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Chitinases Potential as Bio-Control

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ABSTRACT

The richest second polysaccharide in nature later than cellulose is chitin. It is present in the exoskeleton of yeast, fungi, algae and insects. It is also present in the inner structure of different vertebrates. The degradation of chitin is done by chitinases enzymes. In the environment nitrogen and carbon are generated by the contribution of chitinases. In biotechnological applications chitinolytic enzymes and chitin have gaining their significance. In the field of agriculture for the control of pathogens particularly the chitinases demoralized. Some human diseases particularly such as asthma, chitinases have a broad use for human health care. For the preparation of pharmaceutically significant chito-oligosaccharides and preparation of single cell protein, N-acetyl D glucosamine, separation of protoplast from yeast & fungi, for the handling of chitinous squander, to stop the pathogenic fungi and to stop the morphogenesis and mosquitoes etc chitinases has wider range applications. We are discussed a different type of chitinases and the chitinases present in a number of organisms for example plants, bacteria, mammals and fungi in this review.

Introduction

In the sixty's midst, of the emergent uprising, chemical pesticides consumption is considered while the best selection for pest's reserve. But continuously use of these pesticides brought a high quality of toxicity and had a negative effect on groundwater and soil throughout the world [1,2]. Persistent pesticides are those which strongly bind with soil particles and are immobile for a long period of time. To remove the chemical pesticides from soil and groundwater is very difficult. Due to continuous use, they decrease the crop yield, soil quality and hazardous effect on agriculture field [3,4]. Due to these harmful effects there is need to drive non-harmful alternatives. Biocontrol agents and enzymes are used for this purpose. Here we discuss chitinase enzyme which is used as a bio-pesticide [5]. Chitinase is an enzyme which belongs to hydrolytic enzymes which have the capacity to degrade the pathogens chitin e.g. insects and fungi and even the insect larvae [6]. The chitin is major cuticle component of membrane peritrophic which is the protective lining of the gut of many insects. The chitinase enzyme catalyzes this chitin into its monomers.

Many micro-organisms produce this enzyme in which fungi also include e.g. such as Metarhiziumanisopliae, bacteria name ly Bacillus pumilus, Serratia marcescens and Bacillus cereus, acti nomycetes such as Streptomyces spp. and yeasts such as Tilletiopsiswashingtonensiss and Tilletiopsisalbescens [7-9]. Microbes which produce chitinase enzyme used for the control of insect nuisance and efficiency of bio-control related whit production of chitinase. Polysaccharides happen in the numeral of crystalline form except α-chitin is recognized in the insect. Neighbor poly-GlcNAc chains work anti-parallel together in this form. Chitin includes different types of chitin-binding lectins which interact with that protein [10-12]. The mainly second rich biopolymer on this planet is chitin which is β-1, 4-N-acetylglucosamine (GlcNAC), is a linear polymer. It is present on the outside of the skeleton of fungi, algae, insects, shrimps, yeasts, lobsters and crabs. Chitin is also present in the inner structure of other invertebrates [13,14]. The dry weight of chitin is approximately 20-58% and 75% is the overall shellfish (such as shrimp, krill, and crab) weight which is likely as waste. Among a wide range of applications, the configuration of the extracellular chitinase is enhanced by the use of chitin [15,16].

The related materials of chitin have a wider use in the healing of wounds, delivery of drugs, treatment of wastewater and in di-

etary fiber. It is a chief part to make pollution in coastal areas and is the inelastic polysaccharide, hard and white. Chitin is a beneficial chelating agent because it contains (6.89%) nitrogen which is a high percentage. B-chitin and α-chitin are two allomorphic forms [17,18]. Polarities and packing of contiguous chains in the subsequent sheets are varying with these two forms of chitin. Chitinase degrades the chitin. Early cleavage of the polymer of chitin with the help of chitinases into oligosaccharides of chitin and additional cleavage to monosaccharides and N-acetylglucosamine by chit biases is a two-step process of chitin catabolism. 20kDa to 90kDa is approximately the size range of chitinases which are glycosyl hydrolases. These are present in broad varieties of organisms like yeasts, actinomycetes, bacteria, plants, arthropods, fungi and humans. Osteoarthritis treatment has been receiving particular concentration from N-acetylglucosamine (GlcNAc). The role in the bio-control of harmful insects and fungal phytopathogens chitinases has been getting better interest.

In the control of mosquito and defense system of plants beside chitin-containing pathogens chitinases play the significant role [19-22]. Human and animal diseases are caused by chitinases and chitin which are used by pathogens such as metazoan or protozoan. Exterior and interior (in host) environmental protection in pathogens is due to chitin coats. By the use of chitinase, they attack their host. By the use of host chitin-containing structures, the infection is successfully transmitted from one invertebrate to another. Different bacterial species such as Escherichia, Streptomyces, Aeromonas, Alteromonas have the ability to produce chitinase [23,24]. The bacteria which are producing chitinase has been remote from shellfish squander, compost of park waste, soil, burning springs and gardens [25]. There are two main groups of chitinases: Exo-chitinases and endochitinase. The chitin is split randomly at internal sites by endochitinases. Therefore, they form the di-cetylchitobiose dimer and dissolvable lower molecular mass of GlcNAc multimers while chitotetraose and chitotriose. There are two subcategories of exo-chitinases: The chitobiosidases are involving in catalyze the progressive discharge of di-acetylchitobiose which starts at the chitin microfibril non-reducing end [20,26-28]. 1-4-β-glucosaminidases cleave the oligomeric product of chitobiosidases & endo-chitinases, therefore, generate monomers of GlcNAc.

From this nomenclature for the strains HRO-C48, IC1270 and IC14 in Serratia polymathic have been approved by the recognition of varieties of chitinases. In the strains of HRO-C48 & IC 14 produces chitobiase or N-acetyl-β-1-4-D-hexosaminidase of 100kDa and endochitinase. 59kDa molecular mass of endochitinase, 50kDa of chitobiosidases and N-acetyl-β-D-glucosaminidases of 67 and 89 kDa are produced from the strains of IC1270. Chitinases amino acids similarity is considered from different organisms, there are five classes of chitinases have been projected and has been categorizing into two families. They contain 18 and 19 families of glycosyl hydrolases [12,25,28,29]. The large distribution in organisms, as well as bacteria, plants, fungi (class 3rd and 5th), viruses and mammals, are from the 18 chitinases family. Single peptide, isoelectric pH, inducers, localization of the enzyme and N-terminal sequence are based by the chitinases subclassification. Plants are found in chitinases class I and enzymes which are present in fungi, plants and bacteria are in class II. Class I or II enzymes have no similarity in sequence in chitinases of class III. There are similarities in characteristics between class I chitinases and class IV chitinases which includes immunological property. Characteristics of class I chitinases have same as class IV, as well as immunological properties, other than they are considered minor than chitinases of class I [26,30]. Difference in molecular structure, catalytic mechanism and specificity of the substrate are shown by enzymes which are actually the chitinases diverse and huge group. It is beneficial to study the specificity of the substrate of chitinases, but it's not just revealed connection among physiological role and specificity of the substrate, it also allows ones to disgrace chitin into narrative foodstuffs which have industrialized application [5].

It is also known that all chitinase class can also exist in different specificity and reaction mechanism. In tobacco class 3 chitinase which consists of a large amount of lysozyme and also chitinase activity can also exist. In tobacco, class IV can also show the chitinase activity. In tobacco class iii and class, I can also use as an inverting mechanism which is used to the hydrolyzed beta-glycosidic linkage. While the class III chitinase in tobacco has a retaining mechanism. Two different families of chitinase cannot show or share the similar amino acid sequence and different 3D structures as well as molecular mechanism. These families can also evolve from different ancestors. Most of the plant have chitinase binding proteins can also exist which is in form of cysteine-rich chitin-binding domains as result of without the chitinase activity in plant cells. While in plant chitin binding protein are different from chitin binding protein of bacteria. In bacteria which contain 8 conserved cysteine domains. Tryptophan amino acid can also exist in chitinase domains of bacteria that are also involved in the binding of cellulose with cellulose [26,31].

Chitinase in Bacteria

In bacteria chitinase, chitin binding domain can also exist on the carboxy-terminal domains of enzyme and as well as amino terminal. Chitinase can be isolated and sequenced in most of the bacteria which contain family 18 glycosyl hydrolases. The catalytic site of other microbial chitinase and different form of chitinase is C-1. The amino-terminal of C-1chitinase shows similar characteristics and non-catalytic domain of other bacterial catalytic enzymes. Some other strain and species of bacteria can also produce the chitinolytic enzyme. Chitinase that is produced by bacteria its molecular weight is 20-60KDa that weight is smaller in weight of insect chitinase (40-85KDa) which are smaller in plant chitinase. Bacterial chitinase is active at high temperature and high Ph which also depend upon the chitinase that can isolate which type of source.

The different type of endochitinase has the wide range of temperature condition which in range 28-80C. Then pH of bacterial chitinase that is obtained in the range of pH 8-10.075 last time. A wide range of isoelectric points can show by bacterial chitinase. When we provide nutrient such as nitrogen and carbon as food supplement then it will produce the bacterial chitinase. The main point for the production of chitinase is that bacteria degraded the chitin and as result, it produces an energy source.

Some hydrolyze enzyme is present on the fungal cell wall that inhibits the fungal growth. Chitinase use as an antifungal agent that is helpful in biotechnology and use as food and seed preservative agents. Bacterial chitinase is characterized into 18 families. Then the most of bacterial chitinase exist in group A because they are most abundant in nature. Then group B and C are existing in nature are smaller quantity. Bacterial chitinase can exist in multiple functional domains such as CBD (chitinase binding domains) and Fn3 domains that a.re linked to the catalytic domain [8,9,31,32]. The degrading strength of CBD for soluble chitin has already been demonstrated in bacterial chitinase. It is also found that family 19 chitinase is only found in bacterial and plants cells. Multiple enzymes presence has been explained in various microorganism like Bacillus circulans WL-12, Pseudomonas aeruginosa K-187 and as Aeromonas spp. No. 10S-24. The synergistic function of chi-c1, chiA, and chiB of *S. marescens* 2170 has been published by Suzuki (2002) on the degradation of chitin. Instead of having similar catalytic domains Chi A and Chi B were consider as digesting chitin chains in opposite action i.e. Chi A from reducing end other from the non-reducing end [33].

Chitinase in Fungal

Like bacterial chitinase fungal chitinase has also multiple functions like in nutrition, the process involved in the fungal development and the morphogenesis. Chitin is major and important part of the fungal cell wall. There is a great similarity between the chitinase of fungi and class III of plant chitinase this homology is based on the amino acid. Mostly fungal chitinase are from family 18 of glycosyl hydrolase super family. In their structure, there are five domains these domains are as follows

a) Catalytic domains

b) N-terminal signal peptide domains

c) Chitin binding region

d) Threonine/serine-rich region

e) C-terminal extension domain.

In most of the fungal chitinase the three, four and five number domains are absent. These domains are thought that they have no function for the chitinase action as it is observed that there are many enzymes which these regions and they do not has have still performed their enzymatic activity well. As bacterial chitinase is well classified but the chitinase of fungi is not well classified and they are recognized based on the relation to the family 18 chitinases from bacteria or plants. So, the chitinase of fungi divided into plants or fungal chitinase which is related to class III chitinase and is identical to the class V chitinase from fungi, bacteria, and plants. Chitinase of fungi group C is not tilled characterized and is considered as a novel group of fungal chitinase. It is expected that they will be large as 140-170kDa and contain 2lysM domains and a chitin obligatory region. There is a great similarity between them and the toxins which kill the yeast. Its role as the physiological and biological activity is most important including autolytic, parasitic and nutritional roles.

For example, CTS1 chitinase gene disruption in the yeasts *S. cerevisiae* cause the cell unable to separate after the cell division and cause cell clumping this is explained in the (Lorito 1994), Ulhoa and peberdy 19191. They also try to explain in their research about cleansing and depiction of N-acetylglucosaminidase from different specimens of Trichoderms they also concluded by the Na-dodecyulphate polyacrylamide gel electrophoresis that their molecular masses are similar. It is also reported that fungal chitinase involved in the filamentous sporulation as allosamidin and demethyiallosamidin is inhibited by chitinase which led to the fragmentation of hyphae inhibition to arthroconidia. There are many chitinolytic fungi and bacteria that are used against a control of soilborne pathogens of fungi. Chitinases from Talaromycesflavus after purification and characterization indicate their mycoparasitism of soil-based pathogens. (Harman 2007) and Yedidia explained that mycoparasitism is precious effects of Trichoderma on fungus it also includes resistance induction and increased development in plants. Yaun and Crawford 1995 reported that the antifungal biocontrol agent Streptomyces lydicus WYEC108 has the ability to destroy the fungal cell wall hyphae and damage developing oospores of some fungi. It is also concluded that different genes from the Trichoderma harzianum possess role in mycoparasitism. It is reported that ech42 gene disruption changes the extent of mycoparasitism in T. harzianim. The separation of a novel endochitinase called CHIT36 from T. harzianumis explained by the viterbo 2001. More important application of fungal chitinase are

i. Improving plant resistance with genetic manipulation

ii. Anti-fungal activity against many phytopathogenic fungi

iii. Insects control [34-36]

Chitinase of Plant

Chitinase is the structural unit in plants parts like the stems, seeds, flowers, and tubers. They are specific in tissues and regulated throughout development. Based on the sequence of amino acid plant chitinase is divided into six classes. The role of different domains is also involving in the classification. Out of six classes class I, II and IV enzymes contain globular domains. Class three and

four contains 8 alpha helicases and 8 beta strands. In response to the pathogenic attack, plant chitinase produce pathogens related proteins as a self-defense there is some chitinase which is produce. Some of the chitinases which expressed themselves after environmental stress such as increased salt concentration cold and drought. The vital physiological process of some plants e.g. embryogenesis and ethylene synthesis also involve chitinase. Chitinase is made up of polypeptide chains of amino acids and acts as a major pathogenic protein which is accumulated in infected region e.g. tissue extracellularly [14,17,18,37]. In the study of Garg and Gupta, 2010 discuss purification and separation of chitinase enzymes whose sources are moth beans which can be used against fungal pathogens. Macrophomina phaseolina strain 2165. The plant's chitinase can be detected when plants are in their developing stages of growth the plant's chitinase is generally belong to the family of endochitinase whose weight is smaller than the weight of insect chitinase [24,38,39].

Insect Chitinases

The chitinases found within the insects are delineated from genus Manduca sexta and bombycid. These enzymes have vital roles to play as degradative enzymes throughout molting wherever endochitinases arbitrarily break the cuticle to chito-oligosaccharides that are a unit afterward hydrolyzed by exo-enzymes to N-acetyl-glucosamine. The chemical compound is reused for brand new cuticle synthesis. Insect chitinases conjointly play defensive roles against their own parasites, and therefore the accelerator production is regulated by hormones throughout the transformation of the larvae. All gramicidin is that the substance of insect chitinases. Chitinases also are found in crustaceans like shrimps, krills and prawns [22,40].

Mammalian Chitinases

The chitinase of mammals is a group of 18 of glycosylhydrolases (GH18), which divides into proteins that are similar to chitinase with 0% activity of enzymes. Chitotriosidase was an earlier mammalian chitinase to be recognized. The terminal catalytic domain of GH18 family members has fractions of triose-phosphate isomerase fold, that will be characterized by the (β/α) 8 - barrel structure, and in this barrel, β4 strand contains conserved sequence motif. Glutamic acid is the basic portion that is giving a proton necessary for hydrolyzing the β (1-4) glycosidic bond present in chitin; this would be the re-arrangement of that compulsory glutamic acid to glutamine, leucine, and isoleucine that is responsible for the shortage of chitinolytic activity. Anyhow, the barrel will be neutral; it has now the ability of binding to chitin with huge affinity [3,4].

Methods of Production of Chitinase

"Fed-batch fermentation, continuous fermentation, and liquid batch fermentation", are the methods for the production of chitinase. MgSO4·7H2O and KH2PO4 have an excellent effect on the production of chitinase in the presence of chitin. On the other hand, the fractions of yeast have the poor effect on chitinase production. The huge secretion of chitinase with lesser concentration levels is demonstrated by the components such as $MgSO_4 \cdot 7H_2O$, KH_2PO_4, and yeast extract. The increasing effect of glucose on the production of chitinase is described by Bhushan, when glucose was utilized in the medium of production that contains chitin. However, Miyashita 1991, explain that glucose in the production of chitinase would be repressed. Some important factors such as pH, aeration, and temperature have great influence on the production of chitinase described by Bhushan 1998 [41-43]. To increase the chitinases production from several organisms, different methods, like biphasic cell systems, cell immobilization, solid-state fermentation are being used. Portions of both natural and general enzyme inhibitors are present, that has oxidizing/reducing agents. As recommended by crystallographic studies, a disordered Psammaplin A molecule reacts with the vicinity of the active site. Arkadin that is separated from *Clonostachys sp*. FO-7314 is one more inhibitor of chitinase. To attempt the cloning and expression of genes from different organisms into *E. coli*, various steps would be carried out with *S. plym disease*. The genes of Bacillus that encode ChiCW and ChiCH, have transformed into pGEX-6P-1 and show effectiveness in *E. coli*. Most bacteria of Streptomyces and non-Streptomyces have the great appearance in a production of chitin and also are antagonistic against Sclerotinia minor [44-46].

Uses

The useful purpose of chitinases is to change chitin-containing biomass into valuable (depolymerized) components. The control of insect and fungal pathogens of plants is also done by chitinase. The protoplast of fungal species will be explained in a very proper means of experiments to work and study the composition of the cell wall, secretion, enzyme synthesis, and strain improvement for applications of biotechnology. The activity of fungi in soil may also control by an indicator that would be enhanced from chitinase activity. The connection between chitinase activity and fungal population in the soil has been stated very strong. So, it seems that chitinases activity act like a proper indicator of the actively growing fungi in the soil [28, 47].

Medicinal Functions

Chito-oligosaccharides have an enormous pharmaceutical potential. The signaling for root nodule formation is done by them, where they behave as elicitors of defenders of plants and also have a potential to be used in human medicines. GlcNAc which is formed from glucose, then incorporated into glycoproteins and glycosaminoglycans in the human body is an anti-inflammatory drug [41,48-53]. The GlcNAc administered by oral routes, intravenous (IV), and intramuscular (IM) has been reported to be very energetic and very effective as an anti-inflammatory drug, that is used in the treatment of ulcerative colitis and other gastrointestinal inflammation disorders. Chitinases have an important function in human health care. Augmenting the activity of antifungal drugs in therapy for fungal

diseases has been assured by medical use of chitinase. They can have meaningful use in anti-fungal lotions and creams due to their typical applications [54-60]. The derivatives of chitin are also being used in the formation of artificial medical articles like contact lenses, artificial skin, and surgical stitches. Few of the derivatives of chitin are famously known to be non-allergic, nontoxic, biocompatible, and biodegradable due to the huge medical use of these kinds of compounds. Chitinases also have some other medical applications as well, such as the first invention of the involvement of acidic mammalian chitinase (AMCase) in the pathogenesis of asthma was unexpected and novel because mammals did not have the ability to use chitin as a source of energy, nor they generate any structure of chitinase [61-75].

a) Many pieces of evidence are represented regarding the importance of chitinases. It acts as associate degree effecter in the class host system. As a bunch that lacks chitotriosidase is a lot of liable to infection. The explanation is that chitinolytic activity has become low. It permits the parasites to achieve success in the host.

b) Recombinant human chitotriosidase protein has the ability of anti-fungal activity. As a result of it will stop the assembly of Candida albicans hyphae formation [76-80]. Therefore, it conjointly helps in decreasing mortality in mouse models of neutropenic moniliasis and genus Aspergillus.

c) It absolutely was represented by the Zhu and colleagues within their 1st clinical findings that role of chitinase in bronchial asthma {|respiratory disease | respiratory illness | respiratory disorder| wherever overstated quantity of AMCase were detected in the animal tissue cells and macrophages of respiratory organ biopsies taken from patients with asthma.

d) It absolutely was conjointly represented that the lungs of associate degree ovalbumin-induced mouse respiratory disease model may simply stimulate the AMcase level & BAL fluid chitinase activity.

e) It's conjointly found that the patients with the respiratory disease have the great quantity of chitinase-like proteins (e.g. YKL-40) in numerous respiratory organ tissues, liquid body substance and AMcase Mostly mammals don't show the synthesis of polyose.

However, still, they need some chitinolytic enzymes.

i. Acidic class chitinases: e.g. Chitotriosidase &AMCase

ii. CLPs: chitinases like proteins

iii. CBPs: breast regression proteins

iv. BRP-39: Chondrocytes proteins

Chitotriosidase and AMCase typically show chitinase activity in mammals. There are 2 aspects regarding the activity of class chitinases. 1st they carry chitin-binding domain (have half-dozen cyctein residues). So that they may have binding property. Secondly, CLPs don't have any binding sites. However contrary to the primary one it's conjointly high polyose binding affinity [81-90]. If amino alkanoic acid is modified by essential amino acid in CHI3L1 then it couldn't ready to perform its chitinase activity. Bu stills its nice affinity for the chito-oligosaccharide and polyose. It's due to preserved substrate binding sites that weren't modified. It acts as the unhealthful go-between. With the assistance of chitinase containing pathogens, we will defend against the outside agents. Their proteins also are useful and show their effects in animal tissue cells of lungs, duct additionally as against macrophages. In case of human airway respiratory disease once due to TH2 cause inflammation, lungs are studied to point out unharness of AM cases. It absolutely was studied in allergic animal models. It absolutely was represented that just in case of thirteen effector pathway expression & TH2 inflammation, AMCases plays the essential role. In tissue inflammation and tissue modeling the supermolecule, CHI3L1 i.e. Chitinases 3-like super molecule one performs the crux role. it absolutely was studied in liver pathology, inflammatory disease, and cancer. Chitin, CaCO3 and proteins area unit the most contents derived from the dead shell of shellfish. The chitinase gift in Saccharomyces marcescens is used to dissolve the polyose material of their own.

M. verrucaria, S. cerevisiae, S. marcescens, fungus tropicalis area unit the standard species that area unit accustomed get SCP. Wang and Hwang made SCP from polyose waste of *M. verrucaria* & *S.cerevisiae*. They conjointly represented that polyose chemical reaction might be performed through verrucaria chitinase and SCP may prepare from S. cerevisiae. Chitinases plays a serious role in agriculture and two-winged insects' management. It conjointly acts as A pesticides as AN additive [91-104]. It conjointly acts as fungicides. Thus, it production is incredibly useful in lowering the chemical sprays to avoid pollution. Chitin is additionally accustomed convert polyose waste into the fertilizers. Microorganisms secreting chitinase area unit wide get used. They're getting used to forestall plants pathogens and insects' pests to boosts the economy. Chitinase manufacturing organisms can even be used as biocontrol agents. Attributable to their generating proteins conjointly facilitate in dominant pests.

Future Prospects

Researchers are trying to seek out new functions of chitinase enzymes. Chitinase will is also accustomed increase lifetime of food as the food preservative. As we'd realize the enzymes and its therapeutic super molecule we have a tendency to treat the various diseases as like bronchial asthma and also the rhinosinusitis. Chitinase has the versions of chitohexose and chitoheptose that have anti-tumor activity. Thus, chitinase is also used because of the anti-tumor drug. It'd be accustomed enhance the human system. Researcher's area unit finding the new active sites of those enzymes. It'll lead towards the novel functions of chitinase enzymes.

References

1. Ané JM, A Kalil, J Maeda (2016) Chitin oligomers for use in promoting non-leguminous plant growth and development Google Patents.
2. Babashpour S, Aminzadeh S, Farrokhi N, Karkhane A, Haghbeen K, et al. (2012) Characterization of a chitinase (Chit62) from Serratia marcescens B4A and its efficacy as a bioshield against plant fungal pathogens. Biochemical genetics 50(9-10): 722-735.
3. Bierbaum S, Renate Nickel, Anja Koch, Susanne Lau, Klaus A Deichmann, et al. (2005) Polymorphisms and haplotypes of acid mammalian chitinase are associated with bronchial asthma. American journal of respiratory and critical care medicine 172(12): 1505-1509.
4. Bussink AP, Dave Speijer, Johannes MFG Aerts, Rolf G Boot (2007) Evolution of mammalian chitinase (-like) members of family 18 glycosyl hydrolases. Genetics 177(2): 959-970.
5. Bussink AP, Van Eijk M, Renkema GH, Aerts JM, Boot RG, et al. (2006) The biology of the Gaucher cell: the cradle of human chitinases. International review of cytology 252: 71-128.
6. Chawade A, Alexandersson E, Bengtsson T, Andreasson E, Levander F, et al. (2016) Targeted proteomics approach for precision plant breeding. Journal of proteome research 15(2): 638-646.
7. Chisholm ST, Coaker G, Day B, Staskawicz BJ (2006) Host-microbe interactions: shaping the evolution of the plant immune response. Cell 124(4): 803-814.
8. Mishra M, Syed Uzma JalilI, Nimisha SharmaII, Umesh HudedamaniI (2014) An Agrobacterium mediated transformation system of guava (*Psidium guajava L.*) with endochitinase gene. Crop Breeding and Applied Biotechnology 14(4): 232-237.
9. Rathore AS, RD Gupta (2015) Chitinases from bacteria to human: properties, applications, and future perspectives. Enzyme research.
10. Kumar M, Brar A, Vivekanand V, Pareek N (2018) Bioconversion of Chitin to Bioactive Chitooligo saccharides: Amelioration and Coastal Pollution Reduction by Microbial Resources. Marine Biotechnology 20(3): 269-281.
11. Lee CG, Da Silva CA, Dela Cruz CS, Ahangari F, Ma B, Kang MJ, et al. (2011) Role of chitin and chitinase/chitinase-like proteins in inflammation, tissue remodeling, and injury. Annual review of physiology 73: 479-501.
12. Jeong JS, Kim YS, Redillas MC, Jang G, Jung H, et al. (2013) OsNAC5 overexpression enlarges root diameter in rice plants leading to enhanced drought tolerance and increased grain yield in the field. Plant Biotechnology Journal 11(1): 101-114.
13. Chou YT, Yao S, Czerwinski R, Fleming M, Krykbaev R, et al. (2006) Kinetic characterization of recombinant human acidic mammalian chitinase. Biochemistry 45(14): 4444-4454.
14. Daizo K (2005) Application of chitinase in agriculture. J Metals Mater Min 15(1): 33-36.
15. Dagdas YF, Yoshino K, Dagdas G, Ryder LS, Bielska E, et al. (2012) Septin-mediated plant cell invasion by the rice blast fungus Magnaporthe oryzae. Science 336 (6088): 1590-1595.
16. Cui P, Zhang S, Ding F, Ali S, Xiong L, et al. (2014) Dynamic regulation of genome-wide pre-mRNA splicing and stress tolerance by the Sm-like protein LSm5 in Arabidopsis. Genome biology 15(1): R1.
17. De las Mercedes Dana MJA, Pintor Toro, B Cubero (2006) Transgenic tobacco plants overexpressing chitinases of fungal origin show enhanced resistance to biotic and abiotic stress agents. Plant Physiology 142(2): 722-730.
18. Dowd PF, Todd A Naumann, Neil PJPricec, Eric TJohnson (2018) Identification of a maize (Zea mays) chitinase allele sequence suitable for a role in ear rot fungal resistance. Agri Gene 7: 15-22.
19. Fahmy A, et al. (2018) Developing of transgenic wheat cultivars for improved disease resistance. Journal of Applied Biology & Biotechnology 6(2): 31-40.
20. Gaber Y, Mekasha S, Vaaje-Kolstad G, Eijsink VGH, Fraaije MW, et al. (2016) Characterization of a chitinase from the cellulolytic actinomycete Thermobifida fusca. Biochimica et Biophysica Acta (BBA)-Proteins and Proteomics. 1864(9): 1253-1259.
21. Gálusová T, Ľubomír Rybanský, Patrik Mészáros, Nadine Spieß, Beáta Piršelová, et al. (2015) Variable responses of soybean chitinases to arsenic and cadmium stress at the whole plant level. Plant growth regulation, 76(2): 147-155.
22. Gilbert LI (2009) Insect development Morphogenesis molting and metamorphosis. Academic Press.
23. Kzhyshkowska J, A Gratchev, S Goerdt (2007) Human chitinases and chitinase-like proteins as indicators for inflammation and cancer. Biomarker insights 2: 128-46.
24. Jones JD, G Jones, JL Dangl (2006) The plant immune system. Nature 444(7117): 323-329.
25. Kumar M, Amandeep Brar, Monika Yadav, Aakash Chawade, V Vivekanand, et al. (2018) Chitinases Potential Candidates for Enhanced Plant Resistance towards Fungal Pathogens. Agriculture 8(7): 1-12.
26. Kashyap P, R Deswal (2017) A novel class I Chitinase from Hippophae rhamnoides Indications for participating in ICE-CBF cold stress signaling pathway. Plant Science 259: 62-70.
27. Nagpure A, B Choudhary, RK Gupta (2014) Chitinases in agriculture and human healthcare. Critical reviews in biotechnology 34(3): 215-232.
28. Rawway M, Ehab Aly Beltagy, Usama Mohamed Abdul-Raouf, Mohamed Ahmed Elshenawy, Mahmud Saber Kelany, et al. (2018) Optimization of Process Parameters for Chitinase Production by a Marine Aspergillus Flavus MK p. 20.
29. Richa K, Tiwari IM, Devanna BN, Botella JR, Sharma V, et al. (2017) Novel chitinase gene LOC_Os11g47510 from indica rice Tetep provides enhanced resistance against sheath blight pathogen Rhizoctonia solani in rice. Frontiers in plant science 8: 596.
30. Shin S, Caroline A Mackintosh, Janet Lewis, Shane J Heinen, Lorien Radmer, et al. (2008) Transgenic wheat expressing a barley class II chitinase gene has enhanced resistance against Fusarium graminearum. Journal of experimental botany 59(9): 2371-2378.
31. Kavroulakis N, Spyridon Ntougias, Maria I Besi, Pelagia Katsou, Athanasia Damaskinou, et al. (2010) Antagonistic bacteria of composted agro-industrial residues exhibit antibiosis against soil-borne fungal plant pathogens and protection of tomato plants from Fusarium oxysporum f sp radicislycopersici. Plant and Soil 333(1-2): 233-247.
32. Sharma CK, Vineet KumarVishnoi, RC Dubey, DKMaheshwari ,et al. (2018) A twin rhizospheric bacterial consortium induces systemic resistance to a phytopathogen Macrophomina phaseolina in mung bean. Rhizosphere 5: 71-75.
33. Gomaa EZ (2012) Chitinase production by Bacillus thuringiensis and Bacillus licheniformis: their potential in antifungal biocontrol. The Journal of Microbiology 50(1): 103-111.
34. Toufiq N, Tabassum B, Bhatti MU, Khan A, Tariq M, et al. (2018) Improved antifungal activity of barley derived chitinase I gene that overexpress a 32 kDa recombinant chitinase in Escherichia coli host. brazilian journal of microbiology 49(2): 414-421.
35. Veneault Fourrey C, Barooah M, Egan M, Wakley G, Talbot NJ, et al. (2006) Autophagic fungal cell death is necessary for infection by the rice blast fungus. Science 312(5773): 580-583.
36. Zeilinger S, Vijai K Gupta, Tanya ES Dahms, Roberto N Silva, Harikesh B Singh, et al. (2015) Friends or foes? Emerging insights from fungal interactions with plants. FEMS microbiology reviews 40(2): 182-207.
37. Gongora CE, RM Broadway (2002) Plant growth and development influenced by transgenic insertion of bacterial chitinolytic enzymes. Molecular Breeding 9(2): 123-135.
38. Jalil SU, M Mishra, MI Ansari (2015) Current view on chitinase for plant defense. Trends in Biosciences 8(24): 6733-6743.

39. Underwood W (2012) The plant cell wall: a dynamic barrier against pathogen invasion. Frontiers in plant science 3: 85.

40. Puga Freitas R, M Blouin (2015) A review of the effects of soil organisms on plant hormone signalling pathways. Environmental and Experimental Botany 114: 104-116.

41. Synstad B, Vaaje Kolstad G, Cederkvist FH, Saua SF, Horn SJ, et al. (2008) Expression and characterization of endochitinase C from Serratia marcescens BJL200 and its purification by a one-step general chitinase purification method. Bioscience Biotechnology and Biochemistry 72(3): 715-723.

42. Sripriya R, C Parameswari, K Veluthambi (2017) Enhancement of sheath blight tolerance in transgenic rice by combined expression of tobacco osmotin (ap24) and rice chitinase (chi11) genes. In Vitro Cellular & Developmental BiologyPlant 53(1): 12-21.

43. Smith RS, A Habib (2016) Chitooligosaccharides and methods for use in enhancing plant growth. Google Patents.

44. Solgi T, Mehdi Moradyar, Mohammad Reza Zamani, Mostafa Motallebi (2015) Transformation of Canola by Chit33 Gene towards Improving Resistance to Sclerotinia sclerotiorum. Plant Protection Science 51(1): 1-5.

45. Shivalee A, K Lingappa, D Mahesh (2018) Influence of bioprocess variables on the production of extracellular chitinase under submerged fermentation by Streptomyces pratensis strain KLSL55. Journal of Genetic Engineering and Biotechnology 16(2): 424-426.

46. Ryder LS, NJ Talbot (2015) Regulation of appressorium development in pathogenic fungi. Current opinion in plant biology 26: 8-13.

47. Prasad K, Pooja Bhatnagar-Mathur, Farid Waliyar, Kiran K. Sharmae (2013) Overexpression of a chitinase gene in transgenic peanut confers enhanced resistance to major soil borne and foliar fungal pathogens. Journal of plant biochemistry and biotechnology 22(2): 222-233.

48. Zou P, Li K, Liu S, He X, Zhang X, et al. (2016) Effect of sulfated chitooligosaccharides on wheat seedlings (*Triticum aestivum L.*) under salt stress. Journal of agricultural and food chemistry 64(14): 2815-2821.

49. Zhang J, Kopparapu NK, Yan Q, Yang S, Jiang Z et al. (2013) Purification and characterisation of a novel chitinase from persimmon (Diospyros kaki) with antifungal activity. Food chemistry 138(2-3): 1225-1232.

50. Zarinpanjeh N, Motallebi M, Zamani MR, Ziaei M (2016) Enhanced resistance to Sclerotinia sclerotiorum in Brassica napus by co-expression of defensin and chimeric chitinase genes. Journal of applied genetics 57(4): 417-425.

51. Yang S, Fu X, Yan Q, Jiang Z, Wang J, et al. (2016) Biochemical characterization of a novel acidic exochitinase from Rhizomucor miehei with antifungal activity. Journal of agricultural and food chemistry 64(2): 461-469.

52. Winkler AJ, Dominguez Nuñez JA, Aranaz I, Poza Carrión C, Ramonell K, et al. (2017) Short-chain chitin oligomers: Promoters of plant growth. Marine drugs 15(2): 40.

53. Wilson RA, NJ Talbot (2009) Under pressure: investigating the biology of plant infection by Magnaporthe oryzae. Nature Reviews Microbiology 7(3): 185-195.

54. Tang WJ, Fernandez J, Sohn JJ, Amemiya CT, (2015) Chitin is endogenously produced in vertebrates. Current Biology 25(7): 897-900.

55. Cantarel BL, Coutinho PM, Rancurel C, Bernard T, Lombard V, et al(2009) The Carbohydrate-Active EnZymes database (CAZy): An expert resource for glycogenomics. Nucleic acids Res 37(suppl_1):233-238.

56. Merzendorfer H (2011) The cellular basis of chitin synthesis in fungi and insects: common principles and differences. European journal of cell biology 90(9): 759-769.

57. Selin C, de Kievit TR, Belmonte MF, Fernando WG (2016) Elucidating the role of effectors in plant-fungal interactions: Progress and challenges. Frontiers in microbiology 7: 600.

58. Renner T, Specht CD (2013) Inside the trap: Gland morphologies, digestive enzymes, and the evolution of plant carnivory in the Caryophyllales. Current opinion in plant biology16(4): 436-442.

59. Seidl V (2008) Chitinases of filamentous fungi: A large group of diverse proteins with multiple physiological functions. Fungal Biology Reviews 22(1): 36-42.

60. Horiuchi A, Mehwish Aslam, Tamotsu Kanai, Haruyuki Atomi A (2016) structurally novel chitinase from the chitin-degrading hyperthermophilic archaeon, Thermococcus chitonophagus. Applied and environmental microbiology 82(12): 3554-3562.

61. Cletus J, Balasubramanian V, Vashisht D, Sakthivel N (2013) Transgenic expression of plant chitinases to enhance disease resistance. Biotechnology letters 35(11): 1719-1732.

62. Yang J, Liang L, Li J, Zhang KQ (2013) Nematicidal enzymes from microorganisms and their applications. Applied microbiology and biotechnology 97(16): 7081-7095.

63. Chen L, Jiang H, Cheng Q, Chen J, Wu G, et al. (2015) Enhanced nematicidal potential of the chitinase pachi from Pseudomonas aeruginosa in association with Cry21Aa. Scientific reports 5: 14395.

64. de Medeiros SC, José Edvar Monteiro, Gleilton Weyne Passos Sales, Thalles Barbosa Grangeiro, Nádia Accioly Pinto Nogueira (2018) Chitinases as Antibacterial Proteins: A Systematic Review. Journal of Young Pharmacists 10(2): 144-148.

65. Ghasemi S, Ahmadian G, Sadeghi M, Zeigler DR, Rahimian H, et al. (2011) First report of a bifunctional chitinase/lysozyme produced by Bacillus pumilus SG2. Enzyme and microbial technology 48(3): 225-231.

66. Wang SL, WJ Hsiao, WT Chang (2002) Purification and characterization of an antimicrobial chitinase extracellularly produced by Monascus purpureus CCRC31499 in a shrimp and crab shell powder medium. Journal of agricultural and food chemistry 50(8): 2249-2255.

67. Chen YT, Hsu LH, Huang IP, Tsai TC, Lee GC, et al. (2007) Gene cloning and characterization of a novel recombinant antifungal chitinase from papaya (Carica papaya). Journal of agricultural and food chemistry 55(3): 714-722.

68. Wang S, Shao B, Rao P, Lee Y, Ye X (2007) Hypotin, a novel antipathogenic and antiproliferative protein from peanuts with a sequence similar to those of chitinase precursors. Journal of agricultural and food chemistry 55(24): 9792-9799.

69. Qin Cl, Wei Huang, Shi-quan Zhou, Xin-chao Wang, Hui-hui Liu, et al. (2014) Characterization of a novel antimicrobial peptide with chiting-biding domain from Mytilus coruscus. Fish & shellfish immunology 41(2): 362-370.

70. Gonçalves IR, Brouillet S, Soulié MC, Gribaldo S, Sirven C, et al. (2016) Genome-wide analyses of chitin synthases identify horizontal gene transfers towards bacteria and allow a robust and unifying classification into fungi. BMC Evolutionary Biology 16(1): 252.

71. Hosoda N, Yoichi Kurokawa, Yoshihiko Sako, Keizo Nagasaki, Takashi Yoshida, et al. (2011) The functional effect of Gly209 and Ile213 substitutions on lysozyme activity of family 19 chitinase encoded by cyanophage Ma-LMM01. Fisheries Science 77(4): 665-670.

72. Patel AK, Singh VK, Yadav RP, Moir AJ, Jagannadham MV (2009) ICChI, a glycosylated chitinase from the latex of Ipomoea carnea. Phytochemistry 70(10): 1210-1216.

73. de Medeiros SC, José Edvar Monteiro, Gleilton Weyne Passos Sales, Thalles Barbosa Grangeiro , Nádia Accioly Pinto Nogueira (2018) Chitinases as Antibacterial Proteins: A Systematic Review. Journal of Young Pharmacists 10(2): 144-148.

74. Zhanel GG, Lawson CD, Adam H, Schweizer F, Zelenitsky S, et al. (2013) Ceftazidime-avibactam: a novel cephalosporin/β-lactamase inhibitor combination. Drugs 73(2): 159-177.

75. Ragland SA, Criss AK (2017) From bacterial killing to immune modulation: Recent insights into the functions of lysozyme. PLoS pathogens 13(9): e1006512.

76. Wohlkönig A, Huet J, Looze Y, Wintjens R (2010) Structural relationships in the lysozyme superfamily: Significant evidence for glycoside hydrolase signature motifs. PLoS One 5(11): e15388.

77. Kraus D, A Peschel (2008) Staphylococcus aureus evasion of innate antimicrobial defense. Future Microbiol 3(4): 437-451.

78. de Medeiros SC, José Edvar Monteiro, Gleilton Weyne Passos Sales, Thalles Barbosa Grangeiro, Nádia Accioly Pinto Nogueira (2018) Chitinases as Antibacterial Proteins: A Systematic Review. Journal of Young Pharmacists 10(2): 144-148.

79. Manish Kumar, Amandeep Brar, Monika Yadav, Aakash Chawade, V Vivekanand, et al. (2018) Chitinases-Potential Candidates for Enhanced Plant Resistance towards Fungal Pathogens. Agriculture 8(7): 1-12.

80. Bruinsma J (2017) World agriculture: Towards 2015/2030: An FAO study. Routledge.

81. Chawade A, Armoniené R, Berg G, Brazauskas G, Frostgård G, et al. (2018) A transnational and holistic breeding approach is needed for sustainable wheat production in the Baltic Sea region. Physiol plant 164(4): 442-451.

82. Burgess L (2009) Common Diseases of Some Economically Important Crops. Australian Centre for International Agricultural Research: Canberra, Australia 11: 166-167.

83. Hamid R, Khan MA, Ahmad M, Ahmad MM, Abdin MZ, et al. (2013) Chitinases: An update. Journal of pharmacy & bioallied sciences 5(1): 21-29.

84. Bhattacharya D, A Nagpure, Gupta RK (2007) Bacterial chitinases: properties and potential. Critical reviews in biotechnology 27(1): 21-28.

85. Stoykov YM, AI Pavlov, AI Krastanov (2015) Chitinase biotechnology: Production, purification, and application. Engineering in Life Sciences 15(1): 30-38.

86. Smith RS, RM Osburn (2016) Combined used of lipo-chitooligosaccharides and chitinous compounds for enhanced plant growth and yield, Google Patents.

87. Kabir SR, Rahman MM, Tasnim S, Karim MR, Khatun N, et al. (2016) Purification and characterization of a novel chitinase from Trichosanthes dioica seed with antifungal activity. International journal of biological macromolecules 84: 62-68.

88. Zhang J, Kopparapu NK, Yan Q, Yang S, Jiang Z (2013) Purification and characterisation of a novel chitinase from persimmon (Diospyros kaki) with antifungal activity. Food chemistry 138(2-3): 1225-1232.

89. Toufiq N, Tabassum B, Bhatti MU, Khan A, Tariq M, et al. (2018) Improved antifungal activity of barley derived chitinase I gene that overexpress a 32 kDa recombinant chitinase in Escherichia coli host. brazilian journal of microbiology 49(2): 414-421.

90. Kashyap P, R Deswal (2017) A novel class I Chitinase from Hippophae rhamnoides: Indications for participating in ICE-CBF cold stress signaling pathway. Plant Science 259: 62-70.

91. Gálusová T, Lubomír RybanskýPatrik MészárosNadine SpiesBeáta Piršelová, et al. (2015) Variable responses of soybean chitinases to arsenic and cadmium stress at the whole plant level. Plant growth regulation 76(2): 147-155.

92. Bussink AP, Speijer D, Aerts JM, Boot RG (2007) Evolution of mammalian chitinase (-like) members of family 18 glycosyl hydrolases. Genetics 177(2): 959-970.

93. Bussink AP, van Eijk M, Renkema GH, Aerts JM, Boot RG (2006) The biology of the Gaucher cell: the cradle of human chitinases. International review of cytology 252: 71-128.

94. Chou YT, Yao S, Czerwinski R, Fleming M, Krykbaev R, et al. (2006) Kinetic characterization of recombinant human acidic mammalian chitinase. Biochemistry 45(14): 4444-4454.

95. Bierbaum S, Nickel R, Koch A, Lau S, Deichmann KA, et al. (2005) Polymorphisms and haplotypes of acid mammalian chitinase are associated with bronchial asthma. American journal of respiratory and critical care medicine 172(12): 1505-1509.

96. Kzhyshkowska J, A Gratchev, S Goerdt (2007) Human chitinases and chitinase-like proteins as indicators for inflammation and cancer. Biomarker insights 2: 128-146.

97. Lee CG, Da Silva CA, Dela Cruz CS, Ahangari F, Ma B, et al. (2011) Role of chitin and chitinase/chitinase-like proteins in inflammation, tissue remodeling, and injury. Annual review of physiology 73: 479-501.

98. Kumar M, V Vivekanand, N Pareek (2018) Structure, Regulation, and Potential Applications of Insect Chitin-Metabolizing Enzymes, in Trends in Insect Molecular Biology and Biotechnology. Springer pp. 295-316.

99. Gilbert LI (2009) Insect development: Morphogenesis, molting and metamorphosis, Academic Press.

100. Reddy K, MRajam (2016) Targeting chitinase gene of Helicoverpa armigera by host-induced RNA interference confers insect resistance in tobacco and tomato. Plant molecular biology 90(3): 281-292.

101. Osman GH, Shireen K Assem, Rasha M Alreedy, Doaa K El-Ghareeb, Mahmoud A Basry, et al. (2015) Development of insect resistant maize plants expressing a chitinase gene from the cotton leaf worm, Spodoptera littoralis. Scientific Reports 5: 18067.

102. Synstad B, Vaaje-Kolstad G, Cederkvist FH, Saua SF, Horn SJ, et al. (2008) Expression and characterization of endochitinase C from Serratia marcescens BJL200 and its purification by a one-step general chitinase purification method. Bioscience, Biotechnology, and Biochemistry 72(3): 715-723.

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