in (Figs 18-20).



The protein sequence of *oryzata* lectin (PDB ID: 5XFH) was retrieved from Protein Data Bank (<https://www.rcsb.org/>), the crystal structure of the protein is shown in (Fig 21).

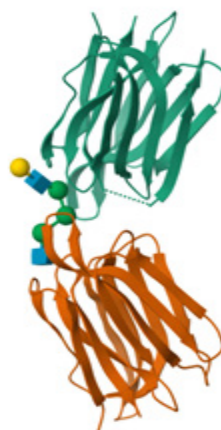
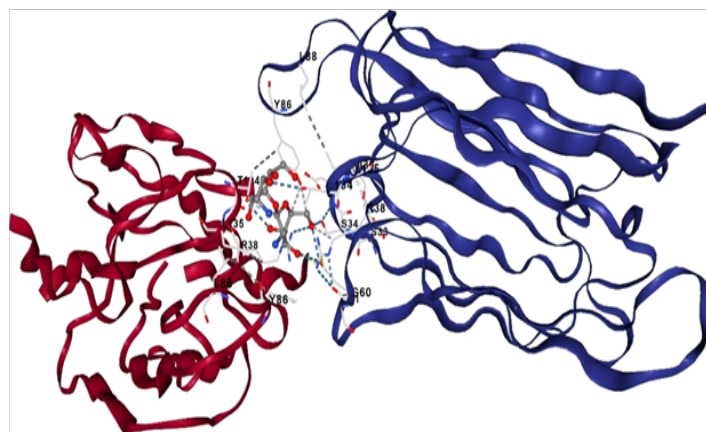
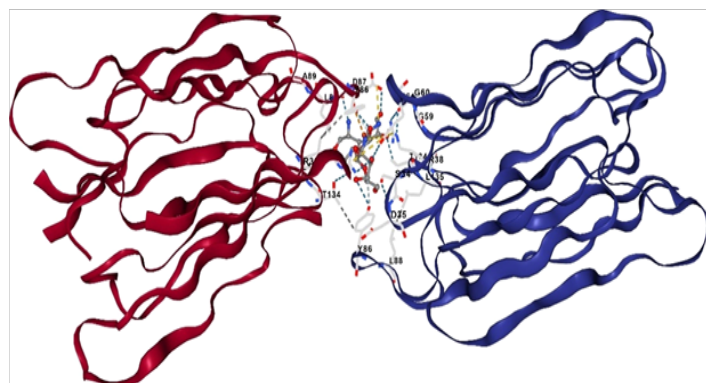
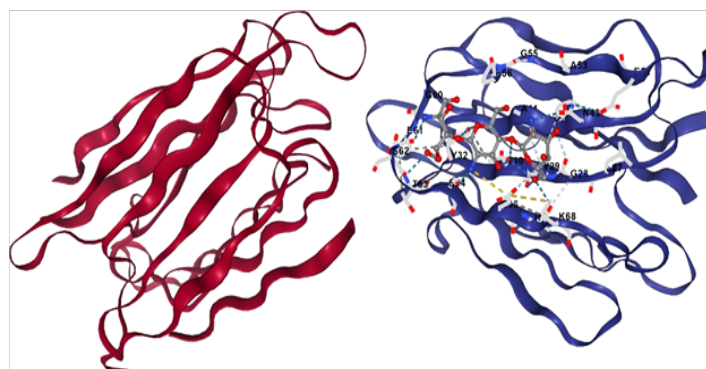


Fig. 21: Crystal Structure of Oryzata lectin (PDB ID: 5XFH)

The protein and the selected ligands were docked individually through structure-based blind docking that utilizes molecular docking methods such as AutoDock [64,65] and AutoDock Vina [66,67]. Five closely related structures were generated but the structure with the least vina score was selected to interpret the contact residues. Alpha chitobiose and chitotriose had similar binding residues while chain A of the protein remained unreactive with chitotetrose. GLY14, ARG38, LEU88, GLY133, THR134, LEU135, ASP137 are the common amino-acid interacting residues. The results from the docking are represented in (Table 2) and the docked structures are visualised in (Figs 22-24).

Table 2: Vina score and contact residues of the protein and the respective ligands

| S. No | Ligand name | Vina score | Contact residues |
|-------|------------------|------------|--|
| | | (Kcal/mol) | |
| 1 | Alpha chitobiose | -6.3 | Chain A - GLY14, GLN17, TYR32, ARG38, PRO56, TRP57, GLY58, GLY59, SER62, THR63, VAL85, TYR86, ASP87, LEU88, ILE91, SER132, GLY133, THR134, LEU135, ILE136, ASP137. |
| | | | Chain B - SER33, SER34, ASP35, ARG38, GLY60, GLU61, THR63, SER64, THR65, PRO84, VAL85, TYR86, ASP87, LEU88, ALA107, GLY108, VAL109, ASN111, THR134, LEU135. |
| 2 | Chitotriose | -5.9 | Chain A- GLY13, GLY14, SER15, ASP35, ARG38, PRO84, VAL85, TYR86, ASP87, LEU88, ILE91, ASN111, SER132, GLY133, THR134, LEU135, ILE136, ASP137. |
| | | | Chain B - THR30, TYR32, SER34, ASP35, ALA36, ARG38, PRO56, GLY59, GLY60, GLU61, SER62, THR63, SER64, TYR86, ASP87, LEU88, THR134, LEU135 |
| 3 | Chitotetrose | -5.5 | Chain B - ASN12, GLY13, GLY14, TYR86, LEU88, ILE91, ARG131, SER132, GLY133, THR134, LEU135, ILE136, ASP137 |

**Fig. 22:** Docked structure of alpha chitobiose and oryzata lectin**Fig. 23:** Docked structure of chitotriose and oryzata lectin**Fig. 24:** Docked structure of chitotetrose and oryzata lectin

5. Resources for lectin research

The contribution of lectins in pathology and physiology is substantial. One important post-translational modification that controls an array of biological processes, including cell fate, is glycosylation. Apart from the conventional death receptors, lectin receptors and a variety of transmembrane glycoproteins can also transduce intracellular signals that end up resulting in cell death. Glycans and endogenous lectins can interact to determine the threshold for cellular survival, differentiation, and activation [68]. Their free radical scavenging potential makes them

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essential for human health [69,70]. Computational efforts of various consortiums and scientific diaspora has led to the emergence of a wealth of lectin-glycan research and poignant visualization strategies that will shed insights into the glycome and degradome of the cell. Some of the

databases, tools and portals are listed below in (Table 3).

Table 3: Resources for lectin-glycan research

| S. No | Name | Description | Link | Reference |
|-------|---|--|---|-----------|
| 1. | Lectin Frontier Database (LFDB) | Provides quantitative interaction data between various glycans and lectins, as well as basic information such as kingdom and monosaccharide specificity on lectins | https://acgg.asia/lfdb2/ | 71 |
| 2. | UniLectin | An interactive database for the classification and curation of lectins, including the prediction of β -propeller lectins | https://unilectin.unige.ch/ | 72 |
| 3. | MCAW-DB | Database providing information on the binding affinity of glycan-binding proteins to glycan substructures by protein family, investigator, and array version | https://mcafdb.glycoinfo.org/ | 73 |
| 4. | Glycan Mass Spectral DataBase (GMDB) | A multistage tandem mass spectral database using a variety of structurally defined glycans | https://jcgdb.jp/rcmg/glycodb/Ms_ResultSearch?doc_no=1 | 74 |
| 5 | Lectindb | A plant lectin database implemented using MySQL, PERL-CGI, and Java tools, providing taxonomic and structural details of lectins | http://nscdb.bic.physics.iisc.ernet.in | 75 |
| 6 | GlyCosmos Portal | A web portal aiming to integrate the glycosciences with the life sciences | https://glycosmos.org/ | 76 |
| 7 | PAConto | RDF Representation of PACDB Data and Ontology of Infectious Diseases Known to Be Related to Glycan Binding. | https://acgg.asia/db/diseases/ | 77 |
| 8 | Glycan Microarray DB (Gly MDB) | Enables users to upload their own microarray data, query binder/non-binder classification, discover glycan-binding motifs, compare glycan array samples, and cross-link microarray samples to PDB structures | http://www.glycanstructure.org/glymdb | 78 |
| 9 | Sugar Bind DB | A curated database providing information on known glycan structures interacting with pathogenic organisms in various diseases | https://sugarbind.expasy.org/ | 79 |
| 10 | Glyco Suite DB | An annotated and curated relational database of glycan structures reported in the literature. | http://www.glycosuite.com | 80 |
| 11 | Japan consortium for Glycobiology and Glycotechnology Database (JCGGDB) | A database integrating all glycan-related data in Japan (glycoprotein, glycolipid, glycosaminoglycans, polysaccharides) | https://jcgdb.jp/database_en.html | 81 |
| 12 | Glycotoolkit | A toolkit consisting of Glycan Array Dashboard (GLAD) and GlycoGlyph for visualizing, analyzing, presenting, and mining glycan array data | https://glycotoolkit.com/ | 82,83 |
| 13 | GRITS Toolbox | A platform for glycomics data processing and archiving | http://www.grits-toolbox.org/ | 84 |

6. Conclusion and future perspectives

With the ever-changing climatic scenarios, population explosion and unsuspecting biotechnological interventions that are strictly regulated, food insecurity is on a steady rise. Lectins are an intricate group of proteins that are present in various species. As a result of their structural diversity and propensity with different carbohydrates, these proteins are fascinating research subjects with a broad spectrum of potential physiological and ecological applications. Functional characterization of rice lectin gene families revealed the myriad of complex biological processes they

participate in. ATP binding, carbohydrate binding, protein serine/threonine kinase activity, transmembrane receptor serine/threonine kinase activity, defence response to bacterium, beta-galactosidase activity, defence response to bacterium are a few notable functions of them. Insecticidal potential of lectins can be exemplified by the entomotoxic activity of mannose-binding lectin and oryza lectin. Glycans are involved in the fine-tuning of several biological processes and given the ability of lectins to specifically recognize the glycoside (carbohydrate code) on different cell surfaces and distinguish between diseased and normal tissues, these additional sites may be viewed as potential drug-carrying sites that could

be exploited for targeted delivery to sites of choice. Compared to DNA and proteins, glycans have a wider variety of chemical structures and information densities, hence their analysis can be a challenging task. Although glycomics is still a budding scientific discipline, it has the potential to be at par with genomics and proteomics notwithstanding we fully optimize the use of lectins due to their ability to bind with carbohydrates reversibly. Advances in glycobiology and glycomics will have far-reaching implications in agriculture for the development of transgenic lines, and pest-resistant and abiotic stress-resistant crops. These strategies will embark on the beginning of next-generation farming and climate-smart agriculture.

7. Acknowledgements

The authors sincerely thank, Director, ICAR- National Academy of Agricultural Research Management, Hyderabad for providing infrastructure and encouragement throughout the project.

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