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Nano-silver as a potential biostimulant for plant – A review

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ABSTRACT

Nanotechnology, as one of the most promising fields of science, brings unlimited possibilities of development of many areas, including agriculture and horticulture. Nano-silver is one of the nanomaterials that its effect on plants are under investigation nowadays. Numerous experiments conducted by scientists evaluated the possibility of using nano-silver as an potential plant growth regulator for crops, and also as a means to extend the post-harvest longevity of cut flowers and ornamental foliage. This paper summarizes a comprehensive and systematic study of the data on nano-silver activity and its application in horticulture, postharvest handling and storage of cut flowers and florist greens.

***Keywords*:** nanomaterials, nanotechnology, cut flowers, ornamental foliage, growth regulator

1. NANOSILVER CHARACTERISTISCS

Researches in the field of nanotechnology are highly prioritized and include sciences such as: chemistry, physics, biology, materials engineering, agriculture and more. Nanotechnology embraces the set of techniques and methods of creating various structures with particle size from 1 nm to 100 nm [1,2]. In recent years we might observe a lot of interest in metallic nanoparticles, both because of their unlimited application capabilities, as well as their unusual biological, chemical and physical properties [3].

Silver is one of the earliest discovered noble metals and its extraordinary medicinal qualities were known in 4000 B.C. [4]. Biocidal functions of silver are known since the ancient times. Its medicinal characteristics were already described by Hippocrates (in IV century B.C.) [5,6]. Silver ions for a long time have been finding their application in medicine and pharmaceuticals, veterinary and food industry, and were used as protection from pathogenetic bacteria, fungi and viruses [6,7]. As a result of fragmenting particles in the nanoscale, the silver acquired new properties which are significantly different from macrostructures and constitutes the same chemical compound [8]. It is a consequence of the presence of a large number of atoms located on the surface of the particle, which have a direct contact with external environment [9]. Silver nanoparticles are characterized by a large surface area relative to the micrometric form, which has a significant influence on absorption properties and biocide activity against microbes [10]. Besides a specific surface nanoparticles of silver are also characterized by large surface-atom fractions and have unique physical and chemical properties [11].

2. NANOSILVER PARTICLES ACTIVITY MECHANISM

Nanometal particles are characterized by far higher biochemical activity than macrometric structures and thus are more efficiently affecting bacteria or fungi [5,6,12]. Nanoparticles of silver have a specific ability to oxidize substances which surround it. A single nanoparticle of silver is characterized by a high electric charge and its shell is devoid of two electrons, which attracts pathogenic microorganisms. By intercepting missing electrons, nanoparticles of silver damage and then destroy the pathogen. This mechanism causes nanosilver particles to be strongly bactericidal, fungicidal and have certain virucidal properties. Mechanism of nanosilver effect on fungi and viruses is analogous to the effect on bacteria cells. Nanosilver disrupts the water balance of fungi and influences the catalytic decomposition of lipid-protein layers of viruses [4]. It has been proved that biocidal activity of nanosilver particles depends on the size and shape of flecks, however, it is important to highlight that the mechanism of microorganisms' deactivation has not been precisely explained so far [13,14].

3. EFFECT OF NANO–SILVER ON CROPS

This review gathers information on nano-silver provided by recent research, especially when is used in horticulture. Applications of nano-silver resulted in an increase in plant height [15,16,18], leaf number [16], weight roots [19,20], biomass of plant [15,16,25,38], seed germination [19,20,25,28,36,37], seed yiel [15,16], quality of fruit [18], stem lenght [22,30], diameter of canopy area [21], root lenght [19,20,22,24,25,27,30,32,35-37], growth and development of explants under in vitro culture condition [31] and number of protoplasts [30]. The addition of an appropriate nano-silver concentration increased chlorophylls content [27], carotenoids [22], flavonoids [31], photosynthetic quantum efficiency [27], enzymatic activity, content of parahydroxy benzoic acid [17], α-terpinyl acetate [21], as well as antioxidative enzymes activities [29]. Experimental results on the use of nano-silver in crops are summarized in Table 1.

Table 1. Biostimulant effects of nano-silveron on crops.

Crop	Nano-silver type and concentration	Method of application	Effects	References
Basil (*Ocimum basilicum*)	Nano-silver (20, 40 and 60 ppm)	Sprayed plant at seed growth stage	● Increased plant height ● Improved dry weight of plant ● Enhanced seed yield	[15]
Borage (*Borago officinalis*)	Nano-silver (20, 40 and 60 ppm)	Sprayed of plant at 125 days after cultivation	● Improved seed yield ● Increased number of leaves ● Enhanced plant height ● Improved dry weight of plant ● Increased dry weight of inflorescences	[16]
Castor (*Ricinus communis*)	Silver nanoparticles (100, 200, 500, 1000, 2000, 4000 mg L^{-1})	Soaking of seeds	● Increased enzymatic activity ● Enhanced content of parahydroxy benzoic acid	[17]
Cucumber (*Cucumis sativus*)	Silver nanoparticles (average size of 50 nm, bulk density 0.92 g ml^{-1}, specific surface area 10.1 m^2 g^{-1}) at 500, 1000, 1500, 2000, 2500 and 3000 ppm)	Sprayed every 7 days for 14 weeks	● Increased plant height ● Improved number of fruits ● Enhanced weight of fruit ● Increased length of fruit	[18]
Fennel (*Foeniculum vulgare*)	Silver nanoparticles (0, 20, 40, 60, 80, 100 mg kg^{-1} and 0, 30, 60, 90,120,150,180 mmol L^{-1})	Adding to medium *in vitro*	● Increased germination percentage ● Improved root fresh weight ● Enhanced root length	[19]

Fenugreek (*Trigonella foenum graecum*)	Nano-silver (0, 10, 20, 30, 40 µg ml L^{-1})	Sedd soaking (15 ml by 12 days)	● Increased root length ● Improved root fresh weight ● Enhanced root dry weight ● Increased seed germination	[20]
Ferula rigidula (*Thymus kotschyanus*)	Nano-silver (0, 20, 40, 60, 80, and 100 ppm)	Soaking of seeds	● Increased diameter of canopy area ● Shortened flowering time ● Improved essential oil ● Enhanced herb yield ● Increased α-terpinyl acetate content	[21]
Fodder beet (*Beta vulgaris*)	Silver nanoparticles (0.5, 15 mg L^{1}or 0.5, 15 mg/kg)	Adding to medium and soil	● Enhanced root lenght ● Increased stem lenght ● Improved carotenoids content	[22]
Ryegrass (*Lolium multiflorum*)	Silver nanoparticles (1, 5, 10, 20, 40 mg L^{-1})	Seed soaking for 1 h	● Inhibited of seedling growth	[23]
Hibiscus (*Hibiscus rosa sinensis*)	Silver nanoparticles with	Adding to IAA and BA	● Enhanced root length ● Increased number of roots	[24]
Lentil (*Lens culinaris*)	Silver nanoparticles (10, 20, 30 and 40 µg m L^{-1})	Adding to seeds (15 ml by 14 days)	● Increased root length ● Improved shoot length ● Increased dry mass ● Enhanced seed germination	[25]
Mung bean (*Phaseolus radiatus*)	Silver nanoparticles (5, 10, 20, 40 mg L^{1} and 500, 1000, 2000 mg kg^{-1})	Adding to agar medium and soil	● Inhibited of seedling growth	[26]

Mustard (*Brassica juncea*)	Silver nanoparticles (25, 50, 100, 200 and 400 ppm)	Adding to medium	● Increased root lenght ● Enhanced chlorophyll content ● Improved photosynthetic quantum efficiency	[27]
Pearl millet (*Pennisetum glaucum*)	Nano-silver (20 and 50 ml L^{-1})	Seed soaking for 2 h	● Increased seed germination ● Improved shoot length ●Enhanced root length	[28]
Pelargonium 'Flowerfairy' and 'Foxi' (*Pelargonium zonale*)	Nano-silver (0, 20, 40, 60, and 80 mg L^{-1})	Sprayed of 50 mL	● Increased antioxidative enzymes activities ● Reduced lipid peroxidation ● Improved petal longevity ● Decreased petal abscission	[29]
Potato (*Solanum tuberosum*)	Nano-silver (0, 1.0, 1.5, and 2.0 ppm)	Adding to medium	● Increased stem length ● Improved root length ● Decreased of number of isolated protoplasts ● Decreased in the viability of isolated protoplasts	[30]
Potato 'White Desiree' (*Solanum tuberosum*)	Silver nanoparticles (average size 20 nm, spherical in shape and specific surface area of 18-22 $m^2 g^{-1}$) at 0, 2, 10, 20 mg L^{-1})	Adding to medium	● Increased flavonoids content ● Enhanced total phenolics ● Improved growth and development of explants under in vitro culture condition	[31]
Radish (*Raphanus sativus*)	Nano-silver (125, 250, and 500 mg L^{-1})	Adding to medium *in vitro*	● Diminished water content ● Decreased root lenght	[32]

Rose (*Rosa hybrida*)	Nano-silver (0, 50, 100 and 150 ppm)	Adding to medium *in vitro*	● Reduced bacterial contamination ● Reduced phenolic exudation rate	[33]
Safflower (*Carthamus tinctorius*)	Silver nanoparticles (20, 40, 60 ppm)	Soaking of seeds	● Increased numbers seed ● Improved number of inflorescences	[34]
Saffron (*Crocus sativus*)	Nano-silver (0, 40, 80 or 120 ppm)	Soaking corms for 90-minute	● Increased number of roots ● Improved root length ● Enhanced leaves dry weight	[35]
Tomato 'Peto Early CH' 'Primo Early' 'Cal.J.n3' 'Early Urbanay VF' 'King Stone' 'Super Stone' 'Super Strain B' (*Lycopersicon esculentum*)	Silver nanoparticles (0, 25, 50, 75 and 100 mg L^{-1})	Soaking of seeds (5 seconds three times of 1h)	● Increased germination index in early stage ● Decreased root length ● Decreased shoots length	[36]
Tomato (*Solanum lycopersicum*)	Silver nanoparticles (0.05, 0.5, 1.5, 2, 2.5 mg L^{-1})	Seed soaking for 2 h	● Increased germination percentage ● Improved germination rate ● Enhanced root length ● Increased seedling fresh and dry weight	[37]
Brassica 'Pusa Jai Kisan' (*Brassica juncea*)	Silver nanoparticles (50 and 75 ppm)	Sprayed of foliar	● Improved shoot dry weight ● Increased shoot fresh weight ● Enhanced shoot lenght	[38]

As demonstrated in many studies [39-41,43,44,46-59], nano-silver may be an effective agent prolonging postharvest longevity of cut flowers. Positive effect of nano-silver on longevity of cut flowers expressed in days was reported for acacia [39], alstroemeria [40], aspidistria [41], carnation [42,43], chrysanthemum [44-46], freesia [47], gerbera [48-50], gladiolus [51], oriental lily [52,53], rose [54-58], tuberose [59,60] and tulip [62]. The results from the literature show that nano-silver has positive effects of on fresh weight of flowers [39,41,49,52-54,59,61], stem diameter [59], survival and succulence of cut flowers [45], solution uptake [39,41,48,50,51-56,58,59], water balance [58], chlorophyll content [40,60,61], stomatal conductance [55], inflorescences opening [44,47], greenness index [41,46] and electrolyte leakage [60]. Literature data supply evidence showing that nano-silver is very effective in limiting development of aqueous microflora [42,45,48,50-53,55], ethylene production [57], as well as bacterial populations [42]. Experimental results on the use of nano-silver in cut flowers and florist greens are summarized in Table 2.

Table 2. Effect of nano-silver on cut flowers and florist greens.

Crop	**Nano-silver type and concentration**	**Method of treatment**	**Effects**	**References**
Acacia (*Acacia holosericea*)	Nano-silver (neutral 4 or 40 mg L^{-1}, acid 0.5 or 5 mg $L^{-1}$and ionic 0.5 or 1 mg L^{-1})	Pulsing for 24 h	● Increased longevity of leafed shots ● Improved mass of leafy shoots ● Enhanced consumption of the solution by the plants	[39]
Alstroemeria 'Rosada' (*Alstroemeria*)	Nano-silver (15, 20 and 25 ppm)	Adding to vase solutions	● Increased vase life ● Decreased bent neck ● Improved chlorophyll content	[40]
Aspidistra (*Aspidistra elatior*)	Colloidal silver (0.01%, 0.02% and 0.04%)	Adding to vase solutions	● Increased greenness index of the laminas ● Improved fresh weight ● Extended vase life ● Increased relative solution uptake	[41]
Carnation (*Dianthus caryophyllus*)	Silver nanoparticles (0, 5, 10 and 15 mg L^{-1})	Pulsing for 24 h	● Reduced oxidative stress ● Improved anti-oxidant system ● Reduced bacterial populations	[42]

Carnation 'Cream Viana' (*Dianthus*)	Nano-silver (2 and 4 ppm)	Pulsing for 48 h	● Extended vase life ● Increased content of anthocyanins	[43]
Chrysanthemum 'Puma' (*Chrysanthemum*)	Silver nanoparticles (0.01, 0.05, 0.1, 0.5, 1, and 5 mM)	Adding to vase solutions	● Promoted inflorescence opening ● Increased vase life	[44]
Chrysanthemum (*Chrysanthemum morifolium*)	Silver nanoparticles (0, 5, 10 and 20 mgl^{-1})	Pulsing for 24 h	● Increased survival and succulence of cut flowers ● Reduced stem bacteria colonies	[45]
Chrysanthemum 'Feeling Green' (*Chrysanthemum*)	Colloidal silver (0.01, 0.02 and 0.04%)	Adding to vase solutions	● Extended vase life ● Inhibited weight loss ● Increased greenness index of leaf	[46]
Freesia (*Freesia*)	Nano silver (5, 10 and 15 ppm)	Adding to vase solutions	● Increased vase life ● Improved number of opened florets	[47]
Gerbera (*Gerbera jamesonii*)	Nano-silver (1, 2, 3, 4 and 5 mg L^{-1})	Adding to preservative solutions	● Inhibited growth of microorganisms in vase solution ● Extended vase-life ● Increased consumption of the solution by the plants	[48]
Gerbera 'Dune' (*Gerbera jamesonii*)	Silver nanoparticles (5 or 10 mg L^{-1})	Adding to vase solutions	● Increased fresh weight ● Extended vase life	[49]
Gerbera 'Ruikou' (*Gerbera jamesonii*)	Nano-silver (2-5 nm) at 5 mg L^{-1}	Pulsing of stems for 24 h	● Inhibited bacteria growth ● Maintained water uptake ● Extended vase life	[50]
Gladiolus 'Eerde' (*Gladiolus hybridus*)	Nano-silver (10, 25, 50 mg L^{-1})	Pulsing for 24 h	● Prolonged vase life ● Increased water uptake ● Reduced water loss ● Inhibited bacterial	[51]

			colonization and biofilm formation on the stem-end cut surface	
Lily 'Bouquet' (*Lilium orientalis*)	Silver nanoparticles (5, 15, 25, 30 ppm)	Nano-silver solutions	● Extended the longevity ● Increased solution uptake ● Improved initial fresh weight ● Decreased bacteria colony during the first 2 days of vase life	[52]
Lily 'Shocking' (*Lilium orientalis*)	Nano-silver (5, 15, 25, 35 ppm)	Adding to vase solutions	● Extended longevity vase ● Increased solution uptake ● Improved fresh weight ● Inhibited bacteria colony during first two days of vase life	[53]
Rosa 'Tineke' (*Rosa hybrida*)	Nano-silver (1, 3, 5 mg L^{-1})	Adding to vase solutions	● Increased vase life ● Improved water content ● Enhanced fresh weight	[54]
Rose 'Avalanche' and 'Fiesta' (*Rosa*)	Nano-silver (50, 100, and 200 mg L^{-1})	Pulsing	● Increased vase life ● Improved water uptake rate ● Increased fresh weight ● Reduced the number of bacteria ● Diminuted water loss ● Increased stomatal conductance ● Improved transpiration rate	[55]
Rose 'Cherry Brandy' (*Rose*)	Nano-silver (1, 2.5 or 5%)	Adding to vase solutions	● Increased vase life ● Improved solution uptake ● Retarded weight loss ● Disinfected vase	[56]

			solution ● Prevented vase solution microbial proliferation	
Rose 'First Red' (*Rose*)	Silver nanoparticles (25, 50 and 100 mg L^{-1})	Pulsing for 24 h	● Prolonged vase life ● Suppressed microbial growth ● Decreased ethylene production	[57]
Rose 'Movie Star' (*Rose*)	Nano-silver (0.5 and 10 mg L^{-1})	Pulsing for 24 h and then kept in a low concentration of NS solution	● Improved water balance ● Prolonged vase life ● Increased mass of flowers	[58]
Tuberose (*Polianthus tuberosa*)	Nano-silver (15, 30 and 45 mg L^{-1})	Adding to preservative solutions	● Extended the longevity ● Increased stem diameter ● Improved water uptake ● Enhanced fresh weight ● Increased relative water uptake	[59]
Tuberose 'Peril' (*Polianthes tuberosa*)	Nano-silver (0.5, 10 and 15 ppm)	Adding to vase solutions	● Increased chlorophyll content ● Decreased electrolyte leakage	[60]
Tulip 'White Parrot' (*Tulipa gesneriana*)	Nano-silver (10, 20 and 40 mg L^{-1})	Adding to vase solutions	● Increasd final fresh weight ● Improved percentage of initial fresh weight ● Enhanced final stem length ● Increased percentage of initial stem length ● Improved chlorophyll content	[61]

4. CONCLUSION

Our review revealed that nano-silver may be used in horticultural practice as a potential plant growth regulator. The efficiency of nano-silver depends on the plant species, concentration, method of application, as well as the growing conditions and developmental stage. So we conclude that further research on controversial or disputable issues, and to focus on unresolved problems associated with the use of nano-silver in crops are necessary.

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