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Application of shellfish shell waste derived chitosan and chitooligosaccharides in agriculture horticulture and post-harvest value addition of agricultural products

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Abstract
Chitosan, chitooligosaccharides and their derivatives have potentially high commercial value. These products are bio-cidal to a broad spectrum of pathogenic microorganisms, insects and pests. Chitindeacetylases play very important role in biological attack and defence system, biological control of fungal plant pathogens. Chitosan derivatives have potential for removal of various aquatic pollutants and detoxification of water and waste water. Naturally occurring amino-polysaccharides have unique physicochemical characteristics and biological activities in agri cultural operations like seed priming coating and spray agents having barrier properties. The patent effect of chitosan derivatives on plant disease control, growth promoter, elicitation of defence responces, thus preserving crop yield and quality.

Keywords: shellfish shell waste, chitooligosaccharides, agriculture horticulture, post-harvest, agricultural products

Introduction

Plant pathogens are considered as economically important agricultural pest in the world. Chemical pesticides provide the primary means of controlling the plant pathogens. Continuous use of such compounds results in the pesticides residues and proliferation of resistance in pest population.

Hence, there is growing emphasis on environmentally friendly organic technologies in pest control, and evaluation of various alternatives to reduce dependency on harmful synthetic pesticides. (Badawi and Rabea, 2011) [58].

Chitosan, Chitooligosaccharides and their derivatives have shown to be stand-alone treatments for a consistently economic level of disease control as an alternative to synthetic pesticides.

In spite of the Chitosan advantage, it is only Soluble in acidic aqueous solution with PH value lower than 6.5 At higher PH values, amino groups of Chitosan macromolecules becomes unprotonated and Chitosan form insoluble. This is the major limiting factor for its utilization and its application in biology.

Fermentation in a biorefinery with yeast (*Saccharomyces cerevisiale*) and molasses as a substrate produces Chitosan derivatives and Chitooligosaccharides. Water soluble Chitosan derivatives are produced and it enhances the biological and Physiological potential of Chitosan (Sahu, *et al.*, 2015). This process increase both solubility and positive charge density of chitosan macromolecules. Water soluble Chitosan derivatives are good candidates for the Poly Cat ionic biocides (Jeom *et al.*, 2001) [1].

Biorefinement of shrimp shell waste

Greener industrial method for the hydrolysis of Chitin and Chitosan is highly desirable as the products are potentially of high commercial value. Even though the specific enzymes as Chitosanases and Chitinases have shown to have excellent performances in Chitooligosaccharide (COS) production but they are too expensive to be utilized in large scale industrial application (Pantaleons *et al.*1992)

Chitin is a natural polysaccharide of major importance and most abundant polymer after cellulose. The most important derivative of Chitin is Chitosan, produced by deacetylation. Chitin and Chitosan have important functional activities, but its poor solubility makes them difficult to use in food and biomedical applications COS are degraded products of Chitin and Chitosan, prepared by enzymatic and chemical hydrolysys. The greater solubility and less viscosity of COS have attracted many researchers for various biomedical applications.

Shellfish Shell waste has high protein (39.6%), Chitin (22.6%) and Ash (28.1%). Bioconversion of Chitin into Chitosan, Chitooligosaccharides and glucosamine through cold fermentation using inherent enzymes, microbes, and molasses as substrate have been developed (Sahu, *et al.*, 2016) [63]. The process has been envisaged as one of the most ecofriendly, safe, technologically flexible and economically viable alternative method for bio-refinement.

Chitosan, Chitooligonaccharides & its Derivatives in Post-Harvest Application

Fruits and vegetables deteriorate rapidly after harvest and in some cases do not reach consumers at optimum quality after transport and marketing.

The main causes of their deterioration are dehydration with the subsequent weight loss, colour change, softening, surface pitting, browning, loss of acidity, and microbial changes.

One of the potential approach to extend storability of these perishable commodity is to apply edible coating or films on surface followed by cold storage (Park, *et al.*, 2005) [3].

Chitosan and Chitooligosaccharides and their derivatives are ideal antimicrobial polymer and have following characteristics (1) Easily and inexpensively synthesized (2) Stable in long term usage and storage at temperature of intended application (3) Soluble in water and neutral media (4) Does not decompose to emit toxic products (5) Not toxic and irritating for handlers (6) Biocidal to a broad spectrum of pathogenic microorganisms, insect and pests. Oligochitosans obtained by hydrolysis are most effective than Chitosans.

Chitosan, Chitooligosaccharides and their derivatives have antimicrobial and plant defence elicit function. Therefore, these compounds are considered a useful pesticides in the control of Plant diseases. Factors affecting the antimicrobial activity of Chitosan and their derivatives are Molecular Weight (MW) DDA, PH, temperature, solubility and derivetization.

Therefore, the use of bioactive substances such as Chitosan derivatives to control post-harvest microbial diseases has attracted much attention due to imminent problem associated with chemical agents, antibiotics, and pesticides.

Chitosan derivatives can become promising alternative treatment of fruits and vegetables due to its natural characteristics, antimicrobial activity and elicitation of defense responses. (Fisk *et al.*, 2008) [4].

Chitosan and Chitooligosaccharide polymer is an ideal preservative coating for fresh fruit and vegetables, because of film-forming and biochemical properties (Muzzarellu, *et al.* 1986) [6] and has led to prolonged storage life and controlled decay of several fruit crops. (Romanazzi, *et al.*, 2002) [7].

Chitosan polymer derivatives as spray and coating is likely to modify internal atmosphere without causing anaerobic respiration, since Chitosan polymer are more selectively permeable to O_2 than CO_2 (Bai, *et al.* 1988) [8].

Fish & Shell Fish Processing By-Product

Fish and Shellfish processing by-products are renewable resource for bio-refinery. Hydrolysis of fish waste through natural cold fermentation is aimed primarily for industrial applications. Beneficial effect of fish hydrolysate (FH), Shellfish hydrolysate (SH) is postulated to be due to balance of free amino acid, fatty acid, micro and micronutrients, oligosaccharides, which are organic products (Sahu, *et al.*, 2017) [65].

Shellfish processing by Products

Shellfish processing by-products have a balance of free amino acid, fatty acid, micro and macro nutrients, Chitin, Chitosan, Chitooligosaccharides and their derivatives.

Shellfish waste hydrolysate contain some value added nutrients like carotenoids, pigments, n-3 poly-unsaturated fatty acid and antioxidants (Sahu, *et al.* 2016, Babu, *et al.*, 2008) [62, 63, 64].

Fermentation technique for utilization of Shellfish Processing by-products

Traditional fermentation depends upon naturally occuring microorganisms and enzymes. Spontaneous fermentation is optimal through back slopping i.e. inoculation of raw material with a small quantity of previously performed successful fermentation. Spontaneous fermentation and back slopping is a cheap and reliable preservation method. This is probably one of the oldest biotechnological process rooted in cultural history of mankind (Hassan and Health, 1986; Sahu *et al.*, 2016) [66, 62, 63].

Micronutrients in Shellfish Shell waste hydrolysates:

Micronutrients are very important for facilitating many critical plant and animal functions. Most critical of these nutrient are Boron (B) Zinc (Zn) Manganese (Mn), Copper (Cu), Cobalt (Co) Molybdenum (Mo) and Sulphur (S). Many trace minerals have proven to be critical in enabling animal and plant cell to produce complete compounds for making them naturally resistant to pest, diseases, better yield and productivity. High amount of iron (haem-iron) present in liquid Shellfish hydrolysate is essential for increasing and stabilizing Chlorophyll and Plankton production. Shellfish shell waste hydrolysate contains Chelated minerals which are easily absorbed into cell membrane and result in increased metabolism. Negative charges on the proteins are responsible for attracting positive minerals, thus this setting phenomenon is known as “Chelation”. Organic compounds bind to metallic ions to form a stable, water soluble complete minerals in food, feed and fertilizer. Liquid shellfish waste hydrolysate helps in phosphate fixation. Chelation prevents fixation and makes both minerals and phosphates available for plant and animal productivity. Shellfish hydrolysate as additive are added in trace amounts in food, feed and fertilizer promote its nutritional characteristics, antioxidant and mold inhibition.

Spontaneous fermentation of Shellfish shell Waste with molasses inherent enzymes and microbes

Spontaneous fermentation with previously performed inoculums, sugar (molasses) and yeast cultures ensures rapid acidification and inhibit unwanted microorganisms, as well as in relatively inexpensive and acceptable to crop and animals (Arbia *et al.*, 2013) [67]. Shellfish shell waste hydrolysate contain mixed cultures of beneficial and naturally occurring microorganisms and enzymes used as inoculants to soil-water-plant ecosystem for increasing the microbial diversity of soil and for soil quality, soil health, for enhancing growth, yield and quality of crops, fodder, food animals finally the welfare of the human being in a ecofriendly and sustainable manner.

Chitin, Chitosan and Chitooligosaccharides for therapeutic use

Chitin and Chitosan in deactivated form are applied in agriculture, water treatment and feed supplement. Liquid waste from Chitin production process could be a feed stock for anti-fungal material. Bio-conversion of Shrimp shell and head waste into bio-fungicide production is quite cost effective. Purified Chitosanas inhibits fungal hyphel extension.

There is a growing interest to convert Chitin and Chitosan into their oligomer that have better functional properties and improved absorption. Fermentative and enzymatic hydrolysis is more preferable method for higher yield of oligomer and higher degree of polymerization. Production of Chitin glucosamine and Carboxymethyl chitin is produced by the above method.

Chitosan and its derivatives have potential application in agriculture like germination of seed, growth promoter, selfprotection against pathogens induce Chitinase activities in encapsulated fertilizer. They induce Chitinase activity and proteinase inhibitor synthesis for antivirus and antibacterial activity.

Shrimp waste hydrolysate peptides have antioxidative & anticarinnogenic properties. They are rich source of phenolic compounds which play an important role in enhancing antioxidative, antimicrobial, and biocontrol of opportunistic, fungal human/ animal/ plant pathogens.

Shrimp hydrolysate are rich in amino compounds. The bioactive material rich liquor of fermentation have beneficial biological functions owing to inherent proteins, peptides, chitooligosaccharide, astaxanthine and anti-fungal bioactive material.

Shellfish shell waste hydrolysate application in Organic farming

Shrimp processing generates considerable quantities of solid waste in the form of head and body carapace. Dumping of organic waste material into the environment partly contribute to global warming phenomenon due to methane gas generation. Methane gas has 21 times higher global warming potential (GWP) than carbondioxide and can severely affect the environment if not properly managed. Biological fermentation of shrimp shell waste leads to self-stable organic fertilizer. Shellfish processing waste and promising renewable biomass. Green processing of shellfish waste in a biorefinery is low cost, simplicity in operation, by reducing the cost of material, energy and labour, but it yields the products which maintains high productivity.

Chitin deacetylases play very important role in biological attack and defense system, they find applications for the biological control of fungal plant pathogens or insects and pests in agriculture and for the biocontrol of opportunistic fungal pathogens. Shellfish hydrolysate contains compounds capable of promoting healthy plant growth.

Protein hydrolysate could well become a proline and amino acid substitute in plant tissue culture application. The role of proline and glutamate in plant growth is very well documented in plant propagation industry.

Saccharides of chitooligo in shrimp waste hydrolysate

Chitosan derivatives have very good potential for removal of various aquatic pollutants. Treatment of water and waste water using chitosan derivatives for removal of metal cat ions and metal ions, radioneuclides, dyes, phenol substituted protein an ions and different miscellaneous pollutants. (Bhatnagar and Silanappa, 2009) [69].

Chitosan derivatives in addition to their antifungal properties they have role in plant growth regulation and plant self-defense induction, secretion of growth hormone, antibacterial metabolites and reduced phytotoxic microbial community (Aizi and Cheba, 2015) [68].

Spray of shellfish waste hydrolysate maintains the health of bud wood and also vigour of tree, control of codling moth and other moth pests. Foliar spray of chitooligosaccharides by table grape growers to control bunch size and shape, fruit size and sugar content. The products are very helpful during blooming, flowering, or at other critical times in the life history of plants. House plant growers can use them for sole source of nutrients in house plants and ornamentals.

Chitosan derivatives can induce plant defense against canker and anthracnoseon apple and water melon.

Post-Harvest Fruits & Vegetables Spray and Coating

Edible coating can be used as a vehicle for incorporating functional ingredients such as antioxidants, flavors, colours antimicrobial agents and neutraceuticals.

1. **Grape Fruits:** Chitosan compounds are used as biopesticides in many grape producing countries. It was reported that Oligochitosan (1500 Da and DA of 20%) at 200 mg/ ml dramatically reduced the infection of grape vine leaves by *Plasmopara viticola* and *B. cinerea* Dose-response experiment showed that maximum defense reactions and control effect of *B. cinerea* were achieved with 75-150 mg/ml (Aziz *et al.*, 2004; Munoz *et al.*, 2009; Trotel-Aziz *et al.*, 2006) [40, 10, 41, 11].
2. **Cherry fruits:** Gray mold and blue mold rots caused by *B.cinerea* and *P expansum* respectively in sweet cherry fruit were reduced by pre-harvest spraying or post-harvest dipping of chitosan (Romanazzi, *et al.*, 2003) [13].
3. **Tomatoes:** Investigation on Chitosan coating of tomatoes has shown that it delays repairing by modifying the internal atmosphere that reduced the spoilage. (EI-Ghaouth *et al.*, 1992) [14].

   Effectiveness of different molecular height Chitosan on the gray mold *(B. Cinerea)* in tomato fruit *(Solanium lycopersicum)* significantly reduced fungal decay and all the compounds at concentration of 2000 to 4000 mg/L exhibited compute fungal control in wound inoculated fruit. Chitosan had potential for elicitation of defense markers and direct fungitoxic properties against the pathogen. (Badawy and Rabea, 2009 Liu, *et al.* 2007) [16] Chitosan treatment induces various defense responses including the elicitation.
4. **Citrus fruit:** *Penicillium* is the most harmful citrus fruit postharvest pathogen and infect, the fruit through micro injuries generated in the flavedo, during harvesting and processing. However, now a day, consumers around the world demand high-quality food, without chemical preservation, leading to increased effort in discovering new natural antimicrobials. Accordingly, the fungistatic effect of Chitosan have been investigated for example, coating of citrus fruit with Chitosan was effective in controlling fruit decay caused by *P. digitatum* and *P. expansum* and Chitosan of 15 KDa of Phenylalanine ammonia lyase (PAL) actively in grape berries Chitinase and B-1, 3-glucanase in oranges, strawberries and raspberries.

Chitosan & its derivatives in plant disease control:

The plant protection activity of Chitosan compounds includes bacteria, fungi and viral diseases in many different plant systems.

1. **Soybean:** The soil borne phytopathogen fungi *F. Solani* and C. lindemultianum FI-Hadrami were inhibited by Chitosan and N-carboxymeltyl, Chitosan (El-hadrami *et al.*, 2010) [14].

   Chitosan derivatives contain polysaccharides that stimulate the activity of beneficial microorganisms in soil such as *Bacillus*, *Fuorescent pseudomonas Actiomycetes*, *Mycorrhiza* and Rhizobacteria. Chitosan derivatives enhances plant defense responses. Concentrations of oligochitosan 0.9-3 mg/ml elicited phytoalexin induction (Hadwiger and Beckman (1980) [18].

2. **Rice:** The effect of Chitosan on rice disease control initiating defense response in the leaves of rice (Agrawal *et al.* 2002) [19]. Treatment with 0.1% Chitosan, necrotic streaking was clearly observed with upper side of rice leaves. Enhanced defense against rice blast pathogen. Oligochitosan 5mg/L showed best effect and the disease control was more than 50% (Lin, *et al.* 2005) [20]. Chitosan application by rice seed soaking and soil application four times throughout cropping season, significantly increased rice yield over the other treatments. However, application by seed soaking and spraying the foliar for times tended to show ability on disease control (Boonlertnirum *et al.*, 2008) [21].
Zing, and Shi (2009) [22] developed a new type of organic rice seed coating agent using Chitosan and found to be effective in inhibiting the growth of two phytopathogens *R. sokni* and *F.moniliforms*.
3. **Wheat:** Oligochitin with a MW of 5-10 KDa and the DA of 65% has good effect on controlling wheat disease. (Burkhanova, *et al.*, 2007) [23]. The ability of oligochitosan to promote wheat resistance to pathogenic toxin has validated (Khairullin, *et al.* 2001) [24]. Chitosan treatment of 2-8 mg/ml of wheat seed *(Norseman* and *max)* significantly improved seed germination and vigour at concentrate 4mg/ml by controlling seed borne *F. graminearum* infection (Liu, *et al.*, 2001) [25]. Seed borne *F.graminearun* infection has checked in wheat by chitooligosaccharide treatment and induced resistance to *Fusarium* species improving the seed quality (Reddy, *et al.*, 1999) [26].
4. **Tobacco:** Tobacco is an important economic crop and a model plant for research. Less acetylated Chitosan was better for inhibition of *P. parasitica* growth, partial acetylated chitosan were better for inhibition of *Phytophthora parasitica* growth and in protecting tobacco against the pathogen by systemic induction of plant immunity (Falcon, et. al, 2008) [27].
5. **Rape Seed:** *Sclerotinia* rot is the most harmful disease on oil seed rape production. Oligosaccharides induce resistance to *Schlrotinia sclerotiorum* on *Brassica napus*. It reduced the frequency and six of rot in oilseed. (Yin, et, al, 2008) [28]. Oligochitosan modulated into steady colloid solution and used as a seed coating agent Oligochitosan concentration of 50 Micro gram/ml with pretreated time was 3 days before inoculation (Lu, *et al.*, 2003) [29].
6. **Potato:** Potato is a tuberous crop from the perennial *Solanum tuberosum* of the *Solanaceae* family. It is an essential crop in the world. Chitosan induced resistance to viral infection was investigated in potato plants. Spraying different molecular weight of oligochitosan solution (1 mg/ml) and the greatest antiviral activity has shown by Chitosan of 120 KDa (Chirkov, *et al.*, 2001) [30].
Chitosan pretreatment significantly decreased the number of systemically infected plants by potato virus X and leaves accumulated less amount of virus than controlled leaves (Chirkov, 2002) [31]. The antiviral activity of Chitosan depends on the average degree of polymerization, the degree of N-deacetylation, the positive charge value, and the character of the chemical modifications of the molecule. Possible mechanisms of suppressing viral infection by chitosan in potato are discussed. (Faoro *et al.*, 2001) [32].
Chitosan applied by spraying or inoculating leaves protected various plant species against local and systemic infections caused by alfalfa mosaic virus (AMV), tobacco necrosis virus (TNV), tobacco mosaic virus (TMV), peanut stunt virus (PSV), cucumber mosaic virus (CMV), and potato virus X Guang Liu and De Yao (2002) [33].
The ability of Chitosan to suppress viral plant infections does not depend on the virus type because Chitosan affects the plant itself by inducing resistances to plant infection. Chitosan induce wide spectrum of protective reaction in plants, which limits systemic spread of viruses and virioids and lead to acquired resistance (Pospieszny *et al.*, 1991; Pospieszny *et al.*, 1997) [34, 35].
7. **Cucumber:** The effect of oligochitosan and oligochitin on gray mold caused by *B. cinerea* in cucumber plants were evaluated by Benshalom *et al.*, 2003 [36]. Oligochitosan and oligochitin had complete inhibition of *Botrytis conidia* germination at 50 ppm Chitosan solution. Antifungal and elicitor activity of Chitosan are necessary for the control of gray mold in cucumber (Postna *et al.*, 2004).
P. aphanidermatum (Ednon) Fitzp is an aggressive economically important pathogen in green house grown cucumbers enzymogenus reduced the number of disease plants (Postma *et al.*, 2009).
Vasyukova *et al.*, 2001. Reported that low molecular weight water soluble chitosan (5KDa) are shown to display elicitor activity. Chitosan induced the accumulation of phytolexins in tissue of host plants.
8. **Pear Fruit:** When pear fruit plants are treated with oligochitosan, controlled two phytopathogenic fungi *A.kikuchiana Tanaka* and *Physalospora piricola*. Oligochitosan treated pear plants increased the activities of chitinase and β-1, 3-glucanase Chitosan treatment significantly increased peroxidase activity of pear fruit. Chitosan and oligochitosan triggered different mechanism for pathogenicity inhibition and disease control.
9. **Grape Vines:** Chitosan compound are used as biopesticides in many grape-producing countries. Oligochitosan (1500 Da and DA of 20%) are 200 kg/ml dramatically reduced the infection of grape in leaves by *Plasmopora viticola* and *B.cinerea*. Maximum defense reactions and control effect of *B cinerea* were achieved with 75-150 Micro gram/ml. Similarly in watermelon and apple Chitosan can induce plant defense against canker and anthracnose.
10. **Maize:** Guan *et al.*, 2009 examined the use of Chitosan to prime maize seed. Although Chitosan had no significant sweet on germination under low temperature, it enhanced germination index, reduced mean germination time, and increased shoot height, root length, and shoot and root dry weights in two tested maize lines. Chitosan induced a decrease in malonyldialdehyde content, altered the

relative permeability of the plasma membrane and increased the concentrations of soluble sugars, proline, peroxidase, and catalase activities.

C-X-Shao, *et al.*, 2005 [44] reported seed priming with Chitosan improved the vigor of maize and wheat seedlings. This treatment had further led to an increase of seed resistance to certain diseases and improves their quality and/or their ability to germinate (Zhoo, *et al.*, 2002) [12]

Peanut seed soaked in chitosan were reported to exhibit an increased rate of germination and energy, lipase activity, and gibberellic acid and indole acetic acid levels (Zhoo *et al.*, 2002) [12] Ruan and Xue., (2002) [46] showed that ries seed coating with Chitosan may accelerate their germination and improve their tolerance to stress conditions.

Carrot seed coating with Chitosan helps restrain further development of *Sclerotinia* rot. (Molloy, *et al.*, 2004) [49].

It has also been reported that Chitosans can activate plant defense to disease on several other plants such as barley (Faoro *et al.*, 2008) [47]; pearl millet (Manjunatha *et al.*, 2008) [48]; sunflower (Nandeesh Kumar *et al.*, 2008) [50]; carrot (Molloy *et al.*, 2004) [49]; coconut (Lizama-Ue, *et al.*, 2007) [51].

11. **Litchi *(Litchi sinensis):*** Effects of Chitosan coating on browning of litchi fruit were also investigated. Chitosan coating irrespective of concentration 1 and 2% dissolved in 2% glutamic acid delayed changes in contents of anthocyanins, flavonoid and total phenolics. It also delayed the increase in polyphenol oxidase (PPO) activity and partially inhibited the increase in peroxidase activity (Li *et al.*, 2001) [52].

    Jiang *et al.*, 2005 reported Chitosan of 2% in 5% acetic acid coating delayed the decrease in anthocyanin content and increase in PPO activity. Such effect of Chitosan coating were also observed with peeled litchi fruit (Dong, *et al.*, 2005) [57] dependence of browning rate of chitosan coated litchi fruit on the initial pericarp water content (Joas, *et al.*, 2005) [53, 55], pericarp PH and dehydration rate during storage (Caro and Joan, 2005) [53, 55].

Societal Benefits of the Research Project

Fishery waste occurs in all stages of fish production value chain from grower to processors, to super markets and consumers (Gustavsson, *et al.*, 2011) [70]. One solution to secure food production, prevent depletion of fishery resources and decrease food waste may be found in the concept of circular economy (CE). By means of closed loop fish production, processing and marketing chain, efficiency of resource use increases and a better balance between economy, environment and society maybe achieved (Ghisellini, *et al.*, 2015) [71].

Circular economy in fishery sector comes from involvement of all actors of the society and their capacity to link and create suitable collaborations and exchange platterns.

Circular business models for fishery waste aims to create solution for environmental issues by integrating novel scientific insights and technologies into new economic system (Dittrich, *et al.*, 2015) [72].

Fish waste biomass and locally available resource which contain nutrients. Fermentation of biomass produces slurries used for agricultures, livestock raising and fish farming. The self-stable slurries are excellent chlorophyll booster and plankton enhancer. The recycled fishery waste products are organic and excellent source for agri-horti-livestock and fish farming. The waste biomass utilization in the objective of circular economy. Circular economy creates environmental solution, offers products and processes to create scientific solutions for both economic, societal and environmental solution affordable to everyone in the world (Mirabells *et al.*, 2014) [73].

Producers, processers and retailers can individually have a great impact in reduction of fishery waste. Taking the holistic value chain in fishery to a complete business model will eventually lead to a zero- fish waste production and consumption value chain in fisheries.

Conclusion

Continues use of synthetic fertilizers and pesticides in agriculture has resulted in environmental degradation, pesticide residue and proliferation of resistance in pest population. Chitosan and chito-oligosaccharides have antibacterial and antifungal properties, in addition to that they have role in plant growth regulation and plant defence induction, secretion of growth hormones, antibacterial metabolites and reduced phytotoxic microbial community. These derivatives have clearly shown to offer a consistently economic level of disease control and are an alternative synthetic pesticide.

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