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Silver Nanoparticles as a Prospective Nematicide against *Meloidogyne incognita* in Sugarbeet Fields

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ABSTRACT

Convinced Nematodes are widespread soil-borne organisms found in sugarbeet cultivation areas, particularly in Egypt's Nubaryia district, and they cause significant economic damage to sugarbeet crops. The root-tie nematode (*Meloidogyne* spp.) is a typical plant-parasitic nematode found in sugarbeet. Substance the executive's choices for root-knot nematode the board in sugarbeet are defective (both biologically and financially), and novel nematicidal assets are expected to resolve this perplexing issue. The reason for this study was to evaluate the viability of silver nanoparticles (AgNP) as a nematicidal dedicated against *M. incognita* in lab, outdoors pots experiments, and field settings. Arrangement A was chosen for dissolving AgNO3 in deionized water to deliver Ag-NPs. Arrangement B is coded for solvency. At the point when second juveniles (J2) were presented to AgNP in water at gradual concentrations, over 95%, of nematodes became inactive in 6 hours or less. After 4 and 2 days of exposure, sugarbeet and soil composite samples infested with *M. incognita* were treated with 150 g/ml AgNP, reducing the number of J2 in the soil, after 4 and 2 days of exposure, by 92% and 82%, respectively, when compared to untreated soil samples. An AgNP field experiment was conducted on a sugarbeet (*Beta vulgaris* subsp. *vulgaris*, var. Sahar) field that was previously infested with *M. incognita*. Fortnightly application of 90.4 mg/m^2 of AgNP improved sugarbeet quality in one year and reduced galls development in the roots in two years, while avoiding phytotoxicity. The use of AgNP did not significantly reduce the quantity of *M. incognita* J2 in plots throughout the growing season. The laboratory assays confirmed that AgNP's had nematicidal effect, and the field evaluation demonstrated its effectiveness in mitigating *M. incognita* damage to sugarbeet.

Keywords: Management, Meloidogyne, nematicide, root-knot nematode, silver nanoparticle, sugarbeet.

1. Introduction

Sugarbeet is the world's second-largest sugar crop, accounting for approximately 40% of global sugar production after sugarcane. Because sugarbeet top yield has a high nutritional value, it is critical to use this crop not only for sugar production but also to feed animals. Egypt is currently dealing with several issues that are affecting the productivity of many crops in general and sugar crops in particular, including sugarbeet, which is experiencing rapid growth. It became Egypt's first source of sugar production, with beets accounting for 67.7% (1835851 tons) of total sugar production, while sugar cane accounts for 32.3% (876064 tons) (Sugar Crops Council, 2021). *Meloidogyne* spp., which is a

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significant polyphagous obstacle in newly reclaimed soils, is one of these barriers as sugarbeet production grows and challenges multiply. Root-knot nematodes, which disrupt the plant's physiology, can cause significant economic losses to sugarbeet crop production and quality. Chemical nematodes are typically preferred due to their efficacy in controlling their populations. However, their excessive and continued use caused direct toxicity to predators, pollinators, fish, and humans, hurt soil health, and left pesticide residues in products. Researchers looked for new alternatives to nematode management programs and promising strategies for controlling PPNs while lowering production costs and increasing crop yield as a result of the issues posed by the use of nematicides. Nanotechnology has developed and extended essentially since its commencement, influencing a wide range of natural and inorganic materials at minuscule scopes, commonly under 100 nm (Abraham *et al.,* 2008). To make NPs successful and harmless to the ecosystem, "regular bio-assets, for example, microorganisms and plant extricates, were utilized (Khan *et al.,* 2009). One of the most commonly utilized nanomaterials (NP) has been demonstrated to be a viable item for controlling phytonematodes. Lim *et al.,* (2012) showed that Ag-NPs cause oxidative pressure in nematode cell tissues. Plant-based silver nanoparticles (Ag-NPs) have shown critical control of *M. incognita* by lessening the quantity of galls and eggmass. This has brought about superior development and a new weight of tomatoes, as exhibited by studies directed by Nour El-Deen and Bahig Ahmed El-Deeb in 2018 and Fouda *et al.,* (2020). This is the first field study to investigate the efficacy of AgNP against root-knot nematodes in sugarbeet. To our knowledge, all previous studies on Ag-NPs and plant-parasitic nematodes have been carried out in laboratories or under greenhouse conditions. Moreover, AgNP is being tried as a nematicide for sugarbeet open-field use. In this review, AgNP was tried against this nematode species in different settings, including lab tests and pot tests.

2. Material and Methods

2.1. Production and characterizations of silver nanoparticles (Ag-NPs)

Based on the study conducted by Fouda *et al.,* in 2020, high concentrations of silver nanoparticles (Ag-NPs) were prepared using two solutions. Solution A consisted of 0.75 g of $AgNO_3$ suspended in 100 mL of deionized water. Solution B, on the other hand, contained 1 g of microcrystalline cellulose (MCC) dissolved in 100 mL of deionized water with 0.2 g NaOH and 1 g MCC. The two solutions were mixed together by gradually adding solution A to solution B while stirring at 75°C for 5 minutes and an additional 15 minutes after the addition. The colorless mixture slowly turned a pale yellow and eventually a deep brown, indicating the formation of Ag-NPs. The resulting solution was stored in the refrigerator for later analysis. The technique used to create Ag-NPs has several advantages, such as the absence of solvents or organics, the ability to scale up production using a high concentration of silver precursor, and the use of an environmentally friendly polymer called MCC. The bulk Ag-NPs colloidal solution was diluted to different concentrations ranging from 5 ppm to 100 ppm. Concentrations of 20, 30, 40, 50, and 60 ppm of Ag-NPs were selected for further analysis.

2.2. Characterization of resulted silver nanoparticles (Ag-NPs)

As per Fouda *et al.,* (2020), silver nanoparticles (Ag-NPs) were delivered utilizing MCC, and their properties were investigated utilizing different procedures. To start with, bright apparent spectroscopy was performed to determine the absorbance of Ag-NPs. Then, the Ag-NPs arrangement was centrifuged at 20,000 rpm for an hour to get Ag-NPs in powder form. An energy-dispersive X-beam (EDX) associated with an SEM instrument was utilized to conduct an essential examination of the powder Ag-NPs. The typical hydrodynamic molecule size of Ag-NPs was estimated using a Zeta sizer instrument. Moreover, the zeta capability of Ag-NPs covered with MCC was estimated to determine the level of adjustment or conglomeration. Particles with zeta potentials greater than 30 mV are known to be immune to clustering, ensuring maximum stability. The variety change in the arrangement showed the development of Ag-NPs, which were found to have serious areas of strength for a band at 408 nm. The TEM investigation affirmed that the Ag-NPs had a little, round shape with a width of around 10 nm. SEM examination affirmed the morphology of the Ag-NPs, while EDX investigation uncovered the presence of silver and MCC. The aftereffects of the molecule size analyzer showed that most of the particles were around 15 nm. The zeta capability of the Ag-NPs demonstrated that they were shaped as non-totaled particles.

2.3. Direct treatment of the purified eggs of *M. incognita* using AgNP in water

Female *Meloidogyne species* were collected from infected roots of the common bean (*Phaseolus vulgaris*) variety Nebraska in Alexandria's West Nubaryia district. Ten out of 21 dissected perineal patterns were used to identify nematode species (Hartman and Sasser, 1985). The eggs were extracted from infected roots with a 0.5% NaOCl solution (Di Vito *et al.,* 1985). Eggs were collected through a 250 µM mesh screen, followed by a 25 µM mesh screen to remove unwanted fractions. The purified eggs were then rinsed with sterile distilled water and kept in a flask. The eggs were counted using a counting cell slide and a 10x light microscope, with an average of three counts per mL suspension.

The experiment involved exposing *M. incognita* nematode eggs extracted from White Pea Bean var. Nebraska to silver nanoparticles (AgNP) in water. Approximately 200 purified eggs were added to solutions containing AgNP concentrations ranging from 0 to 100 ppm, with each solution replicated four times. The experiment took place in a laboratory and the solutions were incubated at room temperature (~25°C). An inverted compound microscope (Leeds Instruments, Inc., Minneapolis, MN) was used to examine the health and activity of nematodes one, three, and six hours after AgNP treatment to determine the effective dose required to affect them. Nematodes in good health curled, while those in bad health had bodies that were rigid or straight. Nematode suspensions were then passed through a 250-mesh screen following treatment with AgNP for 1, 3, or 6 hours. The nematodes gathered from the last option were suspended in water and noticed for an hour to decide if AgNP killed or restrained nematode development. The quantity of solid nematodes was built up to assess the treatment's adequacy. The concentrations used in the direct exposure assay and the outdoor pot treatments with AgNP were replicated four times. Mortality percentages were calculated by subtracting the normal mortality rate in water (control) using a modified Schneider (Püntener, 1981).

Corrected mortality percentages =

$$\frac{\textit{Mortality \% in treatment} - \textit{Mortality \% in control}}{\textit{100 - Mortality \% in control}} \times 100$$

The midpoints of corrected mortality rates and standard deviations for each trial were exposed to additional examination with Microsoft Succeed programming. (Seefeldt *et al.,* 1995).

Composites of white bean and *Phaseolus vulgaris* soil were gathered from two locales (1 km apart) in the West Nubaryia region, km 71st on the West Alexandria desert street, that have as of late been utilized for sugarbeet development. The tested destinations were vigorously pervaded with *M. incognita*, with a normal of 800 ± (5-8) j2 250 cm3 soil and seriously irritated plants. A 25-ml AgNP solution containing 0, 1.5, 3, 15, 30, or 150 mg m^{-1} was added to the homogenized soil sample after it was divided into 100-cm3 plastic containers.

In a totally randomized plan, six distinct medicines were utilized, each with four replications. These medicines were put away at room temperature for 24, 48, or 72 hours. After the predetermined openness time, nematodes were extricated from the dirt with a modified Baermann plate method (Barker, 1985). Following 48 hours of submersion in water, the examples were separated through a strainer (pore size 25 mm). The J2 nematodes were counted using an upset magnifying lens, as portrayed already.

To conduct an outdoor pot treatment with AgNP, composites of sandy soil from white bean and common bean were collected from a site in the West Nubaryia district, km 71st, on the West Alexandria-Cairo desert road that was previously used for sugarbeet cultivation. The soil was sterilized for two hours at 1.5 kg per square centimeter (121.6°C), then filled into 25 cm plastic pots and kept well-ventilated. Lab-synthesized AgNP was used as a soil drench at concentrations of 50, 100, and 150 µg/ml, or water (control). A 50 ml water suspension containing a nematode inoculum (3000 J2 per pot) was distributed uniformly over the soil surface. For soil drenching, nematode inoculation was followed by the application of an equal amount of respective double-strength AgNP solutions immediately after sowing two sugarbeet (var. sahar) seeds in plot 1, with all pots arranged in a complete randomized design with four replications. The newly sprouted sugarbeet seedlings were kept in an outdoor conservation area and watered frequently. The efficacy of various Ag-NP concentrations against root-knot nematodes was assessed.

The density of nematodes in soil was calculated using the Baermann funnel method. Tissue paper was used to wrap soil samples before immersing them in a water-filled funnel. Nematode density (J2)

was examined under a microscope. The disease severity percentage was calculated by recording the gall indices on a scale of 0 to 5 at the end of the experiment (60 days after inoculation). 0 indicated no galls, while 5 indicated more than 100 galls per root system (Taylor and Sasser 1978). The efficacy percentage of the control was calculated using Xue *et al.* (2009) method.

$$\text{Disease severity} = \left(\sum \frac{\textit{Class frequency x Score of rating class}}{\textit{Total number of plants investigated x Maimal disease index}} \textit{ x 100\%} \right)$$

Ag-NP concentration efficacy %

$$= \left(\frac{\textit{Disease severity in control treatment- Disease in Ag-NP conc. treatment}}{\textit{Disease severity in control treatment}} \textit{ x 100\%} \right)$$

2.3. Field studies with AgNP

During the fall seasons of 2022 and 2023, field trials with AgNP were carried out in the West Nubaryia district, which is located at km 71st on the West Alexandria-Cairo desert road. The exploratory locales (fields) were normally pervaded with *M. incognita* and had been utilized to develop sugarbeet for the past decade. The dirt was sandy (91% sand, 5% sediment, 4% mud, and 0.3% natural matter), pH 7.8, and 7.3% $CaCO_3$. The exploratory plots were watered with a dribble water system framework. With the exception of pesticide use on the exploratory site, the traditional sugarbeet crop the board rehearsed stayed reliable. The site of the expanding experiment was laid out entirely randomly block design. The plot was six rows wide and seven meters in length, with 0.5 meters between each line (plot = 21 m^2, or 1/476 hectare). White beans and the common variety Nebraska were the previous crops grown on the site. The six medicines tried in the preliminary field contained 90.4 mg/m^2 of AgNP [0.5 liter of 1,898.4 mg $plot^{-1}$, or 1.9 g $plot^{-1}$]. Each plot contains AgNP blended in with a surfactant (0.1% v/v) and SYLGARDTM OFX-0309. Liquid is a low-sub-atomic weight nonionic silicone polyether surfactant intended to work on the wetting, spreading, and entrance of farming synthetic compounds [®TM brand name of The Dow Synthetic Organization ("Dow")], applied every other week as intended for the six medicines (Table 1). The spray solution was applied at a rate of 90.4 mL per square meter. Following application, 75 to 150 ml of water was applied to all AgNP-treated plots until the dirt was immersed, permitting the dynamic fixings to enter. The medicines were begun in mid-October and supported for the rest of November every year. Untreated control plots and Tervigo 020 SC® or 20g L^{-1} Abamectin were held inside with a pace of 4 L ha^{-1} of (as the fluid plan is a macrocyclic lactone gotten from the dirt bacterium *Streptomyces avermitilis* that has been displayed to have nematicidal properties and an alternate method of activity than the other at present accessible nematicide) applied two times.

Table 1: Scheme of field experiment treatments throughout two fall succeeding seasons.

Treatment	Treatment iterations	Application method
T_1	**Single**	AgNP after sowing directly injection solution injected into the sowing line, after the soil has been partially wetted up during the 2nd quarter of irrigation cycle,
T_2	**Two times**	AgNP after sowing directly injection and the second after thinning (approx. Biweekly)
T_3	**Three times**	AgNP after sowing directly injection and the two other injections with biweekly intervals
T_4	**Four time**	AgNP after sowing directly injection and the three other injections with biweekly intervals
T_5	**Two times**	TERVIGO two applications are permitted per crop, with the first applied injection as a planting whole drench Following the initial at 14 day intervals.
T_6	**Control (untreated)**	Irrigation water without chemicals except surfactant

*All treatments with repeated application restricted by biweekly interval also, surfactant added to a the six treatments

To determine the initial and final root-knot nematode populations (Pi and Pf), 10-15 centers (5 cm width x 25 cm depth) were gathered from the two inward sugarbeet lines of each trial unit on planting and collecting dates. The 10-15 centers were physically mixed, and a 250 cm3 subsample was gathered for nematode examination. The review was led by three repeats performed for every nematode boundary. Wet sieving was utilized to isolate the subsamples through 100, 200, and 325 cross-section strainers. Barker (1985) reports that the material saved on the 325-network strainers was dealt with utilizing the Baermann-Skillet methodology. The extracted nematodes were spread out in water in a gridded counting dish before being identified and counted. All dirt nematode counts were normalized to 250 cm3 of soil. At harvest (210 days subsequent to planting), five underground roots were picked aimlessly from each plot's two internal columns and washed. The quantity of galls in each underground root system was checked. A 15-gram fresh weight subsample was haphazardly picked, and nematode juveniles were removed utilizing the Baermann-Dish strategy. After five days, the nematodes were counted and contrasted with the number found per gram of fresh root. Other subsamples (15 grams of fresh weight) were haphazardly chosen, washed, stained with acidic fuchsine in lactophenol, and put away for 24 hours. The quantity of juvenile nematode hatchlings, females, and egg masses was counted and standardized to be identical per gram of fresh root mass. Three times, the parameters of the nematode were tested. The reproduction factor is determined as follows:

$$RF = \frac{\sum Final\ nematodes\ in\ soil\ and\ roots}{Initial\ population}$$

Tests were conducted on the roots and submitted for examination on a comparable harvest day to the beet gathering lab at Alexandria Sugar Company. The purpose of the tests was to determine the following: sugar percentage as indicated by De Whalley (1964), purity%, and expected sugar yield ha^{-1}. The outer two edges of each plot were used as a belt, while plants from the second and fifth ridges were set aside for analysis of yield, yield parts, and quality. Nematode parameters were measured using two different ridges (third and fourth).

The following nematode parameters were recorded for the trial laying out the site during both growing seasons: number of galls (G), number of egg masses (E.M.), number of immature stages (D.S.), number of second-stage juveniles (J2) in soil, number of final population, and estimation of reproduction factor (R.F.). Endlessly yielding components included tons ha^{-1}, root yield, biological yield, and sugar yield tons. According to technological specifications, the percentage of sugar and the percentage of juice purity were both evaluated.

2.4. Statistical analyses

For the two lab experiments carried out. The homogeneity of variance among parameter sets was evaluated using Bartlett's test (Snedecor and Cochran, 1989). Because there was no significant difference across experiments ($P < 0.05$), data sets were pooled for further analysis.

For field trials, recorded trails or metrics from both growth seasons for each establishing site were gathered and analyzed using ANOVA to identify any treatment effects. When an ANOVA showed a significant treatment effect, the Fisher's least significant difference (LSD) test was used to compare treatment means at $P < 0.05$.

3. Results

Figure 1 represents direct exposure of *M. incognita* to silver nanoparticles in water. In repeated experiments, AgNP effectively and steadily reduced *M. incognita* movement (Bartlett's test for homogeneity, $P = 0.923$). As exposure time and AgNP concentration increased, so did the percentage of J2 mortality. More than 50% of nematodes were deactivated after being exposed to AgNP at concentrations of 50 ppm or higher for more than 1 hour. After three hours, all nematodes treated with 100 ppm AgNP died. After a 6-hour exposure to AgNP at 30 or 100 ppm, 55 to 98% of nematodes died. At the 6-hour exposure time, 30 or 70 ppm AgNP inactivated more than 50% of the nematodes. The first ≥50% mortality occurred at the 1-hr exposure time through concentration 80 ppm, followed by the same mortality percentage at the 3-hr exposure time by 50 ppm concentration, followed by 30 ppm that achieved ≥50% mortality at the 3 hr exposure time. However, neither concentration nor exposure time

increased nematode activity. The proportion of healthy and unhealthy nematodes was positively correlated with AgNP concentrations and exposure time (P > 0.05).

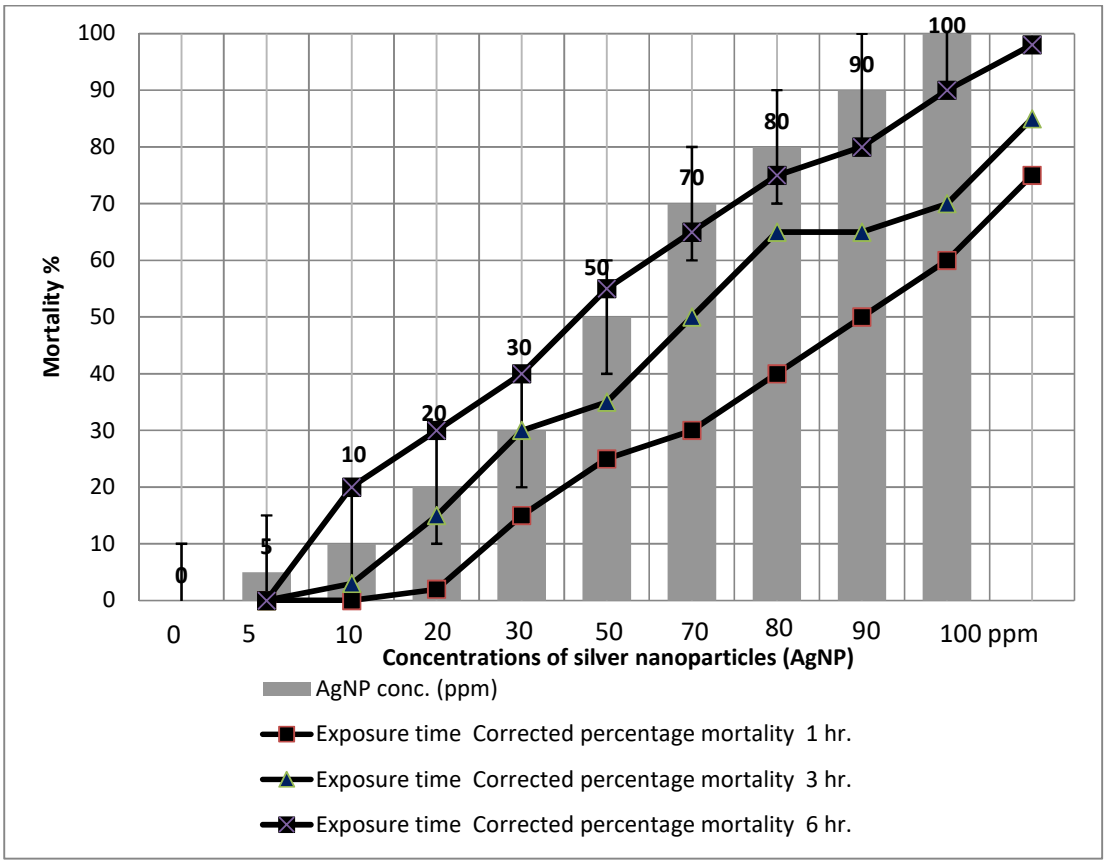

Fig. 1: The mortality Percentage of *Meloidogyne incognita* J2 in relation to the concentrations of silver nanoparticles (AgNP) in water-based laboratory tests.

Silver nanoparticles (Bartlett's homogeneity test, P = 0.955), dissimilar water screening, and 1.5 g/ml of AgNP were ineffective for up to 24 hours in repeated laboratory experiments. Table 2). Juvenile mortality began at 1.5 µg ml^{-1} (21%) and expanded with expanding concentration of AgNP and exposure time ($p \leq 0.05$); however, ≥ 82% mortality was accomplished at groupings of 100 µg/ml or more (92% following 72 hours). There was a critical relationship between exposure time and AgNP concentration ($p < 0.05$). AgNP decreased how much J2 recovered following 2 or 4 days of openness at 150 mg ml^{-1} compared with the untreated control (Table 2). Lower concentrations (15, 3, and 1.5 mg ml^{-1}) of AgNP didn't fundamentally diminish how much J2 was extricated from the soil following 4 days of exposure (Table 1). The association between time and the concentration of AgNP was great ($p \leq 0.05$) (Figure 2).

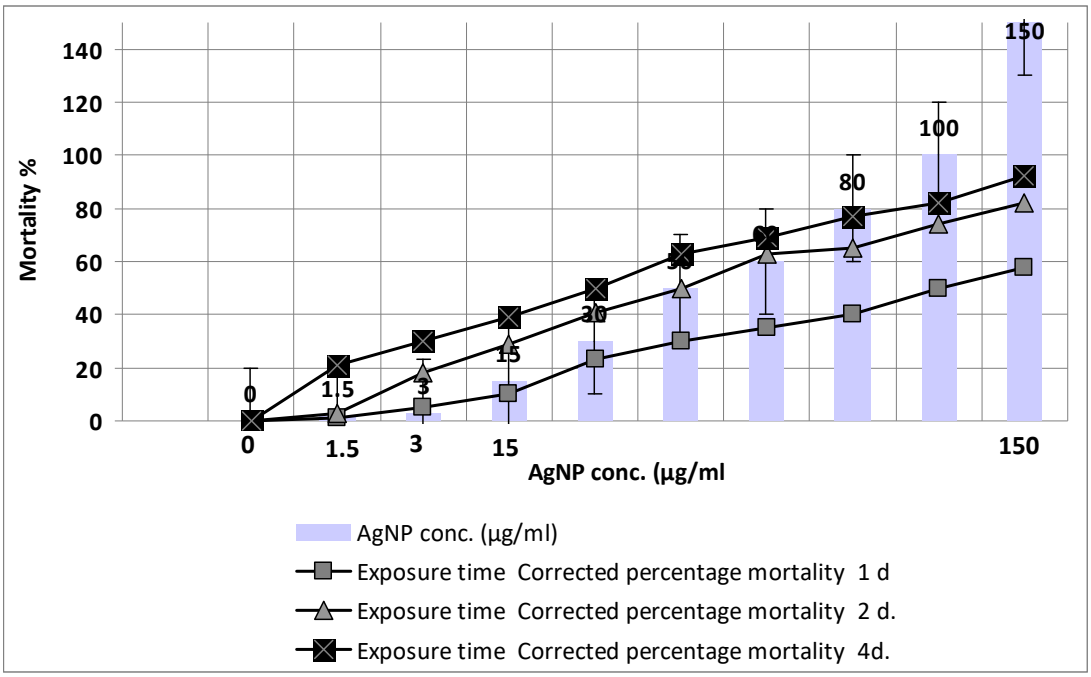

Fig. 2: Percentage mortality of *Meloidogyne incognita* J2 as impacted by quantities of silver nanoparticles (AgNP) in lab experiments with dirt as the medium.

Each one of the tried dosages of silver nanoparticles AgNP estimated the quantity of *Meloidogyne incognita* in the soil, as well as the damage index, galls record, and conceptive variable, in contrast with the untreated control. Regardless of the way that all AgNP doses were genuinely similar, there was a steady reduction in j2 hatchlings in soil, irritating, and reproductive factor as concentrations expanded. Except for j2 numbers in soil between 100 and 150 g ml^{-1} at P 0.05, the effects of various dosages on nematode parameters were significant (Table 2).

Table 2: Shows the effect of Ag-NP concentrations on root-knot nematodes, *Meloidogyne incognita* populations in soil, damage index, gall index, and reproductive factor for sugarbeet roots in pots.

Concentrations of Ag-NPs µgml^{-1}	Root-knot nematode (J2) number g^{-1} soil	Damage index gall index (GI)	Reproductive Factor (RF) Pf/Pi
50	3.7 a (41.3%)*	3.0 a (25.0%)	2.3 a (43.9%)
100	2.2 b (64.8%)	2.1b (47.5%)	1.4 b (65.9%)
150	1.4 bc (77.8%)	1.5 bc (63.5%)	1.0 c (75.6%)
Control (water)	6.3 d	4.0 d	4.1d

In a completely randomized design, values with indistinguishable letters in a column show no significant differences ($p < 0.05$). *Percentage decrease from the most significant value (control).

All tried concentrations of Ag-NP essentially decreased *M. incognita* disease severity (%) compared with the untreated control ($P \leq 0.05$). Notwithstanding being the most minimally tried focus, 50 µg ml^{-1} altogether decreased root-knot disease severities (%) compared with the control treatment. The efficacy (%) of Ag-NP is increasing with increasing concentrations, with significant contrasts seen at each of the four tried levels at $P \leq 0.05$ (see Table 3).

The impact of silver nanoparticle application times on root-knot nematode parameters on sugarbeet as a field assessment, as The main objective of this study is to reduce the root-knot nematode, *M. incognita* parameter, including the quantity of galls, egg masses, and formative stages in underground root mass 1, second stage juveniles (J2) in soil, and final population, as well as the reproduction factor. The timing of silver nanoparticle application differs from that of Tervigo and the control treatments.

Table 3: Effect of Ag-NP concentrations on root-knot disease Severity% and Ag-NP concentration efficacy% roots in pots experiment.

Concentrations of Ag-NPs µgml^{-1}	Root-knot disease Severity%	Ag-NP concentration efficacy%
50	23.0 a	55.7a
100	13.4 b	74.2 b
150	10.6 c	79.6 c
Control (water)	51.9 d	0.0

In a fully randomized design, values with the same letter in a column indicate no significant differences ($p \leq 0.05$).

Table 4 shows the effects of six treatments on root-knot nematode contamination parameters in sugarbeet var. Sahar.

The number of egg masses root system^{-1} (E.M.) reduced with increasing time of silver nanoparticle Ag-NP treatment. As a consequence, T4 had the biggest relative decrease percent (89.2%), followed by T3 (85.6%), and there were no significant changes (0.05) in the root system numbers of the egg masses. There were no significant differences between T3, T4, and T5 (Tervigo 020 SC®), indicating that the silver nanoparticle Ag-NP treatments T4 and T3 were highly effective in decreasing E.M.

Concerning the statistics about the number of immature stages (I.S) root system^{-1} showed that the T4 was the best Ag- NP application to significantly reduce nematode parameters compared to T6 (control). Although, there were insignificant differences among the T3, T4 and T5, (Tervigo 020 SC®) that confirmed the effectiveness of Ag- NP to relatively reduce percentage I.S root system^{-1} oscillated between, 12.8 – 89% (Table, 4).

Table 4: Shows the effects of silver nanoparticles and Tervigo 020 SC® or 20 g/L, a commercial Abamectin preparation, on the number of root-knot nematodes *Meloidogyne incognita* on the sugarbeet variety Sahar, as determined by a combined analysis of the growing fall seasons of 2022 and 2023 in the sugarbeet field.

Treatments	Sum of galls root system^{-1} (G)	Amount of egg masses root system^{-1} (EM)	Account of immature stages root system^{-1} (IS)	Account of juveniles in soil (J2s)	Calculated final population (Pf)	Reproduction factor (R.F)
T_1 Single	77.7 a (13.6%)*	157.8 a (12.0%)	348.3 a (12.8%)	5061.4 a (27.3%)	5409.7 a (26.5%)	6.8 a (26.1%)
T_2 Two times	51.6 b (42.6%)	102.3 b (42.9%)	222.3 b (44.4%)	3866.7 b (44.4%)	4089.0 b (47.0%)	5.1 b (44.6%)
T_3 Three times	11.3 c (72.6%)	25.7 c (85.7%)	58.7 c (85.6%)	1021 c (85.3%)	1079.7 c (85.3%)	1.3 c (85.9%)
T_4 Four time	9.7 c (89.2%)	19.4 c (89.2%)	43.9 c (89.0%)	763.6 c (89.0%)	807.5 c (88.9%)	1.0 c (89.1%)
T_5 TERVIGO*	7.7 c (91.4%)	15.7 c (91.2%)	33.0 c (91.7%)	574 c (91.8%)	607.0 c (91.6%)	0.8 c (91.3%)
T_6 (control)	89.9 d	179.3 d	399.5 d	6957.70 d	7357.2 d	9.2
Mean	41.3	83.4	184.3	3040.7	3225.0	4.0

Values with identical letters in a column indicate no significant differences ($p \leq 0.05$) in a completely randomized design. *Relative reduction percent to the highest value (Control).
Average of Pi = 800 ± (5 – 8) j2 250 cm^3 soil

The juvenile populations (J2) in the soil decreased as more silver nanoparticle (Ag-NNP) applications were made. Subsequently, the highest relative reduction percent (89.0%) was recorded at T4, followed by T3 (85.3%), with insignificant differences between them ($P \leq 0.05$) for the number of juveniles (J2) in 250 cm3 soil^{-1} absolute numbers related to them. There were no significant differences between treatments T3, T4, and T5 (Tervigo 020 SC®), demonstrating the high effectiveness of silver nanoparticle Ag- NP treatments T4 and T3 in reducing the juvenile population (J2) in sugarbeet soil of (Table, 4).

Likewise, the final population (Pf) had a tendency to decrease as more silver nanoparticle (Ag-NP) applications were made. The lowest value of Pf was recorded with the T4 (807.5), i.e. 88.9% relative reduction to control treatment (T6) followed by the T_3 (1021.0), i.e. 85.3% relative reduction. The high efficacy of silver nanoparticle Ag-NP treatments T4 and T3 in reducing the

Table 3 shows how the reproduction factor (R.F.) of *M. incognita*, a root-knot nematode, was tested in a field trial with silver nanoparticle (Ag-NNP) applications. The T4 (89.1% relative reduction) of the T6 (control) was the most effective Ag-NP application on R.F., while the T1 (26.1%) relative reduction was the least effective, indicating that all Ag-NP applications significantly decreased R.F. The relative reduction percentage did not differ significantly between the F4 and T5 (Tervigo 020 SC®), or between the F4 and F3. The R.F. results show that all silver nanoparticle (Ag-NNP) applications in the field significantly decreased the probable R.F. value when compared to the control. T5 (Tervigo 020 SC®) reduced R.F. by 91.3% (0.8 absolute value), whereas T4, the most effective Ag-NP application, did not reduce R.F. but did stop the root-knot nematode, *M. incognita,* from multiplying in sugarbeet (Table 4). Table (4) elucidated the influence of silver nanoparticle (Ag-NNP) applications in field trial on roots, top and sugar yields as well as sucrose and purity percentages of Sahar sugarbeet variety.

Silver nanoparticles Ag-NP were used four times in the T4 to achieve the highest root yield (54.500 tons ha^{-1}) or the highest relative increase percentage (67.11 percent) over the lowest value (control, 23.052 tons). The T3 yielded 54.381 tons, representing a 64.976% increase, but there were no significant differences between the two (P 0.05). It is also worth noting that the silver nanoparticle Ag-NP treatments T4 and T3 resulted in a significant relative increase in root yield tons ha^{-1}, which was very similar to the efficiency achieved by the commercial nematicide Tervigo 020 SC®. This is something that should be considered. All treatments containing silver nanoparticles (Ag-NP) increased root yield tons ha^{-1} by 8.4–117.5%–89.2% (Table 5).

Sugarbeet top yield tons ha^{-1} increased after silver nanoparticles Ag-NP were applied. T4 had the highest relative increment percent (117.5%), followed by T3 (117.1%), with no significant differences ($P \leq 0.05$) regarding weight ha-1 weight. There were no tremendous contrasts between T3, T4, and T5 (Tervigo 020 SC®), demonstrating that silver nanoparticle Ag-NP medicines T4 and T3 were profoundly powerful in keeping a decent weight ha.1 for top yield in polluted sugarbeet soil with *M. incognita* (Table 5).

The silver nanoparticle Ag-NP application (T4) had the highest sugar yield (9.476 tons ha1), followed by T3 (9.381 tons ha1), with no significant difference between them ($P \leq 0.05$ equivalent in efficacy). Tervigo 020 SC® achieved a reasonable sugar yield of 10.095 tons ha1, with no significant differences between them. All treatments with silver nanoparticles Ag-NP increased sugar yield tons ha^{-1} by 15.27-165.43% (see Table 4).

The silver nanoparticles Ag-NP application T4 had the highest sucrose% value (17.40%) and significantly higher sucrose content than the other silver nanoparticles Ag-NP applications, but the difference was insignificant. All treatments with silver nanoparticles (Ag-NP) increased sucrose percentages by 6.25-26.56%. The efficacy of silver nanoparticles Ag-NP treatments was comparable to that of Tervigo 020 SC® (18.01%) in sucrose (Table 4).

Essentially, the silver nanoparticle Ag-NP application T4 had the highest purity value (83.42%), yet it was not fundamentally the same as different treatments, including Tervigo 020 SC® and control treatments (Table 4). Taking everything into account, the given information showed that all treatments with silver nanoparticles (Ag-NP) increased sucrose and purity values. However, T4 and T3Ag-NP applications brought about the most noteworthy root, top, biological, and sugar yields, with little difference between them. Accordingly, the T3Ag-NP application was more successful at supporting solid sugarbeet establishment in *M. incognita*-contaminated soil.

Table 5: Shows the effects of silver nanoparticles and Tervigo 020 SC® or 20 g/L, an Abamectin business plan, on yield and yield components of the sugarbeet variety Sahar using a combined analysis of the growing fall seasons of 2022 and 2023 in a sugarbeet field.

Treatments	Roots yield (tons ha^{-1})	Top yield (tons ha^{-1})	Sugar yield (tons ha^{-1})	Sucrose %	Purity %
T_1 Single	27.178 b (8.5%)	13.100 b (0.03%)	4.119 b (15.27%)	15.12 b (6.25%)	73.32 b (13.44%)
T_2 Two times	32.576 b (30.0%)	15.017 b (5.15%)	5.024 b (41.00%)	15.43 b (8.43%)	78.54 a (15.23%)
T_3 Three times	54.381 a (117.1%)	23.559 a (64.97%)	9.381 a (163.44%)	17.27 a (21.36%)	82.21a (20.61%)
T_4 Four time	54.500 a (117.5%)	23.864 a (67.11%)	9.476 a (165.43%)	17.40 a (22.28%)	83.42 a (22.39%)
T_5 TERVIGO*	56.024 a (123.8%)	26.740 a (87.25%)	10.095 a (183.31%)	18.01 a (26.56%)	85.61 a (25.60
T_6 (control)	23.052 c	14.281 c	3.571 c	14.23c	68.16 b
Mean	42.143	19.524	6.905	16.2	79.2

In a completely random design, values in a column with the same letters indicate no significant differences ($p < 0.05$). Relative increment percent to the most minimal worth (control).

4. Discussion

This work reveals how AgNP has some influence on *M. incognita*, and the findings are consistent with previous research (Cromwell *et al.,* 2014). *M. incognita* J2 inactivation by direct openness and decrease of *M. incognita* J2 in soil medicines demonstrated the high nematicidal impacts of AgNP; resulting nursery tests demonstrated the valuable impacts of AgNP for seriously controlling nematodes while not harming free-living nematodes or plant development, and being plant not entirely set in stone. Thus, the primary field study demonstrates that AgNP has a significant impact on sugarbeet management, including improved quality and reduced root galling. Furthermore, AgNP was deemed safe for sugarbeet, with no detectable phytotoxicity seen even after constant (fortnightly) administrations throughout two development seasons.

When AgNP was directly exposed to water, it had a positive effect on J2 root-knot nematodes. Assuming that the fraction of corrupt larvae after 6 hours of direct exposure did not change after filtration and suspension in water, the phenotypic analysis appears to be a reasonable indication of nematode mortality in this study. Soil treatment with AgNP (150 mg/ml for 2 to 4 days) enhanced nematicidal activity, resulting in a substantial reduction in J2 recovered from the soil.

In this research, the effect of silver nanoparticles (AgNP) on plant-parasitic nematodes was studied. Previous studies were based on non-parasitic nematodes such as *Caenorhabditis elegans* and *Panagrellus redivivus*. The study found that 1.5 µg/ml^{-1} of AgNP was ineffective for soil remediation even after 24 hours of testing. This could be due to AgNP adsorption by soil particles and an increased likelihood of aggregate formation, which reduces AgNP interaction with nematodes. Juvenile mortality of nematodes started at 1.5 µg/ml and increased with higher AgNP concentrations and exposure time. However, at concentrations of 100 µg/ml and higher, more than 82% mortality was observed (92% after 72 hours). In the glasshouse experiments with sterilized or naturally infected soil, the effective gall reduction dosage was at least 2 g/mL. Even when utilizing field soil, 2 µg/ml is still lower than the recently revealed 200 µg/ml. As per Fouda *et al.,* (2020), Ag-NPs can be effectively utilized as an eco-nematicide for root-tie nematodes, *Meloidogyne incognita*, with a particular suggested portion of Ag-NPs in ppm that is obtained at a higher M% and causes numerous deviations during the different phases of *M. incognita* improvement. Gohar *et al.,* (2020) found that silver nanoparticles (Ag-NPs) at different fixations were tried as a nematicidal specialist in outside pot preliminaries. Applying Ag-NPs straightforwardly to plagued sugarbeet pots brought about critical concealment of the root-hitch nematode, *M. incognita*, as estimated by soil dropping numbers, regenerative element, and bunch infection seriousness (%), which were all equivalent to untreated pots. The impacts of various Ag-NPs concentrations and application times on yield components of sugarbeet plants infested with the root-knot nematode, *M. incognita*, were connected with the level of nematode movement concealment. Various convergences of Ag-NPs expanded yield parts, for example, root yield plant^{-1}(g), top yield plant^{-1}(g), and sugar yield plant^{-1}(g), even at low fixations (20 ppm/ml), contrasted with the control

treatment. In pot tests, sugarbeet swarmed with the root-tie nematode *Meloidogyne incognita* showed a similar quality and purity pattern as sucrose. An environmentally friendly method for controlling root-knot nematodes was discovered in this study. The use of AgNP didn't lessen the quantity of *M. incognita* J2 nematodes in the field preliminary, as estimated by reproductive factor (RF), which stayed at one. This means that toward the end of the tried seasons, the initial population Pi was equivalent to the final population Pf, demonstrating that the AgNP application forestalled nematode increases. Nonetheless, the utilization of AgNP improved sugarbeet quality all through the tried-and-tested developing seasons while additionally decreasing the advancement of root galls formation.

It means a lot to take note of that AgNP's failure to lessen J2 nematode levels in field plots might be because of the weakening impact of AgNP. Research center tests uncovered that decreasing J2 levels required 2-4 days of soil treatment with 150 mg/mL AgNP. Nonetheless, complete AgNP immersion in the soil profile in the field demonstrated troublesome results, so a lot of lower portions were utilized. Nematodes may not die immediately or require additional exposure time to become infected as a result. Past examination has shown that sublethal dosages of AgNP can decrease nematode development and reproduction. AgNP dosages going from 0.05 to 0.5 mg ml^{-1} can forestall reproduction for 72 hours or 5 to 50 mg ml^{-1} for 1-3 days. This suggests that at low fixations in the field, the AgNP impact might be imperceptible and durable.

Baronia *et al.,* (2020) found that applying a 1 g/mL concentration of Ag-NP directly to trays significantly reduced root gall formation in glasshouse assays for soilless rice cultivation. In field soil assays, a dosage of 3 g/mL was found to be the most effective for killing nematodes, which is lower than the 150 g/mL reported in the literature.

In field experiments, all treatments with silver nanoparticles (Ag-NP) reduced gall root $system^{-1}$ by 13.6% to 89.2%. The use of silver nanoparticles Ag-NP in T4 (multiple times) resulted in the least galls root system 1, followed by T3 (multiple times), with no significant difference between the two. Surprisingly, silver nanoparticle Ag-NP treatments T4 and T3 were found to be as effective as commercial nematicides in reducing galls root $system^{-1}$ (G).

During a field study, silver nanoparticles (Ag-NP) were used to treat the root-knot nematode *M. incognita* reproduction factor. Every application significantly decreased R.F. The most effective Ag-NP application (T4) did not reduce R.F., but it did prevent *M. incognita* growth in the sugarbeet field. These results are consistent with the findings of Cromwell *et al.,* (2014), who discovered that applying Ag-NP did not significantly reduce the number of root-knot nematodes second infecting juveniles (J2) in rice during the growing season. However, the field trial showed that it was effective at preventing root-knot nematode damage to the crop being studied. In one year, biweekly AgNP application improved crop quality and reduced gall formation in roots while avoiding phytotoxicity. Using AgNP did not significantly reduce the number of knot nematodes second infecting juveniles in rice plots during the growing season. These findings are consistent with the current study's findings, which showed that all treatments containing silver nanoparticles (Ag-NP) increased sugar yield per hectare, sucrose, and purity percentage values. As a result, Ag-NP application is more appropriate for maintaining healthy sugar beet planting in soil contaminated with *M. incognita*.

4. Conclusion

According to this study, AgNP can potentially manage root-knot nematodes in sugarbeet fields. The experiment found that AgNP had robust nematicidal effect on *M. incognita* J2 through direct exposure and soil treatment, leading to inactivation and reduction of the nematode, respectively. In the field trial, AgNP was found to improve the quality of Sugarbeet and reduce root galling in intensively managed sugarbeet crops. AgNP is safe for sugarbeet, with no discernible phytotoxicity when applied every other week during the growing season. Furthermore, AgNP exhibits nematicidal movement, making it a practical substitute to high-risk synthetic nematicide or problematic natural control specialists. Supposedly, no two examinations produce identical detailed results. This study demonstrates that AgNP is a viable solution for controlling root-hitch nematodes in sugarbeet without harming the plant. Higher application rates of AgNP (more than 90.4 mg/m^2) might be required fortnightly to accomplish optimal field results. This is the first review to demonstrate how AgNP can effectively control sugar beet issues. Consolidating AgNP with a water system framework, such as fertigation or tank blending, as well as viable synthetic compounds to improve AgNP nematicidal

impact, may increase its materiality. Further comprehension of its nematicidal component is expected to further develop AgNP's adequacy and viability.

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