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Impact of silver nanoparticles on the photosynthetic activity of pea (*Pisum sativum* L.) under salt stress

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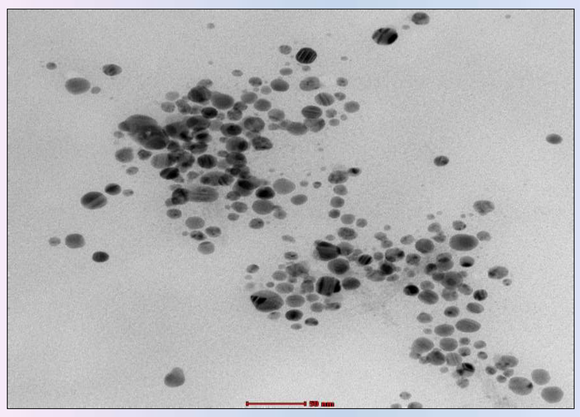
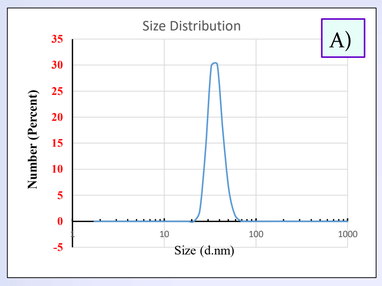
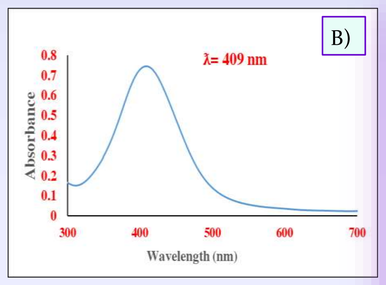
Introduction:
Nanoparticles (NP) play a vital role in plants response to stress. Low concentrations of Ag improve plant germination (germination rate and percentage of germinated seeds), growth parameters, photosynthetic efficiency, phytohormonal balance, which suggests that the treatment of seeds with AgNP may improve plant tolerance to salt stress (Almutairi, 2016; Abou-Zeid & Ismail; 2018).
Aim: The aim of this study was to investigate the effects of silver nanoparticles (AgNPs) on the photosynthesis of pea seedlings (*Pisum sativum* L.) in the presence or absence of 100 mM NaCl in the nutrient solution. Different concentrations of AgNPs (10 mg/L, 25 mg/L and 50 mg/L) were applied by foliar spray on the plants.
Methods and growth conditions:
Pulse amplitude modulated chlorophyll fluorescence, P700 photo-oxidation, pigment composition, electrolyte leakage and some oxidative stress markers (amounts of MDA and H_2O_2) were used to assess the impact of Ag NPs on pea seedling at physiological and salt stress conditions.

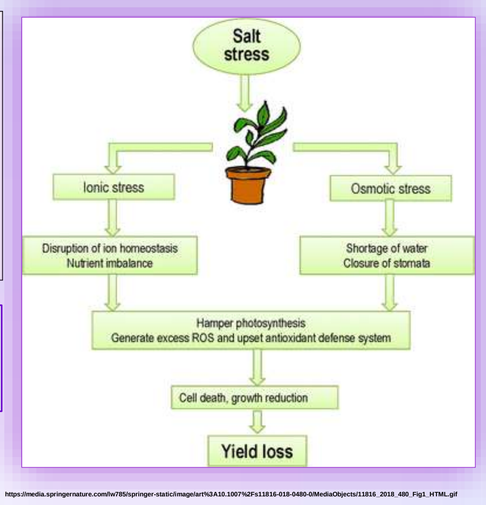


Transmission electron microscopy image of sphere Ag NPs.





A) Particles size spectrum of AgNPs using dynamic light scattering showing average particle size to be 33 nm. B) UV-Vis Spectroscopy spectrum of AgNPs showing peaks at 409 nm.



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Salt stress in plants

Salinity represents a significant problem which affects agriculture worldwide in many different ways and is predicted to become even larger problem in the coming decades.

Salinity has effect on plant growth, water content, photosynthesis, pigments, proteins, leaf anatomy and structure of chloroplast.

Salinity leads to plant death by ionic and osmotic stress, which causes nutrient imbalance, membrane damage and enzymatic inhibition.

Results:

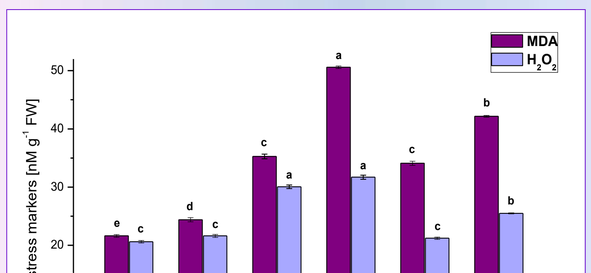
Influence of the highest studied concentration (50 mg/L) of silver nanoparticles (Ag NPs) on some parameters in pea seedlings (*Pisum sativum* L.) in physiological conditions after 8 days of treatment. Different letters indicate significant differences between the values in the column ($p < 0.05$).

Param. / Sample	Chl (a+b) (μg g^{-1}FW)	MDA (nM g^{-1}FW)	H_2O_2 (nM g^{-1}FW)	F_v/F_o	Φ_{PS2}	ETR	R_{Fd}
Control	2351± 8 [a]	21.63 ± 0.23 [b]	20.63 ± 0.21 [b]	4.287 ± 0.111 [a]	0.592 ± 0.008 [a]	47.91± 0.20 [a]	4.271± 0.029 [a]
50 mg/L Ag NPs	2035 ±13 [b]	42.81 ± 0.6 [a]	46.29 ± 0.08 [a]	3.622 ± 0.080 [b]	0.509 ± 0.023 [b]	40.70 ± 0.13 [b]	3.783 ± 0.044 [b]

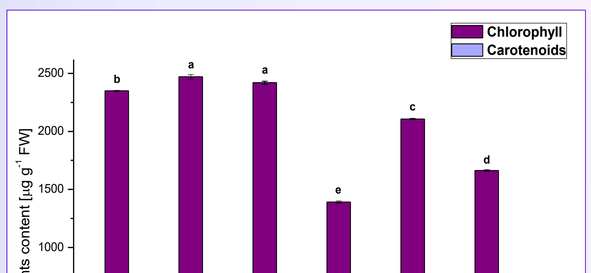
ETR – linear electron transport rate; F_v/F_0 – ratio of photochemical to non-photochemical processes in PSII in dark adapted state; R_{Fd} – chlorophyll fluorescence decrease ratio, correlates to the net photosynthetic rate (P_N) in leaves; Φ_{PSII} – effective quantum yield of PSII photochemistry.

Effects of Ag of different concentrations of Ag NPs (10 and 25 mg/L) on $P700^+$ ($dA/A \times 10^{-3}$) in pea leaves in physiological and salt stress conditions (100 mM NaCl) after 8 days of treatment.

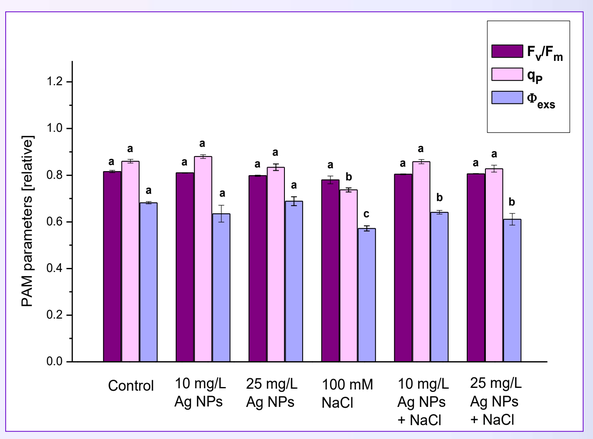
Parameters	Control	10 mg/L NPs	25 mg/L NPs	100 mM NaCl	10 mg/L NPs + NaCl	25 mg/L NPs + NaCl
$P700^+$ ($\Delta A/A \times 10^{-3}$)	14.55 ± 0.10 [a]	14.41 ± 0.13 [a]	14.31 ± 0.09 [a]	9.49 ± 0.10 [d]	13.65 ± 0.09 [b]	12.40 ± 0.19 [c]

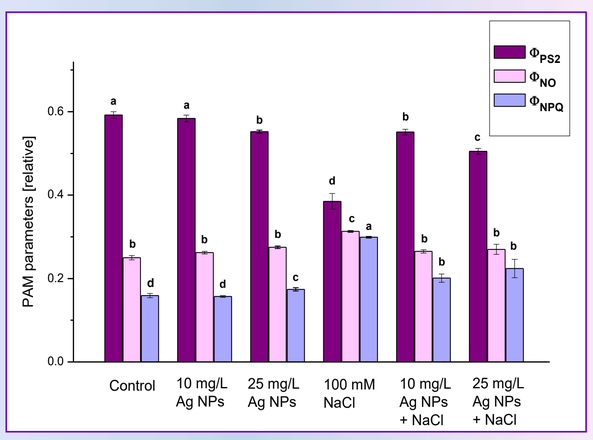


Influence of Ag NPs (10 and 25 mg/L) on some stress oxidative markers (MDA and H_2O_2) in pea seedlings (*Pisum sativum* L.) in physiological and salt stress (100 mM) conditions after 8 days of treatment. Different letters indicate significant differences between the values in the same raw ($p < 0.05$).



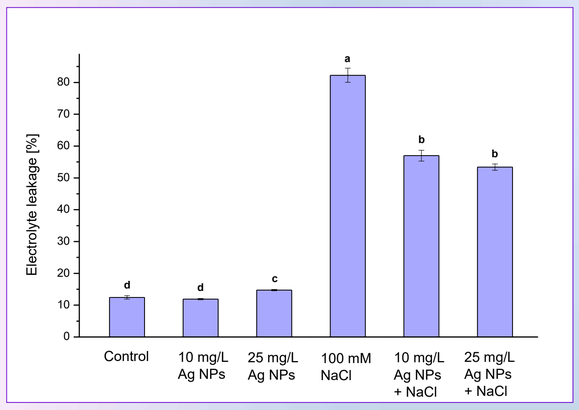
Influence of Ag NPs (10 and 25 mg/L) on the pigments content (Chl and Car) in pea seedlings (*Pisum sativum* L.) in physiological and salt stress (100 mM) conditions after 8 days of treatment. Different letters indicate significant differences between the values in the same raw ($p < 0.05$).





Influence of Ag NPs (10 and 25 mg/L) on the chlorophyll fluorescence parameters (F_v/F_m, q_P, Φ_{exc}, Φ_{PS2}, Φ_{NO}, Φ_{NPQ}) in pea seedlings (*Pisum sativum* L.) in physiological and salt stress (100 mM) conditions after 8 days of treatment. Different letters indicate significant differences between the values in the same raw ($p < 0.05$).

F_v/F_m – maximum quantum efficiency of PSII photochemistry in dark-adapted state,
q_P – photochemical quenching coefficient,
Φ_{exc} – intrinsic efficiency of PSII
Φ_{PSII} – effective quantum yield of PSII photochemistry,
Φ_{NO} – quantum yield of non-photochemical processes PSII,
Φ_{NPQ} – non-photochemical chlorophyll fluorescence quenching.



Influence of Ag NPs (10 and 25 mg/L) on the electrolyte leakage (El, %) in pea seedlings (Pisum sativum L.) in physiological and salt stress (100 mM) conditions after 8 days of treatment. Different letters indicate significant differences between the values in the column ($p < 0.05$).

Conclusions:

Data revealed that the effects of Ag NPs (10 mg/L, 25 mg/L and 50 mg/L) on the pigment composition, the functions of the photosyntethic apparatus and stress markers under physiological conditions depend on the applied concentration, as concentration of 50 mg/L has a negative effect on the plants.

Experimental results have also shown the protective effect of low concentrations of the studied Ag NPs on the functions of photosynthetic apparatus under salt stress (100 mM NaCl).

- **The foliar application of Ag NPs alleviated inhibition of the functions of photosynthetic apparatus induced by salt stress in pea seedlings.**
- **The lipid peroxidation, the levels of H_2O_2 and electrolyte leakage were lowered after combined treatment with Ag NPs and NaCl compared to treatment with NaCl alone.**
- **The protective effects were more pronounced at 10 mg/L NPs compared to 25 mg/L.**

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Almutairi, Z.M. (2016) 'Influence of silver nanoparticles on the salt resistance of tomato (Solanum lycopersicum) during germination', Int. J. Agric. Biol., 18, pp. 449–457.
Abou-Zeid, H.M., Ismail, G.S.M. (2018) 'The role of priming with biosynthesized silver nanoparticles in the response of Triticum aestivum L. to salt stress',Egypt. J. Bot., 58, (1), pp. 73–85.