Biological Forum – An International Journal **15(5): 289-295(2023)**

ISSN No. (Print): 0975-1130
ISSN No. (Online): 2249-3239

Effect of Nano-chitosan, Nano-micronutrients and Bio Capsules on Yield and Quality of Strawberry (*Fragaria × ananassa*) cv. Winter Dawn

Ravi Kumar Singh[1*], Saket Mishra[2] and Vijay Bahadur[3]
[1]Ph.D Scholar, Department of Horticulture,
NAI, SHUATS, Prayagraj (Uttar Pradesh), India.
[2]Assistant Professor, Department of Horticulture,
NAI, SHUATS, Prayagraj (Uttar Pradesh), India.
[3]Associate Professor & Head, Department of Horticulture,
NAI, SHUATS, Prayagraj (Uttar Pradesh), India.

(Corresponding author: Ravi Kumar Singh)*
(Received: 03 March 2023; Revised: 13 April 2023; Accepted: 19 April 2023; Published: 20 May 2023)
(Published by Research Trend)

ABSTRACT: Application of inorganic fertilizers in large amount have been a major challenge for agricultural production. Not only it is reducing the crop production but also damaging the soil fertility. So keeping all this in mind a research entitled "Effect of Nano-chitosan, Nano-micronutrients and Bio capsules on yield and qualitative attributes of Strawberry (*Fragaria × ananassa*) cv. Winter dawn" was carried out at the Research Farm of the Department of Horticulture at Sam Higginbottom University of Agriculture, Technology & Sciences in Prayagraj (U.P.), during the academic years of 2020–2021 and 2021–2022. Fifteen treatments using various combinations of N, P, K, nano chitosan, bio capsules, and nano particles of ZnO and FeO were tested in a Randomised Block Design with three replicates. The experiment's primary objective was to determine the effect of nano technology on the yield and qualitative traits of strawberry cv. Winter dawn. According to the findings of this study, application of Nanochitosan 100 ppm (Soil drenching) + Biocapsule 500ppm + foliar application of ZnO and FeO nano particles (NPs) after 30 and 60 days of transplanting supplemented with recommended N P K (RDF) proved to be most effective treatment to increase yield and qualitative traits of strawberry. However, without synthetic inputs, biocapsules improve fruit quality, yield, and plant health by releasing compounds into the rhizosphere that may inhibit different diseases as biocontrol agents, several of these bacteria have demonstrated the ability to support the growth of strawberry plants.

Keywords: Bio capsules, *Fragaria ananassa*, Nano-chitosan, Nano-micronutrients, Strawberry yield, Quality, Winter Dawn.

INTRODUCTION

Strawberry (*Fragaria × ananassa* Duch.) a member of the family Rosaceae is a "false fruit", which is one of the most delicious, refreshing and nutritious soft fruits of the world native to America (Galletta *et al*., 1990). It was developed in France in the seventeenth century as a monoecious hybrid of two American octaploid species, *Fragaria chiloensis* Duch. and *Fragaria virginiana* Duch (Mitra, 1991).

It is a temperate fruit requiring temperate conditions of temperature below 26°C to initiate flowering (Jackson *et al*., 2011). But it can be grown in subtropical climate and at high altitudes of tropical region (Chattopadhyay, 2013). At present, strawberry is being grown in a wide range of climatic zones due to its genotypic diversity The United States is the largest producing country accounting 30 per cent of world supply where-as in India, it is being cultivated in an area of 1000 hectares with an annual production of 5000 metric tonnes (Anon., 2019).

Besides vitamin C, it also provides a fair source of vitamin A (60 IU/100 g of edible portion). The presence of higher pectin content (0.55 %) in the form of calcium pectate serves as an excellent ingredient for making jelly (Wange and Kzlogoz 1998). Being a rich source of vitamins and minerals coupled with delicate flavor, strawberry has now become an important table fruit of millions of people around the world (Sharma and Singh 1999). Strawberry is the best sources of bioactive compounds containing anthocyanins, carotenoids, vitamins, flavonoids and phenolics with remarkable capacity of antioxidant activities (Giampieri *et al*., 2017).

Recently, illicit fertilizer, pesticides, and biological monitoring findings have created environmental contamination in strawberry agriculture (Zargar *et al.*, 2017). Chemical fertilizers increase crop productivity, but they also introduce harmful residues that harm humans, degrade sustainability, and pollute water (Al-Mamun *et al.*, 2021). Increasing strawberry cultivation is therefore virtually a formidable challenge (Abdel-

Aziz *et al.*, 2021). Thus, nanotechnologies are the ideal way to boost agriculture production and sustainability. The term 'nanotechnology' was first coined by Norio Taniguichi, a professor at Tokyo University of Science, in 1974 (Khan and Rizvi 2014). Nanofertilizers release nutrients when needed, eliminating premature contact with soil, water, and microbes. The nutrients immediately assemble into the plant system. These traits can boost crop nutrient efficiency (De Rosa *et al.*, 2010).

Strawberry plants do much better in good nutrition and controlled nutrient supply in subtropical region, and can produce higher yield. Nano mixed foliar sprays containing nano fertilizer, combining macro and microelements like iron (Fe), copper (Cu), manganese (Mn), and zinc (Zn), are better for field usage production, have superior sustainability, and reduce plant mobility. Foliar nano fertilizers also lower soil-applied macro and micro engineered element toxicity (Abbasifar *et al.,* 2020). Nanochitosan 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, 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 specially *bacillus*, *pseudomonas*. When applied to seed, soil or living plants, it increases soil nutrients or makes them biologically available. (ICAR-Indian Institute of Spices Research, Kozhikode). However, little study has been done on use of bio capsules, nano micro and nano macro fertilizers on strawberry. Keeping in view the above facts this experiment titled **"**Effect of Nano-chitosan, Nano-micronutrients and Bio capsules on yield and qualitative attributes of Strawberry (*Fragaria* × *ananassa*) cv. Winter dawn" was designed and carried out.

MATERIALS AND METHODS

During 2020-21 and 2021-22, the above-mentioned experiment was conducted on the crop research farm of the Department of Horticulture at the Naini Agricultural Institute in Prayagraj, India. The area is located approximately six kilometres south of Prayagraj, on the right bank of the Yamuna River along the South of Rewa Road. It is located at 25024'23" north latitude, 81050'38" east longitude, and 98 metres (MSL) above sea level.The plants were treated with different treatments, i.e., $\mathbf{T_0}$: Control (Without treatment), $\mathbf{T_1}$: N P K (RDF), $\mathbf{T_2}$: Biocapsule 500ppm (Soil drenching), $\mathbf{T_3}$: Nanochitosan 100 ppm (Soil drenching), $\mathbf{T_4}$: Nanochitosan 100 ppm (Soil drenching) + Biocapsule 500ppm, $\mathbf{T_5}$: N P K (RDF) + Bio capsule 500ppm (Soil drenching), $\mathbf{T_6}$: N P K (RDF) + Nano chitosan 100 ppm (Soil drenching), $\mathbf{T_7}$: N P K (RDF) + Nano chitosan 100 ppm (Soil drenching) + Bio capsule 500ppm, $\mathbf{T_8}$: N P K (RDF) – foliar application of ZnO and FeO nano particles (NPs), $\mathbf{T_9}$: Bio capsule 500ppm (Soil drenching)+ foliar application of ZnO and FeO nano particles (NPs), $\mathbf{T_{10}}$: Nano chitosan 100 ppm (Soil drenching) + foliar application of ZnO and FeO nano particles (NPs), $\mathbf{T_{11}}$: Nano chitosan 100 ppm (Soil drenching) + Bio capsule 500ppm + foliar application of ZnO and FeO nano particles (NPs), $\mathbf{T_{12}}$: N P K (RDF) + Bio capsule 500ppm (Soil drenching) + foliar application of ZnO and FeO nano particles (NPs), $\mathbf{T_{13}}$: N P K (RDF) + Nano chitosan 100 ppm (Soil drenching) + foliar application of ZnO and FeO nano particles (NPs) and $\mathbf{T_{14}}$: N P K (RDF) + Nano chitosan 100 ppm (Soil drenching) + Bio capsule 500ppm + foliar application of ZnO and FeO nano particles (NPs).

Agricultural field was deep ploughed by the Disk harrow before one week of transplanting in (45×30) cm spacing. Recommended dose of NPK @ 100:60:140 kg/ha along with FYM & DAP were applied as basal dose and rest doses were applied as per requirement of plant. From CADAGU- Agritech Bangalore, biocapsules were purchased. Each capsule weighed 1 g and contained a concentration of 1,000 ppm. Before application, the capsules were dissolved in 1 litre of lukewarm water for 12 hours. Then, 1 litre of a 500-ppm solution was dissolved in 50 litres of water. On the other hand, Haryana's Nano research element supplied nano chitosan. Ethyl alcohol was used to produce the solution at the treatment-recommended chitosan concentration. Strawberry plants were drenched with chitosan. The first drench both bio-capsule and nano chitosan was given immediately after transplantation, followed by three more at 20-day intervals. Nano-particles of FeO (100ppm) & ZnO (150ppm) were also administered as per treatment with the help of sprayer during the vegetative and reproductive stage of strawberry.

The experiment utilized a Randomized Block Design (Fisher, 1950) with three replications for each of the fifteen treatment combinations. Yield attributes like Fruit weight (g), Yield per plant (g) and Yield per hectare (t/ha) and quality attributes like TSS (ºBrix), Titrable acidity %, Ascorbic acid (mg/100g of edible part), reducing sugar %, non-reducing sugar % and Shelf life (days) were successfully measured and recorded.

RESULTS AND DISCUSSION

The yield and quality characteristics of Strawberry (*Fragaria* × *ananassa*) cv. Winter dawn were studied statistically. According to the results, the incorporation of various treatments significantly improved all characteristics. Since F Cal > F Tab, the evidence indicates that the variances were statistically different.

A. Yield Attributes

Fruit weight (g). According to the perusal of data (Table 1), it was found that the treatment T_{14} [N P K (RDF) + Nanochitosan 100 ppm (Soil drenching) + Biocapsule 500ppm + foliar application of ZnO and FeO nano particles (NPs)] was found best and significantly most effective as compared to other treatments. It was observed significantly the maximum Fruit weight (g) i.e., [19.83 (1st year), 20.82 (2nd year) and 20.33 (pooled)] g according to both the years of study as well as pooled data. It was followed by treatment T_5 [N P K (RDF) + Biocapsule 500ppm (Soil drenching)] with 2nd best significant effect on plant height of strawberry whereas least fruit weight (g) occurred in the treatment T_0 [Control (Without treatment)] with [9.34 (1st year), 9.5 (2nd year) and 9.42 (pooled)] g fruit weight.

Yield per plant (g). The data regarding yield per plant (g) is depicted in Table 1 where the effect of different treatments was found significantly different. From the results it was found that treatment T_{14} [N P K (RDF) + Nanochitosan 100 ppm (Soil drenching) + Biocapsule 500ppm + foliar application of ZnO and FeO nano particles (NPs)] recorded the maximum yield per plant of [247.36 (1st year), 253.74 (2nd year) and 250.55 (pooled)] g where-as minimum Yield per plant of [82.36 (1st year), 84.85 (2nd yr) and 83.61 (pooled)] g was recorded in T_0 [Control (Without treatment)]. Here, the effect of treatment T_3 [Nano chitosan 100 ppm (Soil drenching)] was found 2nd best on yield per plant of strawberry.

Total yield (t/ha). The data regarding total yield (t/ha) (Table 1) shows that the differences in the effect of different treatments were found significantly different. Treatment T_{14} [N P K (RDF) + Nano chitosan 100 ppm (Soil drenching) + Bio capsule 500ppm + foliar application of ZnO and FeO nano particles (NPs)] was found significantly best with maximum total yield of [20.74 (1st year), 21.37 (2nd year) and 21.06 (pooled)] t/ha where-as minimum total yield of [8.23 (1st year), 8.49 (2nd year) and 8.36 (pooled)] t/ha was recorded in T_0 [Control (Without treatment)]. Here, the effect of treatment T_3 [Nano chitosan 100 ppm (Soil drenching)] was found 2nd best on total yield (t/ha) of strawberry.

Table 1: Effect of Nano-chitosan, Nano-micronutrients and Bio capsules on Fruit Weight (g), Yield per plant (gm) and Total Yield (t/ha) of Strawberry (*Fragaria* × *ananassa*) cv. Winter dawn.

Sr. No.	Treatments	Fruit Weight (g)			Yield/ plant (gm)			Total Yield (t/ha)		
		2020-21	2021-22	Pooled	2020-21	2021-22	Pooled	2020-21	2021-22	Pooled
1.	T_0	9.34	9.5	9.42	82.36	84.85	83.61	8.236	8.49	8.36
2.	T_1	13.58	14.47	14.03	192.39	199.35	195.87	16.24	16.94	16.59
3.	T_2	12.79	12.95	12.87	220.83	223.58	222.21	18.08	18.36	18.22
4.	T_3	15.75	16.58	16.17	223.08	226.03	224.56	18.31	18.6	18.46
5.	T_4	13.73	14.93	14.33	194.43	200.65	197.54	15.44	16.07	15.76
6.	T_5	18.21	17.59	17.9	216.66	224.8	220.73	17.67	18.48	18.08
7.	T_6	15.2	15.72	15.46	207.25	211.63	209.44	16.73	17.16	16.95
8.	T_7	12.51	14.8	13.66	181.59	198.23	189.91	14.16	15.82	14.99
9.	T_8	15.83	15.21	15.52	211.42	213.98	212.7	17.14	17.4	17.27
10.	T_9	15.58	16.1	15.84	207.63	208.01	207.82	16.76	16.8	16.78
11.	T_{10}	13.19	15.48	14.34	182.27	200.68	191.48	14.23	16.07	15.15
12.	T_{11}	13.21	15.5	14.36	182.29	197.7	190	14.23	15.77	15
13.	T_{12}	16	14.56	15.28	213.52	215.37	214.45	17.35	17.54	17.45
14.	T_{13}	13.96	16.48	15.22	208.01	212.39	210.2	16.8	17.24	17.02
15.	T_{14}	19.83	20.82	20.33	247.36	253.74	250.55	20.74	21.37	21.06
F-Test		**S**	**S**	**S**	**S**	**S**	**S**	**S**	**S**	**S**
S. Ed. (±)		0.689	0.84	0.453	9.254	10.43	6.369	1.017	1.017	0.852
S. E. (m) (±)		0.487	0.594	0.321	6.544	7.375	4.504	0.719	0.719	0.602
C. D. (P = 0.05)		1.378	1.68	0.907	18.511	20.863	12.74	2.035	2.035	1.704

T_0: Control (Without treatment), **T_1**: N P K (RDF), **T_2**: Biocapsule 500ppm (Soil drenching), **T_3**: Nanochitosan 100 ppm (Soil drenching), **T_4**: Nanochitosan 100 ppm (Soil drenching) + Biocapsule 500ppm, **T_5**: N P K (RDF) + Biocapsule 500ppm (Soil drenching), **T_6**: N P K (RDF) + Nanochitosan 100 ppm (Soil drenching), **T_7**: N P K (RDF) + Nanochitosan 100 ppm (Soil drenching) + Biocapsule 500ppm, **T_8**: N P K (RDF) – foliar application of ZnO and FeO nano particles (NPs), **T_9**: Biocapsule 500ppm (Soil drenching)+ foliar application of ZnO and FeO nano particles (NPs), **T_{10}**: Nanochitosan 100 ppm (Soil drenching) + foliar application of ZnO and FeO nano particles (NPs), **T_{11}**: Nanochitosan 100 ppm (Soil drenching) + Biocapsule 500ppm + foliar application of ZnO and FeO nano particles (NPs), **T_{12}**: N P K (RDF) + Biocapsule 500ppm (Soil drenching) + foliar application of ZnO and FeO nano particles (NPs), **T_{13}**: N P K (RDF) + Nanochitosan 100 ppm (Soil drenching) + foliar application of ZnO and FeO nano particles (NPs) and **T_{14}**: N P K (RDF) + Nanochitosan 100 ppm (Soil drenching) + Biocapsule 500ppm + foliar application of ZnO and FeO nano particles (NPs).

B. Quality Attributes

Total Soluble Solids (ºBrix). The findings of the experiment show that there are statistically significant differences between the effect of different treatments on TSS (ºBrix) of strawberry (Table 2). Treatment T_{13} [N P K (RDF) + Nano chitosan 100 ppm (Soil drenching) + foliar application of ZnO and FeO nano particles (NPs)] was found best and significantly the maximum TSS (ºBrix) i.e., [8.66 (1st year), 9.15 (2nd year) and 8.89 (pooled)] ºBrix according to both the years of study as well as pooled data. It was followed by treatment T_5 [N P K (RDF) + Bio capsule 500ppm (Soil drenching)] with 2nd best significant effect on TSS (ºBrix) of strawberryduring 1st year of study where-as treatment T_{14} [N P K (RDF) + Nano chitosan 100 ppm (Soil drenching) + Bio capsule 500ppm + foliar application of ZnO and FeO nano particles (NPs)] was found 2nd best during 2nd year as well as according to pooled data. However, least TSS (ºBrix) occurred in the treatment T_0 [Control (Without treatment)] with [6.4 (1st year), 6.17 (2nd year) and 6.29 (pooled)] ºBrix TSS.

Titrable Acidity (%). Significant differences in the effect of different treatments was observed on titrable acidity % (Table 2) of strawberry. Treatment T_{13} [N P K (RDF) + Nano chitosan 100 ppm (Soil drenching) + foliar application of ZnO and FeO nano particles (NPs)] was found best and recorded significantly the minimum Titrable Acidity (%) i.e., [0.96 (1st year), 1.02 (2nd year) and 0.99 (pooled)] % according to both the years of study as well as pooled data. It was followed by treatment T_6 [N P K (RDF) + Nano chitosan 100 ppm (Soil drenching)] and T_9 [Bio capsule 500ppm (Soil drenching) + foliar application of ZnO and FeO nano particles (NPs)] with 2nd best significant effect on titrable acidity % of strawberry whereas highest titrable acidity % occurred in the treatment T_{13} [N P K (RDF) + Nano chitosan 100 ppm (Soil drenching) + foliar application of ZnO and FeO nano particles (NPs)] with [1.37 (1st year), 1.45 (2nd year) and 1.4 (pooled)] % titrable acidity.

Ascorbic Acid (mg/100g of edible part). The findings of the experiment show that there are statistically significant differences between the effect of different treatments on ascorbic acid (mg/100g of edible part) of strawberry (Table 2). Treatment T_{13} [N P K (RDF) + Nano chitosan 100 ppm (Soil drenching) + foliar application of ZnO and FeO nano particles (NPs)] was found best and significantly the maximum ascorbic acid i.e., [53.05 (1st year), 56.74 (2nd year) and 54.88 (pooled)] mg per 100g of edible part according to both the years of study as well as pooled data. It was followed by treatment T_{12} [N P K (RDF) + Bio capsule 500ppm (Soil drenching) + foliar application of ZnO and FeO nano particles (NPs)] with 2nd best significant effect on ascorbic acid (mg/100g of edible part) of strawberry during 1st year of study as well as pooled data where-asduring 2nd year treatment T_5 [N P K (RDF) + Bio capsule 500ppm (Soil drenching)] was found 2nd best in ascorbic acid content of strawberry. However, least ascorbic acid (mg/100g of edible part) occurred in the treatment T_0 [Control (Without treatment)] with [32.42 (1st year), 31.10 (2nd year) and 31.76 (pooled)] mg per 100g of edible part ascorbic acid.

Table 2: Effect of Nano-chitosan, Nano-micronutrients and Bio capsules on TSS (°Brix), Titrable acidity (in 100 mg) and Ascorbic Acid (mg/100 g of edible part) of Strawberry (*Fragaria* × *ananassa*) cv. Winter dawn.

Sr. No.	Treatments	TSS (ºBrix)			Titrable acidity (in 100 mg)			Ascorbic Acid (mg/100 g of edible part)		
		2020-21	2021-22	Pooled	2020-21	2021-22	Pooled	2020-21	2021-22	Pooled
1.	T_0	6.4	6.17	6.29	1.23	1.31	1.26	32.42	31.1	31.76
2.	T_1	6.84	7.25	7.03	1.02	1.11	1.05	34.88	37.04	35.94
3.	T_2	7.77	7.86	7.8	1.17	1.26	1.2	40.09	40.46	40.26
4.	T_3	8.19	8.57	8.37	1.01	1.1	1.04	42.47	44.45	43.45
5.	T_4	6.9	7.45	7.16	1.18	1.27	1.21	35.24	38.15	36.68
6.	T_5	8.24	8.45	8.33	1.03	1.12	1.06	44.29	48.96	46.61
7.	T_6	7.31	8.31	7.8	0.97	1.06	1	37.52	40.11	38.8
8.	T_7	6.19	7.21	6.69	1.22	1.31	1.25	32.69	38.31	35.49
9.	T_8	7.86	8.07	7.95	1.1	1.19	1.13	43.91	48.58	46.23
10.	T_9	7.69	8.69	8.18	0.97	1.06	1	37.9	40.49	39.18
11.	T_{10}	6.87	7.89	7.37	1.19	1.27	1.22	33.37	38.99	36.17
12.	T_{11}	6.89	7.91	7.39	1.14	1.23	1.17	33.39	39.01	36.19
13.	T_{12}	7.94	7.65	7.78	1.24	1.32	1.27	48.37	46.89	47.62
14.	T_{13}	8.66	9.15	8.89	1.37	1.45	1.4	53.05	56.74	54.88
15.	T_{14}	8.07	9.07	8.56	0.96	1.02	0.99	38.28	40.87	39.56
F-Test		S	S	S	S	S	S	S	S	S
S. Ed. (±)		0.269	0.304	0.172	0.055	0.066	0.057	1.636	1.605	0.966
S. E. (m) (±)		0.19	0.215	0.122	0.039	0.047	0.04	1.157	1.135	0.683
C. D. (P = 0.05)		0.538	0.607	0.344	0.111	0.132	0.114	3.273	3.21	1.932

T_0: Control (Without treatment), **T_1**: N P K (RDF), **T_2**: Biocapsule 500ppm (Soil drenching), **T_3**: Nanochitosan 100 ppm (Soil drenching), **T_4**: Nanochitosan 100 ppm (Soil drenching) + Biocapsule 500ppm, **T_5**: N P K (RDF) + Biocapsule 500ppm (Soil drenching), **T_6**: N P K (RDF) + Nanochitosan 100 ppm (Soil drenching), **T_7**: N P K (RDF) + Nanochitosan 100 ppm (Soil drenching) + Biocapsule 500ppm, **T_8**: N P K (RDF) – foliar application of ZnO and FeO nano particles (NPs), **T_9**: Biocapsule 500ppm (Soil drenching)+ foliar application of ZnO and FeO nano particles (NPs), **T_{10}**: Nanochitosan 100 ppm (Soil drenching) + foliar application of ZnO and FeO nano particles (NPs), **T_{11}**: Nanochitosan 100 ppm (Soil drenching) + Biocapsule 500ppm + foliar application of ZnO and FeO nano particles (NPs), **T_{12}**: N P K (RDF) + Biocapsule 500ppm (Soil drenching) + foliar application of ZnO and FeO nano particles (NPs), **T_{13}**: N P K (RDF) + Nanochitosan 100 ppm (Soil drenching) + foliar application of ZnO and FeO nano particles (NPs) and **T_{14}**: N P K (RDF) + Nanochitosan 100 ppm (Soil drenching) + Biocapsule 500ppm + foliar application of ZnO and FeO nano particles (NPs).

Reducing sugar %. Significant differences in the effect of different treatments was observed on Reducing sugar % (Table 3) of strawberry. From the result it was depicted that treatment T_{13} [N P K (RDF) + Nano chitosan 100 ppm (Soil drenching) + foliar application of ZnO and FeO nano particles (NPs)] recorded the maximum reducing sugar [4.65 (1st year), 4.9 (2nd year) and 4.76 (pooled)] % where-as the minimum reducing sugar i.e., [3.45 (1st year), 3.34 (2nd year) and 3.4 (pooled)] % was recorded in T_0 [Control (Without treatment)]. During the 1st year Treatment T_5 [N P K (RDF) + Bio capsule 500ppm (Soil drenching)] was found with 2nd best significant effect on Reducing sugar % of strawberry where-as according to 2nd year and pooled analysed data treatment T_{14} [N P K (RDF) + Nano chitosan 100 ppm (Soil drenching) + Bio capsule 500ppm + foliar application of ZnO and FeO nano particles (NPs)] was found 2nd best treatment among all other treatment combination.

Non-Reducing sugar %. The results of the experiment show that there are statistically significant differences between the effect of different treatments on non-Reducing sugar % of strawberry (Table 3). It was depicted that treatment T_{13} [N P K (RDF) + Nano chitosan 100 ppm (Soil drenching) + foliar application of ZnO and FeO nano particles (NPs)] recorded the maximum non-reducing sugar of [1.46 (1st year), 1.62 (2nd year) and 1.52 (pooled)] % where-as the minimum non-reducing sugar i.e., [1.08 (1st year), 1.23 (2nd year) and 1.16 (pooled)] % was recorded in T_0 [Control

(Without treatment)].According to 1st year data, Treatment T_5 [N P K (RDF) + Bio capsule 500ppm (Soil drenching)] & T_{12} [N P K (RDF) + Bio capsule 500ppm (Soil drenching) + foliar application of ZnO and FeO nano particles (NPs)] were found 2nd best with 2nd best significant effect on non-Reducing sugar % of strawberry where-as during 2nd year, treatment T_3 [Nano chitosan 100 ppm (Soil drenching)] was found 2nd best among other. According to pooled data, only T_{12} [N P K (RDF) + Bio capsule 500ppm (Soil drenching) + foliar application of ZnO and FeO nano particles (NPs)] was found 2nd best.

Shelf life (days). The data regarding Shelf life (days) is shown in Table 3. From the data it was depicted that treatment T_{14} [N P K (RDF) + Nano chitosan 100 ppm (Soil drenching) + Bio capsule 500ppm + foliar application of ZnO and FeO nano particles (NPs)] recorded significantly the maximum Shelf life of [2.87 (1st year), 2.97 (2nd year) and 2.91 (pooled)] days where-as the lowest shelf life of [1.84 (1st year), 1.91 (2nd year) and 1.88 (pooled)] days was recorded in T_0 [Control (Without treatment)]. Here, effect of treatment T_{13} [N P K (RDF) + Nano chitosan 100 ppm (Soil drenching) + foliar application of ZnO and FeO nano particles (NPs)] was found 2nd best on shelf life of strawberry.

Table 3: Effect of Nano-chitosan, Nano-micronutrients and Bio capsules on Reducing Sugars, non-Reducing Sugars and Shelf life (days) of Strawberry (*Fragaria* × *ananassa*) cv. Winter dawn.

Sr. No.	Treatments	Reducing Sugars			Non-Reducing Sugars			Shelf life (days)		
		2020-21	2021-22	Pooled	2020-21	2021-22	Pooled	2020-21	2021-22	Pooled
1.	T_0	3.45	3.34	3.4	1.08	1.23	1.16	1.84	1.91	1.88
2.	T_1	3.67	3.88	3.76	1.2	1.38	1.28	2.05	2.15	2.09
3.	T_2	4.1	4.16	4.12	1.32	1.36	1.33	2.03	2.13	2.07
4.	T_3	4.31	4.51	4.39	1.4	1.49	1.43	1.96	2.06	2
5.	T_4	3.7	3.97	3.82	1.17	1.36	1.25	1.9	2	1.94
6.	T_5	4.53	4.41	4.46	1.36	1.44	1.38	2.16	2.26	2.2
7.	T_6	3.89	4.14	4	1.24	1.35	1.28	2.04	2.14	2.08
8.	T_7	3.19	3.69	3.42	1.07	1.27	1.15	1.96	2.06	2
9.	T_8	4.15	4.03	4.08	1.32	1.4	1.34	2.17	2.27	2.21
10.	T_9	4.27	4.52	4.38	1.28	1.39	1.32	2.13	2.23	2.17
11.	T_{10}	3.87	4.37	4.1	1.13	1.34	1.22	2.01	2.11	2.05
12.	T_{11}	3.89	4.39	4.12	1.14	1.34	1.22	2.03	2.13	2.07
13.	T_{12}	4.35	4.08	4.2	1.36	1.46	1.39	2.25	2.35	2.29
14.	T_{13}	4.65	4.9	4.76	1.46	1.62	1.52	2.59	2.69	2.63
15.	T_{14}	4.47	4.81	4.63	1.32	1.43	1.36	2.87	2.97	2.91
F-Test		S	S	S	S	S	S	S	S	S
S. Ed. (±)		0.139	0.175	0.104	0.044	0.043	0.028	0.052	0.041	0.039
S. E. (m) (±)		0.098	0.124	0.073	0.031	0.03	0.02	0.037	0.029	0.028
C. D. (P = 0.05)		0.279	0.35	0.207	0.088	0.085	0.057	0.104	0.083	0.078

T_0: Control (Without treatment), **T_1**: N P K (RDF), **T_2**: Biocapsule 500ppm (Soil drenching), **T_3**: Nanochitosan 100 ppm (Soil drenching), **T_4**: Nanochitosan 100 ppm (Soil drenching) + Biocapsule 500ppm, **T_5**: N P K (RDF) + Biocapsule 500ppm (Soil drenching), **T_6**: N P K (RDF) + Nanochitosan 100 ppm (Soil drenching), **T_7**: N P K (RDF) + Nanochitosan 100 ppm (Soil drenching) + Biocapsule 500ppm, **T_8**: N P K (RDF) – foliar application of ZnO and FeO nano particles (NPs), **T_9**: Biocapsule 500ppm (Soil drenching)+ foliar application of ZnO and FeO nano particles (NPs), **T_{10}**: Nanochitosan 100 ppm (Soil drenching) + foliar application of ZnO and FeO nano particles (NPs), **T_{11}**: Nanochitosan 100 ppm (Soil drenching) + Biocapsule 500ppm + foliar application of ZnO and FeO nano particles (NPs), **T_{12}**: N P K (RDF) + Biocapsule 500ppm (Soil drenching) + foliar application of ZnO and FeO nano particles (NPs), **T_{13}**: N P K (RDF) + Nanochitosan 100 ppm (Soil drenching) + foliar application of ZnO and FeO nano particles (NPs) and **T_{14}**: N P K (RDF) + Nanochitosan 100 ppm (Soil drenching) + Biocapsule 500ppm + foliar application of ZnO and FeO nano particles (NPs)

DISCUSSION

Treatment T_{14} [N P K (RDF) + Nano chitosan 100 ppm (Soil drenching) + Bio capsule 500ppm + foliar application of ZnO and FeO nano particles (NPs)] had the greatest effect and was the most significant in increasing strawberry production and improving strawberry quality.

Fruit weight (g) is one of the most critical criteria in assessing the yield per plant and ultimately yield per hectare of a crop. Increase in yield per plant in the treatment receiving chitosan spray may be due to its effects in stimulating physiological processes, improving vegetative growth, followed by active translocation of photo assimilates from source to sink tissues, resulting in an increase in number of flowers per plant, percentage of fruit set, berry length, berry volume, and berry diameter. Similar results were also obtained by Khan *et al.* (2002); Gornik *et al*. (2008) and Abdel-Mawgoud *et al*. (2010). On the other hand, decrease of yield and other yield attributing characters in water sprayed treatment might be due to moisture stress, hormonal imbalance, decrease in nutrient uptake and photo assimilation. Plants treated with water were more likely to contract phytophthora crown rot and two spotted spider mites than those treated with chitosan. Khan *et al.* (2002) also found similar results. Application of nano particles like ZnO and FeO could have also contributed in increasing the yield attributing characters of strawberry. Sabir *et al.* (2014) also observed 26-30 % increase in yield through use of Zn in form of nano particles as compared to use of conventional $ZnSO_4$. A positive effect of nano ZnO have also been reported by Kumar and Dey (2011) while working on strawberry. Application on these nano particles might have helped in formation of flower primordia due to synthesis of tryptophan resulting in higher yield (Davarpanah *et al.*, 2016).

The fruit's shelf life and its likelihood of being sold before it spoils are highly dependent on its quality. TSS, reducing sugars & non-reducing sugars were higher under treatment T_{14} [N P K (RDF) + Nano chitosan 100 ppm (Soil drenching) + Bio capsule 500ppm + foliar application of ZnO and FeO nano particles (NPs)]. These results are in agreement with those reported by Abdel-Mawgoud *et al.* (2010), who found that sugars to acid ratio increased significantly in response to chitosan application. This could be due to the application of nano chitosan along with bio capsules and other nano particles might have attributed in conversion of higher amount of organic acids (mainly citric and mallic acid) and photosynthates into sugars during fruit ripening stage (Sharma and Singh 1999), resulting in decreased titrable acidity % in fruits.

The ascorbic acid (mg/100g of pulp) content is also an important parameter determining the fruit quality. Application of treatment T_{14} resulted in increased ascorbic acid content of strawberry due to the presence of chitosan coating present on the surface of the fruit. It could be attributed due to low oxygen permeability around the fruit surface, chitosan coating might have lowered the oxygen level and reduced the activity of the ascorbic acid oxidase enzymes which may have prevented the oxidation of ascorbic acid in the fruit (Dang *et al*., 2010). This chitosan coating by reducing respiration and creating modified atmosphere not only helped in maintaining desirable ascorbic acid content of fruit but also helped in increasing its shelf life by increasing the membrane integrity of fruits (Sivakumar *et al*., 2005).

CONCLUSIONS

Based on the results, treatment T_{14}[N P K (RDF) + Nanochitosan 100 ppm (Soil drenching) + Biocapsule 500ppm + foliar application of ZnO and FeO nano particles (NPs)] was the most efficient treatment at boosting yield and quality characteristics. Despite the lack of synthetic inputs, biocapsules have been shown to increase strawberry plant growth, yield, and health by releasing compounds into the rhizosphere that may inhibit various diseases as biocontrol agents. This practice in production of strawberry can be forwarded to the strawberry farmers to enhance their production and productivity.

FUTURE SCOPE

The Role of Biocapsules (PGPRs), Chitosan and nano-micronutrients experimented in this trail can be exploited commercially to increase strawberry quality and quantity with doubling the farmers income.

REFERENCES

Abbasifar, A., Shahrabadi, F. and ValizadehKaji, B. (2020). Effects of green synthesized zinc and copper nano-fertilizers on the morphological and biochemical attributes of basil plant, *J. Plant Nutr*., *43*, 1104–1118.

Abdel-Aziz, H. M., Soliman, M. I., Abo Al-Saoud, A. M., & El-Sherbeny, G. A. (2021). Waste-Derived NPK Nanofertilizer Enhances Growth and Productivity of Capsicum annuum L. *Plants, 10*(6), 1144.

Abdel-Mawgoud, A. M. R., Tantawy, T. A., El-Nemr, M. A. and Sassine, Y. N. (2010). Growth and yield responses of strawberry plants to chitosan application. *European J. Sci. Res*., *39*(1), 170-177.

Al-Mamun, M. R., Hasan, M. Ahommed, M. S., Bacchu, M. S., Ali, M. R. and Khan, M. Z. H. (2021). Nano fertilizers towards sustainable agriculture and environment, *Environ. Technol. Innov*., *23*, 101658.

Anonymous (2019). Horticulture statistics at glance. Ministry of agriculture and farmers welfare, Government of India, pp. 9.

Chattopadhyay, T. K. (2013). A Textbook on Pomology. *Kalyani Publishers*, New Delhi. pp. 88-147.

Dang, Q. F., Yan, J. Q., Li, Y., Cheng, X. J., Liu, C. S. and Chen, X. G. (2010). Chitosan acetate as an active coating material and its effects on the storing of *Prunus avium* L. *J. Food Sci*., *75*, 125-131.

Davarpanah, S., Tehranifar, A., Davarynejad, G., Abadia, J. and Khorasani, R. (2016). Effects of foliar applications of zinc and boron nano-fertilizers on pomegranate (*Punica granatum* cv. *Ardestani*) fruit yield and quality. *Scientia Horticulturae, 210*, 57-64.

De Rosa, G., Lopez-Moreno, M. L., De Haro, D., Botez, C. E., Peralta Videa, J. E. and Gardea Torresdey, J. L. (2013). Effects of ZnO NPs nanoparticles in alfalfa, tomato, and cucumber at the germination stage. Root development and X-ray absorption spectroscopy studies. *Pure Appl. Chem.*, *85*(12), 2161–2174.

Fisher, R. A. (1950). Theory of Statistical Estimation. Pages 11.699a-11.725

Galletta, G. J., Lawrence, F. J. and Scott, D. H. (1990). Strawberry breeding work of the United States Department of Agriculture. *Hortic. Sci., 25*, 895–896.

Giampieri, F., Forbes-Hernandez, T. Y., Gasparrini, M., Afrin, S., Cianciosi, D. and Reboredo-Rodriguez, P. (2017). The healthy effects of strawberry bioactive compounds on molecular pathways related to chronic diseases. *Ann. NY. Acad. Sci., 1398*(1), 62-71.

Gornik, K. M., Grzesik and Duda, B. R. (2008). The effect of chitosan on rooting of grapevine cuttings and on subsequent plant growth under drought and temperature stress. *J Fruit Ornam. Plant Res*., *16*, 333-343.

Jackson, D., Looney, N., Morley, B. and Thiele, G. (2011). Temperate and subtropical fruit production, *Butterworths publication* 1987, New Zealand, 202-225.

Khan, M. H., Singha, K. L. B. and Panda, S. K. (2002). Changes in antioxidant levels in *Oryza sativa* L. roots subjected to NaCl salinity stress. *Acta Physiol. Plant*., *24*, 145-148.

Khan, M. R. and Rizvi, T. F. (2014). Nanotechnology: Scope and application in plant disease management. *Plant Pathol. J., 13*, 214–231.

Kumar, S. and Dey, P. (2011). Effects of different mulches and irrigation methods on root growth, nutrient uptake, water-use efficiency and yield of strawberry. *Sci. Hort., 127*, 318-324.

Mitra, S. K. (1991). The strawberry in: Temperate fruits, Horticulture. *Allied Publications*, Calcutta, India. pp. 549-96.

Sabir, S., Arshad, M. and Chaudhari, S. K. (2014). Zinc Oxide Nanoparticles for Revolutionizing Agriculture: Synthesis and Applications. *The Scientific World Journal*, Vol-14, Article ID- 925494.

Sharma, R. R. and Singh, S. K. (1999). Strawberry cultivation- a highly remunerative farming enterprise. *Agro Indian*, *3*(2), 29-31.

Sivakumar, D., Sultanbawa, Y., Ranasingh, N. and Wijesundera, R. L. C. (2005). Effect of the combined application of chitosan and carbonate salts on the incidence of anthracnose and on the quality of papaya

during storage. *J. Hortic. Sci. Biotechnol*, *80*(4), 447-452.
Wange, R. S. and Kzlogoz, G. A. (1998). Effect of biofertilizer on growth, yield and quality of strawberry. *Ann. Agric. Sci*., *43*(2), 247-254.
Zargar, S. M., Gupta, N., Nazir, M., Mahajan, R., Malik, F. A., Sofi, N. R., Shikari, A. B. and Salgatra, R. K. (2017). Impact of drought on photosynthesis: molecular perspective, *Plant Gene.*, *11*, 154–159.

How to cite this article: Ravi Kumar Singh, Saket Mishra and Vijay Bahadur (2023). Effect of Nano-chitosan, Nano-micronutrients and Bio Capsules on Yield and Quality of Strawberry (*Fragaria* × *ananassa*) cv. Winter Dawn. *Biological Forum – An International Journal, 15*(5): 289-295.