REVIEW ARTICLE
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Bioingene **PSJ**

ISSUE NO. 1 VOLUME NO. 1

A REVIEW ON CHITOSAN: A NEW SOLUTION FOR COMBATING ABIOTIC STRESSES IN AGRICULTURE

Prajwal P. Dongare, Prashant R. Shingote, and Narsing D. Parlawar

Vasantrao Naik College of Agriculture Biotechnology, Yavatmal- 445001, Maharashtra, India.

BIOINGENE PSJ

Article No. : D11MLY20R2
Article type: Review
Accepted: Jan. 2021
Online: March 2021

KEYWORDS

Chitosan,
Biotic,
Abiotic,
Agriculture

Conflict of interest: No

Corresponding author:
Prajwal P. Dongare
prajwal045dongre8@gmail.com

ABSTRACT

Chitosan, a natural polysaccharide, is second most abundant after cellulose. It is derived from chitin by alkaline deacetylation. Chitin occurs naturally in seafood shells, fungi and algae. It is a bio-adhesive, biocompatible, biodegradable, organic molecule. Chitosan has widespread application in agriculture. Chitosan acts as a bio-stimulant which upon application to plants stimulates photosynthetic rate, enhances antioxidant production, increases tolerance to biotic and abiotic stresses. Chitosan causes hydrolysis of peptidoglycan of microbes resulting in death of microbes. Recent studies show that chitosan helps plants relieve from various biotic and abiotic stresses. It can be effective in enhancing a plant's productivity. In this review, we closely look at the genesis, physiological responses and structural alteration of chitosan foliar applications on plants.

Citation:
Dongare, P. D., Shingote, P.R., and Parlawar, N. D. (2021). A Review on Chitosan: A New Solution for Combating Abiotic Stresses in Agriculture. Bioingene PSJ, 1: D11MLY20R2, 1-7. http://bioingene.com/wp-content/uploads/2021/05/D11MLY20R2.pdf

INTRODUCTION

Chitosan, a natural biopolymer, is the second most abundantly extracted biopolymer by deacetylation of chitin. Source of chitosan is seafood shells, algae, and various microbes that produce chitin in cell walls, membranes and spores, including fungi (Castro et al. 2012) and the spines of diatoms (Bartnicki-Garcia et al. 1982). It is produced from crustacean shells by removal of protein, mineral, colour followed by removal of acetyl group (deacetylation) as shown in figure1. Activity of chitosan is predominantly dependent on its degree of deacetylation, molecular weight and pH of solution (Xu et al., 2007). There is a difference between chitin and chitosan in degree of acetylation and deacetylation; chitin-Degree of acetylation- 0.90 and Chitosan- degree of deacetylation- > 0.65 (Daniel Elieh-Ali-Komi et al., 2016). Chitosan was registered as licensed for sale as an active ingredient in 1986 (Chitosan**;** Poly-D-glucosamine (128930) Fact Sheet"). Chitosan is a weak base and is insoluble in water, but soluble in dilute aqueous acidic solutions, where the -NH2 (glucosamine) is converted into the soluble protonated form -NH3+ (Jagadish et al., 2017).

Commercially, chitosan is available with >85% deacetylation units and molecular weight between 100 & 1000kDa. Structure of chitosan was identified by X-ray diffraction, infrared spectra, and enzymatic analysis. Chitosan is composed of D-glucosamine and N-acetyl-D-glucosamine linked with a 1,4-glycosidic bond in which the glucosamine backbone of chitosan contains a high degree of amine group. The glucosamine backbone of chitosan contains an amine group which offers the opportunity to form complexes of chitosan with negative charge DNA molecules (Zhao et al. 2011), that help in transcriptional regulation. It is also used as a nanoparticle (Zhau et al., 2014). There are several derivatives of chitosan like Oligochitosan. Oligo-chitosan (82.20 kDa) was prepared from chitosan (337.73kDa) by application of 100 kGy γ-irradiation (Muley et al.2019). Chitosan, cellulose, alginate and starch have been successfully degraded by application of gamma irradiation as glycosidic bond between C1 and C4 positions of the monomeric sugar residues is broken down and respective oligomers are generated (Cho, Kim, & Rhim, 2003)

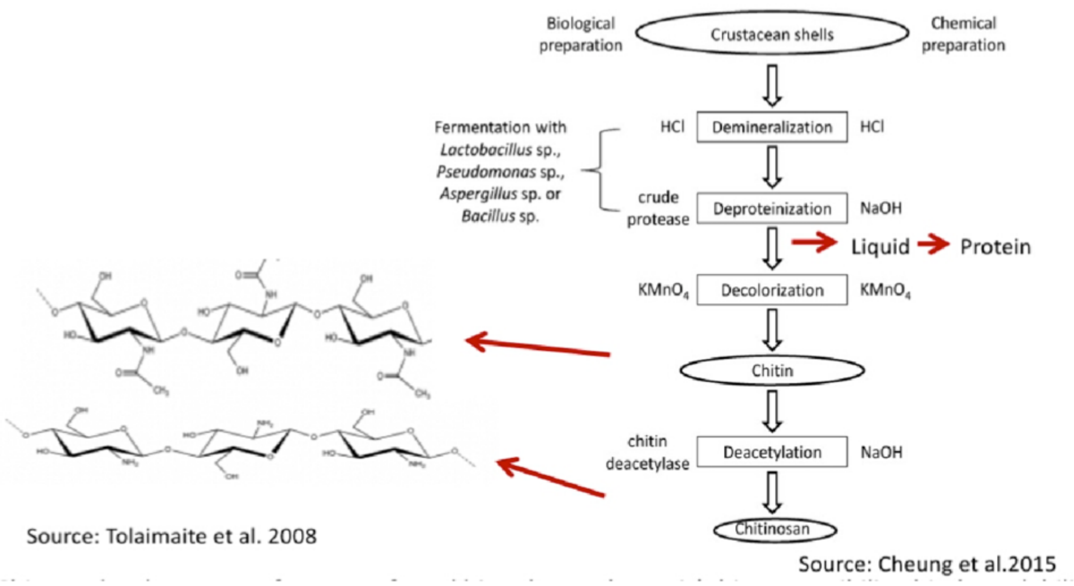

Figure 1 Extraction of chitosan through chemical and biological preparation

.Chitosan forms a gel with high molecular weight (MW) and porous structure that can absorb water (Tamura et al. 2006). Advanced development of chitosan hydrogels has led to new drug delivery systems that can release their active ingredients in response to environmental stimuli (Hamedi et al. 2018).

Chitosan's physicochemical properties include bioadhesive, biocompatible, biodegradable nature and it also shows antimicrobial activity (Sharif et al. 2018), Bio-stimulant (Stimulate Expression of gene), Growth promoter, antioxidant activity, insecticidal activity, osmoprotectant, act as biofertilizer, and modification of post harvest crop as in cotton. In short it is a multi-purpose bio-polymer to help combat abiotic and biotic stresses. Goy et al. (2009) suggested three antimicrobial mechanisms of chitosan; first for cell wall leakage, second for inhibiting protein and m-RNA synthesis, and third for film forming which results in limiting nutrition availability for microorganisms as shown in figure 2.

2.Antimicrobial Activity:

Goy et al. 2009 suggested three properties of chitosan- inhibition of the mRNA and protein synthesis via penetration of chitosan into the nuclei of the microorganism, ionic surface interaction resulting in cell wall leakage, and formation of external barrier for suppression of nutritional uptake. Antimicrobial activity of chitosan helps to destroy the bacterial cell wall (Figure 3) (Sharif et al. 2018; Liang et al. 2014)
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3.Gene Expression:

Hadwiger et al. 1986 reported that chitosan activates genes and inhibits RNA synthesis in fungi and also helps in increasing pathogen protection. In dendrobium, chitosan induced expression of Ycf2 gene in young leaves, conferring enlarged chloroplast (Limpanavech et al. 2008).

4.Surface modification:

Cotton, the most important fibre crop, has intrinsic problems such as shrinkage, wrinkle formation and microbial degradation that may be overcome by surface modification with chitosan (Bhaskar et al. 2012).

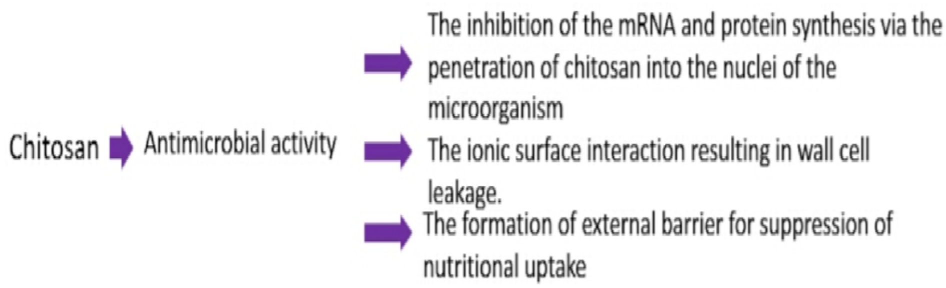

Figure 2 Antimicrobial activity of chitosan

IMPORTANCE

1. Antioxidant Activity:

Chitosan shows antioxidant activity which was estimated by using 1,1-diphenyl-2-picrylhydrzyl (DPPH) and 2,2′azino-bis (3-ethylbenzothiazoline-6-sulphonic acid) (ABTS) assay (Muley et al., 2019).

5.Chitosan-DNA Complex:

Chitosan has been used and studied for its activity to protect DNA against nuclease degradation and transfect DNA to several kinds of cells (Bravo-anaya et al.2016). It is possible because chitosan is composed of D-glucosamine and N-acetyl-D-glucosamine linked with a 1,4-glycosidic bond in which the glucosamine backbone of chitosan contains a high degree of amine group. Amine groups can get interlinked with DNA molecules and form Chitosan-DNA complexes.

6.Biofertilizer:

Day by day chemical use increases in agriculture and due to which there are a lot of adverse effects on the environment and on humans directly or indirectly. Chitosan acts as a biofertilizer that helps to reduce the use of chemicals. Chitosan with lysozyme produces a beneficial role which can reduce the rate of lesions in tomato stems (Mishra et al., 2014). Application of chitosan in soil helps to reduce the late blight disease and also increases nutritional uptake (O'Herlihy et al., 2003)

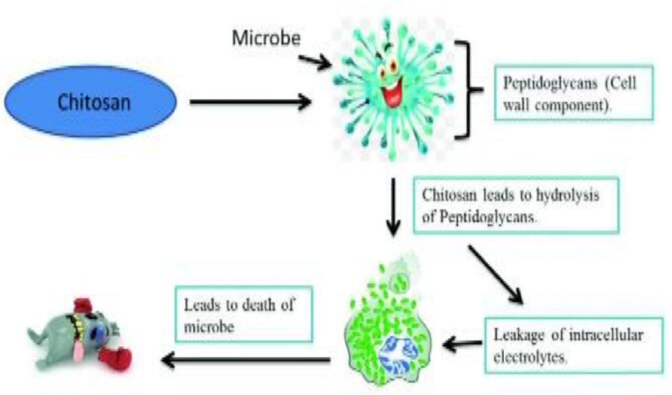

Figure 3: Mechanism of chitosan on cell

7.Effect on Abiotic stresses:

Abiotic stresses is an important multidimensional environmental stresses that damage plant physiology, biochemical propertles and molecular traits. Yang et al.2009, reported, young seedlings of apple were foliar sprayed with chitosan, which showed enhanced antioxidant activity, reduced electrolyte leakage, and restored moisture content under continuous drought stress for 35 days. Muley et al. 2019, reported gamma radiation degradation by chitosan (Oligochitosan) for application in growth promotion and induction of stress tolerance in potato. Chitosan acts as an osmo-protectant and helps in antioxident production. Sharif et al. 2018 explained the positive effects of chitosan against abiotic stresses (drought tolerance in plants like apples, rice, grapevine, moth orchid and heat tolerance). Heat stress, a complicated abiotic issue in agriculture, was overcome with the help of HS related genes induced by chitosan (Zhang et al. 2008; Choi et al. 2013).

8. Insecticidal Activity:

Chitosan and its derivatives show effective insecticidal activities. Chitin derivative was reported to show insecticidal property against the oleander aphid (*Aphis nerii*) and larvae of leaf-worm (*Spodoptera littoralis*) of cotton crops (Rabea et al. 2005). Nano-chitosan is a potential insecticide against soybean insect (Sahab et al. 2015).

9. Growth promotion:

Application of chitosan helps to promote growth. Muley et al. 2019 described that derivatives of chitosan like Oligochitosan, derived by Gamma radiation, promote growth of potato plant as determined by growth associated parameters. Chitosan helps act as an extra reservoir of nitrogen (Shibuya et al. 2001). A 1% concentration of Oligo-chitosan induced growth of Malabar spinach (Rahman et al., 2013).

FUTURE THRUST

The plethora of available and ongoing research on chitosan utilization continues to present its efficacy. The physiological mechanisms and shelf life of fruits and vegetables (post-harvest) showed improved tolerance against biotic and abiotic stress when treated with chitosan. In addition, chitosan derivatives possess insecticidal activity. It regulates gene expression and induces molecular defense systems in plants. Moreover, bio-fertilizer and fertilizer coated in chitosan triggers plant growth more compared to synthetic fertilizers. Chitosan and its derivatives provide effective antifungal activity. Therefore, more research is required to utilize chitosan to decrease abiotic stresses in agriculture.

CONCLUSION

Chitosan research increases day by day. Chitosan proved to be effective in several aspects in terms of biotic and abiotic stress relief in agriculture. Additionally, derivatives of Chitosan like COS or Oligochitosan have positive effects in plant growth promotion, anti-microbial, insecticidal activity. Chitosan also has a role in gene expression, and modification of post harvest crops. Chitosan is also effective as biofertilizers and nanoparticles. More research on chitosan and its properties would prove useful in relieving abiotic stresses in agriculture and reduce the overuse of synthetic fertilizers.

ACKNOWLEDGMENTS

Thanks are due to the Vice-chancellor and Dean (Agri.) Dr. PDKV, Akola for extending all the facilities to carry out the work.

FUNDING

None.

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