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Pre-Planting Application of Colloidal Silver Nanoparticles Enhances Bulb Yield of *Lilium* Grown under NaCl Stress †

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Abstract: Unique properties of nanoparticles arouse great interest in the horticulture industry due to their possible use to improve plant resistance to environmental stresses. Lilies belong to the most important bulbous plants. However, limited information is available on lilies response to nanoparticles under salt stress. In this work, we investigated the effects of colloidal silver nanoparticles (AgNPs) and NaCl on bulb yield of a potted Asian lily. Compared with control, the lilies treated with AgNPs showed an increase in bulb yield. NaCl treatment decreased fresh weight of bulbs and bulb diameter, and AgNPs applied prior to watering with NaCl improved fresh weight of bulbs and bulb diameter. Our results demonstrated that colloidal AgNPs enhanced tolerance of lily plants to salinity.

Keywords: AgNPs; Asian lily; ornamentals; salinity

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1. Introduction

Nanotechnology, as a method based on specific properties of nanoparticles, is present in many fields of science and industry [1,2]. It is also successfully used in agricultural sciences, for example in plant protection, fertilization, growth stimulation or yield enhancement. Nanotechnology based innovations in the horticulture are relatively recent and still require intensive research [3,4].

One of the most commonly used nanomaterials is nano-silver (AgNPs), whose antibacterial properties are well known and documented [5]. AgNPs show multidirectional activity towards plants, and may stimulate or inhibit their growth and development. The effect of AgNPs on plants depends, e.g., on the plant genotype, AgNP concentration, size and shape of nanoparticles, treatment type, and method of NP synthesis [6–8]. Available studies indicated that AgNPs may act synergistically with some growth regulators to increase plant defense capabilities under unfavorable pressure of abiotic factors [9]. One of those factors is salinity, a common problem in the soils and substrates used for growing ornamental plants. Salinity negatively affects plant growth as it disturbs water and nutrient uptake. This is manifested in a decrease of plant yield and quality, and leads to necrosis or even plant death [10,11]. The few reports published so far seem to indicate that nanoparticles may diminish the effect of salinity on cultivated plants [12,13].

Lilies (*Lilium* sp.), together with tulips, belong to the most important bulb plants globally, as evidenced by sales rankings on Dutch flower exchanges [14]. Asian lilies are the most popular group of lilies grown for cut and pot plants, and so their bulbs are in high demand.

Our experiment with Asian lily involved soaking the bulbs in a solution of colloidal AgNPs prior to planting and gradual salinization of the substrate in the vegetative stage of plant growth. Our aim was to demonstrate that AgNPs used in this form can significantly reduce the negative effects of soil salinity in plants.

2. Materials and Methods

The plant material included bulbs of Asian lily 'Bright Pixi'. Before planting, the bulbs were divided into two groups: control ones that were soaked in water, and experimental ones soaked for 60 min in 100 mg dm^{-3} solution of colloidal AgNPs in deionized water. After drying the bulbs were planted on 31 March into pots (16 cm in diameter, 2 dm^3 capacity) filled with TS1 substrate (Kronen, Lasland), pH 6.4 and electrical conductivity (EC) 0.54 mS cm^{-1}.

Plants in the pots were grown on drainage mats spread on tables (Figure 1), under natural photoperiod. After five weeks of cultivation, we began watering the lilies with NaCl (solution EC = 2.32 mS cm^{-1}). Salinity treatment was applied to half of the plants treated with AgNPs and half of those non-treated. NaCl was supplied three times, each time in the volume of 100 mL per pot. The experiment compared four treatments of 20 plants each (5 plants × 4 replications): (1) control, (2) AgNPs, (3) NaCl, (4) AgNPs + NaCl.

(**a**) (**b**)

Figure 1. Asian lily 'Bright Pixi' plants grown in a foil tunnel; (**a**) bud flower stage, (**b**) in full anthesis.

After 100 days of growth the bulbs were removed from the substrate, cleaned, and their yield was assessed. Then they were weighed to determine their fresh weight and their diameters were measured.

The measurements were verified with one-factor variance analysis and Statistica 13.1 package (Statsoft, Kraków, Poland). Significance of differences between means was assessed with Duncan's test ($p \leq 0.05$).

3. Results and Discussion

Climate changes and ensuing difficulties in supplying crops with clean fresh water require increasingly often use of salty water for irrigation [15]. The principles of sustainable development and economic factors also necessitate cultivation of ornamental plants in the soil and substrates of increased salinity [16]. For this reason, the methods to reduce the effects of salinity on the ornamental plants are widely sought after [17,18].

In our study, we used colloidal AgNPs to soak the bulbs before planting and NaCl solution to water the plants. Both treatments significantly affected the bulb yield. The most beneficial results were achieved by soaking the bulbs in AgNPs, as it brought about 13.9%

increase in fresh weight and 14.4% increase in diameter (Tables 1 and 2). It may be assumed that enhanced bulb weight was due to greater fresh weight of the leaves and higher relative content of chlorophyll (unpublished data).

Table 1. Effect of AgNPs and salinity on fresh weight of bulb of lily.

Treatment	Control	AgNPs	Salinity	AgNPs + Salinity
Fresh weight of bulb (g)	37.5 ± 1.5 b	42.7 ± 1.8 a	25.3 ± 2.2 c	36.0 ± 0.4 b
%	100	+13.9	−32.5	−4.0

[1] Means followed by same letters within the same column for each data set are not significantly different at $p \leq 0.05$

Table 2. Effect of AgNPs and salinity on bulb diameter of lily.

Treatment	Control	AgNPs	Salinity	AgNPs + Salinity
Bulb diameter (cm)	53.8 ± 0.4 b	61.5 ± 5.3 a	46.8 ± 2.1 c	53.2 ± 3.0 b
%	100	+14.3	−13.0	−1.1

[1] Means followed by same letters within the same column for each data set are not significantly different at $p \leq 0.05$.

Lily bulbs soaked prior to planting in colloidal AgNPs and grown under salt stress responded with lowered fresh weight and reduced diameter of the daughter bulbs but the differences were insignificant as compared with the control. These findings are consistent with those of Namin and Azari [18], who used NaCl + nano silver to irrigate saffron plants. They did not observe significant differences in the number of cormlets but combining these chemicals clearly improved yield as compared with NaCl only variant.

According to Veatch-Blohm et al. [17] geophyte bulbs may serve as stress buffers. Our study showed that soaking the bulbs in AgNPs can fortify them and improve their tolerance to salt stress. However, it is important to keep in mind that the mechanism of action of nano-silver particles in plants is not fully understood and requires further research.

4. Conclusions

Bulb pretreatment with colloidal AgNPs increases fresh weight and diameter of lily bulbs under salt stress. AgNPs can be recommended as effective stimulators of bulb yield both under optimal and stress conditions. This is the first study proving the positive role of colloidal AgNPs in salinity tolerance of bulbous plants.

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