Silica nanoparticles increased drought resistance in green peas (*Pisum sativum* L.)

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INTRODUCTION

Legumes, especially peas, are sensitive to water shortages, which are becoming increasingly common because of climate change. Peas are beneficial for soil and crop rotation and as a source of protein in nutrition. Therefore, discovering new agrotechnical tools and maintaining plant resistance to environmental influences is essential. The aim of this study was to investigate the effects of silica nanoparticles (SiO_2 NPs) on drought-stressed peas *(Pisum sativum* L., 'Respect') via different exposure routes: through foliar spraying and root watering.

METHODS

The research was conducted in a greenhouse. Ten green pea seeds ('Respect') were sown in 10 L vegetative pots and were thinned up to 7 plants per pot after germination. When the peas reached the 39 BBCH growth stage (had nine or more visibly extended internode), they were foliar sprayed to full wetness (ca. 14±0.5 mL plant^{-1}) or watered (100±1 mL per pot) with suspensions containing 12.5, 25, and 50 ppm of SiO_2 NPs. Untreated NPs plants were watered or sprayed with distilled water. During the 10-day drought period, low substrate moisture (30%) was maintained for peas exposed to SiO_2 NPs, and other plants (controls) were grown under regular substrate moisture (80%). At the end of the experiment, peas were harvested to assess the impact of SiO_2 NPs and drought on plant growth indicators and enzymatic (SOD, GR, APX) and non-enzymatic (TPC, FRAP) antioxidants activity.

1 Picture: Vegetation pots in greenhouse.

2019	Temperature, C^0		Humidity, %	
	Day	Night	Day	Night
Before drought	24.2	14.4	54.1	75.3
During drought	26.2	17	50.1	73.2
After drought	26.7	16.6	52.8	73.5

Table 1. Temperature and humidity in greenhouse during experiment.

CONCLUSION

SiO_2 NPs protected green peas from the adverse effects of drought stress and maintained pea yield.

RESULTS

The results showed that treatment at a concentration of 50 ppm SiO_2 NPs strongly affected pea leaf area, shoot height, and fresh biomass when plants were grown in drought conditions. In addition, positive effects on the activity of enzymatic (APX, CAT, GR, SOD) and non-enzymatic (TPC, DPPH, ABTS, FRAP) antioxidants in the pea plant were found. The SiO_2 NPs reduced hydrogen peroxide and lipid peroxidation in drought-affected plant tissue.

Suspension of SiO_2 NPs	
Zeta potential (ζ; mV)	-20.64 ± 0,333
Polydispersity index (PI)	0.34
NPs size 1-100 nm in suspension, %	70

Table 1. Properties of SiO_2 NPs suspension in DI water.

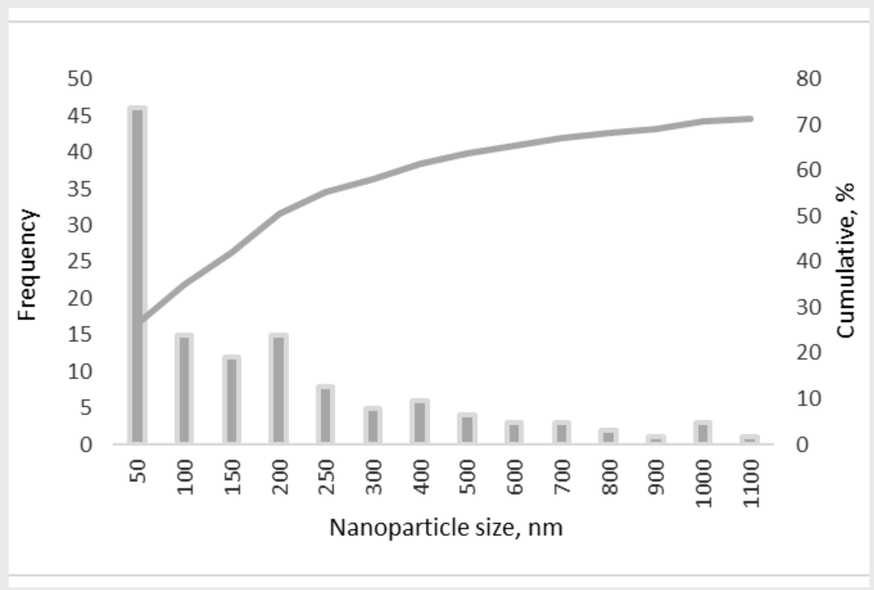

Figure 1. Size distribution of SiO_2 nanoparticles in DI water.

Table 2 The impact of SiO_2 NPs (12,5; 25; 50 ppm) on P. sativum L. grown in the substrate with sufficient (SM 80%) and insufficient (SM 30%) moisture is compared to the control (for SM 80% control means plants grown under SM 80% and NPs untreated; SM 30% control means drought affected but NPs untreated plants) in the heat map. Statistically, significant differences are marked in bold

	SM 80%							SM 30%						
	Watered				Sprayed			Watered				Sprayed		
Treatment SiO_2 NPs, ppm	0	12.5	25	50	12.5	25	50	0	12.5	25	50	12.5	25	50
Plants height, cm	28.4	**30.1**	**32.6**	**34.5**	29.5	29.4	29.2	26.0	**32.0**	**31.2**	**30.8**	**28.1**	**28.9**	**30.7**
Leaf area, cm^2	36.1	36.3	**37.6**	**47.1**	**38.8**	**39.3**	**41.5**	33.1	33.2	**36.6**	**37.2**	**37.0**	**39.0**	**43.1**
Number of nodules	2	**5**	**7**	**9**	3	**4**	3	2	2	2	3	3	3	2
TPC, mg g $^{-1}$ FW	2.19	**1.83**	2.11	2.11	**1.72**	**1.69**	**1.94**	1.67	1.94	**1.98**	**2.06**	**2.01**	**2.09**	**2.18**
FRAP, µmol g $^{-1}$ FW	314	**264**	**276**	**254**	**258**	**279**	**226**	260	269	**314**	**314**	266	**279**	**309**
H_2O_2, µmol g $^{-1}$ FW	14.6	**18.4**	**17.6**	**16.3**	**19.4**	14.6	13.3	34.0	**29.0**	**25.5**	**24.9**	34.2	**29.5**	**26.7**
MDA, nmol g $^{-1}$ FW	44.7	**51.6**	**46.7**	**40.8**	**46.6**	45.3	**42.7**	55.6	**47.1**	**45.5**	**44.9**	**53.9**	**50.4**	**48.4**
GR, µmol NADPH mg^{-1} protein min^{-1}	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	**0.3**	**0.2**	**0.2**	**0.3**
APX, µmol AsA mg $^{-1}$ protein min $^{-1}$	2.2	2.5	**1.9**	**1.5**	2.4	1.6	**1.3**	8.8	**5.6**	**7.4**	8.4	**3.1**	**5.6**	**6.6**
SOD, unit mg $^{-1}$ protein min^{-1}	71	**107**	**103**	**105**	**101**	**105**	**105**	105	**111**	**139**	**144**	**112**	**125**	**130**

Table 3 The impact of SiO_2 NPs (12,5; 25; 50 ppm) on P. sativum L. grown in the substrate with sufficient (SM 80%) and insufficient (SM 30%) moisture is expressed as a percentage change (%) compared to the control (for SM 80% control means plants grown under SM 80% and NPs untreated; SM 30% control means drought affected but NPs untreated plants) in the heat map. Statistically, significant differences are marked in bold

	SM 80%						SM 30%					
	Watered			Sprayed			Watered			Sprayed		
Treatment SiO_2 NPs, ppm	12.5	25	50	12.5	25	50	12.5	25	50	12.5	25	50
Plants height, cm	6	**15**	**21**	4	3	3	**23**	**20**	**18**	**8**	**11**	**24**
Leaf area, cm^2	1	**4**	**31**	**8**	**9**	**15**	0	**11**	**13**	**12**	**18**	**10**
Number of nodules	**200**	**300**	**460**	**100**	**140**	**100**	0	0	**33**	**33**	**50**	**183**
TPC, mg g $^{-1}$ FW	**-17**	-4	-4	**-21**	**-23**	**-12**	**16**	**18**	**23**	**20**	**25**	**30**
FRAP, µmol g $^{-1}$ FW	**-16**	**-12**	**-19**	**-18**	**-11**	**-28**	3	**20**	**20**	2	7	**19**
H_2O_2, µmol g $^{-1}$ FW	**26**	**20**	**12**	**78**	0	**-9**	**-15**	**-25**	**-27**	1	**-13**	**-21**
MDA, nmol g $^{-1}$ FW	**15**	**5**	**-9**	4	1	**-5**	**-15**	**-18**	**-19**	**-3**	**-9**	**-13**
GR, µmol NADPH mg^{-1} protein min^{-1}	2	2	**-13**	7	**-11**	**-19**	2	**21**	**100**	**46**	**55**	**128**
APX, µmol AsA mg $^{-1}$ protein min $^{-1}$	**16**	**-12**	**-32**	13	**-24**	**-38**	**-37**	**-16**	-5	**-65**	**-37**	**-25**
SOD, unit mg $^{-1}$ protein min^{-1}	6	**15**	**21**	4	3	3	**23**	**20**	**18**	**8**	**11**	**24**

Acknowledgments: R.S. is thankful to the Lithuanian Research Centre for Agriculture and Forestry for the opportunity to work with nanoparticles and for donated green pea "Respect" seeds. The authors are also grateful to Joana Bendoraitienė from the Kaunas University of Technology for measuring the size and zeta potential of nanoparticle suspension.