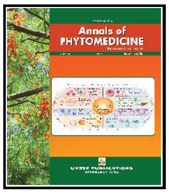
Annals of Phytomedicine 15(1): 900-910, 2026

DOI: http://dx.doi.org/10.54085/ap.2026.15.1.81

Annals of Phytomedicine: An International Journal

http://www.ukaazpublications.com/publications/index.php

Print ISSN : 2278-9839 Online ISSN : 2393-9885



Original Article : Open Access

Enhancement of yield and nutritional quality of potato tuber to combat malnutrition through application of biosynthesized nanoparticles against common scab of potato (*Streptomyces scabies*)

Shivam Kumar*◆, Keerti, Prakash Chandra Tripathy***, Umara Rahmani****, Mansi Mishra***, Ankit Rai***** and Sultan Singh******

** Department of Plant Pathology, Chandra Shekhar Azad University of Agriculture & Technology, Kanpur-208002, Uttar Pradesh, India*
*** Department of Horticulture, C.S.J.M. University, Kanpur-208024, Uttar Pradesh, India*
**** Division of Crop Protection, ICAR-Indian Sugarcane Research Institute, Lucknow-226002, Uttar Pradesh, India*
***** Department of Plant Pathology, Sardar Vallabhbhai Patel University of Agriculture & Technology, Meerut-250110, Uttar Pradesh, India*
****** Department of Entomology, Acharya Narendra Deva University of Agriculture & Technology, Ayodhya-224 229, Uttar Pradesh, India*
******* Faculty of Agriculture, Maharishi Markandeshwar Deemed to be University, Mullana, Ambala-133207, Haryana, India*

Article Info

Article history
Received 1 April 2026
Revised 30 April 2026
Accepted 1 May 2026
Published Online 30 June 2026

Keywords
Streptomyces scabies
Potato yield
Tuber quality
Malnutrition
Ag NPs
ZnO NPs
CuO NPs
MnO NPs
Fe_3O_4 NPs

Abstract

The quality of potato crop is affected by biotic agents, which can negatively impact crop growth, productivity, and quality of potato tuber. However, nanoparticles hold great promise for increasing potato yield, maintaining tuber quality, and thus mitigating biotic stresses. Therefore, the current study was conducted to examine the influences of different biosynthesized nanoparticles, *viz*., Ag, ZnO, CuO, MnO_2 and Fe_3O_4 NPs on the yield and quality traits of potato tubers grown under field conditions. The observations showed that the maximum number of large, medium, small size tubers were harvested from T_5 treatment [T.T. with Azad Nanobiocide (1 Ag NPs : 1 ZnO NPs) @ 200 ppm for 30 min + 3 F.S. of Azad Nanobiocide (1 Ag NPs : 1 ZnO NPs) @ 200 ppm at 45, 60 and 75 DAS], representing 369 tubers large (with total weight 47.04 kg), 658 tubers medium (with total weight 52.55 kg), 548 tubers small (with total weight 21.26 kg) and 380 tubers large (with total weight 48.94 kg), 660 tubers medium (with total weight 54.35 kg), 543 tubers small (with total weight 21.38 kg), during 2022-23 and 2023-24, respectively. Similarly, the maximum yield of potato tubers were harvested in T5 treatment, showing as 122.40 kg/45 m^2 (272.00 q/ha) and 126.74 kg/45 m^2 (281.64 q/ha), during both years 2022-23 and 2023-24, respectively. The data revealed that there was a significantly increase in nutritional quality of potato tuber after application of biosynthesized nanoparticles in all the treatments as compared to the control during 2022-23 and 2023-24 cropping season. Moreover, significant and positive correlations were found among yield and quality traits of potato plants. Thus, it can be concluded that using T5 treatment, significantly improves potato production, productivity and quality traits by mitigating the negative effects of biotic stresses.

1. Introduction

Potato (*Solanum tuberosum* L.) is the most significant vegetable crop in the world, belonging to the family Solanaceae, which designated as a 'Poor Men's Friend. It is a temperate crop, growing and yielding well in cool and humid climates, but it is also cultivated in tropical to sub-polar climatic regions, and represents a major food crop in many Asian countries, particularly in India (Motalebifard, 2017). The potato crop is grown in almost all states of India, except Kerala, under a wide range of agro-climatic conditions (Kumar and Chandra, 2018). Out of 100% total area of potatoes, 90% area is located in subtropical plains, 6% in the hills and the rest 4% located in the plateau region of peninsular India (Chadha, 2009). The potato crop is growing in about 150 countries of the world. The total harvested area of the world in 2023 is about 16.8 million hectares, a decrease from 18.1 million hectares in 2022. Despite this, total production rose to 383 million metric tons in 2023 from 375 million metric tons the previous year, indicating enhanced yield efficiencies. The FAOSTAT (updated in late December, 2024), data revealed that approximately 383 million metric tonnes of potatoes were produced globally in 2023-24, with China (93.49 million metric tons), India (60.14 million metric tons), and Ukraine (21.35 million metric tonnes). The list continued with the United States, Russia, Germany, Bangladesh, France, Poland, and the Netherlands, marking the top 10 potato producing countries. During the fiscal year 2024-25, India's potato production was accounted to be 60.18 million tonnes, which was an increase of 3.13 million tonnes from the previous fiscal year as 57.05 million tonnes (Source: Business Line citing government data, June, 2025). The area got declined and still the production was higher. This shows the productivity level has increased and the efforts of agriculturist scientists in developing high yielding and disease resistant varieties have been fruitful in raising the production. In India, potato is extensively cultivated in Uttar Pradesh followed by West Bengal, Bihar, Gujarat, Madhya Pradesh, Punjab, Haryana,

Corresponding author: Dr. Shivam Kumar
Department of Plant Pathology, Chandra Shekhar Azad University of Agriculture and Technology, Kanpur-208002, Uttar Pradesh, India
E-mail: shivamrajput11238@gmail.com
Tel.: +91-9997534790

Assam, Jharkhand and Chhattisgarh. Majority of the Indian potato came from northern state of Uttar Pradesh, which ranks first in potato production in India and contribute alone 32 per cent of the total production in India (Source: Ministry of Agriculture and Farmer Welfare).

Potato is a versatile, carbohydrate rich food, its content dry matter, edible energy, edible protein and some other beneficial micronutrients are very high when compared with other root and tuber crops (Khalid *et al*., 2020). It is a highly popular carbohydrate rich food in many parts of the world, and is used both for table consumption as well as in processed products. Freshly harvested potato tubers contain around 80% water and 20% dry matter content (Wichrowska, 2022) and about 60 to 80 per cent of the dry matter is starch. On a dry weight basis, potato protein content is similar to cereals but very high when compared with other root and tuber crops. In addition, potatoes contains lower amount of fat (0.10%) but good source of minerals, *i.e*., potassium, phosphorus, magnesium, and various vitamins like C, B_1, and B_3. Potato is a moderate source of iron, and its high vitamin C content promotes iron absorption to prevent loss of vitamins. Potato also contain bioactive compounds are glycoalkaloids such as α-solanil and α-chaconine, which are mainly concentrated in the peel and outer layers of the tuber and act as natural defence compounds (Friedman, 2026). The tuber also rich in phenolic compounds, particularly chlorogenic acid, along with caffeic acid, ferulic acid, and flavonoids like quercetin, which are known for their strong antioxidant properties (Brown, 2005; Ezekiel *et al.,* 2013). The dietary antioxidants, which play a part in preventing diseases related to ageing, and dietary fiber as 1-2 g/100 g fresh weight, which is benefited for digestive health. In addition, dietary fiber from potatoes contributes to better glycemic control by slowing down the digestion and absorption of carbohydrates, which helps in maintaining stable blood glucose levels and is useful in managing diabetes. It also play plays a role in cardiovascular health by helping to lower cholesterol levels and reducing the risk of heart diseases. The unpeeled potatoes contain more dietary fibers than peeled potatoes and it help in lowering cholesterol levels. Pharmacologically, these phytochemicals impart several beneficial biological activities. The phenolic compounds and vitamin C exhibit potent antioxidant activity by scavenging free radicals and reducing oxidative stress (Brown, 2005). Anti-inflammatory effects are contributed to flavonoids and phenolic acids such as chlorgenic acid (Ezekiel *et al.,* 2013). Glycoalkaloids, although toxic at high concentration, have demonstrated antimicrobial and potential anticancer activities when present in control control ammounts (Friedman, 2006). The high potassium content support cardiovascular health by regulating blood pressure (Burlingame *et al.,* 2009). In India, potato is the most popular vegetable crop, at present most of the domestic supply of potatoes is consumed as fresh harvested (68%), processing (7.5%) and as a seed (8.5%) and the rest of the 16% destroyed due to some other reasons. Potato is used for making of Chips, Finger chips, Papad, Flour, and Kurkure, *etc.*

Potato starch is an important ingredient of pharmaceuticals, petroleum, and used in the food industry as thickeners and binders of soups and sauces, and in the textile industry for manufacturing of papers, plastics, adhesive, and boards (Gopal and Khurana, 2006). Moreover, potatoes are also used as fodder for domestic animals. It is also used as alcoholic beverages such as Vodka. The juice of the potato is a dark colored liquid due to the presence of citric and succinic acids. Potato also contains a glycol-alkaloids called solanine. It contains nearly 5 mg solanine per 100 g fresh weight which is far less than the safety limit of 20 mg / 100 g. Pineda *et al* (2022) reported that silver nanoparticles (Ag NPs) are known for their antimicrobial properties, which is why they have become an alternative to traditional plant protection products. This is particularly important nowadays, when efforts are being made to reduce the use of chemical protection products (Bawskar *et al.,* 2021). Despite the antimicrobial properties of protectants, they not only affect the physiology of pathogens eliminating the pathogenic threat but also affect the physiological processes of the plant. Previous reports indicate that, depending on the plant species and its morphological and physiological conditions, the effect of Ag NPs can be either positive, resulting in plant growth and development, or negative inducing DNA damages, causing decrease in the activity of the antioxidant system or breakdown of the cytoplasmic membrane (Yan *et al.,* 2019). In current work, we have hypothesized that tuber treatment and foliar application of Ag NPs, ZnO NPs, CuO NPs, MnO NPs, and Fe_3O_4 NPs at different 150 and 200 ppm concentration and improving the nutritional quality and yield potential of potato tubers. This paper, describes the relationship between methodology of biosynthesis and accumulation of nanoparticles in plants and tubers and increase the nutritional properties of tubers in field potato cultivation.

2. Materials and Methods

2.1 Experiment location

The experiment was conducted at the experimental field area of Student Instructional Form (SIF), Chandra Shekhar Azad University of Agriculture and Technology, Kanpur-208002, Uttar Pradesh, India.

2.2 Collection of seed tuber

Truly labelled potato seed tubers of variety "Kufri Jyoti" was collected from Vegetable Research Farm, Chandra Shekhar Azad University of Agriculture & Technology, Kalyanpur, Kanpur (Uttar Pradesh) to conduct my experiment. The seed tuber of potato crop was sown in 60 x 20 cm (row to row distance 60 cm and plant to plant distance 20 cm) and 15 cm deep in ridge of the plots. The experiment design was laid out in randomized block design (RBD). Three replication per treatment and three plots were sown with untreated seed tuber serve as control.

2.3 Treatment details

The treatments are given as follow:

$\mathbf{T_1}$ = Tuber treatment with biosynthesized Ag NPs @ 150 ppm for 30 min + Three foliar spray with same biosynthesized Ag NPs @ 150 ppm at 45, 60, 75 DAS

$\mathbf{T_2}$ = Tuber treatment with biosynthesized Ag NPs @ 200 ppm for 30 min + Three foliar spray with same biosynthesized Ag NPs @ 200 ppm at 45, 60, 75 DAS

$\mathbf{T_3}$ = Tuber treatment with biosynthesized ZnO NPs @ 150 ppm for 30 min + Three foliar spray with same biosynthesized ZnO NPs @ 150 ppm at 45, 60, 75 DAS

$\mathbf{T_4}$ = Tuber treatment with biosynthesized ZnO NPs @ 200 ppm for 30 min + Three foliar spray with same biosynthesized ZnO NPs @ 200 ppm at 45, 60, 75 DAS

T_5 = Tuber treatment with biosynthesized Azad Nanobiocide @ 200 ppm for 30 min + Three foliar spray with same biosynthesized Azad Nanobiocide @ 200 ppm at 45, 60, 75 DAS

T_6 = Tuber treatment with biosynthesized CuO NPs @ 150 ppm for 30 min + Three foliar spray with same biosynthesized CuO NPs @ 150 ppm at 45, 60, 75 DAS

T_7 = Tuber treatment with biosynthesized CuO NPs @ 200 ppm for 30 min + Three foliar spray with same biosynthesized CuO NPs @ 200 ppm at 45, 60, 75 DAS

T_8 = Tuber treatment with biosynthesized MnO NPs @ 150 ppm for 30 min + Three foliar spray with same biosynthesized MnO NPs @ 150 ppm at 45, 60, 75 DAS

T_9 = Tuber treatment with biosynthesized MnO NPs @ 200 ppm for 30 min + Three foliar spray with same biosynthesized MnO NPs @ 200 ppm at 45, 60, 75 DAS

T_{10} = Tuber treatment with biosynthesized Fe_3O_4 NPs @ 150 ppm for 30 min + Three foliar spray with same biosynthesized Fe_3O_4 NPs @ 150 ppm at 45, 60, 75 DAS

T_{11} = Tuber treatment with biosynthesized Fe_3O_4 NPs @ 200 ppm for 30 min + Three foliar spray with same biosynthesized Fe_3O_4 NPs @ 200 ppm at 45, 60, 75 DAS

T_{12} = Control (Healthy)

T_{13} = Control (Infected)

2.4 Seed tuber treatment

The seed tubers of variety 'Kufri Jyoti' were treated with each biosynthesized nanoparticles (Ag NPs, ZnO NPs, CuO NPs, MnO NPs, and Fe_3O_4 NPs) at different (150 and 200 ppm) concentration for 30 min just before sowing in the field.

2.5 Foliar spray with different biosynthesized nanoparticles (Ag NPs, ZnO NPs, CuO NPs, MnO NPs, Fe_3O_4 NPs)

At 40 days after sowing (DAS), soil inoculated with spore suspension of *S. scabies* (10^6 cfu / ml) and after 120 h plants were sprayed with each biosynthesized nanoparticles (Ag NPs, ZnO NPs, CuO NPs, MnO NPs, and Fe_3O_4 NPs) at different 150 and 200 ppm concentration. Three spray schedules were given at 15 days interval. First spray will be given at 45 DAS followed 60 DAS and 75 DAS**.** Battery operated knapsack sprayer with a hollow cone nozzle was used for foliar spray.

2.6 Harvesting

The haulms of the crop were cut in the last week of February and potato tuber were allowed to remain in ridges for 15-20 days. In the month of March, the crop was harvested manually.

2.7 Effect of biosynthesized nanoparticles on yield parameters of potato under field conditions

To explore the possible effect of biosynthesized nanoparticles, *e.g.,* Ag, ZnO, CuO, MnO, and Fe_3O_4 NPs on yield parameters of potato**.** The observations on number of tuber per plant, tuber diameter per plant, tuber weight per plot and grading of tuber as number of large, medium and small size tubers were taken separately from individual treatment. Four plants from each replication of the treatment were selected randomly and their number of tubers were counted, diameter of tuber or tuber size (mm) was recorded by using Vernier caliper, weight of tubers (g) taken by digital electronic weighing balance, grading of tuber according to weight and size and then averaged. We are categorise larger tuber >100 g, medium size tuber 50-100 g and small size tuber <50 g. The healthy tubers and scab infected tubers of potato were counted during the month of March, when the crop is harvested and calculate the yield of potato by taking weight of all potato in terms of kg.

2.8 Quality analysis of potato tubers

Tuber samples from all treatments were collected at harvest to determine the nutritional quality traits, *viz.,* protein, carbohydrates, fat, energy, vitamin C, P, K, Ca, Mg, Na, Zn, Cu, Mn and Fe.

2.8.1 Protein estimation of potato tuber

The protein content of the tubers is commonly estimated by the Kjeldahl's method, which determines total nitrogen and convert into protein. In this method, a known weight of fresh or dried potato sample is digested with concentrated sulfuric acid in the presence of a catalyst, converting organic nitrogen into ammonium sulphate. The digest is then made alkaline and distilled to release ammonia, which is absorbed in a standard acid solution and subsequently titrated. The amount of nitrogen obtained is multiplied by a conversion factor (6.25) to estimate the crude protein content, expressed as g per 100 g of sample.

Crude protein (%) = Nitrogen content (%) × 6.25.

2.8.2 Carbohydrate estimation of potato tuber

Carbohydrate content in potato tubers is commonly estimated by the anthrone method, a known amount of potato sample is homogenized and hydrolyzed using dilute acid to convert complex carbohydrates such as starch into simple sugars. An aliquot of this extract is then treated with freshly prepared anthrone reagent in presence of concentrated sulphuric acid. Upon heating in a boiling water bath, carbohydrates react with anthrone to produce a green colored complex. The intensity of the color is measured using spectrophotometer at around 620 nm, and the carbohydrate concentration is calculated using a standard glucose curve. Alternatively, total carbohydrate content in the potato sample is expressed in mg per 100 g of sample.

2.8.3 Fat estimation of potato tuber

The fat content of potato tubers can be estimated using the Soxhlet extraction method, where dried and ground tuber samples are extracted with an organic solvent such as petroleum ether or hexane for several hours to remove the lipid fraction. The solvent is then evaporated, and the residue is weighed to determine total fat content (AOAC). This method provides a reliable measure of the lipid fraction in potato tubers, which is generally low compared to other tuber components.

2.8.4 Energy estimation of potato tuber

The energy content of potato tubers is commonly estimated by determining their major biochemical constituents, *e.g.,* carbohydrates, proteins, and fats and then calculating total energy using standard conversion factors. Fresh potato samples are cleaned, weighed, and homogenized. Carbohydrates are usually estimated by difference or by methods such as anthrone, proteins by the Kjeldahl method, and fats by solvent extraction (*e.g.,* Soxhlet apparatus). The total energy is then calculated using at factors 4 kcal/g for carbohydrates, 4 kcal/g for proteins, and 9 kcal/g for fats. The energy value is expressed as kcal per 100 g of fresh weight.

2.8.5 Vitamin C estimation of potato tuber

Vitamin C in potato tubers is commonly determined using the 2,6-dichlorophenolindo phenol (DCPIP) titration method, which is based on the reducing property of ascorbic acid. In this method, fresh potato samples are peeled, weighed, and homogenized with metaphosphoric acid or oxalic acid to prevent oxidation of vitamin C. The extract is filtered and made up to a known volume. A standard ascorbic acid solution is first titrated with DCPIP to determine the dye factor. Then an aliquot of the potato extract is titrated with the dye until a light pink color persists, indicating the endpoint. The amount of vitamin C is calculated using the volume of dye consumed and expressed as mg per 100 g of sample.

2.8.6 P, K, Ca, Mg, Fe, and Zn estimation of potato tuber

The estimation of phosphorus (P) in potato tubers is generally carried out after digestion of the dried plant material using a mixture of nitric and perchloric acids, followed by colorimetric determination using the vanadomolybdate yellow method (AOAC, 2005; Jackson, 1973; Piper, 1966). Potassium (K) is similarly extracted through acid digestion and quantified using flame photometry or atomic absorption spectroscopy (Jackson, 1973). For calcium (Ca) and magnesium (Mg), the digested sample is analyzed either by atomic absorption spectroscopy or complexometric titration with EDTA (Jones *et al.,* 1991; Chapman and Pratt, 1961). The microelements iron (Fe) and zinc (Zn) are determined after nitricperchloric acid digestion, with Fe measured using either colorimetric methods, such as phenanthroline, or atomic absorption spectroscopy, while Zn is quantified primarily by atomic absorption spectroscopy (Piper, 1966; Jones *et al.,* 1991). These methods provide reliable estimation of the essential minerals in potato tubers and are widely used in plant analytical studies.

2.9 Statistical analysis

The field experiment was conducted in a randomized block design (RBD) and *in vitro* experiment under lab conditions conducted in completely randomized design (CRD). The presented values from each experiment were done in triplicates of each treatment and analysis of data through one-way analysis of variance (ANOVA). The critical difference was calculated at 5 per cent of significance and F value was tested for comparing treatment means. C.D. was calculated by following formula:

$$\text{C.D} = \frac{\sqrt{2\text{VE}}}{\text{r}} \times \text{'t' at } 5\%$$

where,

C.D. = Critical difference, VE = Error variance and r = No. of replication is the value at 5% level of significance for error degree of freedom. The significance and non-significance of the treatments at 5% level of probability were calculated out by multiplying the S.Ed. with appropriate tabulated value for error degrees of freedom.

3. Results

3.1 Effect of different biosynthesized nanoparticles on tuber number, size, and yield of potato against common scab of potato under field conditions during 2022-23 and 2023-24

The effect of tuber treatment and foliar spray of different biosynthesized nanoparticles, *viz.,* Ag NPs, CuO NPs, ZnO NPs, MnO NPs and Fe_3O_4 NPs on tuber number, size and yield of potato was studied after harvesting during 2022-23 and 2023-24 cropping season. The potato tubers were graded as large (more than 100 g), medium (50-100 g) and small (less than 50 g) in size.

3.1.1 Large size tuber (>100 g)

The observations on number and size of potato tuber data represented in Tables 1, 2 and Figures 1, 2, showed that the maximum number of large size tubers were harvested from T_5 treatment [T.T. with Azad Nanobiocide (1 Ag NPs : 1 ZnO NPs) @ 200 ppm for 30 min + 3 F.S. of Azad Nanobiocide (1 Ag NPs : 1 ZnO NPs) @ 200 ppm at 45, 60 and 75 DAS], representing 369 tubers, with total weight 47.04 kg and 380 tubers, with total weight 48.94 kg, during 2022-23 and 2023-24, respectively, followed by T_2 treatment [T.T. with Ag NPs (*P. fluorescens*) @ 200 ppm for 30 min + 3 F.S. of Ag NPs (*P. fluorescens*) @ 200 ppm at 45, 60 and 75 DAS], showing 358 tubers, with total weight 46.18 kg and 372 tubers, with total weight 48.12 kg during 2022-23 and 2023-24, respectively, and T_4 treatment [T.T. with ZnO NPs (*P. fluorescens*) @ 150 ppm for 30 min + 3 F.S. of ZnO NPs (*P. fluorescens*) @ 200 ppm at 45, 60 and 75 DAS] showing as 350 tubers, with total weight 42.68 kg and 365 tubers, with total weight 47.31 kg during 2022-23 and 2023-24, respectively. Among all the treatments, the minimum number of large sized tubers was recorded in T_{13} treatment (Infected control), representing as 240 tubers, each with total weight 37.55 kg and 246 tubers, each with total weight 39.55 kg, during 2022-23 and 2023-24 cropping seasons, respectively.

3.1.2 Medium size tuber (50-100 g)

Similarly, the maximum number of medium size tubers were harvested from T_5 treatment [T.T. with Azad Nanobiocide (1 Ag NPs : 1 ZnO NPs) @ 200 ppm for 30 min + 3 F.S. of Azad Nanobiocide (1 Ag NPs : 1 ZnO NPs) @ 200 ppm at 45, 60 and 75 DAS], representing 665 tubers, with total weight 54.10 kg and 671 tubers, with total weight 55.64 kg, during 2022-23 and 2023-24, respectively, followed by T_2 treatment [T.T. with Ag NPs (*P. fluorescens*) @ 200 ppm for 30 min + 3 F.S. of Ag NPs (*P. fluorescens*) @ 200 ppm at 45, 60 and 75 DAS], showing 658 tubers, with total weight 52.55 kg and 660 tubers, with total weight 54.35 kg during 2022-23 and 2023-24, respectively, and T_4 treatment [T.T. with ZnO NPs (*P. fluorescens*) @ 200 ppm for 30 min + 3 F.S. of ZnO NPs (*P. fluorescens*) @ 200 ppm at 45, 60 and 75 DAS] showing as 650 tubers, with total weight 51.72 kg and 649 tubers, with total weight 53.48 kg during 2022-23 and 2023-24, respectively. The treatment T_7 [T.T. with CuO NPs (*Bacilus subtilis*) @ 200 ppm for 30 min + 3 F.S. of CuO NPs (*Bacilus subtilis*) @ 200 ppm at 45, 60 and 75 DAS], representing as 639 tubers, with total weight 50.45 kg and 634 tubers, with total weight 52.25 kg during 2022-23 and 2023-24, respectively, representing 4th highest number of medium size potato tubers among all the treatments. Among all the treatments, the minimum number of medium size tubers was recorded in T_{13} treatment (Infected control), representing as 512 tubers, with total weight 40.85 kg and 503 tubers, with total weight 42.60 kg, during 2022-23 and 2023-24 cropping seasons, respectively.

3.1.3 Small size tuber (<50 g)

On other hand, the maximum number of small size tubers were harvested from T_5 treatment [T.T. with Azad Nanobiocide (1 Ag NPs : 1 ZnO NPs) @ 200 ppm for 30 min + 3 F.S. of Azad Nanobiocide (1 Ag NPs : 1 ZnO NPs) @ 200 ppm at 45, 60 and 75 DAS], representing 548 tubers, with total weight 21.26 kg and 554 tubers, with total weight 22.16 kg, during 2022-23 and 2023-24, respectively, followed by T_2 treatment [T.T. with Ag NPs (*P. fluorescens*) @ 200 ppm for 30 min + 3 F.S. of Ag NPs (*P. fluorescens*) @ 200 ppm at 45, 60 and 75 DAS], showing 542 tubers, with total weight 20.34 kg and 543 tubers, with total weight 21.38 kg during 2022-23 and 2023-24, respectively. The minimum number of small size tubers was recorded in T_{13} treatment (Infected control), representing as 396 tubers, with total weight 11.80 kg and 399 tubers, with total weight 12.25 kg, during 2022-23 and 2023-24 and treatment T_{12} (Healthy control) second lowest number of small size tubers among all the treatments, sowing as 415 tubers, with total weight 12.42 kg and 418 tubers, with total weight 13.62 kg during 2022-23 and 2023-24, respectively.

3.2 Yield of potato (q/ha)

The effect of tuber treatment and foliar spray with different biosynthesized nanoparticles, *viz.,* Ag NPs, CuO NPs, ZnO NPs, MnO NPs and Fe_3O_4 NPs on yield of potato was studied after harvesting during 2022-23 and 2023-24. The observations of yield of potato illustrated in Tables 1 and 2 showed that the maximum yield of potato tubers were harvested from T_5 treatment [T.T. with Azad Nanobiocide (1 Ag NPs : 1 ZnO NPs) @ 200 ppm for 30 min + 3 F.S. of Azad Nanobiocide (1 Ag NPs : 1 ZnO NPs) @ 200 ppm at 45, 60 and 75 DAS], showing as 122.40 kg/45 m^2 (272.00 q/ha) and 126.74 kg/45 m^2 (281.64 q/ha), during 2022-23 and 2023-24, respectively, followed by T_2 treatment [T.T. with Ag NPs (*P. fluorescens*) @ 200 ppm for 30 min + 3 F.S. of Ag NPs (*P. fluorescens*) @ 200 ppm at 45, 60 and 75 DAS], showing as 119.07 kg/45 m^2 (264.60 q/ha) and 123.85 kg/45 m^2 (275.22 q/ha), during 2022-23 and 2023-24, respectively. The T_4 treatment [T.T. with ZnO NPs (*P. fluorescens*) @ 200 ppm for 30 min + 3 F.S. of ZnO NPs (*P. fluorescens*) @ 200 ppm at 45, 60 and 75 DAS] showing as 114.22 kg/45 m^2 (253.82 q/ha) and 121.41 kg/45 m^2 (269.80 q/ha), during 2022-23 and 2023-24, respectively, indicating third highest yield among the treatments. The minimum yield of potato tubers were recorded in T_{13} treatment (Infected control), as 92.20 kg/45 m^2 (200.44 q/ha) and 94.40 kg/45 m^2 (209.77 q/ha), during 2022-23 and 2023-24 cropping seasons and treatment T_{12} (Healthy control) second lowest potato tubers yield among all the treatments, representing as 92.38 kg/45 m^2 (205.28 q/ha) and 97.23 kg/45 m^2 (216.06 q/ha), during 2022-23 and 2023-24, respectively.

Table 1: Effect of different biosynthesized nanoparticles on number and size of tubers under field conditions during 2022-23

Treatments	2022-2023							
	Large (>100 g)		Medium (50-100 g)		Small (<50 g)		Tuber weight per plot (kg)	Tuber yield (q/ha)
	No. of tuber	Weight in kg	No. of tuber	Weight in kg	No. of tuber	Weight in kg		
T_1	322	42.29	590	47.20	480	16.85	106.34	236.31
T_2	358	46.18	658	52.55	542	20.34	119.07	264.60
T_3	309	41.60	578	46.84	465	16.75	104.83	232.95
T_4	350	42.68	650	51.72	536	19.82	114.22	253.82
T_5	369	47.04	665	54.10	548	21.26	122.40	272.00
T_6	295	40.64	560	44.69	450	15.88	101.21	224.91
T_7	342	42.23	639	50.45	528	18.95	111.73	248.28
T_8	271	40.62	532	41.55	425	13.20	95.37	211.93
T_9	331	42.29	605	48.75	495	17.64	108.98	242.17
T_{10}	280	40.45	551	44.35	435	14.81	99.61	221.35
T_{11}	338	42.34	620	49.72	505	18.12	110.18	244.84
T_{12}	259	38.60	521	41.36	415	12.42	92.38	205.28
T_{13}	240	37.55	512	40.85	396	11.80	90.20	200.44
CD at 5%		4.400		4.957		1.751	11.06	24.55
SE (m)		1.499		1.688		0.596	3.767	8.363
SE (d)		2.119		2.387		0.843	5.328	11.82
C.V.		6.193		6.188		6.164	6.162	6.156

Table 2: Effect of different biosynthesized nanoparticles on number and size of tubers under field conditions during 2023-24

Treatments	2023-2024							
	Large (>100 g)		Medium (50-100 g)		Small (<50 g)		Tuber weight per plot (kg)	Tuber yield (q/ha)
	No. of tuber	Weight in kg	No. of tuber	Weight in kg	No. of tuber	Weight in kg		
T_1	320	44.19	589	49.22	478	17.95	111.36	247.46
T_2	372	48.12	660	54.35	543	21.38	123.85	275.22
T_3	312	43.55	574	48.64	464	17.20	109.39	243.08
T_4	365	47.31	649	53.48	530	20.62	121.41	269.80
T_5	380	48.94	671	55.64	554	22.16	126.74	281.64
T_6	301	42.81	562	46.97	446	16.28	106.06	235.68
T_7	352	46.45	634	52.25	530	19.78	118.48	263.28
T_8	276	41.30	531	44.80	422	14.45	100.55	223.44
T_9	329	44.89	607	50.20	496	18.66	113.75	252.77
T_{10}	289	42.15	548	46.16	434	15.58	103.89	230.86
T_{11}	341	45.60	622	51.68	515	19.10	116.38	258.62
T_{12}	264	40.25	523	43.36	418	13.62	97.23	216.06
T_{13}	246	39.55	503	42.60	399	12.25	94.40	209.77
CD at 5%		4.655		5.144		1.811	11.59	25.76
SE (m)		1.585		1.752		0.617	3.949	8.773
SE (d)		2.242		2.477		0.872	5.585	12.40
C.V.		6.207		6.169		6.062	6.160	6.158

3.3 Effect of different biosynthesized nanoparticles on nutritional quality of potato tuber after harvesting during 2022-23 and 2023-34 cropping seasons

The effect of tuber treatment and foliar spray of different biosynthesized nanoparticles, *viz.,* Ag NPs, CuO NPs, ZnO NPs, MnO NPs and Fe_3O_4 NPs on nutritional status of potato tuber. The observations of nutritional status of potato tuber was estimated after harvesting during 2022-23 and 2023-24 cropping season. The data illustrated in Tables 3, 4, 5 and 6, showed that there was a significantly increase in nutritional status of potato tuber after application of biosynthesized nanoparticles as inducers in all the treatments as compared to the control (non-treated plant). The observed value of energy, protein, starch, fat content, vitamin C, P, K, Ca, Mg, Na in potato tuber were ranged 73.59-87.89 kcal, 1.29-2.32 g, 17.02-19.40 g, 0.17-0.39 g, 21.1-26.8 mg, 54.1-69.1 mg, 260.4-473.3 mg, 7.89-18.9 mg, 17.5-26.5 mg, 6.82-7.91 mg and 74.37-88.58 kcal, 1.35-2.39 g, 17.03-19.49 g, 0.18-0.41 g, 21.3-29.0 mg, 54.6-70.8 mg, 271.7-478.9 mg, 8.25-20.1 mg, 18.8-28.9 mg, 6.88-7.97 mg during 2022-23 and 2023-24, respectively, which might be increased due to the effect of biosynthesized nanoparticles.

The highest quantity of energy, protein, starch, fat, vitamin C, P, K, Ca, Mg, Na content were recorded from potato tuber treated with as T.T. with Azad Nanobiocide (1 Ag NPs : 1 ZnO NPs) @ 200 ppm for 30 min + 3 F.S. of Azad Nanobiocide (1 Ag NPs : 1 ZnO NPs) @ 200 ppm at 45 and 75 DAS (T_5 treatments), representing as the value 87.89 kcal, 2.32 g, 19.40 g, 0.39 g, 26.8 mg, 69.1 mg, 473.3 mg, 18.9 mg, 26.5 mg, 7.91 mg/100 g of fresh weight of potato tuber after harvesting and 88.58 kcal, 2.39 g, 19.49 g, 0.41 g, 29.0 mg, 70.8 mg, 478.9 mg, 20.1 mg, 28.9 mg, 28.9 mg, 7.97 mg/100 g of fresh weight of potato tuber after harvesting, during 2022-23 and 2023-24, respectively, followed by T_2 treatment [T.T. with Ag NPs (*P. fluorescens*) @ 200 ppm for 30 min + 3 F.S. of Ag NPs (*P. fluorescens*) @ 200 ppm at 45 and 75 DAS], representing as the value 87.29 kcal, 2.28 g, 19.32 g, 0.37 g, 26.5 mg, 68.6 mg, 464.4 mg, 18.4 mg, 26.3 mg, 7.85 mg/100 g of fresh weight of potato tuber after harvesting and 87.99 kcal, 2.34 g, 19.40 g, 0.39 g, 27.6 mg, 69.4 mg, 470.7 mg, 19.6 mg, 28.6 mg, 7.91 mg/100 g of fresh weight of potato tuber after harvesting and T_4 treatment [T.T. with ZnO NPs (*P. fluorescens*) @ 200 ppm for 30 min + 3 F.S. of ZnO NPs (*P. fluorescens*) @ 200 ppm at 45 and 75 DAS], representing as the value 86.66 kcal, 2.23 g, 19.24 g, 0.35 g, 26.1 mg, 66.7 mg, 459.5 mg, 17.9 mg, 26.2 mg, 7.70 mg/100 g of fresh weight of potato tuber after harvesting and 87.33 kcal, 2.28 g, 19.29 g, 0.37 g, 27.2 mg, 67.9 mg, 464.8 mg, 19.1 mg, 27.4 mg, 7.76 mg/100 g of fresh weight of potato tuber after harvesting, during 2022-23 and 2023-24, respectively.

The observed value of Zn content in potato tuber were ranged 0.24-0.65 mg and 0.25-0.67 mg during 2022-23 and 2023-24, respectively, which might be increased due to the effect of biosynthesized nanoparticles, *viz.,* Ag NPs, CuO NPs, ZnO NPs, MnO NPs and Fe_3O_4 NPs. The highest quantity of Zn content was recorded from potato tuber treated with as T.T. with Azad Nanobiocide (1 Ag NPs : 1 ZnO NPs) @ 200 ppm for 30 min + 3 F.S. of Azad Nanobiocide (1 Ag NPs : 1 ZnO NPs) @ 200 ppm at 45 and 75 DAS (T_5

treatments), representing as the value 0.65 mg/100 g of fresh weight of potato tuber after harvesting and 0.67 mg/100 g of fresh weight of potato tuber after harvesting, during 2022-23 and 2023-24, respectively, followed by T_4 treatment [T.T. with ZnO NPs (*P. fluorescens*) @ 200 ppm for 30 min + 3 F.S. of ZnO NPs (*P. fluorescens*) @ 200 ppm at 45 and 75 DAS], representing as the value 0.63 mg/100 g of fresh weight of potato tuber after harvesting and 0.64 mg/100 g of fresh weight of potato tuber after harvesting and T_3 treatment [T.T. with ZnO NPs (*P. fluorescens*) @ 150 ppm for 30 min + 3 F.S. of ZnO NPs (*P. fluorescens*) @ 150 ppm at 45 and 75 DAS], representing 0.55 mg/100 g of fresh weight of potato tuber after harvesting and 0.56 mg/100 g of fresh weight of potato tuber after harvesting, during 2022-23 and 2023-24, respectively.

The observed value of Cu content in potato tuber were ranged 0.10-0.35 mg and 0.12-0.37 mg during 2022-23 and 2023-24, respectively, which might be increased due to the effect of biosynthesized nanoparticles, *viz.,* Ag NPs, CuO NPs, ZnO NPs, MnO NPs and Fe_3O_4 NPs. The highest quantity of Cu content was recorded from potato tuber treated with as T.T. with biosynthesized CuO NPs @ 200 ppm for 30 min + 3 F.S. with same biosynthesized CuO NPs @ 200 ppm at 45, 60, 75 DAS (T_7 treatments), representing as the value 0.35 mg/100 g of fresh weight of potato tuber after harvesting and 0.37 mg/100 g of fresh weight of potato tuber after harvesting, during 2022-23 and 2023-24, respectively, followed by T_6 treatment [T.T. with biosynthesized CuO NPs @ 150 ppm for 30 min + 3 F.S. with same biosynthesized CuO NPs @ 150 ppm at 45, 60, 75 DAS], representing as the value 0.26 mg/100 g of fresh weight of potato tuber after harvesting and 0.28 mg/100 g of fresh weight of potato tuber after harvesting and T_5 treatment [T.T. with Azad Nanobiocide (1 Ag NPs : 1 ZnO NPs) @ 200 ppm for 30 min + 3 F.S. of Azad Nanobiocide (1 Ag NPs : 1 ZnO NPs) @ 200 ppm at 45 and 75 DAS], representing 0.23 mg/100 g of fresh weight of potato tuber after harvesting and 0.25 mg/100 g of fresh weight of potato tuber after harvesting, during 2022-23 and 2023-24, respectively.

The observed value of Mn content in potato tuber were ranged 0.13-0.41 mg and 0.15-0.43 mg during 2022-23 and 2023-24, respectively, which might be increased due to the effect of biosynthesized nanoparticles, *viz.,* Ag NPs, CuO NPs, ZnO NPs, MnO NPs and Fe_3O_4 NPs. The highest quantity of Mn content was recorded from potato tuber treated with as T.T. with biosynthesized MnO NPs @ 200 ppm for 30 min + 3 F.S. with same biosynthesized MnO NPs @ 200 ppm at 45, 60, 75 DAS (T_9 treatments), representing as the value 0.41 mg/100 g of fresh weight of potato tuber after harvesting and 0.43 mg/100 g of fresh weight of potato tuber after harvesting, during 2022-23 and 2023-24, respectively, followed by T_8 treatment [T.T. with biosynthesized MnO NPs @ 150 ppm for 30 min + 3 F.S. with same biosynthesized MnO NPs @ 150 ppm at 45, 60, 75 DAS], representing as the value 0.37 mg/100 g of fresh weight of potato tuber after harvesting and 0.38 mg/100 g of fresh weight of potato tuber after harvesting and T_5 treatment [T.T. with Azad Nanobiocide (1 Ag NPs : 1 ZnO NPs) @ 200 ppm for 30 min + 3 F.S. of Azad Nanobiocide (1 Ag NPs : 1 ZnO NPs) @ 200 ppm at 45 and 75 DAS], representing 0.25 mg/100 g of fresh weight of potato tuber after harvesting and 0.26 mg/100 g of fresh weight of potato tuber after harvesting, during 2022-23 and 2023-24, respectively.

The observed value of Fe content in potato tuber were ranged 0.72-1.61 mg and 0.76-1.64 mg during 2022-23 and 2023-24, respectively, which might be increased due to the effect of biosynthesized nanoparticles, *viz.,* Ag NPs, CuO NPs, ZnO NPs, MnO NPs and Fe_3O_4 NPs. The highest quantity of Fe content was recorded from potato tuber treated with as T.T. with biosynthesized Fe_3O_4 NPs @ 200 ppm for 30 min + 3 F.S. with same biosynthesized Fe_3O_4 NPs @ 200 ppm at 45, 60, 75 DAS (T_{11} treatments), representing as the value 1.61 mg/100 g of fresh weight of potato tuber after harvesting and 1.64 mg/100 g of fresh weight of potato tuber after harvesting, during 2022-23 and 2023-24, respectively, followed by T_{10} treatment [T.T. with biosynthesized Fe_3O_4 NPs @ 150 ppm for 30 min + 3 F.S. with same biosynthesized Fe_3O_4 NPs @ 150 ppm at 45, 60, 75 DAS], representing as the value 1.48 mg/100 g of fresh weight of potato tuber after harvesting and 1.50 mg/100 g of fresh weight of potato tuber after harvesting and T_5 treatment [T.T. with Azad Nanobiocide (1 Ag NPs : 1 ZnO NPs) @ 200 ppm for 30 min + 3 F.S. of Azad Nanobiocide (1 Ag NPs : 1 ZnO NPs) @ 200 ppm at 45 and 75 DAS], representing 1.35 mg/100 g of fresh weight of potato tuber after harvesting and 1.37 mg/100 g of fresh weight of potato tuber after harvesting, during 2022-23 and 2023-24, respectively. From the Tables 1 and 2, it is also cleared that all the treatments were found to increase the nutritional status of potato tuber after harvesting during both 2022-23 and 2023-24 cropping season.

Table 3: Effect of different biosynthesized nanoparticles on nutritional status of potato tuber after harvesting during 2022-23

Treatments	Energy (kcal)	Protein (g)	Carbohydrate ~ Starch (g)	Fat (g)	Vit. C (mg)
T_1	83.39	1.93	18.78	0.28	24.3
T_2	87.29	2.28	19.32	0.37	26.5
T_3	82.61	1.81	18.67	0.28	24.0
T_4	86.66	2.23	19.24	0.35	26.1
T_5	87.89	2.32	19.40	0.39	26.8
T_6	81.45	1.70	18.52	0.25	23.6
T_7	85.92	2.17	19.14	0.33	25.6
T_8	79.60	1.50	18.24	0.23	22.8
T_9	84.20	2.02	18.90	0.29	24.7
T_{10}	80.43	1.58	18.37	0.24	23.2
T_{11}	85.12	2.10	19.03	0.31	25.1

T_{12}	76.32	1.44	17.51	0.21	22.0
T_{13}	73.59	1.29	17.02	0.17	21.1
CD at 5%	3.227	0.193	0.889	0.04	2.565
SE (m)	1.099	0.066	0.303	0.02	0.874
SE (d)	1.554	0.093	0.428	0.02	1.235
C.V.	2.303	6.069	2.816	9.43	6.228

Table 4: Effect of different biosynthesized nanoparticles on nutritional status of potato tuber after harvesting during 2022-23

Treatments	P(mg)	K(mg)	Ca(mg)	Mg(mg)	Na(mg)	Zn(mg)	Cu(mg)	Mn(mg)	Fe(mg)
T_1	61.7	430.2	15.7	24.1	7.49	0.31	0.18	0.22	1.19
T_2	68.6	464.4	18.4	26.3	7.85	0.42	0.23	0.25	1.32
T_3	60.4	424.1	15.1	23.5	7.43	0.55	0.17	0.21	1.16
T_4	66.7	459.5	17.9	26.2	7.70	0.63	0.22	0.24	1.28
T_5	69.1	473.3	18.9	26.5	7.91	0.65	0.23	0.25	1.35
T_6	59.6	415.4	14.5	22.3	7.36	0.29	0.26	0.20	1.14
T_7	65.5	452.1	17.5	25.4	7.64	0.37	0.35	0.24	1.25
T_8	58.0	395.3	13.4	21.5	7.22	0.28	0.14	0.37	1.03
T_9	62.4	435.6	16.3	24.3	7.55	0.33	0.19	0.41	1.22
T_{10}	58.7	405.4	13.9	21.8	7.29	0.28	0.15	0.19	1.48
T_{11}	64.3	446.3	16.8	25.8	7.59	0.35	0.20	0.23	1.61
T_{12}	57.2	388.7	10.9	19.6	7.04	0.27	0.13	0.16	0.87
T_{13}	54.1	260.4	7.89	17.5	6.82	0.24	0.10	0.13	0.72
CD at 5%	6.52	43.58	1.55	2.44	0.43	0.07	0.05	0.07	0.126
SE (m)	2.22	14.84	0.53	0.83	0.15	0.03	0.02	0.02	0.043
SE (d)	3.14	20.99	0.74	1.17	0.21	0.03	0.02	0.03	0.061
C.V.	6.20	6.132	6.03	6.14	3.45	10.4	14.4	17.3	6.185

Table 5: Effect of different biosynthesized nanoparticles on nutritional status of potato tuber after harvesting during 2023-24

Treatments	Energy (kcal)	Protein (g)	Carbohydrate ~ Starch (g)	Fat (g)	Vit. C (mg)
T_1	84.23	1.97	18.81	0.30	25.2
T_2	87.99	2.34	19.40	0.39	27.6
T_3	83.33	1.85	18.69	0.29	24.5
T_4	87.33	2.28	19.29	0.37	27.2
T_5	88.58	2.39	19.49	0.41	29.0
T_6	82.25	1.74	18.57	0.27	23.9
T_7	86.67	2.22	19.18	0.35	26.7
T_8	80.36	1.54	18.29	0.25	23.0
T_9	85.09	2.06	18.99	0.31	24.7
T_{10}	81.20	1.61	18.39	0.26	23.5
T_{11}	85.84	2.14	19.09	0.33	26.1
T_{12}	77.35	1.49	17.57	0.23	22.5
T_{13}	74.37	1.35	17.03	0.18	21.3
SE (m)	2.463	0.204	0.858	0.05	2.623
SE (d)	0.839	0.069	0.292	0.01	0.893
CD at 5%	1.186	0.098	0.413	0.03	1.264
C.V.	5.214	6.258	2.650	10.4	6.187

Table 6: Effect of different biosynthesized nanoparticles on nutritional status of potato tuber after harvesting during 2023-24

Treatment	P(mg)	K(mg)	Ca (mg)	Mg(mg)	Na (mg)	Zn(mg)	Cu (mg)	Mn (mg)	Fe (mg)
T_1	62.9	436.5	16.8	25.3	7.55	0.34	0.20	0.21	1.20
T_2	69.4	470.7	19.6	28.6	7.91	0.47	0.24	0.26	1.34
T_3	61.7	429.4	16.3	24.9	7.49	0.56	0.19	0.20	1.17
T_4	67.9	464.8	19.1	27.4	7.76	0.64	0.24	0.25	1.30
T_5	70.8	478.9	20.1	28.9	7.97	0.67	0.25	0.26	1.37
T_6	60.4	420.7	15.4	24.1	7.42	0.32	0.28	0.21	1.13
T_7	66.7	457.4	18.6	26.8	7.70	0.41	0.37	0.25	1.27
T_8	58.8	401.2	14.3	22.4	7.28	0.30	0.16	0.38	1.05
T_9	63.6	442.9	17.4	25.5	7.61	0.37	0.21	0.43	1.22
T_{10}	59.9	413.7	14.8	23.4	7.35	0.31	0.17	0.20	1.50
T_{11}	65.5	450.6	17.9	26.7	7.65	0.39	0.22	0.24	1.64
T_{12}	57.8	393.9	12.1	20.9	7.10	0.29	0.15	0.18	0.89
T_{13}	54.6	271.7	8.25	18.8	6.88	0.25	0.12	0.15	0.76
SE (m)	6.59	44.29	1.661	2.59	0.44	0.06	0.05	0.06	0.133
SE (d)	2.24	15.08	0.566	0.88	0.14	0.02	0.01	0.02	0.045
CD at 5%	3.17	21.33	0.800	1.24	0.21	0.03	0.02	0.03	0.064
C.V.	6.17	6.140	6.047	6.13	3.19	9.08	12.9	14.3	6.418

4. Discussion

The observations on number and size of potato tuber showed that the maximum number of large size tubers were harvested from T_5 treatment [T.T. with Azad Nanobiocide (1 Ag NPs : 1 ZnO NPs) @ 200 ppm for 30 min + 3 F.S. of Azad Nanobiocide (1 Ag NPs : 1 ZnO NPs) @ 200 ppm at 45, 60 and 75 DAS], representing 369 tubers, with total weight 47.04 kg and 380 tubers, with total weight 48.94 kg, during 2022-23 and 2023-24, respectively, followed by T_2 treatment [T.T. with Ag NPs (*P. fluorescens*) @ 200 ppm for 30 min + 3 F.S. of Ag NPs (*P. fluorescens*) @ 200 ppm at 45, 60 and 75 DAS], showing 358 tubers, with total weight 46.18 kg and 372 tubers, with total weight 48.12 kg during 2022-23 and 2023-24, respectively. Similarly, the maximum number of medium size tubers were harvested from T_5 treatment [T.T. with Azad Nanobiocide (1 Ag NPs : 1 ZnO NPs) @ 200 ppm for 30 min + 3 F.S. of Azad Nanobiocide (1 Ag NPs : 1 ZnO NPs) @ 200 ppm at 45, 60 and 75 DAS], representing 665 tubers, with total weight 54.10 kg and 671 tubers, with total weight 55.64 kg, during 2022-23 and 2023-24, respectively, followed by T_2 treatment [T.T. with Ag NPs (*P. fluorescens*) @ 200 ppm for 30 min + 3 F.S. of Ag NPs (*P. fluorescens*) @ 200 ppm at 45, 60 and 75 DAS], showing 658 tubers, with total weight 52.55 kg and 660 tubers, with total weight 54.35 kg during 2022-23 and 2023-24, respectively. On other hand, the minimum number of small size tubers was recorded in T_{13} treatment (Infected control), representing as 396 tubers, with total weight 11.80 kg and 399 tubers, with total weight 12.25 kg, during 2022-23 and 2023-24. The observations of yield of potato showed that the maximum yield of potato tubers were harvested from T_5 treatment [T.T. with Azad Nanobiocide (1 Ag NPs : 1 ZnO NPs) @ 200 ppm for 30 min + 3 F.S. of Azad Nanobiocide (1 Ag NPs : 1 ZnO NPs) @ 200 ppm at 45, 60 and 75 DAS], showing as 122.40 kg/45 m^2 (272.00 q/ha) and 126.74 kg/45 m^2 (281.64 q/ha), during 2022-23 and 2023-24, respectively, followed by T_2 treatment [T.T. with Ag NPs (*P. fluorescens*) @ 200 ppm for 30 min + 3 F.S. of Ag NPs (*P. fluorescens*) @ 200 ppm at 45, 60 and 75 DAS], showing as 119.07 kg/45 m^2 (264.60 q/ha) and 123.85 kg/45 m^2 (275.22 q/ha), during 2022-23 and 2023-24, respectively. Similar findings were reported by Jo Y.K. *et al.* (2009), who reported strong antimicrobial activity of silver nanoparticles against plant pathogens. Furthermore, Rai Mahendra *et al.* (2012) highlighted the silver nanoparticles act as effective antimicrobial agents, contributing to enhanced crop productivity. Prasad *et al.* (2012) observed that the enhanced growth and yield in crops treated with ZnO nanoparticles. Khot *et al.* (2012) reported that nanomaterials play significant role in improving crop production and protection. Additionally, Dimkpa Christian *et al.* (2017) emphasized that nanofertilizers enhance nutrient use efficiency, thereby increasing crop yield. The effect of tuber treatment and foliar spray of different biosynthesized nanoparticles, *viz.,* Ag NPs, CuO NPs, ZnO NPs, MnO NPs and Fe3O4 NPs on nutritional status of potato tuber. The observations of nutritional status of potato tuber was estimated after harvesting during 2022-23 and 2023-24. The observed value of energy, protein, starch, fat content, vitamins C, P, K, Ca, Mg, Na in potato tuber were ranged 73.59-87.89 kcal, 1.29-2.32 g, 17.02-19.40 g, 0.17-0.39 g, 21.1-26.8 mg, 54.1-69.1 mg, 260.4-473.3 mg, 7.89-18.9 mg, 17.5-26.5 mg, 6.82-7.91 mg and 74.37-88.58 kcal, 1.35-2.39 g, 17.03-19.49 g, 0.18-0.41 g, 21.3-29.0 mg, 54.6-70.8 mg, 271.7-478.9 mg, 8.25-20.1 mg, 18.8-28.9 mg, 6.88-7.97 mg during 2022-23 and 2023-24, respectively, which might be due to the effect of biosynthesized nanoparticles. The highest quantity of energy, protein, starch, fat, vitamin C, P, K, Ca, Mg, Na content were recorded from potato tuber treated with as T.T. with Azad Nanobiocide (1 Ag NPs : 1 ZnO NPs) @ 200 ppm for 30 min + 3 F.S. of Azad Nanobiocide (1 Ag NPs : 1 ZnO NPs) @ 200 ppm at 45, 60 and 75 DAS [T_5 treatments], representing as the value 87.89 kcal, 2.32 g, 19.40 g, 0.39 g, 26.8 mg, 69.1 mg, 473.3 mg, 18.9 mg, 26.5 mg, 7.91 mg/100 g of fresh weight of potato tuber after harvesting and 88.58 kcal, 2.39 g, 19.49 g, 0.41 g, 29.0 mg, 70.8 mg, 478.9 mg, 20.1 mg, 28.9 mg, 28.9 mg, 7.97 mg/100 g of fresh weight of potato tuber after harvesting, during 2022-23 and 2023-24, respectively, followed by T_2 treatment [T.T. with Ag NPs (*P. fluorescens*) @ 200 ppm for 30 min + 3 F.S. of Ag NPs (*P. fluorescens*) @ 200 ppm at 45, 60 and 75 DAS], representing as the value 87.29 kcal, 2.28 g, 19.32 g, 0.37 g, 26.5 mg, 68.6 mg, 464.4 mg, 18.4 mg, 26.3 mg, 7.85 mg/100 g of fresh weight of potato tuber after harvesting and 87.99 kcal, 2.34 g, 19.40 g, 0.39 g, 27.6 mg, 69.4 mg, 470.7 mg, 19.6 mg, 28.6 mg, 7.91 mg/100 g of fresh weight of potato tuber after harvesting. The observed value of Zn content in potato tuber were ranged 0.24-0.65 mg and 0.25-0.67 mg during 2022-23 and 2023-24, respectively, which might be increased due to the effect of ZnO NPs nanoparticles. The highest quantity of Zn content was recorded from potato tuber treated with as T.T. with Azad Nanobiocide (1 Ag NPs : 1 ZnO NPs) @ 200 ppm for 30 min + 3 F.S. of Azad Nanobiocide (1 Ag NPs : 1 ZnO NPs) @ 200 ppm at 45, 60 and 75 DAS [T_5 treatments], representing as the value 0.65 mg/100 g of fresh weight of potato tuber after harvesting and 0.67 mg/100 g of fresh weight of potato tuber after harvesting, during 2022-23 and 2023-24, respectively. The observed value of Cu content in potato tuber were ranged 0.10-0.35 mg and 0.12-0.37 mg during 2022-23 and 2023-24, respectively, which might be increased due to the effect of CuO nanoparticles. The highest quantity of Cu content was recorded from potato tuber treated with as T.T. with biosynthesized CuO NPs @ 200 ppm for 30 min + 3 F.S. with same biosynthesized CuO NPs @ 200 ppm at 45, 60, 75 DAS [T_7 treatments], representing as the value 0.35 mg/100 g of fresh weight of potato tuber after harvesting and 0.37 mg/100 g of fresh weight of potato tuber after harvesting, during 2022-23 and 2023-24, respectively, followed by T_6 treatment [T.T. with biosynthesized CuO NPs @ 150 ppm for 30 min + 3 F.S. with same biosynthesized CuO NPs @ 150 ppm at 45, 60, 75 DAS], representing as the value 0.26 mg/100 g of fresh weight of potato tuber after harvesting and 0.28 mg/100 g of fresh weight of potato tuber after harvesting. The observed value of Mn content in potato tuber were ranged 0.13-0.41 mg and 0.15-0.43 mg during 2022-23 and 2023-24, respectively, which might be increased due to the effect of MnO nanoparticles. The highest quantity of Mn content was recorded from potato tuber treated with as T.T. with biosynthesized MnO NPs @ 200 ppm for 30 min + 3 F.S. with same biosynthesized MnO NPs @ 200 ppm at 45, 60, 75 DAS [T_9 treatments], representing as the value 0.41 mg/100 g of fresh weight of potato tuber after harvesting and 0.43 mg/100 g of fresh weight of potato tuber after harvesting, during 2022-23 and 2023-24, respectively, followed by T_8 treatment [T.T. with biosynthesized MnO NPs @ 150 ppm for 30 min + 3 F.S. with same biosynthesized MnO NPs @ 150 ppm at 45, 60, 75 DAS], representing as the value 0.37 mg/100 g of fresh weight of potato tuber after harvesting and 0.38 mg/100 g of fresh weight of potato tuber after harvesting. The observed value of Fe content in potato tuber were ranged 0.72-1.61 mg and 0.76-1.64 mg during 2022-23 and 2023-24, respectively, which might be increased due to the effect of Fe_3O_4 nanoparticles. The highest quantity of Fe content was recorded from potato tuber treated with as T.T. with biosynthesized Fe_3O_4 NPs @ 200 ppm for 30 min + 3 F.S. with same biosynthesized Fe_3O_4 NPs @ 200 ppm at 45, 60, 75 DAS [T_{11} treatments], representing as the value 1.61 mg/100 g of fresh weight of potato tuber after harvesting and 1.64 mg/100 g of fresh weight of potato tuber after harvesting, during 2022-23 and 2023-24, respectively, followed by T_{10} treatment [T.T. with biosynthesized Fe_3O_4 NPs @ 150 ppm for 30 min + 3 F.S. with same biosynthesized Fe_3O_4 NPs @ 150 ppm at 45, 60, 75 DAS], representing as the value 1.48 mg/100 g of fresh weight of potato tuber after harvesting and 1.50 mg/100 g of fresh weight of potato tuber after harvesting. Raliya *et al.* (2015) observed that ZnO nanoparticles significantly increased protein content, biomass, Zn accumulation in plants due to improved nutrient uptake and enzyme activation. Similarly, Subbaiah *et al.* (2016) reported enhanced starch and carbohydrate metabolism in potato with Zn based nanoparticles. Dimpka *et al.* (2017) reported that ZnO and CuO nanoaprticles increased antioxidant compounds, including ascorbic acid in edible plant parts. Rastogi *et al.* (2019) found that nanoparticle treatments stimulated secondary metabolite productions, including vitamins. In terms of mineral enrichment, the results align with findings of Liu and Lal (2015), who reported that nanoparticles enhanced nutritional (P, K, Ca, Mg, Na) content in tubers may be linked to improved root absorption and membrane permeability caused by nanoparticles. Sheykhbaglou *et al.* (2010) reported increased nutrient uptake and yield in crops treated with iron nanoparticles, which supports the observed increase in mineral content in potato. Adhikari *et al.* (2015) observed that CuO NPs enhanced nutrient accumulation and growth parameters, while Khodakovskaya *et al.* (2012) reported that Ag NPs improved plant growth and biochemical composition at optimal concentrations.

5. Conclusion

The study remonstrates that biosynthesized nanoparticles (Ag, ZnO, CuO, MnO, and Fe_3O_4), particularly the T_5 treatment [T.T. with Azad Nanobiocide (1 Ag NPs : 1 ZnO NPs) @ 200 ppm for 30 min + 3 F.S. of Azad Nanobiocide (1 Ag NPs : 1 ZnO NPs) @ 200 ppm at 45, 60 and 75 DAS], significantly enhance potato yield, tuber size distribution, and nutritional quality under field conditions. The T_5 treatment produced the highest tuber yield in both years 2022-23 and 2023-24 and improved key quality parameters such as protein, starch, vitamins, and mineral content compared to the control. Overall, the results indicate that nanoparticle based treatments can effectively mitigate biotic stress and substantially improve potato productivity and quality.

Acknowledgements

The authors sincerely thank the Department of Plant Pathology, Chandra Shekhar Azad University of Agriculture and Technology, Kanpur-208002, Uttar Pradesh, India for providing necessary infrastructure, technical support, and continuous encouragement that facilitated the successful execution for this research work.

Conflict of interest

The authors declare no conflict of interest relevant to this article.

References

Adhikari, T.; Kundu, S. and Rao, A. S. (2015). Impact of CuO nanoparticles on plant growth and nutrient uptake. Journal of Plant Nutrition, **38**:1-12.

AOAC (2003). Official Methods of Analysis: Potato Biology and Biotechnology, Journal of Food Composition and Analysis.

AOAC (2005). Official Methods of Analysis (18th ed.). Association of Official Analytical Chemists, Washington, D.C.

Bawskar, M. (2021). Silver nanoparticles as nanofungicide and plant growth promoter: evidences from morphological and chlorophyll 'a' fluorescence analysis. Adv. Mater. Lett. **12** (10):1-7.

Brown, C. R. (2005). Antioxidants in potato. American Journal of Potato Research, **82**(2):163-172.

Burlingame, B.; Mouille, B. and Charrondiere, R. (2009). Nutrient, bioactive non-nutrient and antinutrient composition of potatoes. Journal of Food Composition and Analysis, **22**(6):494-502.

Chadha, K.L. (2009). Potato. Handbook of Horticulture. ICAR, New Delhi, pp:494-498.

Chapman, H. D. and Pratt, P. F. (1961). Methods of Analysis for Soils, Plants, and Waters. University of California, Agriculture Division, Berkeley, CA.

Dimkpa, C. O. and Bindraban, P. S. (2017). Nanofertilizers: New products for the industry, Journal of Agricultural and Food Chemistry, **65**(5):827-844.

Ezekiel, R.; Singh, N.; Sharma, S., and Kaur, A. (2013). Beneficial phytochemicals in potato: A review. Food Research International, **50**(2):487-496.

Friedman, M. (2006). Potato glycoalkaloids and metabolites: Roles in the plant and in the diet. Journal of Agricultural and Food Chemistry, **54**(23):8655-8681.

Gopal, J. and Khurana, S. M. (2006). Handbook of potato production, improvement, and postharvest management. CRC Press.

Jackson, M. (1967). Soil Chemical Analysis; Prentice-Hall of India Pvt. Ltd.: New Delhi, India, pp:498.

Jackson, M. L. (1973). Soil Chemical Analysis. Prentice Hall of India, New Delhi.

Jones, J. B.; Wolf, B. and Mills, H. A. (1991). Plant Analysis Handbook. Micro-Macro Publishing, Athens, GA.

Jo, Y. K.; Kim, B. H. and Jung, G. (2009). Antifungal activity of silver ions and nanoparticles on phytopathogenic fungi. Plant Disease, **93**(10):1037-1043.

Khodakovskaya, M. (2012). Carbon nanotubes and silver nanoparticles enhance plant growth. ACS Nano, **6**:2128-2135.

Khot, L. R.; Sankaran, S.; Maja, J. M.; Ehsani, R. and Schuster, E. W. (2012). Applications of nanomaterials in agricultural production and crop protection: A review. Crop Protection, **35**:64-70.

Kumar, U. and Chandra, G. (2018). A brief review of potash management in potato (*Solanum tuberosum* L.). Journal of Pharmacognosy and Phytochemistry, **1** (7):1718-1721.

Liu, R. and Lal, R. (2015). Potentials of engineered nanoparticles as fertilizers. Science of the Total Environment, **514**:131-139.

Motalebifard, R. (2017). Effects of zinc and phosphorus levels on yield, nutrients uptake and Zinc recovery and agronomic efficiency in potato. Journal of Water and Soil (Agricultural Sciences and Technology).

Nair, R. (2010). Nanoparticulate material delivery to plants. Plant Science, **179**:154-163.

Liu, R. and Lal, R. (2015). Potentials of engineered nanoparticles as fertilizers. Science of the Total Environment, **514**:131-139.

Prasad, T. N. V. K. V. (2012). Effect of nanoscale micronutrients on plant growth. Journal of Plant Nutrition, **35**:905-927.

Pineda, M. E. B.; Forero, L.; Sierra Avila, C. A. and L. M. (2022). Antibacterial activity of biosynthesized silver nanoparticles (AgNps) against *Pectobacterium carotovorum*. Braz J. Microbiol., **53**(3):1175-1186.

Piper, C. S. (1966). Soil and Plant Analysis. Academic Press, New York.

Rai, M.; Yadav, A. and Gade, A. (2012). Silver nanoparticles as a new generation of antimicrobials. Biotechnology Advances, **27**(1):76-83.

Raliya, R. (2015). ZnO nanoparticles improve growth and nutrient content. Agricultural Research, **4**:385-392.

Ranganna, S. (1986). Handbook of Analysis and Quality Control for Fruit and Vegetable Products. Tata McGraw-Hill.

Rastogi, A. (2019). Nanoparticles and plant metabolic pathways. Plant Physiology and Biochemistry, **141**:43-55.

Sit, N.; Misra, S. and Deka, S.C. (2013). Physicochemical, functional, textural and colour characteristics of starches isolated from four taro cultivars of North-E ast India. Starch Stärke, **65** (34):1011-1021.

Sheykhbaglou, R. (2010). Effects of nano-iron oxide on crop yield. Notulae Scientia Biologicae, **2**:112-113.

Subbaiah, L. V. (2016). Nano-fertilizers and their role in crop improvement. Advances in Agricultural Sciences, **4**:1-10.

Wichrowska, D. (2022). Antioxidant Capacity and Nutritional Value of Potato Tubers (*Solanum tuberosum* L.) as a Dependence of Growing Conditions and Long-Term Storage. Agriculture, **12**(1):21-34.

Yan, A. and Chen, Z. (2019). Impacts of silver nanoparticles on plants: a focus on the phytotoxicity and underlying mechanism. Int. J. Mol. Sci., **20** (5):1003-1019.

Citation **Shivam Kumar, Keerti, Prakash Chandra Tripathy, Umara Rahmani, Mansi Mishra, Ankit Rai and Sultan Singh (2026). Enhancement of yield and nutritional quality of potato tuber to combat malnutrition through application of biosynthesized nanoparticles against common scab of potato (*Streptomyces scabies*). Ann. Phytomed., 15(1):900-910, http://dx.doi.org/10.54085/ap.2026.15.1.81.**