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Effect of biosynthesized nanoparticles on onion bulb production and shelf life of bulbs (*Allium cepa* L.)

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Abstract

Biosynthesized nanoparticles are an emerging technology which improves crop production and its quality without affecting the environment. The zinc oxide nanoparticles (ZnO NPs) and silver nanoparticles (Ag NPs) were synthesized by biological method using leaf extract of *Ocimum sanctum*. The particles size was characterized by UV-Visible spectrophotometer and transmission electron microscope (TEM). The characteristic absorbance peak was observed at 385 and 450 nm for ZnO NPs and Ag NPs, respectively to confirm the synthesis of nanoparticles. The particle size of biosynthesized ZnO NPs and Ag NPs was 30-80 nm and 25-75 nm, respectively. The foliar application of biosynthesized ZnO NPs and Ag NPs was undertaken at 45, 60 and 75 days after transplanting of the seedlings @ ZnO NPs 50 ppm (S_1), 75 ppm (S_2), 100 ppm (S_3), 150 ppm (S_4) and Ag NPs @ 50 ppm (S_5), 75 ppm (S_6), 100 ppm (S_7), 150 ppm (S_8) along with untreated control (S_9).

The ZnO NPs @ 150 ppm (S_4) was found superior for plant height (29.33, 59.20 and 60.00 cm at 30, 60 DAT and at harvest), number of leaves (3.87, 8.93 and 13.27 at 30, 60 DAT and at harvest), diameter of the bulb (0.88, 2.78 and 13.90 cm at 30, 60 DAT and at harvest), twin bulbs (2.73%), neck thickness (0.93 cm), bulb yield per plot (38.40 kg), bulb yield per ha (266.64 q) and marketable yield (97.44%). A remarkable result was also recorded in shelf life of onion bulbs. The treatment ZnO NPs @150 ppm (S_4) was found minimum rotting losses (3.97, 4.02 and 2.68% at 30, 60 and 90 days after storage of bulbs), sprouting losses (1.99, 1.98 and 1.93% at 30, 60 and 90 DAS), total losses (5.96, 6.00 and 4.61% at 30, 60 and 90 DAS) and physiological loss in weight (3.80, 9.81 and 17.33% at 30, 60 and 90 DAS) during storage of bulbs than untreated control (S_9).

Keywords: Onion, zinc oxide nanoparticles, silver nanoparticles, bulb production and shelf life

1. Introduction

Since prehistoric times, onions (*Allium cepa* L.) have been grown for food, medicine and as a major vegetable crop that is widely consumed worldwide. India is the world's third-largest exporter of onions, behind the Netherlands and Spain and the second-largest producer and area in the world after China. In India, onion productivity is lower than many other countries. This low productivity is caused due to abiotic and biotic stresses as well as the type of verity. Modern technologies can increase food yield and quality, potentially meeting the world's growing food demand. Nanotechnology may alter crop productivity and seems to have the potential to tackle the problem with food security (Anon., 2009) [1].

In addition to their massive surface area-to-volume ratio, nanoparticles microscopic pieces with a nanoscale dimension ranging from 1 to 100 nm have thermal conductivity, catalytic reactivity, nonlinear optical performance and chemical resilience. The physical, chemical and biological methods are to synthesize nanoparticles. However, because of the toxic chemical compounds used as reducing agents, the physical and chemical techniques are expensive, complicated and potentially environmentally hazardous. Green methods are economical and may be readily scaled up for the synthesis of nanoparticles. Chemical methods (precipitation, vapor transport, microwave solvothermal and hydrothermal processes) and biological methods (using various plant extracts) are used to synthesize ZnO NPs, an inorganic compound that appears as a white powder (Sabir *et al*., 2014, Tymoszuk and Wojnarowicz, 2020, Ali *et al*., 2018 and Wojnarowicz *et al*., 2020) [2-5]. Greenly synthesized nanoparticles are currently preferred over conventionally used nanoparticles due to their superior properties.

The potential of green synthesis methods for decreasing nanoparticle toxicity makes them appealing (Wankhade *et al.*, 2023) [6]. Nowadays, genetically engineered nanomaterial's are the most significant evidence for the field of nanotechnology. They are influencing all areas of existence for humans and according to their unique properties; their range of applications is rapidly growing in comparison to the comparable bulk materials (Roozbeh *et al.*, 2017) [7].

Because of their remarkable optical, physical and antibacterial qualities, zinc oxide nanoparticles have a lot of potential for enhancing agriculture. Both biotic and abiotic stresses influence seed growth and cause economic losses. Due to climate change and global warming, seeds are being exposed to more and more combinations of biotic and abiotic stresses, which negatively impact their development and yield. Seed germination and production of crops were found to be negatively impacted by drought, flood, salt, heavy mineral contamination, cold and heat. Numerous methods have been devised to address these issues, but each has its own set of limitations (Wankhade *et al.*, 2024) [8]. Therefore, the goal of this research is to find out the effect of biosynthesized ZnO NPs and Ag NPs influence onion bulb yield, quality and shelf life.

2. Materials and Methods

2.1 Protocol for biosynthesis of zinc oxide nanoparticles (ZnO NPs) and silver nanoparticles (Ag NPs) using leaf extract of *Ocimum sanctum* L.

2.1.1 Preparation of leaf extract of *Ocimum sanctum* L.

For the preparation of Tulsi (*Ocimum sanctum* L.) leaf extract, fresh tulsi leaves were taken in a beaker and washed several times with water to remove the dust and dirt. The leaves were kept for shade drying at room temperature. Weighed 10 g of shade dried leaves were cut into fine pieces and crushed with the help of mortar and pestle in 100 ml distilled water. After grinding the aqueous extract was taken in a 250 ml beaker and boiled at 80 °C temperature for 10 minutes in a hot water bath. The plant extract was allowed to cool at room temperature and then filtered with Whatman filter paper. The filtrate was centrifuged for 20 to 25 min. at 10,000 rpm, the supernatant light yellow in colour was collected and stored in a refrigerator at 4 °C for further synthesis of zinc oxide nanoparticles and silver nanoparticles.

2.1.2 Biosynthesis of silver nanoparticles (Ag NPs) using leaf extract of *Ocimum sanctum* L.

2.1.2.1 Preparation of 1 mM silver nitrate ($AgNO_3$) stock solution

The 1 mM silver nitrate solution was prepared by dissolving 0.169 g silver nitrate ($AgNO_3$) in 1000 ml distilled water and stored in amber coloured bottle to prevent the self-oxidation of silver nitrate solution.

2.1.2.2 Biosynthesis of silver nanoparticle (Ag NPs)

The 10 ml of tulsi leaf extract and 90 ml 1 mM silver nitrate solution ($AgNO_3$) (1:9 ratio) were mixed. The mixture was heated up at 70 °C for 10 min in a hot water bath. The colour of the solution turns from light yellow to reddish brown which indicates the formation of silver nanoparticles (Ag NPs). The biosynthesized Ag NPs were separated by the process of centrifugation (10,000 rpm for 25 min) and further obtained sediments were washed with distilled water and dried in a hot air oven at 100 °C for 40-45 min. The silver nanoparticles (Ag NPs) obtained were sparkling black in colour.

2.1.3 Biosynthesis of zinc oxide nanoparticles (ZnO NPs) using leaf extract of *Ocimum sanctum* L.

2.1.3.1 Preparation of 1 mM zinc acetate ($ZnC_4H_6O_4$) stock solution

The 1 mM zinc acetate solution was prepared by dissolving 0.219 g zinc acetate ($ZnC_4H_6O_4$) in 1000 ml distilled water and stored in ambient condition for further use.

2.1.3.2 Biosynthesis of zinc oxide nanoparticles (ZnO NPs)

The synthesis of zinc oxide nanoparticles was done by mixing 30 ml of leaf extract and 70 ml of 1mM Zinc Acetate solution (3:7 ratio). The mixture was heated at 80°C for 10 min in a hot water bath. The colour of the solution turns from light yellow to dark yellow indicating the synthesis of zinc oxide nanoparticles. The synthesized ZnO NPs were separated by the process of centrifugation from the reaction mixture (10,000 rpm for 25 min.) and further obtained sediments were washed with distilled water and dried in a hot air oven at 100 to 130 °C for 40-45 min. The powder obtained from ZnO NPs was light yellow in colour.

2.2 Characterization of nanoparticles

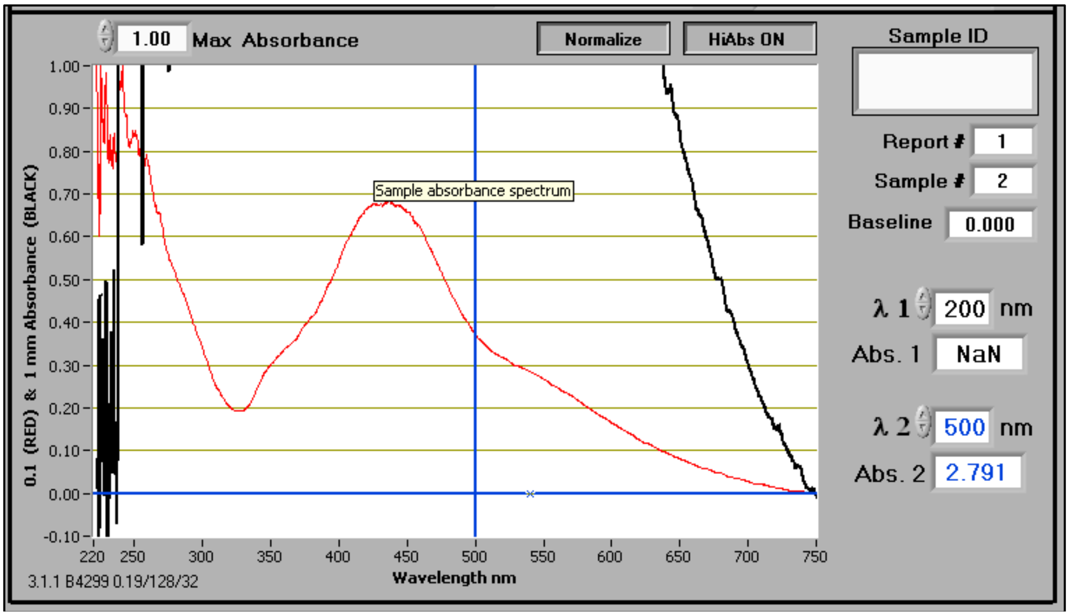
The biosynthesized zinc oxide nanoparticles (ZnO NPs) and silver nanoparticles (Ag NPs) were confirmed by sharp peaks shown by the absorption spectrum in Nanodrop 1000 spectrophotometer (Thermo Scientific) at 385 and 450 nm, respectively at the State Level Biotechnology Centre, MPKV, Rahuri (Fig. 1).

The size of biosynthesized zinc oxide nanoparticles (ZnO NPs) and silver nanoparticles (Ag NPs) were found 30-80 nm and 25-75 nm, respectively (Fig. 1) was characterized by Transmission Electron Microscopy (Jeol Asia Pvt., Ltd., Singapore) at Eco-friendly Disease Management and Beneficial Microbes Research Laboratory, MPKV, Rahuri.

The biosynthesized zinc oxide nanoparticle (ZnO NPs) and silver nanoparticles (Ag NPs) were confirmed by sharp peaks shown by the absorption spectrum in Nanodrop 1000 spectrophotometer (Thermo Scientific) at 385 and 450 nm, respectively at the State Level Biotechnology Centre, MPKV, Rahuri.

2.3 Experimental details

The field experiment entitled effect of biosynthesized zinc oxide nanoparticles (ZnO NPs) and silver nanoparticles (Ag NPs) on bulb production onion and its quality were laid down during *kharif*, 2022 in Randomized Block Design (RBD) with three replications. The seed of the onion variety *Phule Samarth* was used. The experiment was conducted in the field of Seed Technology Research Unit, MPKV, Rahuri.



1.00 Max Absorbance

Report # 1

Sample # 2

Baseline 0.000

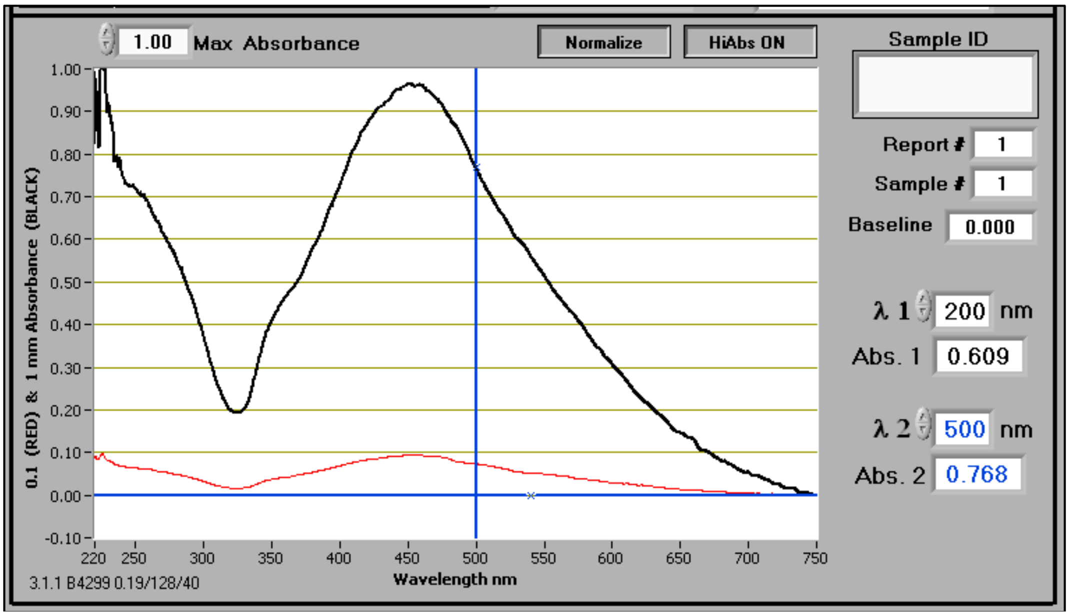
λ 1 200 nm

Abs. 1 NaN

λ 2 500 nm

Abs. 2 2.791

A) Absorbance of biosynthesized zinc oxide nanoparticles (ZnO NPs) at 385 nm



1.00 Max Absorbance

Report # 1

Sample # 1

Baseline 0.000

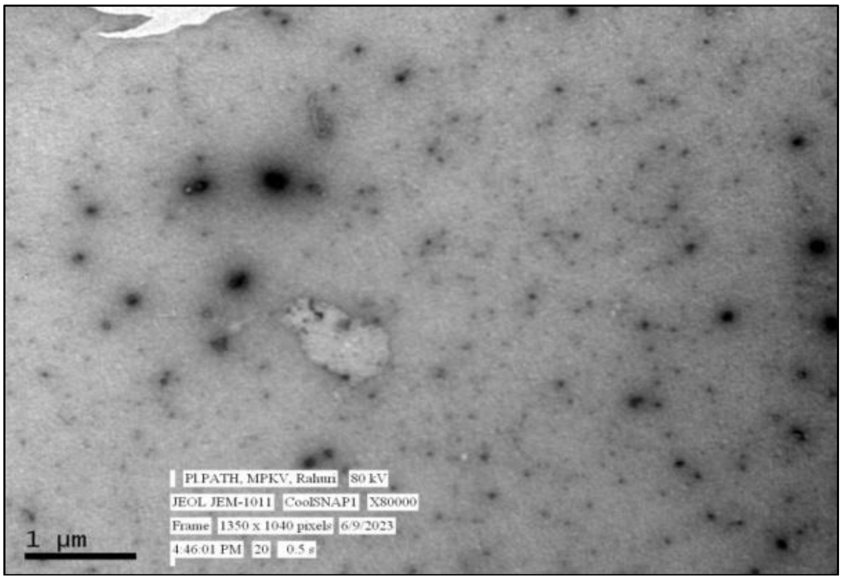
λ 1 200 nm

Abs. 1 0.609

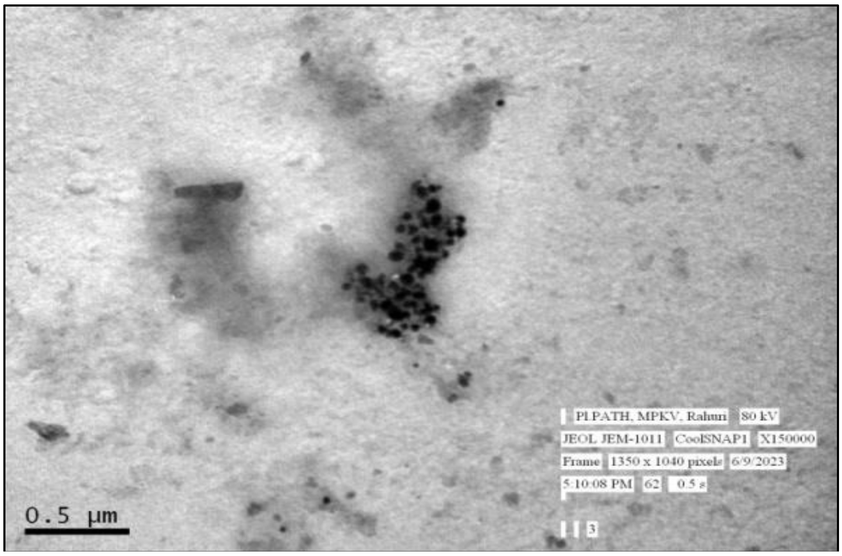
λ 2 500 nm

Abs. 2 0.768

B) Absorbance of biosynthesized silver nanoparticles (Ag NPs) at 450 nm



C) Size of biosynthesised zinc oxide nanoparticles (ZnO NPs) 30-80 nm



D) Size of biosynthesised silver nanoparticles (Ag NPs) 25-75 nm

Fig 1: Characterization of biosynthesized of zinc oxide nanoparticles (ZnO NPs) and silver nanoparticles (Ag NPs).

2.4 Treatments Details

The foliar application of biosynthesized zinc oxide nanoparticles (ZnO NPs) and silver nanoparticles (Ag NPs) was undertaken at 45, 60 and 75 days after transplanting of the seedlings.

S_1: Zinc oxide nanoparticles (ZnO NPs) @ 50 ppm
S_2: Zinc oxide nanoparticles (ZnO NPs) @ 75 ppm
S_3: Zinc oxide nanoparticles (ZnO NPs) @ 100 ppm
S_4: Zinc oxide nanoparticles (ZnO NPs) @ 150 ppm
S_5: Silver nanoparticles (Ag NPs) @ 50 ppm
S_6: Silver nanoparticles (Ag NPs) @ 75 ppm
S_7: Silver nanoparticles (Ag NPs) @ 100 ppm
S_8: Silver nanoparticles (Ag NPs) @ 150 ppm
S_9: Untreated control

2.5 Observations recorded

2.5.1 Plant height

The five plants from each treatment were selected randomly, labelled and plant heights were recorded in centimetre at 30, 60 DAT and at harvest.

2.5.2 Number of leaves

The number of leaves were counted from the randomly selected plants which was recorded at 30, 60 DAT and at harvest.

2.5.3 Diameter of bulb

The soil around the bulbs of selected plants were removed carefully without disturbing the bulbs or root system and diameter was measured by a digital vernier calliper and the soil was placed again. The observation was taken at 30 and 60 days after transplanting of seedlings and at the time of harvesting and expressed in centimeter.

2.5.4 Twin bulbs

The number of twin bulbs (after harvesting) were counted and percentage was calculated over the total number of bulbs in each plot. The premature bolting was calculated by using following the formula.

$$\text{Twin bulbs (\%)} = \frac{\text{Number of twin bulbs}}{\text{Total number of bulbs}} \times 100$$

2.5.5 Neck thickness after filed curing

The neck thickness was measured (after field curing) by digital vernier calliper of five randomly selected bulbs and expressed in centimetre.

2.5.6 Bulb yield per plot

The bulbs obtained from each net plot were weighed and recorded in kilograms.

2.5.7 Bulb yield

The bulb yield per hectare was calculated by multiplying the bulb yield per plot by the hectare factor and recorded in quintal.

2.5.8 Marketable yield

The obtained bulbs, twin bulbs, defective and shrinked bulbs were separated (from each plot) and the weight of healthy bulbs was recorded. The marketable bulbs were calculated by using following the formula.

$$\text{Marketable yield (\%)} = \frac{\text{Weight of the healthy bulbs (kg)}}{\text{Total bulb weight (kg)}} \times 100$$

2.5.9 Storage of bulbs

The onion bulbs from each plot were stored at ambient conditions up to 90 days and percent rotting, sprouting losses, total losses and physiological weight loss was estimated as storage losses.

2.5.10 Rotting losses

The rotted bulbs were separated and weighed from stored onion bulbs at 30, 60 and 90 days after storage of onion bulbs. The rotting losses (%) were calculated by using the following formula (Wolelaw *et al*., 2014) [9].

$$\text{Rotting losses (\%)} = \frac{\text{Weight of rotted bulbs (g)}}{\text{Initial weight of bulbs (g)}} \times 100$$

2.5.11 Sprouting losses

The sprouted bulbs were separated and weighed from stored onion bulbs at 30, 60 and 90 days after storage of onion bulbs. The sprouting losses (%) were calculated by using the following formula (Wolelaw *et al*., 2014) [9].

$$\text{Sprouting losses (\%)} = \frac{\text{Weight of sprouted bulbs (g)}}{\text{Initial weight of bulbs (g)}} \times 100$$

2.5.12 Total losses

The weight of sprouted and rotted bulbs was subtracted from the initial weight of bulbs and converted into a percentage to get total losses.

2.5.13 Physiological weight loss

The physiological weight loss in onion was the weight loss due to its normal biological activities. The physiological weight loss was calculated by using the following formula (Falayi and Yusuf, 2014) [10].

$$\text{PWL (\%)} = \frac{\text{Initial bulb weight (0 DAS)-Fresh bulb weight (g) wt. at 30, 60 and 90 DAS}}{\text{Initial weight of bulbs (g)}} \times 100$$

3. Results and Discussion

A experimentation study entitled “Effect of biosynthesized nanoparticles on onion bulb production and shelf life of bulbs (*Allium cepa* L.) was undertaken to mitigate the challenges in improving the bulb production and maintaining the quality of bulbs.

The field experiment was conducted at Seed Technology Research Unit, Mahatma Phule Krishi Vidyapeeth, Rahuri during *Kharif 2022*. The laboratory studies for biosynthesis of nanoparticles and characterization were carried out at Department of Biochemistry, MPKV, Rahuri, State Level Biotechnology Centre, Eco-friendly Disease Management and Beneficial Microbs Research Laboratory, Mahatma Phule Krishi Vidyapeeth, Rahuri. The findings of the present experimentation as well as relevant result and discussion are as below.

3.1 Plant height

It was observed that the plant height of onion gradually increased with the advancement of crop growth period irrespective biosynthesized nanoparticles treatment. Initially, non-significant differences were recorded among the different concentrations of biosynthesized nanoparticles at 30 days after transplanting of seedlings. However, significant differences were recorded at 60 days after transplanting of seedlings and at harvesting of onion bulbs. The foliar application of biosynthesized zinc oxide nanoparticles (ZnO NPs) @ 150 ppm (S_4) recorded highest plant height at 60 days after transplanting (59.20 cm) of onion seedlings and at harvest (60.00 cm) of onion bulbs, followed by foliar application with biosynthesized silver nanoparticles (Ag NPs) @ 100 ppm (S_7) at 60 days after transplanting (57.67 cm) and at harvest of onion bulbs (56.93 cm), respectively. The lowest plant height (51.53 and 51.00 cm) was exhibited in untreated control (S_9) at 60 days after transplanting of onion seedlings and at harvest of onion bulbs, respectively (Table 1).

Both the biosynthesized nanoparticles showed growth-promoting effects on onion plants as compared to the untreated control. However, the biosynthesized ZnO NPs generally resulted in higher plant heights compared to biosynthesized Ag NPs. It is concluded that foliar application of both biosynthesized ZnO NPs and Ag NPs significantly enhance the growth of onion seedlings compared to the untreated control.

The zinc-rich ZnO NPs may boost the amount of IAA in roots, which speed up seedling growth of onion. It enhances cation-exchange capacity of the roots, which in turn enhances absorption of essential nutrients (Shyla and Natarajan, 2014) [11]. Patra *et al*., (2013) [12] reported that ZnO NPs foliar spray with a limited concentration of 10 mg/L remarkably increased the plant biomass, shoots and root length and root area of cluster bean. Laware and Raskar (2014) [13] stated that, foliar application of ZnO NPs @ 20µg ml^{-1} on onion plant which increseae plant height over control. The similar results were found by Munir *et al.*, (2018) [14] in wheat, Sun *et al.*, (2020) [15] in tomato and Adil *et al*., (2022) [16] in wheat.

Similarly, according to Salama (2012) [17], Ag NPs improved plant growth characteristics in *B. juncea*, *P. vulgaris* and *Z. mays*, including root and shoot length and leaf area. The similar trends were stated by Seif *et al*., (2011) [18] in Borago, Noshad *et al*., (2019) [18] in tomato and Ikhajiagbe and Musa, (2020) [20] in rice.

3.2 Number of leaves

It was observed that the number of leaves in onion gradually increased with the advancement of crop growth period irrespective biosynthesized nanoparticles treatment. Initially, non-significant differences were recorded among the different concentrations of biosynthesized nanoparticles at 30 days after transplanting of seedlings. However, significant differences were recorded at 60 days after transplanting of seedlings and at harvesting of onion bulbs. The foliar application of biosynthesized zinc oxide nanoparticles (ZnO NPs) @ 150 ppm (S_4) recorded highest number of leaves at 60 days after transplanting (8.93) of onion seedlings and at harvest (13.27) of onion bulbs, followed by foliar application of silver nanoparticles (Ag NPs) @ 100 ppm (S_7) at 60 days after transplanting (8.67) and at harvest (13.00), respectively. The lowest number of leaves was exhibited in untreated control (S_9) at 60 days after transplanting (7.80) of onion seedlings and at harvest (11.47)) of onion bulbs, respectively (Table 1).

Both the biosynthesized nanoparticles showed growth promoting effects on onion plants as compared to the untreated control. However, the biosynthesized ZnO NPs generally resulted in higher number of leaves compared to biosynthesized Ag NPs. It is concluded that the foliar application of both biosynthesized ZnO NPs and Ag NPs significantly enhance number of leaves of onion seedlings compared to the untreated control.

The zinc oxide nanoparticles interact in collaboration with meristematic cells and metabolic processes to promote characteristics of growth (Faizan and Hayat, 2019) [21]. Similarly recorded higher number of leaves in withania plants by Peiman *et al*., (2022) [22] and rice by Singh *et al.*, (2023) [23], respectively.

3.3 Bulb diameter

Initially, bulb diameters were recorded non-significant differences among the different concentrations of biosynthesized nanoparticles at 30 days after transplanting of seedlings. However, significant differences were recorded at 60 days after transplanting of seedlings and at harvesting of onion bulbs.

The foliar application of biosynthesized zinc oxide nanoparticles (ZnO NPs) @ 150 ppm (S_4) recorded highest bulb diameter at 60 days after transplanting (2.78 cm) of onion seedlings and at harvest (13.90 cm) of onion bulbs, followed by foliar application of silver nanoparticle (Ag NPs) @ 100 ppm (S_7) at 60 days after transplanting (2.73 cm) and at harvest (13.62 cm), respectively. The lowest bulb diameter was exhibited in untreated control (S_9) at 60 days after transplanting (2.07 cm) of onion seedlings and at harvest (10.07 cm) of onion bulbs, respectively (Table 1).

The biosynthesized nanoparticles (ZnO NPs and Ag NPs) showed growth promoting effects on onion plants as compared to the untreated control. It is concluded that the foliar application of both biosynthesized ZnO NPs and Ag NPs significantly enhances the bulb diameter of onion as compared to the untreated control.

According to Harris and Mathuma (2015) [24], fruit quality, specifically fruit size, is mostly influenced by the zinc nutrient. The zinc is necessary to tomato for fruit set, fruit length and fruit diameter, as well as for the metabolism of RNA and the stimulation of protein, carbohydrate and DNA synthesis. Similarly, Das *et al.,* (2018) [25] found that applying silver nanoparticles (Ag NPs) at 100 ppm to onion seedlings resulted in maximum equatorial diameter, polar diameter, ten bulb weights and number of rings.

3.4 Twin bulb

The foliar application of biosynthesized zinc oxide nanoparticles (ZnO NPs) @ 150 ppm (S_4) recorded lowest twin bulb after harvesting (2.73%) of onion bulbs followed by silver nanoparticle (Ag NPs) @ 100 ppm (S_7) (2.88 %), respectively. The highest twin bulb was exhibited in untreated control (S_9) at harvest (5.27%) of onion bulbs (Table 1).

The biosynthesized nanoparticles showed desirable quality parameter of onion bulbs as compared to the untreated control. However, the biosynthesized ZnO NPs generally resulted in lower twin bulbs compared to biosynthesized Ag NPs. It is concluded that the foliar application of both biosynthesized ZnO NPs and Ag NPs significantly reduces the neck thickness onion bulbs as compared to the untreated control.

3.5 Neck thickness

The foliar application of biosynthesized zinc oxide nanoparticle (ZnO NPs) @ 150 ppm (S_4) recorded lowest neck thickness after field curing (0.93 cm) of onion bulbs followed by silver nanoparticle (Ag NPs) @ 100 ppm (S_7) (0.96 cm), respectively. The highest neck thickness was exhibited in untreated control (S_9) after field curing (1.66 cm) of onion bulbs (Table 1). Both the biosynthesized nanoparticles showed growth promoting effects on onion plants as compared to the untreated control. However, the biosynthesized ZnO NPs generally resulted in lower neck thickness compared to biosynthesized Ag NPs. It is concluded that the foliar application of both biosynthesized ZnO NPs and Ag NPs significantly reduces the neck thickness of onion bulbs as compared to the untreated control.

Table 1: Effect of biosynthesized zinc oxide nanoparticles (ZnO NPs) and silver nanoparticles (Ag NPs) on onion bulb production and quality of bulbs.

Treatments	**Plant height (cm)**			**Number of leaves**			**Bulb diameter (cm)**			**Twin bulbs (%) At Harvest**	**Neck thickness (cm) after field curing**
	30 DAT	**60 DAT**	**At Harvest**	**30 DAT**	**60 DAT**	**At Harvest**	**30 DAT**	**60 DAT**	**At Harvest**		
S_1 (ZnO NPs @ 50 ppm)	28.53	52.73	52.40	3.87	8.20	11.73	0.88	2.21	11.86	3.83 (11.28)	1.14
S_2 (ZnO NPs @ 75 ppm)	29.20	55.33	54.47	3.87	8.40	11.93	0.83	2.25	12.01	3.67 (11.04)	1.13
S_3 (ZnO NPs @ 100 ppm)	28.87	55.93	56.87	3.80	8.60	12.33	0.89	2.36	12.31	3.72 (11.12)	1.12
S_4 (ZnO NPs @ 150 ppm)	29.33	59.20	60.00	3.87	8.93	13.27	0.88	2.78	13.90	2.73 (9.51)	0.93
S_5 (Ag NPs @ 50 ppm)	28.47	49.67	53.33	3.80	8.07	12.40	0.95	2.40	11.85	3.47 (10.73)	1.15
S_6 (Ag NPs @ 75 ppm)	28.60	52.40	52.20	3.93	8.13	11.73	0.87	2.23	11.21	3.39 (10.57)	1.10
S_7 (Ag NPs @ 100 ppm)	29.13	57.67	56.93	3.93	8.67	13.00	0.95	2.73	13.62	2.88 (9.76)	0.96
S_8 (Ag NPs @ 150 ppm)	28.87	53.13	55.00	3.73	7.80	11.33	0.87	2.23	11.10	3.05 (10.05)	1.26
S_9 (Untreated control)	28.67	51.53	51.00	3.87	7.80	11.47	0.89	2.07	10.07	5.27 (13.27)	1.66
SE(±)	0.399	0.693	1.399	0.098	0.126	0.366	0.103	0.028	0.316	0.343	0.033
CD @5%	NS	2.078	4.193	NS	0.378	1.10	NS	0.083	0.948	1.029	0.098

NS-Non significant

DAT-Days after transplanting of seedlings

3.6 Bulb yield per plot

The significant differences were recorded among the different concentrations of biosynthesized nanoparticles (Table 2). The foliar application with biosynthesized zinc oxide nanoparticles (ZnO NPs) @ 150 ppm (S_4) recorded the highest bulb yield per plot (38.40 kg) followed by silver nanoparticles (Ag NPs) @ 100 ppm (S_7) (37.71 kg), respectively. The lowest bulb yield per plot was exhibited with untreated control (S_9) (29.31 kg). The results concluded that, both ZnO NPs and Ag NPs have the potential to enhance onion bulb yield per plot compared to the untreated control.

The beneficial effect of zinc on root proliferation, which permits greater absorption of nutrients from the soil, further translocation of the nutrients to the aerial parts and an increase in plant biomass. Raliya *et al.,* (2016) [26] found that using ZnO NPs increased enzymatic activity of phosphatase and phytase, with Zn acting as a cofactor. Increased chlorophyll content (improved photosynthetic efficiency) was also observed, which can be linked to increased soluble protein and starch content, as well as dry matter (Faizan *et al.*, 2018, Kolencik *et al.*, 2022 and Esper *et al.*, 2020) [27-29] indicating the role of ZnO NPs in enhancing plant growth and productivity. The similar trend of effect of ZnO NPs on yield per plot was observed by Wang *et al.*, (2018) [30] and Adil *et al.*, (2022) [16] in wheat, Razu *et al.*, (2022) [31] in tomato, Kisan *et al.*, (2015) [32] in Spinach, Davarpanah *et al.*, (2016) [33] in pomegranate, Yacoub *et al.*, (2020) [34] and

Yusefi-Tanha *et al.,* (2020) [35] in Soybean, Keerthana *et al.,* (2021) [36] in Okra and Kumar *et al.,* (2023) [37] in Chickpea.

According to Govorov and Carmeli (2007) [38], the enhancement of yield attributes subsequent foliar application of Ag NPs may be the result of silver's functioning as a growth regulator. Acharya *et al.,* (2019) [39], Noshad *et al.,* (2019) [19] and Acharya *et al.,* (2020) [40] conducted studies on the application of silver nanoparticles in watermelon, tomato and onion respectively and reported parallel trends with improved yields.

3.7 Bulb yield per ha

The significant differences were recorded among the different concentrations of biosynthesized nanoparticles (Table 2). The highest bulb yield per ha was recorded by foliar application with biosynthesized zinc oxide nanoparticles (ZnO NPs) @ 150 ppm (S_4) (266.64 q) followed by silver nanoparticles (Ag NPs) @ 100 ppm (S_7) (261.87 q), respectively. The lowest bulb yield per ha was exhibited with untreated control (S_9) (203.55q). Both the biosynthesized nanoparticles resulted in higher bulb yield per ha as compared to the untreated control. However, the biosynthesized ZnO NPs generally resulted in higher bulb yield per ha as compared to biosynthesized Ag NPs. It is concluded that the foliar application of both biosynthesized ZnO NPs and Ag NPs significantly enhance the yield of onion bulbs as compared to the untreated control.

According to the findings of this study, metal nanoparticles such as Ag and ZnO have significant effects on photosynthetic systems by increasing the rate of photosynthesis, which in turn increases plant growth and biomass and ultimately, yield (Raliya and Tarafdar, 2013, Latef *et al.,* 2016 and Tawfik *et al.,* 2017) [41-43]. Wang *et al.,* (2018) [30], ZnO NPs greatly improved tomato shoot growth, chlorophyll content and photosynthetic efficiency, which raised yield. According to Wagi and Ahmed (2019) [44], nanoparticles interact with plant hormones and antioxidants to enhance plant growth and yield. According to Wasaya *et al.,* (2020) [45], foliar spraying of Ag and ZnO NPs on greengram which boosted seed production, demonstrating that the increased yield is due to improved photosynthesis during crop growth. Similar findings have been identified by Pandya *et al.,* (2024) [46] in wheat, Soliman *et al.,* (2015) [47] in *Moringa peregrine* and Gupta *et al.,* (2022) [48] in cucumber while employing ZnO NPs.

According to Das *et al.,* (2018) [25], the highest yield was obtained by applying 100 ppm of silver nanoparticles (Ag NPs) to onion seedlings as opposed to the control. Silver nanoparticles (Ag NPs) have been reported to increase yields in fenugreek (Sadak, 2019) [49], Mung beans (Saeideh and Rashid, 2014) [50] and *Borage officinalis* (Seif *et al.,* 2011) [18].

3.8 Marketable yield

The foliar application of biosynthesized zinc oxide nanoparticles (ZnO NPs) @ 150 ppm (S_4) recorded highest marketable yield (97.44%) followed by foliar application of silver nanoparticles (Ag NPs) @ 100 ppm (S_7) (97.19%), respectively. The lowest marketable yield was exhibited in untreated control (S_9) (87.25%) after harvest of onion bulbs (Table 2). It appears that ZnO NPs generally resulted in higher marketable yield as compared to Ag NPs than untreated control. The results suggested that the ZnO NPs and Ag NPs have the potential to enhance marketable yield of onion bulbs compared to the untreated control.

The foliar application of Ag NPs @ 100 ppm on onion at 45, 60 and 75 days after planting of bulbs, recorded higher marketable yield than untreated control at bulb storage studies Das *et al.,* (2018). The fruit quality, marketability and productivity of pomegranate were all enhanced by zinc oxide nanoparticles (ZnO NPs) treatments, particularly at 200, 300 and 400 ppm (Amer *et al.,* 2020) [51].

3.9 Rotting losses

The significance differences were recorded among the different concentrations of biosynthesized nanoparticles at 30, 60 and 90 days after storage of onion bulbs (Table 2). The rotting losses of onion bulbs decrease at 90 days of onion bulb storage. The lowest rotting losses were recorded in foliar application of biosynthesized zinc oxide nanoparticle (ZnO NPs) @ 150 ppm (S_4) (2.68%) followed by silver nanoparticles (Ag NPs) @ 100 ppm (S_7) (2.91%), respectively. The highest rotting losses were exhibited in untreated control (S_9) at 90 days of bulb storage (4.78%), respectively. It is concluded that the foliar application of both biosynthesized ZnO NPs and Ag NPs significantly reduces rotting losses and enhance the keeping quality of onion bulbs during storage as compared to the untreated control.

Similar results are found by Das *et al.,* (2018) [25] when Ag NPs @ 100 ppm are applied on onion plants at 45, 60 and 75 days after planting of bulbs, which recorded minimum rotting percentage in storage studies than untreated control.

3.10 Sprouting losses

The significance differences of sprouting losses were recorded among the different concentrations of biosynthesized nanoparticles at 30, 60 and 90 days of onion bulbs storage. The sprouting losses decrease at 90 days of onion bulb storage (Table 2). The lowest sprouting losses were recorded in foliar application of biosynthesized zinc oxide nanoparticles (ZnO NPs) @ 150 ppm (S_4) (1.93%) followed by silver nanoparticles (Ag NPs) @ 100 ppm (S_7) (2.20%), respectively. The highest sprouting losses were exhibited in untreated control (S_9) at 90 days of onion bulb storage (5. 79%). The biosynthesized zinc oxide nanoparticles and silver nanoparticles (ZnO NPs and Ag NPs) showed enhanced bulbs quality of onion as compared to the untreated control. It is stated that foliar application of both biosynthesized ZnO NPs and Ag NPs significantly reduces the sprouting losses and enhance the keeping quality of onion bulbs during storage as compared to the untreated control.

Table 2: Effect of biosynthesized zinc oxide nanoparticles (ZnO NPs) and silver nanoparticles (Ag NPs) on onion bulb production and quality of bulbs during storage.

Treatments	Bulb yield (kg/plot)	Bulb yield (q/ha)	Marketable yield (%)	Rotting losses (%)			Sprouting losses (%)		
				30 DAS	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS
S_1 (ZnO NPs @ 50 ppm)	32.81	227.82	95.86 (78.26)	4.87 (12.74)	5.19 (13.16)	3.60 (10.93)	3.17 (10.25)	3.45 (10.25)	2.73 (9.50)
S_2 (ZnO NPs @ 75 ppm)	34.72	241.11	95.59 (77.88)	4.76 (12.60)	4.70 (12.51)	3.45 (10.71)	2.84 (9.68)	3.03 (10.02)	2.66 (9.36)
S_3 (ZnO NPs @ 100 ppm)	35.30	245.11	95.67 (78.99)	4.55 (12.32)	4.58 (12.35)	3.07 (10.09)	2.56 (9.18)	2.83 (9.69)	2.43 (8.96)
S_4 (ZnO NPs @ 150 ppm)	38.40	266.64	97.44 (80.79)	3.97 (11.49)	4.02 (11.57)	2.68 (9.42)	1.99 (8.10)	1.98 (8.08)	1.93 (7.97)
S_5 (Ag NPs @ 50 ppm)	35.02	243.19	96.38 (79.03)	4.60 (12.39)	4.55 (12.32)	3.30 (10.47)	2.82 (9.67)	3.05 (10.05)	2.68 (9.41)
S_6 (Ag NPs @ 75 ppm)	34.54	239.84	96.38 (79.04)	4.70 (12.52)	4.78 (12.62)	3.27 (10.42)	2.83 (9.67)	3.26 (10.40)	2.47 (9.02)
S_7 (Ag NPs @ 100 ppm)	37.71	261.87	97.19 (80.35)	4.43 (12.15)	4.29 (11.95)	2.91 (9.82)	2.28 (8.67)	2.22 (8.56)	2.20 (8.53)
S_8 (Ag NPs @ 150 ppm)	34.49	239.52	95.80 (78.18)	4.60 (12.38)	4.94 (12.84)	3.71 (11.11)	2.81 (9.64)	3.27 (10.41)	2.90 (9.79)
S_9 (Untreated control)	29.31	203.55	87.25 (69.08)	7.82 (16.22)	6.28 (14.45)	4.78 (12.60)	5.85 (13.99)	6.73 (14.59)	5.79 (13.70)
SE(±)	0.338	2.349	0.439	0.236	0.390	0.274	0.295	0.925	0.620
CD @5%	1.014	7.043	1.317	0.708	1.170	0.821	0.885	2.774	1.859
NS-Non significant	DAS-Days after storage of bulbs				Figures in parenthesis are arcsine transformed values				

3.11 Total losses

The significance differences were recorded among the different concentrations of biosynthesized nanoparticles at 30, 60 and 90 days of onion bulbs storage. The total losses of bulbs decrease at 90 days of onion bulb storage. The lowest total losses were recorded in foliar application of biosynthesized zinc oxide nanoparticles (ZnO NPs) @ 150 ppm (S_4) (4.61%) followed by silver nanoparticle (Ag NPs) @ 100 ppm (S_7) (5.12%), respectively. The highest total losses were exhibited in untreated control (S_9) at 90 days of onion bulb storage (10.57%), respectively. Both the biosynthesized nanoparticles showed enhanced quality of onion bulbs during storage as compared to the untreated control. However, the biosynthesized ZnO NPs generally resulted in lower total losses as compared to biosynthesized Ag NPs. It is concluded that foliar application of both biosynthesized ZnO NPs and Ag NPs significantly reduces total losses and enhance the keeping quality of onion bulbs during storage as compared to the untreated control.

When biosynthesized Ag NPs were applied externally to wheat plants at a concentration of 75 mgL^{-1}, Sidra *et al.*, (2022) [52] found that this decreased the yellow rust caused on by *Puccinia striiformis* disease.

3.12. Physiological loss in weight

The significance differences were recorded among the different concentrations of biosynthesized nanoparticles at 30, 60 and 90 days of onion bulbs storage (Table 3). The physiological loss in weight of bulbs decreases at 90 days of onion bulb storage. The lowest physiological loss in weight were recorded in foliar application of biosynthesized zinc oxide nanoparticles (ZnO NPs) @ 150 ppm (S_4) (17.23%) followed by silver nanoparticles (Ag NPs) @ 100 ppm (S_7) (17.63%), respectively. The highest physiological losses in weight were exhibited in untreated control (S_9) at 90 days of onion bulb storage (40.17%). The biosynthesized ZnO NPs and Ag NPs generally resulted in lower physiological loss in weight as compared to untreated control. It is concluded that ZnO NPs and Ag NPs significantly reduces the physiological loss in weight and enhance the storage life of onion bulbs compared to the untreated control.

Similar results are found by Das *et al.*, (2018) [25] when Ag NPs @ 100 ppm are applied on onion plants at 45, 60 and 75 days after planting of bulbs, which recorded minimum physiological losses in weight at three months of storage studies.

Table 3: Effect of biosynthesized zinc oxide nanoparticles (ZnO NPs) and silver nanoparticles (Ag NPs) on quality of bulbs during storage.

Treatments	Total losses (%)			Physiological loss in weight (%)		
	30 DAS	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS
S_1 (ZnO NPs @ 50 ppm)	8.03 (16.46)	8.64 (17.08)	6.33 (14.58)	5.98 (14.06)	12.80 (20.87)	23.75 (29.11)
S_2 (ZnO NPs @ 75 ppm)	7.61 (16.01)	7.72 (16.14)	6.11 (14.31)	5.07 (13.00)	11.10 (19.45)	21.25 (27.44)
S_3 (ZnO NPs @ 100 ppm)	7.11 (15.46)	7.41 (15.80)	5.50 (13.57)	4.60 (12.38)	10.54 (18.94)	20.48 (26.90)
S_4 (ZnO NPs @ 125 ppm)	5.96 (14.12)	6.00 (14.18)	4.61 (12.39)	3.80 (11.24)	9.81 (18.94)	17.23 (24.52)
S_5 (Ag NPs @ 50 ppm)	7.43 (15.81)	7.60 (16.00)	5.99 (14.16)	5.65 (13.66)	11.41 (19.73)	18.38 (25.38)
S_6 (Ag NPs @ 75 ppm)	7.53 (15.92)	8.04 (16.47)	5.74 (13.86)	5.92 (13.92)	11.80 (20.05)	20.31 (26.78)
S_7 (Ag NPs @ 100 ppm)	6.71 (15.01)	6.51 (14.78)	5.12 (13.07)	4.15 (11.75)	10.13 (18.56)	17.63 (24.82)
S_8 (Ag NPs @ 125 ppm)	7.42 (15.79)	8.21 (16.65)	6.61 (14.90)	6.39 (14.58)	12.60 (20.76)	13.91 (20.14)
S_9 (Untreated control)	13.67 (21.68)	13.01 (20.86)	10.57 (18.82)	11.46 (19.71)	23.75 (28.99)	40.17 (39.29)
SE(±)	0.318	0.957	0.628	0.686	0.974	2.247
CD @5%	0.954	2.868	1.883	2.055	0.921	6.735
	DAS-Days after storage of bulbs			Figures in parenthesis are arcsine transformed values		

4. Conclusions

1. The foliar application of biosynthesized zinc oxide nanoparticles (ZnO NPs) @ 150 ppm (S_4) at 45, 60 and 75 days after transplanting of the seedling, improved the growth and yield parameters *viz.*, plant height, number of leaves, bulb diameter, twin bulb percentage, neck thickness, bulb yield per plot, bulb yield per ha and marketable yield than untreated control.
2. The foliar application of biosynthesized zinc oxide nanoparticles (ZnO NPs) @ 150 ppm (S_4) at 45, 60 and 75 days after transplanting of the seedling, improved the shelf life of onion bulbs which reduces rotting losses, sprouting losses, total losses and physiological weight loss than untreated control.
3. It was concluded that foliar application of biosynthesized zinc oxide nanoparticles (ZnO NPs) and silver nanoparticles (Ag NPs) showed positive effect on bulb production and shelf life of onion bulbs var. *Phule Samarth.*

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