Effects of Nano chitosan and Bio capsule on growth, yield and quality of Chilli (*Capsicum annuum* L.) in poly-house condition

ABSTRACT

A field experiment was designed in a Randomized Block Design with 9 treatments replicated thrice on Chilli (*Capsicum annuum* L.) under poly-house condition. The Experiment examined the effect of nano chitosan, bio capsule and NPK @RDF application on growth, yield and quality of chilli and to work out the economics of various treatments. Various treatment combinations were prepared using different doses of Nano chitosan and Bio capusles in combination. It was observed that the treatment T_8 (NPK + Nano chitosan 120ppm + Bio capsule 120ppm) was superior over other treatments in terms of growth, yield and quality of Chilli i.e., plant height (63.73cm), fruit yield per 200m^2 (3.27q), T.S.S. (9.67 ^{0} Brix) and ascorbic acid (143.96 mg/100g). Therefore, use of Nano chitosan @ 120 ppm along with 500 ppm Bio capsule could be used for getting better yield in chilli. Moreover, application of nano chitosan and bio capsule on nutritional quality of chilli could be studied in details further.

Keywords: Nano chitosan, Bio capsule, Chilli, Benefit cost ratio.

INTRODUCTION

Chilli (*Capsicum annuum* L.) belongs to the family Solanaceae having diploid species with mostly 2n=24 chromosomes but wild species with 2n=2x=26 chromosomes have been reported (Pickersgill, 1991). Chilli was introduced into Europe in 1493 by Christopher Columbus, who discovered it in tropical America. Believed to be a native of Mexico and Peru, it was widely used by the people of Central and South America prior to Columbus's discovery. It spread so quickly that by 1542, three types of chilli were already introduced into India. India, Mexico, Japan, Ethiopia, Uganda, Nigeria, Thailand, Turkey, Indonesia, China and Pakistan are the major chilli growing countries. To some extent, it is also grown in Italy, Spain and the United States. India is the largest producer and consumers of chilli in the world. In India chilli is grown on an area of 7.75 lakh ha with production of 14.92 lakh tones (Anonymous 2014). Chilli are varieties of the berry-fruit of the plants from the genus capsicum. They are cultivated for their pungency (spiciness). Chilli peppers are widely used in many cuisines as a spice to add "heat" to dishes. Capsaicin and related compounds known as capsaicinoids are the substances giving chilli peppers their intensity when ingested or applied topically. Other varieties of capsicum include bell peppers (UK: sweet peppers), but

while chilli peppers are (to varying degrees) pungent or "spicy", bell peppers are generally not and provide additional sweetness and flavor to a meal rather than “heat.” Chilli is one of the most valuable crops in India. The crop is grown largely for its fruits all over India as a principal ingredient of various curries, and chutneys. It is used for vegetables, spices, condiments, sauces, and pickles. Dry chillies are used for curry powder. The red colour in chilli is due to “capsanthin”. Pungency in chillies is due to the active constituent “capsaicin”, an alkaloid is extracted from chillies and used to the medicine. Chilli’s vitamins include vitamin C (109 mg), vitamin B6 (0.1mg), vitamin A (530 IU), and minerals like iron (0.5mg), copper (0.1mg), potassium (153 mg). It also contains amino acids making it a high nutritional value food. Green chillies are rich in dietary fibres and also contain zero cholesterol. As per studies, 100gms of chilli contains; total fat (0.1g), sodium (3.2mg), magnesium (11.2mg), carbohydrates (1.8g), dietary fibre (0.7g), glucose (0.8g), protein (0.9g), carbohydrate (4.3g), calcium (8.1mg), water content (39.5g) (USDA, 2017).

Polybags are lower cost alternatives to plastic pots. They are economical and easy to use by the residential greenhouse grower. These heavy-duty re-usable grow bags are made from a durable plastic that provides for a longer life. The bags have pre-punched drain holes and they are self-standing when filled with media. Widely used in greenhouse drip irrigation applications, they work very well with most all mediums and are excellent for bedding plants, tree seedlings, tomatoes, bell peppers, cucumbers, etc.

Chitosan is the N-acetyl derivative of chitin obtained by N-deacetylation. Chitosan is widely used in food and bioengineering industries for encapsulation of active food ingredients, enzyme immobilization, as a carrier for controlled drug delivery, in agriculture as a plant growth promoter. Chitosan is also a defense elicitor and an antimicrobial agent. Chitosan has interesting properties such as biodegradability, biocompatibility, bioactivity, nontoxicity and polycationic nature (Divya and Jisha, 2017). Nano chitosan has broad antimicrobial activity against fungal pathogens however, the bulk size limits its solubility which affects the antimicrobial property. Chitosan nanoparticles have great potential over the bulk counter parts as size can alter several properties compare to bulk material. The exclusive properties of these materials, such as a large surface area and greater reactivity, have also raised concerns about adverse effects on environmental health. Recently, IISR-ICAR (Indian Council of Agricultural Research) scientists have developed the technology to pack bio-fertilizers in tiny capsules. This eliminates the need for farmers to carry the sacks of biofertilizers. It consists of a carrier medium rich in live microorganisms. When applied to seed, soil or living plants,

it increases soil nutrients or makes them biologically available. Easy and reliable technology of storing and delivering PGPR bioagents in hard gelatin capsule termed as Bio capsule. It uses a select combination of beneficial microorganisms such as Trichoderma, Pseudomonas and Bacillus. They form a mutually beneficial or symbiotic relationship with host plants as they grow in the soil.

MATERIAL AND METHODS

The experiment was conducted in Randomized Block Design comprising 9 treatments replicated thrice during August 2021- February 2022 at Jacob Institute of Bio-technology and Bio-engineering (JIBB) poly-house, Faculty of Engineering and Technology, Sam Higginbottom University of Agriculture, Technology and Sciences, Prayagraj. The plants were planted with a spacing of 60 cm between the rows and 50 cm between the plants. The observations were recorded on randomly selected five plants on characters. The treatment details has been given in table 1. In general, soil properties of experimental site showed a typical alluvial soil of eastern region of Uttar Pradesh. Soil was sandy loam in texture, slightly acidic in reaction and having low electrical conductivity, very high in organic carbon, low in available nitrogen low in available phosphorus and moderately high in available potassium given in table 2. Weeding and plant protection measure were followed as and when needed. Observations were recorded at different stages of growth periods. The observations were recorded for characters *viz.* Plant height (cm), No. of branches/plant, Days to first flowering, Days to 50% flowering, No. of flower per plant, No. of fruit per plant, Fruit weight (g), Fruit weight per plant (g/plant), Fruit length (cm), Fruit diameter (cm), Fruit yield per plant, fruit yield per hectare (q), Total soluble solid (TSS), Acidity (%), Ascorbic acid (mg/100g of fruit). The data were statistically analysed by the method suggested by **Fisher and Yates, 1936.**

Table 1. Details of Treatments used

Treatment Notation	Treatment Combination
$\mathbf{T_0}$	NPK (RDF)
$\mathbf{T_1}$	Bio capsule (250ppm)
$\mathbf{T_2}$	Bio capsule (500ppm)
$\mathbf{T_3}$	Nano chitosan (60ppm)
$\mathbf{T_4}$	Nano chitosan (120ppm)
$\mathbf{T_5}$	NPK + Bio capsule (500ppm)
$\mathbf{T_6}$	NPK + Nano chitosan (120ppm)
$\mathbf{T_7}$	NPK + Bio capsule (250ppm) + Nano chitosan (60ppm)
$\mathbf{T_8}$	NPK + Bio capsule (500ppm) + Nano chitosan (120ppm)

Table 2. Physical and chemical properties of soil at Horticulture Research field (SHUATS).

Sl. No.	Particulars	Value (0-30 depth)	Method followed
Physical properties (Initial reading)			
1	Sand	58.70	Boyounce Hydrometer (Piper, 1966)
2	Silt	19.46	
3	Clay	21.84	
4	Textural class	Sandy loam	
Chemical properties (Initial reading)			
1	Soil pH	7.3	Potentiometery (Jackson, 1973)
3	Organic carbon (%)	0.56	Walkley and Black's method (Jackson, 1973)
4	Available nitrogen ($Kg\ ha^{-1}$)	49 kg/ha	Alkaline permanganate method (Subbaiah and Asija, 1956)
5	Available phosphorus ($Kg\ ha^{-1}$)	70 kg/ha	Bray's method (Jackson, 1973).
6	Available potash ($kg\ ha^{-1}$)	67 kg/ha	Ammonium acetate method (Jackson, 1973)

Source: Soil analysis was done by KVK (Krishi Vigyan Kendra, Prayagraj, U.P.)

RESULTS AND DISCUSSION

In the present investigation an attempt has been made to study the effect of different treatment combinations of nano chitosan, bio capsules and NPK@ RDF on growth, yield and

TREATMENTS	30DAT	60DAT	90DAT

quality of chilli in Poly-house condition are discussed. The results obtained are presented in relevant Tables as follows.

A) Growth Parameters

Growth parameters comprised of Plant height (30, 60, 90 DAT), number of branches per plant. The data for these characters observed has been listed out in table 3 and 4.

1. Plant Height (cm) [30, 60 and 90 DAT]

The data pertaining to plant height are presented in table 3. At 30 DAT the maximum height was observed in T_8 (31.20cm) followed by T7 (28.53cm). The minimum plant height was observed in T_3 (21.40cm). At 60 DAT the maximum height was observed in T_8 (46.87cm) followed by T_7 (44.60cm). The minimum plant height was observed in T_3 (32.80cm). At 90 DAT the maximum height was observed in T_8 (63.73cm) followed by T_7 (60.80cm). The minimum plant height was observed in T_3 (45.40cm). Treatment T_8 (NPK100% + Bio capsule 500ppm + Nano chitosan 120ppm) was significantly superior and recorded maximum plant height (63.73cm). Bio capsules played an important role in the fixation of nutrients (N&P) in plants. The probable reason for increased plant height due to more uptake of applied nutrients by the plants, needed for protein and protoplasm synthesis for higher rate of meiosis, resulting in better photosynthesis and plant growth and ultimately increased the plant height. And Nano chitosan prevent the pathogenic attack. Similar result was given by Khati *et al.,* (2017).

T_0 - N P K (RDF)	25.00	37.33	54.13
T_1 – Bio capsule (250ppm)	23.05	34.80	47.87
T_2 – Bio capsule (500ppm)	23.67	35.47	51.20
T_3 – Nano chitosan (60ppm)	21.40	32.80	45.40
T_4 – Nano chitosan (120ppm)	22.33	34.07	47.60
T_5 - NPK + Bio capsule (500ppm)	27.27	41.93	58.67
T_6 - NPK + Nano chitosan (120ppm)	25.93	39.00	56.00
T_7 - NPK + Bio capsule (250ppm) + Nano chitosan (60ppm)	28.53	44.60	60.80
T_8 - NPK + Bio capsule (500ppm) + Nano chitosan (120ppm)	31.20	46.87	63.73
F-TEST	S	S	S
SE(d)	2.03	1.75	1.74
C.V.	9.79	5.57	3.95
C.D. AT 5%	4.30	3.72	3.69

Table 3. Effect of Nano chitosan and Bio capsule on different treatment combinations of chilli plant for plant height [30, 60, 90 DAT]

2. Number of branches/plant

The data pertaining to Number of branches per plant are presented in table 4. Analysis of variance revealed a significant variation in term of number of branches per plant due to different treatments. At 30 DAT the maximum branches were observed in T_8 (5.47) followed by T_7 (5.20). The minimum branches were observed in T_3 (3.20). At 60 DAT the maximum branches were observed in T_8 (10.53) followed by T_7 (10.07). The minimum branches were observed in T_3 (7.13). At 90 DAT the maximum branches were observed in T_8 (17.60) followed by T_7 (16.80). The minimum branches were observed in T_3 (12.93).Treatment T_8 (N.P.K. 100 % + Bio capsule 500 ppm + Nano chitosan 120ppm) was significantly superior and recorded maximum no of branches (17.60). Similar result was given by Jayvanth *et al.*, (2018).

Table 4. Effect of Nano chitosan and Bio capsule on different treatment combinations of chilli plant for number of branches per plant [30, 60, 90 DAT]

TREATMENTS	30DAT	60DAT	90DAT
T_0 - N P K (RDF)	4.27	9.13	14.80
T_1 - Bio capsule (250ppm)	3.60	7.67	13.73
T_2 - Bio capsule (500ppm)	4.07	8.20	14.47
T_3 - Nano chitosan (60ppm)	3.20	7.13	12.93
T_4 - Nano chitosan (120ppm)	3.33	7.40	13.20
T_5 - NPK + Bio capsule (500ppm)	4.93	9.80	16.47
T_6 - NPK + Nano chitosan (120ppm)	4.53	9.40	16.00
T_7 - NPK + Bio capsule (250ppm) + Nano chitosan (60ppm)	5.20	10.07	16.80
T_8 - NPK + Bio capsule (500ppm) + Nano chitosan (120ppm)	5.47	10.53	17.60
F-TEST	S	S	S
SE(d)	0.24	0.41	0.35
C.V.	6.99	5.64	2.87
C.D. AT 5%	0.52	0.86	0.75

B) Flowering Parameter

3. Days to First Flowering, days to 50% flowering and number of flowers per plant

The data on day to First Flowering, days to 50% flowering and number of flowers per plant influenced by organic manure and bio-fertilizer were recorded and presented in table 5. Days to First Flowering varied significantly due to the effect of different treatments. Early Flowering was observed in T8 (42.17) followed by T7. The maximum day to First Flowering was observed in T3 (50.83). Similar result was given by Turan and Sahin (2008). Early flowering (42.17) was recorded for Treatment T8 (N. P.K. 100 % +Nano chitosan 120 ppm + Bio capsule 500 ppm). Days to 50% flowering varied significantly due to the effect of different treatments. Early Flowering was observed in T8 (52.92) followed by T7 (53.67). The maximum day to 50% Flowering was observed in T3 (62.08). Similar result was given by Turan and Sahin (2008). Early flowering (52.92) was recorded for Treatment T8 (N. P.K. 100 % +Nano chitosan 120 ppm + Bio capsule 500 ppm). Maximum No. of Flowers/Plant was observed in T8 (271.08) followed by T7 (268.92). The minimum No. of Flowers/Plant was observed in T3 (262.58). It is due to the presence of N.P.K, Bio capsule and nano chitosan. Bio capsule have ability to fix the nutrient given by fertilizer in soil and tends towards plant mechanism. N.P.K. had played important role in enhancing the reproductive growth in plant and in other hand chitosan had the ability of cation exchange capacity in soil so that it made the availability of micronutrient like Zn, B, Fe and Cl. Similar result was given by Khan *et al.*, (2017). The result was close conformity with Geries *et al*. (2020) for number of flowers per plant.

Table 5. Effect of Nano chitosan and Bio capsule on different treatment combinations of chilli plant for days to first flowering, days to 50% flowering and number of flowers per plant.

TREATMENTS	Days to First Flower	Days to 50% Flower	No. Of Flowers/Plant

T_0 - N P K (RDF)	46.00	56.50	265.58
T_1 - Bio capsule (250ppm)	48.17	59.50	264.00
T_2 - Bio capsule (500ppm)	47.33	58.00	264.50
T_3 - Nano chitosan (60ppm)	50.83	62.08	262.58
T_4 - Nano chitosan (120ppm)	49.08	61.00	263.42
T_5 - NPK + Bio capsule (500ppm)	43.58	54.17	267.83
T_6 - NPK + Nano chitosan (120ppm)	44.67	55.50	267.42
T_7 - NPK + Bio capsule (250ppm) + Nano chitosan (60ppm)	43.00	53.67	268.92
T_8 - NPK + Bio capsule (500ppm) + Nano chitosan (120ppm)	42.17	52.92	271.08
F-TEST	S	S	S
SE(d)	1.07	1.09	2.00
C.V.	2.85	2.35	0.92
C.D. AT 5%	2.28	2.32	4.24

C) Yield parameters

4. Number of fruits per plant

Results of the present study indicated that with the progression of growth stages there was statistically significant increase in No. of Fruit/Plant (Table 6). Higher No. of Fruit/Plant was observed in T8 (148.67) followed by T7 (146.83). The minimum No. of Fruit/Plant was observed in T3 (138.42). It is evident from the data that treatment T8 (N. P.K. 100 % +Nano chitosan 120 ppm + Bio capsule 500 ppm) showed best result amongst the other treatment which is at par with each other whereas treatment T3 (Nano chitosan 60 ppm). This result was close conformity with Geries *et al*. (2020).

5. Fruit weight (g), Fruit yield per plant (kg/plant), Fruit yield per hectare (q)

Fruit weight of chilli showed differences among the different. Results of the present study indicated statistically significant increase in Fruit weight (g), fruit yield per plant (kg/plant)

TREATMENTS	No. of Fruits/Plant	Fruit Weight (g)	Fruit Weight/Plant (kg/plant)	Fruit Yield Quintal/200m^2

and fruit yield per hectare (q) (Table 6). Maximum Fruit weight (g) was observed T8 (7.28g) followed by T7 (6.59g). The minimum Fruit weight (g) was observed in T3 (3.49g). The maximum fruit weight (7.28g), was recorded for Treatment T8 (N.P.K. 100 % +Nano chitosan 120 ppm + Bio capsule 500 ppm). Maximum Fruit yield (g/plant) was observed in T8 (1082.31g) followed by T7 (967.24g). The minimum Fruit yield (kg/plant) was observed in T3 (483.57g). Higher Fruit yield per hectare (q) was observed in T8 (7.24 q) followed by T7 (6.48q). The minimum Fruit yield per hectare (q) was observed in T3 (3.27q).The increase in fruit weight may be due to the combination of N.P.K. fertilizer and Bio capsule and Nano chitosan which promoted vegetative growth and development and have associated with acceleration of higher rate of photosynthesis and their accumulation in economic part of plant. Nano chitosan accumulate micronutrient availability to plants and Bio capsule fixed nutrient given through the N.P.K for plants reproductive phase resulting increased fruit weight. This result was close conformity with Sharif *et al*. (2018), for fruit yield by Mondal *et al*. (2012).

Table 6. Effect of Nano chitosan and Bio capsule on different treatment combinations of chilli plant for fruit weight, fruit yield per plant, fruit yield per hectare.

T_0 - N P K (RDF)	142.58	4.70	670.11	4.50
T_1 - Bio capsule (250ppm)	139.58	3.95	550.65	3.70
T_2 - Bio capsule (500ppm)	141.67	4.28	606.34	4.07
T_3 - Nano chitosan (60ppm)	138.42	3.49	483.57	3.27
T_4 - Nano chitosan (120ppm)	139.08	3.67	510.99	3.44
T_5 - NPK + Bio capsule (500ppm)	146.00	5.91	862.18	5.78
T_6 - NPK + Nano chitosan (120ppm)	144.08	5.29	762.73	5.11
T_7 - NPK + Bio capsule (250ppm) + Nano chitosan (60ppm)	146.83	6.59	967.24	6.48
T_8 - NPK + Bio capsule (500ppm) + Nano chitosan (120ppm)	148.67	7.28	1082.31	7.24
F-TEST	S	S	S	S
SE(d)	1.73	0.09	14.30	0.10
C.V.	1.48	2.14	2.43	2.49
C.D. AT 5%	3.67	0.18	30.31	0.21

6. Fruit length(cm) and Fruit diameter (cm)

Results of the present study indicated that with the progression of growth stages there was statistically significant increase in fruit length (cm) and fruit diameter (cm) (Table 7).

Maximum fruit length (cm) was observed in T8 (10.13cm) followed by T7 (9.27cm. The minimum fruit length (cm) was observed in T3 (6.27cm). Maximum fruit Diameter (cm) was observed in T8 (1.21cm) followed by T7 (1.13cm), T5 (1,06cm), T6 (0.99cm), T0 (0.93cm), T2 (0.92cm), T1 (0.84cm), T4 (0.84cm) and T3. The minimum fruit Diameter (cm) was observed in T3 (0.81cm). It is confirmed from the data that treatment T8 (N. P.K. 100 % +Nano chitosan 120 ppm + Bio capsule 500 ppm) showed best result amongst the other treatment which is at par with each other whereas treatment T4 (Nano chitosan 60 ppm). Similar findings were observed by Rafique *et al*. (2018) for fruit length and Duhana *et al*. for fruit diameter.

Table 7. Effect of Nano chitosan and Bio capsule on different treatment combinations of chilli plant for fruit length and diameter (cm)

TREATMENTS	Fruit Length (cm)	Fruit Diameter (cm)
T_0 - N P K (RDF)	7.57	0.93
T_1 - Bio capsule (250ppm)	6.87	0.84
T_2 - Bio capsule (500ppm)	7.20	0.92
T_3 - Nano chitosan (60ppm)	6.27	0.81
T_4 - Nano chitosan (120ppm)	6.43	0.84
T_5 - NPK + Bio capsule (500ppm)	8.80	1.06
T_6 - NPK + Nano chitosan (120ppm)	8.03	0.99
T_7 - NPK + Bio capsule (250ppm) + Nano chitosan (60ppm)	9.27	1.13
T_8 - NPK + Bio capsule (500ppm) + Nano chitosan (120ppm)	10.13	1.21
F-TEST	S	S
SE(d)	0.32	0.04
C.V.	5.01	5.55
C.D. AT 5%	0.68	0.09

D) Quality parameter

7. TSS (^{0}Brix), acidity, Vitamin C content (mg/100g)

The total Soluble Solid, acidity, Vitamin C content of Chilli showed significant variation among different treatment which is presented in table 8. Maximum value of total Soluble

TREATMENTS	T.S.S. (^{0}Brix)	Acidity %	Vitamin C mg/100g

Solid was observed in T8 (9.67^{o}B) followed by T7 (9.46^{o}B). The minimum total Soluble Solid was observed in T3 (6.97^{o}B). The highest TSS (9.67oB) value was observed for T8 (N.P.K. 100 % +Nano chitosan 120 ppm + Bio capsule 500 ppm). Based on the data it is found that in nine treatment combination, T8 (NPK % + Bio capsule 500ppm + Nano chitosan 120ppm) recorded minimum (0.172%) for acidity followed by T7 (NPK % + Bio capsule 250ppm + Nano chitosan 60ppm) with (0.182%). The maximum vitamin C content was observed in T8 (NPK % + Bio capsule 500ppm + Nano chitosan 120ppm) (143.96 mg) followed by T7 (NPK % + Bio capsule 250ppm + Nano chitosan 60ppm) with (140.02 mg). The minimum Vitamin C was observed in T3 (Nano chitosan 60ppm) with (117.10 mg).When the nutrient supply became insufficient, the limited synthesized carbohydrates meet the requirements of only vegetative parts. Contrary to this, combination of N.P.K. with Bio capsule supplied adequate level of nutrients because of Bio capsule prevent the leaching of nutrient and fixed the nutrient for plant growth. Thus, synthesized carbohydrates translocated to the fruits, which ultimately increased the total soluble solids of fruit. Similar finding was given by Duhana *et al*. (2018) for TSS, acidity and Vitamin C content.

T_0 - N P K (RDF)	8.57	0.219	131.41
T_1 - Bio capsule (250ppm)	7.92	0.234	125.74
T_2 - Bio capsule (500ppm)	8.39	0.227	127.05
T_3 - Nano chitosan (60ppm)	6.97	0.252	117.10
T_4 - Nano chitosan (120ppm)	7.26	0.247	124.82
T_5 - NPK + Bio capsule (500ppm)	9.21	0.196	136.87
T_6 - NPK + Nano chitosan (120ppm)	8.85	0.216	134.01
T_7 - NPK + Bio capsule (250ppm) + Nano chitosan (60ppm)	9.46	0.182	140.02
T_8 - NPK + Bio capsule (500ppm) + Nano chitosan (120ppm)	9.67	0.172	143.96
F-TEST	S	S	S
SE(d)	0.22	0.01	3.98
C.V.	3.18	7.98	3.71
C.D. AT 5%	0.47	0.03	8.43

Table 8. Effect of Nano chitosan and Bio capsule on different treatment combinations of chilli plant for TSS, acidity and Vitamin C content.

CONCLUSION

On the basis of the present investigation, it is concluded that the various treatments applied to enhance the vegetative and growth of chilli treatment T_8 (NPK (RDF) + Nano chitosan 120 ppm + Bio capsule 500ppm) was found to be superior among others, followed by T_7 (NPK (RDF) + Nano chitosan 60ppm + Bio capsule 250ppm) and the lowest was T_3 (Nano chitosan 60 ppm) in every aspect of growth, yield, quality. Therefore, use of Nano chitosan @ 120 ppm along with 500 ppm Bio capsule could be used for getting better yield in chilli. Moreover, application of Nano chitosan and bio capsule on nutritional quality of chilli could be studied in details further.

ACKNOWLDEGEMENT

The author would like express heartfelt gratitude to Dr. Samir E. Topno (Assistant Professor, Department of Horticulture, NAI, SHUATS, Prayagraj) for his continuous guidance and supervision throughout our research period.

REFERENCES

Almaliotis, D., Bladenopoulou, S., Chatzissavvidis, C.H. and Karagiannidis, N. (2007). Broccoli (Brassica oleracia L. Var. Italica) yield as affected by soil fertility parameters in nirthern greece. *Acta Hortic.* 729, 409-413

Ayoola, O. T., & Adeniyan, O. N. (2006). Influence of poultry manure and NPK fertilizer on yield and yield components of crops under different cropping systems in south west Nigeria. *African journal of biotechnology*, *5*(15).

Bosland, P. W. (1996). Capsicums: Innovative uses of an ancient crop. *Progress in new crops. ASHS Press, Arlington, VA*, 479-487.

Baris, O., Sahin, F., Turan, M., Orhan, F., & Gulluce, M. (2014). Use of plant-growth-promoting rhizobacteria (PGPR) seed inoculation as alternative fertilizer inputs in wheat and barley production. *Communications in Soil Science and Plant Analysis*, *45*(18), 2457-2467.

Bakshi, M., Wali, V. K., Bakshi, P., Sharma, A., Sharma, D., & Shah, R. A. (2017). Integrated nutrient management induced changes in nutrient uptake, fruit yield and quality of Kinnow mandarin. *Indian Journal of Agricultural Sciences*, *87*(3), 414-8.

Chiou, K. L., & Hastorf, C. A. (2014). A systematic approach to species–level identification of chile pepper (Capsicum spp.) seeds: Establishing the groundwork for tracking the domestication and movement of chile peppers through the Americas and beyond. *Economic botany*, *68*(3), 316-336.

Carrizo García, C., Barfuss, M. H., Sehr, E. M., Barboza, G. E., Samuel, R., Moscone, E. A., & Ehrendorfer, F. (2016). Phylogenetic relationships, diversification and expansion of chilli peppers (Capsicum, Solanaceae). *Annals of botany*, *118*(1), 35-51.

Choudhary, R. C., Kumari, S., Kumaraswamy, R. V., Sharma, G., Kumar, A., Budhwar, S., & Saharan, V. (2019). Chitosan nanomaterials for smart delivery of bioactive compounds in agriculture. In *Nanoscale engineering in agricultural management* (pp. 124-139). CRC Press.

Duhan, J. S., Kumar, R., Kumar, N., Kaur, P., Nehra, K., & Duhan, S. (2017). Nanotechnology: the new perspective in precision agriculture. Biotechnol Rep 15: 11–23.

Gadalla, M. B. (2020). Knowledge, Attitude and Practice about Health Benefits of Chilli Pepper among Students of University of Science and Technology.

Geries, L., Omnia, H. S., & Marey, R. A. (2020). Soaking and foliar application with chitosan and nano chitosan to enhancing growth, productivity and quality of onion crop. *Plant Arch*, *20*(2), 3584-3591.

Hidangmayum, A., Dwivedi, P., Katiyar, D., & Hemantaranjan, A. (2019). Application of chitosan on plant responses with special reference to abiotic stress. *Physiology and molecular biology of plants*, *25*(2), 313-326.

Islam S, Akanda AM, Prova A, Sultana F and Hossain MM (2015) Isolation and identification of plant growth promoting rhizobacteria from cucumber rhizosphere and their effect on plant growth promotion and disease suppression. Front. Microbiol. 6:1360. doi:10.3389/fmicb.2015.0136

Kraft, K. H., Brown, C. H., Nabhan, G. P., Luedeling, E., Luna Ruiz, J. D. J., Coppens d'Eeckenbrugge, G., ... & Gepts, P. (2014). Multiple lines of evidence for the origin of domesticated chilli pepper, Capsicum annuum, in Mexico. *Proceedings of the National Academy of Sciences*, *111*(17), 6165-6170.

Khan, Insaf, Singh, Devendra and Jat, Bhanwar Lal (2017). Effects of biofertilizers on plant growth and yield characters of Pisum sativum L. *Adv. Res. J. Crop Improv.,* **8 (1)**: 99-108,

Khati, P., Chaudhary, P., Gangola, S., Bhatt, P., & Sharma, A. (2017). Nano chitosan supports growth of Zea mays and also maintains soil health following growth. *3 Biotech*, *7*(1), 1-9.

Kumar, U. J., Bahadur, V., Prasad, V. M., Mishra, S., & Shukla, P. K. (2017). Effect of different concentrations of iron oxide and zinc oxide nanoparticles on growth and yield of strawberry (Fragaria x ananassa Duch) cv. Chandler. *International Journal of Current Microbiology and Applied Sciences*, *6*(8), 2440-2445.

Khalifa, N. S., & Hasaneen, M. N. (2018). The effect of chitosan–PMAA–NPK nanofertilizer on Pisum sativum plants. *3 Biotech*, *8*(4), 1-12.

Kocięcka, J., & Liberacki, D. (2021). The potential of using chitosan on cereal crops in the face of climate change. *Plants*, *10*(6), 1160.

Makinde, E. A., Ayoola, O. T., & Akande, M. O. (2007). Effects of organo-mineral fertilizer application on the growth and yield of egusi melon. *Australian Journal of Basic and applied sciences*, *1*(1), 15-19.

Mondal, M. M., Malek, M. A., Puteh, A. B., Ismail, M. R., Ashrafuzzaman, M., & Naher, L. (2012). Effect of foliar application of chitosan on growth and yield in okra. *Australian Journal of Crop Science*, *6*(5), 918-921.

Malerba, M., & Cerana, R. (2016). Chitosan effects on plant systems. *International journal of molecular sciences*, *17*(7), 996.

Munazza Rafique, Aneela Riaz, Ashfaq Anjum, M. Amjad Qureshi, Fakhar Mujeeb (2018). Role of Bioinoculants for Improving Growth and Yield of Okra (*Abelmoschus esculentus*). *Universal Journal of Agricultural Research* 6(3): 105-112,2018.

Maluin, F. N., & Hussein, M. Z. (2020). Chitosan-based agronanochemicals as a sustainable alternative in crop protection. *Molecules*, *25*(7), 1611.

Orzali, L., Corsi, B., Forni, C., & Riccioni, L. (2017). Chitosan in agriculture: a new challenge for managing plant disease. *Biological activities and application of marine polysaccharides*, 87-96.

Pickersgill, B. (1971). Relationships between weedy and cultivated forms in some species of chilli peppers (genus Capsicum). *Evolution*, *25*(4), 683-691.

Pickersgill, B. A. R. B. A. R. A. (1991). Cytogenetics and evolution of Capsicum L. *Chromosome engineering in plants: genetics, breeding, evolution, part B. Elsevier, Amsterdam*, 139-160.

Singh, A., & Singh, J. N. (2009). Effect of biofertilizers and bioregulators on growth, yield and nutrient status of strawberry cv. Sweet Charlie. *Indian Journal of Horticulture*, *66*(2), 220-224.

Sharif, R., Mujtaba, M., Ur Rahman, M., Shalmani, A., Ahmad, H., Anwar, T., ... & Wang, X. (2018). The multifunctional role of chitosan in horticultural crops; a review. *Molecules*, *23*(4), 872.

Turan, M., Gulluce, M., Cakmakci, R., Oztas, T., Sahin, F., Gilkes, R. J., & Prakongkep, N. (2010, August). The effect of PGPR strain on wheat yield and quality parameters. In *Proceedings of the 19th World Congress of Soil Science: Soil solutions for a changing world, Brisbane, Australia* (Vol. 209, p. 212).

Zayed, M. M., Elkafafi, S. H., Zedan, A. M., & Dawoud, S. F. (2017). Effect of nano chitosan on growth, physiological and biochemical parameters of Phaseolus vulgaris under salt stress. *Journal of Plant Production*, *8*(5), 577-585.