



T.C.  
NİĞDE ÖMER HALİSDEMİR UNIVERSITY  
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES  
DEPARTMENT OF AGRICULTURAL GENETIC ENGINEERING

DETERMINATION OF USING POSSIBILITIES OF DIFFERENT NANO PARTICLES  
FOR SEED COATING AND PRIMING

AYTEN KÜBRA YAGIZ

December 2020



T.C.  
NİĞDE ÖMER HALİSDEMİR UNIVERSITY  
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES  
DEPARTMENT OF AGRICULTURAL GENETIC ENGINEERING

DETERMINATION OF USING POSSIBILITIES OF DIFFERENT NANO PARTICLES  
FOR SEED COATING AND PRIMING

AYTEN KÜBRA YAGIZ

Doctoral Thesis

Supervisor

Prof. Dr. Mehmet Emin ÇALIŞKAN

December 2020

The study titled “**Determination of Using Possibilities of Different Nano Particles for Seed Coating and Priming**” and presented by Ayten Kübra YAGIZ under the supervision of Prof. Dr. Mehmet Emin ÇALIŞKAN has been accepted as Doctoral thesis by the jury at the Department of Agricultural Genetic Engineering of Niğde Ömer Halisdemir University, Graduate School of Natural and Applied Sciences.

Head : Prof. Dr. Mehmet Emin ÇALIŞKAN, Niğde Ömer Halisdemir University, Ayhan Şahenk Faculty of Agricultural Sciences and Technologies, Department of Agricultural Genetic Engineering

Member : Prof Dr. Mehmet ARSLAN, Erciyes University, Seyrani Faculty of Agriculture, Department of Agricultural Biotechnology

Member : Assoc. Prof. Dr. Ufuk DEMİREL, Niğde Ömer Halisdemir University, Ayhan Şahenk Faculty of Agricultural Sciences and Technologies, Department of Agricultural Genetic Engineering

Member : Assoc. Prof. Kahraman GÜRÇAN, Erciyes University, Seyrani Faculty of Agriculture, Department of Agricultural Biotechnology

Member : Assist. Prof. Dr. Allah BAKHSH, Niğde Ömer Halisdemir University, Ayhan Şahenk Faculty of Agricultural Sciences and Technologies, Department of Agricultural Genetic Engineering

#### **CONFIRMATION:**

This thesis has been found appropriate at the date of ....../....../2020 by the jury mentioned above who have been designated by Board of Directors of Graduate School of Natural and Applied Sciences and has been confirmed with the resolution of Board of Directors dated ....../....../2020 and numbered .....

/ /2020

Prof. Dr. Murat BARUT  
DIRECTOR

## THESIS DECLARATION

I declare that this thesis was written by myself, and I further confirm that all information included in this Thesis is scientific and is in accordance with the University's rules and regulations. Any information and materials used from external sources as well as help received and all sources used in preparing and finalizing this thesis research work, have been duly acknowledged in the Thesis.

Ayten Kübra YAGIZ

## ÖZET

### FARKLI NANO PARTİKÜLLERİN TOHUM KAPLAMA VE PRIMİNG AMACIYLA KULLANIM OLANAKLARININ BELİRLENMESİ

YAGIZ, Ayten Kübra

Niğde Ömer Halisdemir Üniversitesi

Fen Bilimleri Enstitüsü

Tarımsal Genetik Mühendisliği Anabilim Dalı

Danışman : Prof. Dr. Mehmet Emin ÇALIŞKAN

Aralık 2020, 221 sayfa

Tohum kalitesini ve gücünü yükseltmek için en sık kullanılan teknikler arasında priming ve kaplama yöntemleri bulunmaktadır. Bu tez çalışmasında, domates, mısır ve fasulye tohumlarının, KNT, TiO<sub>2</sub> ve SiO<sub>2</sub> nanopartikülleri kullanılarak, nanopriming yöntemi ile iyileştirilmesi hedeflenmiştir. Laboratuvar koşullarında nanopriming uygulanan tohumların çimlenme ve güç analizleri yapılmış ve bu tohumlardan gelişen bitkilerin gelişimi incelenmiştir. Ayrıca seçilen konsantrasyonlardaki nanopriming uygulamaları seraya taşınmış ve bu uygulamaların verim ve bitki üzerindeki fizyolojik etkileri incelenmiştir. Tüm bu veriler ışığında belirtilen nanopartiküllerin kitosan, jelatin ve aljinat polimerleri kullanılarak tohum kaplamada kullanılabilirliği araştırılmıştır. Son olarak da nanopriming tekniğinin domates ve mısır tohumlarının kuraklık ve tuzluluk stresine karşı cevaplarına olan etkisi incelenmiştir. Nanopriming uygulamaları domates, mısır ve fasulye tohumlarının gücünü arttırmıştır. Ayrıca, nanopartiküllerin bitki içerisinde farklı bölgelere, özellikle bitkinin yenilebilir kısımlarına, taşınmadığı gözlenmiştir. TiO<sub>2</sub> kuraklık stresi altında bitki cevabını en çok arttıran nanopartikülken, CNT tuzluluk stresinde bitki toleransını güçlendirmiştir. CNT nanoprimin uygulamasının domates bitkiciklerinde MDA içeriğini düşürürken prolin ve H<sub>2</sub>O<sub>2</sub> içeriğini arttırdığı gözlenmiştir.

*Anahtar kelimeler: Nanopriming, nanopartikül, TiO<sub>2</sub>, SiO<sub>2</sub>, KNT*

## SUMMARY

### DETERMINATION OF USING POSSIBILITIES OF DIFFERENT NANO PARTICLES FOR SEED COATING AND PRIMING

YAGIZ, Ayten Kübra

Nigde Ömer Halisdemir University

Graduate School of Natural and Applied Sciences

Department of Agricultural Genetic Engineering

Supervisor : Prof. Dr. Mehmet Emin ÇALIŞKAN

December 2020, 221 pages

Priming and coating are the most common ones among these techniques. In the current study, it is aimed to improve the quality of tomato, maize and bean seeds by nanopriming of seeds by CNT, TiO<sub>2</sub> and SiO<sub>2</sub> nanoparticles. In this context, germination and vigor analysis were conducted of these seeds under laboratory conditions and development of seedlings, grown from nanoprimed seeds, was examined. Besides, the selected concentrations of nanopriming were transferred to greenhouse conditions and the effect of applications on crop yield and physiological properties of plants were observed. In addition to these, the translocation of nanoparticles in plant was monitored. In the light of these data, the usability of determined nanoparticles for seed coating by chitosan, gelatin and alginate was searched. Finally, the effect of nanopriming technique on response of tomato and maize seeds to drought and salinity stress was examined. Nanopriming techniques improved the seed vigor of tomato, maize and bean seeds. Besides, the nanoparticles did not translocate the other parts of the plants, especially edible parts. When the TiO<sub>2</sub> improve the drought stress tolerance of plants, CNT increased the salinity stress tolerance. The MDA content of tomato seedlings decreased by CNT nanopriming, when proline and H<sub>2</sub>O<sub>2</sub> content was increased.

*Keywords: Nanopriming, nanoparticle, TiO<sub>2</sub>, SiO<sub>2</sub>, CNT*

## ACKNOWLEDGEMENTS

I would like to present my deepest gratitude to my advisor Prof Dr. Mehmet Emin ÇALIŞKAN for his continuous support of my Ph.D. study, for his motivation, enthusiasm, and immense knowledge. I could not have imagined having a better advisor and mentor for my academic life.

Besides my advisor, I would like to thank Prof Dr. Sevgi ÇALIŞKAN for her support both my academic and personal life. Also, I would like to express my gratitude to Dr. Emre AKSOY for encouragement of me, when I was felt depressed. Moreover, I could not deny the support of Assoc Prof Dr. Ufuk DEMİREL during my Ph.D. thesis study and research assistantship and would like to express my appreciation. Finally, I would like thank to all the academic staff of Agricultural Genetic Engineering Department.

I would like to thank Niğde Ömer Halisdemir University Research Project Unit for supporting my thesis with FEB2017/13-BAGEP numbered project.

My sincere thanks go to potato group members, who have been very good and supportive friends to me. My special thanks go to Ress. Asist. Caner YAVUZ, Ress. Assist. Ramazan İlhan AYTEKİN and Cehibe TARIM, who are indispensable friends to me. Besides, I would like to express my deepest appreciation to Gizem ÜNAL and Mehmet BEDİR, who were always there for me.

Last but not the least, I would like to express my gratitude and love to my parents, Dr. Hasan Hüseyin TÜRKMEN and Hilal TÜRKMEN, who are always support me and never give up on me. Besides, I would like to thank my little sisters, Dr. Ayça Esra BALTACIOĞLU and Asena Merve TÜRKMEN, who is my favourite life coach and I would never forget the encouragement on me to finish this thesis. I would like to thank Sevil YAGIZ, Mustafa YAGIZ, and Ayşe YAGIZ for supporting me.

My deepest thanks and love go to my lovely husband Osman Ozan YAGIZ and our little boy Atlas YAGIZ, who brought the joy, luck, and meaning to our lives.

## TABLE OF CONTENTS

|  |      |
|--|------|
| ÖZET .....   | iv   |
| SUMMARY .....  | v    |
| ACKNOWLEDGEMENTS .....                                 | vi   |
| TABLE OF CONENTS.....                                  | vii  |
| LIST OF TABLES .....                                   | xi   |
| LIST OF FIGURES.....                                   | xvii |
| SYMBOLS AND ABBREVIATIONS.....                         | xxv  |
| CHAPTER I INTRODUCTION.....                            | 1    |
| CHAPTER II LITERATURE REVIEW .....                     | 5    |
| 2.1 Importance of Seed in Agriculture .....            | 5    |
| 2.1 Seed Germination .....                             | 7    |
| 2.2 Effects of Abiotic Stress on Seed Germination..... | 9    |
| 2.2.1 Drought stress.....                              | 10   |
| 2.2.2 Salinity Stress .....                            | 12   |
| 2.3 Nanotechnology.....                                | 13   |
| 2.3.1 Nanotechnology in Agriculture .....              | 14   |
| 2.3.1.1 Nanofertilizers .....                          | 15   |
| 2.3.1.2 Nanopesticides .....                           | 15   |
| 2.3.1.3 Nano-biosensors in agriculture .....           | 16   |
| 2.3.2 Nanoparticles in Agriculture .....               | 17   |
| 2.3.2.1 Polymer Based NP .....                         | 18   |
| 2.3.2.2 Lipid Based NP .....                           | 19   |
| 2.3.2.3 Metal/Oxide Based NP .....                     | 21   |
| 2.4 Seed Priming .....                                 | 25   |
| 2.4.1 Nanopriming.....                                 | 26   |
| 2.5 Seed Coating .....                                 | 28   |
| CHAPTER III MATERIALS AND METHODS.....                 | 31   |

|  |   |    |
|--|---|----|
| 3.1                                    | Characterization of NPs .....   | 31 |
| 3.2                                    | Effects of nano-priming applications with NPs at different concentrations on germination under laboratory conditions (WP-I).....                  | 32 |
| 3.2.1                                  | Surface sterilization and nano-priming of seeds.....  | 33 |
| 3.2.2                                  | Seed germination experiments .....  | 33 |
| 3.3                                    | Effects of nano-priming applications with NPs at different concentrations on emergence, growth and yield under greenhouse conditions (WP-II)..... | 35 |
| 3.4                                    | Effects of NP containing polymer coating of seed on seed germination under laboratory conditions (WP-III).....                                    | 37 |
| 3.4.1                                  | Treatment with gelatine: .....  | 37 |
| 3.4.2                                  | Treatment with chitosan:.....   | 38 |
| 3.4.3                                  | Treatment with sodium alginate: .....   | 39 |
| 3.5                                    | Effects of nano-priming applications with NPs at different concentrations on seed germination under abiotic stresses (WP-IV).....                 | 39 |
| 3.5.1                                  | MDA content.....  | 41 |
| 3.5.2                                  | H <sub>2</sub> O <sub>2</sub> content.....  | 42 |
| 3.5.3                                  | Proline content.....  | 42 |
| 3.6                                    | Statistical Analysis .....  | 42 |
| CHAPTER IV RESULTS AND DISCUSSION..... |   | 43 |
| 4.1                                    | Effects of nano-priming applications with NPs at different concentrations on seed germination under laboratory conditions (WP-I).....             | 43 |
| 4.1.1.1                                | Germination rate (%).....   | 43 |
| 4.1.1.2                                | Shoot and root growth.....  | 44 |
| 4.1.2                                  | Effects of nanopriming with SiO <sub>2</sub> on tomato seeds.....   | 47 |
| 4.1.2.1                                | Germination rate (%).....   | 47 |
| 4.1.2.2                                | Shoot and root growth.....  | 47 |
| 4.1.3                                  | Effects of nanopriming with CNT on tomato seeds .....   | 50 |
| 4.1.3.1                                | Germination rate (%).....   | 50 |
| 4.1.3.2                                | Shoot and root growth.....  | 50 |
| 4.1.4                                  | Effects of nanopriming with TiO <sub>2</sub> on bean seeds .....  | 53 |
| 4.1.4.1                                | Shoot and root growth.....  | 53 |
| 4.1.5                                  | Effects of nanopriming with SiO <sub>2</sub> on bean seeds .....  | 56 |
| 4.1.5.1                                | Shoot and root growth.....  | 56 |
| 4.1.6                                  | Effects of nanopriming with CNT on bean seeds.....  | 59 |

|         |   |     |
|---------|---|-----|
| 4.1.6.1 | Shoot and root growth.....  | 59  |
| 4.1.7   | Effects of nanopriming with TiO <sub>2</sub> on maize seeds.....  | 62  |
| 4.1.7.1 | Germination rate (%).....   | 62  |
| 4.1.7.2 | Shoot and root growth.....  | 62  |
| 4.1.8   | Effects of nanopriming with SiO <sub>2</sub> on maize seeds.....  | 65  |
| 4.1.8.1 | Germination rate (%).....   | 65  |
| 4.1.8.2 | Shoot and root growth.....  | 65  |
| 4.1.9   | Effects of nanopriming with CNT on maize seeds.....   | 68  |
| 4.1.9.1 | Germination rate (%).....   | 68  |
| 4.1.9.2 | Shoot and root growth.....  | 68  |
| 4.1.10  | Comparison of the effects of nanopriming with CNT, SiO <sub>2</sub> and TiO <sub>2</sub> on seed germination and seedling development.....        | 71  |
| 4.1.11  | Water uptake (%).....   | 75  |
| 4.1.12  | Overall evaluation and discussion of the results.....   | 77  |
| 4.2     | Effects of nano-priming applications with NPs at different concentrations on emergence, growth and yield under greenhouse conditions (WP-II)..... | 79  |
| 4.2.1   | Stem length.....  | 80  |
| 4.2.2   | Chlorophyll index.....  | 83  |
| 4.2.3   | Photosynthesis velocity, transpiration velocity and stomata conductance.....  | 87  |
| 4.2.4   | Yield analysis.....   | 91  |
| 4.2.5   | Nanoparticle translocation in plants.....   | 97  |
| 4.2.5.1 | XRF analysis.....   | 98  |
| 4.2.5.2 | Raman spectroscopy.....   | 100 |
| 4.3     | Effects of NP containing polymer coating of seed on seed germination under laboratory conditions (WP III).....                                    | 102 |
| 4.3.1   | Treatment with alginate.....  | 102 |
| 4.3.1.1 | Germination rate (%).....   | 102 |
| 4.3.1.2 | Shoot and root growth.....  | 103 |
| 4.3.2   | Treatment with gelatin.....   | 111 |
| 4.3.2.1 | Germination rate (%).....   | 111 |
| 4.3.2.2 | Shoot and root growth.....  | 112 |
| 4.3.3   | Treatment with chitosan.....  | 121 |
| 4.3.3.1 | Germination rate (%).....   | 121 |
| 4.3.3.2 | Shoot and root growth.....  | 122 |

|   |     |
|---|-----|
| 4.4 Effects of nano-priming applications with NPs at different concentrations on seed germination under abiotic stresses (WP-IV)..... | 126 |
| 4.4.1 Drought stress.....   | 126 |
| 4.4.1.1 Germination rate (%).....   | 126 |
| 4.4.1.2 Shoot and root growth.....  | 132 |
| 4.4.2 Salinity stress.....  | 158 |
| 4.4.2.1 Germination rate (%).....   | 158 |
| 4.4.2.2 Shoot and root growth.....  | 164 |
| 4.4.2.3 MDA content .....   | 189 |
| 4.4.2.1 Proline content .....   | 190 |
| 4.4.2.1 H <sub>2</sub> O <sub>2</sub> content .....   | 190 |
| CHAPTER V CONCLUSION.....   | 192 |
| REFERENCES.....   | 194 |
| CURRICULUM VITEA.....   | 221 |

## LIST OF TABLES

|  |     |
|--|-----|
| Table 2.1. List of metal/oxides based nanoparticles affect different pathogens.....                                      | 21  |
| Table 2.2. List of metal/oxide based nanoparticles as growth regulators .....  | 24  |
| Table 3.1. Informations about nanoparticles used in thesis .....   | 31  |
| Table 3.2. Types and concentrations of NPs for WP-1 .....  | 33  |
| Table 3.3. MS media component for germination of bean, maize and tomato seeds .....                                      | 34  |
| Table 3.4. Selected nanoparticle concentrations for each plant type .....  | 36  |
| Table 3.5. Solid matrix content for gelatin encapsulation.....   | 38  |
| Table 3.6. Solid matrix content for chitosan encapsulation.....  | 38  |
| Table 3.7. Solid matrix content for Na-alginate encapsulation .....  | 39  |
| Table 3.8. Abiotic stress conditions for tomato seed germination.....  | 41  |
| Table 3.9. Abiotic stress conditions for bean and maize seed germination.....  | 41  |
| Table 4.1. ANOVA table for germination rate and seed vigor index of tomato seeds<br>after nanopriming applications ..... | 71  |
| Table 4.2. ANOVA table for shoot and root length of tomato seedlings after<br>nanopriming applications .....             | 71  |
| Table 4.3. ANOVA table for shoot and root fresh weight of tomato seedlings after<br>nanopriming applications .....       | 72  |
| Table 4.4. ANOVA table for shoot and root dry weight of tomato seedlings after<br>nanopriming applications .....         | 72  |
| Table 4.5. ANOVA table for germination rate and seed vigor index of mazie seeds<br>after nanopriming applications .....  | 73  |
| Table 4.6. ANOVA table for shoot and root length of maize seedlings after<br>nanopriming applications .....              | 73  |
| Table 4.7. ANOVA table for shoot and root fresh weight of maize seedlings after<br>nanopriming applications .....        | 74  |
| Table 4.8. ANOVA table for shoot and root dry weight of maize seedlings after<br>nanopriming applications .....          | 74  |
| Table 4.9. Germination rates (%) of tomato seeds under drought stress after CNT<br>nanopriming.....                      | 127 |

|   |     |
|---|-----|
| Table 4.10. Germination rates (%) of maize seeds under drought stress after CNT nanoprimering .....               | 128 |
| Table 4.11. Germination rates (%) of tomato seeds under drought stress after SiO <sub>2</sub> nanoprimering ..... | 129 |
| Table 4.12. Germination rates (%) of maize seeds under drought stress after SiO <sub>2</sub> nanoprimering .....  | 130 |
| Table 4.13. Germination rates (%) of tomato seeds under drought stress after TiO <sub>2</sub> nanoprimering ..... | 131 |
| Table 4.14. Germination rates (%) of maize seeds under drought stress after TiO <sub>2</sub> nanoprimering .....  | 132 |
| Table 4.15. Shoot length (SL) of tomato seedlings under drought stress after CNT nanoprimering .....              | 133 |
| Table 4.16. Root length (RL) of tomato seedlings under drought stress after CNT nanoprimering .....               | 133 |
| Table 4.17. Shoot fresh weight (SFW) of tomato seedlings under drought stress after CNT nanoprimering .....       | 134 |
| Table 4.18. Root fresh weight (RFW) of tomato seedlings under drought stress after CNT nanoprimering .....        | 135 |
| Table 4.19. Shoot dry weight (SDW) of tomato seedlings under drought stress after CNT nanoprimering .....         | 135 |
| Table 4.20. Root dry weight (SDW) of tomato seedlings under drought stress after CNT nanoprimering .....          | 136 |
| Table 4.21. Shoot length (SL) of maize seedlings under drought stress after CNT nanoprimering .....               | 137 |
| Table 4.22. Root length (RL) of maize seedlings under drought stress after CNT nanoprimering .....                | 137 |
| Table 4.23. Shoot fresh weight (SFW) of maize seedlings under drought stress after CNT nanoprimering .....        | 138 |
| Table 4.24. Root fresh weight (RFW) of maize seedlings under drought stress after CNT nanoprimering .....         | 139 |
| Table 4.25. Shoot dry weight (SDW) of maize seedlings under drought stress after CNT nanoprimering .....          | 139 |
| Table 4.26. Root dry weight (RDW) of maize seedlings under drought stress after CNT nanoprimering .....           | 140 |

|  |     |
|--|-----|
| Table 4.27. Shoot length (SL) of tomato seedlings under drought stress after SiO <sub>2</sub> nanopriming .....        | 141 |
| Table 4.28. Root length (RL) of tomato seedlings under drought stress after SiO <sub>2</sub> nanopriming .....         | 141 |
| Table 4.29. Shoot fresh weight (SFW) of tomato seedlings under drought stress after SiO <sub>2</sub> nanopriming.....  | 142 |
| Table 4.30. Root fresh weight (RFW) of tomato seedlings under drought stress after SiO <sub>2</sub> nanopriming.....   | 143 |
| Table 4.31. Shoot dry weight (SDW) of tomato seedlings under drought stress after SiO <sub>2</sub> nanopriming.....    | 143 |
| Table 4.32. Root dry weight (RDW) of tomato seedlings under drought stress after SiO <sub>2</sub> nanopriming .....    | 144 |
| Table 4.33. Shoot length (SL) of maize seedlings under drought stress after SiO <sub>2</sub> nanopriming .....         | 145 |
| Table 4.34. Root length (RL) of maize seedlings under drought stress after SiO <sub>2</sub> nanopriming .....          | 145 |
| Table 4.35. Shoot fresh weight (SFW) of maize seedlings under drought stress after SiO <sub>2</sub> nanopriming.....   | 146 |
| Table 4.36. Root fresh weight (RFW) of maize seedlings under drought stress after SiO <sub>2</sub> nanopriming.....    | 147 |
| Table 4.37. Shoot dry weight (SDW) of maize seedlings under drought stress after SiO <sub>2</sub> nanopriming .....    | 147 |
| Table 4.38. Root dry weight (RDW) of maize seedlings under drought stress after SiO <sub>2</sub> nanopriming .....     | 148 |
| Table 4.39. Shoot length (SL) of tomato seedlings under drought stress after TiO <sub>2</sub> nanopriming .....        | 149 |
| Table 4.40. Root length (RL) of tomato seedlings under drought stress after TiO <sub>2</sub> nanopriming .....         | 149 |
| Table 4.41. Shoot fresh weight (SFW) of tomato seedlings under drought stress after TiO <sub>2</sub> nanopriming ..... | 150 |
| Table 4.42. Root fresh weight (RFW) of tomato seedlings under drought stress after TiO <sub>2</sub> nanopriming .....  | 151 |
| Table 4.43. Shoot dry weight (SDW) of tomato seedlings under drought stress after TiO <sub>2</sub> nanopriming.....    | 151 |

|   |     |
|---|-----|
| Table 4.44. Root dry weight (RDW) of tomato seedlings under drought stress after TiO <sub>2</sub> nanopriming .....   | 152 |
| Table 4.45. Shoot length (SL) of maize seedlings under drought stress after TiO <sub>2</sub> nanopriming .....        | 153 |
| Table 4.46. Root length (RL) of maize seedlings under drought stress after TiO <sub>2</sub> nanopriming .....         | 153 |
| Table 4.47. Shoot fresh weight (SFW) of maize seedlings under drought stress after TiO <sub>2</sub> nanopriming ..... | 154 |
| Table 4.48. Root fresh weight (RFW) of maize seedlings under drought stress after TiO <sub>2</sub> nanopriming .....  | 155 |
| Table 4.49. Shoot dry weight (SDW) of maize seedlings under drought stress after TiO <sub>2</sub> nanopriming .....   | 155 |
| Table 4.50. Root fresh weight (RFW) of maize seedlings under drought stress after TiO <sub>2</sub> nanopriming .....  | 156 |
| Table 4.51. Germination rates (%) of tomato seeds under salinity stress after CNT nanopriming .....                   | 158 |
| Table 4.52. Germination rates (%) of maize seeds under salinity stress after CNT nanopriming .....                    | 159 |
| Table 4.53. Germination rates (%) of tomato seeds under salinity stress after SiO <sub>2</sub> nanopriming .....      | 160 |
| Table 4.54. Germination rates (%) of maize seeds under salinity stress after SiO <sub>2</sub> nanopriming .....       | 161 |
| Table 4.55. Germination rates (%) of tomato seeds under salinity stress after TiO <sub>2</sub> nanopriming .....      | 162 |
| Table 4.56. Germination rates (%) of maize seeds under salinity stress after TiO <sub>2</sub> nanopriming .....       | 163 |
| Table 4.57. Shoot length (SL) of tomato seedlings under salinity stress after CNT nanopriming .....                   | 164 |
| Table 4.58. Root length (RL) of tomato seedlings under salinity stress after CNT nanopriming .....                    | 165 |
| Table 4.59. Shoot fresh weight (SFW) of tomato seedlings under salinity stress after CNT nanopriming .....            | 166 |
| Table 4.60. Root fresh weight (RFW) of tomato seedlings under salinity stress after CNT nanopriming .....             | 166 |

|   |     |
|---|-----|
| Table 4.61. Shoot dry weight (SDW) of tomato seedlings under salinity stress after CNT nanopriming .....                | 167 |
| Table 4.62. Root dry weight (RDW) of tomato seedlings under salinity stress after CNT nanopriming .....                 | 167 |
| Table 4.63. Shoot length (SL) of maize seedlings under salinity stress after CNT nanopriming .....                      | 168 |
| Table 4.64. Root length (RL) of maize seedlings under salinity stress after CNT nanopriming .....                       | 169 |
| Table 4.65. Shoot fresh weight (SFW) of maize seedlings under salinity stress after CNT nanopriming .....               | 170 |
| Table 4.66. Root fresh weight (RFW) of maize seedlings under salinity stress after CNT nanopriming .....                | 170 |
| Table 4.67. Shoot dry weight (SDW) of maize seedlings under salinity stress after CNT nanopriming .....                 | 171 |
| Table 4.68. Root dry weight (RDW) of maize seedlings under salinity stress after CNT nanopriming .....                  | 171 |
| Table 4.69. Shoot length (SL) of tomato seedlings under salinity stress after SiO <sub>2</sub> nanopriming .....        | 172 |
| Table 4.70. Root length (RL) of tomato seedlings under salinity stress after SiO <sub>2</sub> nanopriming .....         | 173 |
| Table 4.71. Shoot fresh weight (SFW) of tomato seedlings under salinity stress after SiO <sub>2</sub> nanopriming ..... | 174 |
| Table 4.72. Root fresh weight (RFW) of tomato seeds under salinity stress after SiO <sub>2</sub> nanopriming .....      | 174 |
| Table 4.73. Shoot dry weight (SDW) of tomato seedlings under salinity stress after SiO <sub>2</sub> nanopriming .....   | 175 |
| Table 4.74. Root dry weight (RDW) of tomato seedlings under salinity stress after SiO <sub>2</sub> nanopriming .....    | 175 |
| Table 4.75. Shoot length (SL) of maize seedlings under salinity stress after SiO <sub>2</sub> nanopriming .....         | 176 |
| Table 4.76. Root length (RL) of maize seedlings under salinity stress after SiO <sub>2</sub> nanopriming .....          | 177 |
| Table 4.77. Shoot fresh weight (SFW) of maize seedlings under salinity stress after SiO <sub>2</sub> nanopriming .....  | 178 |

|   |     |
|---|-----|
| Table 4.78. Root fresh weight (RFW) of maize seedlings under salinity stress after SiO <sub>2</sub> nanopriming .....   | 178 |
| Table 4.79. Shoot dry weight (SDW) of maize seedlings under salinity stress after SiO <sub>2</sub> nanopriming .....    | 179 |
| Table 4.80. Root dry weight (RDW) of maize seedlings under salinity stress after SiO <sub>2</sub> nanopriming .....     | 179 |
| Table 4.81. Shoot length (SL) of tomato seedlings under salinity stress after TiO <sub>2</sub> nanopriming .....        | 180 |
| Table 4.82. Root length (RL) of tomato seedlings under salinity stress after TiO <sub>2</sub> nanopriming .....         | 181 |
| Table 4.83. Shoot fresh weight (SFW) of tomato seedlings under salinity stress after TiO <sub>2</sub> nanopriming ..... | 182 |
| Table 4.84. Root fresh weight (RFW) of tomato seedlings under salinity stress after TiO <sub>2</sub> nanopriming .....  | 182 |
| Table 4.85. Shoot dry weight (SDW) of tomato seedlings under salinity stress after TiO <sub>2</sub> nanopriming .....   | 183 |
| Table 4.86. Root dry weight (RDW) of tomato seeds under salinity stress after TiO <sub>2</sub> nanopriming .....        | 183 |
| Table 4.87. Shoot length (SL) of maize seedlings under salinity stress after TiO <sub>2</sub> nanopriming .....         | 184 |
| Table 4.88. Root length (RL) of maize seedlings under salinity stress after TiO <sub>2</sub> nanopriming .....          | 185 |
| Table 4.89. Shoot fresh weight (SFW) of maize seedlings under salinity stress after TiO <sub>2</sub> nanopriming .....  | 186 |
| Table 4.90. Root fresh weight (RFW) of maize seedlings under salinity stress after TiO <sub>2</sub> nanopriming .....   | 187 |
| Table 4.91. Shoot dry weight (SDW) of maize seedlings under salinity stress after TiO <sub>2</sub> nanopriming .....    | 187 |
| Table 4.92. Root dry weight (RDW) of maize seedlings under salinity stress after TiO <sub>2</sub> nanopriming .....     | 188 |
| Table 4.93. MDA content of tomato seedlings after CNT nanopriming .....   | 190 |
| Table 4.94. Proline content of tomato seedlings after CNT nanopriming .....   | 190 |
| Table 4.95. H <sub>2</sub> O <sub>2</sub> content of tomato seedlings after CNT nanopriming .....                       | 191 |

## LIST OF FIGURES

|   |    |
|---|----|
| Figure 2.1. The regulation of dormancy-germination by ABA and GA in response to the environment in <i>A. Thaliana</i> (Footitt and Finch-Savage, 2017).....                 | 7  |
| Figure 2.2. The physical and metabolic events occurring during germination .....  | 9  |
| Figure 2.3. Presentation of top-down and bottom-up approaches in nanotechnology ...   | 14 |
| Figure 2.4. Mechanistic function of nano-structured biosensors and their designs .....  | 17 |
| Figure 2.5. Different techniques for encapsulation of pesticides with polymers in nano size. Nanocapsule (a), Nanosphere (b), Micelle (c) and Nanofiber (d) .....           | 19 |
| Figure 2.6. Structure of a liposome.....  | 19 |
| Figure 2.7. Schematic structure of solid lipid nanoparticle (SLN) (a), Homogenous matrix SLN (b), Bioactive enriched shell SLN (c) and Bioactive enriched core SLN (d)..... | 20 |
| Figure 2.8. Possible antimicrobial activities of silver nanoparticles on both gram positive and gram negative bacteria, (Pandey <i>et al.</i> , 2014).....                  | 21 |
| Figure 2.9. The comparison of water uptake behaviour of seed during germination with and without seed priming (Khalaki <i>et al.</i> , 2020) .....                          | 25 |
| Figure 3.1. XRD patterns of CNT (a), SiO <sub>2</sub> (b) and TiO <sub>2</sub> (c) .....  | 31 |
| Figure 3.2. SEM images of CNT (a), SiO <sub>2</sub> (b) and TiO <sub>2</sub> (c).....   | 32 |
| Figure 4.1. Seed germination rate (%) of tomato seeds after TiO <sub>2</sub> nanopriming .....  | 44 |
| Figure 4.2. Shoot length (a) and root length (b) of tomato seeds after TiO <sub>2</sub> nanopriming .....   | 44 |
| Figure 4.3. The tomato seedlings after TiO <sub>2</sub> nanopriming.....  | 45 |
| Figure 4.4. Shoot fresh weight (a); root fresh weight (b); shoot dry weight (c); root dry weight and (d) of tomato seeds after TiO <sub>2</sub> nanopriming .....           | 46 |
| Figure 4.5. Seed Vigor Index (SVI) of tomato seeds after TiO <sub>2</sub> nanopriming application .....   | 46 |
| Figure 4.6. Seed germination rate (%) of tomato seeds after SiO <sub>2</sub> nanopriming .....  | 47 |
| Figure 4.7. Shoot length (a) and root length (b) of tomato seeds after SiO <sub>2</sub> nanopriming .....   | 48 |
| Figure 4.8. The tomato seedlings after SiO <sub>2</sub> nanopriming .....   | 48 |

|   |    |
|---|----|
| Figure 4.9. Shoot fresh weight (a), root fresh weight (b), shoot dry weight (c) and root dry weight (d) of tomato seeds after SiO <sub>2</sub> nanopriming..... | 49 |
| Figure 4.10. Seed Vigor Index (SVI) of tomato seeds after SiO <sub>2</sub> nanopriming application. ....  | 49 |
| Figure 4.11. Seed germination rate (%) of tomato seeds after CNT nanopriming. ....  | 50 |
| Figure 4.12. Shoot length (a) and root length (b) of tomato seeds after CNT nanopriming. ....   | 51 |
| Figure 4.13. The tomato seedlings after CNT nanopriming. ....   | 51 |
| Figure 4.14. Shoot fresh weight (a), root fresh weight (b), shoot dry weight (c) and root dry weight (d) of tomato seeds after CNT nanopriming. ....            | 52 |
| Figure 4.15. Seed Vigor Index (SVI) of tomato seeds after CNT nanopriming application. ....   | 52 |
| Figure 4.16. Shoot length (a) and root length (b) of bean seeds after TiO <sub>2</sub> nanopriming. ....  | 53 |
| Figure 4.17. The bean seedlings after TiO <sub>2</sub> nanopriming.....   | 54 |
| Figure 4.18. Shoot fresh weight (a), root fresh weight (b), shoot dry weight (c) and root dry weight (d) of bean seeds after TiO <sub>2</sub> nanopriming.....  | 55 |
| Figure 4.19. Seed Vigor Index (SVI) of bean seeds after TiO <sub>2</sub> nanopriming application. ....  | 55 |
| Figure 4.20. Shoot length (a) and root length (b) of bean seeds after SiO <sub>2</sub> nanopriming. ....  | 56 |
| Figure 4.21. The bean seedlings after SiO <sub>2</sub> nanopriming.....   | 57 |
| Figure 4.22. Shoot fresh weight (a), root fresh weight (b), shoot dry weight (c) and root dry weight (d) of bean seeds after SiO <sub>2</sub> nanopriming.....  | 58 |
| Figure 4.23. Seed Vigor Index (SVI) of bean seeds after SiO <sub>2</sub> nanopriming application. ....  | 58 |
| Figure 4.24. Shoot length (a) and root length (b) of bean seeds after CNT nanopriming. ....   | 59 |
| Figure 4.25. The bean seedlings after CNT nanopriming. ....   | 60 |
| Figure 4.26. Shoot fresh weight (a), root fresh weight (b), shoot dry weight (c) and root dry weight (d) of bean seeds after CNT nanopriming. ....              | 61 |
| Figure 4.27. Seed Vigor Index (SVI) of bean seeds after CNT nanopriming application. ....   | 61 |
| Figure 4.28. Seed germination rate (%) of maize seeds after TiO <sub>2</sub> nanopriming. ....  | 62 |

|   |    |
|---|----|
| Figure 4.29. Shoot length (a) and root length (b) of maize seeds after TiO <sub>2</sub> nanopriming.  | 63 |
| Figure 4.30. Maize seedlings after TiO <sub>2</sub> nanopriming   | 63 |
| Figure 4.31. Shoot fresh weight (a), root fresh weight (b), shoot dry weight (c) and root dry weight (d) of maize seeds after TiO <sub>2</sub> nanopriming  | 64 |
| Figure 4.32. Seed Vigor Index (SVI) of maize seeds after TiO <sub>2</sub> nanopriming application.  | 64 |
| Figure 4.33. Seed germination rate (%) of maize seeds after SiO <sub>2</sub> nanopriming.   | 65 |
| Figure 4.34. Shoot length (a) and root length (b) of maize seeds after SiO <sub>2</sub> nanopriming.  | 66 |
| Figure 4.35. The maize seedlings after SiO <sub>2</sub> nanopriming.  | 66 |
| Figure 4.36. Shoot fresh weight (a), root fresh weight (b), shoot dry weight (c) and root dry weight (d) of maize seeds after SiO <sub>2</sub> nanopriming. | 67 |
| Figure 4.37. Seed Vigor Index (SVI) of maize seeds after SiO <sub>2</sub> nanopriming application.  | 67 |
| Figure 4.38. Seed germination rate (%) of maize seeds after CNT nanopriming.  | 68 |
| Figure 4.39. Shoot length (a) and root length (b) of maize seeds after CNT nanopriming.   | 69 |
| Figure 4.40. Maize seedlings after CNT nanopriming  | 69 |
| Figure 4.41. Shoot fresh weight (a), root fresh weight (b), shoot dry weight (c) and root dry weight (d) of maize seeds after CNT nanopriming.              | 70 |
| Figure 4.42. Seed Vigor Index (SVI) of maize seeds after CNT nanopriming application.   | 70 |
| Figure 4.43. The water uptake (%) of tomato seeds after nanoprimed by TiO <sub>2</sub> (a), CNT (b) and SiO <sub>2</sub> (c)                                | 75 |
| Figure 4.44. The water uptake (%) of bean seeds after nanoprimed by TiO <sub>2</sub> (a), CNT (b) and SiO <sub>2</sub> (c)                                  | 76 |
| Figure 4.45. The water uptake (%) of maize seeds after nanoprimed by TiO <sub>2</sub> (a), CNT (b) and SiO <sub>2</sub> (c)                                 | 77 |
| Figure 4.46. Stem length of tomato plants.  | 80 |
| Figure 4.47. Tomato plants grown in greenhouse.   | 80 |
| Figure 4.48. Stem length of bean plants.  | 81 |
| Figure 4.49. Bean plants grown in greenhouse.   | 81 |
| Figure 4.50. Stem length of maize plants.   | 82 |

|   |     |
|---|-----|
| Figure 4.51. Maize plants grown in greenhouse. ....   | 82  |
| Figure 4.52. Mean SPAD value of tomato plants .....   | 84  |
| Figure 4.53. Total chlorophyll content of tomato plants .....                                       | 84  |
| Figure 4.54 Mean SPAD value of bean plants.....   | 85  |
| Figure 4.55. Total chlorophyll content of bean plants .....   | 85  |
| Figure 4.56. Mean SPAD value of maize plants.....   | 86  |
| Figure 4.57. Total chlorophyll content of bean plants .....   | 86  |
| Figure 4.58. Photosynthesis rate of tomato plants .....   | 87  |
| Figure 4.59. Stomatal conductance of tomato plants. ....  | 88  |
| Figure 4.60. Photosynthesis rate of bean plants.....  | 88  |
| Figure 4.61. Stomatal conductance of bean plants.....   | 89  |
| Figure 4.62. Photosynthesis rate of maize plants.....   | 89  |
| Figure 4.63. Stomatal conductance of maize plants.....  | 90  |
| Figure 4.64. Yield of tomato plants in weight .....   | 91  |
| Figure 4.65. Yield of tomato plants in fruit numbers.....   | 91  |
| Figure 4.66. Mean fruit number of tomato plants .....   | 92  |
| Figure 4.67. Tomato fruits grown under greenhouse conditions .....                                  | 92  |
| Figure 4.68. Yield of bean plants in weight.....  | 93  |
| Figure 4.69. Yield of bean plants in fruit numbers .....  | 93  |
| Figure 4.70. Mean bean fruit weight .....   | 94  |
| Figure 4.71. Bean fruits grown under greenhouse conditions .....                                    | 94  |
| Figure 4.72. Yield of maize plants in weight.....   | 95  |
| Figure 4.73. Yield of maize in kernel numbers .....   | 95  |
| Figure 4.74. 1000 seed weight of maize kernels.....   | 96  |
| Figure 4.75. Corncob grown under greenhouse conditions. ....  | 96  |
| Figure 4.76. SiO <sub>2</sub> content of parts of tomato plant. ....                                | 98  |
| Figure 4.77. SiO <sub>2</sub> content of parts of bean plant. ....                                  | 98  |
| Figure 4.78. SiO <sub>2</sub> content of parts of maize plant. ....                                 | 99  |
| Figure 4.79. TiO <sub>2</sub> content of parts of tomato plant. ....                                | 99  |
| Figure 4.80. Raman spectroscopy root (a), stem (b), leaf (c) and fruit (d) of tomato plant<br>..... | 100 |
| Figure 4.81. Raman spectroscopy root (a), stem (b), leaf (c) and grain (d) of bean plant.<br>.....  | 100 |
| Figure 4.82. Raman spectroscopy root (a), stem (b), leaf (c) and kernel (d) of maize plant.         |     |

|  |     |
|--|-----|
| .....  | 101 |
| Figure 4.83. Germination rate (%) of alginate coated tomato seeds .....  | 102 |
| Figure 4.84. Germination rate (%) of alginate coated maize seeds .....   | 103 |
| Figure 4.85. Shoot (a) and root (b) length of alginate/CNT coated tomato seeds .....   | 103 |
| Figure 4.86. Shoot (a) and root (b) length of alginate/CNT coated maize seeds.....   | 104 |
| Figure 4.87. Shoot fresh weight (a), root fresh weight (b), shoot dry weight (c), and root<br>dry weight (d) of alginate/CNT coated tomato seeds. ....             | 104 |
| Figure 4.88. Shoot fresh weight (a), root fresh weight (b), shoot dry weight (c) and root<br>dry weight (d) of alginate/CNT coated maize seeds.....                | 105 |
| Figure 4.89. Shoot (a) and root (b) length of alginate/SiO <sub>2</sub> coated tomato seeds.....   | 106 |
| Figure 4.90. Shoot (a) and root (b) length of alginate/SiO <sub>2</sub> coated maize seeds .....   | 106 |
| Figure 4.91. Shoot fresh weight (a), root fresh weight (b), shoot dry weight (c) and root<br>dry weight (d) of alginate/SiO <sub>2</sub> coated tomato seeds.....  | 107 |
| Figure 4.92. Shoot fresh weight (a), root fresh weight (b), shoot dry weight (c) and root<br>dry weight (d) of alginate/SiO <sub>2</sub> coated maize seeds. ....  | 108 |
| Figure 4.93. Shoot (a) and root (b) length of alginate/TiO <sub>2</sub> coated tomato seeds.....   | 108 |
| Figure 4.94. Shoot (a) and root (b) length of alginate/TiO <sub>2</sub> coated maize seeds.....  | 109 |
| Figure 4.95. Shoot fresh weight (a), root fresh weight (b), shoot dry weight (c) and root<br>dry weight (d) of alginate/TiO <sub>2</sub> coated tomato seeds. .... | 109 |
| Figure 4.96. Shoot fresh weight (a), root fresh weight (b), shoot dry weight (c) and root<br>dry weight (d) of alginate/TiO <sub>2</sub> coated maize seeds.....   | 110 |
| Figure 4.97. Germination rate (%) of gelatin coated tomato seeds.....  | 111 |
| Figure 4.98. Germination rate (%) of gelatin coated maize seeds .....  | 112 |
| Figure 4.99. Shoot (a) and root (b) length of gelatin/CNT coated tomato seeds.....   | 112 |
| Figure 4.100. Shoot (a) and root (b) length of gelatin/CNT coated maize seeds. ....  | 113 |
| Figure 4.101. Shoot fresh weight (a), root fresh weight (b), shoot dry weight (c) and root<br>dry weight (d) of gelatin/CNT coated tomato seeds.....               | 114 |
| Figure 4.102. Shoot fresh weight (a), root fresh weight (b), shoot dry weight (c) and root<br>dry weight (d) of gelatin/CNT coated maize seeds. ....               | 115 |
| Figure 4.103. Shoot (a) and root (b) length of gelatin/SiO <sub>2</sub> coated tomato seeds. ....  | 116 |
| Figure 4.104. Shoot (a) and root (b) length of gelatin/SiO <sub>2</sub> coated maize seeds.....  | 116 |
| Figure 4.105. Shoot fresh weight (a), root fresh weight (b), shoot dry weight (c) and root<br>dry weight (d) of gelatin/SiO <sub>2</sub> coated tomato seeds. .... | 117 |
| Figure 4.106. Shoot fresh weight (a), root fresh weight (b), shoot dry weight (c) and root   |     |

|  |     |
|--|-----|
| dry weight (d) of gelatin/SiO <sub>2</sub> coated maize seeds.....   | 118 |
| Figure 4.107. Shoot (a) and root (b) length of gelatin/TiO <sub>2</sub> coated tomato seeds. ....  | 118 |
| Figure 4.108. Shoot (a) and root (b) length of gelatin/TiO <sub>2</sub> coated maize seeds.....  | 119 |
| Figure 4.109. Shoot fresh weight (a), root fresh weight (b), shoot dry weight (c) and root<br>dry weight (d) of gelatin/TiO <sub>2</sub> coated tomato seeds. ....               | 119 |
| Figure 4.110. Shoot fresh weight (a), root fresh weight (b), shoot dry weight (c) and root<br>dry weight (d) of gelatin/TiO <sub>2</sub> coated maize seeds. ....                | 120 |
| Figure 4.111. Germination rate (%) of chitosan coated tomato seeds .....   | 122 |
| Figure 4.112. Shoot (a) and root (b) length of chitosan/CNT coated tomato seeds.....   | 122 |
| Figure 4.113. Shoot fresh weight (a), root fresh weight (b), shoot dry weight (c) and root<br>dry weight (d) of chitosan/CNT coated tomato seeds .....                           | 123 |
| Figure 4.114. Shoot (a) and root (b) length of chitosan/SiO <sub>2</sub> coated tomato seeds .....   | 124 |
| Figure 4.115. Shoot fresh weight (a), root fresh weight (b), shoot dry weight (c) and root<br>dry weight (d) of chitosan/SiO <sub>2</sub> coated tomato seeds.....               | 124 |
| Figure 4.116. Shoot (a) and root (b) length of chitosan/TiO <sub>2</sub> coated tomato seeds.....  | 125 |
| Figure 4.117. Shoot fresh weight (a), root fresh weight (b), shoot dry weight (c) and root<br>dry weight (d) of chitosan/TiO <sub>2</sub> coated tomato seeds.....               | 125 |
| Figure 4.118. Germination rates (%) of tomato seeds under drought stress after CNT<br>nanopriming .....  | 127 |
| Figure 4.119. Germination rates (%) of maize seeds under drought stress after CNT<br>nanopriming. ....   | 128 |
| Figure 4.120. Germination rates (%) of tomato seeds under drought stress after SiO <sub>2</sub><br>nanopriming. ....   | 129 |
| Figure 4.121. Germination rates (%) of maize seeds under drought stress after SiO <sub>2</sub><br>nanopriming. ....  | 130 |
| Figure 4.122. Germination rates (%) of tomato seeds under drought stress after TiO <sub>2</sub><br>nanopriming. ....   | 131 |
| Figure 4.123. Germination rates (%) of maize seeds under drought stress after TiO <sub>2</sub><br>nanopriming .....  | 132 |
| Figure 4.124. Shoot length (a) and root length (b) of tomato seeds under drought stress<br>after CNT nanopriming.....  | 134 |
| Figure 4.125. Shoot fresh weight (a), root fresh weight (b), shoot dry weight (c) and root<br>dry weight (d) of tomato seeds under drought stress after CNT<br>nanopriming ..... | 136 |

|   |     |
|---|-----|
| Figure 4.126. Shoot length (a) and root length (b) of maize seeds under drought stress after CNT nanopriming.....   | 138 |
| Figure 4.127. Shoot fresh weight (a), root fresh weight (b), shoot dry weight (c) and root dry weight (d) of maize seeds under drought stress after CNT nanopriming .....               | 140 |
| Figure 4.128. Shoot length (a) and root length (b) of tomato seeds under drought stress after SiO <sub>2</sub> nanopriming .....  | 142 |
| Figure 4.129. Shoot fresh weight (a), root fresh weight (b), shoot dry weight (c) and root dry weight (d) of tomato seeds under drought stress after SiO <sub>2</sub> nanopriming ..... | 144 |
| Figure 4.130. Shoot length (a) and root length (b) of maize seeds under drought stress after SiO <sub>2</sub> nanopriming .....   | 146 |
| Figure 4.131. Shoot fresh weight (a), root fresh weight (b), shoot dry weight (c) and root dry weight (d) of maize seeds under drought stress after SiO <sub>2</sub> nanopriming .....  | 148 |
| Figure 4.132. Shoot length (a) and root length (b) of tomato seeds under drought stress after TiO <sub>2</sub> nanopriming .....  | 150 |
| Figure 4.133. Shoot fresh weight (a), root fresh weight (b), shoot dry weight (c) and root dry weight (d) of tomato seeds under drought stress after TiO <sub>2</sub> nanopriming ..... | 152 |
| Figure 4.134. Shoot length (a) and root length (b) of maize seeds under drought stress after TiO <sub>2</sub> nanopriming .....   | 154 |
| Figure 4.135. Shoot fresh weight (a), root fresh weight (b), shoot dry weight (c) and root dry weight (d) of maize seeds under drought stress after TiO <sub>2</sub> nanopriming .....  | 156 |
| Figure 4.136. Germination rates (%) of tomato seeds under salinity stress after CNT nanopriming. ....   | 159 |
| Figure 4.137. Germination rates (%) of maize seeds under salinity stress after CNT nanopriming. ....  | 160 |
| Figure 4.138. Germination rates (%) of tomato seeds under salinity stress after SiO <sub>2</sub> nanopriming. ....  | 161 |
| Figure 4.139. Germination rates (%) of maize seeds under salinity stress after SiO <sub>2</sub> nanopriming. ....   | 162 |
| Figure 4.140. Germination rates (%) of tomato seeds under salinity stress after TiO <sub>2</sub>  |     |

|  |     |
|--|-----|
| nanopriming. ....  | 163 |
| Figure 4.141. Germination rates (%) of maize seeds under salinity stress after TiO <sub>2</sub> nanopriming. ....  | 164 |
| Figure 4.142. Shoot length (a) and root length (b) of tomato seeds under salinity stress after CNT nanopriming.....  | 165 |
| Figure 4.143. Shoot fresh weight (a), root fresh weight (b), shoot dry weight (c) and root dry weight (d) of tomato seeds under salinity stress after CNT nanopriming .....              | 168 |
| Figure 4.144. Shoot length (a) and root length (b) of maize seeds under salinity stress after CNT nanopriming.....   | 169 |
| Figure 4.145. Shoot fresh weight (a), root fresh weight (b), shoot dry weight (c) and root dry weight (d) of maize seeds under salinity stress after CNT nanopriming .....               | 172 |
| Figure 4.146. Shoot length (a) and root length (b) of tomato seeds under salinity stress after SiO <sub>2</sub> nanopriming .....  | 173 |
| Figure 4.147. Shoot fresh weight (a), root fresh weight (b), shoot dry weight (c) and root dry weight (d) of tomato seeds under salinity stress after SiO <sub>2</sub> nanopriming ..... | 176 |
| Figure 4.148. Shoot length (a) and root length (b) of maize seeds under salinity stress after SiO <sub>2</sub> nanopriming .....   | 177 |
| Figure 4.149. Shoot fresh weight (a), root fresh weight (b), shoot dry weight (c) and root dry weight (d) of maize seeds under salinity stress after SiO <sub>2</sub> nanopriming .....  | 180 |
| Figure 4.150. Shoot length (a) and root length (b) of tomato seeds under salinity stress after TiO <sub>2</sub> nanopriming .....  | 181 |
| Figure 4.151. Shoot fresh weight (a), root fresh weight (b), shoot dry weight (c) and root dry weight (d) of tomato seeds under salinity stress after TiO <sub>2</sub> nanopriming ..... | 184 |
| Figure 4.152. Shoot length (a) and root length (b) of maize seeds under salinity stress after TiO <sub>2</sub> nanopriming .....   | 185 |
| Figure 4.153. Shoot fresh weight (a), root fresh weight (b), shoot dry weight (c) and root dry weight (d) of maize seeds under salinity stress after TiO <sub>2</sub> nanopriming .....  | 188 |

## SYMBOLS AND ABBREVIATIONS

| <b>Symbols</b> | <b>Description</b> |
|----------------|--------------------|
| mm             | Millimetre         |
| g              | Gram               |
| L              | Litter             |
| ml             | Millilitre         |
| mg             | Milligram          |
| g              | gram               |
| %              | Percent            |
| pH             | pH meter           |
| mM             | Milimollar         |
| $\mu$ mol      | Mikromollar        |

| <b>Abbreviations</b>          | <b>Description</b> |
|-------------------------------|--------------------|
| NaCl                          | Sodium Chloride    |
| MS                            | Murasige- Skoog    |
| M                             | Mollar             |
| MDA                           | Malondialdehyde    |
| H <sub>2</sub> O <sub>2</sub> | Hydrogen Peroxide  |
| TiO <sub>2</sub>              | Titanium Dioxide   |
| SiO <sub>2</sub>              | Sillicium Dioxide  |
| CNT                           | Carbon Nanotube    |
| NP                            | Nanoparticle       |

## CHAPTER I

### INTRODUCTION

Since the beginning of the life on the earth, plants have been main food supply for all living organisms. Different parts of the plants; leaves, fruits, roots, shoots and seeds have been used for both human and animal feeding. Among this parts seeds have another importance for plants: reproduction of life. Plants are reproduced in two ways: sexually and asexually (Bidlack and Jansky, 2003). In asexual production, plants are propagated vegetatively and new plants are clones of mother plant. In contrast to asexual production; sexual production creates variation and plants are propagated via seeds, which are reproduction units of flowering plants. Plenty of factors affects yield and quality of crops. Successful germination and stand establishment are prerequisites of successful crop production since unsynchronised emergence or poor seed germination negatively affect cultivation practices as well as growth and yield of crop.

Growers and seed scientists have used various techniques to improve germination and seedling growth for ages. When Greek farmers soaked seeds in water or milk and honey before sowing, Russians preferred to soak in salty solutions (Parera and Cantliffe, 1994). The term of priming was used by Malnassy (1971) to describe the pre-sowing seed treatment to induce emergence of seedlings even in adverse environmental conditions. The seed priming techniques have been developed by years and different materials have been used for this purpose. In recent years, using of nanoparticles, which particles with a size in range the between 10 - 100 nm (Mohanraj and Chen, 2006), gain popularity in agriculture. Nanoparticles have extraordinary physicochemical properties take their source from small size, pure chemical composition, surface structure, solubility and shape (Nel *et al.*, 2006).

Many mineral elements, like nitrogen, phosphorus, potassium, iron, copper, have been used as fertilizers for promoting plants growth, development and productivity (Saad and Elshahed, 2012). However, the fertilizers are pollutants for the environment when they used continuously especially in excess amount (Court and Stephen, 1964). Plants were subjected to nano-sized metals or their oxides, such as TiO<sub>2</sub>, SiO<sub>2</sub>, carbon nanotubes (CNT) and ZnO, to increase plant growth, resistance to abiotic stresses, photosynthesis

rate or seed germination (Almutairi, 2016; Almutairi and Amjad, 2015; Dhoke *et al.*, 2013; Gao *et al.*, 2006). Nanoparticles have been employed to decrease the toxic effects and increase the efficiency of fertilizers; but, the action mechanism and environmental effects of those particles have not been illuminated yet (Gogos, Knauer, and Bucheli, 2012). For this purpose; instead of application the nanoparticles directly to soil or irrigation water, they can be used as priming agent for seeds. This type of priming is called as 'nanoprimering'.

There are different types of nanoparticles: polymer, lipid or metal/oxide based. According to the application area, each type of nanoparticle can be used in agriculture. Polymer based nanoparticles are employed for nano-encapsulation of ingredients by different techniques like, sphere, capsule, micelle and fibers (Hellmann, Greiner, and Wendorff, 2011; Nuruzzaman *et al.*, 2016; Perlatti *et al.*, 2013). Lipid based nanomaterials are used for encapsulation of hydrophobic or lipophilic ingredients. Nanoliposomes, solid lipid nanoparticles and nano-lipid carriers have been reported as encapsulation systems for active compounds (Nuruzzaman *et al.*, 2016). Another type of nanoparticle is metal/oxide based nanoparticles. The different behaviour of materials in nanosize have gained a new view to agriculture. It was illuminated that using of nano-sized metal/oxide materials are very effective on pest control and plant development.

Various plants are subjected to nano-size metals and their oxides like TiO<sub>2</sub>, SiO<sub>2</sub>, Carbon nanotubes (CNT), ZnO to increase their growth, resistance to abiotic stress, photosynthesis rate or seed germination (Almutairi, 2016; Almutairi and Amjad, 2015; Dhoke *et al.*, 2013; Gao *et al.*, 2006). Studies stated that Ag, CNT, SiO<sub>2</sub>, FeO, ZnO and ZnFeCu oxide promote seed germination of different plants; however, the pathway of these mechanisms is not clear yet (Almutairi and Amjad, 2015; Khodakovskaya *et al.*, 2009; Lahiani *et al.*, 2013; Lu *et al.*, 2015; Mohsen Janmohammadi, 2015; Roohizadeh, Majd, and Arbabian, 2015; Wang *et al.*, 2012). Moreover, many different studies have been showed that TiO<sub>2</sub> increases the photosynthesis rate and chlorophyll content of the plants (Gao *et al.*, 2006, 2008; Hong *et al.*, 2005; Mahmoodzadeh, 2013). Apart from seed germination and plant development; it was reported that, nanoparticles could be used to control abiotic stress. Application of Si and SiO<sub>2</sub> nanoparticles increase the abiotic stress tolerance (Almutairi, 2016; Ashkavand *et al.*, 2015; Sabaghnia and Janmohammadi, 2014). Almutairi *et al.* (2016) and Sabaghnia *et al.* (2014) performed their

studies on salinity stress on tomato and lentil, respectively, and they indicated the application of SiO<sub>2</sub> increased the response of crops to the salinity stress (Almutairi, 2016; Sabaghnia and Janmohammadi, 2014).

Liu et al (2009) demonstrated that single walled CNT could penetrate through the both plant cell wall and membrane, even intracellular organelles (Liu *et al.*, 2009). And they indicated that, this property of CNT could be used as for DNA delivery at the future. Studies on tomato, barley, soybean and corn, were conducted by Khodakovskaya et al (2009) and Lahiani et al (2013), confirmed the results of Liu (2009) and both group showed that multiwalled CNT could also penetrate into the cell wall even into the thick seed coat and increased the water uptake ability of the seeds (Khodakovskaya *et al.*, 2009; Lahiani *et al.*, 2013; Liu *et al.*, 2009).

The other application to increase seed vigor and germination is seed coating. Seed coating is the process of covering of seed surface with different materials (Pedrini *et al.*, 2017). There are two aims of seed coating; (i) modify the shape and size of the seed to improve handling of seeds, (ii) deliver the active ingredients in coating material to increase seed germination and development (Avelar *et al.*, 2012; Halmer, 2008; Kaufman, 1991). According to the seed type and aim of the coating the coating techniques change. There are three types of seed coating techniques; (i) film coating, where a very thin layer coating is performed and seed weight only 10% increases, (ii) encrusting is another coating technique, where the shape of the seed is protected when the weight of the seed increases 1-5 times more than its original weight (Gregg and Billups, 2016; Halmer, 2000), (iii) pelleting is the last type of seed coating, where the shape of the seed changes and becomes spherical (Taylor, Klein, and Whitlow, 1988). Quite a lot of materials are used for seed coating purposes. One of these materials is polymers, which contain monomers and polymerise after drying. Besides retention of active ingredients in this polymer layer is possible. Gelatine, methylcellulose, polyethylene glycol, chitosan, polyvinyl alcohol, ethyl cellulose, polyvinyl acetate, and gum arabic are most reported polymer used for seed coating purpose (Pedrini *et al.*, 2016). The first aim of this study was to introduce the different nanomaterials in seed science to increase seed germination rate and plant development both under laboratory and greenhouse conditions. For this purpose, three different nanoparticles; TiO<sub>2</sub>, SiO<sub>2</sub> and CNT were employed for nanopriming with tomato, maize and bean seeds. Besides, effect of these nanoparticles under drought and

salinity stress was examined with tomato and maize seeds. The other aim of the present study was to examine the seed coating performance of these nanoparticles, encapsulated by gelatin, chitosan and alginate.



## CHAPTER II

### LITERATURE REVIEW

#### 2.1 Importance of Seed in Agriculture

Seed forms via fertilization, combination of male and female gametes. The fertilization process starts with landing of the pollen grain on stigma and continues with germination of pollen grain towards the embryo sac. At the end of the journey, two pollen sperms enter the embryo sac. One of the sperm (N) fuses with egg cell (N) and forms embryo (2N), the other sperm (N) fuses with polar nuclei (2N) and forms endosperm (3N). After embryogenesis, endosperm and seed coat development mature seed forms (Copeland and McDonald, 1999).

The history of seed is as old as the history of agriculture. In the early days, seeds were taken from healthy and well-developed plants and used in the next year. Or those seeds were introduced to new geographic areas and climate conditions. However, day by day, new techniques like; selection, hybridization, mutation, polyploidization and plant biotechnology were introduced to seed technologies. Thus, scientists were able to develop plenty of varieties with different properties. On the other hand, all these improvements are useless if they are not useful for farmers. A farmer wants to get seeds with genetically pure, healthy, high germination percentage and vigour. If a seed lot does not have these characteristics the yield and plant quality will be below the expectations (Raikwar, 1975).

Seeds are the most valuable input of plant production (Finch-Savage and Leubner-Metzger, 2006). A high quality seed will be a nice and lucky start for plant production. In contrast, any seed originated problem will affect all plant production processes. One of the most important characteristics for a seed lot is high germination rate. Germination ratio directly affects the yield, by reduction in the plant number in the field. In these days, when agricultural fields are very important, low germination rate prevents the efficient use of these fields. The other important characteristic for a seed lot is synchronised germination. Otherwise, arranging all production processes will be difficult (Finch-savage and Bassel, 2016). Since the different germination times, plants will be at different developmental stages. The different developmental stages will prevent suitable plant production processes.

It will be difficult to decide the suitable time for application of fertilization, pesticide, herbicide etc. Not to applying the chemicals on time will decrease the crop and harvestable part quality. On the other hand, when some plants will be mature, some will not at the harvesting time. Thus, immature plants, fruits, grains etc. will decrease yield and will make the harvesting process difficult. Along these lines, synchronisation between germination time of seeds will both increase yield and crop quality. Another seed originated problem during the plant production is weak seedling development. There are different factors that affect seedling development. One of them is seed health and quality. With low quality and unhealthy seed, it is impossible to get well-developed seedling (Bayat et. al. 2020). For this reason, production of high-quality seeds is vital for plant production.

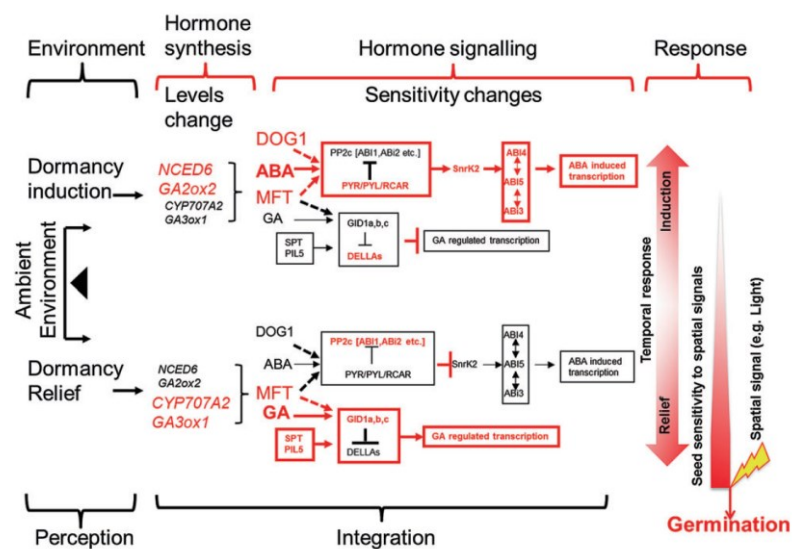
Apart from seed originated problems, there are environmental factors affect seed germination and development. Improper environmental conditions like soil, climate, pest etc. affect both seed germination and seedling development. However, developments in seed science and technologies help to farmers to fight with these obstacles. Different chemicals like fertilizers, pesticides or seed coating technologies or seed priming techniques are used to improve both seed quality and fight with environment originated problems during plant production (Halmer, 2008; Pedrini *et al.*, 2016).

When the lack of seed germination is main problem in the crop production, weak seedling development is as important as seed germination. Both seed originated and environmental problems cause weak seedling development. Low seed vigour is one of the main reason of low crop yield. On the other hand, low seed vigour increases the effect of biotic and abiotic stresses on plant, which also reduce crop yield. The best solution is to improve seedling quality is the production of high quality seeds. However, production of high quality seeds is not possible always or cost is very expensive. For this reason, with some applications it is possible to increase seedling development. These applications can be listed as fertilization, pesticide, herbicide, seed coating, pelleting and priming (Finch-savage et. al., 2004; Halmer, 2008; Pedrini et al., 2016). Fertilizers, pesticides and herbicides are chemicals and using these materials could cause damages on both environment and crops. Today, people prefer to eat chemical free foods. For this reason, alternative applications gain more importance.

In conclusion, seeds are main and most important input of plant production. Thus, using high quality seeds is getting more and more important day by day due to the decreasing in agriculture fields. Unfortunately, there are different seed born problems in crop production like low seed germination rate, unsynchronized germination and weak seedling development. In addition to these problems environmental conditions also affect seed germination and seedling development. For this purpose, development of various techniques to solve these problems is very important for plant production. Development of new technologies to the traditional techniques, like fertilization, is highly important to both decrease the cost and save the environment.

## 2.2 Seed Germination

The germination-dormancy cycle is controlled by Absisic acid (ABA)/Gibberellic acid (GA) balance. When the ABA promotes dormancy and inhibits germination, GA inhibits dormancy and promotes germination (Footitt and Finch-Savage, 2017). The inverse relationship between ABA and GA hormone levels regulates dormancy/germination related genes by altering seed sensitivity to environmental conditions. Figure 2.1 shows the schematic description of ABA/GA regulation pathway on dormancy and germination.



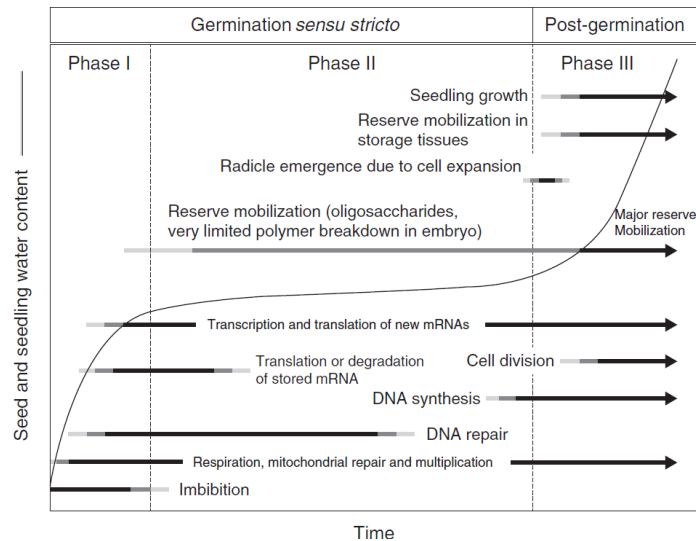
**Figure 2.1.** The regulation of dormancy-germination by ABA and GA in response to the environment in *A. Thaliana* (Footitt and Finch-Savage, 2017)

Dormancy is directly related with soil temperature. When the soil temperature is low, dormancy increases during winter season. In contrast to winter, dormancy decreases in spring time due to the increasing level of soil temperature in most plants (Footitt *et al.*, 2011). Increasing in the expression of key genes, related in ABA biosynthesis (NCED6; a nine-cisepoxycarotenoid dioxygenase family member) and GA catabolism (GA2ox2; GA2-oxidase) increases dormancy. On the contrary, the expression of genes, regulates ABA catabolism, (CYP707A2; an ABA 8-hydroxylase family member) and GA biosynthesis (GA3ox1; GA3-oxidase) increases during summer season and decreases dormancy (Footitt *et al.*, 2011; Graeber *et al.*, 2012).

The other important gene for regulation of dormancy/germination balance is DELAY OF GERMINATION1 (DOG1). DOG1 expression increases during seed maturation and dormancy state at the end of the seed maturation is related to DOG1 expression. By the decreasing in the temperature increases DOG1 expression level and vice versa works in the same way (Footitt *et al.*, 2011; Hou *et. al.*, 2016).

The soil temperature is one of the most important factor on seed germination and dormancy. Seed can sense the soil temperature and its position via environmental signs. Soil temperature changes according the season. During the winter season the soil temperature is low, which induces seed dormancy. By the time of spring the soil temperature increases, which inhibits dormancy. On the other hand, the microbial activity during the summer time increases that drives the soil CO<sub>2</sub> and nitrogen cycle. The nutritional change in soil under warm conditions also promotes seed germination (Finch-savage and Footitt, 2018; Footitt and Finch-savage, 2015; Footitt *et al.*, 2011).

In no-dormant seeds germination starts with imbibition of water under proper environmental conditions. The water imbibition occurs with three phases, which is presented in Figure 2.2 (Bewley, 1997).



**Figure 2.2.** The physical and metabolic events occurring during germination

The first phase is rapid uptake of water by both alive (endosperm) and death (testa) cells. The second phase, plateau phase, is the phase, where the seed reaches its maximum size by water imbibition. During second phase, all cellular mechanism and components repaired. When the cellular components are re-established; mitochondria and cell membranes are repaired in order to prevent any liquid leakage from cell and fix the respiration mechanism; DNA damages, occurs during dormant state, are fixed and cytoskeleton is repaired to maintain transportation system in the cell. In the third phase, cells expand and embryo growth finalizes with radicle extension. The driving forces, turgor and accumulation of osmotically active substances, weakens the cell wall in the embryo. At the end, radicle ruptures testa and emerges. Thus, germination of a non-dormant seed is completed (Footitt and Finch-savage, 2017; Nonogaki et. al., 2010).

### 2.3 Effects of Abiotic Stress on Seed Germination

Each plant needs proper environmental conditions, like temperature, light, CO<sub>2</sub>, radiation etc., for growth and development. The deviation from optimal conditions causes negative effects on plant development, growth and productivity. Extreme temperatures (cold, heat or freezing), drought, too high or low radiation, lack of nutrients in the soil, high soil salinity content are considered as detrimental of abiotic stress factors (Bray, 2000). Especially drought and salinity are a big threat for plant production all over the world. The rising in population and global climate change also increases the effects of these

threats (Gleick, 1994, 1998). Last century the average temperature has been increased approximately 1°C due to the increasing of CO<sub>2</sub> and other trace gases levels in atmosphere (IPCC, 2007). Besides, it is estimated that the average temperature will increase 3-9°C by the end of the century. This increase in temperature also will increase the impact of salinity and drought stress, which have devastating global effects on arable land (Wang et. al., 2003). The main reason of yield loss is abiotic stress with more than 50% lost (Bray, 2000; Wang et. al., 2003) and it is predicted that this loss will increase due to global warming (Evans, 2008; Wang et. al., 2003). Water scarcity and desertification will increase threat on human health, plant production and economy of different countries. It is, therefore, different solutions should be generated for drought and salinity stress on plants. Plants, which can fight with water deficiency due to low water potential of soil, CO<sub>2</sub> uptake restriction and ion toxicity, can survive under drought or salinity stress conditions.

Seeds are highly important part for plants to transfer their genes to next generation. For this reason, completion of seed germination successfully, depends on the metabolic activity of embryo, is vital step for plant production (Rajjou et al., 2012; Vishal and Kumar, 2018). Germination is regulated by different plant hormones like ABA, GA, ethylene and auxin (Han and Yang, 2015). Also environmental factors, like abiotic stresses, affect seed germination (Han and Yang, 2015; Rajjou et al., 2012). These abiotic stresses affect ABA and GA pathway and metabolism of seed (Holdsworth and Soppe, 2008) . The most common abiotic stresses affect plant production is drought and salinity stress, which causes different biochemical, physiological and metabolic changes. (Xiong and Zhu, 2002). Drought and salinity stress also delay and/or inhibit seed germination and seedling development (Almansouri et. al., 2001). High salt concentration in soil affects germination by reducing osmotic potential and preventing water uptake ability of seed or toxicity of high Na<sub>2</sub><sup>+</sup> and Cl<sup>-</sup> ions (Khajeh-Hosseini, Powell, and Bingham, 2003). The response mechanism of the plants to the both drought and salinity stress is very similar and based on reducing the water loss of the seed cells (Tavili et al., 2011).

### **2.3.1 Drought stress**

The reducing in precipitation (meteorological drought) and increase in evaporation causes agricultural drought (Mishra and Cherkauer, 2010). Agricultural drought is lack of

sufficient moisture for plant growth and development (Manivannan et. al., 2008). The cell division and expansion, leaf size, stem and root elongation and stomatal activities are reduced due to drought stress, which reduces plant growth, development and water use efficiency (WUE) (Farooq et al., 2009).

Seeds are the main elements, shape the plant communities with seed life, germination, seedling development, which are also affected environmental factors (Schupp, 1995). Germination, growth and developing into a new seedling of a seed are critical phases of reproduction mechanism of sexual reproduction (Kaor and Fenner, 2000; Sánchez-gómez et al., 2005). The surviving ability of a seedling depends on the effect of various environmental factors like water, temperature, radiation, pathogens and herbs (Moles and Westoby, 2004). After all, the main factor on seed mortality is drought stress (Garcia-fayos and Verdu, 1998; Moles and Westoby, 2004).

The embryo in the seed has desiccation tolerance; however, this property is lost during germination. For this reason, skipping the early stages of seed germination and seedling development rapidly is highly important under drought stress conditions (Aronne and Micco, 2004; Young and Martens, 1991). Growth in the root is the main response to the drought tolerance in early seedling development. Larger and longer root development allows seedling to get more water and nutritious from deeper parts of the soil (Padilla et al., 2007) (Davis 1989). Besides, size of the seed determines the level of tolerance to drought stress of that seed. Larger seeds contain more water and more nutritious compare to smaller seeds, which also develop shorter and smaller roots in the early development stages (Fenner and Kitajima 1999). The root development of drought tolerant species and grown in dry climates are larger than other species (Sharp et al., 2004). Yet, the mechanism of root development whether depends on genetic properties or environmental factors is not clarified yet (Padilla et al., 2007). On the other hand, drought stress can be increase the effect of other abiotic stresses, like irradiation. The effect of light reduction increases under drought stress conditions and decrease the accumulation of biomass of both above and below ground parts (Kubiske et. al., 1996). Moreover, shadier conditions decrease the harmful effect of drought stress (Sánchez-gómez et al., 2005). For this reason, “nurse plants” facilities have been developed to obtain shadier environment to other species (target species). Besides, nurse plants develop microhabitats, which

increases seed germination rate and seedling development. These facilities have been used to re-establish the vegetation in arid areas (Ren et. al., 2008).

Apart from root development hairy structure of the hypocotyl increase the water uptake and prompt physical support under drought conditions (Aronne and Veronica, 2004).

### **2.3.2 Salinity Stress**

Long before the humanity and agriculture, salinity occurred in the soil, but the salt concentration in the soil has increased by agricultural practises (Zhu, 2001). The salt affects soil in two ways; saline soil and sodic soil. Saline soils contain soluble salts like NaCl and Na<sub>2</sub>SO<sub>4</sub> and sometimes also contains various ions at high concentration like Cl<sup>-</sup> and SO<sub>4</sub><sup>-</sup> form CaCl<sub>2</sub> and MgSO<sub>4</sub>. Sodic soils contain alkaline hydrolysis like Na<sup>+</sup> from Na<sub>2</sub>CO (Szabolcs and Julius, 1974).

There are two reasons causes salinity in the soil. The primary reason is natural reasons. One of them is breaking down of the rocks, which releases salts. The second primary reason is the salts from ocean, transferred via wind. This two reasons are the natural reason increase the soil salinity (Parihar et. al., 2015). The secondary reason is human induced reason. The water application to the soil and water use of agricultural crops change salt content of the soil. Besides, production of annual crops instead of perennial crops increases the salt concentration in soil (Manchanda and Garg, 2008).

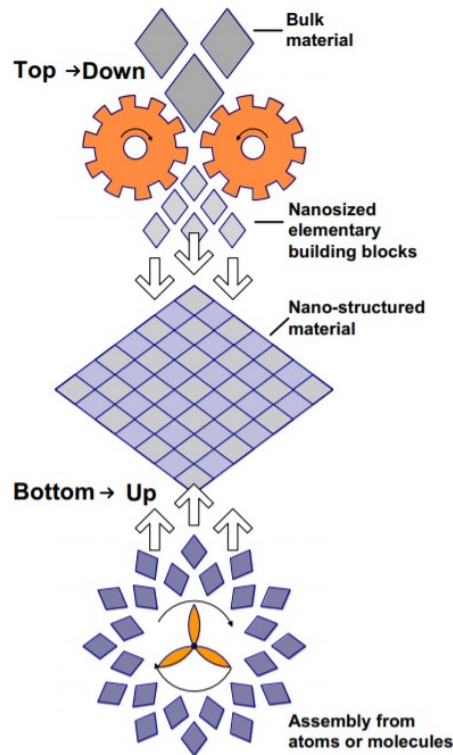
Salinity stress affects plant growth and development in two ways. First one is called water-deficient effect of salinity, which inhibits the water uptake ability of plants by covering the root by salt molecules. The second one is called ion-excess effect of salinity, which leads to plant uptake overdose salt ion and causes cellular damages (Greenway and Rana, 1980). As a result, salt stress both creates water deficiency in the plant and causes ion imbalance in plant cells, which decreases plant growth and development.

It was mentioned that in different studies, salinity stress has negative impact on seed germination in different species like wheat, rice, maize (Akbarimoghaddam *et al.*, 2011; Carpıcı, Celik, and Bayram, 2009; Khodarahmpour and Motamedi, 2012; Xu *et al.*, 2011). High salt concentration affects seed germination at different levels. High salt

concentration inhibits water uptake of seed due to lower osmotic potential (Khan et. al., 2004); causes toxicity, responsible for loss of enzymatic activity and changing in metabolism of nucleic acid (Gomes-Filho *et al.*, 2008); changing protein metabolism (Dantas, De Sá Ribeiro, and Aragão, 2007), changing the hormonal system (Khan and Rizvi, 1994) and decrease maintains of nutritious of the seed (Othman *et al.*, 2006). Lauchli and Grattan (2007) reported a negative correlation between germination rate and salinity stress and mentioned that increasing in salt concentration caused more reducing in seed germination rate. It was also stated that salinity stress decreases seed germination speed (Bybordí, 2010). Salinity stress not only reduces seed germination rate and speed, but also radicle and plumule length and seed vigour (Khodarahmpour and Motamedi, 2012).

## **2.4 Nanotechnology**

Richard P. Feynman introduced nanotechnology with this saying: “*There’s Plenty of Room at the Bottom*” (Feynman, 1960). This idea of Feynman, rebuilding of materials at very small scale revolutionized in physics, chemistry, biology and all areas related to any material. Understand, control and restructure of materials in nanoscale (less than 100 nm) to gain materials new properties and function is called as nanotechnology (NTSC, 2007). Nanotechnology is developed in two approaches. First one is top-down, which is creating nanomaterials by breaking down a bulk material. The molecular structure of these nanomaterials is exactly same with the bulk material. The second approach is bottom-up, which is also called as molecular nanotechnology. The atoms or molecules are employed to build nanomaterials (Drexler *et al.*, 1991). These two approaches are schematically presented in Figure 2.3.



**Figure 2.3.** Schematic presentation of top-down and bottom-up approaches in nanotechnology (Sobolev and Gutiérrez, 2005)

#### 2.4.1 Nanotechnology in Agriculture

Increasing in population of the world, climate change, environmental contamination and lack of water and energy resources are main problems of today's plant production (Usman *et al.*, 2020). More than three billion of plant production is performed all over the world, which needs 187 million tonnes of fertilizers, 4 million tonnes of pesticides, 2.7 trillion m<sup>3</sup> water, and more than 2 quadrillion British thermal units (BTU) of energy (Kah, Tufenkji, and White, 2019; Usman *et al.*, 2020). Besides, it is estimated that the world population will be reach 10 billion of people in 2050 (FAO, 2017). It is therefore, new strategies in plant production should be developed to feed all people on the world, with wise usage of global resources and minimum environmental contamination. One of these strategies is employing of nanotechnology in agriculture (Kah, Tufenkji, and White, 2019; Parisi, Vigani, and Rodríguez-Cerezo, 2015).

There are various application possibilities of using nanotechnology in agriculture like nanofertilizers, nanopesticides and nanobiosensors (Usman *et al.*, 2020).

#### **2.4.1.1 Nanofertilizers**

Intense studies in breeding programs have increased the yield of the crops, which caused more nutrition need. In order to supply this nutrition need, more chemical fertilizers have been used. However, both efficiency of chemical fertilizers and damage to environment is the matter in question. It is therefore, improvement in new alternatives have become a must (Usman *et al.*, 2020). Under this conditions, nanotechnology becomes a good alternative with low nutrient loss, slow release ability and transferring the poorly available nutrients to target plants (Kah *et al.*, 2018). Nanofertilizers can be either nano-scale micro or macro nutrients or carriers/additives for the nutrients (Kah *et al.*, 2018). Besides, encapsulated nutrients in nano-scale are used as nanofertilizers (Derosa *et al.*, 2010).

Nanofertilizers improve the sustainability of agriculture by two ways; (i) improvement in nutrient use efficiency and (ii) decreasing the cost approximately 18-29% (Kah *et al.*, 2018). It is reported that, using nano-phosphatic fertilizer increased growth 32% and seed yield 20% of soybean compared to traditional fertilizers (Liu and Lal, 2014). Application of nanofertilizers improves plant metabolism and nutrients uptake by nano-scale pores developed by molecular transporters and nanostructure cuticle pores (Rico *et al.*, 2011). Slow or controlled release of fertilizers by nanotechnology also increases nutrient use efficiency and reduces the releasing of fertilizers to environment (Liu and Lal, 2014). As it is known, uptaking of phosphatic fertilizers is harder than other fertilizers due to chemical bonds in the soil; however, by using nanofertilizers efficiency of phosphatic fertilizers have been increased (Giroto *et al.*, 2017). Slow release products inhibit conversion of fertilizers to gas form or leaching in the soil, also it is possible to release of fertilizers according to plant signals (Derosa *et al.*, 2010). Besides, development of intelligent fertilizers can also obtain communication between plants and microbiota in the soil (Mastronardi *et al.*, 2015).

#### **2.4.1.2 Nanopesticides**

Using of pesticides is standard process of plant production, and development of target specific pesticide is very important both for crop health and environmental issues. A large number of pesticides have been screening in each year (Resha and Carde, 2009);

however, only 0,1% of pesticides reach the target plants and rest of is released to environment (Carriger et al., 2006). This undesirable release of pesticide causes development of pesticide resistant weeds, insects and pathogens (Rai and Ingle, 2012).

Slow degradation and controlled release of nanopesticides increase the pesticide efficiency (Chhipa, 2017) . The behaviour of nanopesticides differs from conventional ones (Kah *et al.*, 2018). The difference between nano scaled and conventional form of the same ingredient is the nanoparticles can be present in dissolved and colloidal states (Kumpiene, Lagerkvist, and Maurice, 2008) . The solibility of AI can be increased by nanopesticides and decrease the harm impact of pesticide in the environment compared to traditional pesticides (Kah and Hofmann, 2014).

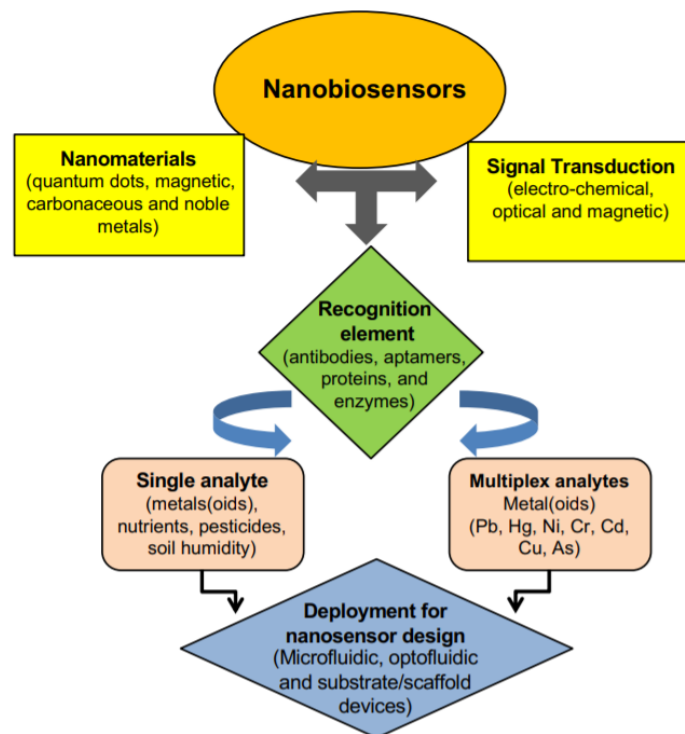
Besides, application of nanopesticid in smaller amount and less frequently help to energy and water conservation. On the other hand, nanopesticides can show more efficiency and increase crop yield and decrease the cost by reducing waste and labour cost. However, environmental protection agency (EPA, USA) listed the risks of nanopesticides on health; (i) dermal absorption due to very small size; (ii) they can place in lungs via respiration and brain by crossing blood brain barrier; (iii) durability and reactive potential of some nanomaterials; (iv) lack of knowledge about engineered nanomaterials in environmental concern (Ragaei and Hassan Sabry, 2014).

It is obvious that, both benefices and risks of nanopesticides at cellular and molecular level should be illuminated.

#### **2.4.1.3 Nano-biosensors in agriculture**

Biosensors have been designed to detect a specific biological analyte by its hybrid system of receptor-transducer with its biological detector (Sun et al., 2006). Nanobiosensors are biosensor with more sensitive and compact detection system, which can sense ultra-low concentrations. This technology can improve the crop production by quick decision for management irrigation, fertilizers and pesticides. The advantages of nanobiosensors over traditional biosensors can be listed as rapid electron transfer kinetics, high sensitivity and more stable structure (Scognamiglio, 2013). Nano-scale materials are used as receptor on the transducer that obtain signal to recognition element for detection of analyte.

Fictionalization, immobilization and miniaturization, which are combined with biocomponents of a transduction system improves the analytical performance of the nanomaterial (Arduini et al., 2016). The working principle of nanobiosensors is turn on/off mechanism, and can detect ultra-low concentration like parts per trillion and limits the analyte according to nanoformulation (Figure 2.4) (Antonacci et al., 2018).



**Figure 2.4.** Mechanistic function of nano-structured biosensors and their designs (Antonacci *et al.*, 2018)

The nanobiosensors are mostly used to analyse soil and water samples. If the pollutant in the soil can detect early, the environmental damage can be prevented (Gruber *et al.*, 2017). The adoption of nanomaterials to sensor technology have obtained rapid detection of any analyte even at very low concentrations.

#### 2.4.2 Nanoparticles in Agriculture

The concept of nanoparticles (NP) cannot be defined as a single category or to a very narrow definition; it contains various products like polymers, lipids and metal particles in nano size. The advantages of using nanoparticles are to both increase the solubility and decrease the premature degradation of active ingredients and design of target focusing

particles. For this purpose, two strategies might be followed; developing the effect of active ingredients or introducing new ingredients, which are not known clearly, yet (Kah et al., 2013).

The application of NPs can increase the seed germination rate, seedling development, growth and yield in different plant types. On the other hand, application of nanoparticles, increase the stress tolerance of plants by the effect on the expression of stress tolerant genes (Van Aken, 2015) and stress proteins (Giraldo et al., 2014). Nanoparticles (NPs) mostly applied by irrigation or foliage.

Apart from the benefits of NPs, there are some toxic effect on plants, environment, animal and human health (Menard, Drobne, and Jemec, 2011). The toxic effect of NPs can be listed as prohibiting seed germination, decreasing of seedling numbers, prohibiting stem and root growth and reduction the yield (El-Temsah and Joner, 2010; Li *et al.*, 2015). The toxicity of a nanoparticle depends on element composition, porosity, average size, surface area, surface charge, aggregation propensity, and hydrodynamic diameter (Peralta-Videa *et al.*, 2011).

#### **2.4.2.1 Polymer Based NP**

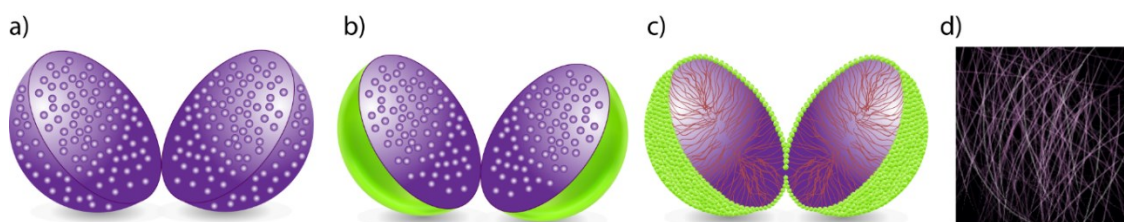
There are four different ways to encapsulate active ingredients; sphere, capsule, micelle and fibers (Hellmann, Greiner, and Wendorff, 2011; Nuruzzaman et al., 2016; Perlatti et al., 2013). Figure 2.5 shows morphological structures of polymeric nano-encapsulated pesticides.

*Nanocapsules*, encapsulation of active compounds in a liquid matrix by a polymeric membrane, are better in controlling the target species (Nuruzzaman et al., 2016). Furthermore, encapsulation material gives new characters to pesticides and using low concentrations of the active compound suffices by increasing the efficiency (Chowdhury et al., 2011; Feng and Zhang, 2011).

*Nanospheres* contain active ingredients homogeneously in a polymeric matrix (Haynes and Duyne, 2001). That type of nanoparticles slow down releasing of active compounds and decreases the presence of free pesticides in the soil (Wanyika, 2013).

Micelles are single layered liposome capsules, with hydrophilic outer and hydrophobic inner layer (Lucy and Glauert, 1964). Micelles are optimal carriers, especially for water-insoluble compounds (Nuruzzaman et al., 2016). This system is mostly used for controlled release of chemicals (Adak et al., 2012).

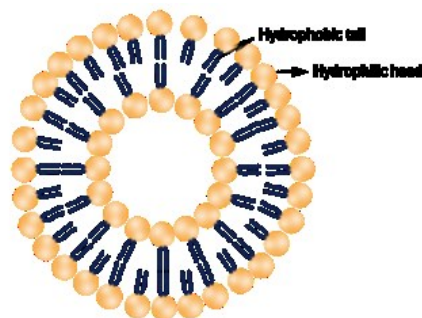
*Nanofibers* are tiny fiber webs with diameter less than 100 nm (Huang et al., 2003). Due to the small diameter and production technique, the nanofibers provide high stiffness and strength. Stability of nanofibers makes them to be chosen for pesticide carrier candidate in the fields (Hellmann et. al., 2011; Huang et al., 2003).



**Figure 2.5.** Different techniques for encapsulation of pesticides with polymers in nano size. Nanocapsule (a), Nanosphere (b), Micelle (c) and Nanofiber (d)

#### 2.4.2.2 Lipid Based NP

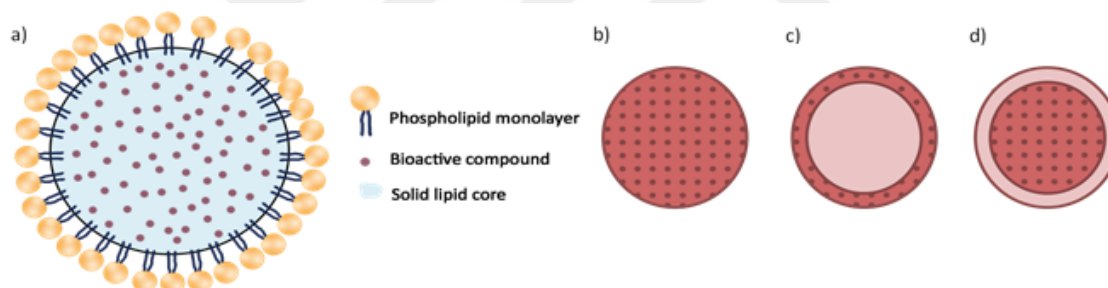
Hydrophilic, hydrophobic and lipophilic compounds are able to be encapsulated by lipid-based nanomaterials. Nanoliposomes, solid lipid nanoparticles and nano lipid carriers have been reported as encapsulation systems for active compounds (Nuruzzaman *et al.*, 2016).



**Figure 2.6.** Structure of a liposome

*Nanoliposomes* are nano sized liposomes, spherical vesicles with at least one lipid bilayer (Mozafari et al., 2008). A lipid contains hydrophilic head and hydrophobic tail, for lipid bilayer the hydrophobic tails stay inside of the layer and hydrophilic heads present at outer layer (Pereira et. al., 2014). The structure of a liposome is shown in Figure 2.6.

*Solid lipid nanoparticles* (SLNs) are raising colloidal carrier-materials for controlled delivery systems (Müller et. al., 2000). The advantages of SLNs from other colloidal carriers are physical and chemical storage stability, loading capacity, production scale and target-oriented releasing properties (Mehnert and Mader, 2001). The schematic structure of a solid lipid nanoparticle is presented in Figure 2.7. Solid lipid core could be made from phospholipids, triglycerides, glycerides, fatty acids, waxes and steroids (Saupe and Rades, 2006). The bioactive compound is distributed in lipid matrix in three ways; homogenous matrix, bioactive enriched shell, bioactive enriched core (Wissing et. al., 2004).

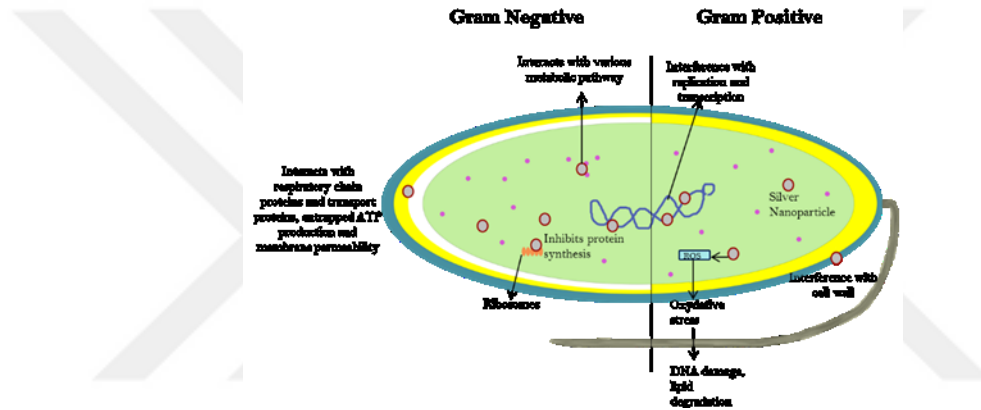


**Figure 2.7.** Schematic structure of solid lipid nanoparticle (SLN) (a), Homogenous matrix SLN (b), Bioactive enriched shell SLN (c) and Bioactive enriched core SLN (d)

*Nanostructured lipid carriers* (NLCs) are second generation of SLNs and those structures have both liquid and solid lipid core at room temperature instead of solid lipid core (Müller et al., 2007). The liquid lipid, oil, prevents higher loading capacity and controlled release (Tamjidi et al., 2013).

### 2.4.2.3 Metal/Oxide Based NP

Organic pesticides have been used for decades for management of weeds, although their environmental toxicity and mixing potential in both surface and underground water (Al-Degs et. al., 2009). The new alternative to organic pesticides, for elimination of disadvantages, metal/oxide based inorganic materials have been adopted. The most preferred nanomaterial as pesticide is silver. Antimicrobial activity of silver has been defined in many studies (Guzman et. al., 2012; Salem et al., 2015; Singh et al., 2014) and possible mechanisms of antibacterial activity of silver were defined by Kumar et. al. (2014) in Figure 2.8. (Guzman et. al., 2012; Pandey et al., 2014; Salem et al., 2015)



**Figure 2.8.** Possible antimicrobial activities of silver nanoparticles on both gram positive and gram negative bacteria, (Pandey *et al.*, 2014)

The antifungal activity of silver nanoparticles on Colletotrichum family has been investigated in field and it was understood that even very small amounts (50 ppm) of silver nanoparticles were enough to control the pathogen (Lamsal et al., 2011). In another study, Ag nanoparticles were grown on graphene oxide to make Ag particles to interact whole surface of the *Xanthomanas perforans* cells (Ocoy et al., 2013). Beside silver nanoparticles, various nanoparticles like copper were used and Ag nanoparticles, Cu nanoparticles and Ag/Cu nanoparticles were able to manage both *Batrytis cinerea* and *Alternaria alternate* (Ouda, 2014). Other metal/oxides based nanoparticles and their properties are listed in Table 2.1.

**Table 2.1.** List of metal/oxides based nanoparticles affect different pathogens

| Material             | Pathogen   | Concentration           | Particle Size  | Reference                      |
|----------------------|--|-------------------------|----------------|--------------------------------|
| Ag                   | <i>Colletotrichum sp.</i>  | 50 ppm                  | 4-8 nm         | <i>Lamsal et. al., 2011a</i>   |
| Ag                   | <i>Xanthomonas perforans</i>   | 20 ppm<br>16 ppm        | 18 nm<br>5 nm  | <i>Oscay et. al., 2013</i>     |
| Ag<br>Cu<br>Ag/Cu    | <i>Alternaria alternata</i><br><i>Batrytis cinerea</i>   | 15 ppm                  | 38 nm<br>20 nm | <i>Ouda, 2014</i>              |
| Cu                   | <i>Phoma destructiva</i><br><i>Curvularia lunata</i><br><i>Alternaria alternate</i><br><i>Fusarium oxysporum</i> | 20 mg/disc              | 5-10 nm        | <i>Kandeh et. al., 2014</i>    |
| CuO                  | <i>Phytophyhora</i>  | 15 gr/hl <sup>-1</sup>  | 14 nm          | <i>Giannousi et. al., 2013</i> |
| Cu <sub>2</sub> O    | <i>infestans</i>   | 34 gr/hl <sup>-1</sup>  | 13 nm          |                                |
| Cu/Cu <sub>2</sub> O | <i>Batrytis cinerea</i>  | > 3mmol.l <sup>-1</sup> | 11 nm          |                                |
| ZnO                  | <i>Penicillium expansum</i>  | 6 mmol.l <sup>-1</sup>  | 70±15 nm       | <i>He et. al., 2011</i>        |
| TiO <sub>2</sub>     | <i>P.s. pv. lachrymans</i><br><i>Psilocybe cubensis</i>  | 1.6 %                   | 52.9 nm        | <i>Cui et. al. 2009</i>        |
| Ag                   | Powdery mildew<br><i>Phoma glomerata</i><br><i>Phoma herbarum</i>  | 100 ppm                 | 7-25 nm        | <i>Lamsal et. al., 2011b</i>   |
| Ag                   | <i>Fusarium semitectum</i><br><i>Trichoderma sp.</i><br><i>Condida albicans</i>                                  | 20 µl/disc              | 20-60 nm       | <i>Gajbhije et. al., 2009</i>  |

Lots of elements, like nitrogen, hydrogen, iron, copper, are called as micro or macro nutrients, which have unquestionable role on plant development (Saad and Elshahed, 2012). In this fashion, these elements are used as fertilizer during the crop production. However, the fertilizers are pollutants for environment as well as they are useful for plants like herbicides and pesticides (Court, Stephen, and Waidj, 1964). Although to decrease toxic effect and increase the efficiency of fertilizers, nanoparticles have been employed, the influence mechanism and environmental effects of those particles have not been illuminated yet (Gogos, Knauer, and Bucheli, 2012). Plants are subjected to nano-size metals and their oxides like TiO<sub>2</sub>, SiO<sub>2</sub>, Carbon nanotubes (CNT), ZnO to increase their growth, resistance to abiotic stress, photosynthesis rate or seed germination (Almutairi, 2016; Almutairi and Amjad, 2015; Dhoke *et al.*, 2013; Gao *et al.*, 2006).

The studies present that; Ag, CNT, SiO<sub>2</sub>, FeO, ZnO and ZnFeCu oxide promote seed germination of various plants. The pathway of these mechanisms is not clear yet. (Almutairi and Amjad, 2015; Janmohammadi *et al.*, 2016; Khodakovskaya *et al.*, 2009; Lahiani *et al.*, 2013; Lu *et al.*, 2015; Roohizadeh, Majd, and Arbabian, 2015; Wang *et al.*, 2012). ZnO nanoparticles increased the root development by rising auxin level in the root (Pandey, Sanjay, and Yadav, 2010). Liu *et al.* (2009) demonstrated that single walled CNT could penetrate through the both plant cell wall and membrane, even intracellular organelles (Liu *et al.*, 2009). And they indicated that, this property of CNT could be used as for DNA delivery at the future. Studies on tomato, barley, soybean and corn, were conducted by Khodakovskaya *et al.* (2009) and Lahiani *et al.* (2013), confirmed the results of Liu (2009) and both group showed that multiwalled CNT could also penetrate into the cell wall even into the thick seed coat and increased the water uptake ability of the seeds (Khodakovskaya *et al.*, 2009; Lahiani *et al.*, 2013; Liu *et al.*, 2009). Khodakovskaya *et al.* (2012) used CNT on tobacco cells and they showed that, the expression of some genes like NtPIP1, which is responsible of regulation of tobacco cells water channels, increased.

Another effect of nanomaterials on plants is increasing in photosynthesis ratio. Many different studies have been showed that TiO<sub>2</sub> increases the photosynthesis ratio and chlorophyll content of the plants (Gao *et al.*, 2006, 2008; Hong *et al.*, 2005; Mahmoodzadeh, 2013). Firstly, Hong *et al.* (2005) pointed out that, TiO<sub>2</sub> raised photosynthesis ratio of spinach by promoting photochemical reactions of chloroplast (Hong *et al.*, 2005). Formerly, the studies performed by Gao *et al.* in 2006 and 2008 illuminated that TiO<sub>2</sub> caused a conformational change in rubisco activase enzyme, which increased the activity of the enzyme (Gao *et al.*, 2006, 2008). TiO<sub>2</sub> nanoparticles were used under N-deficient conditions, and managed nitrogen deficiency in spinach by increase the nitrate reductase activity (Yang *et al.*, 2006, 2007).

Apart from all this, Si and SiO<sub>2</sub> nanoparticles not only support plant development, but also increase the abiotic stress tolerance of the plants (Almutairi, 2016; Ashkavand *et al.*, 2015; Sabaghnia and Janmohammadi, 2014). Almutairi *et al.* (2016) and Sabaghnia *et al.* (2014) performed their studies on salinity stress on tomato and lentil respectively, and they indicated SiO<sub>2</sub> increases the response of crops to the salinity stress (Almutairi, 2016; Sabaghnia and Janmohammadi, 2014). Besides, Almutairi performed molecular analysis and showed that genes, which are expressed with salinity stress in tomato (*TASI4*, *APX2*,

*LOX1, MAPK2, EFR1 and MAPK3*) were expressed in the medium with SiO<sub>2</sub>, without NaCl. Those data clarified that SiO<sub>2</sub> has important function on salinity stress response. Additionally, drought stress could be controlled by Si nanoparticles, which manage the physiological and biochemical actions of plants under the stress conditions (Ashkavand *et al.*, 2015). List of metal/oxides that are used in agriculture is given in Table 2.2.

**Table 2.2.** List of metal/oxide based nanoparticles as growth regulators

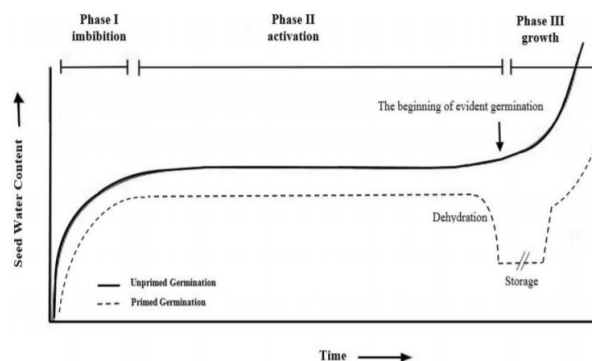
| Material         | Size of Particle | Concentration              | Organism                     | Reference                        |
|------------------|------------------|----------------------------|------------------------------|----------------------------------|
| SiO <sub>2</sub> | 10-15 nm         | 40-60 mg.L <sup>-1</sup>   | Tall watergrass              | <i>Azimi et al, 2014</i>         |
| SiO <sub>2</sub> | 10-15 nm         | 40-60 mg.L <sup>-1</sup>   | <i>Astragalus squarrosus</i> | <i>Azimi et al, 2016</i>         |
| TiO <sub>2</sub> | <100 nm          | 2.5%                       | <i>Vicia narbonensis</i>     | <i>Castiglione et al, 2011</i>   |
|                  |                  |                            | <i>Zea mays</i>              |                                  |
| ZnO              | 20 nm            | 20 ppm                     |                              |                                  |
|                  | 100 nm           | 50 ppm                     | <i>Vigna radiata</i>         | <i>Dhoke et al, 2013</i>         |
| FeO              | 20-40 nm         | 50 ppm                     |                              |                                  |
| TiO <sub>2</sub> | 4-6 nm           | 0.25%                      | Spinach                      | <i>Gao et al, 2006</i>           |
| TiO <sub>2</sub> | 5 nm             | 0.03%                      | Spinach                      | <i>Gao et al, 2008</i>           |
| TiO <sub>2</sub> | --               | 0.25%                      | Spinach                      | <i>Hong, 2005</i>                |
| SiO <sub>2</sub> | 20-30 nm         | 0.2-0.6 mM                 | Sunflower                    | <i>Janmohammadi et al, 2015</i>  |
| MWCNT            | --               | 10-40 µg.ml <sup>-1</sup>  | Tomato                       | <i>Khodakovskaya et al, 2009</i> |
| MWCNT            | --               | 5-500 µg.ml <sup>-1</sup>  | Tobacco                      | <i>Khodakovskaya et al, 2012</i> |
| MWCNT            | 125-250 nm       | 50-200 µg.ml <sup>-1</sup> | Tomato                       | <i>Khodakovskaya et al, 2013</i> |
|                  | 15-40 nm         |                            | Barley                       |                                  |
| MWCNT            |                  | 50-200 µg.ml <sup>-1</sup> | Soybean                      | <i>Lahiani et al, 2013</i>       |
|                  | (in diameter)    |                            | Corn                         |                                  |
| SiO <sub>2</sub> | 40-46.5 nm       | 1-10 g.L <sup>-1</sup>     | Tomato                       | <i>Lu et al, 2015</i>            |
| TiO <sub>2</sub> | 20 nm            | 0-2000 ppm                 | Wheat                        | <i>Mahmoodzadeh et al, 2013</i>  |
| ZnO              | 20-30 nm         | 20 ppm                     | <i>Cicer arietinum</i>       | <i>Pandey et al, 2010</i>        |
| SiO <sub>2</sub> | --               | 1.5-3 mM                   | <i>Vicia faba</i>            | <i>Roohizadeh et al, 2015</i>    |

\*MWNCT: Multiwalled Carbon Nanotube

## 2.5 Seed Priming

One of the most important problem of crop production is the difference between seedling emergence time. Rapid and synchronised seed germination ends with healthy seedling development and deep root system (Azimi *et al.*, 2014; Khalaki *et al.*, 2020). Various seed treatment techniques have been used to synchronize the field emergence. When Greek farmers soaked seeds in water or milk and honey before sowing, Russians preferred to soak in salty solutions (Parera and Cantliffe, 1994). The term of priming was used by Malnassy (1971) to describe the presowing seed treatment to induce emergence of seedlings even in adverse environmental conditions (Malnassy, 1971). Priming application increases germination ratio, germination speed, seed vigour index, root and shoot development, dry and fresh weight of seedling etc. (Khalaki *et al.*, 2020; Siddique and Bose, 2007).

The aim of the seed priming is preparing the seed to germinate by imbibe in an osmotic solution without letting radicle protrusion through the seed coat (Figure 2.9). Inorganic salts ( $KNO_3$ ) or chemically inert compounds (PEG6000) could be used for preparation of osmotic solutions. The osmotic solutions are not only seed priming materials. In 1988 Kubik *et. al.* and Taylor *et. al.* introduced the term “solid matrix priming” (SMP), a seed treatment technique with solid matrix instead of osmotic solutions. When materials like leonardite shale or calcined clay were used in 1990s, hydrogels are popular today (Olszewski *et al.*, 2012; Taylor, Klein, and Whitlow, 1988).



**Figure 2.9.** The comparison of water uptake behaviour of seed during germination with and without seed priming (Khalaki *et al.*, 2020)

Orka is one of the preferred crop for seed priming and different materials have been used for induction of seed germination; like calcium aluminium silicate, humic acid, clay, crystalline quartz (Merreddy *et al.*, 2000; Sharma *et al.*, 2013). Additionally, seed priming techniques are very beneficial to prevent the decreasing in seed germination under abiotic stresses. The studies have showed that different seed priming can increase the seedling emergence under abiotic stress conditions, like water or temperature (Imran *et al.*, 2013; Rahimi, 2013).

There are various types of priming; hydropriming, soaking of seeds in water (Finch-savage, Dent, and Clark, 2004) (Finch-Savage *et al.* 2004); osmopriming, soaking of seeds in osmotic solutions (Abbasi Khalaki *et al.* 2018); halopriming, soaking of seeds in inorganic salt solutions (Bekhrad *et al.* 2015); hormo-priming, soaking of seeds in plant hormon solutions (Abbasi Khalaki *et al.* 2018); matrix priming, incubation of seeds at low and high temperatures; bio-priming, soaking the seeds in an organic matter solution (Moameri *et al.* 2018a); and nano-priming soaking of the seed in nanomaterials (Moameri *et al.* 2018; Abbasi Khalaki *et al.* 2019) (Finch-savage, Dent, and Clark, 2004; Khalaki, Ghorbani, and Ouri, 2019; Moameri M, Alijafari E, Abbasi khalaki M, 2018).

### **2.5.1 Nanopriming**

Nanopriming can be simply described as soaking of seeds in nanomaterial (Khalaki, Ghorbani, and Ouri, 2019; Moameri M, Alijafari E, Abbasi khalaki M, 2018). Introducing of this technique in seed science can help to decrease the damage of chemical fertilizer and pesticides on environment. Hence, application of nanoparticle both decreases this damage and increases the establishment of seedling (Derosa *et al.*, 2010; Nair *et al.*, 2010). The mechanism of nanopriming is increasing of water uptake by settling of nanoparticles in seed coat (Dutta, 2018). There are both positive and negative effect of metal and metal oxide nanoparticles on seed germination (Feizi *et al.*, 2013A). Nevertheless, Ag, Au, CuO, ZnO, CeO<sub>2</sub>, SiO<sub>2</sub> and TiO<sub>2</sub> are the most common nanoparticles, which took the attention of scientists (Maroufpoor *et al.* 2019).

The binding ability of nanoparticles to seed coat is higher than other agents like PEG, water (Anand *et al.*, 2019; Mahakham *et al.*, 2017). The importance of GA and ABA phytohormones on seed germination was mentioned above. The application of

nanoparticles affects the regulation of phytohormones (Yang *et al.*, 2017). Seeds recognise NPs as external agents and only the GA and ABA dependent responses are known (Anand *et al.*, 2019; Mahakham *et al.*, 2017). When the nanoparticles enter the seed coat, ROS accumulate, which starts some chains of downstream events (Guha *et al.*, 2018). Increasing of ROS concentration in the seed cell breaks the seed dormancy via activation of GA synthesis and transformation of storage proteins (Dietz, Mittler, and Noctor, 2016). ROS is required for breaking seed dormancy by activation of phytohormones and few studies showed the ROS accumulation in nanoprimered seeds (Chandrasekaran *et al.*, 2020; Oracz and Karpiński, 2016). The crosstalk between ROS and GA/ABA is highly important mechanism for seed dormancy and germination pathways (Bailly, 2019; Bailly and Kranner, 2011). Thus, it is possible that increasing in accumulation of ROS in nanoprimered seed helps to break seed dormancy and promotes seed germination (Chandrasekaran *et al.*, 2020).

Nanoprimering increases  $\alpha$ -amylase activity and starts rapid starch degradation (Mahakham *et al.*, 2017; Man *et al.*, 2013). The activity of  $\alpha$ -amylase depends on GA and this relationship increases with entegration of nanoparticles in the seed (Mahakham *et al.*, 2017). Effect of nanoprimering on phytohormones enhances sugar signalling factors, which promotes seed germination (Laby *et al.*, 2000).

Rhizome extract of galanga plant was used as nanoprimering agent for 10 year aged maize seeds, and it is reported that this application both increased the seed germination and seedling development. However, any nanoparticle was detected in the vegetative parts (Mahakham *et al.*, 2016). In another study, Ag nanoparticles is used for nanoprimering on aged rice seeds. Usage of Ag nanoparticles internalize seed coat and increased imbibition capacity of seeds; besides, nanoprimering application increased ROS concentration, which promotes seed germination (Mahakham *et al.*, 2017). Ag nanoparticles also employed for nanoprimering purpose on aged faba seeds and its reported that mitotic activity was increased by nanoprimering, which increases seed germination and seed vigour index (Younis and Heikal, 2019). Bayat (2020) used iron, zinc and their combination for nanoprimering on red bean seeds and mentioned that nanoprimered seeds showed more germination and plantlet establishment performance (Bayat, Ghanbari, and Bayramzade, 2020). They also reported that combination of iron and zinc nanoparticles had positive effect on grain yield (Bayat, Ghanbari, and Bayramzade, 2020). MgO was used for

nanoprimering on green gram seeds and application of 100 mg/L MgO nanoparticles increased seed germination and seed vigour compared to hydropriming (Anand *et al.*, 2020). Apart from the promoting seed germination and seedling development, using nanoparticles as priming agent inhibits direct interaction of NPs with soil and environmental hazardous effect (Mahakham *et al.*, 2017).

## 2.6 Seed Coating

Seed coating is active ingredient application on the surface of a seed to make handling of the seed and improve the appearance, or protect the seed against pests with that ingredients and seed germination ratio and plant establishment ability of the seed (Halmer, 2008; Pedrini *et al.*, 2017). In 1930s the first seed coating was performed on cereal seeds and right after that, commercial usage of seed coating started in 1960s (Kaufman, 1991). Today, almost every seed production company do not sell their product without coating (Pedrini *et al.*, 2017). There are different seed coating ingredients like color and tracers; pesticides; soil adjuvants; germination, growth and stress resistance stimulating ingredients; and microbial inoculants (Ehsanfar and Modarres-Sanavy, 2005; Pedrini *et al.*, 2017; Scott, 1989).

There are various seed coating process, developed by different companies; however, the basic principle is same for all seed coating process. In general, a coated seed contains a seed in the core and the seed is coated by an adhesive compound, a bulking agent and active in gradient, depends on the coating aim (Accinelli *et al.*, 2016; P. Padhi and Pattanayak, 2018; Scott, 1989). The bulking agents, as microbial carriers and size and shape modifier, can be peat; talc ; lime (Berninger, Mitter, and Preininger, 2016; Hameeda *et al.*, 2010; P. Padhi and Pattanayak, 2018). Components like alginate can be employed as boyt filler and binder (Anis, Zaki, and Dawar, 2012; Lally *et al.*, 2017). Nowadays, other polymer based materials like biochar and chitosan also used as filler or microbial component carrier for seed coating purpose (Głodowska *et al.*, 2016, 2017; Ruiz de la Cruz *et al.*, 2017). The aim of using adhesive compounds is to bind all components and keep clean the final product and mostly polymers are used for these purposes like methyl cellulose, gum Arabic, and Polgel (Amutha, 2017; Dawar *et al.*, 2008; Li *et al.*, 2002; Lopisso, Kühlmann, and Siebold, 2017; Pedrini *et al.*, 2017; Singh *et al.*, 2014; Ugoji, Laing, and Hunter, 2006).

There are three types of seed coating techniques; seed dressing, film coating and pelleting (Accinelli, Abbas, and Shier, 2018; Jacob *et al.*, 2016; Rocha *et al.*, 2019; Shahzad *et al.*, 2017). The simplest coating technique is seed dressing, which is coating of seed with small amount of component, mostly pesticides (Scott, 1989). However, some scientist using seed dressing term as synonym for seed coating (Choi *et al.*, 2016; Murphy, Doohan, and Hodgkinson, 2017; Shahzad *et al.*, 2017). Most common used technique for seed coating is film coating; which is a thin layer coating of seed with little changes in seed shape and weight (Halmer, 2008) (Halmer, 2000;). The last technique is pelleting, which causes significant changes in seed size, shape and weight (Halmer, 2009). The purpose of the seed pelleting is to improve the seed handling, planting for small and irregular shaped seeds (Halmer, 2008).

Different active ingredients are employed for seed coating like pesticides, fertilizers etc. By the introduction of nanoparticles in agriculture, these novel materials are used for seed coating purposes recently (Tian *et al.*, 2019). However, there are very limited study on this novel topic. Tian and colleagues (2019) reported that chitosan/nano-TiO<sub>2</sub> and chitosan/nano-SiO<sub>2</sub> film coating have improved storage process of *Ginkgo biloba* seeds (Tian *et al.*, 2019). Besides, different studies stated that using these materials as seed coating material prolonged storage of tomato and loquat fruit seeds (Kaewklin *et al.*, 2018; Song *et al.*, 2016). Polymer film coating contains 25 mg/L Fe nanoparticles induced seed germination and seedling establishment of pigeonpea seeds (Raju and Rai, 2017).

Nanotechnology have introduced an innovation to agriculture. There are different application techniques of nanotechnology in agriculture like nano encapsulation of fertilizers and pesticides or nanobiosensors. The other technique is nanoparticle treatment. However, the balance between advantages and disadvantages of using nanoparticles in plant production is not illuminated yet. The nanoparticle can be sprayed to leaves, mixed in the soil or growing media or priming technique can be used. Continuous application of nanoparticles to the plant can increase the nanoparticle content of plant and soil and the harms of nanoparticles is not known clearly. Thus, nanopriming technique seems most harmless technique for now. Not enough research in this area have been conducted yet. Taking into account all of these, the aim of the thesis is improving the knowledge of this area by using both nanopriming technique to promote

seed germination and seedling development under control, drought and salinity stress conditions and using nanoparticles as seed encapsulation agent.



## CHAPTER III

### MATERIALS AND METHODS

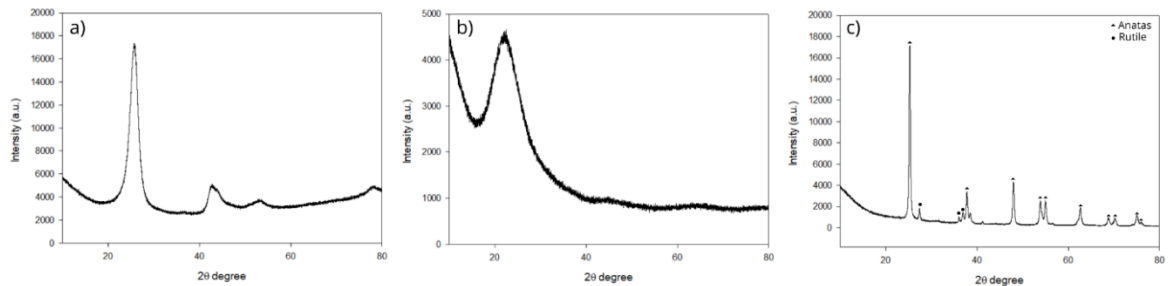
The thesis aimed to determine the usability of three different nanoparticles as seed priming and coating agent. For this purpose, three different crop species, dry bean, (*Phaseolus vulgaris* L.) cv. Asya, maize (*Zea mays* L.) cv. Capuzi, and tomato (*Solanum lycopersicum* L.) cv. Altar F1 and three different nanoparticles were used (Table 3.1). The bean and maize seeds were kindly supplied by May Seed, Bursa, Turkey and tomato seeds were kindly supplied by Yüksel Seed, Antalya, Turkey. All experiments were performed in the laboratories and greenhouse of the Faculty of Agricultural Sciences and Technologies, Niğde Ömer Halisdemir University.

**Table 3.1.** Information about nanoparticles used in thesis

| Name                         | Symbol           | Size    | Firm          |
|------------------------------|------------------|---------|---------------|
| Multi-Walled Carbon Nanotube | CNT              | <100 nm | Cheaptubes    |
| Titanium Dioxide             | TiO <sub>2</sub> | <100 nm | Alfa Aesar    |
| Silicon Dioxide              | SiO <sub>2</sub> | <100 nm | Sigma Aldrich |

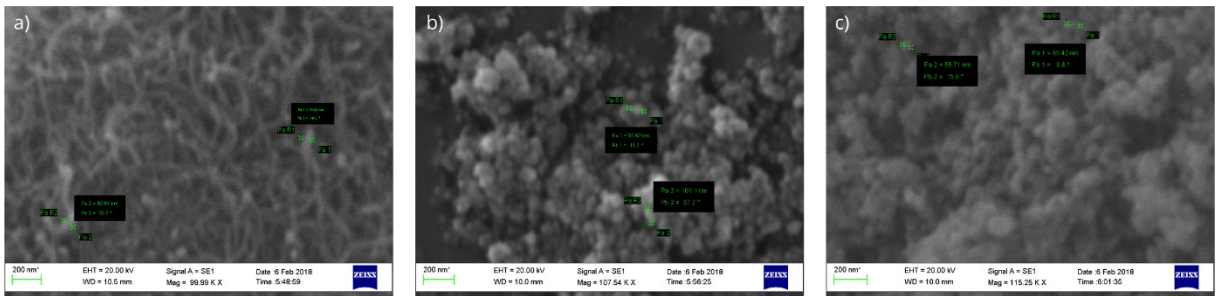
#### 3.1 Characterization of NPs

Before starting experiments, the scanning electron microscope (SEM) images were taken to measure NPs size, and the purity of nanoparticles was detected by X-Ray diffraction (XRD) at Niğde Ömer Halisdemir University Central Research Laboratory.



**Figure 3.1.** XRD patterns of CNT (a), SiO<sub>2</sub> (b) and TiO<sub>2</sub> (c)

The XRD analysis was performed to detect purity of nanoparticles. There should be two pikes for CNT (Fathi et al., 2017), as presented in Figure 3.1a. The amorphous structure of SiO<sub>2</sub> nanoparticle (Venkatachalam, 2011) was determined by XRD analysis as showed in Figure 3.1b. Finally, the crystalline structure of TiO<sub>2</sub> was presented in Figure 3.1c (Chougala and Kamble, 2017).



**Figure 3.2.** SEM images of CNT (a), SiO<sub>2</sub> (b) and TiO<sub>2</sub> (c)

Figure 3.2 presents the SEM images of nanoparticles used in thesis. According to the figure, the sizes of all nanoparticles is less than 100 nm.

The thesis was conducted under four work packages (WPs), which were explained in details below;

### **3.2 Effects of nano-priming applications with NPs at different concentrations on seed germination under laboratory conditions (WP-I)**

The purpose of this WP was the investigation of the effects three nanoparticles at different concentrations on seed germination of three crop species under *in vitro* conditions. The tested NPs and their concentration are given in Table 3.2, distilled water was used as matrix.

**Table 3.2.** Types and concentrations of NPs for WP-1

| Type of NP       | Concentrations (mg.L <sup>-1</sup> ) |    |    |    |     |     |     | Reference                         |
|------------------|--------------------------------------|----|----|----|-----|-----|-----|-----------------------------------|
| MWCNT            | 0                                    | 5  | 10 | 50 | 100 | 250 | 500 | <i>Rahimi et. al., 2016</i>       |
| TiO <sub>2</sub> | 0                                    | 5  | 10 | 50 | 100 | 250 | 500 | <i>Dehkourdi and Mosavi, 2013</i> |
| SiO <sub>2</sub> | 0                                    | 10 | 20 | 40 | 60  | 80  | 100 | <i>Azimi et. al., 2016</i>        |

### 3.2.1 Surface sterilization and nano-priming of seeds

Before transferring the seeds to the germination medium, the surface sterilization of seeds was performed to prevent fungal and bacterial contamination. For this reason, the tomato seeds were shaken in 0.7% NaClO for 4 minutes and rinsed with sterile distilled water. The maize seeds were firstly shaken in 70% ethanol for two minutes, and the sterilization continued with 1% NaClO for 10 minutes, and finally, seeds were rinsed with sterile distilled water. The bean seeds were shaken in 1% of NaClO for 20 minutes and rinsed with sterile distilled water.

Seed nano-priming was conducted after surface sterilization of the seeds. The NPs suspensions were prepared according to Table 3.2 and sterilized with autoclave. For this step, seeds were incubated in NP suspensions for 24 hours for tomato, 8 hours for maize, and 1 hour for dry bean. The durations of nanoprimering for each seed types were determined after preliminary studies. After incubations, the seeds were rinsed with sterile distilled water for 2 min. Then, seeds were dried at room temperature in a sterile cabinet.

### 3.2.2 Seed germination experiments

A separate germination experiment was conducted for each NP using different concentrations given in Table 3.1 in each crop. All experiments were laid on Completely Randomized Design with five replications, and each replica had 30 seeds. A half-strength MS0 medium without sucrose was used for germination experiments of dry bean and maize. Tomato seeds were germinated on a quarter-strength MS0 medium containing 1.5% sucrose. A gelling agent containing 0.8% of phytoagar was used for both medium, and the pH of mediums was adjusted to 5.6-5.8 (Table 3.3).

**Table 3.3.** MS media component for germination of bean, maize and tomato seeds

| <b>Ingredient</b>   | <b>Bean and Maize</b> | <b>Tomato</b> |
|---------------------|-----------------------|---------------|
| MS Salt (Duchefa)   | 2,2 g/L               | 1,1 g/L       |
| Sucrose (Duchefa)   | 0,0 g/L               | 15,0 g/L      |
| Phytoagar (Duchefa) | 8,0 g/L               | 8,0 g/L       |

Bean and tomato seed germination tests were conducted in germination cabinets at 20°C under 16/8 h light/dark conditions at the Seed Laboratory of Niğde Ömer Halisdemir University, Faculty of Agricultural Sciences and Technologies. Maize seed germination tests were conducted in growth chambers at 24°C under light conditions at Tissue Culture Laboratory of Niğde Ömer Halisdemir University, Faculty of Agricultural Sciences and Technologies.

Seeds were considered as germinated when around 2 mm of radicle became visible. Germinated seeds were counted daily, and experiments were terminated on the 7th day for maize, on the 10th day for dry bean, and 21st day for tomato. After germination tests were completed, the following parameters were determined for each crop;

**Germination rate (%):** To calculate the germination percentage (GP), the germinated seeds were counted and GP was calculated by the formula given below:

$$GP = (\text{Germinated seed number} / \text{Total seed number}) \times 100$$

**Shoot length (mm):** To measure the shoot length plant images were taken by EPSON (Expression 11000 XL) Scanner and shoot length was measured by ImageJ software.

**Root length (mm):** To measure the root length plant images were taken by EPSON (Expression 11000 XL) Scanner and root length was measured by ImageJ software.

**Fresh weight of shoot and root (g):** The plants were cut to separate shoot and root. The shoot and root fresh weight was measured by precision scales (Shimatzu).

**Dry weight of shoot and root (g):** The plants were cut to separate shoot and root and each part was dried at 70°C for two days. Then, shoot and root dry weight was measured by precision scales (Shimatzu).

**Seed vigor index:** The seed vigor index was calculated according to the formula, given below (Dehkourdi and Mosavi, 2013):

$$VI = (RL + SL)/GP$$

Where VI is the seed vigor index, RL and SL is radicle and shoot length respectively and GP is germination percentage.

**Water uptake (%):** Weight of tomato, maize, and bean seeds were measured and nanopriming were applied seeds as mentioned in section 3.2.2. Then the weight of the seeds measured after nanopriming. The water uptake rate was calculated according to the formula given below:

$$\text{Water uptake (\%)} = [(SW \text{ after priming} - SW \text{ before priming}) / SW \text{ before priming}] * 100$$

SW: Seed weight

### **3.3 Effects of nano-priming applications with NPs at different concentrations on emergence, growth and yield under greenhouse conditions (WP-II)**

The purpose of WP-II was the investigation of the effects three nanoparticles on plant development of tomato, bean and maize crops under *in vivo* conditions and determination of translocation of nanoparticles in different parts of plants.

Three pot experiments were conducted to determine the effects of nano-priming of bean, maize and tomato seeds with three different types of NPs at the Research and Implementation Greenhouses of Agricultural Genetic Engineering Department. All experiments were laid out in Completely Randomized Design with 5 replications. The experimental unit was three pots (12 L, 26 cm in diameter) with one plant in each pot. The best concentration for each nanoparticle from WP-I was selected for WP-II (Table

3.4). Before sowing the seeds, the seed nano-priming was conducted with same method in WP-I.

**Table 3.4.** Selected nanoparticle concentrations for each plant type

| <b>Nanoparticle/Plant</b> | <b>Tomato</b> | <b>Maize</b> | <b>Bean</b> |
|---------------------------|---------------|--------------|-------------|
| <b>TiO<sub>2</sub></b>    | 10 ppm        | 500 ppm      | 500 ppm     |
| <b>SiO<sub>2</sub></b>    | 10 ppm        | 20 ppm       | 100 ppm     |
| <b>CNT</b>                | 5 ppm         | 10 ppm       | 100 ppm     |

The pots were filled with peat and perlite mixture in 2:1 ratio (v/v). A composed fertilizer of NPK (18+18+18+ microelements ) was incorporated into the peat+perlite mixture before sowing. Three seeds were sown to each pot on 14 June 2019 and thinned to one plant in each pot after emergence. Sowing depth of the seeds changed according to the crop species and the depth was 7-8 cm for bean and maize and 3 cm for tomato. The plants were checked daily and irrigated as needed.

The emergence of seeds was observed daily, and the average emergence date were determined for each treatment in each experiment.

**Stem length (cm):** At inflorescence stage, stem length of the plants was measured (53<sup>rd</sup> day after planting (DAP) for bean, 75<sup>th</sup> DAP for maize and tomato).

**Chlorophyll index (SPAD):** Chlorophyll content was measured with SPAD-502 Plus chlorophyll meter (Konica Minolta) with 15 days intervals starting from the 26<sup>th</sup> day of planting.

**Chlorophyll content:** The same leaves, which was used for chlorophyll index measurement, was harvested for chlorophyll content determination. The fresh weight of the leaf samples was measured (around 0.2 g), and the leaves was grinded very well by tissuelyser. Then, 1 ml of 80% acetone was added onto samples and shook and incubated overnight at +4°C. After overnight incubation, the samples were centrifuged for 5 min. at 13.000 g and the supernatant was collected. The supernatant, which had the chlorophyll, was measured at 470, 646.8 and 663.2 nm. The total chlorophyll content was calculated by “(7.15 A<sub>663.2</sub> + 18.71 A<sub>646.8</sub>)/1000/leaf fresh weight” formula.

**Photosynthetic rate, transpiration rate and stomatal conductance:** Photosynthetic rate, transpiration rate and stomatal conductance were measured on the fully expanded youngest leaves using a portable photosynthesis system (LI-6400 XT, LICOR, USA) with two weeks interval starting from 28<sup>th</sup> day after planting.

**Yield and yield components:** After harvest, the yield performance of each plant was measured regarding to their products; fruit number and weight for tomato, grain number and total grains and kernels weight for bean and maize plants respectively. The bean grains were harvested three times; on 57<sup>th</sup>, 66<sup>th</sup> and 97<sup>th</sup> DAP. The tomato fruits also harvested three times; on 110<sup>th</sup> day, 128<sup>th</sup> day and 154<sup>th</sup> DAP. Maize was harvested on 145<sup>th</sup> DAP.

**NP translocation in plants:** In order to track NPs in plants, samples from root, shoot, leaf, flower, and seeds of next generation were taken. All samples were dried at 70°C and well grinded for further analysis. Presence of TiO<sub>2</sub> and SiO<sub>2</sub> in samples were monitored under X-Ray Fluorescence and CNT with Raman Microscopy, which are located in Niğde Ömer Halisdemir University Central Laboratory.

### **3.4 Effects of NP containing polymer coating of seed on seed germination under laboratory conditions (WP-III)**

The best concentrations for germination of seeds, determined in WP-II according to seedling length, was used for WP-III. Three different polymers were used as solid matrix; gelatin, chitosan and sodium alginate. The determined concentration of each NP was added in polymer films for seed priming. And seeds were encapsulated with polymers, containing NPs. The aim of the WP is to determine the possibility of NPs as seed coating agent.

#### **3.4.1 Treatment with gelatine:**

For gelatine treatment three different gelatine concentrations were investigated for induction of seed germination and encapsulation materials are listed in Table 3.5.

**Table 3.5.** Solid matrix content for gelatin encapsulation

| Name                       | Concentration |       |        |       |        |       |
|----------------------------|---------------|-------|--------|-------|--------|-------|
|                            | %6            |       | %8     |       | %10    |       |
| Gelatin                    | Tomato        | Maize | Tomato | Maize | Tomato | Maize |
| Gelatin + CNT              | 5             | 10    | 5      | 10    | 5      | 10    |
| Gelatin + TiO <sub>2</sub> | 10            | 500   | 10     | 500   | 10     | 500   |
| Gelatin + SiO <sub>2</sub> | 10            | 20    | 10     | 20    | 10     | 20    |

Gelatin was dissolved in distilled water (around 55-60°C), NPs were added in solvent and sterilized with autoclave. Seeds were dipped into the suspension and put on ice for polymerization.

### 3.4.2 Treatment with chitosan:

For chitosan treatment three different chitosan concentrations were investigated for induction of seed germination and encapsulation materials are listed in Table 3.6.

**Table 3.6.** Solid matrix content for chitosan encapsulation

| Name                        | Concentration |       |        |       |        |       |
|-----------------------------|---------------|-------|--------|-------|--------|-------|
|                             | %0.1          |       | %0.5   |       | %1     |       |
| Chitosan                    | Tomato        | Maize | Tomato | Maize | Tomato | Maize |
| Chitosan + CNT              | 5             | 10    | 5      | 10    | 5      | 10    |
| Chitosan + TiO <sub>2</sub> | 10            | 500   | 10     | 500   | 10     | 500   |
| Chitosan + SiO <sub>2</sub> | 10            | 20    | 10     | 20    | 10     | 20    |

Chitosan was dissolved in 1% acid. Later, sterile NPs were added in the solution and stirred. Sterilization was performed with autoclave. Seeds were dipped into the suspension and placed onto petri dishes and incubated for 24 h under sterile cabinet at room temperature. All process was conducted under sterile conditions.

### 3.4.3 Treatment with sodium alginate:

For seed encapsulation sodium alginate-calcium chloride system was used. Concentrations for sodium-alginate system are listed in Table 3.7.

**Table 3.7.** Solid matrix content for Na-alginate encapsulation

| Name                     | Concentration |       |        |       |        |       |
|--------------------------|---------------|-------|--------|-------|--------|-------|
|                          | %1            |       | %1.5   |       | %2     |       |
| Na-Al                    | Tomato        | Maize | Tomato | Maize | Tomato | Maize |
| Na-Al + CNT              | 5             | 10    | 5      | 10    | 5      | 10    |
| Na-Al + TiO <sub>2</sub> | 10            | 500   | 10     | 500   | 10     | 500   |
| Na-Al + SiO <sub>2</sub> | 10            | 20    | 10     | 20    | 10     | 20    |

Sodium-alginate and 100 mM calcium chloride were dissolved in distilled water in a separated beaker and NPs were added in alginate solution. The sterilization was performed with autoclave. For seed coating, the seeds were covered with sodium alginate solution and they were dropped into calcium chloride. Then, the seeds were washed with distilled water and dried at room temperature. All procedure was conducted under sterile conditions.

After seed coating with solid matrix, the process which is explained in WP-I was followed.

### 3.5 Effects of nano-priming applications with NPs at different concentrations on seed germination under abiotic stresses (WP-IV)

The aim of WP-IV is to observe the effect of nano-priming on seed germination under drought and salinity stress conditions. For this purpose, four levels for each abiotic stress factor were applied to the seeds.

The same NPs and concentrations in WP-I were used for WP-IV and *in vitro* germination of seeds was observed under different abiotic stress conditions.

Tomato seed germination tests were conducted in germination cabinets at 20°C under 16/8 h light/dark conditions at the Seed Laboratory of Niğde Ömer Halisdemir University,

Faculty of Agricultural Sciences and Technologies. Maize seed germination tests were conducted in growth chambers at 24°C under light conditions at Tissue Culture Laboratory of Niğde Ömer Halisdemir University, Faculty of Agricultural Sciences and Technologies.

The seeds were considered as germinated when around 2 mm of radicle became visible. Germinated seeds were counted daily, and experiments were terminated on the 7th day for maize and the 21st day for tomato. After germination tests were completed, the following parameters were determined for each crop;

**Germination rate (%):** To calculate the germination percentage (GP), the germinated seeds were counted and GP was calculated by the formula given below:

$$GP = (\text{Germinated seed number} / \text{Total seed number}) / 100$$

**Shoot length (mm):** To measure the shoot length plant images were taken by EPSON (Expression 11000 XL) Scanner and shoot length was measured by ImageJ software.

**Root length (mm):** To measure the root length plant images were taken by EPSON (Expression 11000 XL) Scanner and root length was measured by ImageJ software.

**Fresh weight of shoot and root (g):** The plants were cut to separate shoot and root. The shoot and root fresh weight was measured by precision scales (Shimatzu).

**Dry weight of shoot and root (g):** The plants were cut to separate shoot and root and each part was dried at 70°C for two days. Then, shoot and root dry weight was measured by precision scales (Shimatzu).

**Seed vigor index:** The seed vigor index was calculated according to the formula, given below (Dehkourdi and Mosavi, 2013):

$$VI = (RL + SL) / GP$$

The germination mediums for abiotic stresses are given in Table 3.8 and Table 3.9.

**Table 3.8.** Abiotic stress conditions for tomato seed germination

| <b>Stress</b> | <b>MS salt<br/>(g/L)</b> | <b>Sucrose<br/>(g/L)</b> | <b>Agar<br/>(g/L)</b> | <b>pH</b> | <b>NaCl<br/>(mM)</b> | <b>PEG6000<br/>(%)</b> |
|---------------|--------------------------|--------------------------|-----------------------|-----------|----------------------|------------------------|
| Drought-0     | 1,1                      | 15                       | 8                     | 5.7       | 0                    | <b>0</b>               |
| Drought-1     | 1,1                      | 15                       | 8                     | 5.7       | 0                    | <b>10</b>              |
| Drought-2     | 1,1                      | 15                       | 8                     | 5.7       | 0                    | <b>20</b>              |
| Drought-3     | 1,1                      | 15                       | 8                     | 5.7       | 0                    | <b>30</b>              |
| Salinity-0    | 1,1                      | 15                       | 8                     | 5.7       | <b>0</b>             | 0                      |
| Salinity-1    | 1,1                      | 15                       | 8                     | 5.7       | <b>50</b>            | 0                      |
| Salinity-2    | 1,1                      | 15                       | 8                     | 5.7       | <b>100</b>           | 0                      |
| Salinity-3    | 1,1                      | 15                       | 8                     | 5.7       | <b>150</b>           | 0                      |

**Table 3.9.** Abiotic stress conditions for bean and maize seed germination

| <b>Stress</b> | <b>MS salt<br/>(g/L)</b> | <b>Agar<br/>(g/L)</b> | <b>pH</b> | <b>NaCl<br/>(mM)</b> | <b>PEG6000<br/>(%)</b> |
|---------------|--------------------------|-----------------------|-----------|----------------------|------------------------|
| Drought-0     | 2,2                      | 8                     | 5.7       | 0                    | <b>0</b>               |
| Drought-1     | 2,2                      | 8                     | 5.7       | 0                    | <b>10</b>              |
| Drought-2     | 2,2                      | 8                     | 5.7       | 0                    | <b>20</b>              |
| Drought-3     | 2,2                      | 8                     | 5.7       | 0                    | <b>30</b>              |
| Salinity-0    | 2,2                      | 8                     | 5.7       | <b>0</b>             | 0                      |
| Salinity-1    | 2,2                      | 8                     | 5.7       | <b>50</b>            | 0                      |
| Salinity-2    | 2,2                      | 8                     | 5.7       | <b>100</b>           | 0                      |
| Salinity-3    | 2,2                      | 8                     | 5.7       | <b>150</b>           | 0                      |

Leaf samples were collected on same day seedling measurement taking and malonyldialdehyde (MDA), hydrogen peroxide, and proline content of the leaves were determined for each stress treatment using the following methods:

### 3.5.1 MDA content

0.2 g of leave sample was homogenized in 10 ml of 0.1% of trichloro acetic acid (TCA) and centrifuged for 5 minutes at 15.000 g. 4 ml of TCA:TBA (tiobarbituric acid) 20:0.5 solution was added onto 1 ml of supernatant. The suspension was incubated at 95°C for 30 minutes and cooled down immediately on ice. Thereafter, the suspension was

centrifuged at 10000 g for 10 minutes. Finally, absorbance values of supernatant at 532 and 600 nm were determined using a spectrophotometer, and MDA content was calculated according to the formula given below (Sairam and Srivastava 2000):

$$\text{MDA (nmol/ml)} = [(A_{532}-A_{600})/155.000] \times 10^6 \times \text{df}$$

### **3.5.2 H<sub>2</sub>O<sub>2</sub> content**

0.2 g of leaf sample was homogenized in 6 ml of 1% TCA. The suspension was centrifuged at 10000 g for 10 minutes at 4°C. 0.75 ml of 10 mM K-P buffer (pH 7.0) and 1.5 ml of 1M KI was added onto 0.75 ml of supernatant. Finally, absorbance values of supernatant at 390 nm were measured using a spectrophotometer, and the concentration of H<sub>2</sub>O<sub>2</sub> was calculated by a standard curve (Loreto and Velikova, 2001).

### **3.5.3 Proline content**

0.2 gr of leaf was homogenized in 10 ml of 3% sulfosalicylic acid, the suspension was centrifuged at 10000 g 10 minutes. 2 ml supernatant was mixed with fresh ninhydrin solution (1.25 g ninhydrine, 30 ml glacial acetic acid and 20 ml 6 M orthophosphoric acid). The suspension was incubated at 90°C for 30 minutes. After incubation, the reaction was terminated on ice. Then, 5 ml of toluene was added and vortexed for 15 seconds and incubated for 20 minutes in the dark. The absorbance value of the toluene phase was measured at 520 nm and proline concentration was calculated according to standard curve (Bates et. al., 1973).

## **3.6 Statistical Analysis**

The data obtained from experiments were examined by ANOVA test by using MINITAB software. The differences between groups were determined by Fisher's post-hoc analysis. The split-plot analysis was performed by SAS. The data obtained from XRF analysis were examined by t-test by using MINITAB software.

## CHAPTER IV

### RESULTS AND DISCUSSION

#### 4.1 Effects of nano-priming applications with NPs at different concentrations on seed germination under laboratory conditions (WP-I)

The nano-priming was applied on three different seed types (tomato, bean and maize) with three different nanoparticles ( $\text{TiO}_2$ ,  $\text{SiO}_2$  and CNT). Six concentrations were used for each nanoparticle. These concentrations were 5, 10, 50, 100, 250 and 500 ppm for  $\text{TiO}_2$  and CNT; 10, 20, 40, 60, 80, 100 ppm for  $\text{SiO}_2$ . Hydropriming was the control group of the experiments.

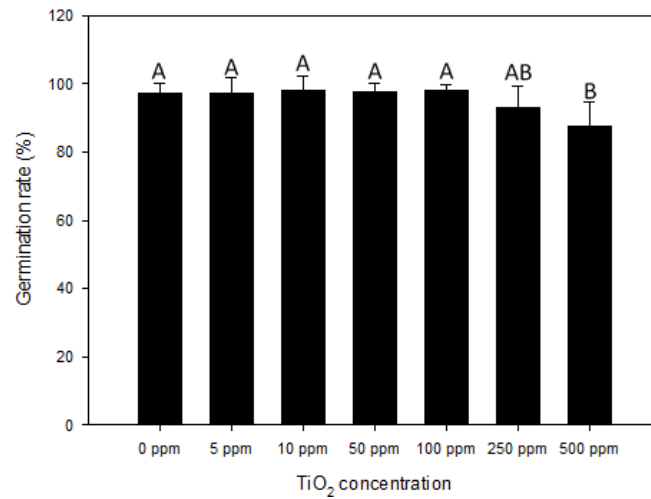
##### 4.2.1 Effects of nano-priming with $\text{TiO}_2$ on tomato seeds

The seeds of cv. Altar F1 species were planted in half strength MS medium and germination tests were performed for 21 days.

###### 4.1.1.1 Germination rate (%)

21<sup>st</sup> day after planting was the harvest day of tomato seeds. The first analysis of harvest is to investigate seed germination ratio (%). The germination percentage of the tomato seeds after nano-priming with  $\text{TiO}_2$  nanoparticles is presented in Figure 4.1.

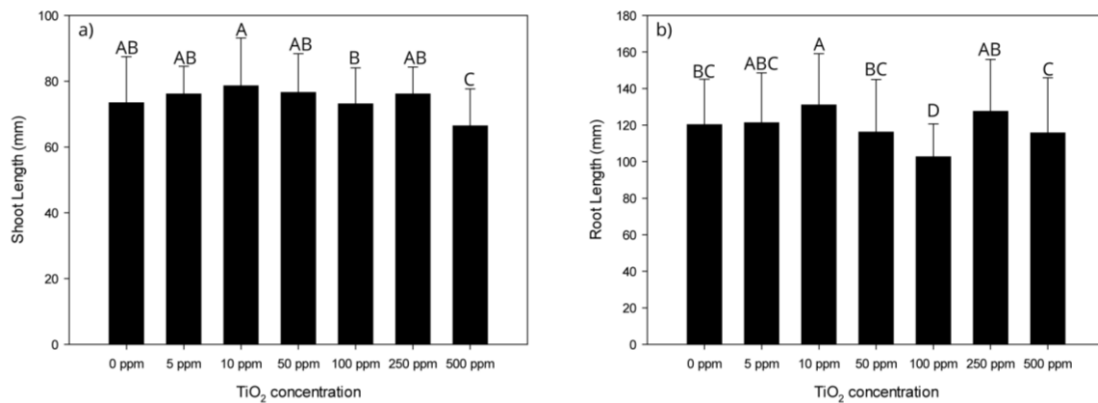
The germination rate of tomato seeds was already high after hydropriming and the germination ratio of seeds did not decrease after nano-priming application except 500 ppm. The increase in the  $\text{TiO}_2$  concentration had toxic effect on tomato seed germination.



**Figure 4.1.** Seed germination rate (%) of tomato seeds after TiO<sub>2</sub> nanopriming

#### 4.1.1.2 Shoot and root growth

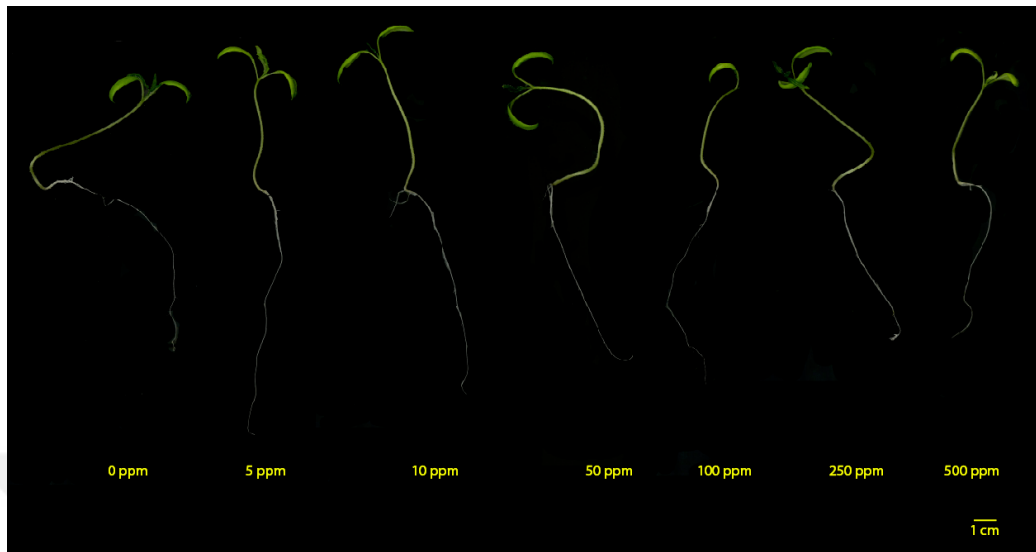
After germination of all seeds was completed; shoot and root length, fresh and dry weight were investigated of tomato seedlings. Figure 4.2 shows the shoot length (a) and root length (b) of tomato seedlings after TiO<sub>2</sub> nanopriming.



**Figure 4.2.** Shoot length (a) and root length (b) of tomato seeds after TiO<sub>2</sub> nanopriming

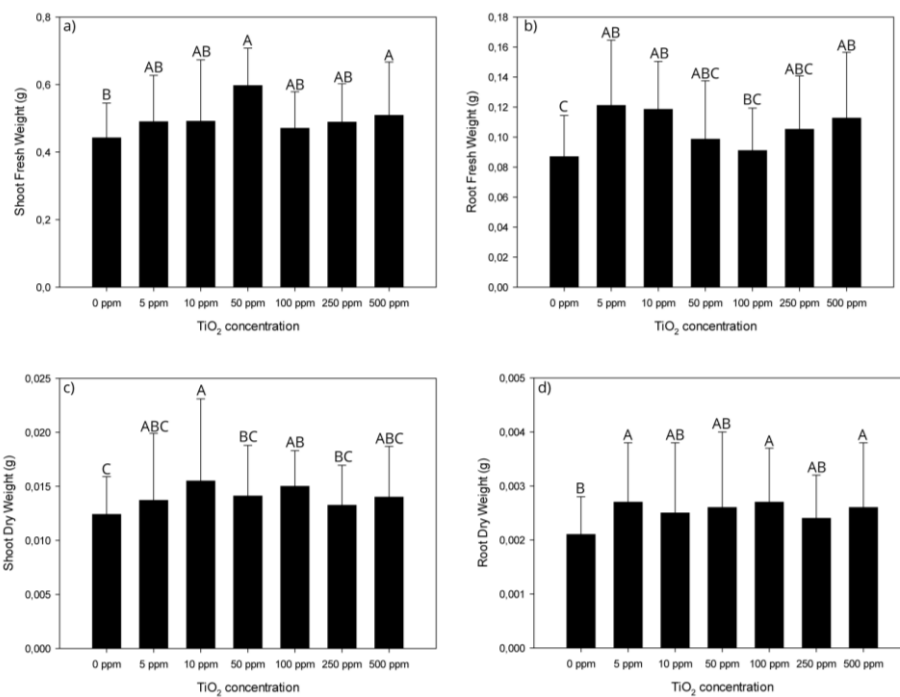
The shoot length of tomato seedlings was approximately the same in 0, 5, 10, 50 and 250 ppm. However, the shortest shoot length was observed at 500 ppm concentration. Besides, 100 ppm also decreased shoot length as in same in germination. The longest root development was observed at 10 ppm TiO<sub>2</sub> concentration. The shortest root length was observed at 100 ppm. On the other hand, root development decreased by the application

of 500 ppm of TiO<sub>2</sub>. The tomato seedlings after TiO<sub>2</sub> nanopriming is presented in Figure 4.3.



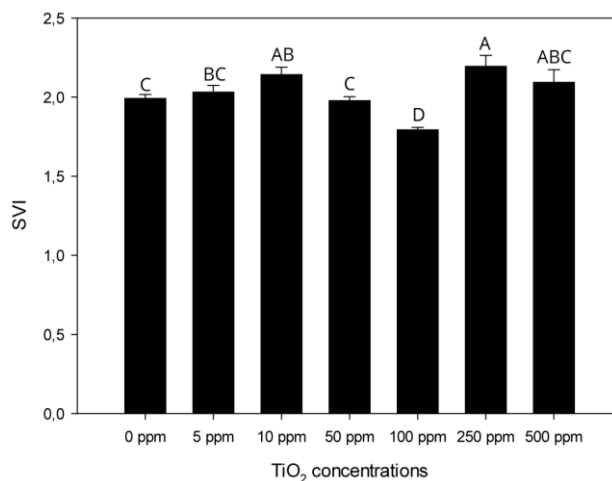
**Figure 4.3.** The tomato seedlings after TiO<sub>2</sub> nanopriming

Other important parameters for plant development are fresh and dry weight. In this case, the TiO<sub>2</sub> nanopriming application increased both shoot and root fresh weight (Figure 4.4. a-b) Yet, the different concentration of TiO<sub>2</sub> did not affect the fresh weight of seedlings. Likewise, the dry weight of the nanoprimed seeds had more dry weight than the hydropriming one (Figure 4.4 c-d). It can be concluded that, TiO<sub>2</sub> nanoparticles increased the biomass of tomato seedlings after nanopriming.



**Figure 4.4.** Shoot fresh weight (a); root fresh weight (b); shoot dry weight (c); root dry weight and (d) of tomato seeds after TiO<sub>2</sub> nanopriming

Seed Vigor Index (SVI) is another parameter shows the seed vigor. In present study, the SVI increased by the TiO<sub>2</sub> nanopriming application, and 0 ppm application showed the lowest SVI compare to nanopriming application. Besides, 250 ppm concentration of TiO<sub>2</sub> had the highest seed vigor (Figure 4.5).



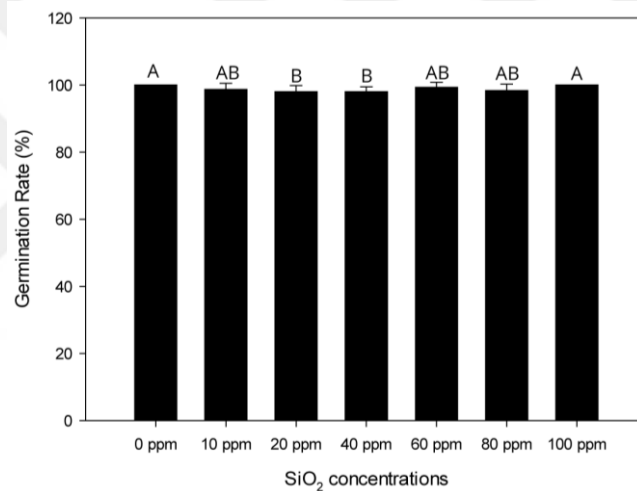
**Figure 4.5.** Seed Vigor Index (SVI) of tomato seeds after TiO<sub>2</sub> nanopriming application

#### 4.1.2 Effects of nanoprimering with SiO<sub>2</sub> on tomato seeds

Nanoprimering of tomato seeds with SiO<sub>2</sub> was performed under same conditions with TiO<sub>2</sub>, described in section 4.1.1.

##### 4.1.2.1 Germination rate (%)

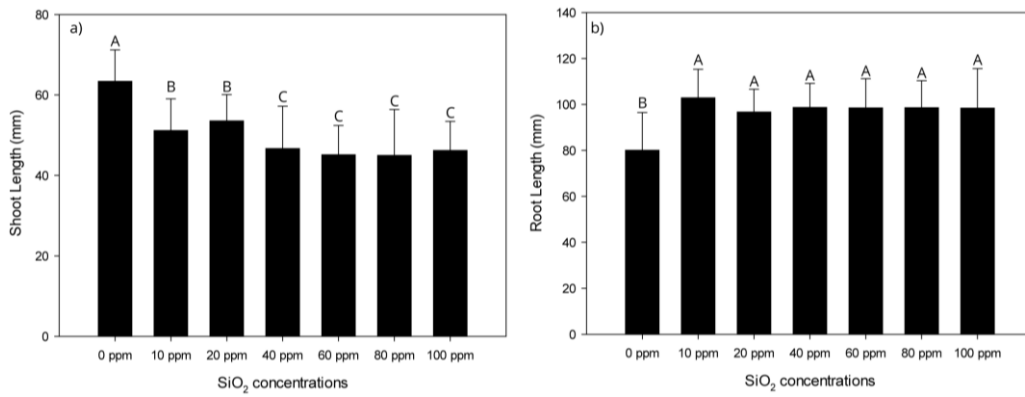
The germination rate of tomato seeds was decreased at 20 and 40 ppm of SiO<sub>2</sub> concentrations after nanoprimering. By increasing in SiO<sub>2</sub> concentration, the seed germination rate increased and at 100 ppm of SiO<sub>2</sub>, the germination rate was 100% (Figure 4.6).



**Figure 4.6.** Seed germination rate (%) of tomato seeds after SiO<sub>2</sub> nanoprimering

##### 4.1.2.2 Shoot and root growth

The morphological analysis was performed 21<sup>st</sup> day after planting. The parameters of morphological analysis shoot and root length, fresh and dry weight were investigated of tomato seedlings. Figure 4.7 shows the shoot length (a) and root length (b) of tomato seedlings after SiO<sub>2</sub> nanoprimering.



**Figure 4.7.** Shoot length (a) and root length (b) of tomato seeds after SiO<sub>2</sub> nanopriming

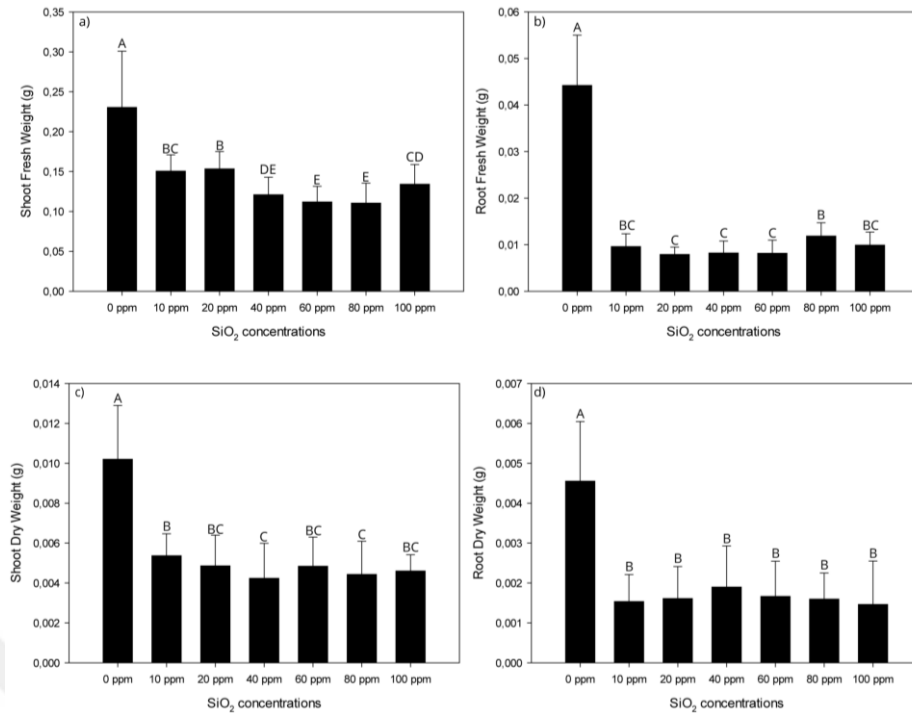
The shoot length of tomato seedlings was decreased after SiO<sub>2</sub> nanopriming application. Besides, increasing in concertation of SiO<sub>2</sub> caused more reducing in shoot length. On the other hand, SiO<sub>2</sub> nanoparticles increased root length of seedlings and concentration did not affect the length of tomato seedling roots.

Figure 4.8 presents the seedling after SiO<sub>2</sub> nanopriming application.



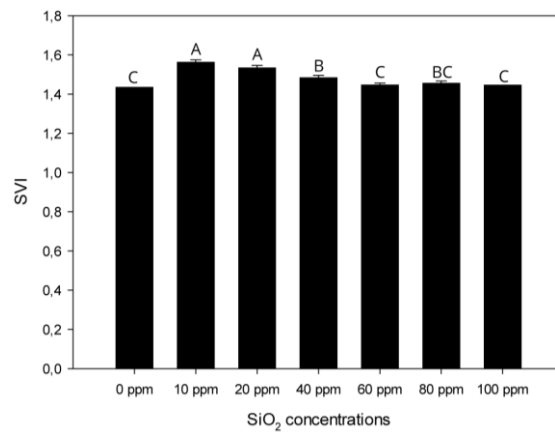
**Figure 4.8.** The tomato seedlings after SiO<sub>2</sub> nanopriming

Shoot (a) and root (b) fresh weight and shoot (c) and root (d) dry weight is presented in Figure 4.9. The biomass of the tomato plantlets were decreased after nanopriming with SiO<sub>2</sub> nanoparticles according to Figure 4.9. Besides, the concentrations of SiO<sub>2</sub> did not affect the root development.



**Figure 4.9.** Shoot fresh weight (a), root fresh weight (b), shoot dry weight (c) and root dry weight (d) of tomato seeds after SiO<sub>2</sub> nanopriming

SVI of nanoprimed tomato seeds after nanopriming with SiO<sub>2</sub> is presented in Figure 4.10. The seed vigor index of tomato seedlings increased by SiO<sub>2</sub> nanopriming at 10, 20 and 40 ppm concentrations.



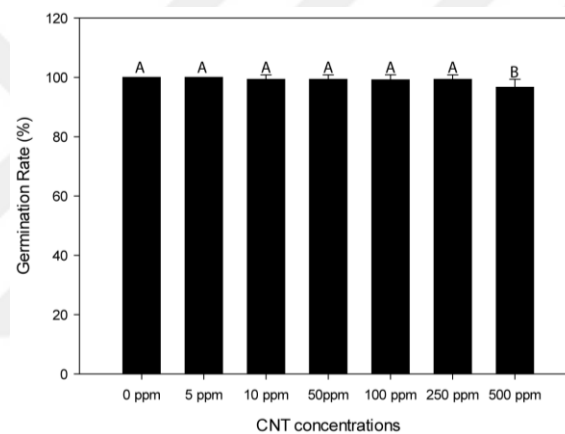
**Figure 4.10.** Seed Vigor Index (SVI) of tomato seeds after SiO<sub>2</sub> nanopriming application

### 4.1.3 Effects of nanoprimering with CNT on tomato seeds

Nanoprimering of tomato seeds with CNT was performed under same conditions with TiO<sub>2</sub>, described in section 4.1.1.

#### 4.1.3.1 Germination rate (%)

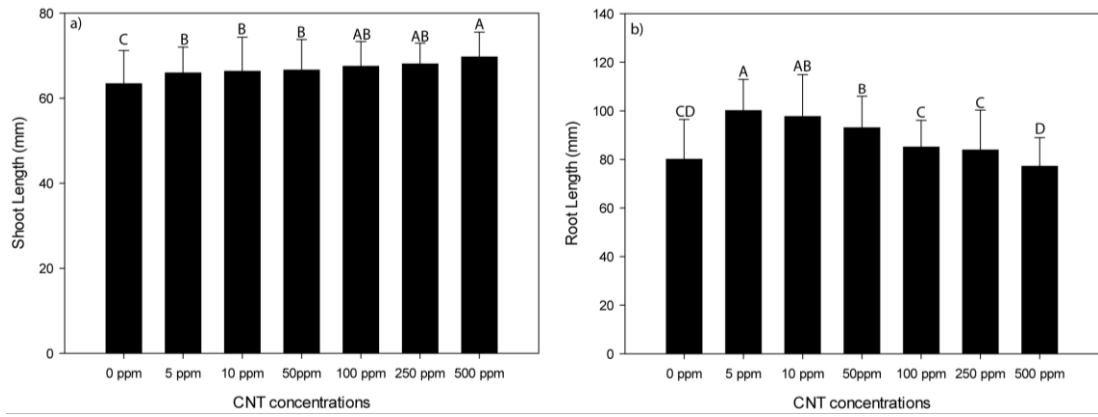
CNT nanoprimering of tomato seeds did not affect the germination rate up to 500 ppm of CNT concentration (Figure 4.11). The germination percentage of hydropriming seeds were already high, thus there was no toxic effect on seed germination rate for 5, 10, 50, 100 and 250 ppm of CNT.



**Figure 4.11.** Seed germination rate (%) of tomato seeds after CNT nanoprimering

#### 4.1.3.2 Shoot and root growth

The seed length (a) and root length (b) of tomato seeds, which are presented in Figure 4.12, were increased after nanoprimering with CNT. The shoot length was increased by increasing in concentration of CNT. At 500 ppm the longest shoot length of tomato seedlings was observed.

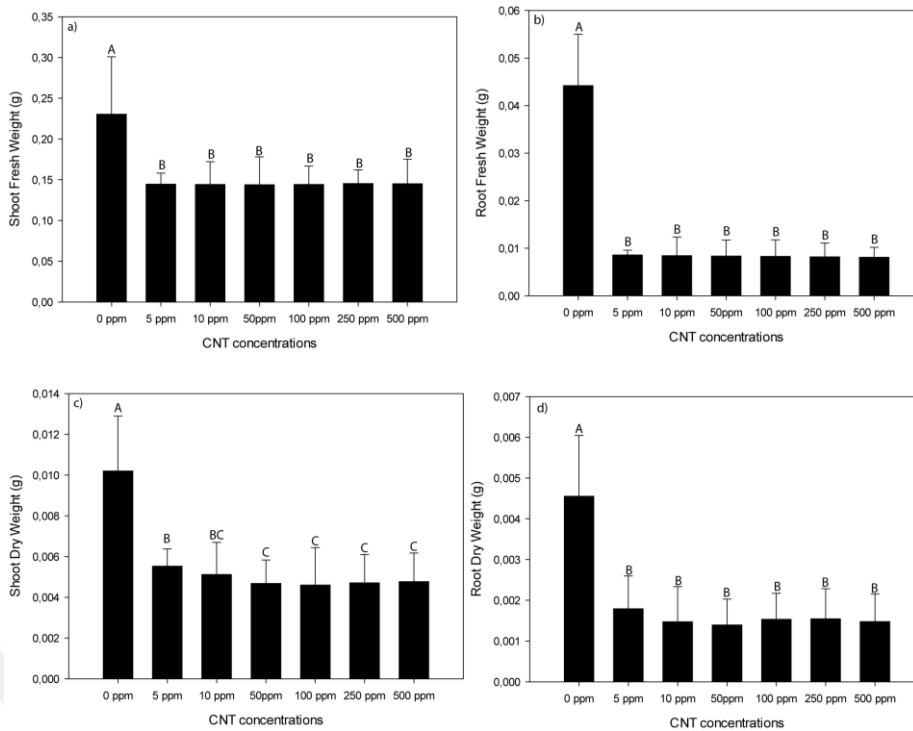


**Figure 4.12.** Shoot length (a) and root length (b) of tomato seeds after CNT nanopriming

The root length of tomato seedlings increased up to 100 ppm of CNT. At 5 and 10 ppm of CNT concentration were enough to increase root development for tomato seedlings. On the other hand, using of more than 50 ppm of CNT did not affect root development compared to hydropriming. Figure 4.13 presents tomato seedlings after CNT nanopriming.

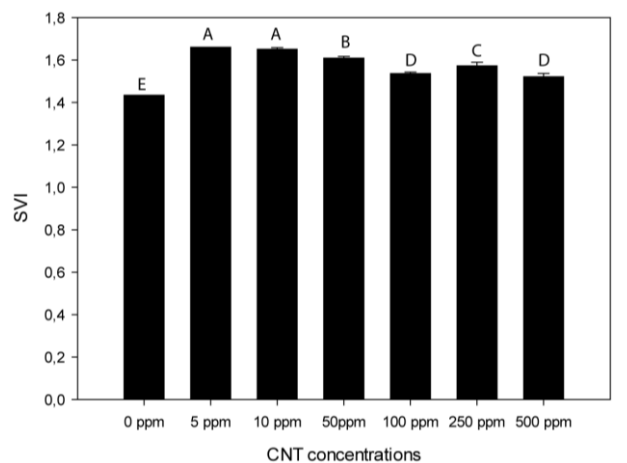


**Figure 4.13.** The tomato seedlings after CNT nanopriming



**Figure 4.14.** Shoot fresh weight (a), root fresh weight (b), shoot dry weight (c) and root dry weight (d) of tomato seeds after CNT nanopriming

Apart from shoot and root length the biomass of them gives the idea about seedling development after seed priming with CNT. The shoot (a) and root (b) fresh weight and shoot (c) and root (d) dry weight were shown in Figure 4.14. According to figure, the biomass of the seedlings was decreased after seed priming of tomato seeds with CNT.



**Figure 4.15.** Seed Vigor Index (SVI) of tomato seeds after CNT nanopriming application

The seed vigor index (SVI) of tomato seeds were increased after seed nanopriming with CNT at all concentrations (Figure 4.15). However, the 5 and 10 ppm of CNT for nanopriming reached the highest SVI. The increase in SVI was decreased at higher concentrations.

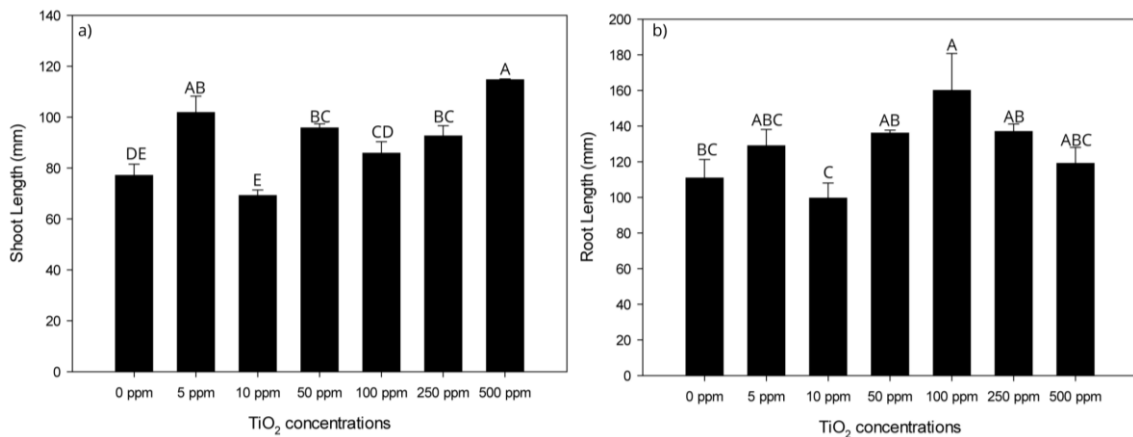
#### 4.1.4 Effects of nanopriming with TiO<sub>2</sub> on bean seeds

The bean seeds were provided commercially and cv. Asya cultivar was used as bean seeds. The seeds were planted in quarter strength MS medium and germination tests were performed for 10 days. Each experiment was laid out in Completely Randomized Design with 5 replications with 30 seeds.

The germination rate of bean seeds for all concentrations were same, 100%.

##### 4.1.4.1 Shoot and root growth

The morphological analysis contains shoot and root length and shoot-root fresh and dry weight.



**Figure 4.16.** Shoot length (a) and root length (b) of bean seeds after TiO<sub>2</sub> nanopriming

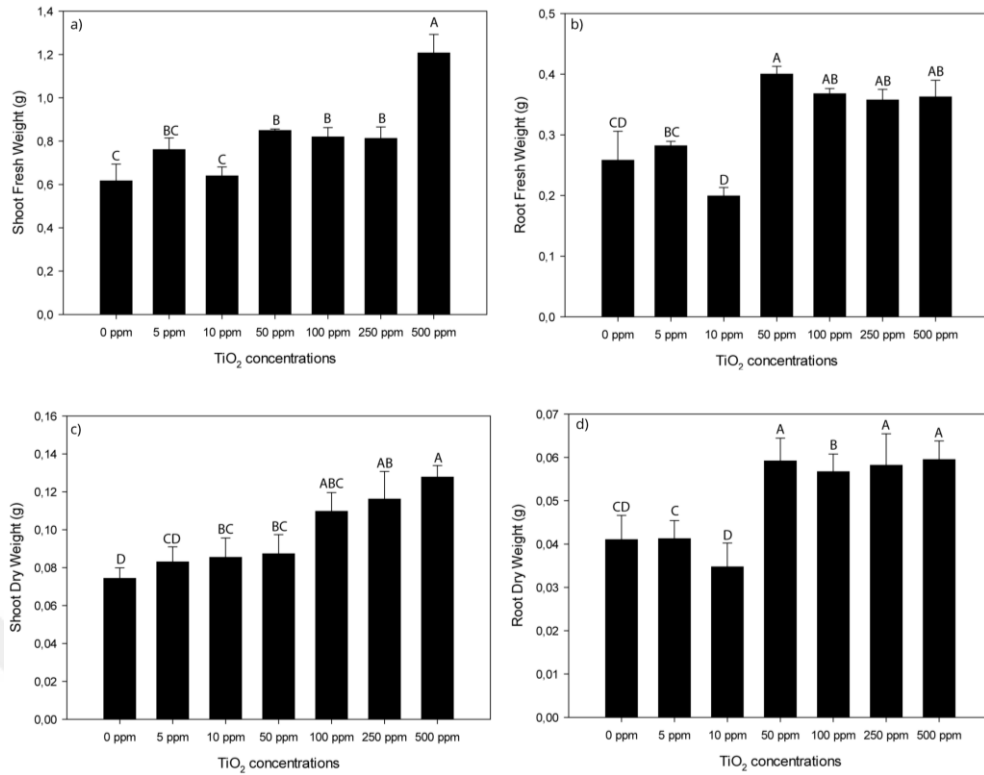
The shoot length of bean seedlings was increased by TiO<sub>2</sub> nanopriming application (Figure 4.16). The shoot length of 500 ppm of TiO<sub>2</sub> holds the first rank. In the Figure 4.16a it is shown that, the shoot length decreased at 10 ppm concentration. However, rest of the concentrations increased shoot development. Figure 4.16b presents root

development of bean seedlings after TiO<sub>2</sub> nanopriming application. The application did not affect root development of bean seedlings in terms of length except 100 ppm concentration. The root length reached highest value at 100 ppm concentration. Figure 4.17 presents



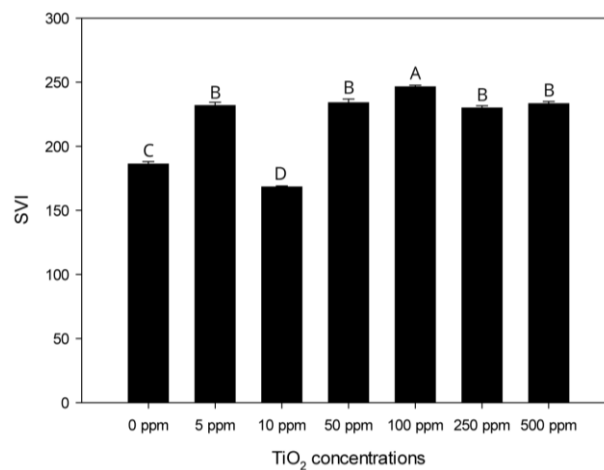
**Figure 4.17.** The bean seedlings after TiO<sub>2</sub> nanopriming

Figure 4.18. shows the fresh and dry weight of bean seedlings. According to Figure 4.18a the shoot fresh weight of the bean seedlings increased by the increasing TiO<sub>2</sub> concentrations. The 500 ppm concentration had the most increasing effect of shoot development. Figure 4.18b shows the root fresh weight of bean seedlings and, as the shoot weight, increasing in concentrations increased root fresh weight up to 50 ppm. More than 50 ppm concentrations didn't affect the root development. The shoot dry weight also increased by the increasing in concentrations as fresh weight (Figure 4.18c). the dry weight of bean roots are shown in Figure 4.18b . As the same in fresh weight of root, the dry weight also increased by increasing in the concentration to 50 ppm and more TiO<sub>2</sub> concentrations did not affect root dry weight of bean seedlings. In conclusion, the TiO<sub>2</sub> application increased bean seedling biomass.



**Figure 4.18.** Shoot fresh weight (a), root fresh weight (b), shoot dry weight (c) and root dry weight (d) of bean seeds after TiO<sub>2</sub> nanopriming

Seed vigor index (SVI) is another parameter that shows seed vigor. SVI of bean seeds after TiO<sub>2</sub> nanopriming is presented in Figure 4.19. According to figure, the seed vigor index increased by nanopriming and 100 ppm showed the highest value.



**Figure 4.19.** Seed Vigor Index (SVI) of bean seeds after TiO<sub>2</sub> nanopriming application

#### 4.1.5 Effects of nanopriming with SiO<sub>2</sub> on bean seeds

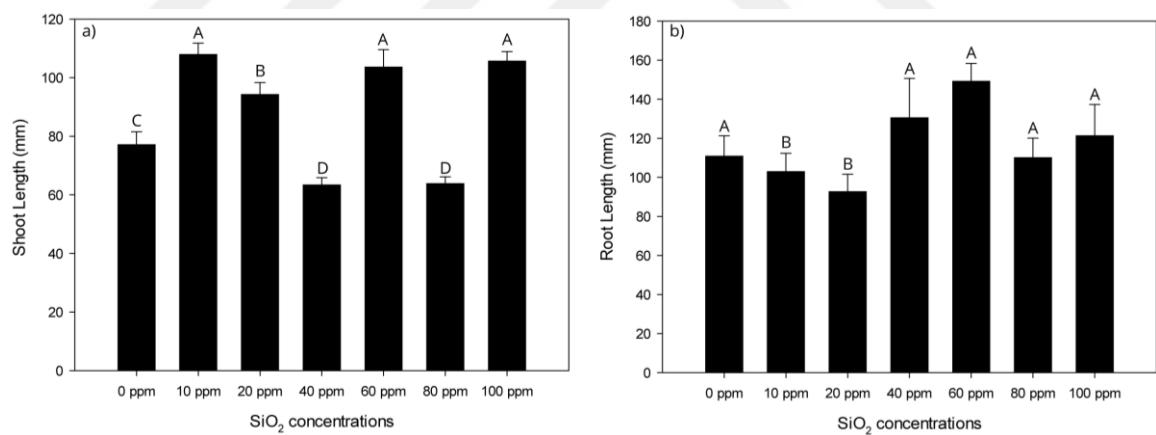
Nanopriming of bean seeds with SiO<sub>2</sub> was performed under same conditions with TiO<sub>2</sub>, described in section 4.1.4.

The germination rates were same for all concentrations; 100%.

##### 4.1.5.1 Shoot and root growth

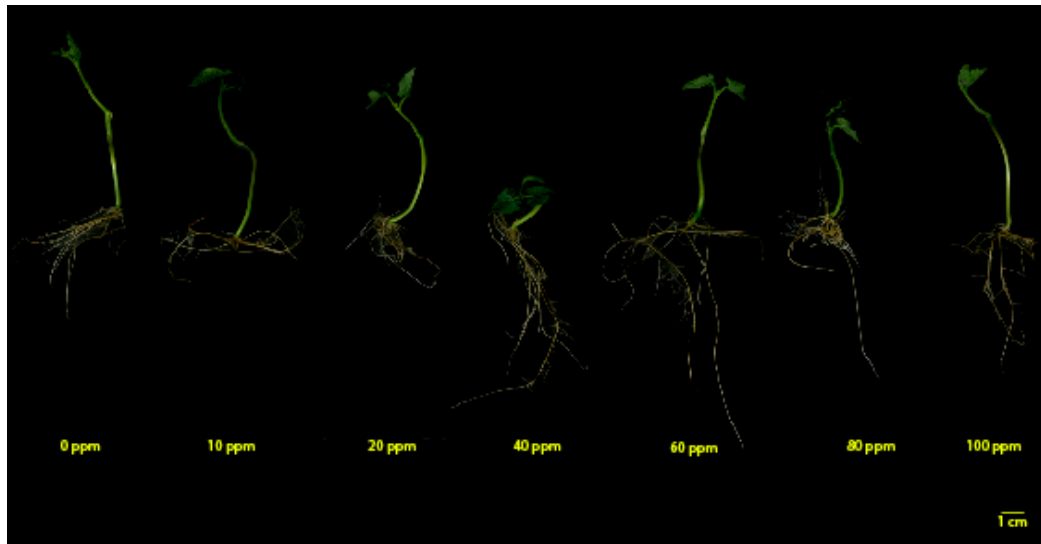
Shoot length of bean seeds, as shown in Figure 4.20a, was increased at 10, 20, 60 and 100 ppm concentration of SiO<sub>2</sub>. On the other hand, 40 and 80 ppm of SiO<sub>2</sub> were decreased root development of bean seedlings.

The root length of bean seedlings (Figure 4.20b) was decreased at 10 and 20 ppm of SiO<sub>2</sub> concentrations. Rest of the concentrations did not affect the root development of bean seedlings.



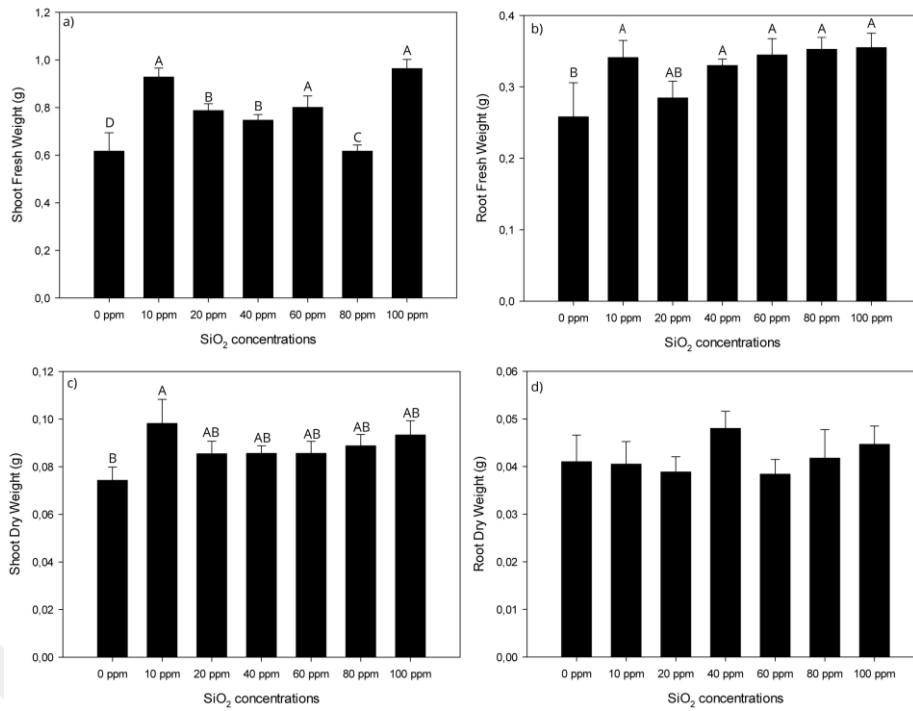
**Figure 4.20.** Shoot length (a) and root length (b) of bean seeds after SiO<sub>2</sub> nanopriming

Figure 4.21 presents bean seedlings after SiO<sub>2</sub> nanopriming.



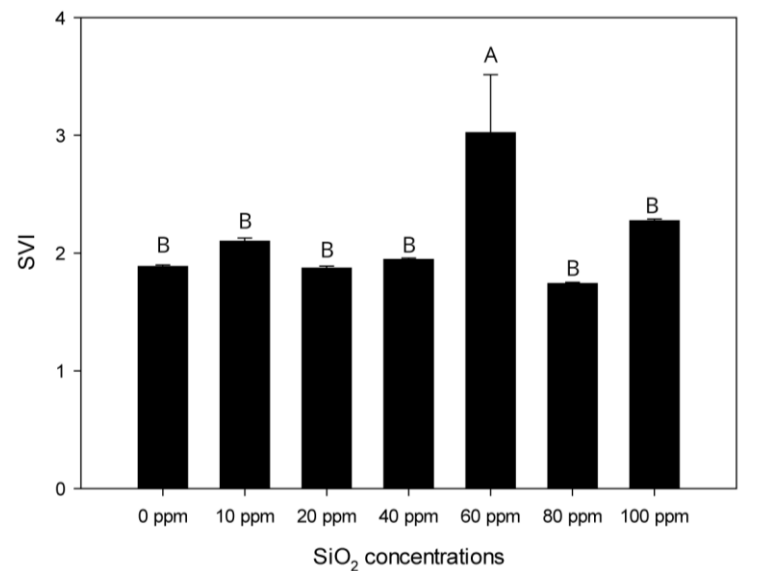
**Figure 4.21.** The bean seedlings after SiO<sub>2</sub> nanopriming

Other important parameters to investigate seedling development are shoot and root fresh and dry weight. The shoot fresh weight increased after nanopriming of bean seeds (Figure 4.22a). As it is presented in Figure 4.22b, the root fresh weight also increased by SiO<sub>2</sub> nanopriming. However, the SiO<sub>2</sub> concentration didn't affect the root fresh weight. The all concentrations affected root development, in terms of weight, at same level. The shoot dry weight (Figure 4.22c) increased after SiO<sub>2</sub> nanopriming application and the shoot dry weight was same at all concentrations. The root dry weight (Figure 4.22d) was not affected from SiO<sub>2</sub> nanopriming applications.



**Figure 4.22.** Shoot fresh weight (a), root fresh weight (b), shoot dry weight (c) and root dry weight (d) of bean seeds after SiO<sub>2</sub> nanopriming

The seed vigor index (SVI) is increased at 60 ppm, but the rest of the concentration did not affect SVI.



**Figure 4.23.** Seed Vigor Index (SVI) of bean seeds after SiO<sub>2</sub> nanopriming application

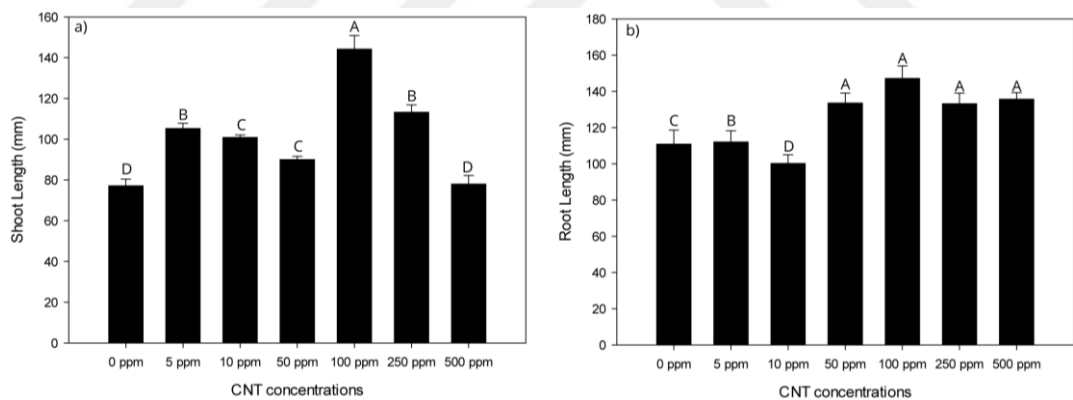
#### 4.1.6 Effects of nanoprimering with CNT on bean seeds

Nanoprimering of bean seeds with CNT was performed under same conditions with TiO<sub>2</sub>, described in section 4.1.4.

The germination rates were same for all concentrations; 100%.

##### 4.1.6.1 Shoot and root growth

The shoot length of bean seedlings increased by CNT nanoprimering application as it is shown in Figure 4.24a. The shoot length of 100 ppm had the highest value, and 500 ppm of CNT nanoprimering did not affect shoot length. In Figure 4.24b shows the root length of bean seedlings after nanoprimering with CNT. The root length also increased by this application. As the shoot length, 100 ppm affected more than other concentrations and increasing in the concentration did not affect root development more. However, 10 ppm of CNT decreased root length of bean seedlings.



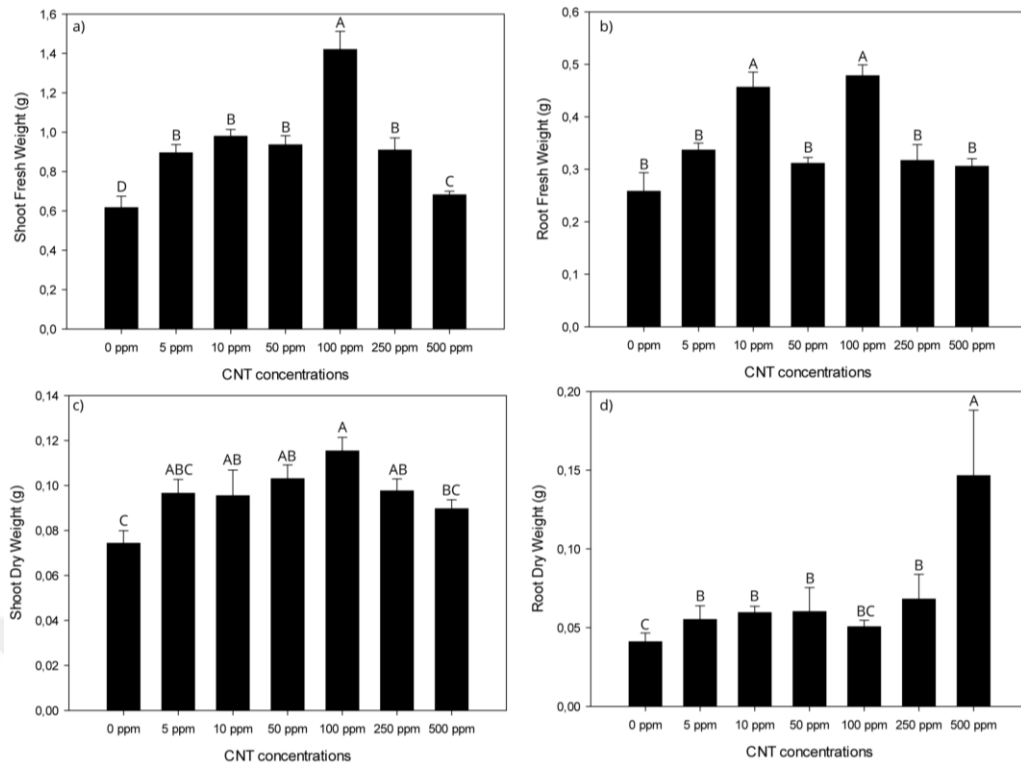
**Figure 4.24.** Shoot length (a) and root length (b) of bean seeds after CNT nanoprimering

Figure 4.25 shows the bean seedlings after CNT nanoprimering.



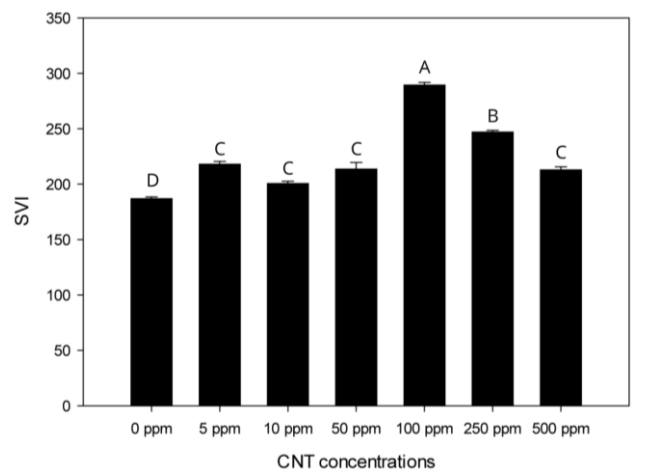
**Figure 4.25.** The bean seedlings after CNT nanopriming

Figure 4.26a presents shoot fresh weight of bean seedlings. CNT nanopriming increased the shoot fresh weight and reached highest value at 100 ppm concentration. The bigger concentrations' effect decreased and increase in shoot length is not as much as 100 ppm. Figure 4.26b shows the root fresh weight of bean seedlings after CNT nanopriming. Under this condition, 10 and 100 ppm increased the root weight; however, other concentrations did not affect the root development. Figure 4.26c presents shoot dry weight. All concentrations increased the shoot dry weight, where the 100 ppm had the highest value. The 500 ppm concentration's effect was not as much as other concentrations. Finally, Figure 4.26c presents root dry weight of the bean seedlings after CNT nanopriming. All concentrations had positive effect on root development. In this case, 500 ppm hold the first rank. In conclusion, CNT nanopriming increased biomass of bean seedlings.



**Figure 4.26.** Shoot fresh weight (a), root fresh weight (b), shoot dry weight (c) and root dry weight (d) of bean seeds after CNT nanopriming

Seed vigor index (SVI) of bean seeds increased by CNT nanopriming. At 100 ppm, the SVI was maximum value. The effect of 250 and 500 ppm of CNT decreased compare to 100 ppm.



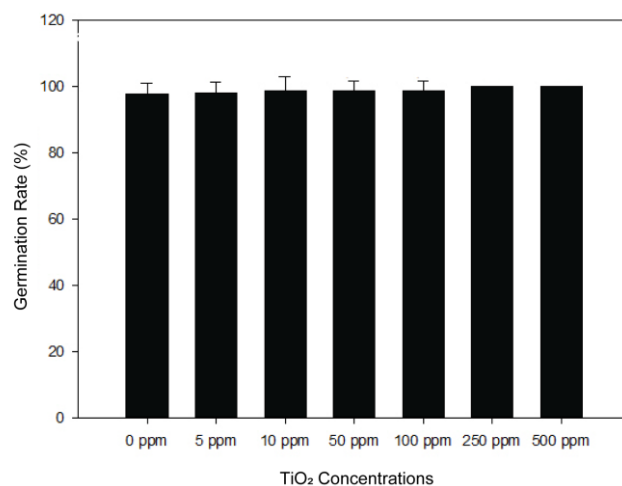
**Figure 4.27.** Seed Vigor Index (SVI) of bean seeds after CNT nanopriming application

#### 4.1.7 Effects of nanopriming with TiO<sub>2</sub> on maize seeds

The maize seeds were provided commercially and Capuzi cultivar was used as maize seeds. The seeds were planted in quarter strength MS medium and germination tests were performed for 7 days. Each experiment was laid out in Completely Randomized Design with 5 replications with 30 seeds.

##### 4.1.7.1 Germination rate (%)

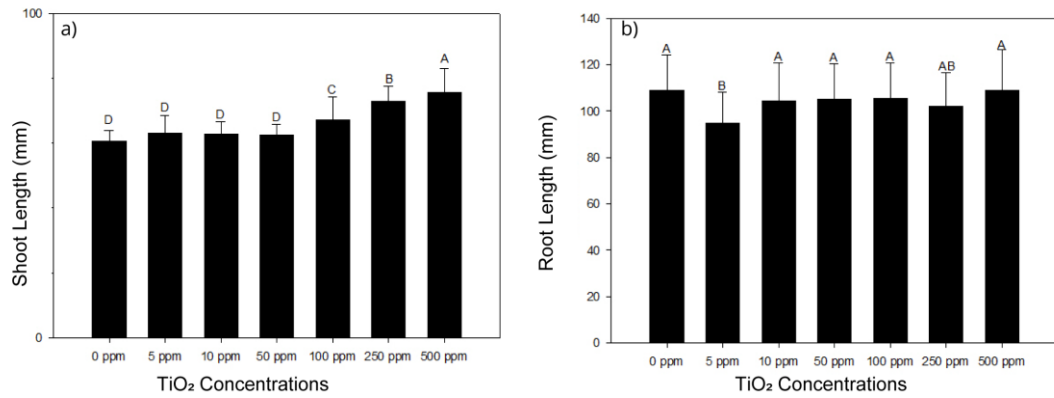
The germination analysis performed for maize seeds after 7 days of germination period. The germination ratio of the seeds did not affected of TiO<sub>2</sub> nanopriming as it is shown in Figure 4.28.



**Figure 4.28.** Seed germination rate (%) of maize seeds after TiO<sub>2</sub> nanopriming

##### 4.1.7.2 Shoot and root growth

The morphological analysis contains shoot and root length and shoot and root fresh and dry weight. The shoot length of maize seedlings after TiO<sub>2</sub> nanopriming increased under more than 50 ppm TiO<sub>2</sub> concentrations (Figure 4.29a). Shoot length of the maize seedlings did not change under 5, 10 and 50 ppm of TiO<sub>2</sub> nanopriming.



**Figure 4.29.** Shoot length (a) and root length (b) of maize seeds after TiO<sub>2</sub> nanopriming

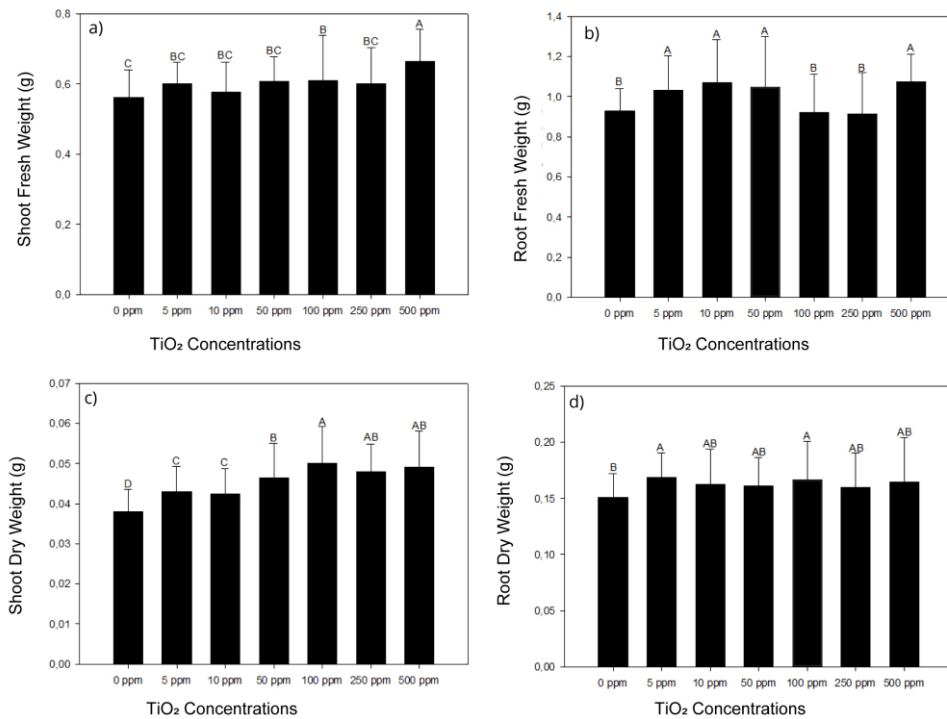
Figure 4.30 presents maize seedlings after TiO<sub>2</sub> nanopriming.



**Figure 4.30.** Maize seedlings after TiO<sub>2</sub> nanopriming

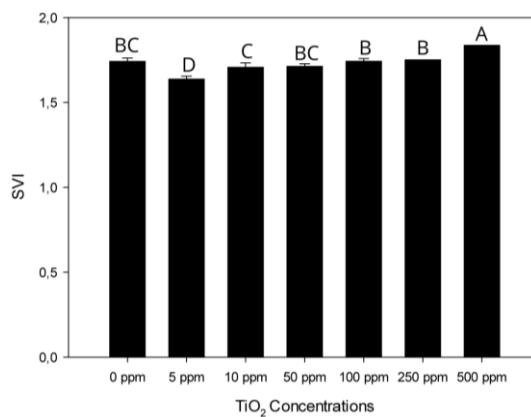
The shoot fresh weight of maize seedling after TiO<sub>2</sub> nanopriming is presented in Figure 4.31a. Length of seedlings increased by nanopriming application. Effect of 5, 10, 50, 100 and 250 ppm of TiO<sub>2</sub> was same and 500 ppm of TiO<sub>2</sub> showed the highest performance. The fresh weight of root also increased by TiO<sub>2</sub> nanopriming at 5, 10, 50 and 500 ppm. The 100 and 250 ppm application did not affect the root fresh weight (Figure 4.31b). Dry weight of both shoot and root increased by TiO<sub>2</sub> nanopriming (Figure 4.31c-d). The shoot

dry weight most increased at 100 ppm of TiO<sub>2</sub> and the root dry weight was not affected from TiO<sub>2</sub> concentrations and same in all concentrations.



**Figure 4.31.** Shoot fresh weight (a), root fresh weight (b), shoot dry weight (c) and root dry weight (d) of maize seeds after TiO<sub>2</sub> nanoprimering

The seed vigor index (SVI) decreased at 5 and 10 ppm of TiO<sub>2</sub> concentration and was not affected from 50, 100 and 250 ppm. However, SVI increased at 500 ppm of TiO<sub>2</sub> as presented in Figure 4.32.



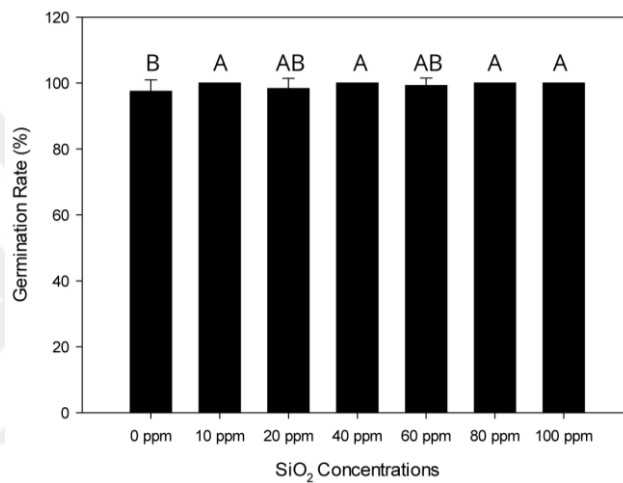
**Figure 4.32.** Seed Vigor Index (SVI) of maize seeds after TiO<sub>2</sub> nanopriming application

#### 4.1.8 Effects of nanopriming with SiO<sub>2</sub> on maize seeds

Nanopriming of maize seeds with SiO<sub>2</sub> was performed under same conditions with TiO<sub>2</sub>, described in section 4.1.7.

##### 4.1.8.1 Germination rate (%)

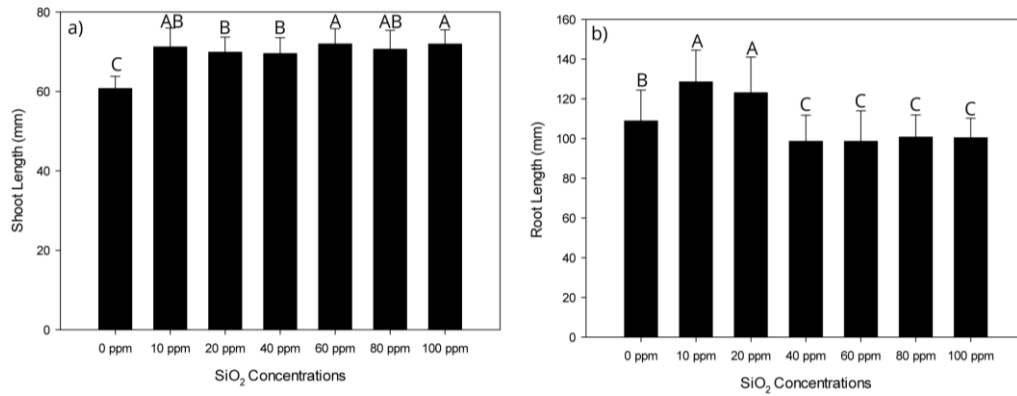
The germination of maize seeds after SiO<sub>2</sub> nanopriming increased at all concentrations as it is presented in Figure 4.33.



**Figure 4.33.** Seed germination rate (%) of maize seeds after SiO<sub>2</sub> nanopriming

##### 4.1.8.2 Shoot and root growth

The shoot length of maize seedling after SiO<sub>2</sub> nanopriming increased at all concentrations (Figure 4.34a). The increase in 20 and 40 ppm was less than other concentrations. The root length of maize seedlings increased at 10 and 20 ppm of SiO<sub>2</sub> concentrations. However, rest of the concentrations decreased root length of maize seedlings as presented in Figure 4.34b.



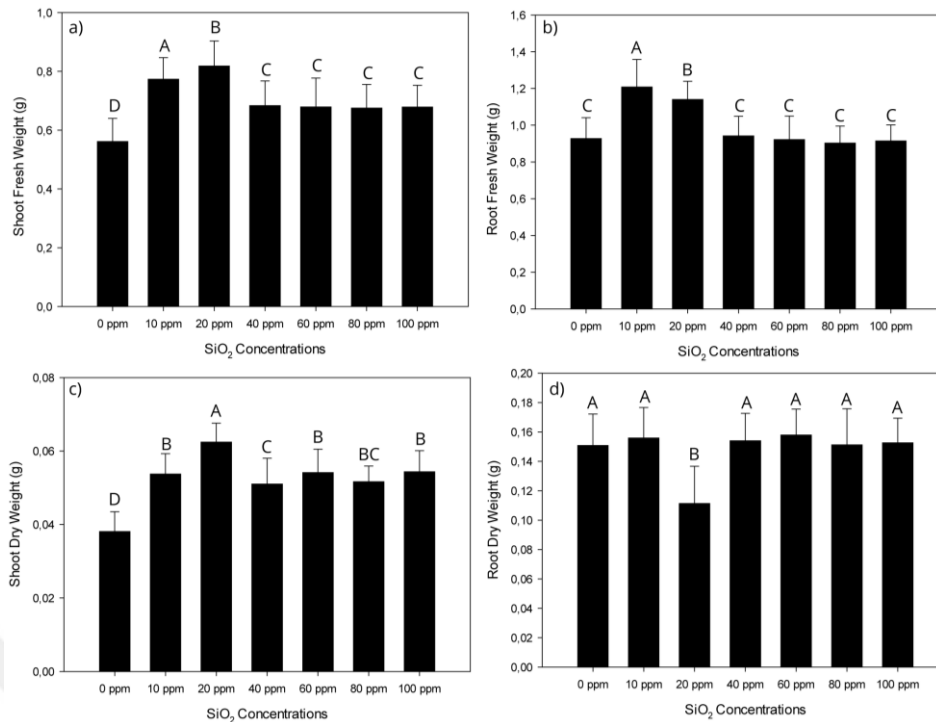
**Figure 4.34.** Shoot length (a) and root length (b) of maize seeds after SiO<sub>2</sub> nanopriming

The maize seedling developed after SiO<sub>2</sub> nanopriming is presented in Figure 4.35.



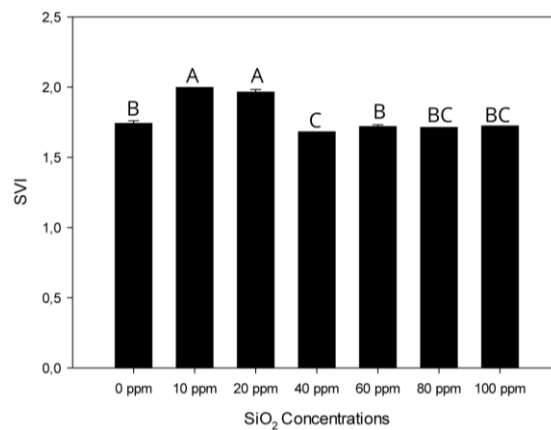
**Figure 4.35.** The maize seedlings after SiO<sub>2</sub> nanopriming

Shoot fresh weight of maize seedlings after SiO<sub>2</sub> nanopriming is presented in Figure 4.36a. The shoot fresh weight increased by nanopriming. However, after 20 ppm of SiO<sub>2</sub> concentration shoot fresh weight decreased and concentration of SiO<sub>2</sub> did not affect. Figure 4.36b presents root fresh weight of maize seedlings after SiO<sub>2</sub> nanopriming. The root fresh weight increased by 10 and 20 ppm and more than 20 ppm concentrations did not affect the root fresh weight of the seedlings. The dry weight of shoot of maize seedlings increased after SiO<sub>2</sub> nanopriming (Figure 4.36c). The maize seedlings developed under 20 ppm of SiO<sub>2</sub> nanopriming conditions had the heaviest shoot dry weight. The rest of the concentrations had the same effect on shoot dry weight. The SiO<sub>2</sub> nanopriming had no effect on root dry weight of maize seedlings except from 20 ppm (Figure 4.36d). 20 ppm concentration decreased root dry weight.



**Figure 4.36.** Shoot fresh weight (a), root fresh weight (b), shoot dry weight (c) and root dry weight (d) of maize seeds after SiO<sub>2</sub> nanopriming

Figure 4.37 presents seed vigor index (SVI) of maize seeds after SiO<sub>2</sub> nanopriming. SVI increased at 10 and 20 ppm of SiO<sub>2</sub>; however, rest of the concentrations did not affect SVI.



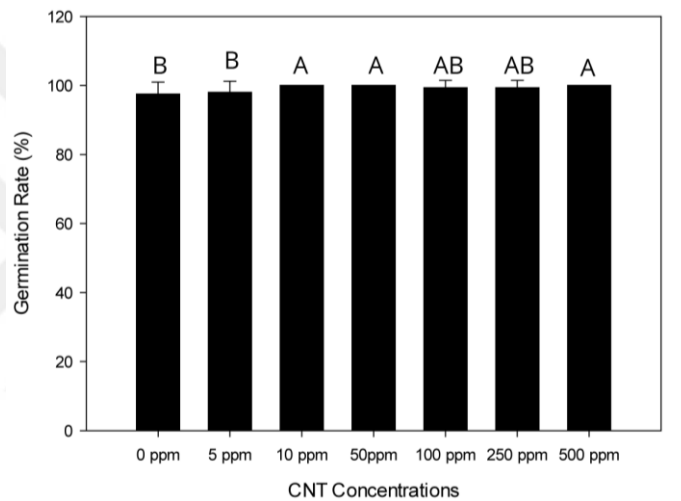
**Figure 4.37.** Seed Vigor Index (SVI) of maize seeds after SiO<sub>2</sub> nanopriming application

#### 4.1.9 Effects of nanoprimering with CNT on maize seeds

Nanoprimering of maize seeds with CNT was performed under same conditions with TiO<sub>2</sub>, described in section 4.1.7.

##### 4.1.9.1 Germination rate (%)

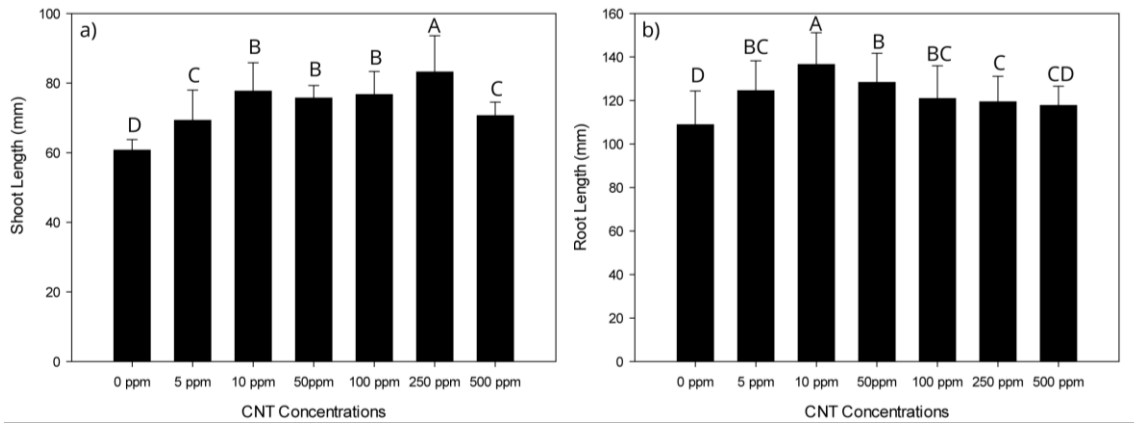
The germination of maize seeds after CNT nanoprimering increased at all concentrations except from 5 ppm (Figure 4.38). 5 ppm of CNT concentration did not affect seed germination rate of maize seeds.



**Figure 4.38.** Seed germination rate (%) of maize seeds after CNT nanoprimering

##### 4.1.9.2 Shoot and root growth

Shoot length of maize seedlings after CNT nanoprimering was increased as presented in Figure 4.39a. The effect of CNT was increased up to 250 ppm and decreased at 500 ppm again. The effect of 10, 50 and 100 ppm on shoot length was same. The root length of maize seedlings also increased after CNT nanoprimering. The most increase was observed at 10 ppm of CNT and after 10 ppm concentration the increase was decreased gradually (Figure 4.39b).



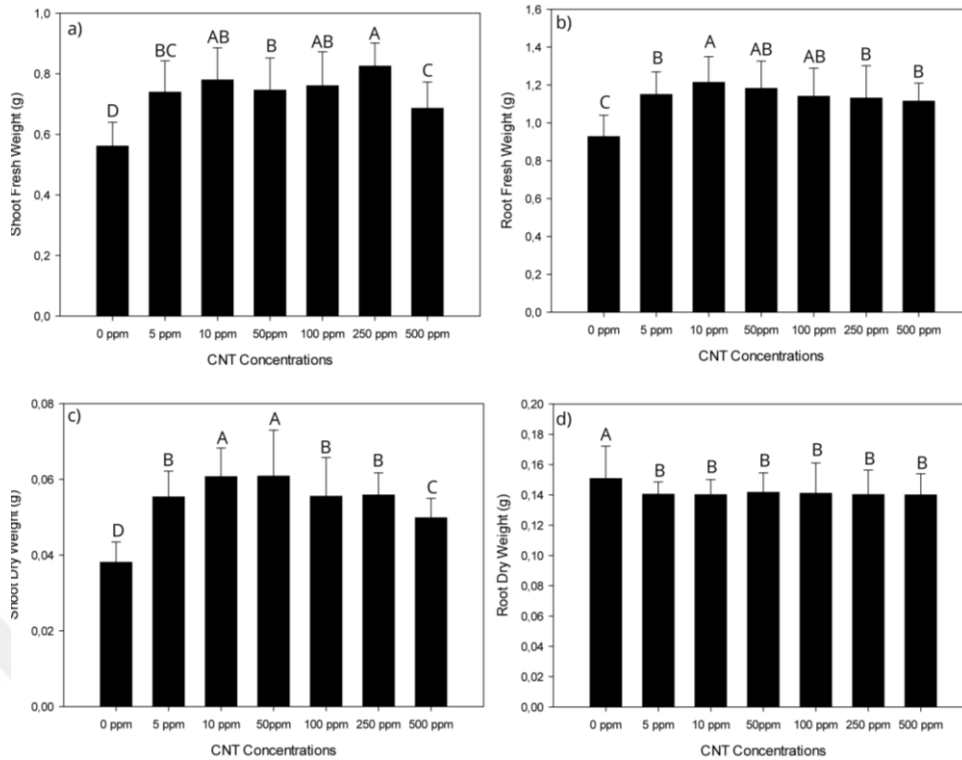
**Figure 4.39.** Shoot length (a) and root length (b) of maize seeds after CNT nanopriming

Figure 4.40 presents maize seedling after CNT nanopriming



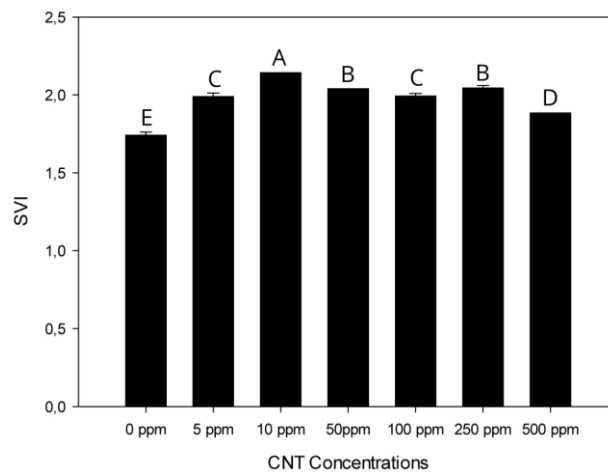
**Figure 4.40.** Maize seedlings after CNT nanopriming

Figure 4.41a presents shoot fresh weight of maize seedlings after CNT nanopriming. The shoot fresh weight was increased by CNT nanopriming at all concentrations. At 250 ppm heaviest shoots were developed and at 500 ppm the increase in shoot fresh weight decreased. Figure 4.41b presents root fresh weight after CNT nanopriming and increase was observed at all concentrations. The most increase was observed at 10 ppm of CNT concentration and rest of the concentrations had almost same effect on root development in terms of fresh weight. The shoot dry weight of maize seedlings after CNT nanopriming is shown in Figure 4.41c. The dry weight of the shoots was increased under all conditions. However, at 10 and 50 ppm the shoot dry weight increased highly and more than these concentrations the increase of shoot dry weight decreased. Figure 4.41d presents root dry weight after CNT nanopriming, which was affected negatively at all concentrations.



**Figure 4.41.** Shoot fresh weight (a), root fresh weight (b), shoot dry weight (c) and root dry weight (d) of maize seeds after CNT nanoprimering

Seed vigor index (SVI) of maize seeds after CNT nanoprimering increased at all concentrations. 10 ppm of CNT had highest effect on vigor of maize seeds and the effect on SVI decreased by increasing in concentration of CNT.



**Figure 4.42.** Seed Vigor Index (SVI) of maize seeds after CNT nanoprimering application

#### 4.1.10 Comparison of the effects of nanoprimering with CNT, SiO<sub>2</sub> and TiO<sub>2</sub> on seed germination and seedling development

In order to determine the effect of nanoprimering application on seed germination and seedling development split-plot analysis was performed.

**Table 4.1.** ANOVA table for germination rate and seed vigor index of tomato seeds after nanoprimering applications

| Source           | df  | Germination rate |         | Seed vigor index |          |
|------------------|-----|------------------|---------|------------------|----------|
|                  |     | Sum of           | F value | Sum of           | F value  |
| Replication      | 4   | 22,53            | 0,72    | 0,09             | 8,56**   |
| NP               | 2   | 224,84           | 14,29** | 0,41             | 80,10**  |
| Error I          | 8   | 74,88            | 1,19    | 0,18             | 8,91**   |
| Concentration    | 10  | 440,79           | 5,60**  | 8,49             | 332,28** |
| NP*Concentration | 8   | 163,95           | 2,61*   | 8,04             | 393,09** |
| Error II         | 72  | 566,37           |         | 0,18             |          |
| Corrected total  | 104 | 1493,37          |         | 17,40            |          |
| CV               |     | 2,86             |         | 3,24             |          |

(\*p<0,05) (\*\*p<0,01)

The germination rate and seed vigor index of the tomato seeds was changed by nanoprimering application with different nanoparticles at different concentrations. On the other hand, interaction between nanoparticle and concentration affected the germination rate and seed vigor index of tomato seeds (Table 4.1).

**Table 4.2.** ANOVA table for shoot and root length of tomato seedlings after nanoprimering applications

| Source           | df  | Shoot length |          | Root length |         |
|------------------|-----|--------------|----------|-------------|---------|
|                  |     | Sum of       | F value  | Sum of      | F value |
| Replication      | 4   | 323,99       | 3,35*    | 589,56      | 1,51    |
| NP               | 2   | 2817,59      | 200,13** | 13077,22    | 66,79** |
| Error I          | 8   | 292,02       | 1,51     | 2207,64     | 2,82**  |
| Concentration    | 10  | 873,53       | 3,61**   | 9662,14     | 9,87**  |
| NP*Concentration | 8   | 1576,29      | 8,14**   | 4061,05     | 5,19**  |
| Error II         | 72  | 1742,70      |          | 7048,79     |         |
| Corrected total  | 104 | 14496,32     |          | 36646,41    |         |
| CV               |     |              | 7,78     |             | 9,93    |

(\*p<0,05) (\*\*p<0,01)

Table 4.2 presents the ANOVA table for shoot and root length of tomato seedlings after nanopriming applications. According to the table, different nanoparticles had different effect on shoot and root length of tomato seedlings. Besides, different concentrations and different concentrations of these nanoparticles affected shoot and root length of tomato seedlings.

**Table 4.3.** ANOVA table for shoot and root fresh weight of tomato seedlings after nanopriming applications

| Source                  | df  | Shoot fresh weight |          | Root fresh weight |          |
|-------------------------|-----|--------------------|----------|-------------------|----------|
|                         |     | Sum of             | F value  | Sum of            | F value  |
| <b>Replication</b>      | 4   | 0,001              | 0,06     | 0,002             | 0,77     |
| <b>NP</b>               | 2   | 2,28               | 390,34** | 0,20              | 158,23** |
| <b>Error I</b>          | 8   | 0,001              | 0,04     | 0,005             | 0,99     |
| <b>Concentration</b>    | 10  | 0,06               | 2,11*    | 0,005             | 0,72     |
| <b>NP*Concentration</b> | 8   | 0,35               | 14,77**  | 0,04              | 7,24**   |
| <b>Error II</b>         | 72  | 0,21               |          | 0,05              |          |
| <b>Corrected total</b>  | 104 | 2,90               |          | 0,29              |          |
| <b>CV</b>               |     |                    | 21,18    |                   | 56,17    |

(\*p<0,05) (\*\*p<0,01)

The using of different nanoparticles affected the shoot and root fresh weight of tomato seedlings. On the other hand, interaction of nanoparticle and concentration showed effect on shoot and root fresh weight of the tomato seedlings (Table 4.3).

**Table 4.4.** ANOVA table for shoot and root dry weight of tomato seedlings after nanopriming applications

| Source                  | df  | Shoot dry weight |          | Root dry weight |         |
|-------------------------|-----|------------------|----------|-----------------|---------|
|                         |     | Sum of           | F value  | Sum of          | F value |
| <b>Replication</b>      | 4   | 0,00             | 0,66     | 0,00            | 3,37*   |
| <b>NP</b>               | 2   | 0,001            | 264,73** | 0,00            | 51,38** |
| <b>Error I</b>          | 8   | 0,00             | 0,53     | 0,00            | 1,32    |
| <b>Concentration</b>    | 10  | 0,00             | 3,34**   | 0,00            | 60,22** |
| <b>NP*Concentration</b> | 8   | 0,00             | 11,25**  | 0,00            | 2,81**  |
| <b>Error II</b>         | 72  | 0,00             |          | 0,00            |         |
| <b>Corrected total</b>  | 104 | 0,002            |          | 0,00            |         |
| <b>CV</b>               |     |                  | 20,36    |                 | 17,09   |

(\*p<0,05) (\*\*p<0,01)

The nanopriming applications with different nanoparticles, the concentration of nanoparticles and interaction between nanoparticles and concentrations affected the shoot and root dry weight of the tomato seedlings (Table 4.4). According to the results explained above, the nanopriming with 10 ppm of TiO<sub>2</sub> improved the tomato seedling development the more.

**Table 4.5.** ANOVA table for germination rate and seed vigor index of maize seeds after nanopriming applications

| Source           | df  | Germination rate |         | Seed vigor index |          |
|------------------|-----|------------------|---------|------------------|----------|
|                  |     | Sum of           | F value | Sum of           | F value  |
| Replication      | 4   | 4,26             | 0,46    | 0,003            | 0,56     |
| NP               | 2   | 4,38             | 0,95    | 1,08             | 373,97** |
| Error I          | 8   | 7,24             | 0,39    | 0,004            | 0,37     |
| Concentration    | 10  | 90,02            | 3,89**  | 0,69             | 47,53**  |
| NP*Concentration | 8   | 10,37            | 0,56    | 0,46             | 39,77**  |
| Error II         | 72  | 166,60           |         | 0,10             |          |
| Corrected total  | 104 | 282,88           |         | 2,34             |          |
| CV               |     |                  | 1,53    |                  | 2,08     |

(\*p<0,05) (\*\*p<0,01)

The germination rate of the maize seeds was only affected by different concentrations of nanoparticles. However, seed vigor index of the maize seeds changed by nanopriming application with different nanoparticles at different concentrations (Table 4.5).

**Table 4.6.** ANOVA table for shoot and root length of maize seedlings after nanopriming applications

| Source           | df  | Shoot length |         | Root length |         |
|------------------|-----|--------------|---------|-------------|---------|
|                  |     | Sum of       | F value | Sum of      | F value |
| Replication      | 4   | 10,99        | 0,58    | 38,22       | 0,28    |
| NP               | 2   | 924,30       | 96,98** | 5803,28     | 84,17** |
| Error I          | 8   | 31,03        | 0,81    | 193,91      | 0,70    |
| Concentration    | 10  | 2227,53      | 46,74** | 5241,08     | 15,20** |
| NP*Concentration | 8   | 785,70       | 20,61** | 2341,91     | 8,49**  |
| Error II         | 72  | 343,13       |         | 2482,18     |         |
| Corrected total  | 104 | 4322,68      |         | 16100,58    |         |
| CV               |     |              | 3,13    |             | 5,23    |

(\*p<0,05) (\*\*p<0,01)

The shoot and root length of maize seedlings were changed by nanopriming application with different nanoparticles at different concentrations. On the other hand, the interaction between nanoparticles and concentration changed the shoot and root length of the maize seedlings (Table 4.6).

**Table 4.7.** ANOVA table for shoot and root fresh weight of maize seedlings after nanopriming applications

| Source           | df  | Shoot fresh weight |          | Root fresh weight |         |
|------------------|-----|--------------------|----------|-------------------|---------|
|                  |     | Sum of             | F value  | Sum of            | F value |
| Replication      | 4   | 0,01               | 1,95     | 0,02              | 0,95    |
| NP               | 2   | 0,31               | 115,16** | 0,37              | 42,26** |
| Error I          | 8   | 0,01               | 0,73     | 0,03              | 0,97    |
| Concentration    | 10  | 0,31               | 23,22**  | 0,72              | 16,47** |
| NP*Concentration | 8   | 0,12               | 11,12**  | 0,14              | 3,94**  |
| Error II         | 72  | 0,09               |          | 0,32              |         |
| Corrected total  | 104 | 0,85               |          | 1,60              |         |
| CV               |     |                    | 5,41     |                   | 6,39    |

(\*p<0,05) (\*\*p<0,01)

The shoot and root fresh weight of maize seedlings were changed by nanopriming application with different nanoparticles at different concentrations. On the other hand, the interaction between nanoparticles and concentration changed the shoot and root fresh weight of the maize seedlings (Table 4.7).

**Table 4.8.** ANOVA table for shoot and root dry weight of maize seedlings after nanopriming applications

| Source           | df  | Shoot dry weight |          | Root dry weight |         |
|------------------|-----|------------------|----------|-----------------|---------|
|                  |     | Sum of           | F value  | Sum of          | F value |
| Replication      | 4   | 0,00             | 2,62*    | 0,00            | 0,52    |
| NP               | 2   | 0,001            | 135,32** | 0,01            | 43,10** |
| Error I          | 8   | 0,00             | 1,78     | 0,001           | 1,06    |
| Concentration    | 10  | 0,003            | 61,96**  | 0,01            | 10,14** |
| NP*Concentration | 8   | 0,00             | 16,94**  | 0,001           | 2,11*   |
| Error II         | 72  | 0,00             |          | 0,006           |         |
| Corrected total  | 104 | 0,005            |          | 0,02            |         |
| CV               |     |                  | 4,49     |                 | 6,02    |

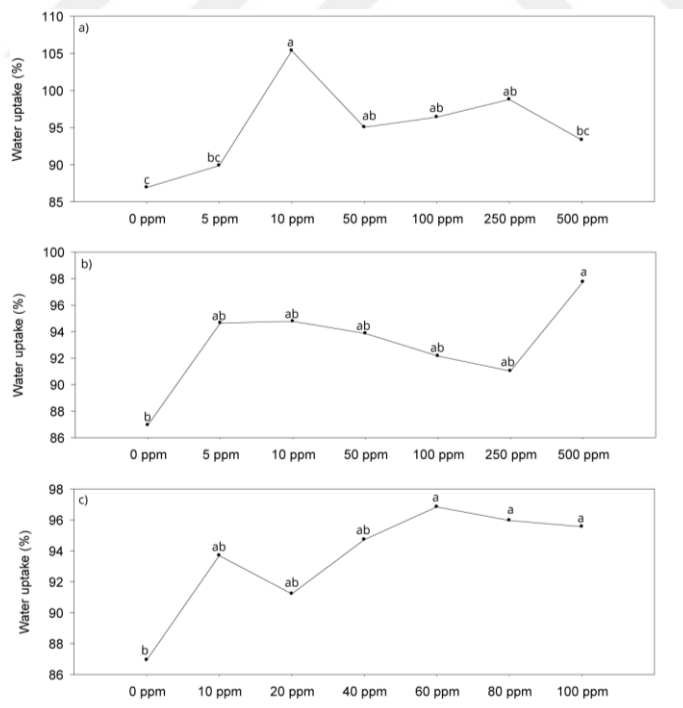
(\*p<0,05) (\*\*p<0,01)

The biomass of maize seedling was changed by nanoprimering with different nanoparticles at different concentrations. On the other hand, interaction between type of nanoparticles and concentration changed the shoot and root dry weight of the maize seedlings (Table 4.8).

CNT nanoprimering showed the most positive effect on seedling development of maize and bean seedlings. When the 10 ppm of CNT improved the maize seedling development, 100 ppm of CNT also increased the bean seedling development the most.

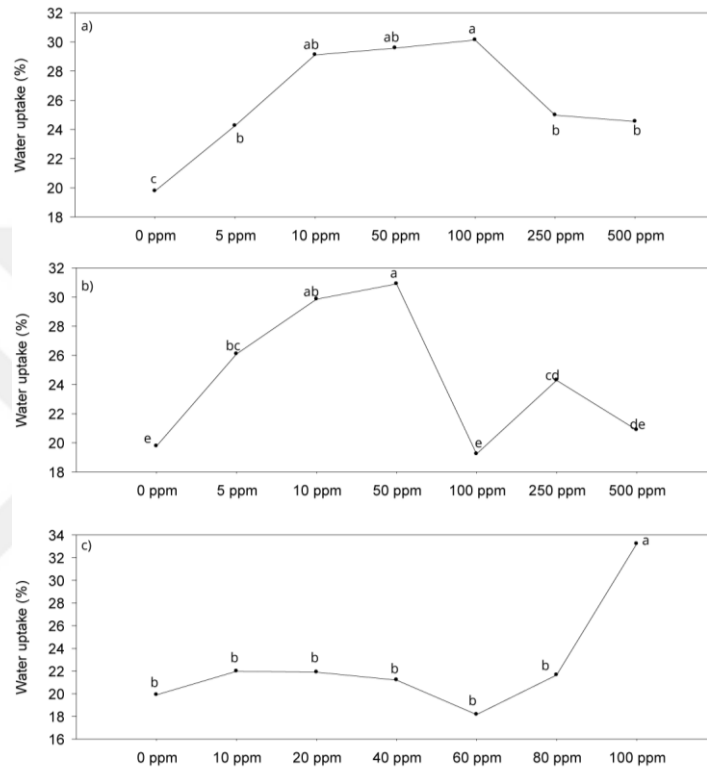
#### 4.1.11 Water uptake (%)

The water uptake ability of tomato seeds were increased by nanoprimering as presented in Figure 4.43. 10 ppm of  $\text{TiO}_2$  increased the water imbibition by tomato seeds and by increasing in the  $\text{TiO}_2$  concentration, the water uptake rate of tomato seeds decreased. On the other hand, CNT and  $\text{SiO}_2$  nanoprimering increased the water uptake rate of the tomato seeds, where 500 ppm of CNT and 60, 80, 100 pp of  $\text{SiO}_2$ , increased the most.



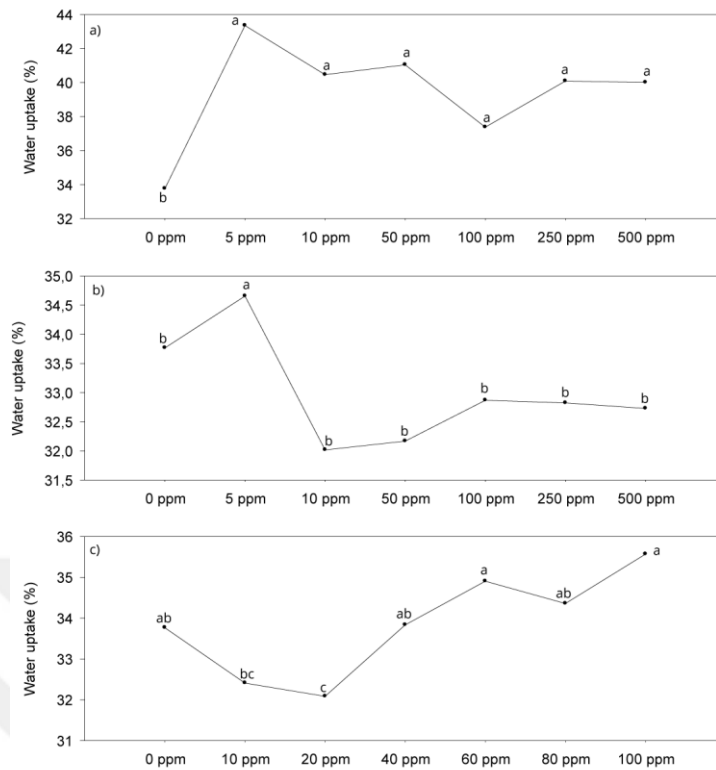
**Figure 4.43.** The water uptake (%) of tomato seeds after nanoprimered by  $\text{TiO}_2$  (a), CNT (b) and  $\text{SiO}_2$ (c)

The water uptake ability of bean seeds increased by priming with nanoparticles (Figure 4.44). 100 ppm of TiO<sub>2</sub> increased the water uptake capacity of bean seeds approximately 50%. On the other hand, 50 ppm of CNT increased the water uptake ability of bean seeds the most and increased in CNT concentration decreased the water uptake ability. Besides, only 100 ppm of SiO<sub>2</sub> could have been increased the water uptake ability of bean seeds, and rest of the concentration did not affect the water uptake of bean seeds.



**Figure 4.44.** The water uptake (%) of bean seeds after nanoprimered by TiO<sub>2</sub> (a), CNT (b) and SiO<sub>2</sub>(c)

Water uptake capacity of maize seeds increased by TiO<sub>2</sub> nanoprimering at all concentration. On the other hand, only 5 ppm of CNT increased the water uptake capacity of maize seeds and rest of CNT nanoprimering applications did not affect. SiO<sub>2</sub> nanoprimering decreased the water uptake capacity of maize seeds at low concentration and by increasing in the SiO<sub>2</sub> concentration increased the water uptake capacity of maize plants.



**Figure 4.45.** The water uptake (%) of maize seeds after nanoprimered by TiO<sub>2</sub> (a), CNT (b) and SiO<sub>2</sub>(c)

#### 4.1.12 Overall evaluation and discussion of the results

The germination of tomato, bean and maize seeds were promoted by nanoprimering with three different nanoparticles; TiO<sub>2</sub>, SiO<sub>2</sub> and CNT.

The mechanism behind the increasing seed germination may be the activation of active oxygen radicals by TiO<sub>2</sub> nanoparticles and increase the water and O<sub>2</sub> uptake ability of the seeds, which improves the seed germination (Feizi et al., 2013A, 2013B). Recillas (2011) reported that the germination of tomato seeds was decreased with 320 mg/L concentration of TiO<sub>2</sub> nanoparticles (Recillas et al., 2011). On the other hand, 100 and 200 mg/L concentration of TiO<sub>2</sub> nanoparticle were increased tomato seed germination (Haghighi and Teixeira Da Silva, 2014). Thus, it can be concluded that the tomato seed germination is correlated with concentration of TiO<sub>2</sub> nanoparticles as mentioned in current study. However, Song and collages reported that germination of tomato seeds were not affected by TiO<sub>2</sub> nanoparticle applications (Song *et al.*, 2013A). Besides, the effect of SiO<sub>2</sub> on

germination could be due to the increasing in absorption and utilization of SiO<sub>2</sub> nanoparticles (Suriyaprabha et al., 2012). The seed germination rate of tomato seeds was increased with 8 g/L of SiO<sub>2</sub> nanoparticles (Siddiqui and Al-Whaibi, 2014). The germination ability of rice seeds was increased by SiO<sub>2</sub> nanoparticles (Nair et al., 2011). When the effect of TiO<sub>2</sub> and SiO<sub>2</sub> nanoparticles at 1000 mg/L concentration on maize seed germination investigated, it was observed that TiO<sub>2</sub> inhibits maize seed germination in contrast to SiO<sub>2</sub>, which promotes seed germination (Karunakaran et al., 2016). One of the purpose of the thesis was to decrease the toxic effect of nanoparticles on seed germination and development. For this purpose, decreasing in concentration and changing application type inhibited the toxic effect of TiO<sub>2</sub> on maize seed germination. Khodakovskaya (2009) and colligates reported first time the penetration of CNT in seed coat and increase the water uptake ability of seeds, which increases and accelerates seed germination (Khodakovskaya et al., 2009). In general, nanoprimering increases α-amylase activity and starts rapid starch degradation (Mahakham et al., 2017; Man et al., 2013). The activity of α-amylase depends on GA and this relationship increases with entegration of nanoparticles in the seed (Mahakham et al., 2017). Effect of nanoprimering on phytohormones enhances sugar signalling factors, which promotes seed germination (Laby et al., 2000).

In current study, the seeds had already high germination ability, thus the effect of nanoparticles on seed germination could not observed clearly. However, no toxic effect of nanoparticles at low concentrations on seed germination was observed. Besides, for better observation of nanoparticle effect on seed germination and seedling development different abiotic stresses were applied to seeds during germination and the results will be discussed in section 4.4.

Apart from seed germination, the various studies have mentioned the increase in both shoot and root length in various plants like tomato (Haghighi and Da Silva, 2014; Su et al. 2009), spinach (Zheng et al., 2005), onion (Haghighi and Da Silva, 2014) by application of TiO<sub>2</sub>. However, Song (2013) reported that, application of TiO<sub>2</sub> at 1000 and 5000 concentration decreased shoot and root development in potato plant (Song *et al.*, 2013A). A study showed that the application of TiO<sub>2</sub> nanoparticles on spinach affected the nitrogen metabolism, which increased the activity of some vital enzymes. Thus, the plant development increased after TiO<sub>2</sub> application (Yang et al., 2006). The addition of

TiO<sub>2</sub> nanoparticles in the soil increased both fresh weight and number of stem, fruit and leaves (Bakshi et al., 2019). The positive effect of TiO<sub>2</sub> on maize seedling development and increase in root biomass was reported (Ghoto et al., 2020). Likewise, SiO<sub>2</sub> increases biomass of tomato (Siddiqui and Al-Whaibi, 2014), safflower (Janmohammadi *et al.*, 2016) and bean (Alshaal et al., 2017). On the other hand, nano-SiO<sub>2</sub> application increased SVI of tomato seeds (Siddiqui and Al-Whaibi, 2014). Besides there are phytotoxic effect on Arabidopsis development of SiO<sub>2</sub> nanoparticles in terms of biomass and root and shoot length like effect on tomato seedlings in current study (Slomberg and Schoenfisch, 2012). In different studies the positive effect of CNT on seedling development was mentioned. For example, sorghum (Pandey et al., 2018), tomato (Khodakovskaya et al., 2009, 2011), maize, soybean and barley (Lahiani et al., 2013).

Nanoparticle application for plant production could be both beneficial or hazardous. The main reason of this issue is both concentration of nanoparticle and application style. In order to decrease the environmental and phyto hazard of this nanoparticle, nanopriming could be an alternative (Mahakham et al., 2017).

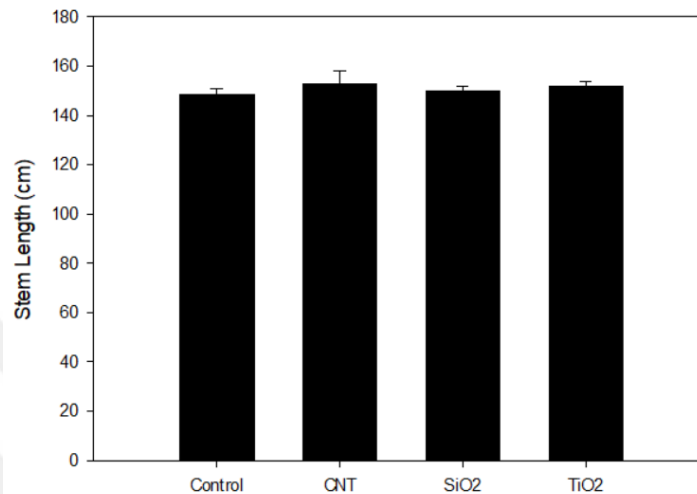
#### **4.2 Effects of nano-priming applications with NPs at different concentrations on emergence, growth and yield under greenhouse conditions (WP-II)**

The most efficient concentrations of nanoparticles for seed priming for each seed type was detected in WP-I. The selected concentrations of nanoparticles are given in Table 3.4. According to Table 3.4 seed nanopriming was performed as described in section 3.1.2. The seeds were planted in Niğde Ömer Halisdemir University, Faculty of Agricultural Science and Technology Agricultural Genetic Engineering Department net house. Seeds were planted on 14.06.2019 with 5 replications and each replication had 3 plants.

The 50% of germination was recorded 4 days for maize, 5 days for bean and 6 days for tomato.

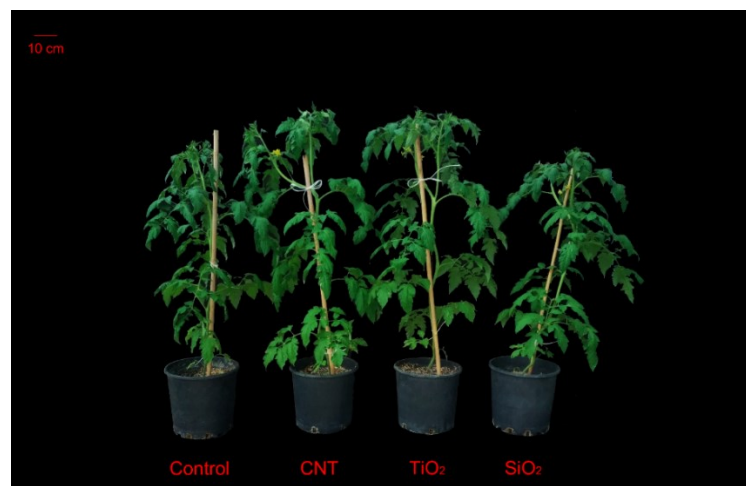
### 4.2.1 Stem length

The stem length of plants was measured at flowering period of each plant type (53<sup>rd</sup> day for bean, 75<sup>th</sup> day for maize and tomato).



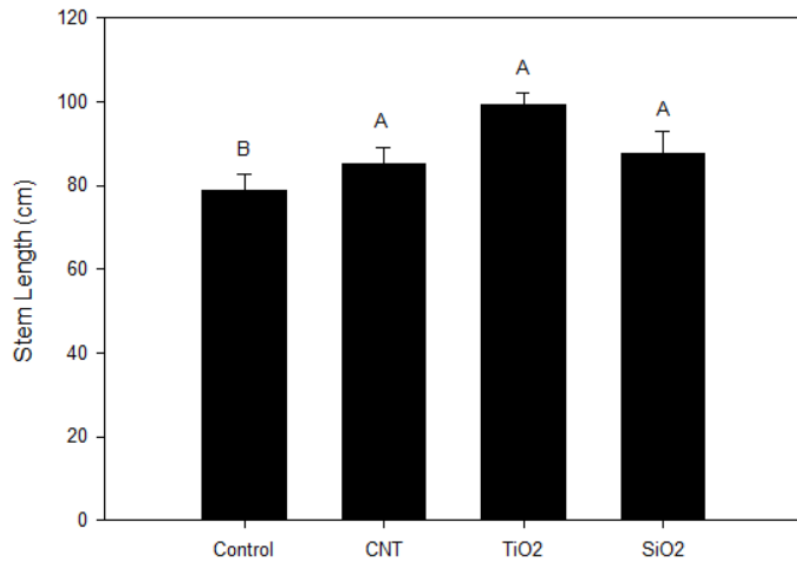
**Figure 4.46.** Stem length of tomato plants

The stem length of tomato plants, grown in greenhouse, is presented in Figure 4.46. The nanoprimering applications did not affect stem length significantly and all plants were approximately same length after nanoprimering.



**Figure 4.47.** Tomato plants grown in greenhouse

Figure 4.47 presents tomato plants grown in green house at flowering period.



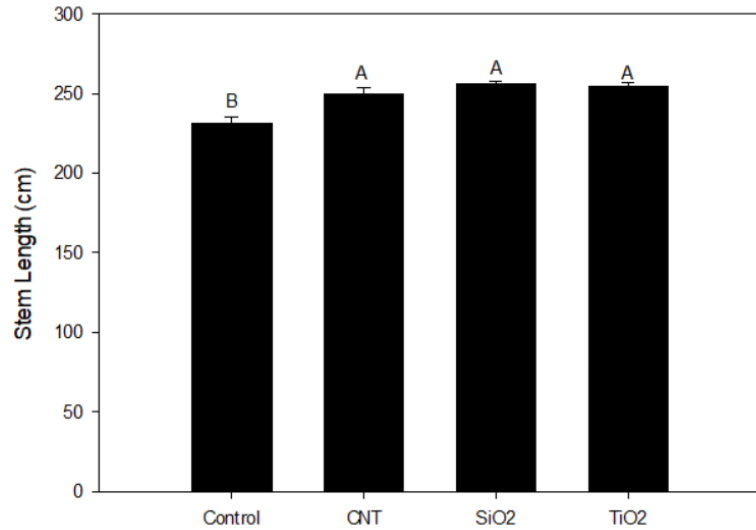
**Figure 4.48.** Stem length of bean plants

The stem length of bean plants was increased after nanoparticles as presented in Figure 4.48. All nanoparticles had the same effect and stem length of plants developed from nanoprimed seeds was same.



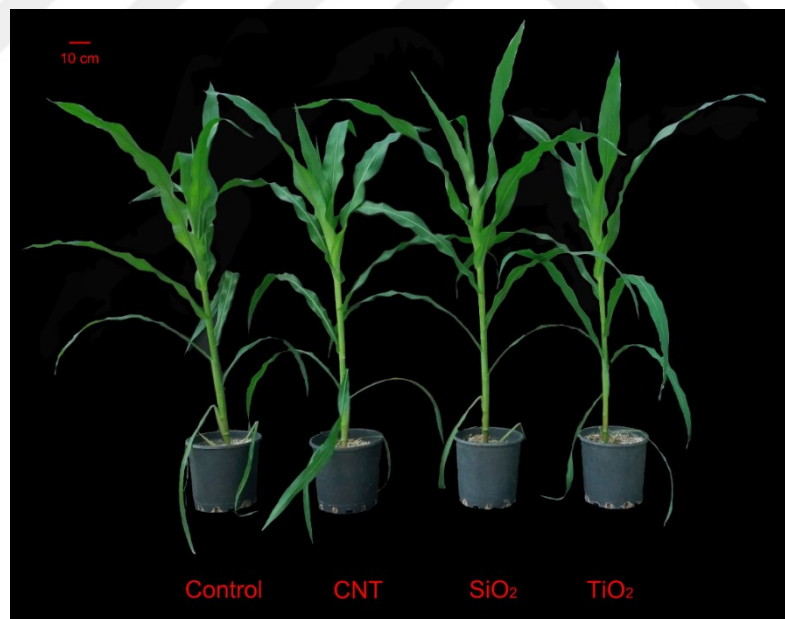
**Figure 4.49.** Bean plants grown in greenhouse

Figure 4.49 presents bean plants developed in greenhouse.



**Figure 4.50.** Stem length of maize plants

The stem length of maize plants was increased after nanoparticles as presented in Figure 4.50. All nanoparticles had the same effect and stem length of plants developed from nanoprimed seeds was same.



**Figure 4.51.** Maize plants grown in greenhouse

Figure 4.51 presents maize plants developed in greenhouse.

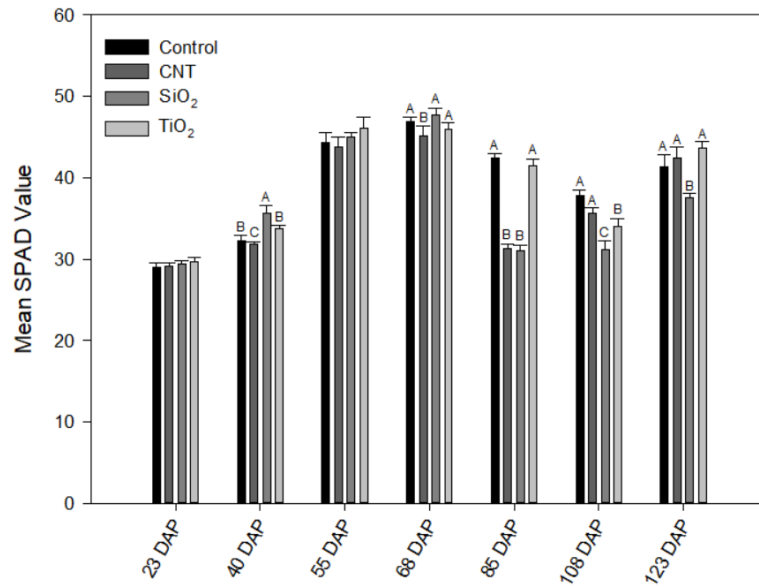
It is reported that TiO<sub>2</sub> application to directly the soil increased stem length of wheat plants same as bean and maize plants in current study (Rafique et al., 2014). The study,

conducted in green house, indicated the positive effect of TiO<sub>2</sub> nanoparticles on stem length of mung bean (Raliya et al., 2015). 60 mg/kg TiO<sub>2</sub> in the soil increased wheat stem length in greenhouse (Rafique et al., 2018). Song and colleagues determined negative effect of TiO<sub>2</sub> on stem length of tomato plants under greenhouse conditions (Song et al., 2013). However, the phytotoxic effect of TiO<sub>2</sub> on tomato plants was prevented by nanopriming method in this thesis. Positive effect of SiO<sub>2</sub> nanoparticles on wheat plants was reported at different concentrations (300-1200 mg/kg) under greenhouse conditions (Ali et al., 2019). The field experiment conducted by Galaktionova et al. (2020) presented the promoted of SiO<sub>2</sub> nanoparticle at 10<sup>-4</sup> mg/L the pea plant growth (Galaktionova et al., 2020). The penetration of CNT to plant cell increases the vegetative parts development of plants (Cañas et al., 2008; Khodakovskaya et al., 2012). It is reported that the maize, peanut and garlic root and stem development increased by CNT application (Srivastava and Rao, 2014).

In thesis, the nanoparticles were applied by nanopriming method and the positive effect of nanoparticles was still determined on stem length of tomato, maize and bean plants. Nevertheless, the nanoparticles did not contaminate the soil.

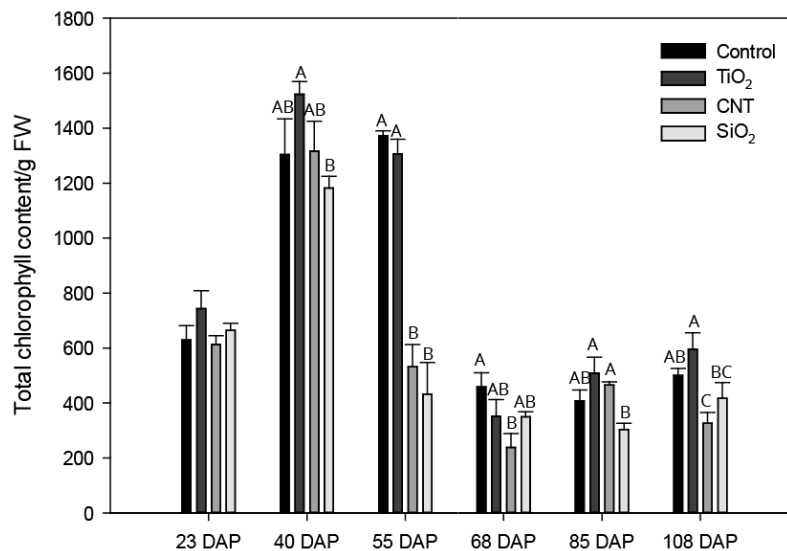
#### **4.2.2 Chlorophyll index**

The chlorophyll index of plants, grown in greenhouse, was measured with SPAD-502 Plus chlorophyll meter (Konica Minolta) on every 15 days starting from 26<sup>th</sup> day of planting. Figure 4.52 presents chlorophyll index of tomato plants. The first measurement was conducted on 23 day after planting (DAP). There were no differences between treatments at the first measurement. The next measurement was performed on 40 DAP and when the SiO<sub>2</sub> treatment increased the chlorophyll index of tomato plants, CNT treatment decreased. On the 55<sup>th</sup> after planting, near the end of the vegetative growth, there was no differences between treatments. During the flowering stage, the plants developed after CNT nanopriming had less chlorophyll index. Close to the maturation, the chlorophyll index of plants developed from SiO<sub>2</sub> nanoprimed seeds decreased. TiO<sub>2</sub> treatment did not affect chlorophyll index of tomato plants at any stage.



**Figure 4.52.** Mean SPAD value of tomato plants

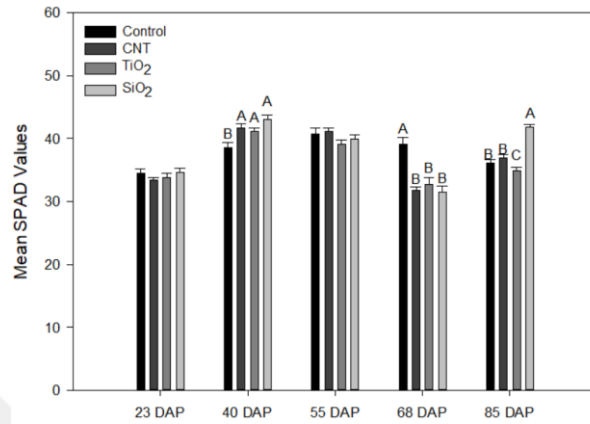
Figure 4.53 presents the total chlorophyll content of tomato plants, developed under greenhouse conditions. The total chlorophyll content of tomato plants did not change on 23 DAP. However, after 40 DAP the chlorophyll content of TiO<sub>2</sub> nanoprimed tomato plants increased and other nanoparticles decreased the chlorophyll content.



**Figure 4.53.** Total chlorophyll content of tomato plants

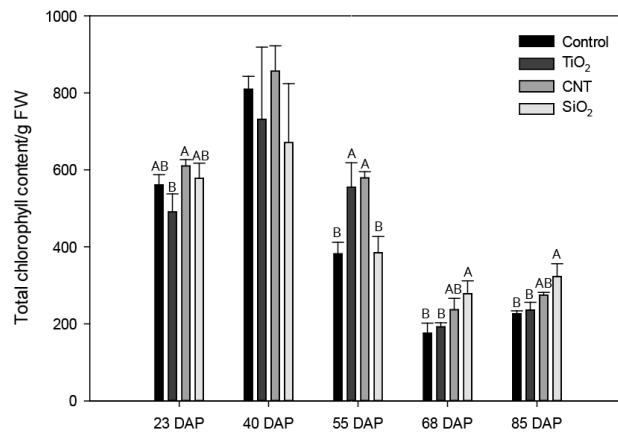
Figure 4.54 presents the chlorophyll index of bean plants. When the plants were very young and at flowering stage there were no differences between applications. On the other hand, nanopriming application increase the chlorophyll index of bean plants during

vegetative growth. During reproductive stage the chlorophyll index of bean plants developed from nanoprimed seeds decreased. However, at the maturation the plants developed from SiO<sub>2</sub> nanoprimed seeds kept chlorophyll index higher than other treatments.



**Figure 4.54** Mean SPAD value of bean plants

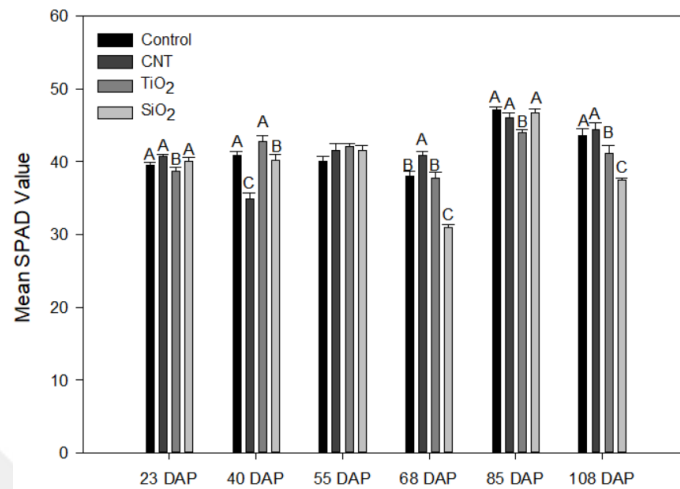
**Figure 4.55** Figure 4.55 presents the total chlorophyll content of bean plants. The CNT nanopriming of bean seeds increased the total chlorophyll content of bean plants in general. On the other hand, when the TiO<sub>2</sub> nanopriming increased the chlorophyll content at early stages, the impact of TiO<sub>2</sub> on chlorophyll content was disappeared at late stages.



**Figure 4.55.** Total chlorophyll content of bean plants

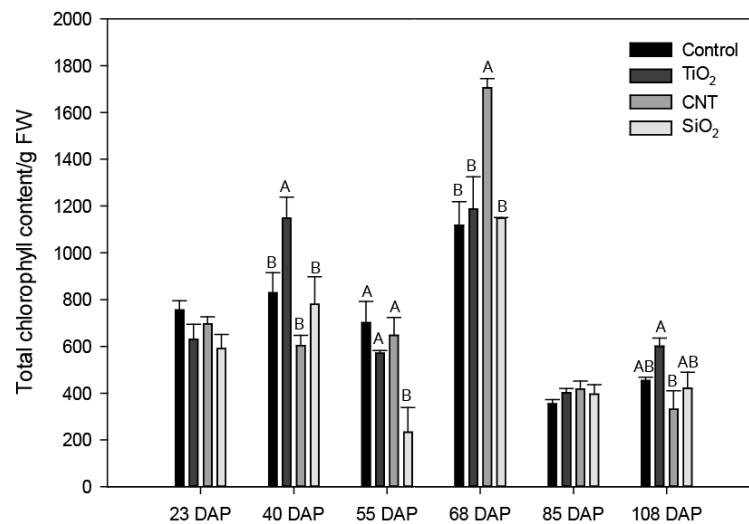
Figure 4.56 presents the chlorophyll index of maize plants. The chlorophyll index of maize plants, developed from TiO<sub>2</sub> and SiO<sub>2</sub> nanoprimed seeds, was lower than other

treatments in general. On the other hand, CNT nanopriming mostly did not affect chlorophyll index of maize plants.



**Figure 4.56.** Mean SPAD value of maize plants

The total chlorophyll content of maize plants at different stages is presented in Figure 4.57. The effect of nanoparticles on total chlorophyll content of maize differs at different stages. However, SiO<sub>2</sub> application decreased the total chlorophyll content of maize plants.



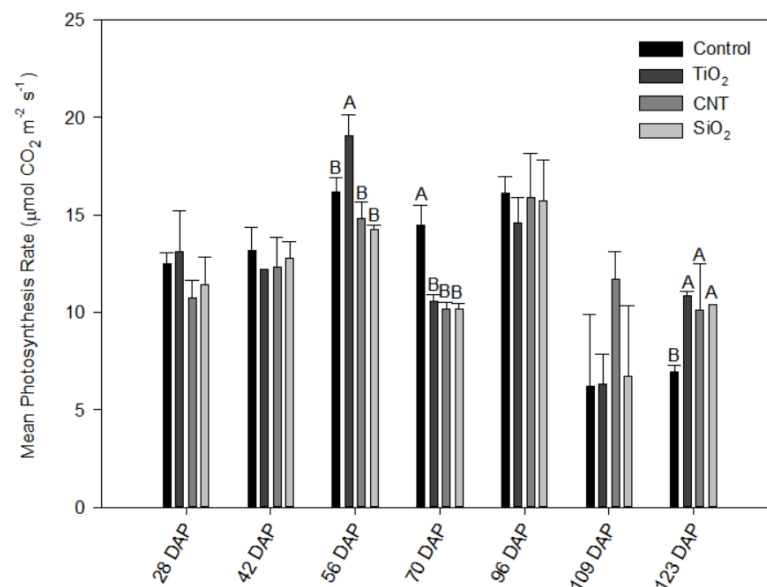
**Figure 4.57.** Total chlorophyll content of bean plants

The chlorophyll index is the indicator of greenness of leaves, which is used to determine the nutrition deficiency and condition of chlorophyll (Ali et al., 2017). Besides, chlorophyll index is used to estimate crop biomass (Liu et al., 2019). There are different

parameters affect chlorophyll index. The basic parameter is nitrogen content of leaves (Kalacska et. al., 2015; Wang et al., 2014). On the other hand, various studies reported that nanoparticle treatment affects the chlorophyll index of crops. Mahdavi (2016) indicates the positive correlation between nano-SiO<sub>2</sub> and chlorophyll index of ryegrass (Mahdavi et al., 2016). Besides, CNT treatment increased the chlorophyll content of sunflower under lead and cadmium stress (Oloumi et. al., 2018). CNT treatment also increased the total chlorophyll content of carrot (Park and Ahn, 2016). In contrast to CNT and SiO<sub>2</sub>, TiO<sub>2</sub> nanoparticles decreased chlorophyll index of maize plants (Dağhan, 2018). In this research the TiO<sub>2</sub> nanopriming also decreased maize chlorophyll index. Nanoparticle treatment was applied with nanopriming technique. For this reason, the effect on chlorophyll index of nanoparticles may decrease.

#### 4.2.3 Photosynthesis velocity, transpiration velocity and stomata conductance

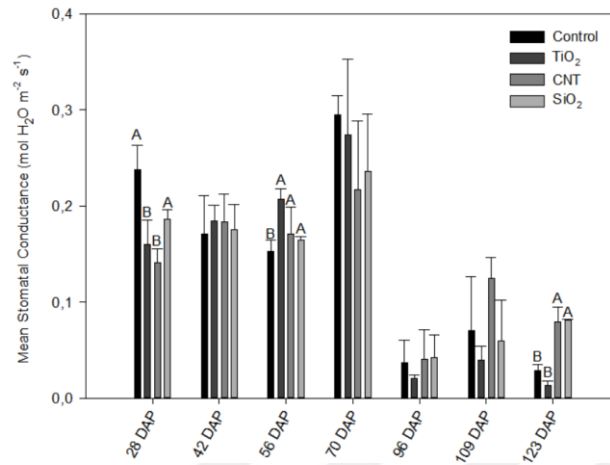
Photosynthesis rate and stomatal conductance were measured from youngest mature leaves will be measured by mobile photosynthesis system (LI-6400 XT, LICOR, USA) in every two weeks started from 28<sup>th</sup> day after planting.



**Figure 4.58.** Photosynthesis rate of tomato plants

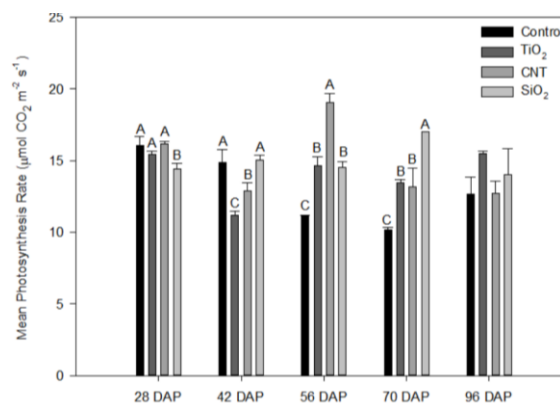
The photosynthesis rate of tomato plants is presented in Figure 4.58. When the plants were young there were no differences between plants developed from nanoprimed seeds and control group. However, at flowering stage, nanoparticle treatment decreased the

photosynthesis rate. In contrast to flowering stage, the nanoparticle treatment increased the photosynthesis rate of tomato plants.



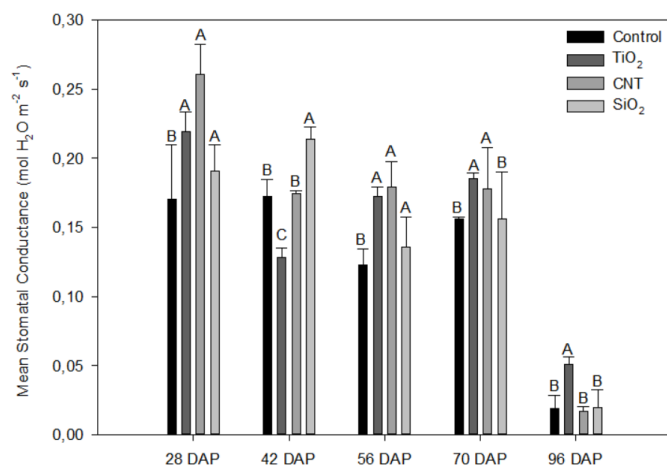
**Figure 4.59.** Stomatal conductance of tomato plants

Figure 4.59 presents stomatal conductance of tomato plants. In early stage of plant development TiO<sub>2</sub> and CNT nanoprimering decreased stomatal conductance. On the other hand, nanoparticle treatment increased stomatal conductance at flowering stage. At maturation, when TiO<sub>2</sub> did not affect the stomatal conductance and CNT and SiO<sub>2</sub> treatments increased.



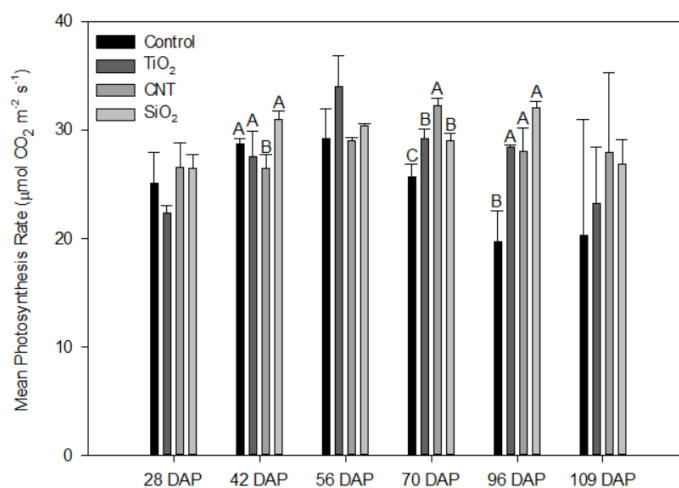
**Figure 4.60.** Photosynthesis rate of bean plants

Figure 4.60 presents the photosynthesis rate of bean plants. In the early stages of bean plants, the nanoprimering applications decreased photosynthesis rate. However, during the flowering stage all nanoprimering applications increased the rate of photosynthesis. At maturation stage there was no effect of nanoprimering application on photosynthesis rate.



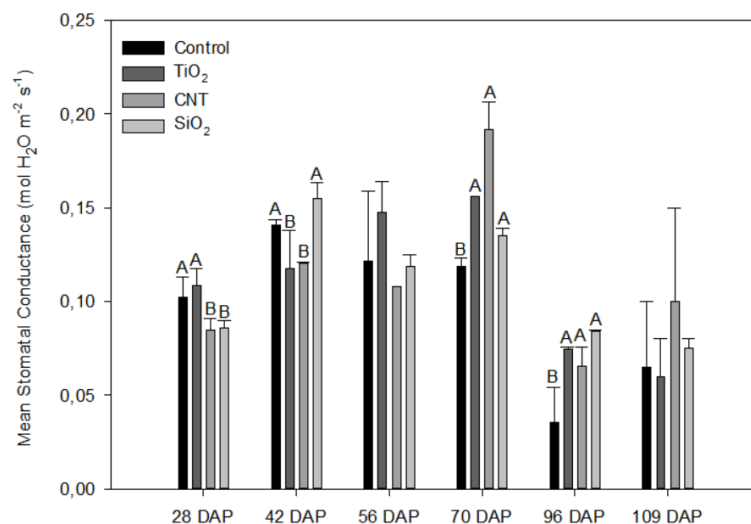
**Figure 4.61.** Stomatal conductance of bean plants

Mean stomatal conductance of bean plants was shown in Figure 4.61. The stomatal conductance of bean plants mostly increased by nanoparticle treatment. At the early stage of the plant development all treatments were increased the stomatal conductance. During the flowering stage the increase in the stomatal conductance by nanopriming application was observed. However, the effect of SiO<sub>2</sub> nanoparticle decreased at the end of the flowering stage. TiO<sub>2</sub> nanoparticle had the highest value in the mature plants and other applications did not affect the stomatal conductance.



**Figure 4.62.** Photosynthesis rate of maize plants

Figure 4.62 presents the photosynthesis rate of maize plants. TiO<sub>2</sub> nanoparticle increased the photosynthesis rate at flowering stage and there was no effect of other stages. CNT decreased the photosynthesis rate in early stages, but increased at flowering stage. Finally, SiO<sub>2</sub> nanoparticle increased photosynthesis rate of maize plants in general.



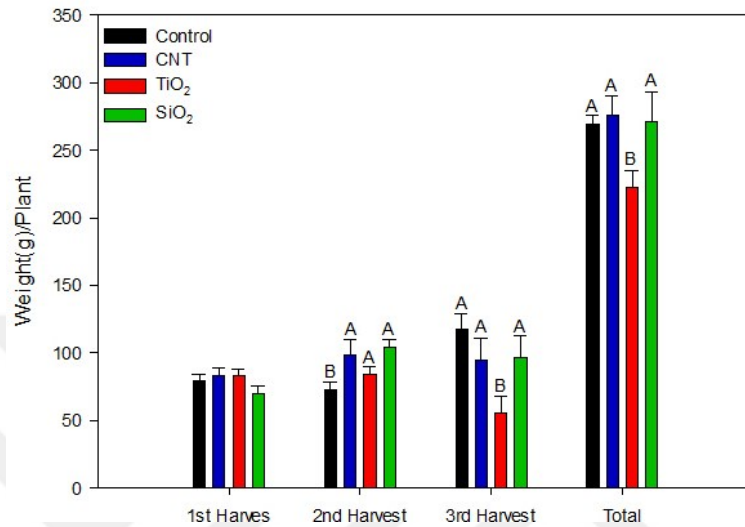
**Figure 4.63.** Stomatal conductance of maize plants

The stomatal conductance of maize plants is presented in Figure 4.63. At early stages the CNT and SiO<sub>2</sub> treatments decreased the stomatal conductance of maize plants. However, during the flowering stage the stomatal conductance was increased by nanopriming applications with all nanoparticle types.

Many different studies have been showed that TiO<sub>2</sub> increases the photosynthesis ratio (Gao et al., 2006, 2008; Hong et al., 2005; Mahmoodzadeh, 2013). Firstly, Hong et al (2005) pointed out that, TiO<sub>2</sub> raised photosynthesis ratio of spinach by promoting photochemical reactions of chloroplast (Hong et al., 2005). Formerly, the studies performed by Gao et al in 2006 and 2008 illuminated that TiO<sub>2</sub> caused a conformational change in rubisco activase enzyme, which increased the activity of the enzyme (Gao et al., 2006, 2008). SiO<sub>2</sub> treatment by both foliar and direct application to soil, increased photosynthesis rate and stomatal conductance in wheat plants. Siddique et. al. mentioned the increase in photosynthetic rate of tomato plants after SiO<sub>2</sub> application (Siddiqui and Al-Whaibi, 2014). In the current study, there was no effect of SiO<sub>2</sub> nanoparticle on tomato plants. This may be caused by the treatment technique, which is nanopriming. The accumulation of silicon in leaves and chloroplasts by SiO<sub>2</sub> nanoparticles increased the photosynthesis rate in wheat (Sun et al., 2016). SiO<sub>2</sub> nanoparticles may improve photosynthetic rate by increase the activity of photosynthetic enzymes and pigments (Siddiqui et. al., 2015; Xie et al., 2012). It is reported that, the CNT embedded chloroplasts had three times more photosynthetic activity (Giraldo et al., 2014).

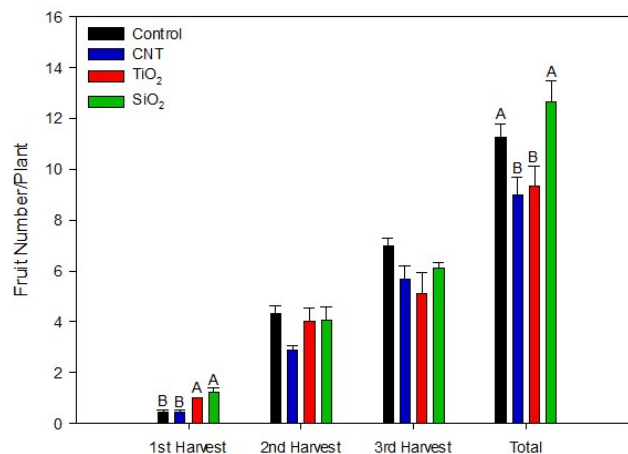
#### 4.2.4 Yield analysis

The yield performance of each plant was measured regarding to their products; fruit number and weight for tomato, grain number and total grains and kernels weight for bean and maize.



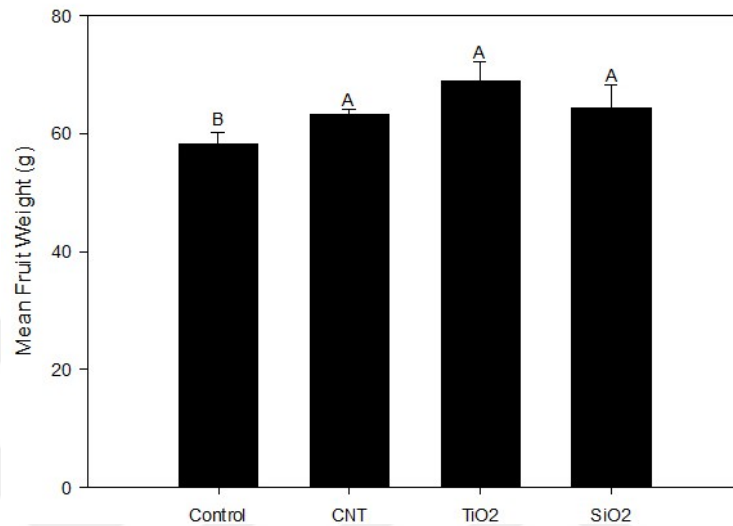
**Figure 4.64.** Yield of tomato plants in weight

Figure 4.64 presents the yield of tomato plants in weight. There were no differences between nanoparticle treatments and control group in first harvest. However, the nanoprimering treatments increased the yield in weight in second harvest. There were no differences between SiO<sub>2</sub>, CNT treatment and control group, in contrast to TiO<sub>2</sub>, which decreased the yield. In total, when TiO<sub>2</sub> nanoprimering application decreased the yield of tomato, CNT and SiO<sub>2</sub> application did not affect.



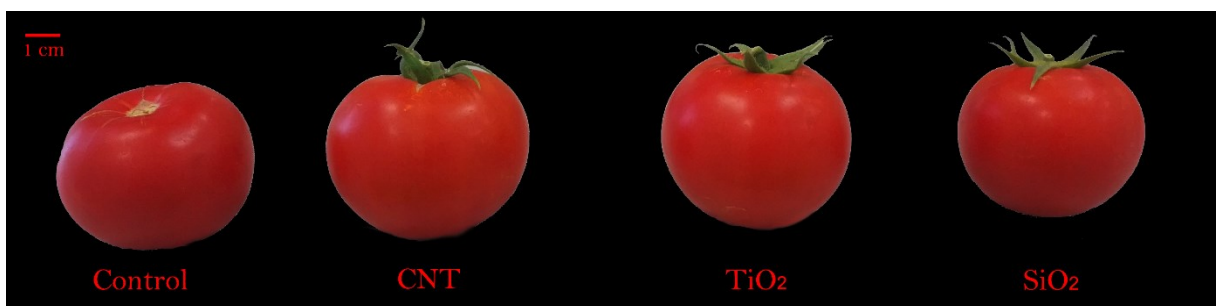
**Figure 4.65.** Yield of tomato plants in fruit numbers

The fruit number per plant were increased in the first harvest by  $\text{TiO}_2$  and  $\text{SiO}_2$  nanopriming applications. There was no effect of nanopriming on tomato yield in fruits. The total yield of tomato fruits were decreased by CNT and  $\text{TiO}_2$  nanopriming applications (Figure 4.66).



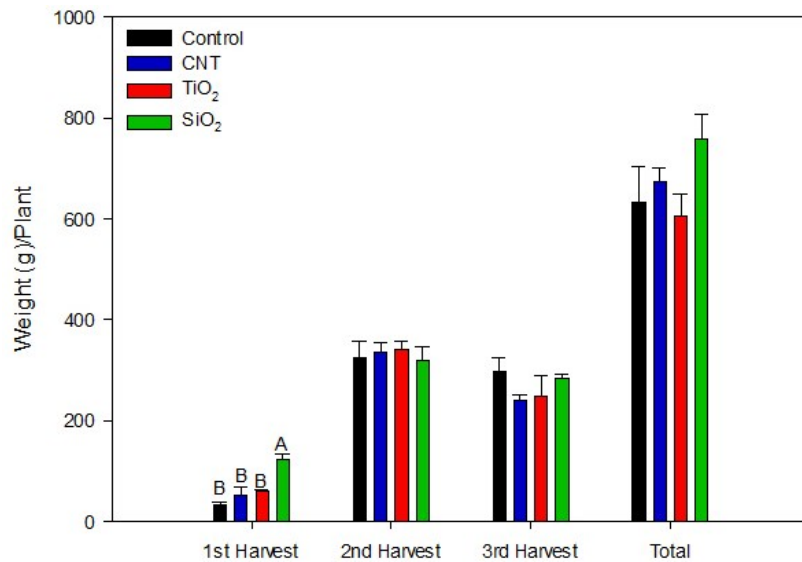
**Figure 4.66.** Mean fruit number of tomato plants

The mean fruit weight per plant is shown in Figure 4.66. The mean fruit weight was calculated by total weight/fruit number. According to figure, the fruit weight was increased by nanopriming application and there was no difference between nanoparticle types.



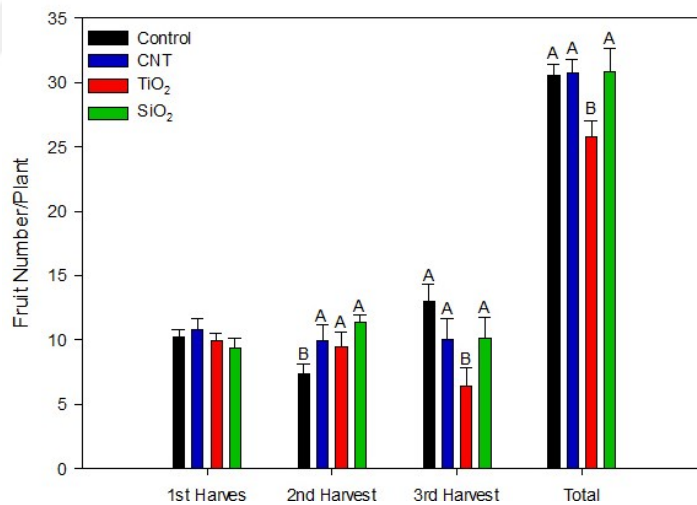
**Figure 4.67.** Tomato fruits grown under greenhouse conditions

Also the shape and color of the fruits were same for all applications as shown in Figure 4.67.



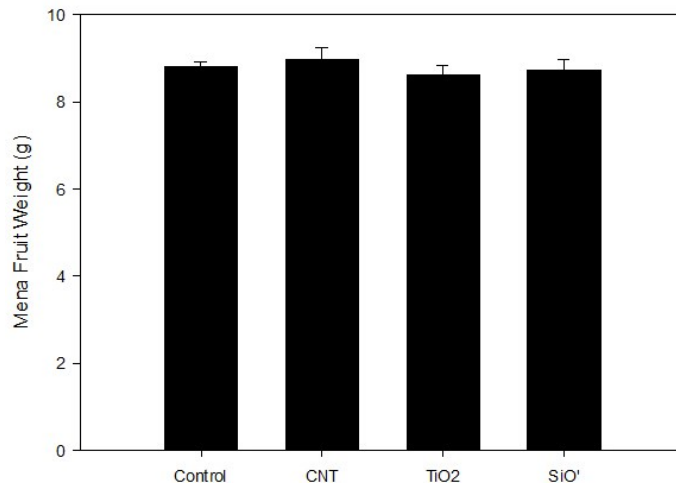
**Figure 4.68.** Yield of bean plants in weight

The nanopriming application of bean seeds were not effective on yield in weight. Only, SiO<sub>2</sub> nanopriming increased the yield during first harvest (Figure 4.68).



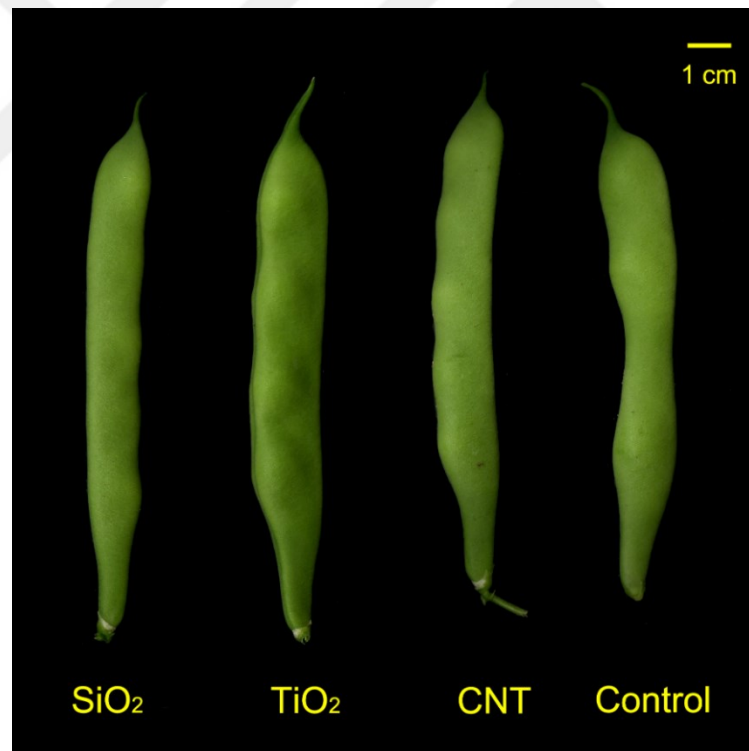
**Figure 4.69.** Yield of bean plants in fruit numbers

Figure 4.69 presents the yield of bean plants in fruit numbers. There was no difference between applications in the first harvest. Yet, the nanopriming applications increased the bean yield in the second harvest, when TiO<sub>2</sub> treatment decreased the yield in third harvest and total harvest.



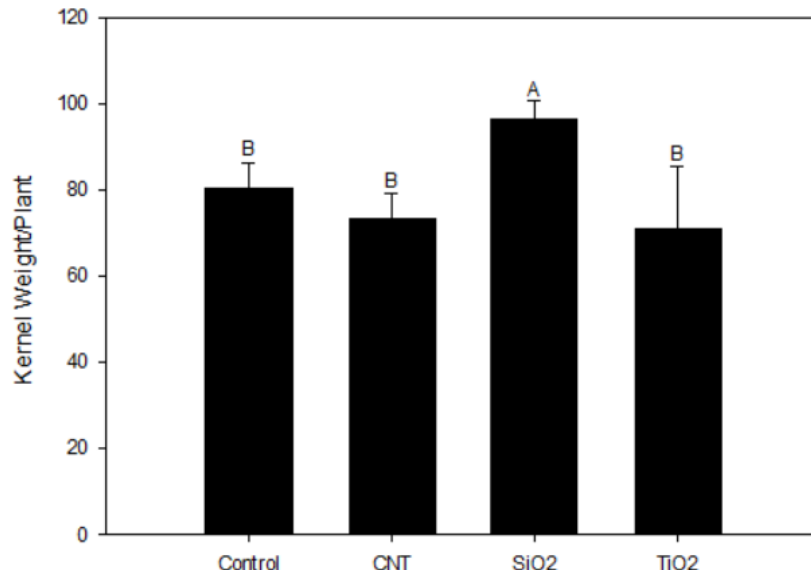
**Figure 4.70.** Mean bean fruit weight

The nanopriming application to bean seeds did not change the bean fruits weight grown in greenhouse.

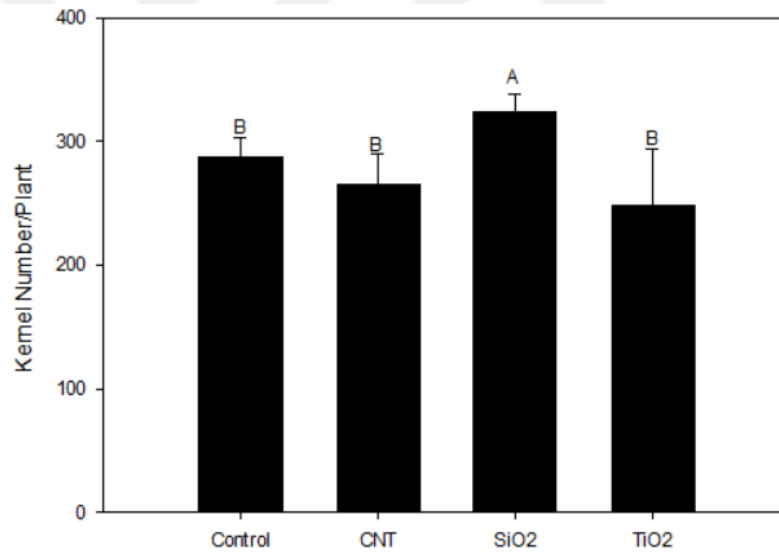


**Figure 4.71.** Bean fruits grown under greenhouse conditions

Using of nanoparticles as priming agent did not cause any shape or color changes in bean fruit as presented in Figure 4.71.

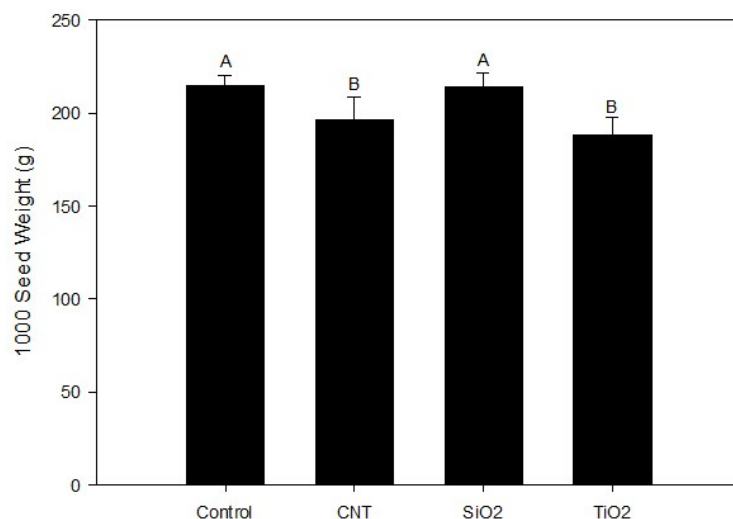


**Figure 4.72.** Yield of maize plants in weight



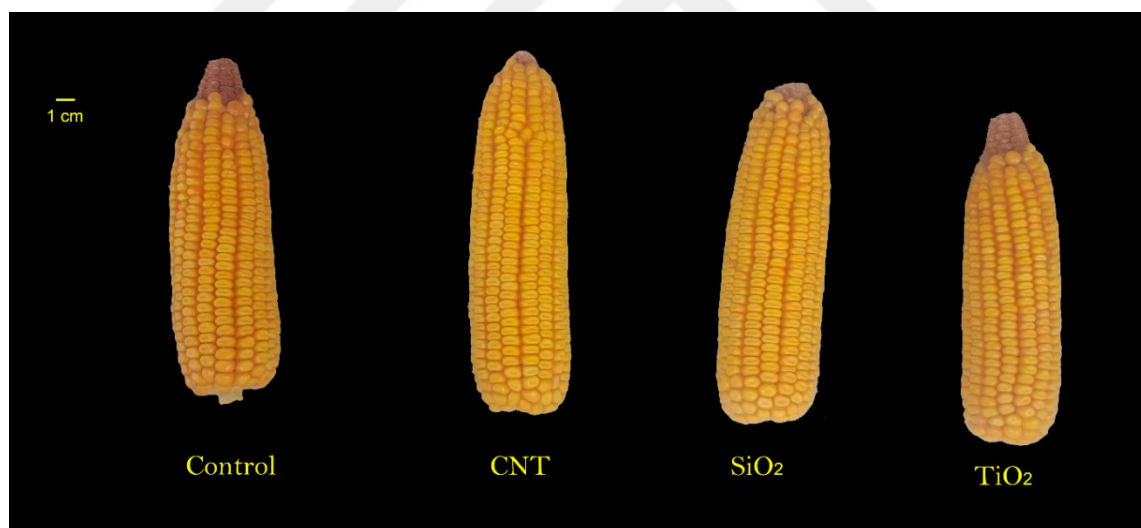
**Figure 4.73.** Yield of maize in kernel numbers

The yield of maize plants grown in greenhouse is presented in Figure 4.72 (in weight) and Figure 4.73 (in kernel numbers). SiO<sub>2</sub> nanopriming increased the yield of maize plants in terms of both weight and kernel numbers.



**Figure 4.74.** 1000 seed weight of maize kernels

As presented in Figure 4.74, 1000 seed weight of maize kernels decreased by CNT and TiO<sub>2</sub> nanoprimer application. Figure 4.75 shows the corncob grown under greenhouse conditions.



**Figure 4.75.** Corncob grown under greenhouse conditions

The yield of crops is affected from various parameters like genetic background or environmental conditions. This section the effect of nanoprimer on crop yield was investigated. There are two important things in terms of crop harvest; more yield and early harvest. In this study, application of nanoprimer did not speed up fruit or grain development. Despite, the fruit yield increased by TiO<sub>2</sub> and SiO<sub>2</sub> nanoprimer and bean yield increased by SiO<sub>2</sub> nanoprimer in the first harvest. The total yield was reduced by

TiO<sub>2</sub> nanopriming for both crop type. The maize plants were harvested once and the yield of the maize was increased by SiO<sub>2</sub> nanopriming application.

The yield of wheat also increased by SiO<sub>2</sub> nanoparticle application (Behboudi et al., 2018). Nano-SiO<sub>2</sub> treatment increased efficiency of micro and macro nutrient, which improves crop yield (Suriyaprabha et al., 2012). Foliar application of SiO<sub>2</sub> nanoparticles to leaves with chitosan increased the soybean yield compare to control group and chitosan treatment (Phu et al., 2017). The two years study of Khater pointed out that application of very small amount of TiO<sub>2</sub>, like 2 to 6 ppm, increased the yield of coriander plants (Khater, 2015). In another study, increasing in cowpea yield by the foliar application of TiO<sub>2</sub> was reported (Owolade and Ogunleti, 2008). The effect of TiO<sub>2</sub> nanoparticle on yield depends on concentration and time of application (Janmohammadi et al., 2016). The priming of bread wheat seeds by MWCNT 63% increased the crop yield in the field (Joshi et al., 2018). CNT can absorb nitrogen from ammonia and releases hydrogen ions, which increases water and nutrition absorption ability of crops. Thus, application of CNT increases the N, P, K efficiency on the crops and increases the yield and quality of harvestable parts (Wu et al., 2010).

In conclusion, there are many parameters affecting plant growth, development physiological and biochemical properties of crops. Application of nanoparticles is one of these parameters. However, there are different nanopriming application techniques like foliar, addition to irrigation water, addition to growth media or priming (Behboudi et al., 2018; Khodakovskaya et al., 2009; Mahakham et al., 2017). The main purpose of nanopriming is to decrease any possible environmental or phytotoxicity (Mahakham et al., 2017). For this purpose, the seeds were subjected to very less amount of nanoparticles. Thus, the effect of nanoparticles is not as much as other techniques.

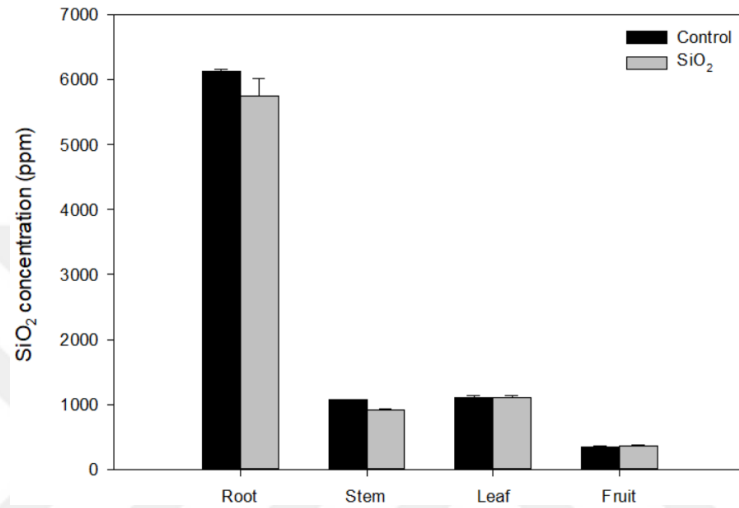
#### **4.2.5 Nanoparticle translocation in plants**

Nanoparticles mostly accumulate in roots and in some cases translocate to other parts of the plants (Ma et al., 2010; Nair et al., 2010). The accumulation and translocation depends on the physiochemical parameters of nanoparticles (Larue et al., 2012). One of the aim of the study is inhibiting the nanoparticle translocation to other parts of the plant, especially

edible parts. For this purpose, the nanoparticle presence in the different parts of the plants were investigated by XRF ( $\text{TiO}_2$  and  $\text{SiO}_2$ ) and RAMAN spectroscopy (CNT).

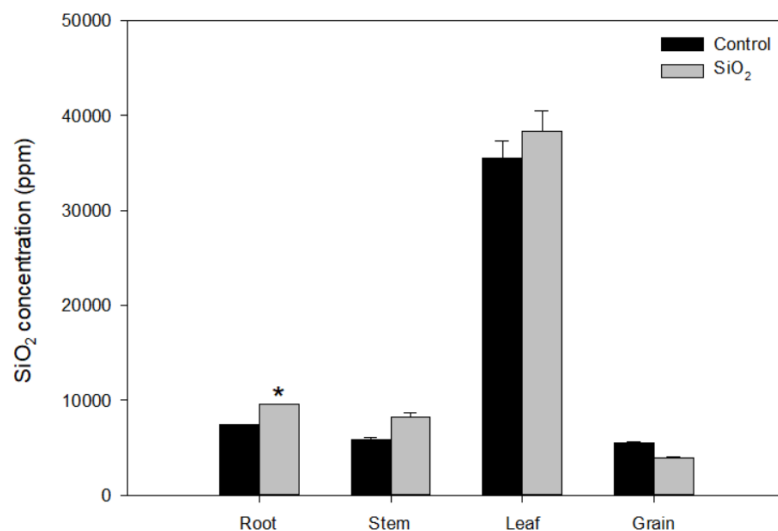
#### 4.2.5.1 XRF analysis

XRF was used to determine  $\text{SiO}_2$  and  $\text{TiO}_2$  content of different parts of the plants.



**Figure 4.76.**  $\text{SiO}_2$  content of parts of tomato plant

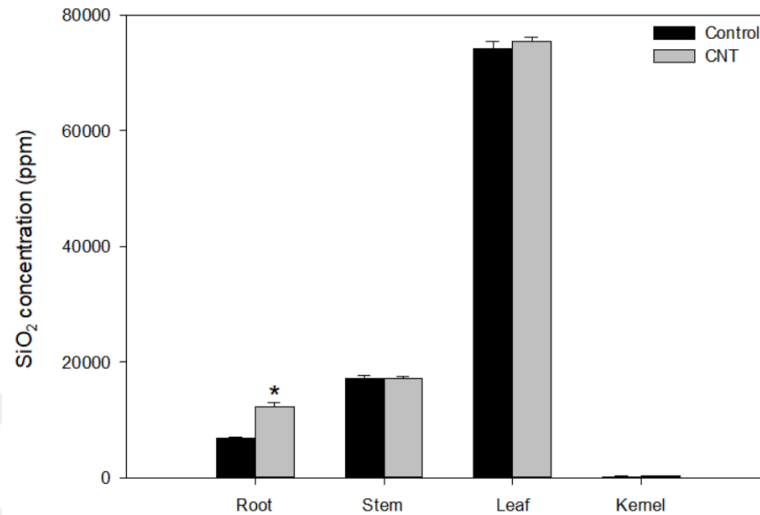
Figure 4.76 presents  $\text{SiO}_2$  content of different parts of tomato plants. According to figure, the  $\text{SiO}_2$  treatment did not change the  $\text{SiO}_2$  content of any part of the tomato plants.



(\*) indicates significant difference ( $p < 0.05$ ) between groups.

**Figure 4.77.**  $\text{SiO}_2$  content of parts of bean plant

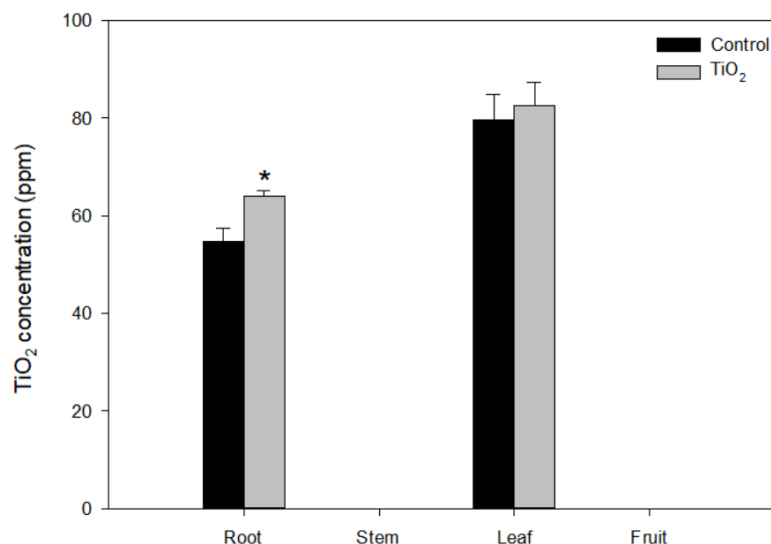
SiO<sub>2</sub> nanoprimer application increased 28% of SiO<sub>2</sub> content in root of bean plant and did not affect the other parts (Figure 4.77). Besides, the SiO<sub>2</sub> content of maize root also 76% increased by SiO<sub>2</sub> nanoprimer of the seeds (Figure 4.78)



(\*) indicates significant difference ( $p < 0.05$ ) between groups.

**Figure 4.78.** SiO<sub>2</sub> content of parts of maize plant

TiO<sub>2</sub> content of the plants were investigated also by XRF. TiO<sub>2</sub> did not found in any parts of bean and maize plants. Also, there was no TiO<sub>2</sub> in stem and fruit of tomato plants. On the other hand, TiO<sub>2</sub> nanoprimer increased the TiO<sub>2</sub> content of root by 17% (Figure 4.79)

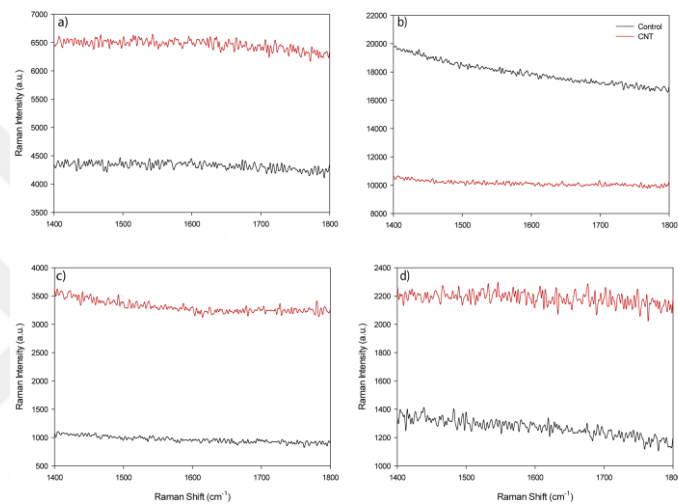


(\*) indicates significant difference ( $p < 0.05$ ) between groups.

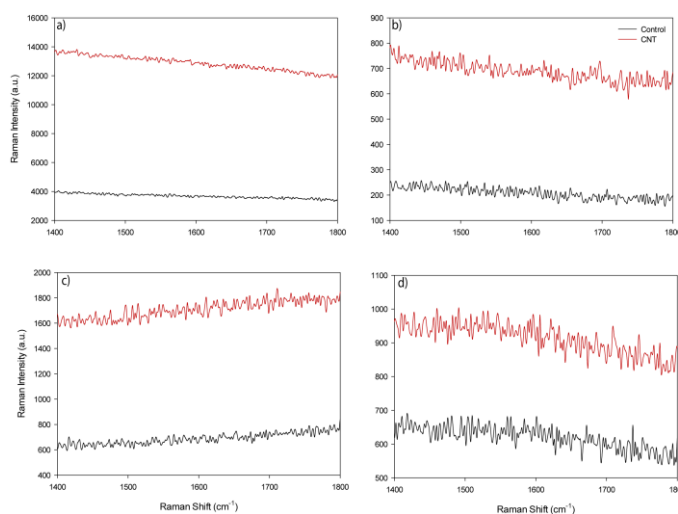
**Figure 4.79.** TiO<sub>2</sub> content of parts of tomato plant

#### 4.2.5.2 Raman spectroscopy

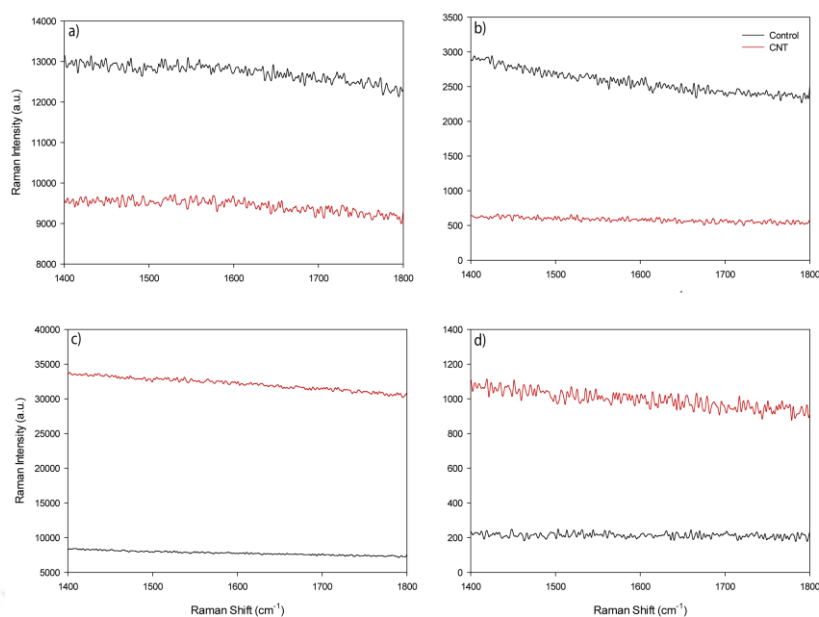
Raman spectroscopy was employed to determine absence or presence of CNT in different parts of the plants. CNT has a characteristic Raman spectrum with disorder-induced D band at  $1343\text{ cm}^{-1}$ , and G band at  $1576\text{ cm}^{-1}$ , which indicates the presence of CNT (Zhang et al., 2016). Figures given below presents the CNT spectrum of tomato (Figure 4.80), bean (Figure 4.81) and maize (Figure 4.82). Any part of the none of the plants contained CNT. Thus, it can be concluded that the CNT did not translocate in the plants.



**Figure 4.80.** Raman spectroscopy root (a), stem (b), leaf (c) and fruit (d) of tomato plant



**Figure 4.81.** Raman spectroscopy root (a), stem (b), leaf (c) and grain (d) of bean plant



**Figure 4.82.** Raman spectroscopy root (a), stem (b), leaf (c) and kernel (d) of maize plant

The translocation and accumulation of nanoparticles depend on type of crop and type, functionalization, stability and chemical component of nanoparticle. The nanoparticles can enter the plant cell via various ways. These ways can be listed as aquaporins, ion channels, endocytosis or by creating new pores (especially CNT) (Rico *et al.*, 2011). Nanoparticles have more surface area compared to their bulk forms, which creates more reactivity with their environment. Thus, nanoparticles can produce complexes with membrane transporters and transported to plant cells through this way (Tio *et al.*, 2010; Watanabe *et al.*, 2008). Most of the metal based nanoparticles can be taken up by ion transporters (Hall *et al.*, 2003). The nanoparticles taken up by a cell can transport to other cells apoplastically, symplastically or plasmodesmata. Nevertheless, more studies are needed to explore the mechanisms of translocation of nanoparticles in plants (Rico *et al.*, 2011).

Various studies on genetic effect on edible plants were conducted. The chromosomal and genetic changes in plant cells have been reported (Kumari *et al.*, 2009; Shen *et al.*, 2010; Tan and Fugetsu, 2007; Tan, *et al.*, 2009). Thus, inhibiting of translocation of nanoparticles to the edible parts of the plant is very important. In the current study, any nanoparticle residual was detected in the edible parts of the plants. By using nanopriming

technique, instead of continuous nanoparticle application to plants, the translocation of nanoparticles in plants were inhibited.

### 4.3 Effects of NP containing polymer coating of seed on seed germination under laboratory conditions (WP III)

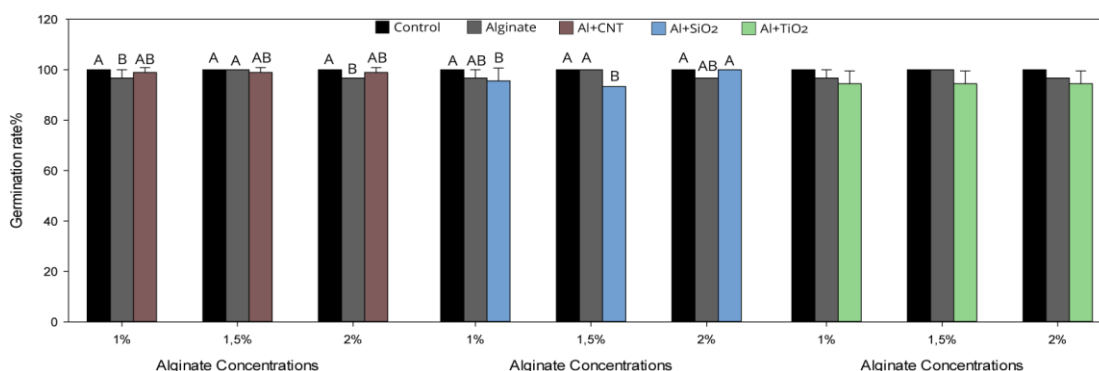
The coating of tomato and maize seeds was performed by gelatin, alginate and chitosan with CNT, SiO<sub>2</sub> and TiO<sub>2</sub> at concentrations defined in Table 3.4.

#### 4.3.1 Treatment with alginate

Both tomato and maize seeds were coated with alginate at 1%, 1,5% and 2% concentrations with and without nanoparticles. The germination test was conducted as described in section 3.1.

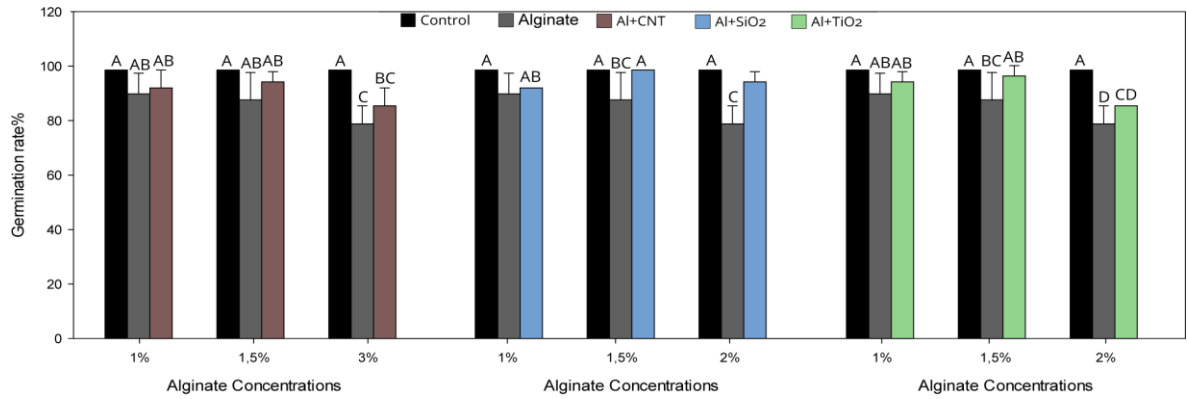
##### 4.3.1.1 Germination rate (%)

Right after the coating of both tomato and maize seeds by alginate the germination rate was calculated at the end of the germination test.



**Figure 4.83.** Germination rate (%) of alginate coated tomato seeds

The seed germination rate of tomato seeds after coating with alginate was not changed in general. Addition of CNT and TiO<sub>2</sub> did not affect the germination rate of tomato seeds. However, SiO<sub>2</sub> addition to alginate matrix decreased the germination rate at 1 and 1,5% pf alginate and increased at 2% alginate (Figure 4.83).

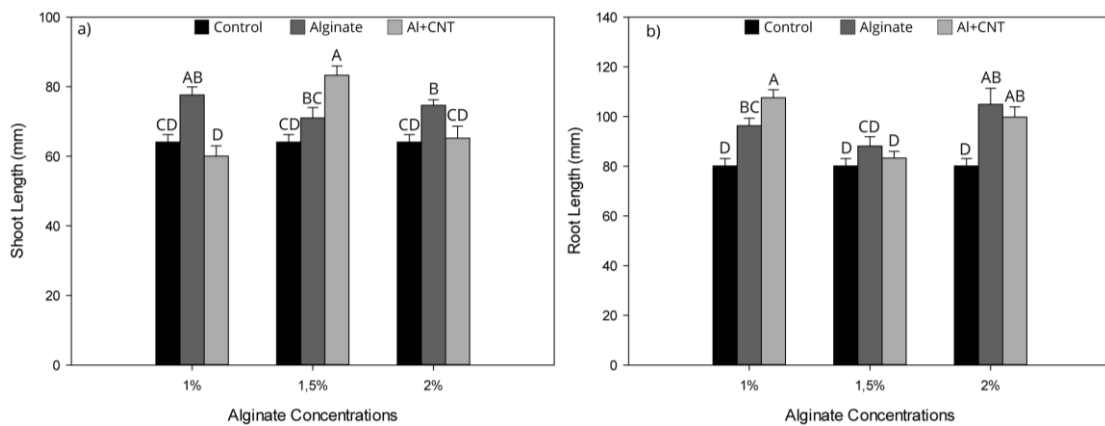


**Figure 4.84.** Germination rate (%) of alginate coated maize seeds

The germination rate of maize seeds was decreased by alginate coating by increasing in the alginate concentration. On the other hand, addition of nanoparticle to alginate matrix increased the germination rate of maize seeds (Figure 4.84).

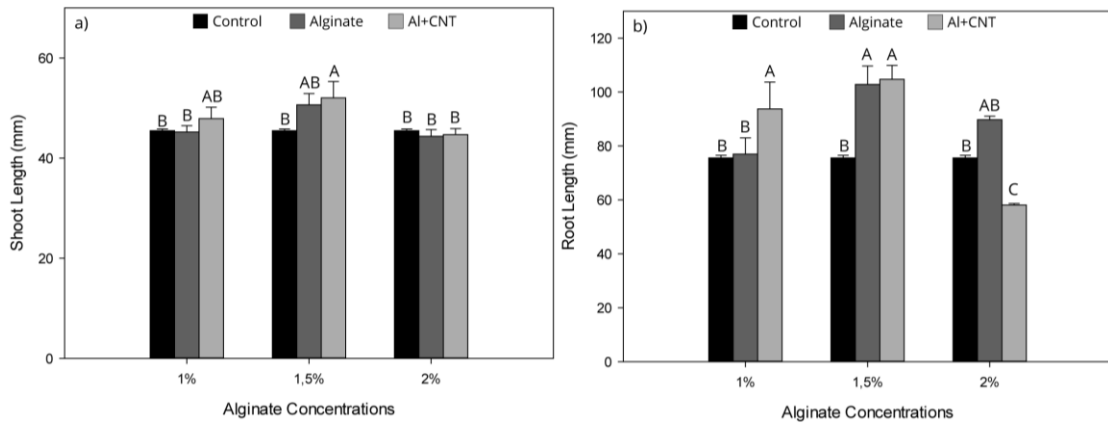
#### 4.3.1.2 Shoot and root growth

Shoot and root growth of tomato and maize seedling were determined by measuring shoot and root length, shoot and root fresh and dry weight.



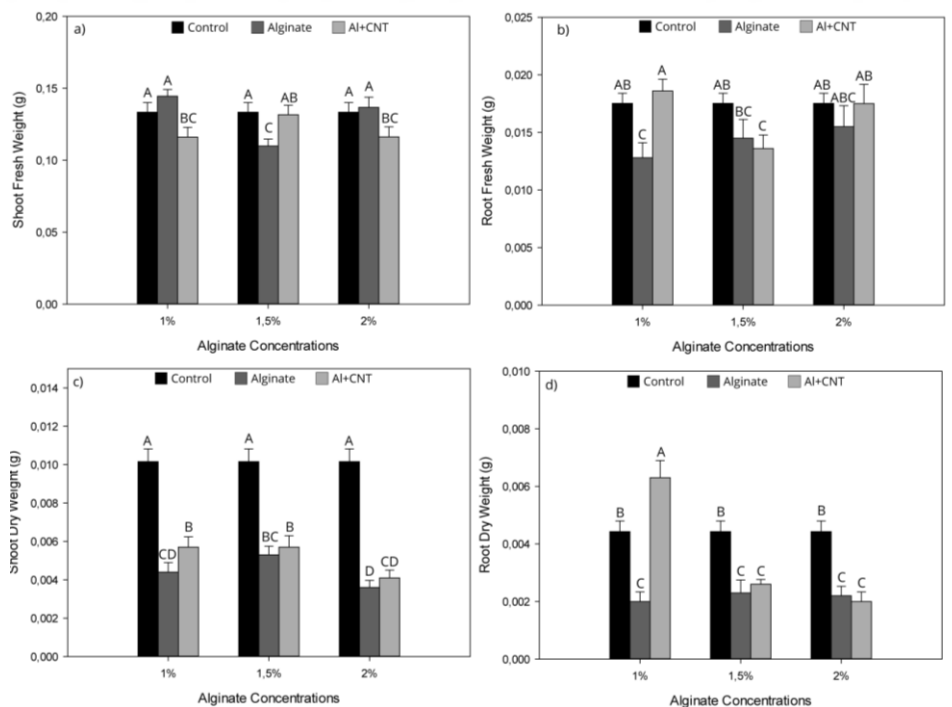
**Figure 4.85.** Shoot (a) and root (b) length of alginate/CNT coated tomato seeds

Alginate coating of tomato seeds increased both shoot (a) and root (b) length. Addition of CNT to alginate matrix decreased shoot length at 1 and 2%. However, addition of CNT to 1.5% alginate matrix increased shoot length. On the other hand, CNT addition to 1% of alginate increased root length and did not change in 1.5 and 2% of alginate.



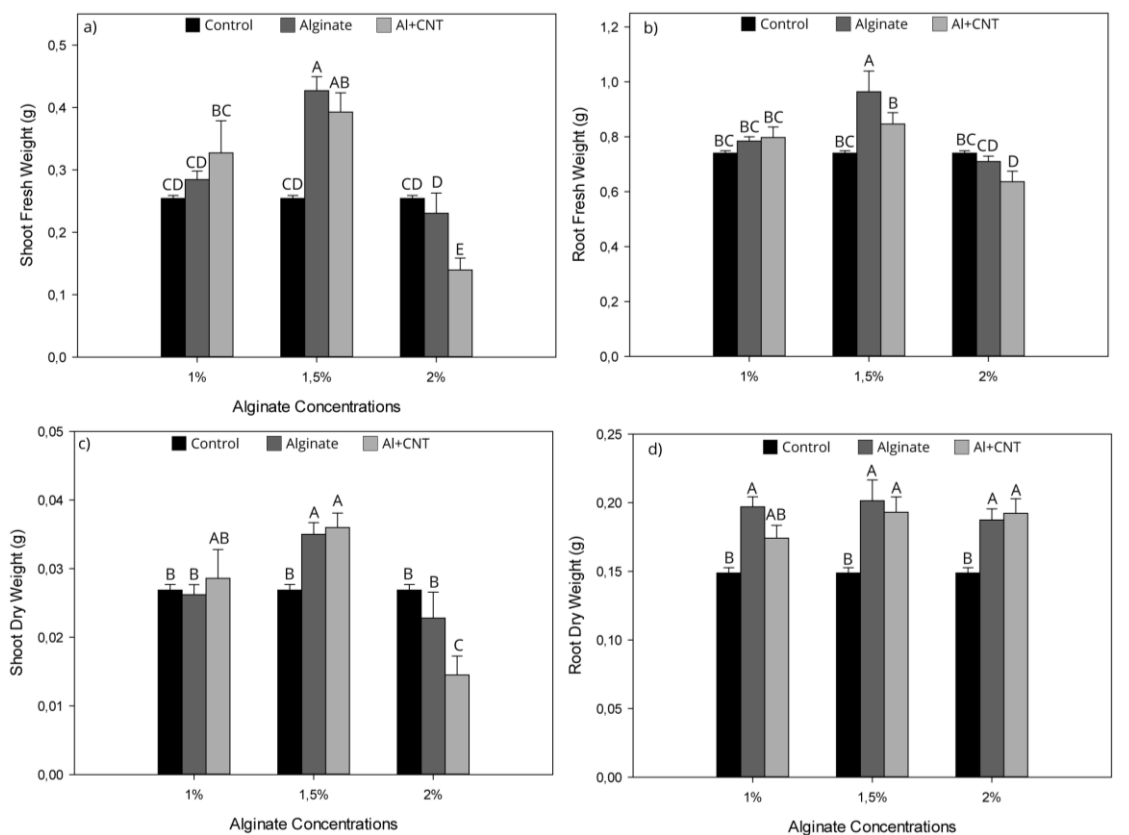
**Figure 4.86.** Shoot (a) and root (b) length of alginate/CNT coated maize seeds

Alginate coating of maize seeds increased the shoot length at 1,5% of concentration and did not change at other concentrations (Figure 4.86a). Likewise, root length of maize seedlings was not changed at 1% of alginate coating and increased by 1,5 and 2% of alginate (Figure 4.86b). Addition of CNT to alginate matrix increased shoot length at 1 and 1,5% concentrations and did not change at 2% concentration. In terms of root length, addition of CNT increased at 1% and effect of CNT decreased by increasing in alginate concentration. Thus, addition of CNT to 2% of alginate decreased the root length.



**Figure 4.87.** Shoot fresh weight (a), root fresh weight (b), shoot dry weight (c), and root dry weight (d) of alginate/CNT coated tomato seeds

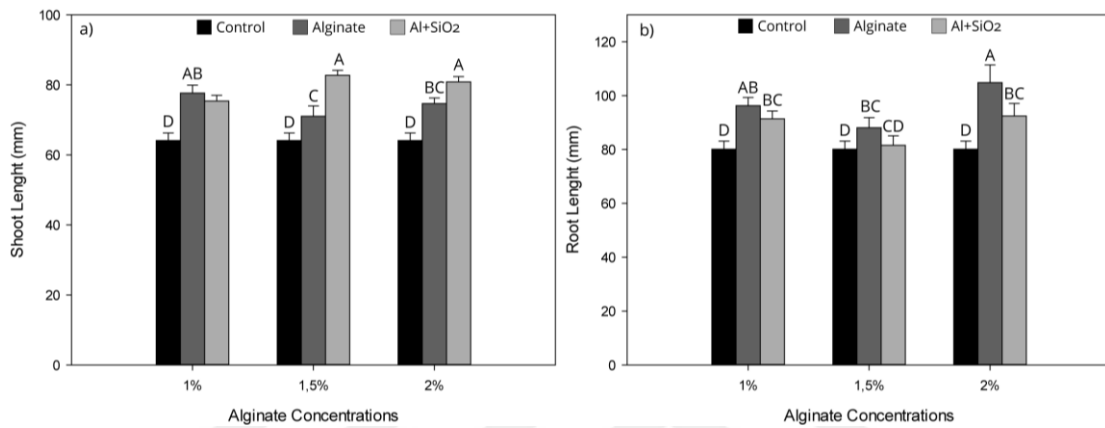
The biomass of tomato seedlings coated with alginate/CNT is presented in Figure 4.87. alginate coating of tomato seeds did not change the shoot length at 1 and 2% and decreased at 1,5% of alginate. The addition of CNT decreased the shoot length to 1 and 2% alginate and increased at 1,5% concentration the shoot length of tomato seedlings (Figure 4.87a). Alginate coating of seeds decreased the root length of tomato seedlings and level of decreasing reduced by increasing in alginate concentration. The addition of CNT increased the root length at 1 and 2% of alginate and decreased at 1,5% (Figure 4.87b). Both shoot (c) and root (d) dry weight of tomato seedling decreased by alginate coating and addition CNT did not change the effect of alginate (Figure 4.87).



**Figure 4.88.** Shoot fresh weight (a), root fresh weight (b), shoot dry weight (c) and root dry weight (d) of alginate/CNT coated maize seeds

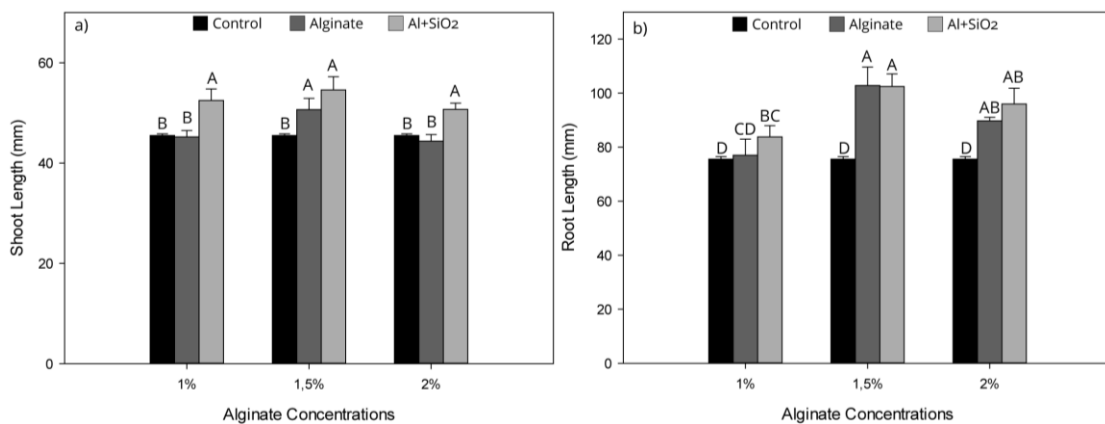
The coating of maize seeds with alginate did not change the shoot fresh weight of maize seedling at 1 and 2%, but increased at 1,5% of alginate concentration. However, addition of CNT increased shoot fresh weight to 1% of alginate, did not change to 1,5% alginate and decreased at 2% of alginate concentration (Figure 4.88a). The impact of alginate coating of maize seeds changes according to concentration to root fresh weight. At 1% of concentration the root fresh weight was constant, at 1,5% increased and at 2% decreased.

Addition of CNT did not change root fresh weight to 1% of alginate and decreased the rest of concentrations (Figure 4.88b). Figure 4.88c presents the shoot dry weight, where did not change at 1 and 2% of alginate concentrations and increased at 1,5%. Addition of CNT increased shoot dry weight at 1% of alginate, did not change at 1,5% of alginate and decreased at 2% of alginate. The root dry weight of maize seedlings increased by alginate coating and addition of CNT did not change the impact of alginate as presented in Figure 4.88d.



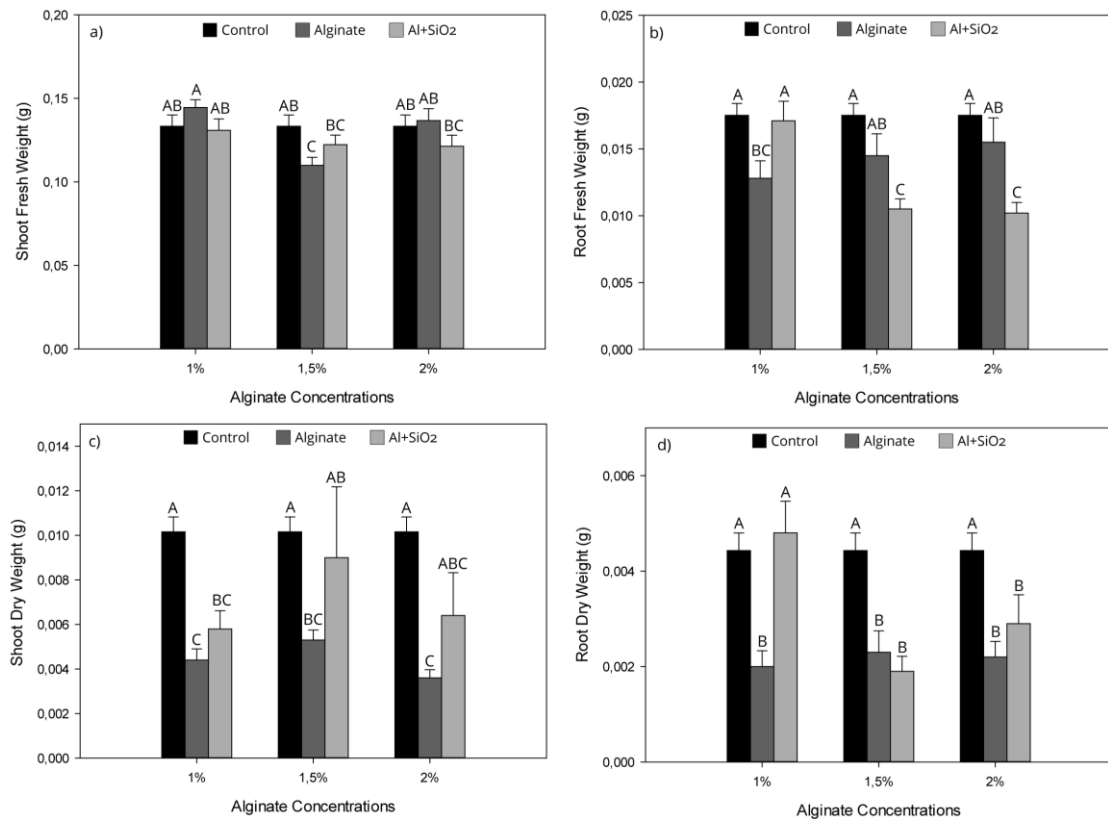
**Figure 4.89.** Shoot (a) and root (b) length of alginate/SiO<sub>2</sub> coated tomato seeds

The effect of alginate on tomato seedling length discussed above. However, addition of SiO<sub>2</sub> to alginate matrix increased shoot length of tomato seedlings at 1,5 and 2% of alginate and did not change at 1% (Figure 4.89a). Addition of SiO<sub>2</sub> to alginate matrix decreased the impact of alginate on root length (Figure 4.89b).



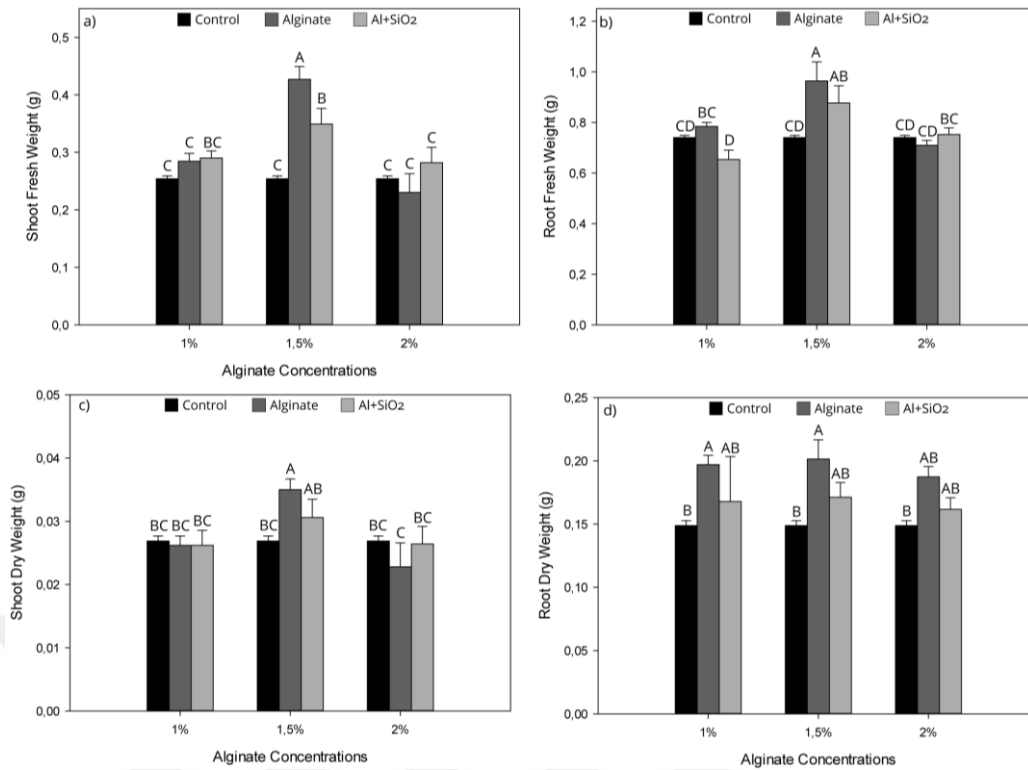
**Figure 4.90.** Shoot (a) and root (b) length of alginate/SiO<sub>2</sub> coated maize seeds

The addition of SiO<sub>2</sub> to alginate matrix increased the shoot length of maize seedlings at 1 and 2% of concentrations; however, did not change at 1,5% concentration (Figure 4.90a). The root length of maize seedlings increased by addition of SiO<sub>2</sub> to 1% of alginate and did not change at the rest of concentrations (Figure 4.90b).



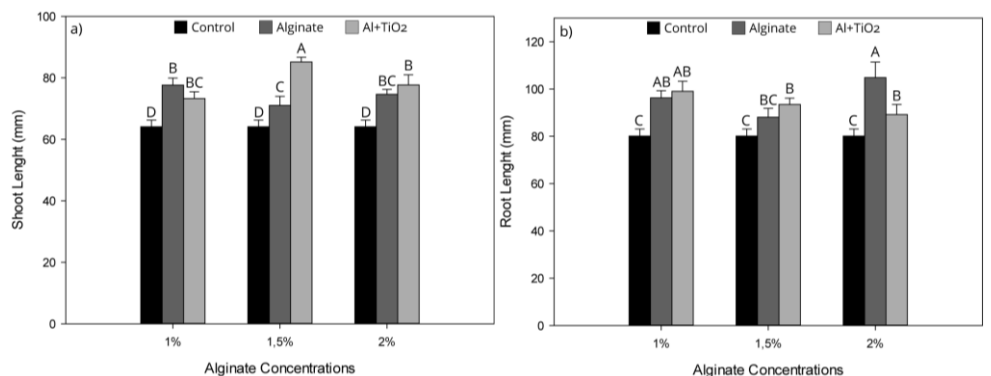
**Figure 4.91.** Shoot fresh weight (a), root fresh weight (b), shoot dry weight (c) and root dry weight (d) of alginate/SiO<sub>2</sub> coated tomato seeds

Addition of SiO<sub>2</sub> to alginate matrix decreased the shoot fresh weight at 1 and 2% of alginate and increased at 1,5% (Figure 4.91a). The root fresh weight was decreased by addition of SiO<sub>2</sub> to 1,5 and 2% of alginate and increased at 1% (Figure 4.91b). The shoot dry weight of tomato seedlings increased by addition of SiO<sub>2</sub> to alginate matrix (Figure 4.91c). On the other hand, SiO<sub>2</sub> addition did not change the impact of alginate at 1,5 and 2% on root dry weight, where increased at 1% (Figure 4.91d).



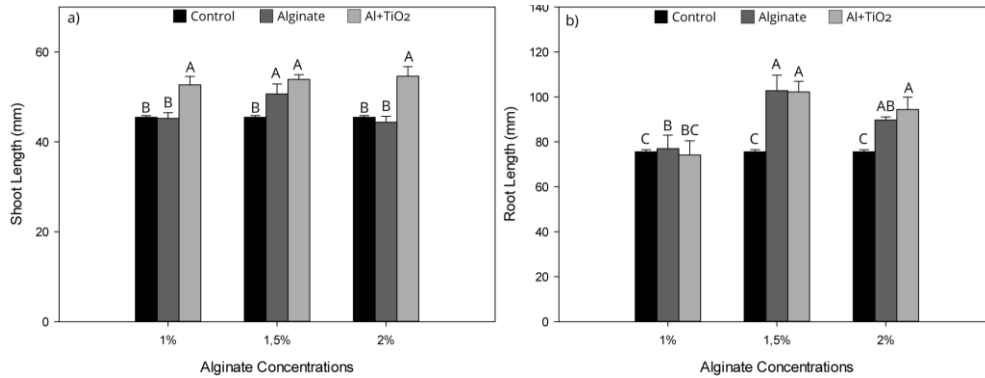
**Figure 4.92.** Shoot fresh weight (a), root fresh weight (b), shoot dry weight (c) and root dry weight (d) of alginate/SiO<sub>2</sub> coated maize seeds

Addition of SiO<sub>2</sub> to alginate matrix decreased the impact of alginate at 1,5% and did not change the effect at 1 and 2% of alginate on shoot (Figure 4.92a). SiO<sub>2</sub> addition to coating material decreased root fresh weight to 1 and 1,5% of alginate and increased at 2% (Figure 4.92b). Both shoot (c) and root (d) dry weight of maize seedlings was not changed by addition of SiO<sub>2</sub> to alginate matrix (Figure 4.92).



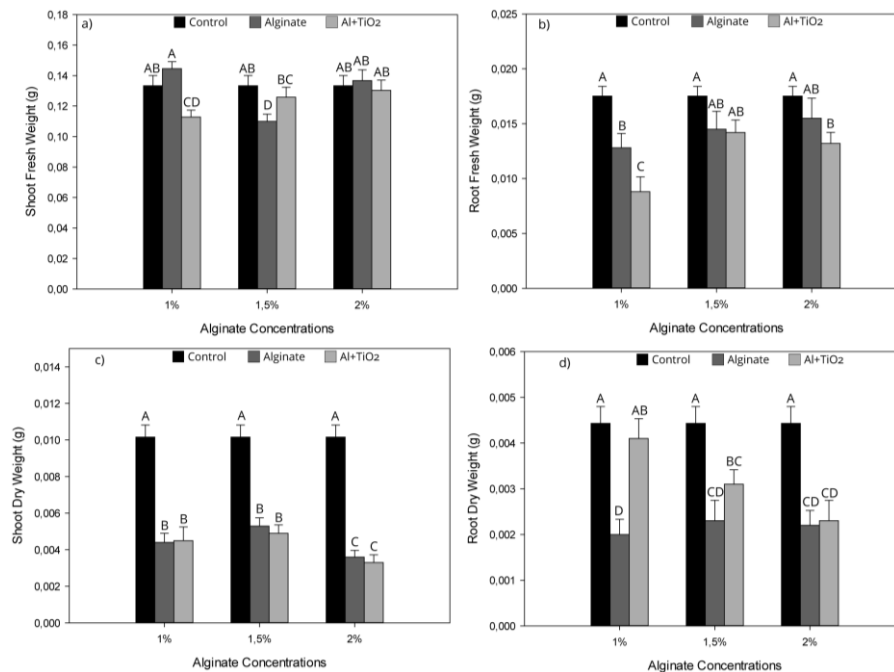
**Figure 4.93.** Shoot (a) and root (b) length of alginate/TiO<sub>2</sub> coated tomato seeds

Addition of TiO<sub>2</sub> to alginate matrix did not change the shoot length at 1 and 2% and increased at 1,5% of alginate (Figure 4.93a). Besides, root length of tomato seedlings did not change at 1 and 1,5% of alginate by addition of TiO<sub>2</sub> and decreased at 2%.



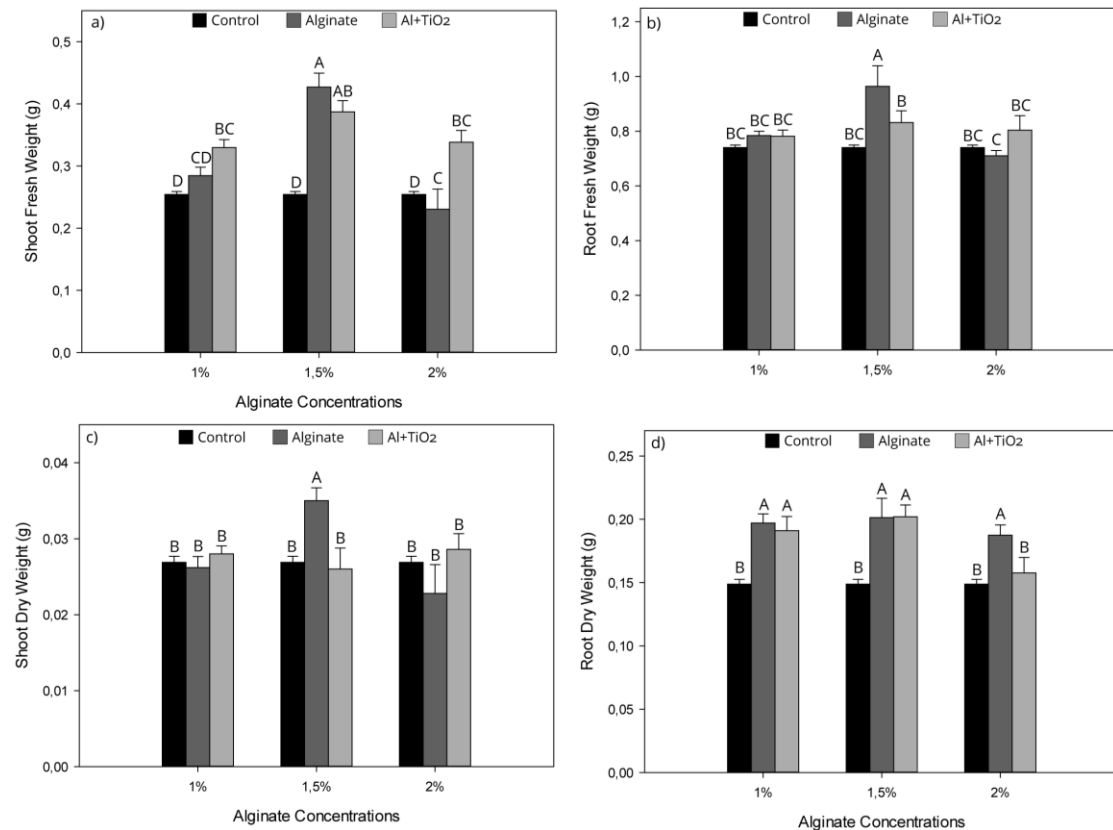
**Figure 4.94.** Shoot (a) and root (b) length of alginate/TiO<sub>2</sub> coated maize seeds

The shoot length of the maize seedlings was increased after coating with 1 and 2% of alginate containing TiO<sub>2</sub>. However, TiO<sub>2</sub> did not change the effect of alginate at 1,5% concentration of alginate (Figure 4.94a). On the other hand, root length of maize seedlings did not change by addition of TiO<sub>2</sub> to alginate matrix (Figure 4.94b).



**Figure 4.95.** Shoot fresh weight (a), root fresh weight (b), shoot dry weight (c) and root dry weight (d) of alginate/TiO<sub>2</sub> coated tomato seeds

Addition of TiO<sub>2</sub> to alginate matrix decreased the shoot fresh weight of tomato seedlings at 1% and increased at 1,5% (Figure 4.95a). The root fresh weight decreased by addition of TiO<sub>2</sub> to alginate matrix at 1 and 1,5% concentration (Figure 4.95b). On the other hand, there was no effect of TiO<sub>2</sub> on shoot dry weight (Figure 4.95c). At 1% and 1,5% of alginate, the root dry weight increased by addition of TiO<sub>2</sub> as presented in Figure 4.95d.



**Figure 4.96.** Shoot fresh weight (a), root fresh weight (b), shoot dry weight (c) and root dry weight (d) of alginate/TiO<sub>2</sub> coated maize seeds

The shoot fresh weight of maize seedlings increased by addition of TiO<sub>2</sub> at 1 and 2% of alginate and did not change at 1,5% as presented in Figure 4.96a. On the other hand, root fresh weight did not change by addition of TiO<sub>2</sub> 1 and 2%, but decreased at 1,5% (Figure 4.96b). Addition of TiO<sub>2</sub> to alginate matrix did not change the shoot dry weight at 1 and 2%, and decreased the impact of 1,5% of alginate (Figure 4.96c). Figure 4.96d presents the root dry weight of maize seedlings, which was not change by TiO<sub>2</sub> addition to alginate matrix at 1 and 1,5% and decreased at 2%.

The alginate treatment of maize seeds increased  $\alpha$  and  $\beta$ -amylase activity which promotes the seed germination. Also alginate increased the root development of maize seedlings

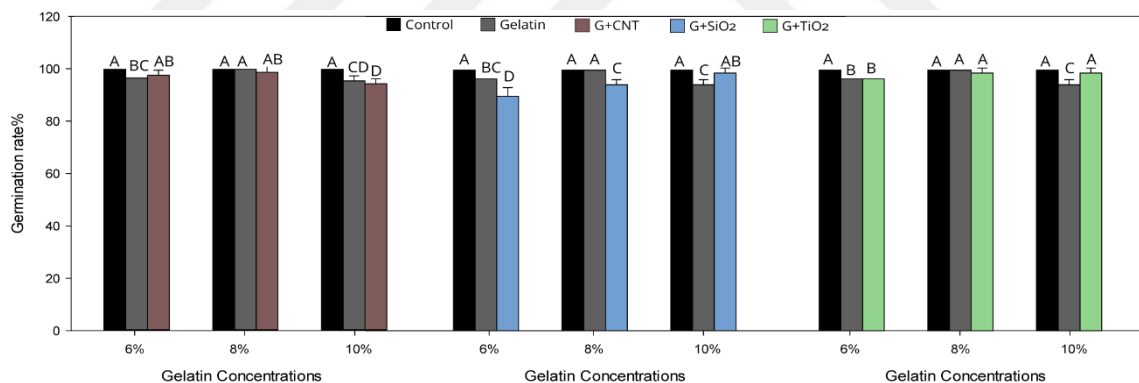
(Hu et. al., 2004). In the current study, hybrid seeds, which already had high germination rate; thus, the effect of alginate on seed germination was not observed. However, addition of nanoparticles to alginate matrix increased maize seed germination. Addition of CNT and SiO<sub>2</sub> to 1% of alginate increased the biomass of seedlings. Thus, this novel coating material could be used to seeds especially have immature embryo.

### 4.3.2 Treatment with gelatin

Both tomato and maize seeds were coated with gelatin at 6%, 8% and 10% concentrations with and without nanoparticle. The germination test was conducted as described in section 3.1.

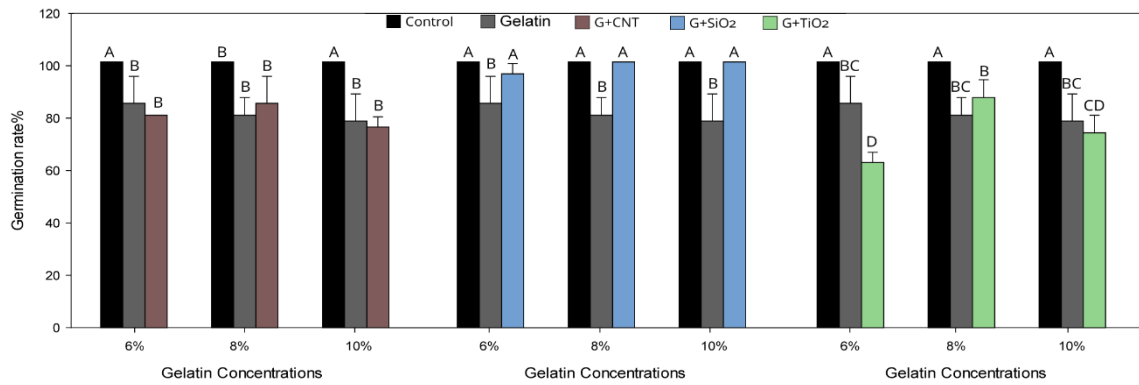
#### 4.3.2.1 Germination rate (%)

At the end of the germination test tomato (21<sup>st</sup> day) and maize (7<sup>th</sup> day) seedlings were harvested. The first analysis was germination rate.



**Figure 4.97.** Germination rate (%) of gelatin coated tomato seeds

Figure 4.97 presents the germination rate of tomato seeds after gelatin coating. According to the figure, 8% of gelatin showed best performance in terms of seed germination. 6 and 10% of gelatin decreased seed germination. On the other hand, CNT and SiO<sub>2</sub> addition to coating material also decreased seed germination rate. However, TiO<sub>2</sub> addition to gelatin matrix as coating material did not change seed germination rate.

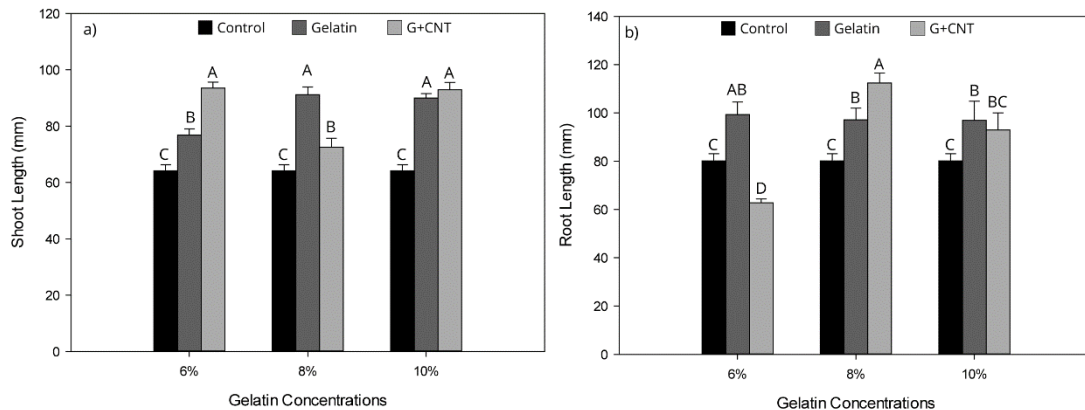


**Figure 4.98.** Germination rate (%) of gelatin coated maize seeds

Figure 4.98 presents the germination rate of maize seeds after gelatin coating. The gelatin coating of maize seeds decreased the seed germination. Besides, addition of SiO<sub>2</sub> increased the seed germination rate. However, CNT and TiO<sub>2</sub> treatment did not affect the germination rate of maize seeds.

#### 4.3.2.2 Shoot and root growth

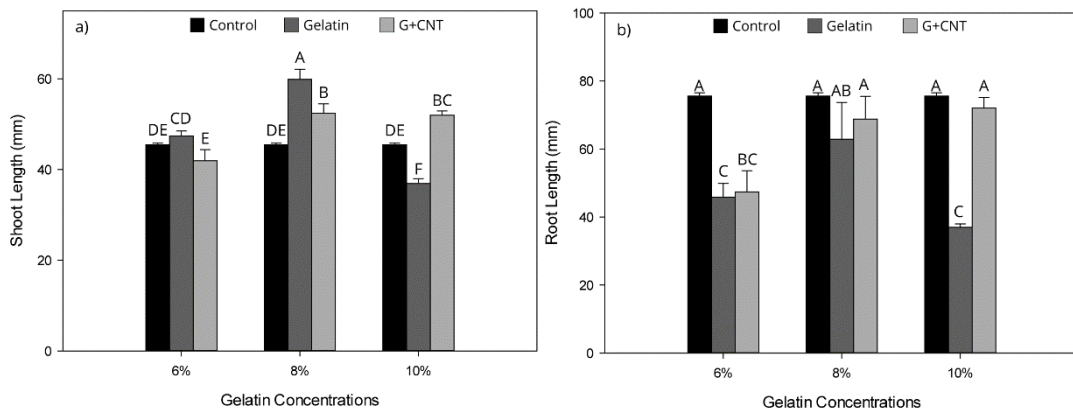
Shoot and root growth of tomato and maize seedling were determined by measuring shoot and root length, shoot and root fresh and dry weight.



**Figure 4.99.** Shoot (a) and root (b) length of gelatin/CNT coated tomato seeds

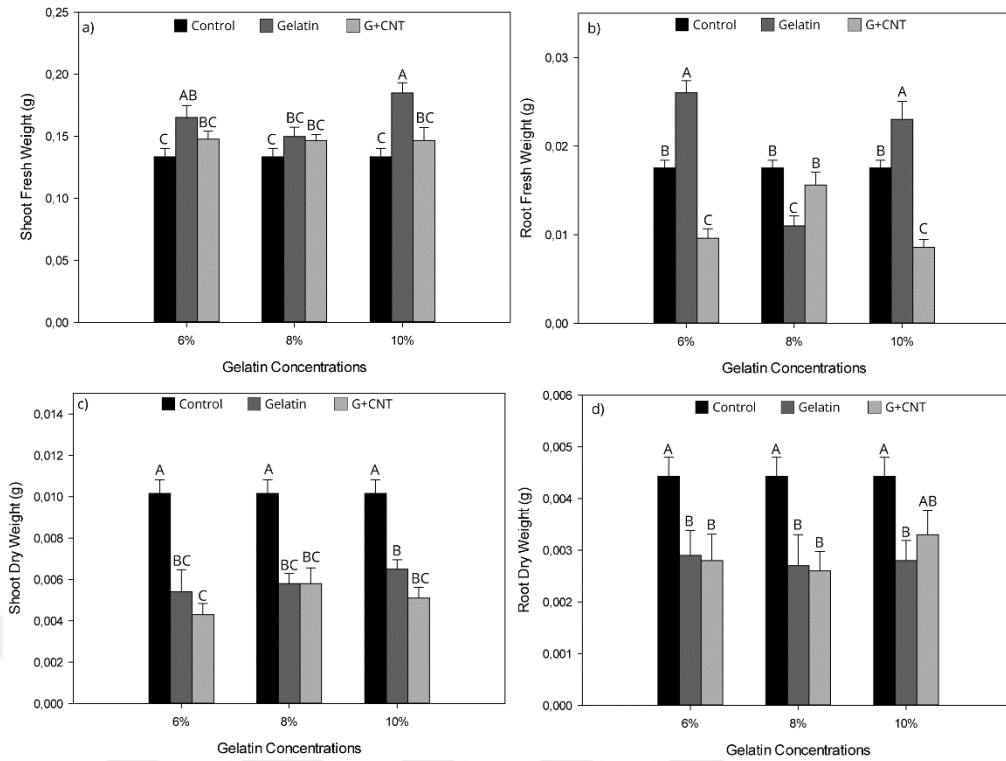
The shoot length of tomato seedlings was improved by gelatin coating. 8 and 10% of gelatin matrix gave the most effective results. Besides, addition of CNT to 6% of gelatin matrix increased the shoot length of tomato seedlings (Figure 4.99a). Likewise, gelatin coating improved the root development (Figure 4.99b). 6% of gelatin showed best performance on tomato root length development. However, addition of CNT decreased

shoot development 6 and 10% of gelatin, when the 8% gelatin with CNT addition had the longest root of tomato seedlings.



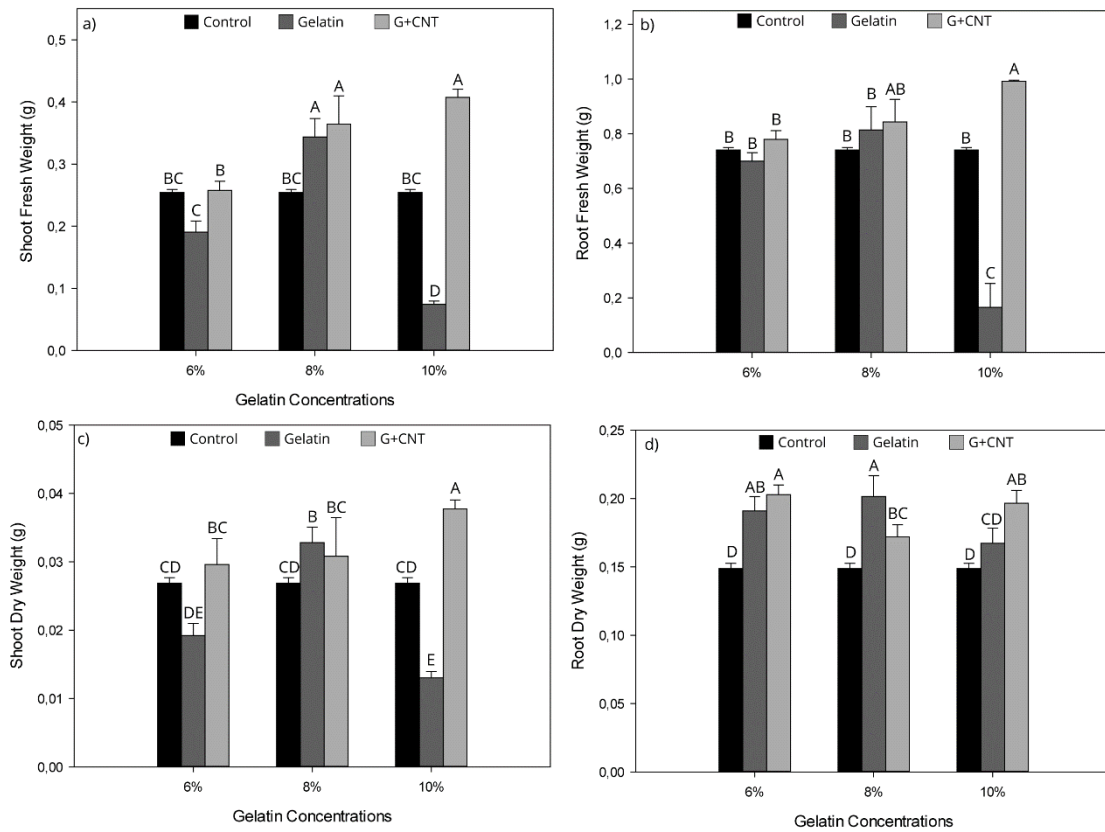
**Figure 4.100.** Shoot (a) and root (b) length of gelatin/CNT coated maize seeds

When the 6 and 8% of gelatin coating increased the shoot length of maize seedlings, the 10% of gelatin decreased the seedling length (Figure 4.100a). The addition of CNT to gelatin matrix decreased the shoot length in 6 and 8% concentrations. However, addition of CNT compensated decreasing in shoot length by 10% of gelatin and increased the shoot length. The root length of maize seedlings was decreased by gelatin treatment as presented in Figure 4.100b. Nonetheless, addition of CNT increased seedling root length in maize seeds.



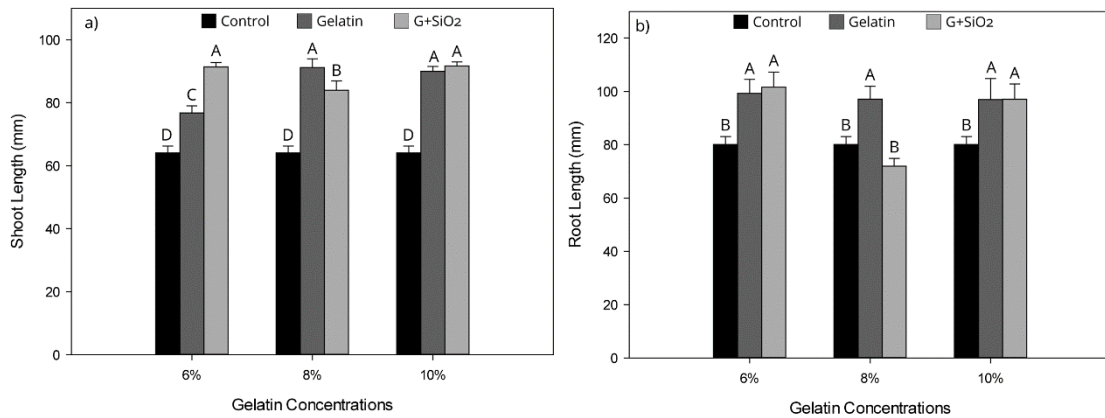
**Figure 4.101.** Shoot fresh weight (a), root fresh weight (b), shoot dry weight (c) and root dry weight (d) of gelatin/CNT coated tomato seeds

Other shoot and root growth parameters are fresh and dry weight of the root and shoot. The shoot fresh weight (Figure 4.101a) and root fresh weight (Figure 4.101b) increased by gelatin coating of seeds. However, 8% of gelatin decreased root fresh weight. However, addition of CNT to gelatin matrix decreased the biomass of seedlings in terms of fresh weight. On the other hand, gelatin coating decreased both shoot dry weight (Figure 4.101c) and root dry weight (Figure 4.101d). Additionally, CNT application to tomato seeds did not affect seedlings shoot and root dry weight.



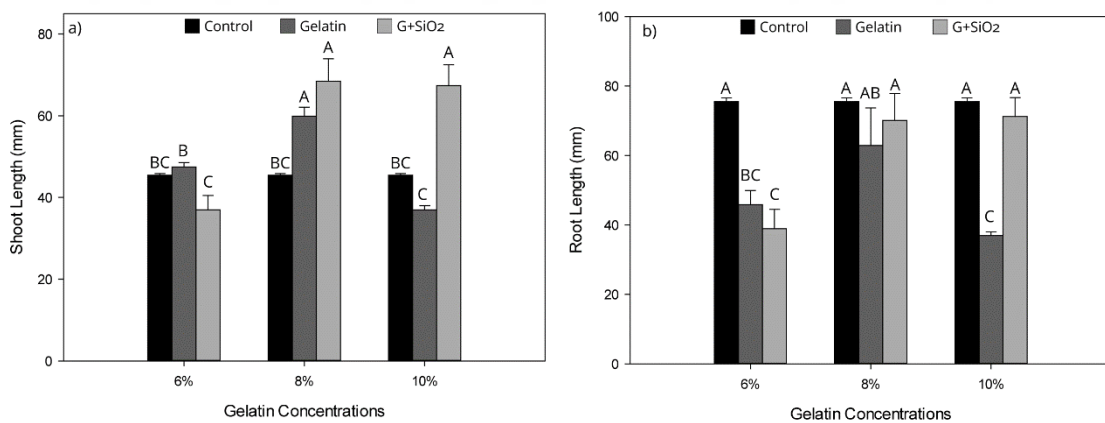
**Figure 4.102.** Shoot fresh weight (a), root fresh weight (b), shoot dry weight (c) and root dry weight (d) of gelatin/CNT coated maize seeds

Gelatin coating decreased the shoot fresh weight of maize seedlings at 6 and 10% concentrations. In contrast, 8% of gelatin coating increased the shoot fresh weight (Figure 4.102a). The same results were obtained for shoot dry weight (Figure 4.102c). Luckily, addition of CNT increased shoot both fresh and dry weight. On the other hand, gelatin coating did not change root fresh weight in 6 and 8%, where the 10% decreased (Figure 4.102b). The root fresh weight did not change by addition of CNT in 6 and 8% of gelatin matrix. However, the root fresh weight highly increased by 10% gelatin with CNT addition. The root dry weight increased by gelatin coating at all concentrations (Figure 4.102d). Addition of CNT to gelatin matrix increased the impact of gelatin on root dry weight.



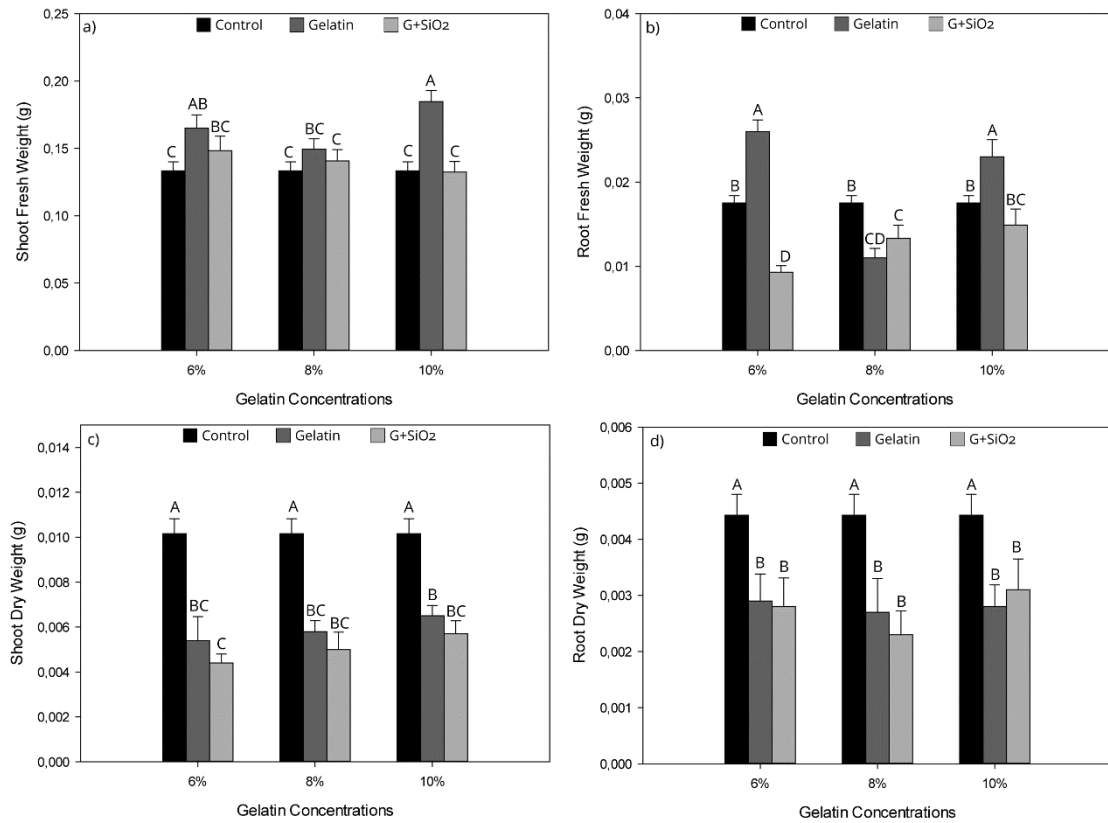
**Figure 4.103.** Shoot (a) and root (b) length of gelatin/SiO<sub>2</sub> coated tomato seeds

The effect of gelatin coating of tomato seeds on shoot and root length was discussed above. However, Figure 4.103 presents the effect of SiO<sub>2</sub> addition to gelatin matrix on shoot length (a), and root length (b). As presented in the figure, SiO<sub>2</sub> addition increased the shoot length at 6% and did not change the root length. When the SiO<sub>2</sub> was added to 8% gelatin matrix both shoot and root length decreased and addition of SiO<sub>2</sub> in 10% gelatin did not have any effect on shoot and root length of tomato seeds as presented in the figure.



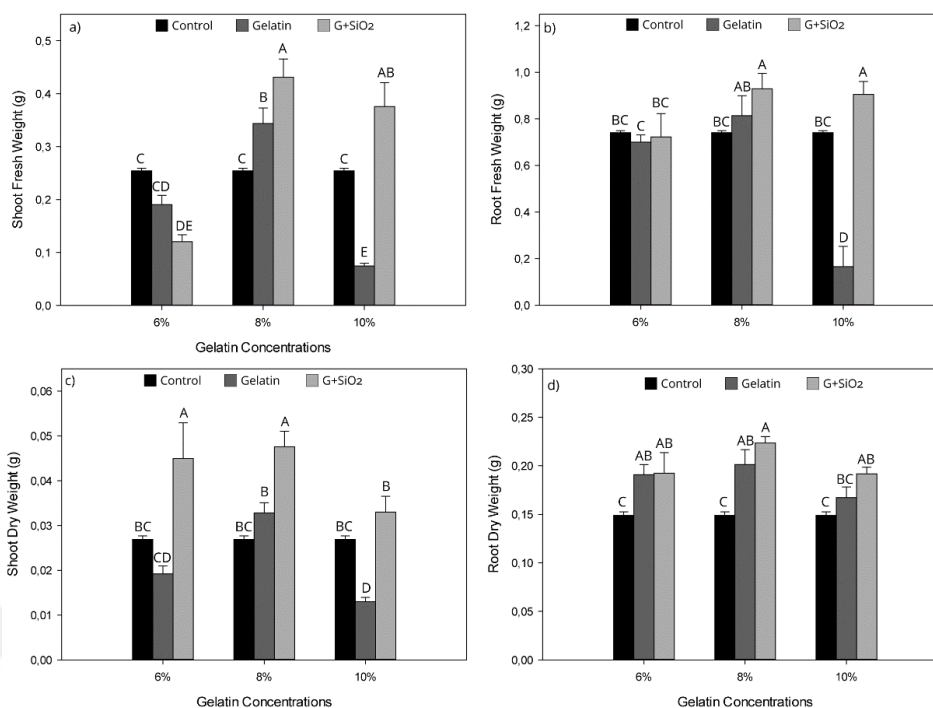
**Figure 4.104.** Shoot (a) and root (b) length of gelatin/SiO<sub>2</sub> coated maize seeds

The addition of SiO<sub>2</sub> to gelatin matrix decreased both shoot (a) and root (b) length of maize seedlings (Figure 4.104). However, this treatment did not change the effect of gelatin at 8% concentration, where increased the at 10% of concentration.



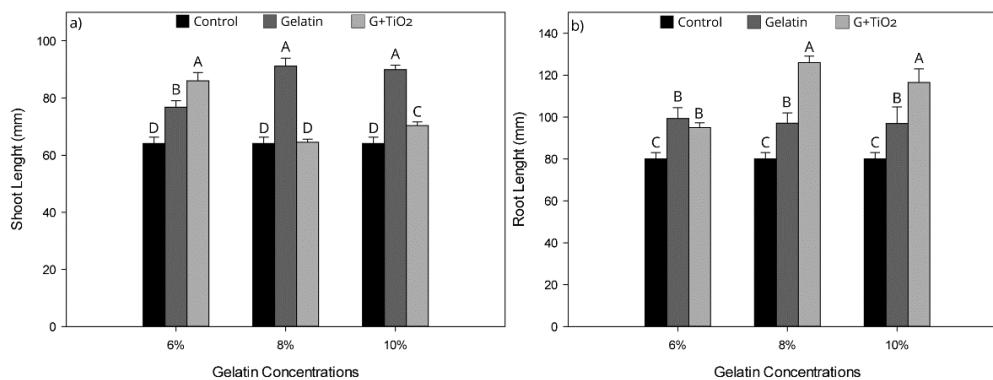
**Figure 4.105.** Shoot fresh weight (a), root fresh weight (b), shoot dry weight (c) and root dry weight (d) of gelatin/SiO<sub>2</sub> coated tomato seeds

The effect of gelatin coating on tomato seedling biomass was discussed above. However, addition of SiO<sub>2</sub> decreased the impact of gelatin on shoot (a) and root (b) fresh weight. Likewise CNT, addition of SiO<sub>2</sub> did not change the effect of gelatin at all concentrations in terms of shoot (c) and root (d) dry weight as presented in Figure 4.105.



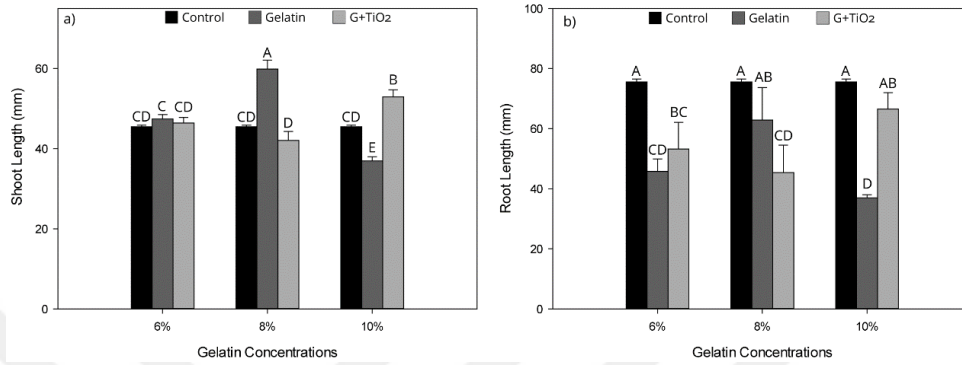
**Figure 4.106.** Shoot fresh weight (a), root fresh weight (b), shoot dry weight (c) and root dry weight (d) of gelatin/SiO<sub>2</sub> coated maize seeds

When the addition of SiO<sub>2</sub> decreased the shoot fresh weight of maize seedlings to 6% of gelatin, it increased the impact of gelatin coating at 8 and 10% (Figure 4.106a). On the other hand, the addition of SiO<sub>2</sub> did not change the effect of gelatin on root fresh weight at 6 and 8% and increased at 10% of gelatin (Figure 4.106b). It was observed that, the addition of SiO<sub>2</sub> to gelatin coating increased the both shoot (c) and root (d) dry weight as presented in Figure 4.106.



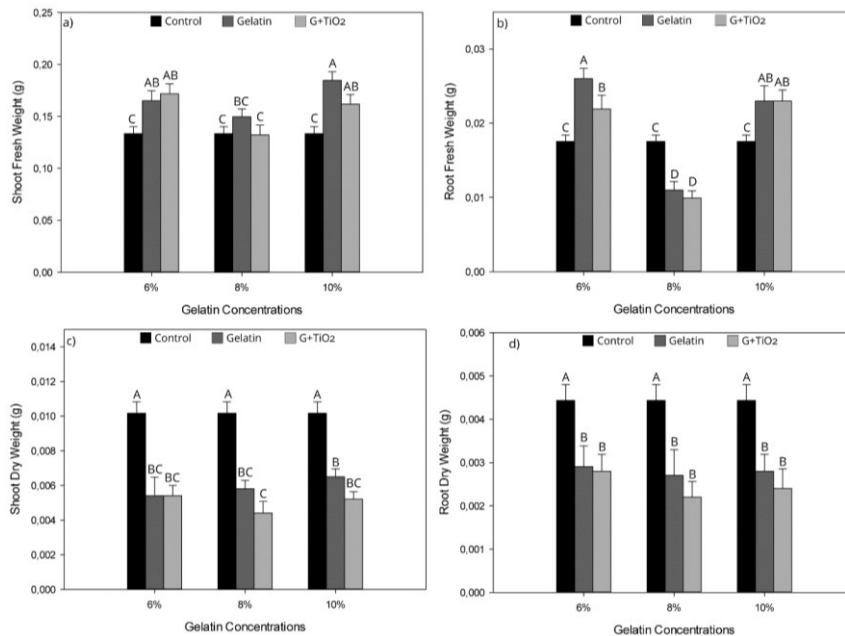
**Figure 4.107.** Shoot (a) and root (b) length of gelatin/TiO<sub>2</sub> coated tomato seeds

Figure 4.107 presents the effect of gelatin/TiO<sub>2</sub> coating on shoot (a) and root (b) length of tomato seedlings. Addition of TiO<sub>2</sub> to gelatin matrix increased the shoot length at 6% and decreased at 8 and 10% of gelatin. On the other hand, root length did not change by addition of TiO<sub>2</sub> at 6%, but increased at 8 and 10%.



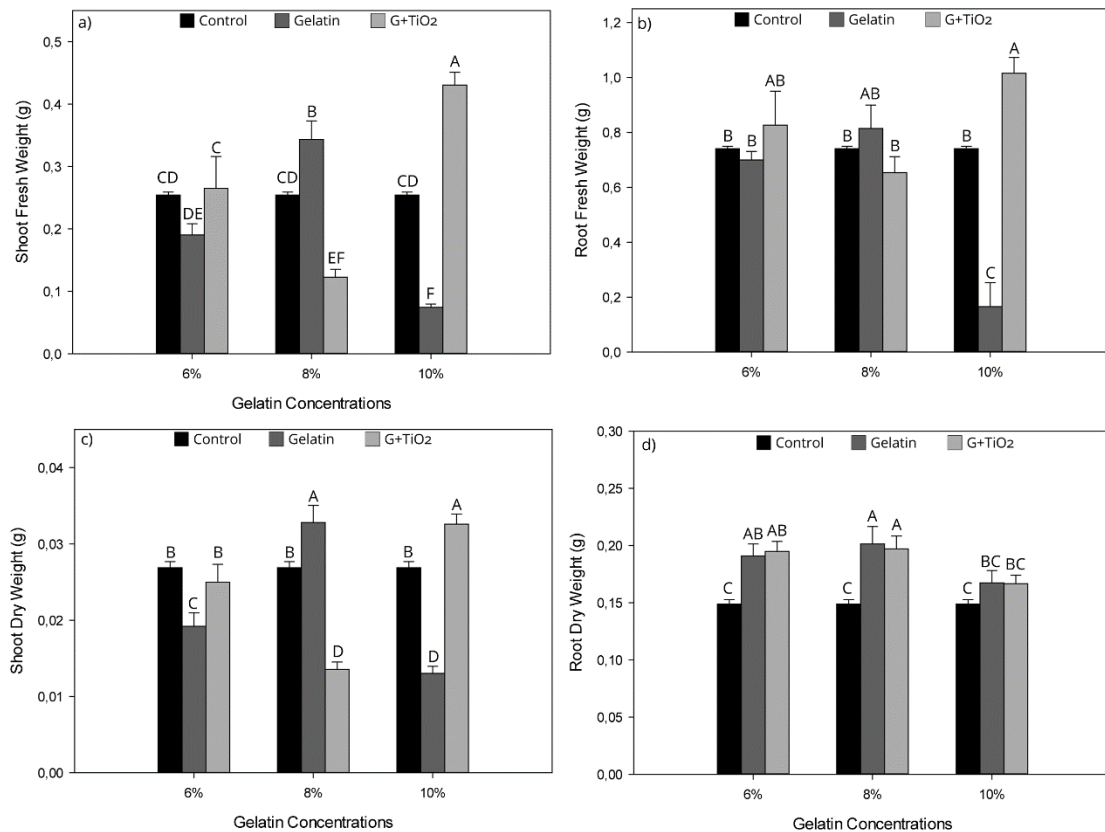
**Figure 4.108.** Shoot (a) and root (b) length of gelatin/TiO<sub>2</sub> coated maize seeds

Addition of TiO<sub>2</sub> to gelatin matrix did not change both shoot and root length at 6% of gelatin. However, it decreased seedling length at 8% of gelatin and increased at 10% (Figure 4.108).



**Figure 4.109.** Shoot fresh weight (a), root fresh weight (b), shoot dry weight (c) and root dry weight (d) of gelatin/TiO<sub>2</sub> coated tomato seeds

Addition of TiO<sub>2</sub> did not change the shoot fresh weight of tomato seedlings at any concentration (Figure 4.109a). The effect of TiO<sub>2</sub> addition to gelatin matrix on root fresh weight is presented in Figure 4.109b. The root fresh weight decreased at 6% of gelatin by addition of TiO<sub>2</sub>, but increased at 8 and 10%. On the other hand, TiO<sub>2</sub> addition did not change the effect of gelatin on both shoot (c) and root (d) dry weight (Figure 4.109).



**Figure 4.110.** Shoot fresh weight (a), root fresh weight (b), shoot dry weight (c) and root dry weight (d) of gelatin/TiO<sub>2</sub> coated maize seeds

Addition of TiO<sub>2</sub> to gelatin matrix to coat maize seeds increased shoot fresh weight at 6 and 10%, where decreased at 8% (Figure 4.110a). But then, there was no impact on root fresh weight at 6 and 8% where increased at 10% (Figure 4.110b). The shoot dry weight did not change by addition of TiO<sub>2</sub> to gelatin matrix at 6% and decreased at 8%. However, TiO<sub>2</sub> increased the shoot dry weight at 10% of gelatin (Figure 4.110c). No effect of TiO<sub>2</sub> was observed on root dry weight by seed coating with gelatin.

Gelatin have been employed as seed coating agent in various studies. Cucumber seeds were placed into gelatin capsules and it is reported that, gelatin capsules increased the growth parameters of cucumber, tomato, pepper and maize plants like leaf area, plant

high, and biomass (Wilson et. al., 2018). Wilson et. al. pointed out that, gelatin treatment of cucumber seeds increased N uptake by activated some amino acid and ammonium transporter genes (Wilson et. al., 2015). In the current study, gelatin treatment increased plant development both maize and tomato plants. However, maize plants were more affected than tomato plants. On the other hand, addition of nanoparticles, the original idea of the thesis, increased the both shoot and root length. TiO<sub>2</sub> addition to gelatin film creates new –NH<sub>2</sub> groups in gelatin and –OH group on surface of TiO<sub>2</sub>, which changes the characteristic of classic gelatin films (Li et. al., 2016; He et. al., 2016-Fathi2019). Besides, addition of nanoparticles to gelatin film increased the strength of coating materials (Hosseini et. al., 2018).

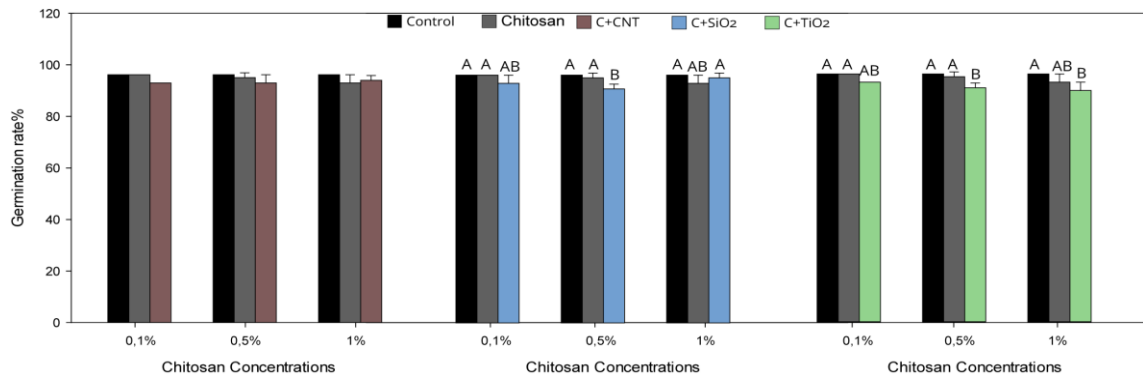
The effect of nanoparticles as seed coating material with gelatin have not been illuminated yet and there is limited literature about this topic. Thus, the gelatin-nanoparticle interaction and effects of this interactions on seed germination and plant development should be studied in detailed.

### **4.3.3 Treatment with chitosan**

Both tomato and maize seeds were coated with chitosan at 0,1%, 0,5% and 1% concentrations with and without nanoparticles. The germination test was conducted as described in section 3.1.

#### **4.3.3.1 Germination rate (%)**

Both tomato and maize seeds were coated with chitosan at defined concentrations. The maize seeds did not germinate after coated by chitosan, probably the acetic acid content of chitosan. The germination rate of tomato seeds is presented in Figure 4.111.

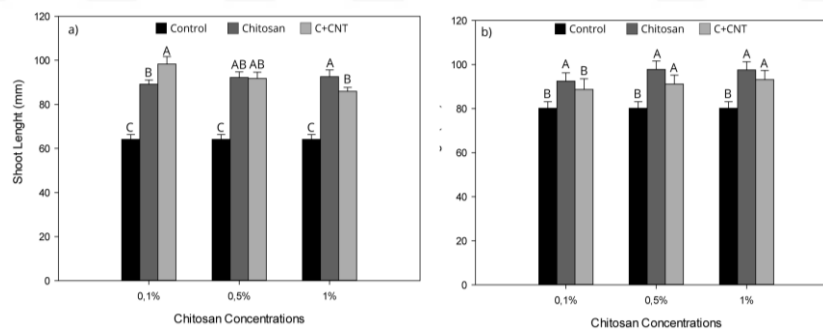


**Figure 4.111.** Germination rate (%) of chitosan coated tomato seeds

Coating of tomato seeds with chitosan did not affect the germination rate. Also, addition of CNT did not change the germination rate. However, addition of both SiO<sub>2</sub> and TiO<sub>2</sub> decreased germination rate of tomato seeds.

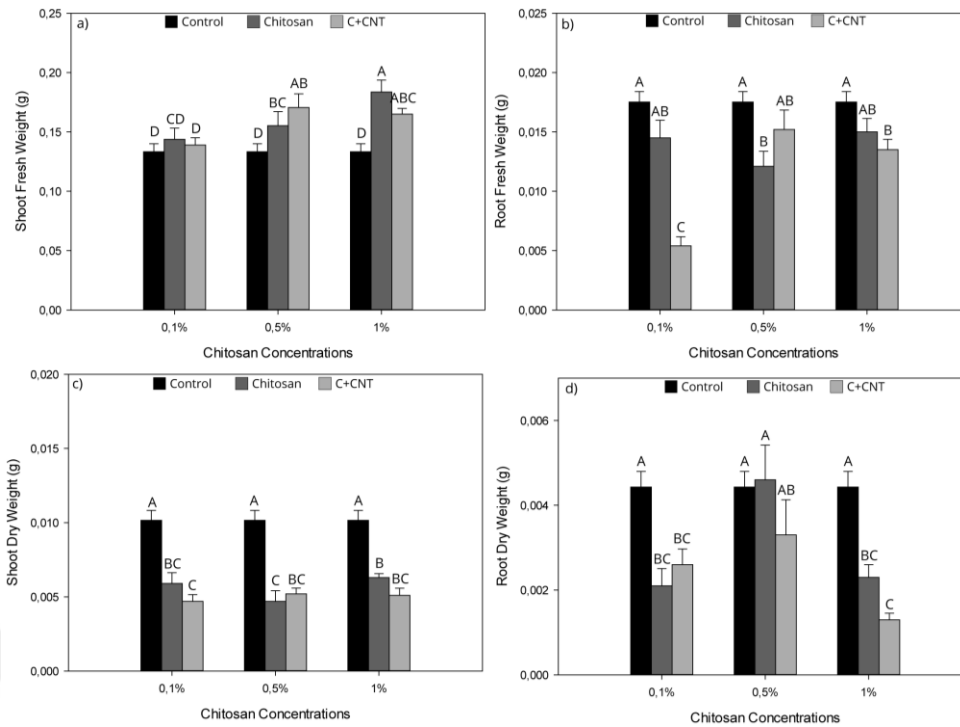
#### 4.3.3.2 Shoot and root growth

Shoot and root growth of tomato seedlings were determined by measuring shoot and root length, shoot and root fresh and dry weight.



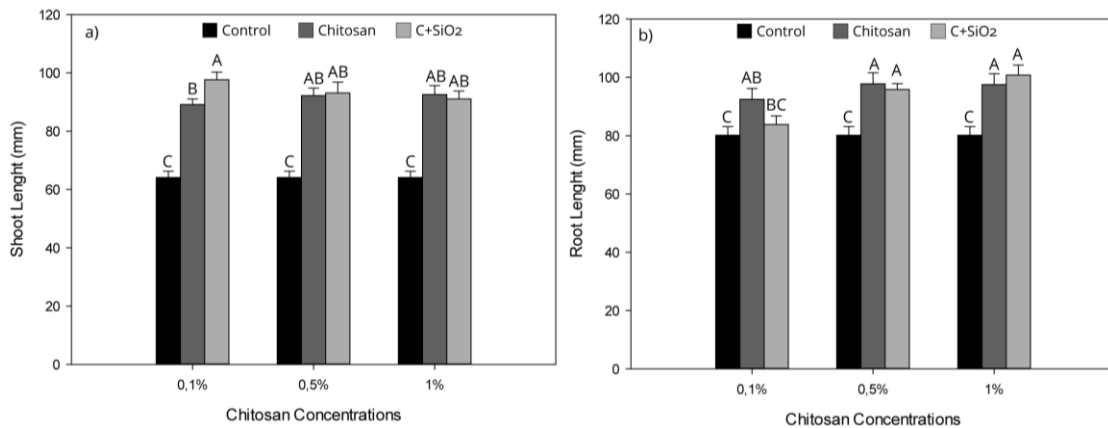
**Figure 4.112.** Shoot (a) and root (b) length of chitosan/CNT coated tomato seeds

Both shoot (a) and root (b) length increased by chitosan coating of tomato seeds (Figure 4.112). Addition of CNT to chitosan matrix increased shoot length at 0,1% of concentration and decreased at 1% of concentration. On the other hand, root length decreased by addition of CNT to 0,1% chitosan (Figure 4.112b).



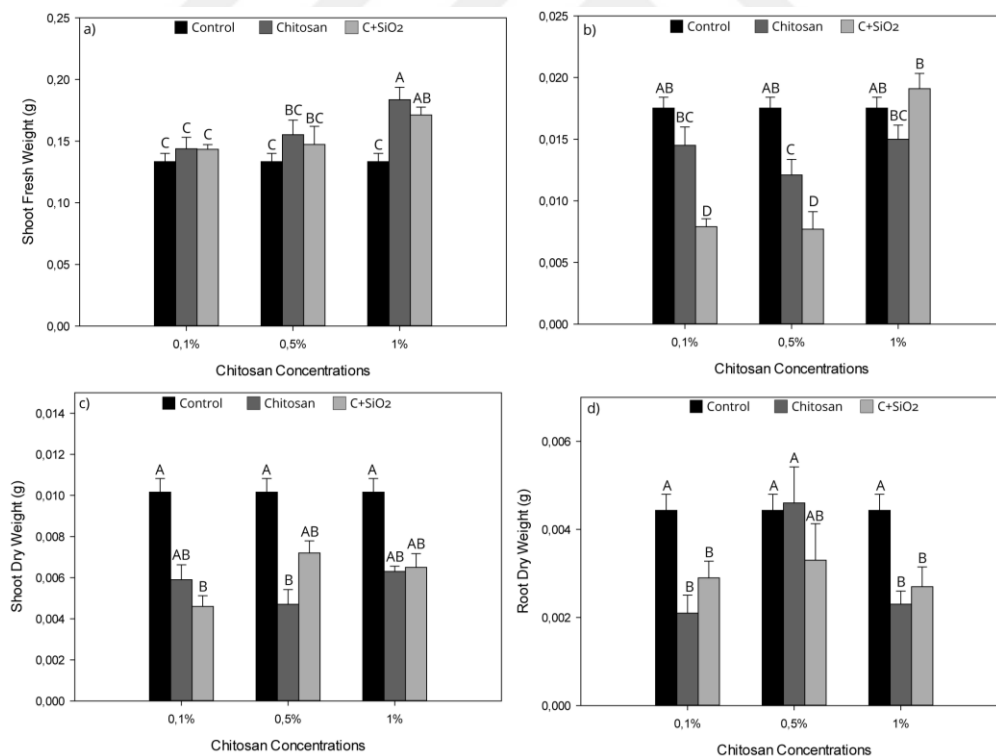
**Figure 4.113.** Shoot fresh weight (a), root fresh weight (b), shoot dry weight (c) and root dry weight (d) of chitosan/CNT coated tomato seeds

Chitosan coating of tomato seeds increased the shoot fresh weight, and the increasing in chitosan concentration increased the shoot fresh weight of tomato seedlings. On the other hand, addition of CNT to chitosan matrix increased the shoot fresh weight of tomato seedlings at 0,5% of concentration and decreased the rest of the concentrations (Figure 4.113a). The root fresh weight of tomato seedlings were decreased by chitosan coating of tomato seeds as presented in Figure 4.113b. Addition of CNT increased the impact of chitosan at 0,1 and 1% and decreased at 0,5%. The shoot dry weight decreased by chitosan coating and addition of CNT to coating material did not change the impact of chitosan (Figure 4.113c). Likewise, chitosan coating decreased root dry weight at 0,1 and 1% and did not change at 1,5%. Addition of CNT did not change the effect of chitosan coating on root dry weight (Figure 4.113d).



**Figure 4.114.** Shoot (a) and root (b) length of chitosan/SiO<sub>2</sub> coated tomato seeds

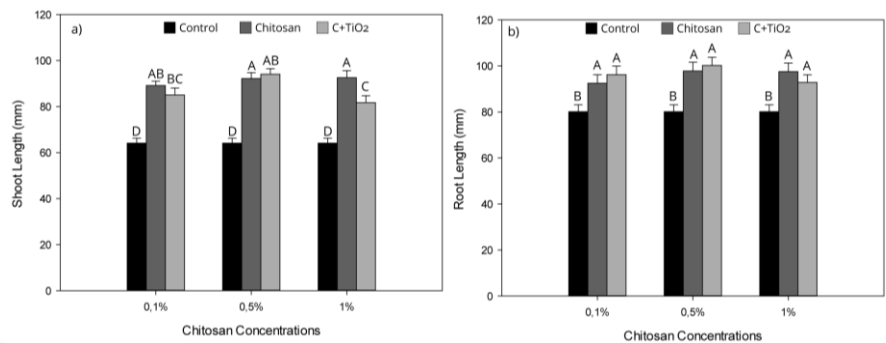
Addition of SiO<sub>2</sub> to chitosan matrix increased the shoot length of tomato seedlings at 0,1 concentration of chitosan and did not change at other concentrations (Figure 4.114a). In contrast, addition of SiO<sub>2</sub> to 0,1% of chitosan decreased the impact of chitosan on root length (Figure 4.114b).



**Figure 4.115.** Shoot fresh weight (a), root fresh weight (b), shoot dry weight (c) and root dry weight (d) of chitosan/SiO<sub>2</sub> coated tomato seeds

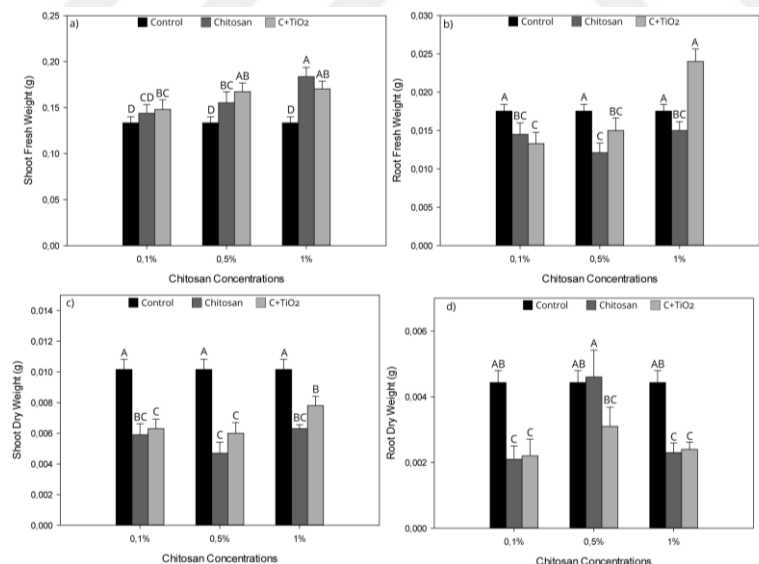
Addition of SiO<sub>2</sub> to chitosan matrix had no effect on shoot fresh weight of tomato seedlings (Figure 4.115a). On the other hand, the root fresh weight decreased by addition

of SiO<sub>2</sub> to chitosan matrix at 0,1 and 0,5% concentrations and did not changed at 1% (Figure 4.115b). the shoot dry weight of tomato seedlings decreased when SiO<sub>2</sub> was added to 0,1% of chitosan and increased at 0,5% (Figure 4.115c). Addition of SiO<sub>2</sub> to chitosan matrix did not change the impact of chitosan on root dry weight of tomato seedlings (Figure 4.115d).



**Figure 4.116.** Shoot (a) and root (b) length of chitosan/TiO<sub>2</sub> coated tomato seeds

When the addition of TiO<sub>2</sub> to chitosan matrix decreased the shoot length (a), did not change the impact of chitosan on root length (Figure 4.116)



**Figure 4.117.** Shoot fresh weight (a), root fresh weight (b), shoot dry weight (c) and root dry weight (d) of chitosan/TiO<sub>2</sub> coated tomato seeds

Addition of TiO<sub>2</sub> to chitosan matrix increased the impact of chitosan on shoot fresh weight as presented in Figure 4.117a. The root fresh weight of tomato seedlings was decreased by addition of TiO<sub>2</sub> to 0,1% of chitosan, where increased at 0,5 and 1% of chitosan (Figure

4.117b). The shoot and root dry weight of tomato seedlings did not change by addition of TiO<sub>2</sub> (Figure 4.117c-d). However, root dry weight of 0,5% chitosan containing TiO<sub>2</sub> decreased root dry weight.

Addition TiO<sub>2</sub> and SiO<sub>2</sub> nanoparticles increased the strength of chitosan films and decreased decay rate, shrinkage rate, respiration rate, ethylene production rate (Tian et. al., 2019). Thus, addition of nanoparticles decreased seed germination for this purpose in the thesis. On the other hand, Cu-chitosan nanoparticles increased the seed germination and seedling development of maize seedling by increasing the activity of amylase (Saharan et. al., 2016). Using of nanoparticles with chitosan presents hopeful improvement in seed science.

#### **4.4 Effects of nano-priming applications with NPs at different concentrations on seed germination under abiotic stresses (WP-IV)**

Two different abiotic stress types, drought and salinity, were applied to tomato and maize seeds to identify the effect of nanopriming on tolerance levels of seeds to abiotic stresses.

##### **4.4.1 Drought stress**

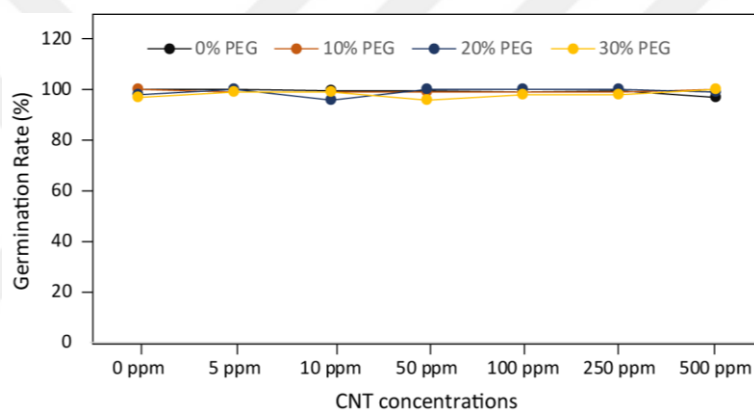
In order to mimic drought stress under laboratory conditions PEG6000 was added to MS medium at 10%, 20% and 30% (w/v) concentrations.

##### **4.4.1.1 Germination rate (%)**

Table 4.9 presents the germination rate of tomato seeds under drought seeds. The germination rate of tomato seeds, nanoprimed with CNT, decreased at 500 ppm CNT concentration under control conditions. The germination rate was not affected under 10% PEG stress condition by CNT nanopriming. On the other hand, the germination rates decreased by increasing in stress level (Figure 4.118). Nanopriming with CNT increased the seed germination rate under 20 and 30% PEG conditions.

**Table 4.9.** Germination rates (%) of tomato seeds under drought stress after CNT nanopriming

| CNT | Germination Rate (%) |                    |                    |                     |
|-----|----------------------|--------------------|--------------------|---------------------|
|     | 0%PEG                | 10%PEG             | 20%PEG             | 30%PEG              |
| 0   | 100,0 <sup>a</sup>   | 100,0 <sup>a</sup> | 97,8 <sup>b</sup>  | 96,7 <sup>bc</sup>  |
| 5   | 100,0 <sup>a</sup>   | 98,9 <sup>a</sup>  | 100,0 <sup>a</sup> | 98,9 <sup>ab</sup>  |
| 10  | 99,3 <sup>a</sup>    | 98,9 <sup>a</sup>  | 95,6 <sup>c</sup>  | 98,9 <sup>ab</sup>  |
| 50  | 99,3 <sup>a</sup>    | 98,9 <sup>a</sup>  | 100,0 <sup>a</sup> | 95,6 <sup>c</sup>   |
| 100 | 99,7 <sup>a</sup>    | 98,9 <sup>a</sup>  | 100,0 <sup>a</sup> | 97,8 <sup>abc</sup> |
| 250 | 99,3 <sup>a</sup>    | 98,9 <sup>a</sup>  | 100,0 <sup>a</sup> | 97,8 <sup>abc</sup> |
| 500 | 96,7 <sup>b</sup>    | 100,0 <sup>a</sup> | 98,9 <sup>ab</sup> | 100,0 <sup>a</sup>  |

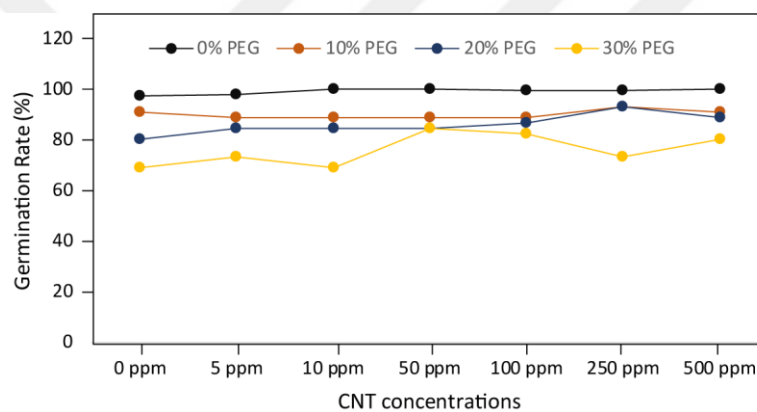


**Figure 4.118.** Germination rates (%) of tomato seeds under drought stress after CNT nanopriming

The increase in germination rate of maize seeds was presented on Table 4.10. the germination rate of maize seeds also decreased by drought stress (Figure 4.119). When the 5 and 10 ppm of CNT showed best performance in terms of germination rate of maize seeds, 250 ppm of CNT increased seed germination rate under 10 and 20% PEG. The severe drought stress was applied by 30% PEG and 100 ppm of CNT holds the first rank with 82,2% of germination rate.

**Table 4.10.** Germination rates (%) of maize seeds under drought stress after CNT nanopriming

| CNT | Germination Rate (%) |                    |                     |                    |
|-----|----------------------|--------------------|---------------------|--------------------|
|     | 0%PEG                | 10%PEG             | 20%PEG              | 30%PEG             |
| 0   | 97,5 <sup>b</sup>    | 91,1 <sup>bc</sup> | 80,0 <sup>c</sup>   | 68,9 <sup>c</sup>  |
| 5   | 98,0 <sup>b</sup>    | 88,9 <sup>c</sup>  | 84,4 <sup>bc</sup>  | 73,3 <sup>bc</sup> |
| 10  | 100,0 <sup>a</sup>   | 88,9 <sup>c</sup>  | 84,4 <sup>bc</sup>  | 68,9 <sup>c</sup>  |
| 50  | 100,0 <sup>a</sup>   | 88,9 <sup>c</sup>  | 84,4 <sup>bc</sup>  | 84,4 <sup>a</sup>  |
| 100 | 99,3 <sup>ab</sup>   | 88,9 <sup>c</sup>  | 86,7 <sup>abc</sup> | 82,2 <sup>ab</sup> |
| 250 | 99,3 <sup>ab</sup>   | 93,3 <sup>a</sup>  | 93,3 <sup>a</sup>   | 73,3 <sup>bc</sup> |
| 500 | 100,0 <sup>a</sup>   | 91,1 <sup>bc</sup> | 88,9 <sup>ab</sup>  | 80,0 <sup>ab</sup> |

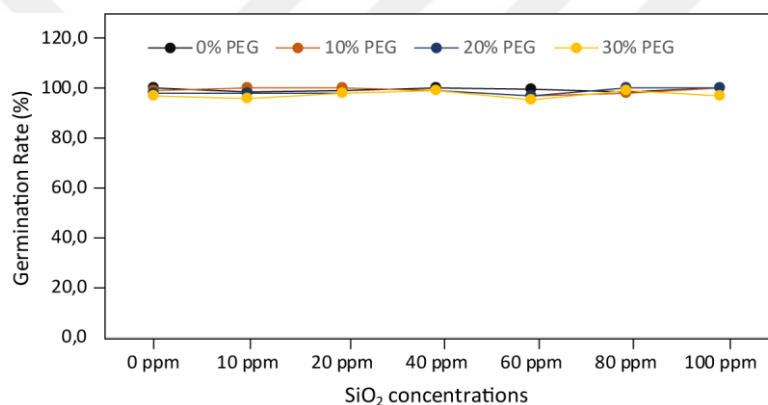


**Figure 4.119.** Germination rates (%) of maize seeds under drought stress after CNT nanopriming.

The germination rate of tomato seeds was not affected by SiO<sub>2</sub> nanopriming (Table 4.11). However, SiO<sub>2</sub> application decreased seed germination at 60 ppm under 10%PEG conditions, and at 10 ppm under 30% PEG conditions. The overall germination rate of tomato seeds under drought stress was presented in Figure 4.120.

**Table 4.11.** Germination rates (%) of tomato seeds under drought stress after SiO<sub>2</sub> nanopriming

| SiO <sub>2</sub> Conc.<br>(ppm) | Germination Rate (%) |                    |                    |                    |
|---------------------------------|----------------------|--------------------|--------------------|--------------------|
|                                 | 0% PEG               | 10% PEG            | 20% PEG            | 30% PEG            |
| 0                               | 100,0 <sup>a</sup>   | 98,9 <sup>ab</sup> | 97,8 <sup>a</sup>  | 96,7 <sup>ab</sup> |
| 10                              | 98,7 <sup>ab</sup>   | 100,0 <sup>a</sup> | 97,8 <sup>a</sup>  | 95,6 <sup>b</sup>  |
| 20                              | 98,0 <sup>b</sup>    | 100,0 <sup>a</sup> | 97,8 <sup>a</sup>  | 97,8 <sup>ab</sup> |
| 40                              | 98,0 <sup>b</sup>    | 98,9 <sup>ab</sup> | 98,9 <sup>a</sup>  | 98,9 <sup>ab</sup> |
| 60                              | 99,3 <sup>ab</sup>   | 96,7 <sup>b</sup>  | 96,7 <sup>a</sup>  | 100,0 <sup>a</sup> |
| 80                              | 98,3 <sup>ab</sup>   | 97,8 <sup>ab</sup> | 100,0 <sup>a</sup> | 98,9 <sup>ab</sup> |
| 100                             | 100,0 <sup>a</sup>   | 100,0 <sup>a</sup> | 100,0 <sup>a</sup> | 96,7 <sup>ab</sup> |

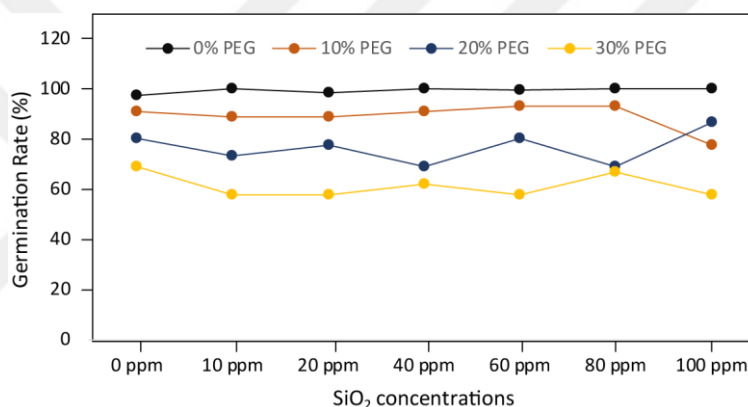


**Figure 4.120.** Germination rates (%) of tomato seeds under drought stress after SiO<sub>2</sub> nanopriming

The germination rate of maize seedlings after SiO<sub>2</sub> nanopriming under drought conditions was presented on Table 4.12. The SiO<sub>2</sub> application did not affect seed germination rate of maize seeds under drought conditions. On the other hand, the germination rate of maize seeds were decreased by increasing in drought level (Figure 4.121).

**Table 4.12.** Germination rates (%) of maize seeds under drought stress after SiO<sub>2</sub> nanopriming

| SiO <sub>2</sub> Conc.<br>(ppm) | Germination Rate (%) |                   |                    |                   |
|---------------------------------|----------------------|-------------------|--------------------|-------------------|
|                                 | 0% PEG               | 10% PEG           | 20% PEG            | 30% PEG           |
| 0                               | 97,5 <sup>b</sup>    | 91,1 <sup>a</sup> | 80,0 <sup>ab</sup> | 68,9 <sup>a</sup> |
| 10                              | 100,0 <sup>a</sup>   | 88,9 <sup>a</sup> | 73,3 <sup>bc</sup> | 57,8 <sup>a</sup> |
| 20                              | 98,3 <sup>ab</sup>   | 88,9 <sup>a</sup> | 77,8 <sup>b</sup>  | 57,8 <sup>a</sup> |
| 40                              | 100,0 <sup>a</sup>   | 91,1 <sup>a</sup> | 68,9 <sup>c</sup>  | 62,2 <sup>a</sup> |
| 60                              | 99,3 <sup>ab</sup>   | 93,3 <sup>a</sup> | 80,0 <sup>ab</sup> | 57,8 <sup>a</sup> |
| 80                              | 100,0 <sup>a</sup>   | 93,3 <sup>a</sup> | 68,9 <sup>c</sup>  | 66,7 <sup>a</sup> |
| 100                             | 100,0 <sup>a</sup>   | 77,8 <sup>b</sup> | 86,7 <sup>a</sup>  | 57,8 <sup>a</sup> |

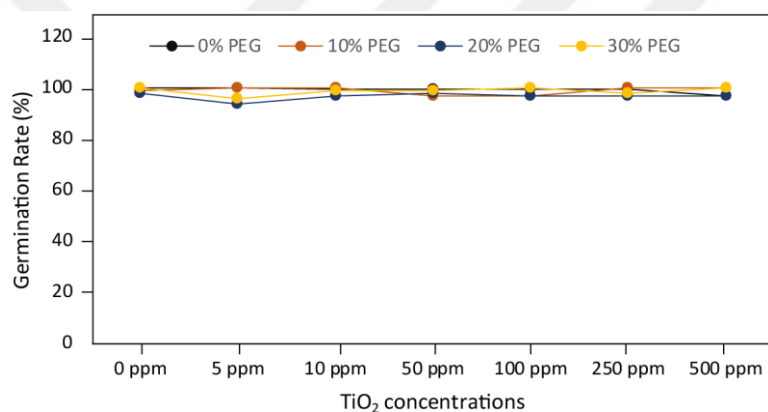


**Figure 4.121.** Germination rates (%) of maize seeds under drought stress after SiO<sub>2</sub> nanopriming

The germination rate of tomato seeds was decreased at 500 ppm of TiO<sub>2</sub> under control conditions. On the other hand, TiO<sub>2</sub> application did not affect seed germination rate under drought stress conditions at any level (Table 4.13). Drought stress did not affect germination rate of tomato seeds at any level of drought stress as presented in Figure 4.122.

**Table 4.13.** Germination rates (%) of tomato seeds under drought stress after TiO<sub>2</sub> nanopriming

| TiO <sub>2</sub> Conc.<br>(ppm) | Germination Rate (%) |                    |                    |                    |
|---------------------------------|----------------------|--------------------|--------------------|--------------------|
|                                 | 0% PEG               | 10% PEG            | 20% PEG            | 30% PEG            |
| 0                               | 97,3 <sup>a</sup>    | 98,9 <sup>a</sup>  | 97,8 <sup>a</sup>  | 100,0 <sup>a</sup> |
| 5                               | 97,3 <sup>a</sup>    | 100,0 <sup>a</sup> | 93,3 <sup>b</sup>  | 95,6 <sup>b</sup>  |
| 10                              | 98,0 <sup>a</sup>    | 100,0 <sup>a</sup> | 96,7 <sup>ab</sup> | 98,9 <sup>ab</sup> |
| 50                              | 97,5 <sup>a</sup>    | 96,7 <sup>a</sup>  | 97,8 <sup>a</sup>  | 98,9 <sup>ab</sup> |
| 100                             | 98,0 <sup>a</sup>    | 96,7 <sup>a</sup>  | 96,7 <sup>ab</sup> | 100,0 <sup>a</sup> |
| 250                             | 93,1 <sup>ab</sup>   | 100,0 <sup>a</sup> | 96,7 <sup>ab</sup> | 97,8 <sup>ab</sup> |
| 500                             | 87,5 <sup>b</sup>    | 100,0 <sup>a</sup> | 96,7 <sup>ab</sup> | 100,0 <sup>a</sup> |

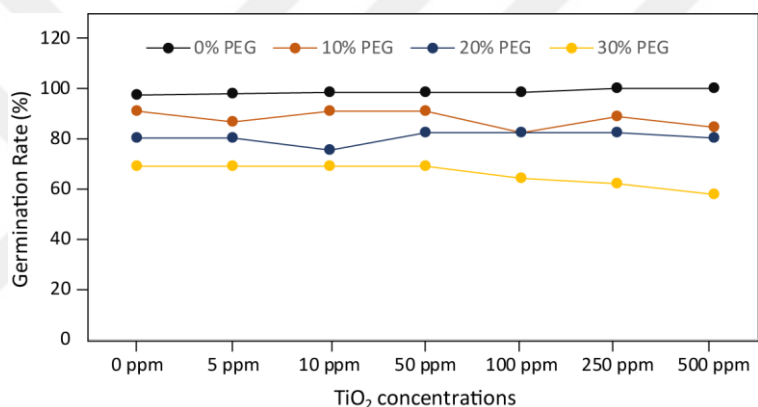


**Figure 4.122.** Germination rates (%) of tomato seeds under drought stress after TiO<sub>2</sub> nanopriming

The germination rate of maize seeds was not affected by TiO<sub>2</sub> application at any level of drought stress (Table 4.14). Besides, decreasing in germination level of maize seeds was shown in Figure 4.123.

**Table 4.14.** Germination rates (%) of maize seeds under drought stress after TiO<sub>2</sub> nanopriming

| TiO <sub>2</sub> Conc.<br>(ppm) | Germination Rate (%) |                     |                   |                    |
|---------------------------------|----------------------|---------------------|-------------------|--------------------|
|                                 | 0% PEG               | 10% PEG             | 20% PEG           | 30% PEG            |
| 0                               | 97,5 <sup>a</sup>    | 91,1 <sup>a</sup>   | 80,0 <sup>a</sup> | 68,9 <sup>a</sup>  |
| 5                               | 98,0 <sup>a</sup>    | 86,7 <sup>abc</sup> | 80,0 <sup>a</sup> | 68,9 <sup>a</sup>  |
| 10                              | 98,7 <sup>a</sup>    | 91,1 <sup>a</sup>   | 75,6 <sup>a</sup> | 68,9 <sup>a</sup>  |
| 50                              | 98,7 <sup>a</sup>    | 91,1 <sup>a</sup>   | 82,2 <sup>a</sup> | 68,9 <sup>a</sup>  |
| 100                             | 98,7 <sup>a</sup>    | 82,2 <sup>c</sup>   | 82,2 <sup>a</sup> | 64,4 <sup>ab</sup> |
| 250                             | 100,0 <sup>a</sup>   | 88,9 <sup>ab</sup>  | 82,2 <sup>a</sup> | 62,2 <sup>ab</sup> |
| 500                             | 100,0 <sup>a</sup>   | 84,4 <sup>bc</sup>  | 80,0 <sup>a</sup> | 57,8 <sup>b</sup>  |



**Figure 4.123.** Germination rates (%) of maize seeds under drought stress after TiO<sub>2</sub> nanopriming

#### 4.4.1.2 Shoot and root growth

The shoot length of tomato seedlings was increased by CNT application under control group. On the other hand, control group had the highest shoot length under 10 and 30% PEG conditions. However, 250 ppm CNT treatment increased the shoot length under all drought stress conditions (Table 4.15).

**Table 4.15.** Shoot length (SL) of tomato seedlings under drought stress after CNT nanopriming

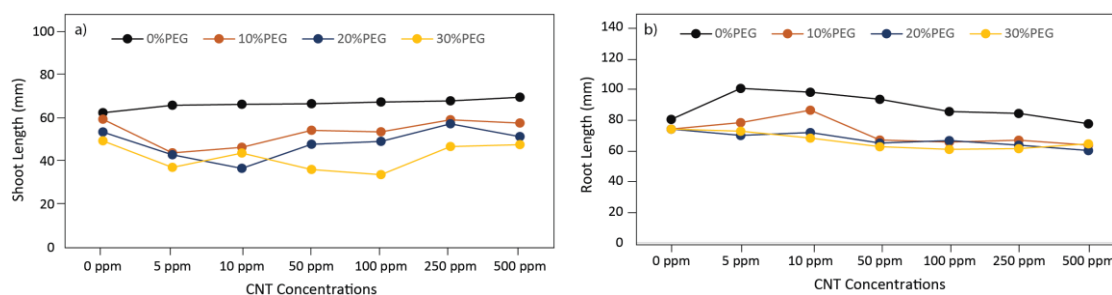
| CNT | Shoot Length (mm)   |                     |                     |                     |
|-----|---------------------|---------------------|---------------------|---------------------|
|     | 0%PEG               | 10%PEG              | 20%PEG              | 30%PEG              |
| 0   | 62,53 <sup>c</sup>  | 59,54 <sup>a</sup>  | 53,56 <sup>b</sup>  | 49,54 <sup>a</sup>  |
| 5   | 65,99 <sup>b</sup>  | 43,96 <sup>d</sup>  | 43,09 <sup>d</sup>  | 37,16 <sup>c</sup>  |
| 10  | 66,40 <sup>b</sup>  | 46,55 <sup>d</sup>  | 36,80 <sup>e</sup>  | 43,86 <sup>b</sup>  |
| 50  | 66,70 <sup>b</sup>  | 54,39 <sup>bc</sup> | 47,94 <sup>c</sup>  | 36,22 <sup>cd</sup> |
| 100 | 67,49 <sup>ab</sup> | 53,64 <sup>c</sup>  | 49,29 <sup>bc</sup> | 33,88 <sup>d</sup>  |
| 250 | 68,04 <sup>ab</sup> | 59,24 <sup>a</sup>  | 57,44 <sup>a</sup>  | 46,87 <sup>a</sup>  |
| 500 | 69,69 <sup>a</sup>  | 57,80 <sup>ab</sup> | 51,44 <sup>b</sup>  | 47,78 <sup>a</sup>  |

The root length of tomato seedlings under drought stress conditions was decreased. However, application of 10 ppm of CNT increased the root length under 10% of PEG. On the other hand, increasing in CNT concentration decreased the root length of tomato (Table 4.16).

**Table 4.16.** Root length (RL) of tomato seedlings under drought stress after CNT nanopriming

| CNT | Root Length (mm)    |                     |                     |                     |
|-----|---------------------|---------------------|---------------------|---------------------|
|     | 0%PEG               | 10%PEG              | 20%PEG              | 30%PEG              |
| 0   | 80,02 <sup>cd</sup> | 73,66 <sup>bc</sup> | 73,66 <sup>a</sup>  | 73,66 <sup>a</sup>  |
| 5   | 100,07 <sup>a</sup> | 77,86 <sup>ab</sup> | 69,51 <sup>ab</sup> | 72,26 <sup>a</sup>  |
| 10  | 97,61 <sup>ab</sup> | 85,92 <sup>a</sup>  | 71,38 <sup>ab</sup> | 67,76 <sup>bc</sup> |
| 50  | 92,98 <sup>b</sup>  | 66,56 <sup>cd</sup> | 64,57 <sup>bc</sup> | 62,24 <sup>c</sup>  |
| 100 | 85,05 <sup>c</sup>  | 65,22 <sup>cd</sup> | 66,16 <sup>bc</sup> | 60,46 <sup>d</sup>  |
| 250 | 83,81 <sup>c</sup>  | 66,47 <sup>cd</sup> | 63,18 <sup>bc</sup> | 61,06 <sup>cd</sup> |
| 500 | 77,14 <sup>d</sup>  | 63,18 <sup>d</sup>  | 59,72 <sup>c</sup>  | 64,07 <sup>c</sup>  |

The general state of shoot and root length of tomato seedlings under drought conditions was presented in Figure 4.124.



**Figure 4.124.** Shoot length (a) and root length (b) of tomato seeds under drought stress after CNT nanoprimering

The shoot fresh weight of tomato seedlings was increased by CNT treatment under drought stress conditions (Table 4.17). The shoot fresh weight of tomato seedlings developed under 10 and 20% PEG drought conditions, increased by CNT application at all concentrations. On the other hand, 10 ppm of CNT application was enough for to get highest shoot fresh weight of tomato seedlings under 30% of drought stress condition.

**Table 4.17.** Shoot fresh weight (SFW) of tomato seedlings under drought stress after CNT nanoprimering

| CNT | Shoot Fresh Weight (g) |                      |                      |                      |
|-----|------------------------|----------------------|----------------------|----------------------|
|     | 0%PEG                  | 10%PEG               | 20%PEG               | 30%PEG               |
| 0   | 0,1504 <sup>a</sup>    | 0,0884 <sup>c</sup>  | 0,0884 <sup>c</sup>  | 0,0884 <sup>b</sup>  |
| 5   | 0,1446 <sup>b</sup>    | 0,1424 <sup>ab</sup> | 0,1179 <sup>b</sup>  | 0,0951 <sup>ab</sup> |
| 10  | 0,1442 <sup>b</sup>    | 0,1291 <sup>b</sup>  | 0,0974 <sup>c</sup>  | 0,1067 <sup>a</sup>  |
| 50  | 0,1439 <sup>b</sup>    | 0,135 <sup>ab</sup>  | 0,119 <sup>b</sup>   | 0,0983 <sup>ab</sup> |
| 100 | 0,1441 <sup>b</sup>    | 0,1301 <sup>ab</sup> | 0,1217 <sup>ab</sup> | 0,0907 <sup>b</sup>  |
| 250 | 0,1453 <sup>b</sup>    | 0,1375 <sup>ab</sup> | 0,1369 <sup>a</sup>  | 0,0959 <sup>ab</sup> |
| 500 | 0,1451 <sup>b</sup>    | 0,1456 <sup>a</sup>  | 0,1281 <sup>ab</sup> | 0,0962 <sup>ab</sup> |

In contrast to shoot fresh weight, application of CNT to tomato seeds decreased the root fresh weight under drought stress conditions. Hydropriming application presented the best results in terms of root fresh weight. Besides, increasing in CNT concentration reduced the root fresh weight (Table 4.18).

**Table 4.18.** Root fresh weight (RFW) of tomato seedlings under drought stress after CNT nanopriming

| CNT | Root Fresh Weight (g) |                     |                      |                     |
|-----|-----------------------|---------------------|----------------------|---------------------|
|     | 0%PEG                 | 10%PEG              | 20%PEG               | 30%PEG              |
| 0   | 0,0174 <sup>a</sup>   | 0,0168 <sup>a</sup> | 0,0162 <sup>a</sup>  | 0,0154 <sup>a</sup> |
| 5   | 0,0147 <sup>ab</sup>  | 0,0129 <sup>b</sup> | 0,0112 <sup>b</sup>  | 0,0079 <sup>c</sup> |
| 10  | 0,0170 <sup>a</sup>   | 0,0124 <sup>b</sup> | 0,0119 <sup>b</sup>  | 0,0079 <sup>c</sup> |
| 50  | 0,0164 <sup>ab</sup>  | 0,0158 <sup>a</sup> | 0,0152 <sup>a</sup>  | 0,0118 <sup>b</sup> |
| 100 | 0,0171 <sup>a</sup>   | 0,0096 <sup>b</sup> | 0,0086 <sup>b</sup>  | 0,0089 <sup>c</sup> |
| 250 | 0,0161 <sup>ab</sup>  | 0,0096 <sup>b</sup> | 0,0074 <sup>cd</sup> | 0,0057 <sup>d</sup> |
| 500 | 0,0133 <sup>b</sup>   | 0,0084 <sup>b</sup> | 0,0069 <sup>d</sup>  | 0,0058 <sup>d</sup> |

Shoot dry weight of tomato seedlings, developed under drought stress, was increased by 5 ppm of CNT treatment under 10% and 20% of PEG conditions. On the other hand, CNT application decreased the shoot dry weight under 30% of PEG conditions (Table 4.19).

**Table 4.19.** Shoot dry weight (SDW) of tomato seedlings under drought stress after CNT nanopriming

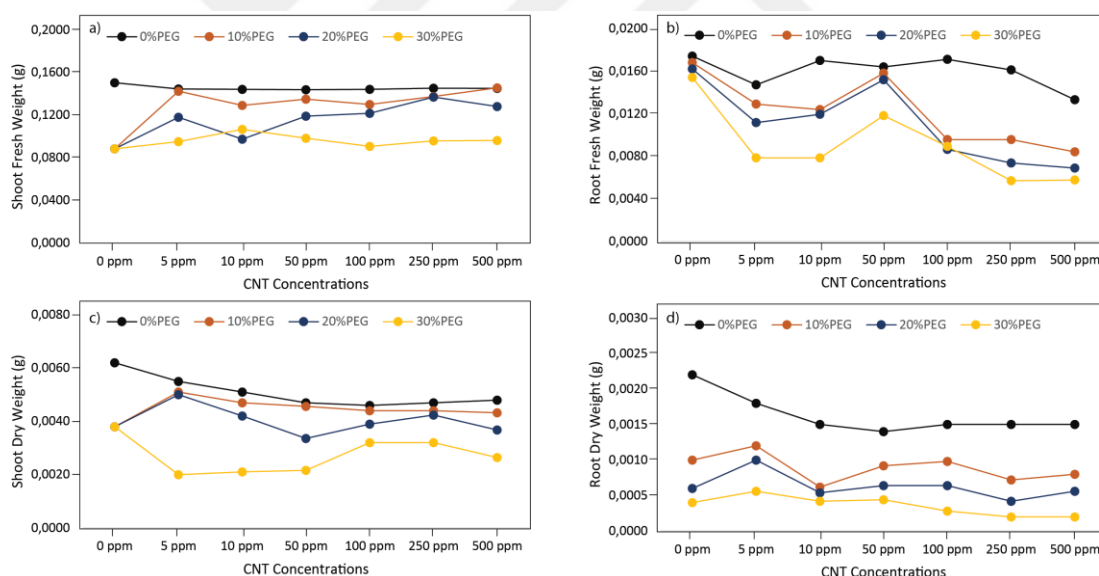
| CNT | Shoot Dry Weight (g) |                     |                     |                      |
|-----|----------------------|---------------------|---------------------|----------------------|
|     | 0%PEG                | 10%PEG              | 20%PEG              | 30%PEG               |
| 0   | 0,0062 <sup>a</sup>  | 0,0038 <sup>b</sup> | 0,0038 <sup>b</sup> | 0,0038 <sup>a</sup>  |
| 5   | 0,0055 <sup>b</sup>  | 0,0051 <sup>a</sup> | 0,0050 <sup>a</sup> | 0,0020 <sup>d</sup>  |
| 10  | 0,0051 <sup>bc</sup> | 0,0047 <sup>b</sup> | 0,0042 <sup>b</sup> | 0,0021 <sup>d</sup>  |
| 50  | 0,0047 <sup>c</sup>  | 0,0046 <sup>b</sup> | 0,0034 <sup>b</sup> | 0,0022 <sup>d</sup>  |
| 100 | 0,0046 <sup>c</sup>  | 0,0044 <sup>b</sup> | 0,0039 <sup>b</sup> | 0,0032 <sup>b</sup>  |
| 250 | 0,0047 <sup>c</sup>  | 0,0044 <sup>b</sup> | 0,0042 <sup>b</sup> | 0,0032 <sup>b</sup>  |
| 500 | 0,0048 <sup>c</sup>  | 0,0043 <sup>b</sup> | 0,0037 <sup>b</sup> | 0,0026 <sup>cd</sup> |

The root dry weight of tomato seedlings under 10% of PEG conditions was not improved by CNT. However, 5 ppm of CNT treatment, under 10 and 20% of PEG conditions, increased the root dry weight of tomato seedlings (Table 4.20).

**Table 4.20.** Root dry weight (SDW) of tomato seedlings under drought stress after CNT nanopriming

| CNT | Root Dry Weight (g) |                     |                      |                     |
|-----|---------------------|---------------------|----------------------|---------------------|
|     | 0%PEG               | 10%PEG              | 20%PEG               | 30%PEG              |
| 0   | 0,0022 <sup>a</sup> | 0,0022 <sup>a</sup> | 0,0010 <sup>ab</sup> | 0,0006 <sup>b</sup> |
| 5   | 0,0018 <sup>b</sup> | 0,0018 <sup>b</sup> | 0,0012 <sup>a</sup>  | 0,0010 <sup>a</sup> |
| 10  | 0,0015 <sup>b</sup> | 0,0015 <sup>c</sup> | 0,0006 <sup>c</sup>  | 0,0005 <sup>b</sup> |
| 50  | 0,0014 <sup>b</sup> | 0,0014 <sup>c</sup> | 0,0009 <sup>b</sup>  | 0,0006 <sup>b</sup> |
| 100 | 0,0015 <sup>b</sup> | 0,0015 <sup>c</sup> | 0,0010 <sup>ab</sup> | 0,0006 <sup>b</sup> |
| 250 | 0,0015 <sup>b</sup> | 0,0015 <sup>c</sup> | 0,0007 <sup>c</sup>  | 0,0004 <sup>b</sup> |
| 500 | 0,0015 <sup>b</sup> | 0,0015 <sup>c</sup> | 0,0008 <sup>b</sup>  | 0,0006 <sup>b</sup> |

The biomass of tomato seedlings, developed under drought conditions after CNT nanopriming was presented in Figure 4.125.



**Figure 4.125.** Shoot fresh weight (a), root fresh weight (b), shoot dry weight (c) and root dry weight (d) of tomato seeds under drought stress after CNT nanopriming

The shoot length of maize seedlings, grown under drought stress conditions, was increased by CNT nanopriming. 10 ppm of CNT showed the best performance on maize seedling shoot length under 10, 20 and 30% of PEG with 40.12; 34.64 and 35.51 mm respectively (Table 4.21).

**Table 4.21.** Shoot length (SL) of maize seedlings under drought stress after CNT nanopriming

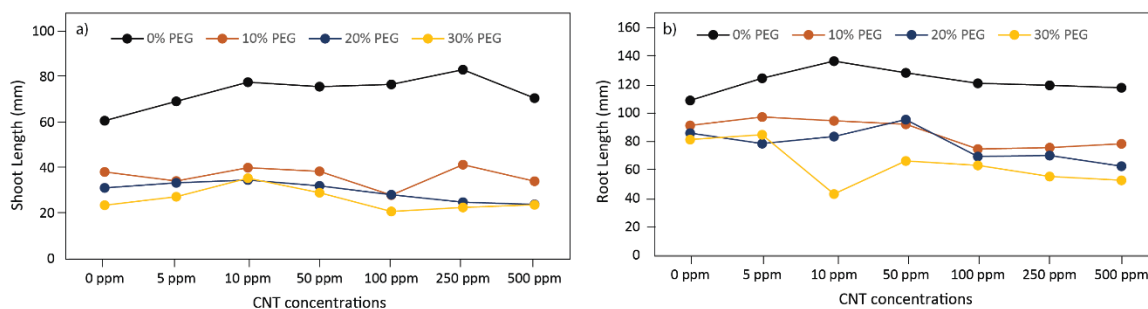
| CNT | Shoot Length (mm)  |                     |                     |                     |
|-----|--------------------|---------------------|---------------------|---------------------|
|     | 0%PEG              | 10%PEG              | 20%PEG              | 30%PEG              |
| 0   | 60,72 <sup>d</sup> | 38,24 <sup>ab</sup> | 31,21 <sup>ab</sup> | 23,63 <sup>cd</sup> |
| 5   | 69,27 <sup>c</sup> | 34,21 <sup>bc</sup> | 33,41 <sup>ab</sup> | 27,32 <sup>b</sup>  |
| 10  | 77,65 <sup>b</sup> | 40,12 <sup>a</sup>  | 34,64 <sup>a</sup>  | 35,51 <sup>a</sup>  |
| 50  | 75,68 <sup>b</sup> | 38,47 <sup>ab</sup> | 32,07 <sup>ab</sup> | 29,13 <sup>b</sup>  |
| 100 | 76,69 <sup>b</sup> | 28,04 <sup>c</sup>  | 28,18 <sup>bc</sup> | 20,83 <sup>d</sup>  |
| 250 | 83,16 <sup>a</sup> | 41,45 <sup>a</sup>  | 24,89 <sup>c</sup>  | 22,61 <sup>cd</sup> |
| 500 | 70,62 <sup>c</sup> | 34,15 <sup>bc</sup> | 23,97 <sup>c</sup>  | 23,74 <sup>cd</sup> |

The root length of maize seedlings, grown under drought conditions, was not affected by CNT nanopriming at 10% PEG concentrations. The root length of the seedlings developed under 20% of PEG concentration, had longest root, with 95,30 mm at 50 ppm of CNT nanopriming. However, more than 50 ppm of concentration showed toxic effect on root length of maize. At 30% PEG, the root length decreased by increasing CNT concentration (Table 4.22).

**Table 4.22.** Root length (RL) of maize seedlings under drought stress after CNT nanopriming

| CNT | Root Length (mm)     |                    |                      |                     |
|-----|----------------------|--------------------|----------------------|---------------------|
|     | 0%PEG                | 10%PEG             | 20%PEG               | 30%PEG              |
| 0   | 108,88 <sup>d</sup>  | 91,20 <sup>a</sup> | 85,80 <sup>ab</sup>  | 81,37 <sup>a</sup>  |
| 5   | 124,49 <sup>bc</sup> | 97,27 <sup>a</sup> | 78,55 <sup>bcd</sup> | 84,70 <sup>a</sup>  |
| 10  | 136,52 <sup>a</sup>  | 94,52 <sup>a</sup> | 83,50 <sup>abc</sup> | 43,05 <sup>c</sup>  |
| 50  | 128,26 <sup>b</sup>  | 92,05 <sup>a</sup> | 95,30 <sup>a</sup>   | 66,27 <sup>b</sup>  |
| 100 | 120,88 <sup>bc</sup> | 74,73 <sup>a</sup> | 69,43 <sup>cd</sup>  | 63,18 <sup>b</sup>  |
| 250 | 119,39 <sup>c</sup>  | 75,61 <sup>a</sup> | 70,11 <sup>cd</sup>  | 55,42 <sup>bc</sup> |
| 500 | 117,72 <sup>cd</sup> | 78,42 <sup>a</sup> | 62,55 <sup>d</sup>   | 52,72 <sup>bc</sup> |

The shoot and root length of maize seedlings, developed under control and drought stress, were presented in Figure 4.126.



**Figure 4.126.** Shoot length (a) and root length (b) of maize seeds under drought stress after CNT nanopriming

The shoot fresh weight of maize seedlings, developed under 10 % PEG drought stress, was decreased and the decreasing level was not affected by concentration of CNT. Nevertheless, 10 ppm of CNT nanopriming increased the shoot fresh weight of maize seedlings under 20 and 30% PEG conditions (Table 4.23). Shoot fresh weight (SFW) of maize seedlings under drought stress after CNT nanopriming.

**Table 4.23.** Shoot fresh weight (SFW) of maize seedlings under drought stress after CNT nanopriming

| CNT | Shoot Fresh Weight (g) |                     |                       |                      |
|-----|------------------------|---------------------|-----------------------|----------------------|
|     | 0%PEG                  | 10%PEG              | 20%PEG                | 30%PEG               |
| 0   | 0,5612 <sup>d</sup>    | 0,5099 <sup>a</sup> | 0,2112 <sup>bc</sup>  | 0,2039 <sup>ab</sup> |
| 5   | 0,7392 <sup>bc</sup>   | 0,2878 <sup>b</sup> | 0,2045 <sup>bcd</sup> | 0,1767 <sup>bc</sup> |
| 10  | 0,7794 <sup>ab</sup>   | 0,3300 <sup>b</sup> | 0,2616 <sup>a</sup>   | 0,2218 <sup>a</sup>  |
| 50  | 0,7459 <sup>b</sup>    | 0,3327 <sup>b</sup> | 0,2456 <sup>ab</sup>  | 0,1613 <sup>c</sup>  |
| 100 | 0,7601 <sup>ab</sup>   | 0,2400 <sup>b</sup> | 0,1685 <sup>cde</sup> | 0,0968 <sup>d</sup>  |
| 250 | 0,8253 <sup>a</sup>    | 0,3232 <sup>b</sup> | 0,1600 <sup>de</sup>  | 0,0968 <sup>d</sup>  |
| 500 | 0,6859 <sup>c</sup>    | 0,2862 <sup>b</sup> | 0,1470 <sup>c</sup>   | 0,1150 <sup>d</sup>  |

The root fresh weight of maize seedlings, grown under drought stress, was not affected by CNT nanopriming except at 100 and 500 ppm concentrations. The root fresh weight of maize seedlings decreased by 100 and 500 ppm of CNT treatment (Table 4.24).

**Table 4.24.** Root fresh weight (RFW) of maize seedlings under drought stress after CNT nanopriming

| CNT | Root Fresh Weight (g) |                      |                      |                       |
|-----|-----------------------|----------------------|----------------------|-----------------------|
|     | 0%PEG                 | 10%PEG               | 20%PEG               | 30%PEG                |
| 0   | 0,9272 <sup>c</sup>   | 0,8680 <sup>a</sup>  | 0,8141 <sup>a</sup>  | 0,8001 <sup>ab</sup>  |
| 5   | 1,1497 <sup>b</sup>   | 0,9270 <sup>a</sup>  | 0,7693 <sup>ab</sup> | 0,8240 <sup>ab</sup>  |
| 10  | 1,2135 <sup>a</sup>   | 0,8702 <sup>a</sup>  | 0,7738 <sup>ab</sup> | 0,9010 <sup>a</sup>   |
| 50  | 1,1820 <sup>ab</sup>  | 0,9923 <sup>a</sup>  | 0,8752 <sup>a</sup>  | 0,7390 <sup>abc</sup> |
| 100 | 1,1401 <sup>ab</sup>  | 0,6347 <sup>b</sup>  | 0,5568 <sup>c</sup>  | 0,5768 <sup>c</sup>   |
| 250 | 1,1312 <sup>b</sup>   | 0,8946 <sup>a</sup>  | 0,9120 <sup>a</sup>  | 0,6614 <sup>bc</sup>  |
| 500 | 1,1147 <sup>b</sup>   | 0,8274 <sup>ab</sup> | 0,6468 <sup>bc</sup> | 0,5865 <sup>c</sup>   |

The root dry weight of maize seedlings was decreased by CNT treatment under 10% PEG conditions. However, shoot dry weight increased by 10 ppm CNT treatment under 20 and 30% PEG conditions (Table 4.25).

**Table 4.25.** Shoot dry weight (SDW) of maize seedlings under drought stress after CNT nanopriming

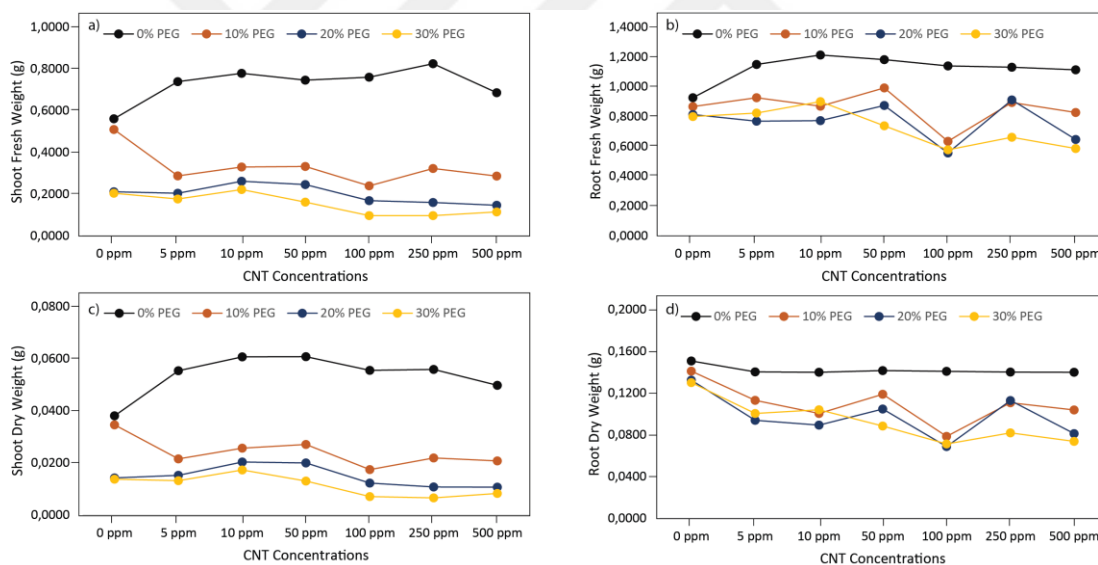
| CNT | Shoot Dry Weight (g) |                      |                      |                     |
|-----|----------------------|----------------------|----------------------|---------------------|
|     | 0%PEG                | 10%PEG               | 20%PEG               | 30%PEG              |
| 0   | 0,0381 <sup>d</sup>  | 0,0346 <sup>a</sup>  | 0,0143 <sup>c</sup>  | 0,0138 <sup>b</sup> |
| 5   | 0,0554 <sup>b</sup>  | 0,0216 <sup>cd</sup> | 0,0153 <sup>bc</sup> | 0,0132 <sup>b</sup> |
| 10  | 0,0607 <sup>a</sup>  | 0,0257 <sup>b</sup>  | 0,0204 <sup>a</sup>  | 0,0173 <sup>a</sup> |
| 50  | 0,0608 <sup>a</sup>  | 0,0271 <sup>b</sup>  | 0,0200 <sup>b</sup>  | 0,0131 <sup>b</sup> |
| 100 | 0,0555 <sup>b</sup>  | 0,0175 <sup>d</sup>  | 0,0123 <sup>d</sup>  | 0,0071 <sup>c</sup> |
| 250 | 0,0559 <sup>b</sup>  | 0,0219 <sup>cd</sup> | 0,0108 <sup>e</sup>  | 0,0066 <sup>c</sup> |
| 500 | 0,0498 <sup>c</sup>  | 0,0208 <sup>d</sup>  | 0,0107 <sup>e</sup>  | 0,0083 <sup>c</sup> |

The root dry weight of maize seedlings decreased after CNT nanopriming under drought stress conditions. 100 ppm of CNT caused the most decrease in shoot dry weight (Table 4.26).

**Table 4.26.** Root dry weight (RDW) of maize seedlings under drought stress after CNT nanopriming

| CNT | Root Dry Weight (g) |                      |                      |                      |
|-----|---------------------|----------------------|----------------------|----------------------|
|     | 0%PEG               | 10%PEG               | 20%PEG               | 30%PEG               |
| 0   | 0,1508 <sup>a</sup> | 0,1412 <sup>a</sup>  | 0,1324 <sup>a</sup>  | 0,1301 <sup>a</sup>  |
| 5   | 0,1404 <sup>b</sup> | 0,1132 <sup>b</sup>  | 0,0939 <sup>bc</sup> | 0,1006 <sup>b</sup>  |
| 10  | 0,1401 <sup>b</sup> | 0,1005 <sup>bc</sup> | 0,0893 <sup>c</sup>  | 0,1040 <sup>b</sup>  |
| 50  | 0,1416 <sup>b</sup> | 0,1189 <sup>b</sup>  | 0,1048 <sup>b</sup>  | 0,0885 <sup>c</sup>  |
| 100 | 0,1410 <sup>b</sup> | 0,0785 <sup>c</sup>  | 0,0689 <sup>d</sup>  | 0,0713 <sup>d</sup>  |
| 250 | 0,1402 <sup>b</sup> | 0,1109 <sup>b</sup>  | 0,1130 <sup>b</sup>  | 0,0820 <sup>c</sup>  |
| 500 | 0,1400 <sup>b</sup> | 0,1039 <sup>b</sup>  | 0,0812 <sup>c</sup>  | 0,0737 <sup>cd</sup> |

CNT nanopriming application of maize seeds under drought stress conditions; increased the shoot growth, when decreased the root growth (Figure 4.127).



**Figure 4.127.** Shoot fresh weight (a), root fresh weight (b), shoot dry weight (c) and root dry weight (d) of maize seeds under drought stress after CNT nanopriming

The shoot length of tomato seedlings was increased by SiO<sub>2</sub> treatment under drought stress conditions. The increase in concentration of SiO<sub>2</sub> also caused more increasing in shoot length of tomato seedlings (Table 4.27).

**Table 4.27.** Shoot length (SL) of tomato seedlings under drought stress after SiO<sub>2</sub> nanopriming

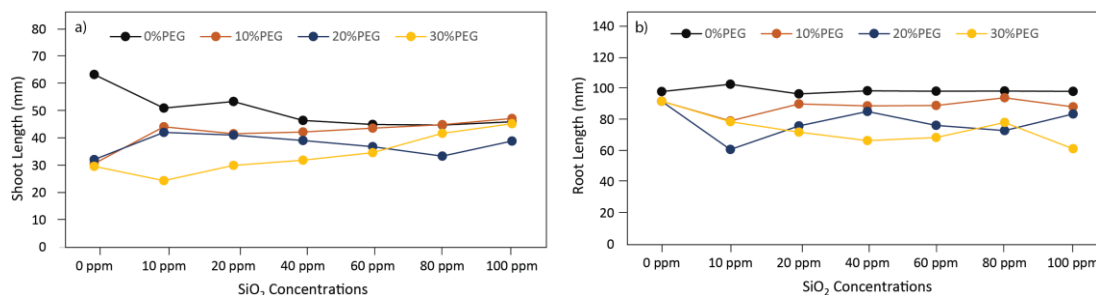
| SiO <sub>2</sub> Conc.<br>(ppm) | Shoot Length (mm)  |                      |                     |                     |
|---------------------------------|--------------------|----------------------|---------------------|---------------------|
|                                 | 0% PEG             | 10% PEG              | 20% PEG             | 30% PEG             |
| 0                               | 63,50 <sup>a</sup> | 30,77 <sup>c</sup>   | 32,26 <sup>c</sup>  | 29,77 <sup>d</sup>  |
| 10                              | 51,16 <sup>b</sup> | 44,30 <sup>bc</sup>  | 42,23 <sup>a</sup>  | 24,50 <sup>e</sup>  |
| 20                              | 53,56 <sup>b</sup> | 41,76 <sup>d</sup>   | 41,26 <sup>a</sup>  | 30,12 <sup>d</sup>  |
| 40                              | 46,65 <sup>c</sup> | 42,37 <sup>cd</sup>  | 39,27 <sup>ab</sup> | 32,07 <sup>cd</sup> |
| 60                              | 45,15 <sup>c</sup> | 43,84 <sup>bcd</sup> | 37,02 <sup>bc</sup> | 34,80 <sup>c</sup>  |
| 80                              | 44,97 <sup>c</sup> | 45,10 <sup>ab</sup>  | 33,55 <sup>c</sup>  | 41,87 <sup>b</sup>  |
| 100                             | 46,18 <sup>c</sup> | 47,36 <sup>a</sup>   | 39,08 <sup>ab</sup> | 45,45 <sup>a</sup>  |

The root length of tomato seedlings was not affected by SiO<sub>2</sub> treatment under 10% PEG drought conditions. However, by increasing in the drought level, SiO<sub>2</sub> caused more decrease in root length of tomato seedlings (Table 4.28).

**Table 4.28.** Root length (RL) of tomato seedlings under drought stress after SiO<sub>2</sub> nanopriming

| SiO <sub>2</sub> Conc.<br>(ppm) | Root Length (mm)    |                     |                     |                     |
|---------------------------------|---------------------|---------------------|---------------------|---------------------|
|                                 | 0% PEG              | 10% PEG             | 20% PEG             | 30% PEG             |
| 0                               | 98,26 <sup>a</sup>  | 91,08 <sup>a</sup>  | 91,05 <sup>a</sup>  | 90,08 <sup>a</sup>  |
| 10                              | 102,89 <sup>a</sup> | 79,39 <sup>b</sup>  | 61,00 <sup>d</sup>  | 78,82 <sup>ab</sup> |
| 20                              | 96,69 <sup>a</sup>  | 90,33 <sup>ab</sup> | 76,10 <sup>bc</sup> | 72,16 <sup>bc</sup> |
| 40                              | 98,67 <sup>a</sup>  | 89,09 <sup>ab</sup> | 85,44 <sup>ab</sup> | 66,76 <sup>bc</sup> |
| 60                              | 98,50 <sup>a</sup>  | 89,35 <sup>ab</sup> | 76,50 <sup>bc</sup> | 68,74 <sup>bc</sup> |
| 80                              | 98,56 <sup>a</sup>  | 94,23 <sup>a</sup>  | 73,18 <sup>c</sup>  | 78,39 <sup>ab</sup> |
| 100                             | 98,38 <sup>a</sup>  | 88,39 <sup>ab</sup> | 83,86 <sup>ab</sup> | 61,50 <sup>c</sup>  |

The general state of shoot and root length of tomato seedlings, developed under drought conditions, after SiO<sub>2</sub> nanopriming was presented in Figure 4.128.



**Figure 4.128.** Shoot length (a) and root length (b) of tomato seeds under drought stress after SiO<sub>2</sub> nanopriming

The shoot fresh weigh of tomato seedlings, developed under 10% and 20% PEG conditions, was increased by 10 and 20 ppm of SiO<sub>2</sub> treatment. However, SiO<sub>2</sub> treatment showed toxic effect on shoot fresh weight under 30% PEG condition (Table 4.29).

**Table 4.29.** Shoot fresh weight (SFW) of tomato seedlings under drought stress after SiO<sub>2</sub> nanopriming

| SiO <sub>2</sub> Conc.<br>(ppm) | Shoot Fresh Weight (g) |                     |                      |                     |
|---------------------------------|------------------------|---------------------|----------------------|---------------------|
|                                 | 0% PEG                 | 10% PEG             | 20% PEG              | 30% PEG             |
| 0                               | 0,2393 <sup>a</sup>    | 0,0884 <sup>b</sup> | 0,0881 <sup>b</sup>  | 0,0884 <sup>a</sup> |
| 10                              | 0,1505 <sup>bc</sup>   | 0,1427 <sup>a</sup> | 0,1407 <sup>a</sup>  | 0,0559 <sup>b</sup> |
| 20                              | 0,1534 <sup>b</sup>    | 0,1469 <sup>a</sup> | 0,1327 <sup>a</sup>  | 0,0662 <sup>b</sup> |
| 40                              | 0,1209 <sup>de</sup>   | 0,0979 <sup>b</sup> | 0,0734 <sup>c</sup>  | 0,0473 <sup>b</sup> |
| 60                              | 0,1119 <sup>c</sup>    | 0,0853 <sup>b</sup> | 0,0904 <sup>b</sup>  | 0,0565 <sup>b</sup> |
| 80                              | 0,1104 <sup>c</sup>    | 0,0833 <sup>b</sup> | 0,0800 <sup>bc</sup> | 0,0603 <sup>b</sup> |
| 100                             | 0,1341 <sup>cd</sup>   | 0,0952 <sup>b</sup> | 0,0811 <sup>b</sup>  | 0,0578 <sup>b</sup> |

The root fresh weight of tomato seedlings was not also increased by SiO<sub>2</sub> application under drought conditions. 10 and 20ppm of SiO<sub>2</sub> decreased root fresh weight under 10% PEG conditions. On the other hand, 20 ppm and bigger concentrations then 20 ppm caused reducing in root fresh weight of tomato seedlings under 20 and 30% of PEG concentrations (Table 4.30).

**Table 4.30.** Root fresh weight (RFW) of tomato seedlings under drought stress after SiO<sub>2</sub> nanopriming

| SiO <sub>2</sub> Conc.<br>(ppm) | Root Fresh Weight (g) |                      |                      |                      |
|---------------------------------|-----------------------|----------------------|----------------------|----------------------|
|                                 | 0% PEG                | 10% PEG              | 20% PEG              | 30% PEG              |
| 0                               | 0,0182 <sup>a</sup>   | 0,0090 <sup>a</sup>  | 0,0072 <sup>a</sup>  | 0,0065 <sup>a</sup>  |
| 10                              | 0,0096 <sup>bc</sup>  | 0,0051 <sup>b</sup>  | 0,0053 <sup>ab</sup> | 0,0053 <sup>ab</sup> |
| 20                              | 0,0079 <sup>c</sup>   | 0,0045 <sup>b</sup>  | 0,0039 <sup>b</sup>  | 0,0032 <sup>b</sup>  |
| 40                              | 0,0082 <sup>c</sup>   | 0,0059 <sup>ab</sup> | 0,0042 <sup>b</sup>  | 0,0029 <sup>b</sup>  |
| 60                              | 0,0082 <sup>c</sup>   | 0,0071 <sup>ab</sup> | 0,0046 <sup>b</sup>  | 0,0021 <sup>b</sup>  |
| 80                              | 0,0118 <sup>b</sup>   | 0,0080 <sup>ab</sup> | 0,0047 <sup>b</sup>  | 0,0023 <sup>b</sup>  |
| 100                             | 0,0099 <sup>bc</sup>  | 0,0078 <sup>ab</sup> | 0,0055 <sup>ab</sup> | 0,0019 <sup>b</sup>  |

The shoot dry weight of tomato seedlings was increased by SiO<sub>2</sub> treatment under 10% PEG of drought conditions. 20 ppm of SiO<sub>2</sub> was the most effective concentration of SiO<sub>2</sub> on shoot dry weight. On the other hand, 60 ppm of SiO<sub>2</sub> was the application that increased the shoot dry weight the most under 20 and 30% PEG of drought conditions (Table 4.31).

**Table 4.31.** Shoot dry weight (SDW) of tomato seedlings under drought stress after SiO<sub>2</sub> nanopriming

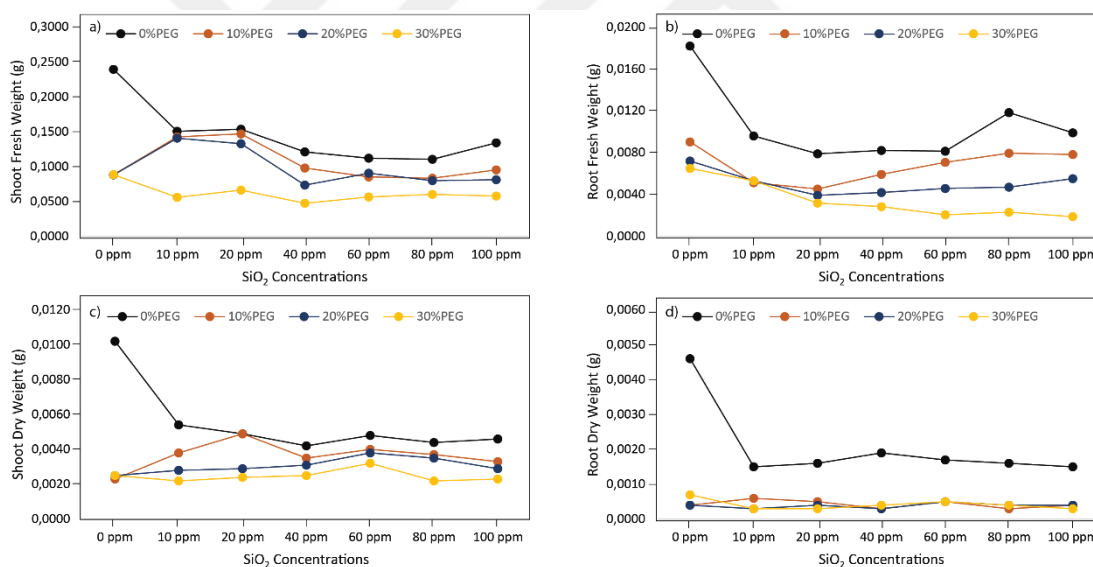
| SiO <sub>2</sub> Conc.<br>(ppm) | Shoot Dry Weight (g) |                      |                      |                     |
|---------------------------------|----------------------|----------------------|----------------------|---------------------|
|                                 | 0% PEG               | 10% PEG              | 20% PEG              | 30% PEG             |
| 0                               | 0,0102 <sup>a</sup>  | 0,0023 <sup>c</sup>  | 0,0025 <sup>c</sup>  | 0,0025 <sup>b</sup> |
| 10                              | 0,0054 <sup>b</sup>  | 0,0038 <sup>ab</sup> | 0,0028 <sup>bc</sup> | 0,0022 <sup>b</sup> |
| 20                              | 0,0049 <sup>bc</sup> | 0,0049 <sup>a</sup>  | 0,0029 <sup>bc</sup> | 0,0024 <sup>b</sup> |
| 40                              | 0,0042 <sup>c</sup>  | 0,0035 <sup>b</sup>  | 0,0031 <sup>b</sup>  | 0,0025 <sup>b</sup> |
| 60                              | 0,0048 <sup>bc</sup> | 0,0040 <sup>ab</sup> | 0,0038 <sup>a</sup>  | 0,0032 <sup>a</sup> |
| 80                              | 0,0044 <sup>c</sup>  | 0,0037 <sup>b</sup>  | 0,0035 <sup>a</sup>  | 0,0022 <sup>b</sup> |
| 100                             | 0,0046 <sup>bc</sup> | 0,0033 <sup>b</sup>  | 0,0029 <sup>bc</sup> | 0,0023 <sup>b</sup> |

Even if SiO<sub>2</sub> decreased root length and fresh weight, it increased the root dry weight of tomato seedlings. 10 and 60 ppm of SiO<sub>2</sub> increased the root dry weight the most under 20 and 30% PEG of drought conditions respectively. Under 30% PEG of drought conditions, SiO<sub>2</sub> treatment decreased the root dry weight (Table 4.32).

**Table 4.32.** Root dry weight (RDW) of tomato seedlings under drought stress after SiO<sub>2</sub> nanopriming

| SiO <sub>2</sub> Conc.<br>(ppm) | Root Dry Weight (g) |                      |                     |                      |
|---------------------------------|---------------------|----------------------|---------------------|----------------------|
|                                 | 0% PEG              | 10% PEG              | 20% PEG             | 30% PEG              |
| 0                               | 0,0046 <sup>a</sup> | 0,0004 <sup>b</sup>  | 0,0004 <sup>b</sup> | 0,0007 <sup>a</sup>  |
| 10                              | 0,0015 <sup>b</sup> | 0,0006 <sup>a</sup>  | 0,0003 <sup>b</sup> | 0,0003 <sup>b</sup>  |
| 20                              | 0,0016 <sup>b</sup> | 0,0005 <sup>ab</sup> | 0,0004 <sup>b</sup> | 0,0003 <sup>b</sup>  |
| 40                              | 0,0019 <sup>b</sup> | 0,0003 <sup>b</sup>  | 0,0003 <sup>b</sup> | 0,0004 <sup>b</sup>  |
| 60                              | 0,0017 <sup>b</sup> | 0,0005 <sup>ab</sup> | 0,0005 <sup>a</sup> | 0,0005 <sup>ab</sup> |
| 80                              | 0,0016 <sup>b</sup> | 0,0003 <sup>b</sup>  | 0,0004 <sup>b</sup> | 0,0004 <sup>b</sup>  |
| 100                             | 0,0015 <sup>b</sup> | 0,0004 <sup>b</sup>  | 0,0004 <sup>b</sup> | 0,0003 <sup>b</sup>  |

The SiO<sub>2</sub> treatment increased the shoot growth of tomato seedling, when decreases the root growth (Figure 4.129).



**Figure 4.129.** Shoot fresh weight (a), root fresh weight (b), shoot dry weight (c) and root dry weight (d) of tomato seeds under drought stress after SiO<sub>2</sub> nanopriming

The shoot length of maize seedlings developed under drought conditions was increased by SiO<sub>2</sub> treatment. 80 ppm of SiO<sub>2</sub> treatment increased the shoot length of maize seedlings the most under drought conditions at all levels (Table 4.33).

**Table 4.33.** Shoot length (SL) of maize seedlings under drought stress after SiO<sub>2</sub> nanopriming

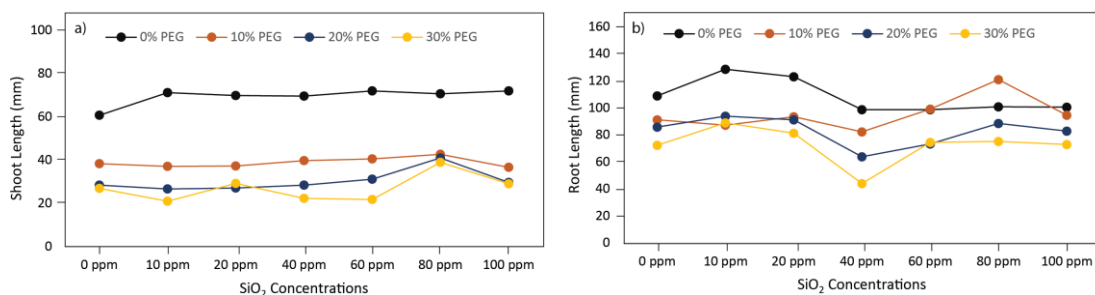
| SiO <sub>2</sub> Conc.<br>(ppm) | Shoot Length (mm)   |                     |                    |                    |
|---------------------------------|---------------------|---------------------|--------------------|--------------------|
|                                 | 0% PEG              | 10% PEG             | 20% PEG            | 30% PEG            |
| 0                               | 60,72 <sup>c</sup>  | 38,24 <sup>b</sup>  | 28,37 <sup>b</sup> | 26,82 <sup>b</sup> |
| 10                              | 71,19 <sup>ab</sup> | 37,01 <sup>b</sup>  | 26,57 <sup>b</sup> | 20,88 <sup>c</sup> |
| 20                              | 69,86 <sup>b</sup>  | 37,21 <sup>b</sup>  | 27,02 <sup>b</sup> | 29,16 <sup>b</sup> |
| 40                              | 69,54 <sup>b</sup>  | 39,67 <sup>ab</sup> | 28,36 <sup>b</sup> | 22,26 <sup>c</sup> |
| 60                              | 71,94 <sup>a</sup>  | 40,46 <sup>ab</sup> | 31,10 <sup>b</sup> | 21,68 <sup>c</sup> |
| 80                              | 70,59 <sup>ab</sup> | 42,65 <sup>a</sup>  | 40,97 <sup>a</sup> | 38,90 <sup>a</sup> |
| 100                             | 71,91 <sup>a</sup>  | 36,59 <sup>b</sup>  | 29,59 <sup>b</sup> | 29,01 <sup>b</sup> |

The root length of maize seedlings developed under 10% PEG of drought stress was increased by SiO<sub>2</sub> treatment, and 80 ppm of SiO<sub>2</sub> treatment increased the root length of maize seedlings up to 120,83 mm. On the other hand, 10 ppm of SiO<sub>2</sub> treatment increased the root length of maize seedlings, growth under 20 and 30% PEG conditions and 93,80 and 88,93 mm of root development was observed respectively (Table 4.34).

**Table 4.34.** Root length (RL) of maize seedlings under drought stress after SiO<sub>2</sub> nanopriming

| SiO <sub>2</sub> Conc.<br>(ppm) | Root Length (mm)    |                     |                     |                     |
|---------------------------------|---------------------|---------------------|---------------------|---------------------|
|                                 | 0% PEG              | 10% PEG             | 20% PEG             | 30% PEG             |
| 0                               | 108,88 <sup>b</sup> | 91,20 <sup>b</sup>  | 85,80 <sup>ab</sup> | 72,32 <sup>b</sup>  |
| 10                              | 128,56 <sup>a</sup> | 87,10 <sup>b</sup>  | 93,80 <sup>a</sup>  | 88,93 <sup>a</sup>  |
| 20                              | 123,08 <sup>a</sup> | 93,45 <sup>b</sup>  | 91,16 <sup>ab</sup> | 81,19 <sup>ab</sup> |
| 40                              | 98,59 <sup>c</sup>  | 82,19 <sup>b</sup>  | 63,80 <sup>c</sup>  | 43,88 <sup>c</sup>  |
| 60                              | 98,60 <sup>c</sup>  | 99,00 <sup>ab</sup> | 73,33 <sup>bc</sup> | 74,34 <sup>b</sup>  |
| 80                              | 100,72 <sup>c</sup> | 120,83 <sup>a</sup> | 88,39 <sup>ab</sup> | 75,05 <sup>ab</sup> |
| 100                             | 100,43 <sup>c</sup> | 94,58 <sup>b</sup>  | 82,78 <sup>ab</sup> | 72,88 <sup>b</sup>  |

SiO<sub>2</sub> treatment of maize seedlings increased both shoot and root length of maize seedlings under drought stress conditions (Figure 4.130).



**Figure 4.130.** Shoot length (a) and root length (b) of maize seeds under drought stress after SiO<sub>2</sub> nanopriming

The shoot fresh weight of maize seedlings developed under drought conditions, increased by SiO<sub>2</sub> nanopriming. 80 ppm SiO<sub>2</sub> provided the heaviest shoot fresh weight under drought stress conditions at all levels. The shoot fresh weight of maize seedlings increased the approximately 50% compare to 0 ppm of each drought stress level (Table 4.35).

**Table 4.35.** Shoot fresh weight (SFW) of maize seedlings under drought stress after SiO<sub>2</sub> nanopriming

| SiO <sub>2</sub> Conc.<br>(ppm) | Shoot Fresh Weight (g) |                      |                      |                      |
|---------------------------------|------------------------|----------------------|----------------------|----------------------|
|                                 | 0% PEG                 | 10% PEG              | 20% PEG              | 30% PEG              |
| 0                               | 0,5612 <sup>d</sup>    | 0,3569 <sup>cd</sup> | 0,2112 <sup>b</sup>  | 0,2039 <sup>b</sup>  |
| 10                              | 0,7733 <sup>b</sup>    | 0,3046 <sup>cd</sup> | 0,1648 <sup>c</sup>  | 0,1538 <sup>c</sup>  |
| 20                              | 0,8182 <sup>a</sup>    | 0,4176 <sup>bc</sup> | 0,1516 <sup>c</sup>  | 0,1798 <sup>bc</sup> |
| 40                              | 0,6835 <sup>c</sup>    | 0,2904 <sup>d</sup>  | 0,1696 <sup>c</sup>  | 0,1044 <sup>d</sup>  |
| 60                              | 0,6791 <sup>c</sup>    | 0,4682 <sup>b</sup>  | 0,1944 <sup>bc</sup> | 0,1486 <sup>cd</sup> |
| 80                              | 0,6750 <sup>c</sup>    | 0,5970 <sup>a</sup>  | 0,2980 <sup>a</sup>  | 0,2806 <sup>a</sup>  |
| 100                             | 0,6786 <sup>c</sup>    | 0,3086 <sup>cd</sup> | 0,2184 <sup>b</sup>  | 0,1904 <sup>bc</sup> |

The root fresh weight of maize seedlings, developed under drought condition, increased by SiO<sub>2</sub> application. The root fresh weight of seedlings, developed under 10% PEG drought condition, was increased from 0,8680 to 1,0376 g by 20 ppm of SiO<sub>2</sub> treatment. 20 ppm of SiO<sub>2</sub> treatment also increased root fresh weight of maize seedlings under 20% PEG of drought conditions up to 1,0570 g. The SiO<sub>2</sub> treatment did not affect root fresh weight of maize seedlings under 30% PEG of drought stress (Table 4.36).

**Table 4.36.** Root fresh weight (RFW) of maize seedlings under drought stress after SiO<sub>2</sub> nanopriming

| SiO <sub>2</sub> Conc.<br>(ppm) | Root Fresh Weight (g) |                      |                      |                      |
|---------------------------------|-----------------------|----------------------|----------------------|----------------------|
|                                 | 0% PEG                | 10% PEG              | 20% PEG              | 30% PEG              |
| 0                               | 0,9272 <sup>c</sup>   | 0,8680 <sup>c</sup>  | 0,8141 <sup>b</sup>  | 0,8001 <sup>a</sup>  |
| 10                              | 1,2082 <sup>a</sup>   | 0,8870 <sup>bc</sup> | 0,8504 <sup>ab</sup> | 0,9040 <sup>a</sup>  |
| 20                              | 1,1398 <sup>b</sup>   | 1,0376 <sup>a</sup>  | 1,0570 <sup>a</sup>  | 0,7954 <sup>ab</sup> |
| 40                              | 0,9418 <sup>c</sup>   | 0,8352 <sup>bc</sup> | 0,7128 <sup>b</sup>  | 0,6228 <sup>b</sup>  |
| 60                              | 0,9219 <sup>c</sup>   | 0,9944 <sup>ab</sup> | 0,8656 <sup>ab</sup> | 0,9118 <sup>a</sup>  |
| 80                              | 0,9030 <sup>c</sup>   | 0,8650 <sup>c</sup>  | 0,7726 <sup>b</sup>  | 0,7974 <sup>ab</sup> |
| 100                             | 0,9148 <sup>c</sup>   | 0,9278 <sup>ab</sup> | 0,9396 <sup>ab</sup> | 0,7876 <sup>ab</sup> |

The shoot dry weight of maize seedlings was increased by 80 ppm of SiO<sub>2</sub> application at all stress levels. The shoot dry weight of maize seedlings increased to 0,0457 g at 10% PEG; 0,0228 g at 20% PEG and 0,0215 g at 30% PEG conditions (Table 4.37).

**Table 4.37.** Shoot dry weight (SDW) of maize seedlings under drought stress after SiO<sub>2</sub> nanopriming

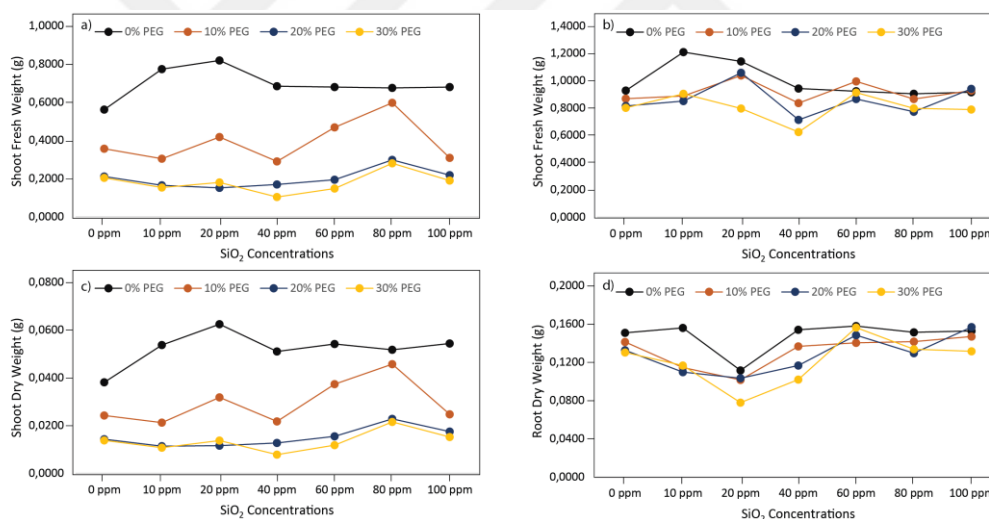
| SiO <sub>2</sub> Conc.<br>(ppm) | Shoot Dry Weight (g) |                     |                      |                      |
|---------------------------------|----------------------|---------------------|----------------------|----------------------|
|                                 | 0% PEG               | 10% PEG             | 20% PEG              | 30% PEG              |
| 0                               | 0,0381 <sup>d</sup>  | 0,0242 <sup>c</sup> | 0,0143 <sup>c</sup>  | 0,0138 <sup>cd</sup> |
| 10                              | 0,0537 <sup>b</sup>  | 0,0212 <sup>d</sup> | 0,0114 <sup>d</sup>  | 0,0107 <sup>d</sup>  |
| 20                              | 0,0624 <sup>a</sup>  | 0,0318 <sup>b</sup> | 0,0116 <sup>d</sup>  | 0,0137 <sup>c</sup>  |
| 40                              | 0,0510 <sup>c</sup>  | 0,0217 <sup>d</sup> | 0,0127 <sup>cd</sup> | 0,0078 <sup>e</sup>  |
| 60                              | 0,0541 <sup>b</sup>  | 0,0373 <sup>b</sup> | 0,0155 <sup>bc</sup> | 0,0118 <sup>d</sup>  |
| 80                              | 0,0517 <sup>bc</sup> | 0,0457 <sup>a</sup> | 0,0228 <sup>a</sup>  | 0,0215 <sup>a</sup>  |
| 100                             | 0,0543 <sup>b</sup>  | 0,0247 <sup>c</sup> | 0,0175 <sup>b</sup>  | 0,0152 <sup>c</sup>  |

The root dry weight of maize seedlings was decreased the most at 20 ppm SiO<sub>2</sub> application. However, increasing in SiO<sub>2</sub> concentration also increased the effect of SiO<sub>2</sub> on root dry weight and 60 ppm of SiO<sub>2</sub> caused the most increase in root dry weight of maize seedlings, developed under all stress level conditions (Table 4.38).

**Table 4.38.** Root dry weight (RDW) of maize seedlings under drought stress after SiO<sub>2</sub> nanoprimering

| SiO <sub>2</sub> Conc.<br>(ppm) | Root Dry Weight (g) |                      |                      |                     |
|---------------------------------|---------------------|----------------------|----------------------|---------------------|
|                                 | 0% PEG              | 10% PEG              | 20% PEG              | 30% PEG             |
| 0                               | 0,1508 <sup>a</sup> | 0,1412 <sup>a</sup>  | 0,1324 <sup>ab</sup> | 0,1301 <sup>b</sup> |
| 10                              | 0,1559 <sup>a</sup> | 0,1145 <sup>c</sup>  | 0,1097 <sup>c</sup>  | 0,1166 <sup>c</sup> |
| 20                              | 0,1114 <sup>b</sup> | 0,1014 <sup>c</sup>  | 0,1033 <sup>c</sup>  | 0,0777 <sup>d</sup> |
| 40                              | 0,1540 <sup>a</sup> | 0,1366 <sup>bc</sup> | 0,1166 <sup>c</sup>  | 0,1018 <sup>c</sup> |
| 60                              | 0,1579 <sup>a</sup> | 0,1403 <sup>a</sup>  | 0,1483 <sup>a</sup>  | 0,1562 <sup>a</sup> |
| 80                              | 0,1512 <sup>a</sup> | 0,1416 <sup>a</sup>  | 0,1294 <sup>b</sup>  | 0,1335 <sup>b</sup> |
| 100                             | 0,1526 <sup>a</sup> | 0,1469 <sup>a</sup>  | 0,1567 <sup>a</sup>  | 0,1314 <sup>b</sup> |

The effect of both drought stress and SiO<sub>2</sub> treatment on maize seedlings was presented in Figure 4.131.



**Figure 4.131.** Shoot fresh weight (a), root fresh weight (b), shoot dry weight (c) and root dry weight (d) of maize seeds under drought stress after SiO<sub>2</sub> nanoprimering

The shoot length of tomato seedlings developed under drought stress at different levels after TiO<sub>2</sub> nanoprimering was presented on Table 4.39. The tomato seedlings, developed under 10% PEG drought condition, had longer shoot at 250 ppm TiO<sub>2</sub> application compare to 0 ppm. The shoot length of seedling developed under 20% PEG of drought conditions was increased by 10 ppm TiO<sub>2</sub> treatment. Besides, the shoot length of tomato plantlets developed under 30% PEG of drought conditions was increased at 50 ppm of TiO<sub>2</sub> treatment.

**Table 4.39.** Shoot length (SL) of tomato seedlings under drought stress after TiO<sub>2</sub> nanopriming

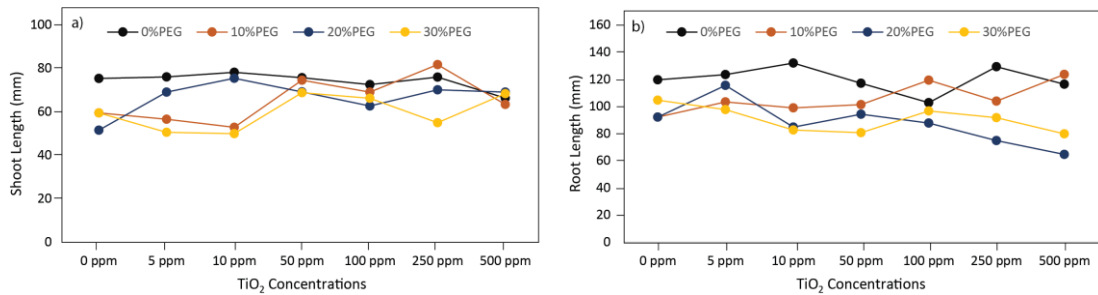
| TiO <sub>2</sub> Conc.<br>(ppm) | Shoot Length (mm)   |                    |                    |                     |
|---------------------------------|---------------------|--------------------|--------------------|---------------------|
|                                 | 0% PEG              | 10% PEG            | 20% PEG            | 30% PEG             |
| 0                               | 75,40 <sup>ab</sup> | 59,54 <sup>c</sup> | 51,55 <sup>c</sup> | 59,54 <sup>c</sup>  |
| 5                               | 76,14 <sup>ab</sup> | 56,64 <sup>f</sup> | 69,09 <sup>c</sup> | 50,58 <sup>e</sup>  |
| 10                              | 78,28 <sup>a</sup>  | 52,86 <sup>g</sup> | 75,48 <sup>a</sup> | 49,95 <sup>e</sup>  |
| 50                              | 75,73 <sup>ab</sup> | 74,62 <sup>b</sup> | 69,18 <sup>b</sup> | 68,86 <sup>a</sup>  |
| 100                             | 72,54 <sup>b</sup>  | 69,11 <sup>c</sup> | 62,77 <sup>d</sup> | 66,3 <sup>b</sup>   |
| 250                             | 76,03 <sup>ab</sup> | 81,78 <sup>a</sup> | 70,14 <sup>b</sup> | 55,02 <sup>d</sup>  |
| 500                             | 66,37 <sup>c</sup>  | 63,47 <sup>d</sup> | 69,1 <sup>b</sup>  | 68,39 <sup>ab</sup> |

The root length of tomato seedlings was increased by TiO<sub>2</sub> treatment under drought stress condition. 100 ppm of TiO<sub>2</sub> increase the root length of tomato seeds under 10% PEG drought stress conditions. On the other hand, 5 ppm of TiO<sub>2</sub> increased the root length of tomato plants up to 115,47 mm. However, TiO<sub>2</sub> did not increase the root length of tomato seedlings, developed under 30% PEG of drought stress conditions (Table 4.40).

**Table 4.40.** Root length (RL) of tomato seedlings under drought stress after TiO<sub>2</sub> nanopriming

| TiO <sub>2</sub> Conc.<br>(ppm) | Root Length (mm)      |                      |                     |                     |
|---------------------------------|-----------------------|----------------------|---------------------|---------------------|
|                                 | 0% PEG                | 10% PEG              | 20% PEG             | 30% PEG             |
| 0                               | 119,64 <sup>bc</sup>  | 92,08 <sup>c</sup>   | 92,08 <sup>b</sup>  | 104,58 <sup>a</sup> |
| 5                               | 123,42 <sup>abc</sup> | 103,27 <sup>bc</sup> | 115,47 <sup>a</sup> | 97,64 <sup>b</sup>  |
| 10                              | 132,02 <sup>a</sup>   | 98,98 <sup>bc</sup>  | 84,69 <sup>bc</sup> | 82,58 <sup>cd</sup> |
| 50                              | 117,09 <sup>bc</sup>  | 101,3 <sup>bc</sup>  | 94,24 <sup>b</sup>  | 80,58 <sup>de</sup> |
| 100                             | 102,72 <sup>d</sup>   | 119,32 <sup>a</sup>  | 87,75 <sup>bc</sup> | 96,65 <sup>ab</sup> |
| 250                             | 129,24 <sup>ab</sup>  | 103,96 <sup>b</sup>  | 74,77 <sup>cd</sup> | 91,68 <sup>bc</sup> |
| 500                             | 116,43 <sup>c</sup>   | 123,53 <sup>a</sup>  | 64,62 <sup>d</sup>  | 79,75 <sup>e</sup>  |

The effect of drought stress and TiO<sub>2</sub> nanopriming on shoot and root length of tomato seedlings were presented in Figure 4.132.



**Figure 4.132.** Shoot length (a) and root length (b) of tomato seeds under drought stress after TiO<sub>2</sub> nanopriming

The shoot fresh weight of tomato seedlings increased by TiO<sub>2</sub> nanopriming under drought stress condition. The shoot fresh weight of tomato was increased to 0,1459 g from 0,0837 g by 20 ppm of TiO<sub>2</sub> nanopriming application. 50 ppm of TiO<sub>2</sub> application displayed best performance with 0,1244 g. The seedling developed under 30% of PEG conditions had heaviest shoot fresh weight at 50 and 100 ppm of TiO<sub>2</sub> nanopriming (Table 4.41).

**Table 4.41.** Shoot fresh weight (SFW) of tomato seedlings under drought stress after TiO<sub>2</sub> nanopriming

| TiO <sub>2</sub> Conc.<br>(ppm) | Shoot Fresh Weight (g) |                      |                      |                      |
|---------------------------------|------------------------|----------------------|----------------------|----------------------|
|                                 | 0% PEG                 | 10% PEG              | 20% PEG              | 30% PEG              |
| 0                               | 0,1328 <sup>b</sup>    | 0,0837 <sup>d</sup>  | 0,0884 <sup>d</sup>  | 0,0798 <sup>b</sup>  |
| 5                               | 0,1470 <sup>ab</sup>   | 0,1376 <sup>bc</sup> | 0,0986 <sup>cd</sup> | 0,0788 <sup>bc</sup> |
| 10                              | 0,1496 <sup>ab</sup>   | 0,1459 <sup>a</sup>  | 0,0935 <sup>d</sup>  | 0,0757 <sup>c</sup>  |
| 50                              | 0,1561 <sup>a</sup>    | 0,1402 <sup>b</sup>  | 0,1244 <sup>a</sup>  | 0,1000 <sup>a</sup>  |
| 100                             | 0,1434 <sup>ab</sup>   | 0,1275 <sup>c</sup>  | 0,1218 <sup>ab</sup> | 0,1009 <sup>a</sup>  |
| 250                             | 0,1505 <sup>ab</sup>   | 0,1401 <sup>b</sup>  | 0,1324 <sup>a</sup>  | 0,0846 <sup>bc</sup> |
| 500                             | 0,1574 <sup>a</sup>    | 0,1247 <sup>c</sup>  | 0,1095 <sup>bc</sup> | 0,0869 <sup>b</sup>  |

10 ppm of TiO<sub>2</sub> nanopriming application increased the root fresh weight under both 10 and 20% of PEG conditions with 0,0269 and 0,0226 g respectively. On the other hand TiO<sub>2</sub> application decreased the root fresh weight of tomato seedlings under 30% of PEG conditions (Table 4.42).

**Table 4.42.** Root fresh weight (RFW) of tomato seedlings under drought stress after TiO<sub>2</sub> nanopriming

| TiO <sub>2</sub> Conc.<br>(ppm) | Root Fresh Weight (g) |                     |                     |                      |
|---------------------------------|-----------------------|---------------------|---------------------|----------------------|
|                                 | 0% PEG                | 10% PEG             | 20% PEG             | 30% PEG              |
| 0                               | 0,0889 <sup>c</sup>   | 0,0187 <sup>b</sup> | 0,0159 <sup>b</sup> | 0,0301 <sup>a</sup>  |
| 5                               | 0,1283 <sup>ab</sup>  | 0,0262 <sup>a</sup> | 0,0165 <sup>b</sup> | 0,0163 <sup>b</sup>  |
| 10                              | 0,1436 <sup>a</sup>   | 0,0269 <sup>a</sup> | 0,0226 <sup>a</sup> | 0,0153 <sup>b</sup>  |
| 50                              | 0,1091 <sup>abc</sup> | 0,0151 <sup>b</sup> | 0,0166 <sup>b</sup> | 0,0187 <sup>ab</sup> |
| 100                             | 0,0934 <sup>bc</sup>  | 0,0169 <sup>b</sup> | 0,0175 <sup>b</sup> | 0,0168 <sup>b</sup>  |
| 250                             | 0,1075 <sup>abc</sup> | 0,0152 <sup>b</sup> | 0,0169 <sup>b</sup> | 0,0176 <sup>b</sup>  |
| 500                             | 0,1199 <sup>abc</sup> | 0,0169 <sup>b</sup> | 0,0163 <sup>b</sup> | 0,0123 <sup>b</sup>  |

Table 4.43 presents the shoot dry weight of tomato seedlings under drought stress conditions after TiO<sub>2</sub> nanopriming application. The shoot dry weight of tomato seedlings was increased at 5 ppm of TiO<sub>2</sub> nanopriming application under 10 and 20% of PEG conditions with 0,0054 and 0,0045 g respectively. However, shoot dry weight of tomato seedlings decreased by TiO<sub>2</sub> nanopriming applications under 30% of PEG conditions, only 10 ppm of TiO<sub>2</sub> had same weight with control group.

**Table 4.43.** Shoot dry weight (SDW) of tomato seedlings under drought stress after TiO<sub>2</sub> nanopriming

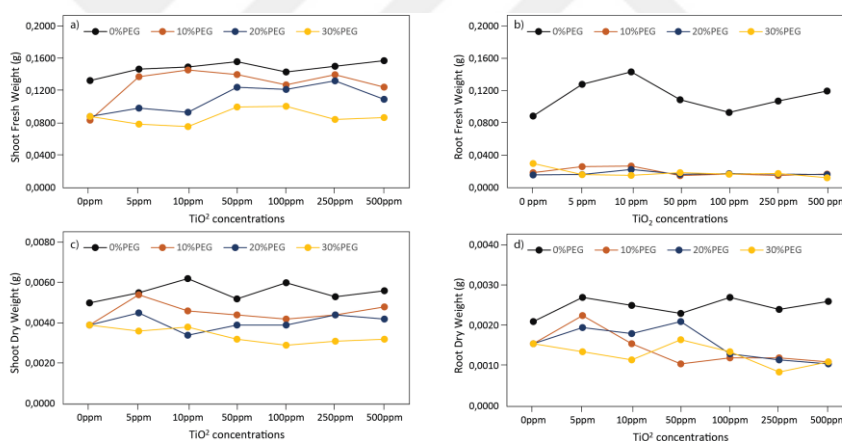
| TiO <sub>2</sub> Conc.<br>(ppm) | Shoot Dry Weight (g)  |                     |                     |                     |
|---------------------------------|-----------------------|---------------------|---------------------|---------------------|
|                                 | 0% PEG                | 10% PEG             | 20% PEG             | 30% PEG             |
| 0                               | 0,0050 <sup>c</sup>   | 0,0039 <sup>b</sup> | 0,0039 <sup>b</sup> | 0,0039 <sup>a</sup> |
| 5                               | 0,0055 <sup>abc</sup> | 0,0054 <sup>a</sup> | 0,0045 <sup>a</sup> | 0,0036 <sup>b</sup> |
| 10                              | 0,0062 <sup>a</sup>   | 0,0046 <sup>b</sup> | 0,0034 <sup>b</sup> | 0,0038 <sup>a</sup> |
| 50                              | 0,0052 <sup>bc</sup>  | 0,0044 <sup>b</sup> | 0,0039 <sup>b</sup> | 0,0032 <sup>c</sup> |
| 100                             | 0,0060 <sup>ab</sup>  | 0,0042 <sup>b</sup> | 0,0039 <sup>b</sup> | 0,0029 <sup>c</sup> |
| 250                             | 0,0053 <sup>bc</sup>  | 0,0044 <sup>b</sup> | 0,0044 <sup>a</sup> | 0,0031 <sup>c</sup> |
| 500                             | 0,0056 <sup>abc</sup> | 0,0048 <sup>b</sup> | 0,0042 <sup>b</sup> | 0,0032 <sup>c</sup> |

Likewise shoot dry weight, root dry weight also increased by 5 ppm of TiO<sub>2</sub> application under 10 and 20% of PEG conditions. Also, the root dry weight of tomato seedlings decreased by TiO<sub>2</sub> application under 30% of PEG condition (Table 4.44).

**Table 4.44.** Root dry weight (RDW) of tomato seedlings under drought stress after TiO<sub>2</sub> nanopriming

| TiO <sub>2</sub> Conc.<br>(ppm) | Root Dry Weight (g)  |                     |                      |                      |
|---------------------------------|----------------------|---------------------|----------------------|----------------------|
|                                 | 0% PEG               | 10% PEG             | 20% PEG              | 30% PEG              |
| 0                               | 0,0021 <sup>b</sup>  | 0,0016 <sup>b</sup> | 0,0016 <sup>b</sup>  | 0,0016 <sup>a</sup>  |
| 5                               | 0,0027 <sup>a</sup>  | 0,0023 <sup>a</sup> | 0,0020 <sup>a</sup>  | 0,0014 <sup>bc</sup> |
| 10                              | 0,0025 <sup>ab</sup> | 0,0016 <sup>b</sup> | 0,0018 <sup>ab</sup> | 0,0012 <sup>c</sup>  |
| 50                              | 0,0023 <sup>ab</sup> | 0,0011 <sup>c</sup> | 0,0021 <sup>a</sup>  | 0,0017 <sup>a</sup>  |
| 100                             | 0,0027 <sup>a</sup>  | 0,0012 <sup>c</sup> | 0,0013 <sup>c</sup>  | 0,0014 <sup>bc</sup> |
| 250                             | 0,0024 <sup>ab</sup> | 0,0012 <sup>c</sup> | 0,0012 <sup>c</sup>  | 0,0009 <sup>c</sup>  |
| 500                             | 0,0026 <sup>a</sup>  | 0,0011 <sup>c</sup> | 0,0011 <sup>c</sup>  | 0,0011 <sup>c</sup>  |

Figure 4.133 presents the effect of TiO<sub>2</sub> application to tomato seeds under drought conditions.



**Figure 4.133.** Shoot fresh weight (a), root fresh weight (b), shoot dry weight (c) and root dry weight (d) of tomato seeds under drought stress after TiO<sub>2</sub> nanopriming

The shoot length of maize seedling was increased by TiO<sub>2</sub> nanopriming under drought stress conditions. The shoot length of maize seedlings, developed under 10% of PEG conditions, increased by 100 ppm of TiO<sub>2</sub> with 62,09 mm. On the other hand, 5 ppm of TiO<sub>2</sub> holds the first rank of shoot length of maize seedlings, developed under 20% of PEG condition. Finally, 10 ppm of TiO<sub>2</sub> increased the shoot length of maize seedlings from 26,82 mm to 29,04 mm (Table 4.45).

**Table 4.45.** Shoot length (SL) of maize seedlings under drought stress after TiO<sub>2</sub> nanopriming

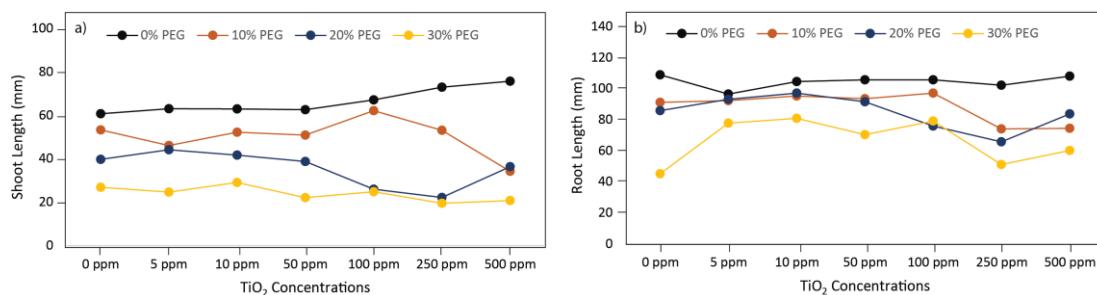
| TiO <sub>2</sub> Conc.<br>(ppm) | Shoot Length (mm)  |                     |                     |                     |
|---------------------------------|--------------------|---------------------|---------------------|---------------------|
|                                 | 0% PEG             | 10% PEG             | 20% PEG             | 30% PEG             |
| 0                               | 60,72 <sup>d</sup> | 53,27 <sup>b</sup>  | 39,72 <sup>ab</sup> | 26,82 <sup>ab</sup> |
| 5                               | 63,01 <sup>d</sup> | 46,05 <sup>c</sup>  | 44,10 <sup>a</sup>  | 24,67 <sup>bc</sup> |
| 10                              | 62,92 <sup>d</sup> | 52,17 <sup>bc</sup> | 41,65 <sup>ab</sup> | 29,04 <sup>a</sup>  |
| 50                              | 62,54 <sup>d</sup> | 50,87 <sup>bc</sup> | 38,76 <sup>ab</sup> | 22,11 <sup>cd</sup> |
| 100                             | 67,04 <sup>c</sup> | 62,09 <sup>a</sup>  | 26,01 <sup>c</sup>  | 24,83 <sup>bc</sup> |
| 250                             | 72,92 <sup>b</sup> | 53,06 <sup>b</sup>  | 22,20 <sup>c</sup>  | 19,48 <sup>d</sup>  |
| 500                             | 75,71 <sup>a</sup> | 34,19 <sup>d</sup>  | 36,30 <sup>b</sup>  | 20,74 <sup>cd</sup> |

As presented in Table 4.46, the root length of maize seedling was increased by TiO<sub>2</sub> nanopriming under drought stress conditions. The root length of maize seedlings was increased to 97,06 mm by 100 ppm of TiO<sub>2</sub> application under 10% of PEG condition. On the other hand, 10 ppm of TiO<sub>2</sub> increased root length of maize seedlings from 85,80 to 97,06 under 20% of PEG condition. The root length of maize seedlings increased by all concentrations of TiO<sub>2</sub> application under 30% of PEG condition.

**Table 4.46.** Root length (RL) of maize seedlings under drought stress after TiO<sub>2</sub> nanopriming

| TiO <sub>2</sub> Conc.<br>(ppm) | Root Length (mm)     |                      |                     |                     |
|---------------------------------|----------------------|----------------------|---------------------|---------------------|
|                                 | 0% PEG               | 10% PEG              | 20% PEG             | 30% PEG             |
| 0                               | 108,88 <sup>a</sup>  | 91,20 <sup>ab</sup>  | 85,80 <sup>bc</sup> | 45,20 <sup>d</sup>  |
| 5                               | 96,47 <sup>b</sup>   | 92,27 <sup>ab</sup>  | 93,12 <sup>ab</sup> | 77,78 <sup>a</sup>  |
| 10                              | 104,53 <sup>a</sup>  | 95,24 <sup>abc</sup> | 97,06 <sup>a</sup>  | 80,87 <sup>a</sup>  |
| 50                              | 105,69 <sup>a</sup>  | 93,46 <sup>abc</sup> | 91,47 <sup>b</sup>  | 70,32 <sup>ab</sup> |
| 100                             | 105,63 <sup>a</sup>  | 97,06 <sup>a</sup>   | 75,84 <sup>cd</sup> | 79,13 <sup>a</sup>  |
| 250                             | 102,16 <sup>ab</sup> | 74,00 <sup>c</sup>   | 65,70 <sup>d</sup>  | 51,05 <sup>cd</sup> |
| 500                             | 107,96 <sup>a</sup>  | 74,46 <sup>bc</sup>  | 83,70 <sup>bc</sup> | 60,15 <sup>bc</sup> |

The effect of TiO<sub>2</sub> nanopriming and drought stress on maize seedlings were presented in Figure 4.134.



**Figure 4.134.** Shoot length (a) and root length (b) of maize seeds under drought stress after TiO<sub>2</sub> nanoprimering

The shoot fresh weight of maize seedling was no change by TiO<sub>2</sub> application under 10% of PEG condition. However, 5 ppm of TiO<sub>2</sub> nanoprimering increased the shoot fresh weight of maize seedlings under 20% of PEG condition to 0,3583 g. Besides, 10ppm of TiO<sub>2</sub> application increased the root length of maize seedlings under 30% of PEG conditions to 0,1887 g from 0,1631 g (Table 4.47).

**Table 4.47.** Shoot fresh weight (SFW) of maize seedlings under drought stress after TiO<sub>2</sub> nanoprimering

| TiO <sub>2</sub> Conc.<br>(ppm) | Shoot Fresh Weight (g) |                      |                      |                       |
|---------------------------------|------------------------|----------------------|----------------------|-----------------------|
|                                 | 0% PEG                 | 10% PEG              | 20% PEG              | 30% PEG               |
| 0                               | 0,5612 <sup>c</sup>    | 0,2550 <sup>a</sup>  | 0,2956 <sup>b</sup>  | 0,1631 <sup>b</sup>   |
| 5                               | 0,6008 <sup>bc</sup>   | 0,2545 <sup>a</sup>  | 0,3583 <sup>a</sup>  | 0,1367 <sup>c</sup>   |
| 10                              | 0,5772 <sup>bc</sup>   | 0,2714 <sup>a</sup>  | 0,2693 <sup>b</sup>  | 0,1887 <sup>a</sup>   |
| 50                              | 0,6084 <sup>bc</sup>   | 0,2622 <sup>a</sup>  | 0,2617 <sup>bc</sup> | 0,0963 <sup>d</sup>   |
| 100                             | 0,6091 <sup>b</sup>    | 0,2783 <sup>a</sup>  | 0,1776 <sup>d</sup>  | 0,1578 <sup>abc</sup> |
| 250                             | 0,6014 <sup>bc</sup>   | 0,2190 <sup>ab</sup> | 0,1638 <sup>d</sup>  | 0,0696 <sup>d</sup>   |
| 500                             | 0,6634 <sup>a</sup>    | 0,1815 <sup>b</sup>  | 0,2018 <sup>cd</sup> | 0,0805 <sup>d</sup>   |

Likewise, the shoot fresh weight, the root fresh weight of maize seedlings did not change by TiO<sub>2</sub> application under 10% of PEG condition. However, 50 ppm of TiO<sub>2</sub> increased the root fresh weight to 1,003 g under 20% of PEG condition. Moreover, 10 and 100 ppm of TiO<sub>2</sub> nanoprimering increased the root fresh weight of maize seedlings to 0,8912 g and 0,9490 g under 30% of PEG conditions respectively (Table 4.48).

**Table 4.48.** Root fresh weight (RFW) of maize seedlings under drought stress after TiO<sub>2</sub> nanopriming

| TiO <sub>2</sub> Conc.<br>(ppm) | Root Fresh Weight (g) |                      |                      |                     |
|---------------------------------|-----------------------|----------------------|----------------------|---------------------|
|                                 | 0% PEG                | 10% PEG              | 20% PEG              | 30% PEG             |
| 0                               | 0,9272 <sup>b</sup>   | 0,8680 <sup>a</sup>  | 0,8141 <sup>b</sup>  | 0,4001 <sup>c</sup> |
| 5                               | 1,0307 <sup>a</sup>   | 0,8596 <sup>ab</sup> | 0,8264 <sup>ab</sup> | 0,6900 <sup>b</sup> |
| 10                              | 1,0710 <sup>a</sup>   | 0,8770 <sup>ab</sup> | 0,8507 <sup>ab</sup> | 0,8912 <sup>a</sup> |
| 50                              | 1,0488 <sup>a</sup>   | 0,8688 <sup>ab</sup> | 1,0033 <sup>a</sup>  | 0,6535 <sup>b</sup> |
| 100                             | 0,9205 <sup>b</sup>   | 0,8364 <sup>ab</sup> | 0,8106 <sup>b</sup>  | 0,9490 <sup>a</sup> |
| 250                             | 0,9147 <sup>b</sup>   | 0,7303 <sup>ab</sup> | 0,6734 <sup>d</sup>  | 0,5530 <sup>b</sup> |
| 500                             | 1,0601 <sup>a</sup>   | 0,7018 <sup>b</sup>  | 0,7628 <sup>cd</sup> | 0,5833 <sup>b</sup> |

TiO<sub>2</sub> nanopriming promoted the biomass accumulation in maize shoot under drought conditions. Like, the shoot dry weight of maize seedlings increased by 100 ppm of TiO<sub>2</sub> nanopriming under 10% and 30% of PEG condition. Also, 5 ppm of TiO<sub>2</sub> application increased the shoot dry weight of maize seedlings to 0,0256 g under 20% of PEG condition (Table 4.49).

**Table 4.49.** Shoot dry weight (SDW) of maize seedlings under drought stress after TiO<sub>2</sub> nanopriming

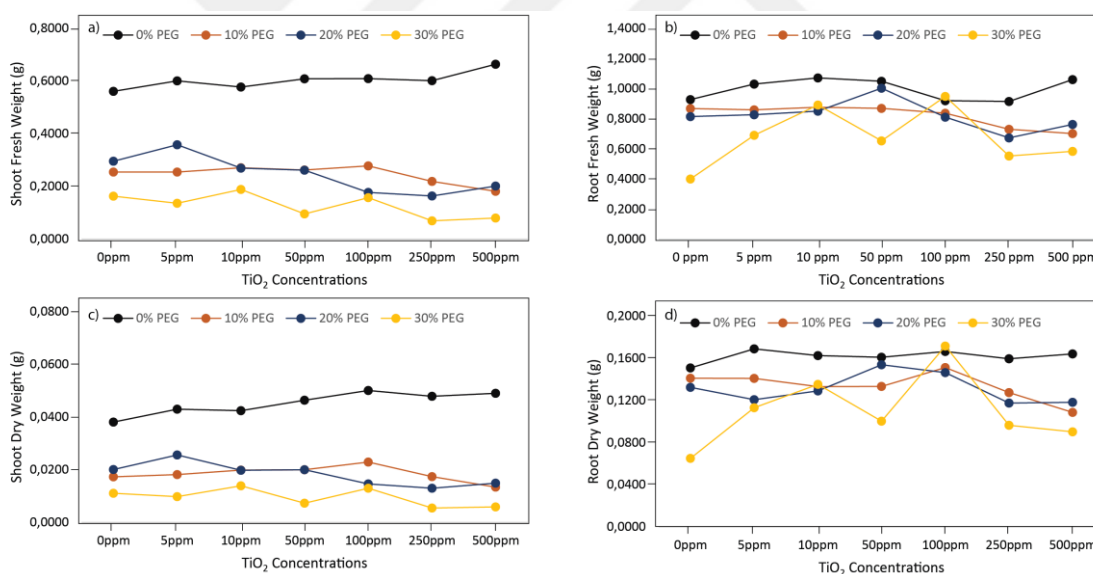
| TiO <sub>2</sub> Conc.<br>(ppm) | Shoot Dry Weight (g) |                      |                     |                      |
|---------------------------------|----------------------|----------------------|---------------------|----------------------|
|                                 | 0% PEG               | 10% PEG              | 20% PEG             | 30% PEG              |
| 0                               | 0,0381 <sup>d</sup>  | 0,0173 <sup>c</sup>  | 0,0201 <sup>b</sup> | 0,0111 <sup>c</sup>  |
| 5                               | 0,0430 <sup>c</sup>  | 0,0182 <sup>bc</sup> | 0,0256 <sup>a</sup> | 0,0098 <sup>c</sup>  |
| 10                              | 0,0424 <sup>c</sup>  | 0,0199 <sup>b</sup>  | 0,0198 <sup>b</sup> | 0,0139 <sup>b</sup>  |
| 50                              | 0,0464 <sup>b</sup>  | 0,0200 <sup>b</sup>  | 0,0200 <sup>b</sup> | 0,0073 <sup>cd</sup> |
| 100                             | 0,0501 <sup>a</sup>  | 0,0229 <sup>a</sup>  | 0,0146 <sup>c</sup> | 0,0130 <sup>a</sup>  |
| 250                             | 0,0479 <sup>ab</sup> | 0,0174 <sup>c</sup>  | 0,0130 <sup>c</sup> | 0,0055 <sup>d</sup>  |
| 500                             | 0,0490 <sup>ab</sup> | 0,0134 <sup>d</sup>  | 0,0149 <sup>c</sup> | 0,0059 <sup>d</sup>  |

100 ppm TiO<sub>2</sub> application to maize seeds, increased the root dry weight under all drought stress levels with 0,1512; 0,1465; 0,1716 g respectively (Table 4.50).

**Table 4.50.** Root fresh weight (RFW) of maize seedlings under drought stress after TiO<sub>2</sub> nanopriming

| TiO <sub>2</sub> Conc.<br>(ppm) | Root Dry Weight (g)  |                      |                      |                      |
|---------------------------------|----------------------|----------------------|----------------------|----------------------|
|                                 | 0% PEG               | 10% PEG              | 20% PEG              | 30% PEG              |
| 0                               | 0,1508 <sup>b</sup>  | 0,1412 <sup>b</sup>  | 0,1324 <sup>b</sup>  | 0,0651 <sup>d</sup>  |
| 5                               | 0,1690 <sup>a</sup>  | 0,1409 <sup>b</sup>  | 0,1207 <sup>bc</sup> | 0,1131 <sup>bc</sup> |
| 10                              | 0,1625 <sup>ab</sup> | 0,1331 <sup>c</sup>  | 0,1291 <sup>bc</sup> | 0,1352 <sup>b</sup>  |
| 50                              | 0,1609 <sup>ab</sup> | 0,1333 <sup>c</sup>  | 0,1539 <sup>a</sup>  | 0,1003 <sup>c</sup>  |
| 100                             | 0,1664 <sup>a</sup>  | 0,1512 <sup>a</sup>  | 0,1465 <sup>a</sup>  | 0,1716 <sup>a</sup>  |
| 250                             | 0,1596 <sup>ab</sup> | 0,1274 <sup>cd</sup> | 0,1175 <sup>c</sup>  | 0,0965 <sup>c</sup>  |
| 500                             | 0,1642 <sup>ab</sup> | 0,1087 <sup>d</sup>  | 0,1182 <sup>c</sup>  | 0,0903 <sup>c</sup>  |

The effect of TiO<sub>2</sub> nanopriming and drought stress on shoot and root fresh and dry weight of maize seedlings presented in Figure 4.135.



**Figure 4.135.** Shoot fresh weight (a), root fresh weight (b), shoot dry weight (c) and root dry weight (d) of maize seeds under drought stress after TiO<sub>2</sub> nanopriming

There are conflicting studies on effect of nanoparticles on seed germination and plant development and mechanism of nanoparticle effect on plants has not been illuminated yet with current literature. Likewise, in the current study, the results do not indicate only positive or negative effect of nanopriming on seed germination and seedling development under abiotic stresses.

Altar F1 and Capuzi cultivars were used as seed samples for tomato and maize respectively. Both of the cultivars are hybrid seeds and have very high germination rate. For these purpose the application of SiO<sub>2</sub> and TiO<sub>2</sub> did not affect the seed germination rate. However, application of CNT increased both tomato and maize seeds under drought stress. Khodokovskaya et al (2009) and Lahiani et al (2013) indicated the penetration ability of multiwalled-CNT into seed coat, even the thick ones, and increases the water uptake ability of seeds. Thus, the CNT application increased the seed germination rate in the current study (Khodokovskaya et al, 2009; Lahiani et al, 2013).

CNT nanopriming mostly increased the root growth of tomato seedling under drought stress; when did not affect the maize seedling development. CNT nanopriming application under drought stress increased the root growth of hopbush and did not chance the shoot development (Yousafi et. al., 2017). The study conducted on *Alnus subcordata* presented hopeful results to use of CNT nanopriming under drought stress by increasing in both seed germination and seedling development (Rahimi et. al., 2016). It is pointed out that, using low dosage of CNT promoted the seed germination and seedling development of *Hyoscyamus niger* under drought stress by increasing water uptake ability of seeds and activating plants defence system (Hatami et. al., 2017). Cano et. al. indicated that, CNT did not affect the drought tolerance ability of maize seedlings (Cano et. al., 2016). Likewise, the current study, the drought tolerance level of maize seeds did not affect by CNT application at low concentrations and decreased by application of higher concentrations. The toxic effect of high concentration of CNT on drought tolerance of plants due inactivation of cellular antioxidant enzymes (Hatami et. al., 2017).

SiO<sub>2</sub> nanopriming increased the shoot growth of both tomato and maize seedlings in the present study. On the other hand, SiO<sub>2</sub> application increased the root growth of maize seedling. Ashkavand pointed out that, the pre-treatment of soil with SiO<sub>2</sub> nanoparticles increased the drought tolerance of hawthorn seedlings (Ashkavand et. al., 2015). The study performed on mahaleb indicated that using of SiO<sub>2</sub> nanoparticles increased the root biomass accumulation and increase the tolerance to drought stress (Ashkavadet et al., 2018). It is reported that, SiO<sub>2</sub> nanoparticle application to leaves of *Pinus nigra* increased the drought tolerance by increasing the water potential and relative water content also biomass of the plants (Dehghan et. al., 2016).

In the current study it was observed that, TiO<sub>2</sub> nanopriming increased the plant growth under 10% and 20% of PEG stimulated drought stress of tomato seedlings and 20% and 30% of PEG stimulated drought stress of maize seedlings. It is reported that, foliar application of TiO<sub>2</sub> nanoparticles decreased the effect of drought stress on *L. iberica* by increasing the catalase and superoxide dismutase enzyme activity (Sattari et. al., 2020). Besides, the foliar application of TiO<sub>2</sub> nanoparticles decreased the membrane deficiency caused by drought stress (Mohammadi, 2016). The TiO<sub>2</sub> application to wheat seeds also increased the both seed germination and seedling growth under PEG stimulate drought conditions (Faraji and Sepehri, 2016).

#### 4.4.2 Salinity stress

In order to mimic salinity stress under laboratory conditions NaCl was added to MS medium at 50 mM, 100 mM and 150 mM concentrations.

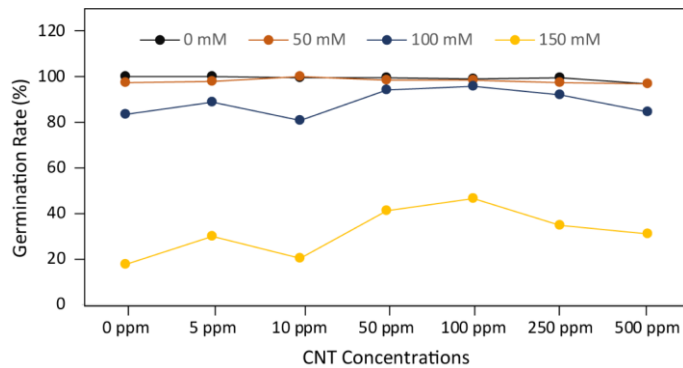
##### 4.4.2.1 Germination rate (%)

Table 4.51 presents the germination rate of tomato seeds under salinity stress after CNT nanopriming. 50 mM of NaCl application did not affect seed germination rate of tomato. However, 50 and 100 ppm of CNT nanopriming increased the seed germination rate of tomato under 100 and 150 mM of NaCl stress.

**Table 4.51.** Germination rates (%) of tomato seeds under salinity stress after CNT nanopriming.

| CNT Conc.<br>(ppm) | Germination Rate (%) |                    |                     |                     |
|--------------------|----------------------|--------------------|---------------------|---------------------|
|                    | 0 mM NaCl            | 50 mM NaCl         | 100 mM NaCl         | 150 mM NaCl         |
| 0                  | 100,0 <sup>a</sup>   | 97,3 <sup>a</sup>  | 83,4 <sup>cd</sup>  | 17,3 <sup>d</sup>   |
| 5                  | 100,0 <sup>a</sup>   | 98,2 <sup>a</sup>  | 88,7 <sup>abc</sup> | 30,0 <sup>bcd</sup> |
| 10                 | 99,3 <sup>a</sup>    | 100,0 <sup>a</sup> | 80,8 <sup>d</sup>   | 20,0 <sup>cd</sup>  |
| 50                 | 99,3 <sup>a</sup>    | 98,8 <sup>a</sup>  | 94,0 <sup>a</sup>   | 41,1 <sup>ab</sup>  |
| 100                | 99,7 <sup>a</sup>    | 98,8 <sup>a</sup>  | 96,0 <sup>a</sup>   | 46,8 <sup>a</sup>   |
| 250                | 99,3 <sup>a</sup>    | 97,3 <sup>a</sup>  | 92,0 <sup>ab</sup>  | 34,8 <sup>ab</sup>  |
| 500                | 96,7 <sup>b</sup>    | 96,7 <sup>a</sup>  | 84,8 <sup>bcd</sup> | 30,8 <sup>bc</sup>  |

The effect of CNT nanopriming and salinity stress on tomato seed germination was presented in Figure 4.136.



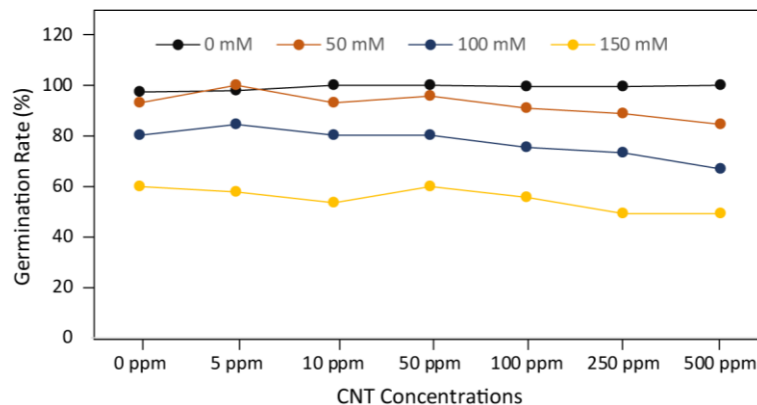
**Figure 4.136.** Germination rates (%) of tomato seeds under salinity stress after CNT nanopriming

The germination rate of maize seeds decreased by increasing in CNT concentration under 50 and 100 mM of NaCl stress. However, there was no effect of CNT nanopriming on seed germination rate of maize seeds under 150 mM of NaCl stress (Table 4.52).

**Table 4.52.** Germination rates (%) of maize seeds under salinity stress after CNT nanopriming

| CNT Conc.<br>(ppm) | Germination Rate (%) |                    |                     |                   |
|--------------------|----------------------|--------------------|---------------------|-------------------|
|                    | 0 mM NaCl            | 50 mM NaCl         | 100 mM NaCl         | 150 mM NaCl       |
| 0                  | 97,5 <sup>b</sup>    | 93,3 <sup>ab</sup> | 80,0 <sup>ab</sup>  | 60,0 <sup>a</sup> |
| 5                  | 98,0 <sup>b</sup>    | 100,0 <sup>a</sup> | 84,4 <sup>a</sup>   | 57,8 <sup>a</sup> |
| 10                 | 100,0 <sup>a</sup>   | 93,3 <sup>ab</sup> | 80,0 <sup>ab</sup>  | 53,3 <sup>a</sup> |
| 50                 | 100,0 <sup>a</sup>   | 95,6 <sup>ab</sup> | 80,0 <sup>ab</sup>  | 60,0 <sup>a</sup> |
| 100                | 99,3 <sup>ab</sup>   | 91,1 <sup>bc</sup> | 75,6 <sup>abc</sup> | 55,6 <sup>a</sup> |
| 250                | 99,3 <sup>ab</sup>   | 88,9 <sup>bc</sup> | 73,3 <sup>bc</sup>  | 48,9 <sup>a</sup> |
| 500                | 100,0 <sup>a</sup>   | 84,4 <sup>c</sup>  | 66,7 <sup>c</sup>   | 48,9 <sup>a</sup> |

The effect of salinity stress and CNT nanopriming on maize seeds was shown in Figure 4.137.



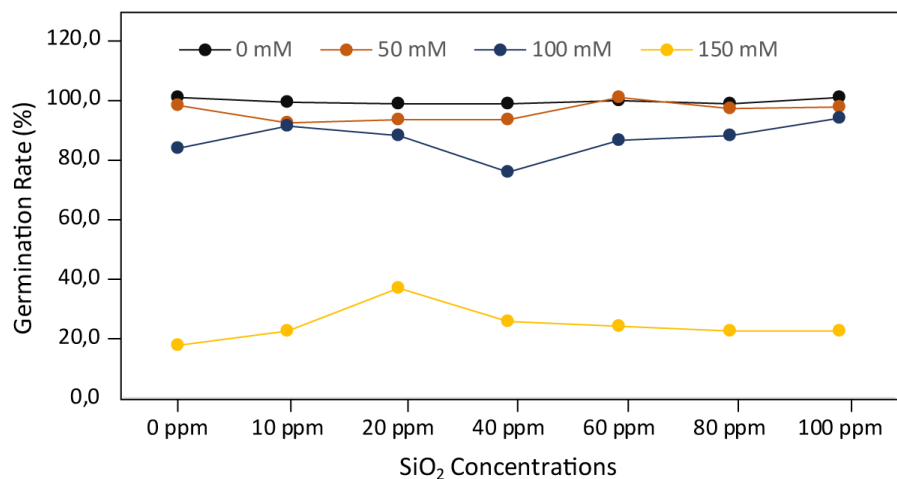
**Figure 4.137.** Germination rates (%) of maize seeds under salinity stress after CNT nanopriming

SiO<sub>2</sub> nanopriming increased the seed germination rate of tomato seeds under salinity stress. 60 ppm of SiO<sub>2</sub> increased the seed germination rate of tomato seeds up to 100% under 50 mM of NaCl stress. On the other hand, the germination rate of seeds, germinated under 100 mM of NaCl, were increased at all SiO<sub>2</sub> concentrations except 40 ppm. 20 ppm of SiO<sub>2</sub> nanopriming, increased the seed germination rate of tomato under 150 mM NaCl and rest of the concentrations did not affect the germination rate (Table 4.53).

**Table 4.53.** Germination rates (%) of tomato seeds under salinity stress after SiO<sub>2</sub> nanopriming

| SiO <sub>2</sub> Conc.<br>(ppm) | Germination Rate (%) |                    |                    |                   |
|---------------------------------|----------------------|--------------------|--------------------|-------------------|
|                                 | 0 mM NaCl            | 50 mM NaCl         | 100 mM NaCl        | 150 mM NaCl       |
| 0                               | 100,0 <sup>a</sup>   | 97,6 <sup>ab</sup> | 83,3 <sup>ab</sup> | 17,3 <sup>b</sup> |
| 10                              | 98,7 <sup>ab</sup>   | 92,0 <sup>b</sup>  | 90,8 <sup>a</sup>  | 22,0 <sup>b</sup> |
| 20                              | 98,0 <sup>b</sup>    | 92,7 <sup>b</sup>  | 87,3 <sup>a</sup>  | 36,7 <sup>a</sup> |
| 40                              | 98,0 <sup>b</sup>    | 92,7 <sup>b</sup>  | 75,3 <sup>b</sup>  | 25,3 <sup>b</sup> |
| 60                              | 99,3 <sup>ab</sup>   | 100,0 <sup>a</sup> | 86,0 <sup>a</sup>  | 24,0 <sup>b</sup> |
| 80                              | 98,3 <sup>ab</sup>   | 96,7 <sup>ab</sup> | 87,5 <sup>a</sup>  | 22,0 <sup>b</sup> |
| 100                             | 100,0 <sup>a</sup>   | 97,3 <sup>ab</sup> | 93,3 <sup>a</sup>  | 22,0 <sup>b</sup> |

The effect of salinity stress and SiO<sub>2</sub> nanopriming on tomato seed germination rate were presented in Figure 4.138.



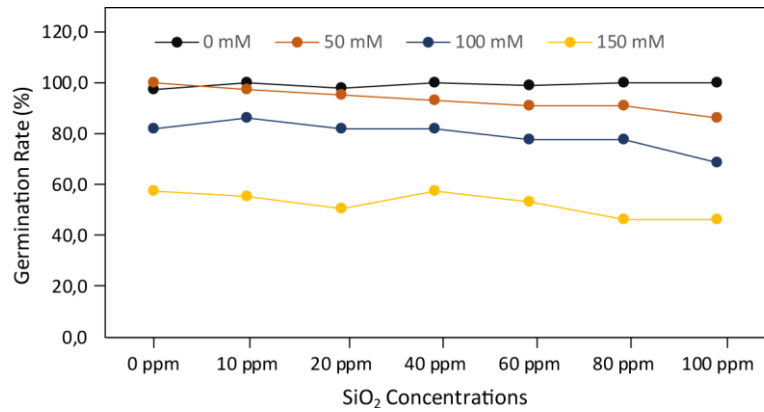
**Figure 4.138.** Germination rates (%) of tomato seeds under salinity stress after SiO<sub>2</sub> nanopriming

SiO<sub>2</sub> nanopriming did not increase the seed germination rate of maize seeds as presented in Table 4.54. The germination rate of maize seeds was decreased by increasing SiO<sub>2</sub> concentration under 50 and 100 mM NaCl conditions. Besides, there was no effect of SiO<sub>2</sub> nanopriming on seed germination rate of maize seeds under 150 mM of NaCl condition.

**Table 4.54.** Germination rates (%) of maize seeds under salinity stress after SiO<sub>2</sub> nanopriming

| SiO <sub>2</sub> Conc.<br>(ppm) | Germination Rate (%) |                     |                    |                   |
|---------------------------------|----------------------|---------------------|--------------------|-------------------|
|                                 | 0 mM NaCl            | 50 mM NaCl          | 100 mM NaCl        | 150 mM NaCl       |
| 0                               | 97,5 <sup>b</sup>    | 100,0 <sup>a</sup>  | 82,2 <sup>a</sup>  | 57,8 <sup>a</sup> |
| 10                              | 100,0 <sup>a</sup>   | 97,8 <sup>ab</sup>  | 86,7 <sup>a</sup>  | 55,6 <sup>a</sup> |
| 20                              | 98,3 <sup>ab</sup>   | 95,6 <sup>ab</sup>  | 82,2 <sup>a</sup>  | 51,1 <sup>a</sup> |
| 40                              | 100,0 <sup>a</sup>   | 93,3 <sup>abc</sup> | 82,2 <sup>a</sup>  | 57,8 <sup>a</sup> |
| 60                              | 99,3 <sup>ab</sup>   | 91,1 <sup>bc</sup>  | 77,8 <sup>ab</sup> | 53,3 <sup>a</sup> |
| 80                              | 100,0 <sup>a</sup>   | 91,1 <sup>bc</sup>  | 77,8 <sup>ab</sup> | 46,7 <sup>a</sup> |
| 100                             | 100,0 <sup>a</sup>   | 86,7 <sup>c</sup>   | 68,9 <sup>b</sup>  | 46,7 <sup>a</sup> |

The effect of salinity stress and SiO<sub>2</sub> nanopriming on maize seed germination rate were presented in Figure 4.139.



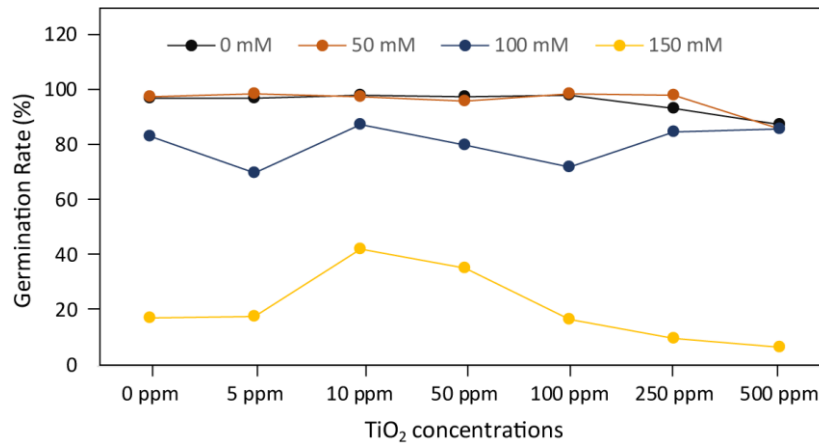
**Figure 4.139.** Germination rates (%) of maize seeds under salinity stress after SiO<sub>2</sub> nanopriming

TiO<sub>2</sub> nanopriming of tomato seeds did not affect seed germination rate under 50 mM of NaCl conditions except 500 ppm of TiO<sub>2</sub> concentration. The 500 ppm of TiO<sub>2</sub> decreased the seed germination rate of tomato seeds under 50 mM NaCl condition. On the other hand, seed germination rate of tomato seeds were increased under 100 and 150 mM NaCl at 10 ppm of TiO<sub>2</sub> treatment (Table 4.55).

**Table 4.55.** Germination rates (%) of tomato seeds under salinity stress after TiO<sub>2</sub> nanopriming

| TiO <sub>2</sub> Conc.<br>(ppm) | Germination Rate (%) |                   |                    |                   |
|---------------------------------|----------------------|-------------------|--------------------|-------------------|
|                                 | 0 mM NaCl            | 50 mM NaCl        | 100 mM NaCl        | 150 mM NaCl       |
| 0                               | 97,3 <sup>a</sup>    | 97,3 <sup>a</sup> | 83,3 <sup>ab</sup> | 17,3 <sup>c</sup> |
| 5                               | 97,3 <sup>a</sup>    | 98,7 <sup>a</sup> | 70,0 <sup>c</sup>  | 17,8 <sup>c</sup> |
| 10                              | 98,0 <sup>a</sup>    | 97,5 <sup>a</sup> | 87,5 <sup>a</sup>  | 42,2 <sup>a</sup> |
| 50                              | 97,5 <sup>a</sup>    | 96,0 <sup>a</sup> | 80,0 <sup>b</sup>  | 35,5 <sup>b</sup> |
| 100                             | 98,0 <sup>a</sup>    | 98,7 <sup>a</sup> | 72,2 <sup>c</sup>  | 16,7 <sup>c</sup> |
| 250                             | 93,1 <sup>ab</sup>   | 98,3 <sup>a</sup> | 84,7 <sup>ab</sup> | 10,0 <sup>d</sup> |
| 500                             | 87,5 <sup>b</sup>    | 85,8 <sup>b</sup> | 85,8 <sup>a</sup>  | 6,7 <sup>d</sup>  |

The effect of salinity stress and TiO<sub>2</sub> nanopriming on tomato seed germination rate were presented in Figure 4.140.



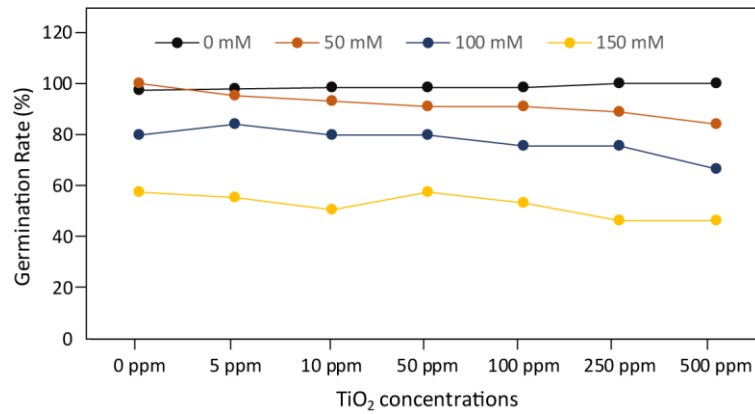
**Figure 4.140.** Germination rates (%) of tomato seeds under salinity stress after TiO<sub>2</sub> nanopriming

TiO<sub>2</sub> nanopriming did not increase the seed germination rate of maize seeds under salinity stress. Besides, the germination rate of maize seeds was decreased by increasing TiO<sub>2</sub> concentration under 50 and 100 mM NaCl (Table 4.56).

**Table 4.56.** Germination rates (%) of maize seeds under salinity stress after TiO<sub>2</sub> nanopriming

| TiO <sub>2</sub> Conc.<br>(ppm) | Germination Rate (%) |                    |                    |                   |
|---------------------------------|----------------------|--------------------|--------------------|-------------------|
|                                 | 0 mM NaCl            | 50 mM NaCl         | 100 mM NaCl        | 150 mM NaCl       |
| 0                               | 97,5 <sup>a</sup>    | 100,0 <sup>a</sup> | 80,0 <sup>a</sup>  | 57,8 <sup>a</sup> |
| 5                               | 98,0 <sup>a</sup>    | 95,6 <sup>ab</sup> | 84,4 <sup>a</sup>  | 55,6 <sup>a</sup> |
| 10                              | 98,7 <sup>a</sup>    | 93,3 <sup>ab</sup> | 80,0 <sup>a</sup>  | 51,1 <sup>a</sup> |
| 50                              | 98,7 <sup>a</sup>    | 91,1 <sup>bc</sup> | 80,0 <sup>a</sup>  | 57,8 <sup>a</sup> |
| 100                             | 98,7 <sup>a</sup>    | 91,1 <sup>bc</sup> | 75,6 <sup>ab</sup> | 53,3 <sup>a</sup> |
| 250                             | 100,0 <sup>a</sup>   | 88,9 <sup>bc</sup> | 75,6 <sup>ab</sup> | 46,7 <sup>a</sup> |
| 500                             | 100,0 <sup>a</sup>   | 84,4 <sup>c</sup>  | 66,7 <sup>b</sup>  | 46,7 <sup>a</sup> |

The effect of salinity stress and TiO<sub>2</sub> nanopriming on maize seed germination rate were presented in Figure 4.141.



**Figure 4.141.** Germination rates (%) of maize seeds under salinity stress after TiO<sub>2</sub> nanopriming

#### 4.4.2.2 Shoot and root growth

Table 4.57 presents the shoot length of tomato seedlings, developed under salinity stress after CNT nanopriming. The shoot length of tomato seedling increased by 5 ppm of CNT nanopriming under 50 mM of NaCl concentration. On the other hand, CNT nanopriming did not affect the shoot length of tomato seeds, developed under 100 mM of NaCl conditions at 5, 10, 50, and 100 ppm; and decreased at 250 and 500 ppm of CNT. 100 ppm of CNT induced the shoot length the most under 150 mM NaCl condition.

**Table 4.57.** Shoot length (SL) of tomato seedlings under salinity stress after CNT nanopriming

| CNT Conc.<br>(ppm) | Shoot Length (mm)   |                     |                     |                     |
|--------------------|---------------------|---------------------|---------------------|---------------------|
|                    | 0 mM NaCl           | 50 mM NaCl          | 100 mM NaCl         | 150 mM NaCl         |
| 0                  | 62,53 <sup>c</sup>  | 58,30 <sup>b</sup>  | 48,68 <sup>a</sup>  | 38,49 <sup>bc</sup> |
| 5                  | 65,99 <sup>b</sup>  | 67,26 <sup>a</sup>  | 49,66 <sup>a</sup>  | 41,36 <sup>ab</sup> |
| 10                 | 66,40 <sup>b</sup>  | 59,99 <sup>b</sup>  | 49,86 <sup>a</sup>  | 39,07 <sup>bc</sup> |
| 50                 | 66,70 <sup>b</sup>  | 54,76 <sup>c</sup>  | 49,35 <sup>a</sup>  | 38,11 <sup>bc</sup> |
| 100                | 67,49 <sup>ab</sup> | 54,80 <sup>c</sup>  | 48,60 <sup>ab</sup> | 43,76 <sup>a</sup>  |
| 250                | 68,04 <sup>ab</sup> | 51,47 <sup>cd</sup> | 45,94 <sup>bc</sup> | 41,22 <sup>ab</sup> |
| 500                | 69,69 <sup>a</sup>  | 49,52 <sup>d</sup>  | 45,37 <sup>c</sup>  | 36,71 <sup>c</sup>  |

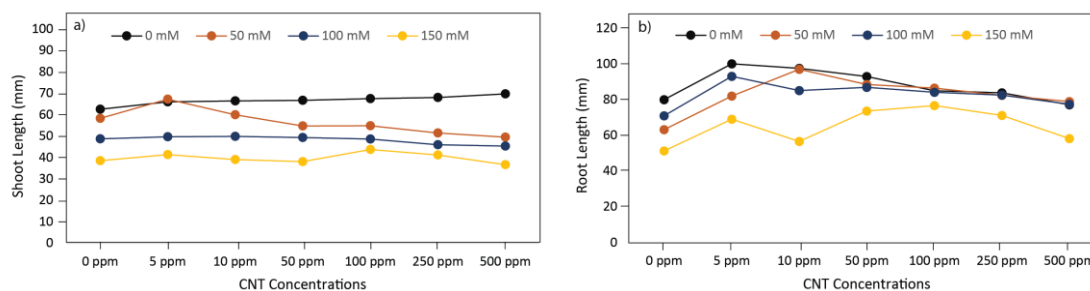
The root length of tomato seedlings, developed under salinity stress conditions, was increased by CNT nanopriming. 10 ppm of CNT increased the root length of tomato

seedlings from 63,21 mm to 97,08 mm under 50 mM NaCl condition. Besides, 5 ppm of CNT increased the root length of tomato seedlings to 93,06 under 100 mM NaCl concentration. 100 ppm of CNT showed the best performance to increase root length of tomato seedlings under 150 mM NaCl condition (Table 4.58).

**Table 4.58.** Root length (RL) of tomato seedlings under salinity stress after CNT nanopriming

| CNT Conc.<br>(ppm) | Root Length (mm)    |                     |                     |                     |
|--------------------|---------------------|---------------------|---------------------|---------------------|
|                    | 0 mM NaCl           | 50 mM NaCl          | 100 mM NaCl         | 150 mM NaCl         |
| 0                  | 80,02 <sup>cd</sup> | 63,21 <sup>d</sup>  | 71,00 <sup>d</sup>  | 51,33 <sup>e</sup>  |
| 5                  | 100,07 <sup>a</sup> | 82,01 <sup>bc</sup> | 93,06 <sup>a</sup>  | 69,09 <sup>c</sup>  |
| 10                 | 97,61 <sup>ab</sup> | 97,08 <sup>a</sup>  | 85,11 <sup>b</sup>  | 56,65 <sup>d</sup>  |
| 50                 | 92,98 <sup>b</sup>  | 88,53 <sup>b</sup>  | 86,88 <sup>ab</sup> | 73,69 <sup>ab</sup> |
| 100                | 85,05 <sup>c</sup>  | 86,50 <sup>b</sup>  | 84,20 <sup>bc</sup> | 76,69 <sup>a</sup>  |
| 250                | 83,81 <sup>c</sup>  | 82,48 <sup>bc</sup> | 82,59 <sup>bc</sup> | 71,22 <sup>b</sup>  |
| 500                | 77,14 <sup>d</sup>  | 78,96 <sup>c</sup>  | 77,43 <sup>cd</sup> | 58,19 <sup>d</sup>  |

Figure 4.142 present the effect of salinity stress and CNT nanopriming on tomato shoot and root length.



**Figure 4.142.** Shoot length (a) and root length (b) of tomato seeds under salinity stress after CNT nanopriming

CNT nanopriming of tomato seeds increased the shoot fresh weight of seedlings under 50 and 100 mM of NaCl condition. When the 5 ppm of CNT increased the shoot fresh weight of tomato seedlings to 0,1168 g under 50 mM of NaCl condition, 10 ppm of CNT increased the shoot fresh weight of tomato seedlings up to 0,0960 g under 100 mM NaCl. On the other hand, CNT nanopriming decreased the shoot fresh weight of tomato seedlings under 150 mM of NaCl concentration (Table 4.59).

**Table 4.59.** Shoot fresh weight (SFW) of tomato seedlings under salinity stress after CNT nanopriming

| CNT Conc.<br>(ppm) | Shoot Fresh Weight (g) |                      |                      |                      |
|--------------------|------------------------|----------------------|----------------------|----------------------|
|                    | 0 mM NaCl              | 50 mM NaCl           | 100 mM NaCl          | 150 mM NaCl          |
| 0                  | 0,1504 <sup>a</sup>    | 0,0923 <sup>e</sup>  | 0,0762 <sup>d</sup>  | 0,0948 <sup>a</sup>  |
| 5                  | 0,1446 <sup>b</sup>    | 0,1168 <sup>a</sup>  | 0,0918 <sup>ab</sup> | 0,0534 <sup>cd</sup> |
| 10                 | 0,1442 <sup>b</sup>    | 0,1123 <sup>ab</sup> | 0,0960 <sup>a</sup>  | 0,0553 <sup>cd</sup> |
| 50                 | 0,1439 <sup>b</sup>    | 0,0915 <sup>de</sup> | 0,0929 <sup>ab</sup> | 0,0518 <sup>cd</sup> |
| 100                | 0,1441 <sup>b</sup>    | 0,1040 <sup>bc</sup> | 0,0856 <sup>bc</sup> | 0,0701 <sup>b</sup>  |
| 250                | 0,1453 <sup>b</sup>    | 0,1006 <sup>cd</sup> | 0,0777 <sup>cd</sup> | 0,0643 <sup>bc</sup> |
| 500                | 0,1451 <sup>b</sup>    | 0,0840 <sup>e</sup>  | 0,0733 <sup>d</sup>  | 0,0504 <sup>d</sup>  |

The CNT nanopriming application decreased the root fresh weight of tomato seedlings under 50 and 100 mM of NaCl conditions. On the other hand, 50 ppm CNT application increased then root fresh weight under 150 mM NaCl and the root fresh weight decreased by increasing in CNT concentration (Table 4.60).

**Table 4.60.** Root fresh weight (RFW) of tomato seedlings under salinity stress after CNT nanopriming

| CNT Conc.<br>(ppm) | Root Fresh Weight (g) |                     |                     |                      |
|--------------------|-----------------------|---------------------|---------------------|----------------------|
|                    | 0 mM NaCl             | 50 mM NaCl          | 100 mM NaCl         | 150 mM NaCl          |
| 0                  | 0,0174 <sup>a</sup>   | 0,0082 <sup>a</sup> | 0,0100 <sup>a</sup> | 0,0033 <sup>d</sup>  |
| 5                  | 0,0147 <sup>ab</sup>  | 0,0086 <sup>b</sup> | 0,0066 <sup>b</sup> | 0,0032 <sup>d</sup>  |
| 10                 | 0,0170 <sup>a</sup>   | 0,0084 <sup>b</sup> | 0,0093 <sup>a</sup> | 0,0051 <sup>b</sup>  |
| 50                 | 0,0164 <sup>ab</sup>  | 0,0084 <sup>b</sup> | 0,0066 <sup>b</sup> | 0,0060 <sup>a</sup>  |
| 100                | 0,0171 <sup>a</sup>   | 0,0083 <sup>b</sup> | 0,0059 <sup>b</sup> | 0,0049 <sup>bc</sup> |
| 250                | 0,0161 <sup>ab</sup>  | 0,0082 <sup>b</sup> | 0,0073 <sup>b</sup> | 0,0043 <sup>cd</sup> |
| 500                | 0,0133 <sup>b</sup>   | 0,0081 <sup>b</sup> | 0,0101 <sup>a</sup> | 0,0039 <sup>cd</sup> |

100 ppm of CNT nanopriming increased the shoot dry weight of tomato seedlings under 50 and 100 mM of NaCl conditions. However, CNT application to tomato seeds decreased the shoot dry weight of tomato seedlings under 150 mM of NaCl condition (Table 4.61).

**Table 4.61.** Shoot dry weight (SDW) of tomato seedlings under salinity stress after CNT nanopriming

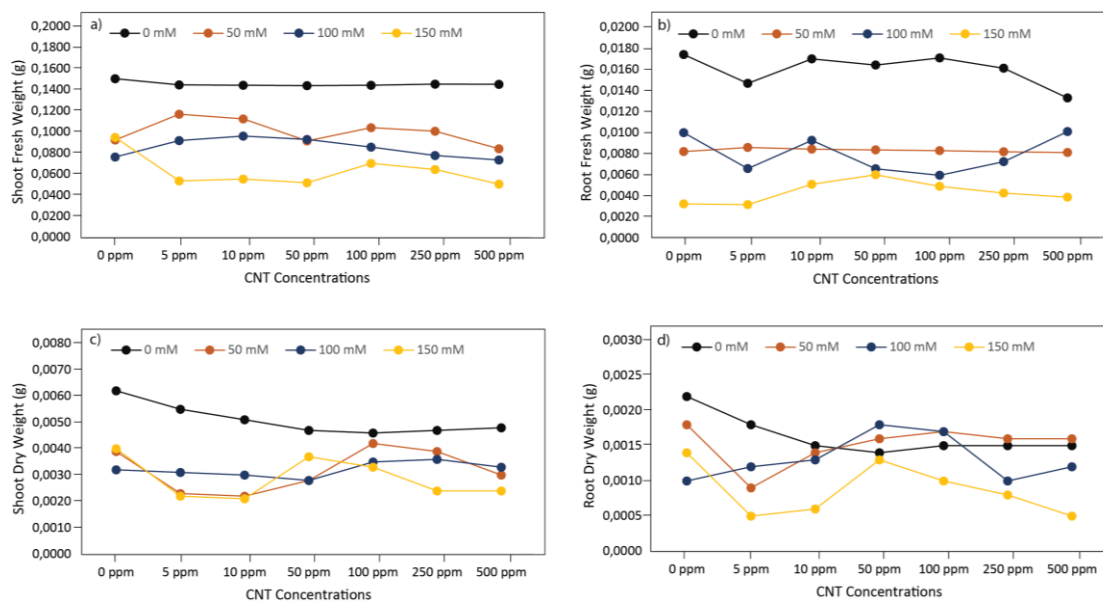
| CNT Conc.<br>(ppm) | Shoot Dry Weight (g) |                      |                      |                      |
|--------------------|----------------------|----------------------|----------------------|----------------------|
|                    | 0 mM NaCl            | 50 mM NaCl           | 100 mM NaCl          | 150 mM NaCl          |
| 0                  | 0,0062 <sup>a</sup>  | 0,0039 <sup>b</sup>  | 0,0032 <sup>b</sup>  | 0,0040 <sup>a</sup>  |
| 5                  | 0,0055 <sup>b</sup>  | 0,0023 <sup>d</sup>  | 0,0031 <sup>b</sup>  | 0,0022 <sup>d</sup>  |
| 10                 | 0,0051 <sup>bc</sup> | 0,0022 <sup>d</sup>  | 0,0030 <sup>bc</sup> | 0,0021 <sup>d</sup>  |
| 50                 | 0,0047 <sup>c</sup>  | 0,0028 <sup>cd</sup> | 0,0028 <sup>c</sup>  | 0,0037 <sup>ab</sup> |
| 100                | 0,0046 <sup>c</sup>  | 0,0042 <sup>a</sup>  | 0,0035 <sup>a</sup>  | 0,0033 <sup>b</sup>  |
| 250                | 0,0047 <sup>c</sup>  | 0,0039 <sup>b</sup>  | 0,0036 <sup>a</sup>  | 0,0024 <sup>cd</sup> |
| 500                | 0,0048 <sup>c</sup>  | 0,0030 <sup>c</sup>  | 0,0033 <sup>b</sup>  | 0,0024 <sup>cd</sup> |

The root dry weight of tomato seedlings decreased by CNT application under 50 and 150 mM of NaCl conditions. However, 50 ppm of CNT increased the root dry weight of tomato seedlings under 150 mM of NaCl condition (Table 4.62)

**Table 4.62.** Root dry weight (RDW) of tomato seedlings under salinity stress after CNT nanopriming

| CNT Conc.<br>(ppm) | Root Dry Weight (g) |                     |                      |                      |
|--------------------|---------------------|---------------------|----------------------|----------------------|
|                    | 0 mM NaCl           | 50 mM NaCl          | 100 mM NaCl          | 150 mM NaCl          |
| 0                  | 0,0022 <sup>a</sup> | 0,0018 <sup>a</sup> | 0,0010 <sup>d</sup>  | 0,0014 <sup>a</sup>  |
| 5                  | 0,0018 <sup>b</sup> | 0,0009 <sup>d</sup> | 0,0012 <sup>cd</sup> | 0,0005 <sup>e</sup>  |
| 10                 | 0,0015 <sup>b</sup> | 0,0014 <sup>c</sup> | 0,0013 <sup>cd</sup> | 0,0006 <sup>e</sup>  |
| 50                 | 0,0014 <sup>b</sup> | 0,0016 <sup>b</sup> | 0,0018 <sup>a</sup>  | 0,0013 <sup>b</sup>  |
| 100                | 0,0015 <sup>b</sup> | 0,0017 <sup>a</sup> | 0,0017 <sup>b</sup>  | 0,0010 <sup>cd</sup> |
| 250                | 0,0015 <sup>b</sup> | 0,0016 <sup>b</sup> | 0,0010 <sup>d</sup>  | 0,0008 <sup>d</sup>  |
| 500                | 0,0015 <sup>b</sup> | 0,0016 <sup>b</sup> | 0,0012 <sup>cd</sup> | 0,0005 <sup>e</sup>  |

Figure 4.143 presents the effect of CNT nanopriming and salinity stress on shoot and root fresh and dry weight of tomato seedlings.



**Figure 4.143.** Shoot fresh weight (a), root fresh weight (b), shoot dry weight (c) and root dry weight (d) of tomato seeds under salinity stress after CNT nanopriming

The CNT nanopriming of maize seeds did not increase the shoot length of maize seeds under 50 and 100 mM of NaCl. The shoot length of maize seedlings after nanopriming by CNT decreased the shoot length under 50 mM of NaCl condition. On the other hand, the CNT nanopriming did not affect the shoot length of maize seedlings, developed under 100 mM of NaCl conditions. However, the CNT nanopriming application increased the shoot length of maize seedlings, developed under 150 mM of NaCl stress conditions (Table 4.63).

**Table 4.63.** Shoot length (SL) of maize seedlings under salinity stress after CNT nanopriming

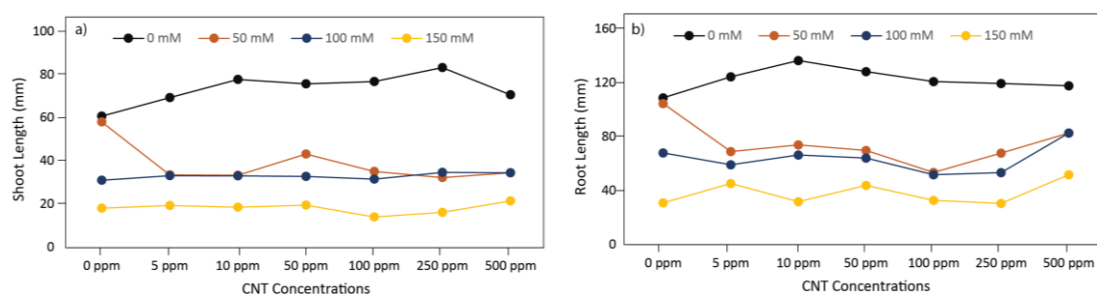
| CNT Conc.<br>(ppm) | Shoot Length (mm)  |                     |                    |                      |
|--------------------|--------------------|---------------------|--------------------|----------------------|
|                    | 0 mM NaCl          | 50 mM NaCl          | 100 mM NaCl        | 150 mM NaCl          |
| <b>0</b>           | 60,72 <sup>d</sup> | 58,02 <sup>a</sup>  | 31,04 <sup>a</sup> | 18,09 <sup>bc</sup>  |
| <b>5</b>           | 69,27 <sup>c</sup> | 33,46 <sup>c</sup>  | 33,12 <sup>a</sup> | 19,28 <sup>abc</sup> |
| <b>10</b>          | 77,65 <sup>b</sup> | 13,35 <sup>d</sup>  | 33,04 <sup>a</sup> | 18,47 <sup>abc</sup> |
| <b>50</b>          | 75,68 <sup>b</sup> | 43,12 <sup>b</sup>  | 32,79 <sup>a</sup> | 19,52 <sup>ab</sup>  |
| <b>100</b>         | 76,69 <sup>b</sup> | 20,10 <sup>d</sup>  | 31,50 <sup>a</sup> | 14,03 <sup>d</sup>   |
| <b>250</b>         | 83,16 <sup>a</sup> | 32,21 <sup>c</sup>  | 34,61 <sup>a</sup> | 16,12 <sup>cd</sup>  |
| <b>500</b>         | 70,62 <sup>c</sup> | 34,44 <sup>bc</sup> | 34,44 <sup>a</sup> | 21,41 <sup>a</sup>   |

The root length of maize seedlings, developed under 50 mM of NaCl decreased after CNT nanopriming. However, 500 ppm of CNT nanopriming increased the root length of maize seedlings up to 82,68 mm. The root length of maize seedlings, developed under 150 mM of NaCl, increased by 50 ppm of CNT nanopriming (Table 4.64).

**Table 4.64.** Root length (RL) of maize seedlings under salinity stress after CNT nanopriming

| CNT Conc.<br>(ppm) | Root Length (mm)     |                     |                      |                    |
|--------------------|----------------------|---------------------|----------------------|--------------------|
|                    | 0 mM NaCl            | 50 mM NaCl          | 100 mM NaCl          | 150 mM NaCl        |
| 0                  | 108,88 <sup>d</sup>  | 104,56 <sup>a</sup> | 68,02 <sup>b</sup>   | 31,06 <sup>b</sup> |
| 5                  | 124,49 <sup>bc</sup> | 68,95 <sup>bc</sup> | 59,18 <sup>bc</sup>  | 45,28 <sup>a</sup> |
| 10                 | 136,52 <sup>a</sup>  | 13,89 <sup>d</sup>  | 66,45 <sup>abc</sup> | 31,80 <sup>b</sup> |
| 50                 | 128,26 <sup>b</sup>  | 69,83 <sup>bc</sup> | 64,21 <sup>bc</sup>  | 43,96 <sup>a</sup> |
| 100                | 120,88 <sup>bc</sup> | 53,50 <sup>c</sup>  | 51,87 <sup>c</sup>   | 32,86 <sup>b</sup> |
| 250                | 119,39 <sup>c</sup>  | 67,88 <sup>bc</sup> | 53,47 <sup>c</sup>   | 30,56 <sup>b</sup> |
| 500                | 117,72 <sup>cd</sup> | 82,68 <sup>b</sup>  | 82,68 <sup>a</sup>   | 51,82 <sup>a</sup> |

The effect of salinity and CNT nanopriming on shoot and root length of maize seedlings were presented in Figure 4.144.



**Figure 4.144.** Shoot length (a) and root length (b) of maize seeds under salinity stress after CNT nanopriming

Shoot fresh weight of maize seedlings, developed under 50 mM of NaCl condition, was decreased by CNT nanopriming except 500 ppm. The 500 ppm of CNT application did not change the shoot fresh weight of maize seedlings. On the other hand, 5 ppm of CNT nanopriming increased the shoot fresh weight almost two times under 100 mM of NaCl

condition. The seedlings, developed under 150 mM of NaCl condition, had heaviest shoot after nanoprimed with 50 ppm of CNT (Table 4.65).

**Table 4.65.** Shoot fresh weight (SFW) of maize seedlings under salinity stress after CNT nanopriming

| CNT Conc.<br>(ppm) | Shoot Fresh Weight (g) |                      |                      |                     |
|--------------------|------------------------|----------------------|----------------------|---------------------|
|                    | 0 mM NaCl              | 50 mM NaCl           | 100 mM NaCl          | 150 mM NaCl         |
| 0                  | 0,5612 <sup>d</sup>    | 0,4869 <sup>a</sup>  | 0,1868 <sup>d</sup>  | 0,0676 <sup>c</sup> |
| 5                  | 0,7392 <sup>bc</sup>   | 0,3306 <sup>bc</sup> | 0,3133 <sup>a</sup>  | 0,1282 <sup>b</sup> |
| 10                 | 0,7794 <sup>ab</sup>   | 0,3537 <sup>bc</sup> | 0,2965 <sup>ab</sup> | 0,1220 <sup>b</sup> |
| 50                 | 0,7459 <sup>b</sup>    | 0,4081 <sup>b</sup>  | 0,2792 <sup>b</sup>  | 0,1643 <sup>a</sup> |
| 100                | 0,7601 <sup>ab</sup>   | 0,2420 <sup>c</sup>  | 0,2078 <sup>cd</sup> | 0,1015 <sup>b</sup> |
| 250                | 0,8253 <sup>a</sup>    | 0,2440 <sup>c</sup>  | 0,2286 <sup>c</sup>  | 0,1167 <sup>b</sup> |
| 500                | 0,6859 <sup>c</sup>    | 0,4790 <sup>a</sup>  | 0,2790 <sup>b</sup>  | 0,1690 <sup>a</sup> |

50 ppm of CNT nanopriming of CNT caused the most increase in root fresh weight under salinity stress at all levels as presented on Table 4.66.

**Table 4.66.** Root fresh weight (RFW) of maize seedlings under salinity stress after CNT nanopriming

| CNT Conc.<br>(ppm) | Root Fresh Weight (g) |                      |                      |                      |
|--------------------|-----------------------|----------------------|----------------------|----------------------|
|                    | 0 mM NaCl             | 50 mM NaCl           | 100 mM NaCl          | 150 mM NaCl          |
| 0                  | 0,9272 <sup>c</sup>   | 0,7273 <sup>b</sup>  | 0,5795 <sup>c</sup>  | 0,3090 <sup>d</sup>  |
| 5                  | 1,1497 <sup>b</sup>   | 0,7346 <sup>b</sup>  | 0,7807 <sup>ab</sup> | 0,5482 <sup>c</sup>  |
| 10                 | 1,2135 <sup>a</sup>   | 0,8425 <sup>a</sup>  | 0,8155 <sup>ab</sup> | 0,6970 <sup>ab</sup> |
| 50                 | 1,1820 <sup>ab</sup>  | 0,8770 <sup>a</sup>  | 0,8630 <sup>a</sup>  | 0,7818 <sup>a</sup>  |
| 100                | 1,1401 <sup>ab</sup>  | 0,7270 <sup>b</sup>  | 0,6970 <sup>b</sup>  | 0,5433 <sup>c</sup>  |
| 250                | 1,1312 <sup>b</sup>   | 0,7900 <sup>ab</sup> | 0,8018 <sup>ab</sup> | 0,7590 <sup>ab</sup> |
| 500                | 1,1147 <sup>b</sup>   | 0,7577 <sup>ab</sup> | 0,7577 <sup>ab</sup> | 0,6584 <sup>bc</sup> |

CNT nanopriming increased the shoot dry weight of maize seedlings, developed under salinity stress (Table 4.67). The shoot dry weight of maize seedlings increased up to 0,0195 g at 50 ppm of CNT nanopriming under 50 mM of NaCl stress condition. On the other hand, the shoot dry weight of maize seedlings increased at 10 ppm of CNT, under

100 mM of NaCl stress. Besides, 50 ppm of CNT nanopriming increased the shoot dry weight to 0,0099 g under 150 mM of NaCl (Table 4.67).

**Table 4.67.** Shoot dry weight (SDW) of maize seedlings under salinity stress after CNT nanopriming

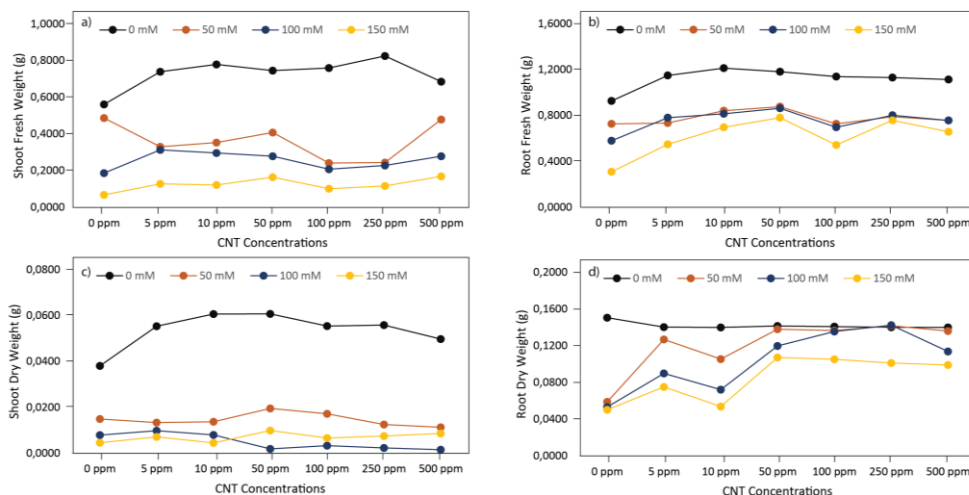
| CNT Conc.<br>(ppm) | Shoot dry Weight (g) |                      |                     |                      |
|--------------------|----------------------|----------------------|---------------------|----------------------|
|                    | 0 mM NaCl            | 50 mM NaCl           | 100 mM NaCl         | 150 mM NaCl          |
| 0                  | 0,0381 <sup>d</sup>  | 0,0149 <sup>cd</sup> | 0,0079 <sup>b</sup> | 0,0046 <sup>d</sup>  |
| 5                  | 0,0554 <sup>b</sup>  | 0,0134 <sup>d</sup>  | 0,0098 <sup>a</sup> | 0,0071 <sup>bc</sup> |
| 10                 | 0,0607 <sup>a</sup>  | 0,0137 <sup>d</sup>  | 0,0080 <sup>b</sup> | 0,0045 <sup>d</sup>  |
| 50                 | 0,0608 <sup>a</sup>  | 0,0195 <sup>a</sup>  | 0,0019 <sup>d</sup> | 0,0099 <sup>a</sup>  |
| 100                | 0,0555 <sup>b</sup>  | 0,0172 <sup>b</sup>  | 0,0033 <sup>c</sup> | 0,0066 <sup>d</sup>  |
| 250                | 0,0559 <sup>b</sup>  | 0,0125 <sup>d</sup>  | 0,0023 <sup>c</sup> | 0,0075 <sup>bc</sup> |
| 500                | 0,0498 <sup>c</sup>  | 0,0113 <sup>d</sup>  | 0,0015 <sup>d</sup> | 0,0086 <sup>b</sup>  |

The root dry weight of maize seedlings was increased with 250 ppm of CNT nanopriming under 50 and 100 mM of NaCl stress conditions with 0,1419 and 0,1425 g respectively. 50, 100 and 250 ppm of CNT increased the root dry weight of maize seedlings under 150 mM of NaCl stress conditions (Table 4.68).

**Table 4.68.** Root dry weight (RDW) of maize seedlings under salinity stress after CNT nanopriming

| CNT Conc.<br>(ppm) | Root Dry Weight (g) |                      |                      |                      |
|--------------------|---------------------|----------------------|----------------------|----------------------|
|                    | 0 mM NaCl           | 50 mM NaCl           | 100 mM NaCl          | 150 mM NaCl          |
| 0                  | 0,1508 <sup>a</sup> | 0,0589 <sup>d</sup>  | 0,0532 <sup>c</sup>  | 0,0503 <sup>b</sup>  |
| 5                  | 0,1404 <sup>b</sup> | 0,1270 <sup>bc</sup> | 0,0899 <sup>c</sup>  | 0,0753 <sup>b</sup>  |
| 10                 | 0,1401 <sup>b</sup> | 0,1055 <sup>c</sup>  | 0,0723 <sup>c</sup>  | 0,0538 <sup>b</sup>  |
| 50                 | 0,1416 <sup>b</sup> | 0,1381 <sup>b</sup>  | 0,1199 <sup>b</sup>  | 0,1073 <sup>a</sup>  |
| 100                | 0,1410 <sup>b</sup> | 0,1367 <sup>b</sup>  | 0,1356 <sup>ab</sup> | 0,1053 <sup>a</sup>  |
| 250                | 0,1402 <sup>b</sup> | 0,1419 <sup>a</sup>  | 0,1425 <sup>a</sup>  | 0,1012 <sup>a</sup>  |
| 500                | 0,1400 <sup>b</sup> | 0,1361 <sup>b</sup>  | 0,1139 <sup>b</sup>  | 0,0992 <sup>ab</sup> |

The effect of salinity stress and CNT nanopriming on maize seedling development was presented in Figure 4.145.



**Figure 4.145.** Shoot fresh weight (a), root fresh weight (b), shoot dry weight (c) and root dry weight (d) of maize seeds under salinity stress after CNT nanopriming

The shoot length of tomato seedlings developed under 50 mM of NaCl stress was increased by 20 ppm of SiO<sub>2</sub> application. Besides, 60 ppm of SiO<sub>2</sub> application increased the shoot length of tomato seedlings, developed under 100 mM of NaCl condition. However, the SiO<sub>2</sub> priming decreased the shoot length of tomato seedlings, developed under 150 mM of NaCl (Table 4.69).

**Table 4.69.** Shoot length (SL) of tomato seedlings under salinity stress after SiO<sub>2</sub> nanopriming

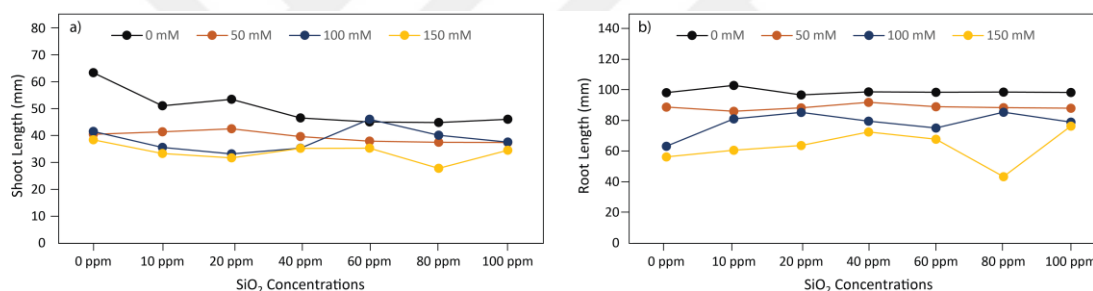
| SiO <sub>2</sub> Conc.<br>(ppm) | Shoot Length (mm)  |                     |                    |                     |
|---------------------------------|--------------------|---------------------|--------------------|---------------------|
|                                 | 0 mM NaCl          | 50 mM NaCl          | 100 mM NaCl        | 150 mM NaCl         |
| 0                               | 63,50 <sup>a</sup> | 40,57 <sup>b</sup>  | 41,64 <sup>b</sup> | 38,49 <sup>a</sup>  |
| 10                              | 51,16 <sup>b</sup> | 41,46 <sup>ab</sup> | 35,67 <sup>d</sup> | 33,41 <sup>b</sup>  |
| 20                              | 53,56 <sup>b</sup> | 42,59 <sup>a</sup>  | 33,26 <sup>e</sup> | 31,74 <sup>bc</sup> |
| 40                              | 46,65 <sup>c</sup> | 39,71 <sup>bc</sup> | 35,38 <sup>d</sup> | 35,27 <sup>ab</sup> |
| 60                              | 45,15 <sup>c</sup> | 37,98 <sup>c</sup>  | 46,16 <sup>a</sup> | 35,38 <sup>ab</sup> |
| 80                              | 44,97 <sup>c</sup> | 37,60 <sup>c</sup>  | 40,21 <sup>b</sup> | 27,89 <sup>c</sup>  |
| 100                             | 46,18 <sup>c</sup> | 37,51 <sup>c</sup>  | 37,62 <sup>c</sup> | 34,59 <sup>ab</sup> |

Root length of tomato seedlings, developed under 50 mM of NaCl concentration, did not change by SiO<sub>2</sub> nanopriming. However, SiO<sub>2</sub> nanopriming increased the root length of tomato seedlings, developed under 100 and 150 mM of NaCl conditions, at 20 and 40 ppm concentrations respectively (Table 4.70).

**Table 4.70.** Root length (RL) of tomato seedlings under salinity stress after SiO<sub>2</sub> nanopriming

| SiO <sub>2</sub> Conc.<br>(ppm) | Root Length (mm)    |                    |                     |                     |
|---------------------------------|---------------------|--------------------|---------------------|---------------------|
|                                 | 0 mM NaCl           | 50 mM NaCl         | 100 mM NaCl         | 150 mM NaCl         |
| 0                               | 98,26 <sup>a</sup>  | 88,76 <sup>a</sup> | 63,21 <sup>d</sup>  | 56,33 <sup>b</sup>  |
| 10                              | 102,89 <sup>a</sup> | 86,07 <sup>b</sup> | 81,11 <sup>b</sup>  | 60,67 <sup>b</sup>  |
| 20                              | 96,69 <sup>a</sup>  | 88,26 <sup>a</sup> | 85,28 <sup>a</sup>  | 63,70 <sup>b</sup>  |
| 40                              | 98,67 <sup>a</sup>  | 91,92 <sup>a</sup> | 79,63 <sup>bc</sup> | 72,57 <sup>a</sup>  |
| 60                              | 98,50 <sup>a</sup>  | 89,04 <sup>a</sup> | 75,16 <sup>c</sup>  | 67,83 <sup>ab</sup> |
| 80                              | 98,56 <sup>a</sup>  | 88,41 <sup>a</sup> | 85,41 <sup>a</sup>  | 43,41 <sup>c</sup>  |
| 100                             | 98,38 <sup>a</sup>  | 88,09 <sup>a</sup> | 78,96 <sup>bc</sup> | 76,39 <sup>a</sup>  |

Figure 4.146 presents the effect of salinity stress and SiO<sub>2</sub> nanopriming on tomato shoot and root length development.



**Figure 4.146.** Shoot length (a) and root length (b) of tomato seeds under salinity stress after SiO<sub>2</sub> nanopriming

60 and 80 ppm of SiO<sub>2</sub> nanopriming increased the shoot fresh weight of tomato seedlings developed under 50 mM of NaCl stress. The shoot fresh weight of tomato seedlings, developed under 100 mM of NaCl, was increased by 20 and 100ppm of SiO<sub>2</sub> nanopriming. However, SiO<sub>2</sub> nanopriming decreased the shoot fresh weight of tomato seedlings, developed under 150 mM of NaCl (Table 4.71).

**Table 4.71.** Shoot fresh weight (SFW) of tomato seedlings under salinity stress after SiO<sub>2</sub> nanopriming

| SiO <sub>2</sub> Conc.<br>(ppm) | Shoot Fresh Weight (g) |                      |                      |                     |
|---------------------------------|------------------------|----------------------|----------------------|---------------------|
|                                 | 0 mM NaCl              | 50 mM NaCl           | 100 mM NaCl          | 150 mM NaCl         |
| 0                               | 0,2393 <sup>a</sup>    | 0,0923 <sup>ab</sup> | 0,0762 <sup>d</sup>  | 0,0948 <sup>a</sup> |
| 10                              | 0,1505 <sup>bc</sup>   | 0,0634 <sup>d</sup>  | 0,0853 <sup>bc</sup> | 0,0624 <sup>b</sup> |
| 20                              | 0,1534 <sup>b</sup>    | 0,0700 <sup>d</sup>  | 0,0951 <sup>a</sup>  | 0,0668 <sup>b</sup> |
| 40                              | 0,1209 <sup>de</sup>   | 0,0819 <sup>c</sup>  | 0,0799 <sup>cd</sup> | 0,1060 <sup>a</sup> |
| 60                              | 0,1119 <sup>c</sup>    | 0,0981 <sup>a</sup>  | 0,0812 <sup>cd</sup> | 0,0763 <sup>b</sup> |
| 80                              | 0,1104 <sup>c</sup>    | 0,0978 <sup>a</sup>  | 0,0901 <sup>ab</sup> | 0,0610 <sup>b</sup> |
| 100                             | 0,1341 <sup>cd</sup>   | 0,0883 <sup>bc</sup> | 0,0976 <sup>a</sup>  | 0,0714 <sup>b</sup> |

The SiO<sub>2</sub> nanopriming of tomato seeds decreased the root fresh weight of tomato seedling developed under salinity stress conditions as presented on Table 4.72.

**Table 4.72.** Root fresh weight (RFW) of tomato seeds under salinity stress after SiO<sub>2</sub> nanopriming

| SiO <sub>2</sub> Conc.<br>(ppm) | Root Fresh Weight (g) |                      |                      |                      |
|---------------------------------|-----------------------|----------------------|----------------------|----------------------|
|                                 | 0 mM NaCl             | 50 mM NaCl           | 100 mM NaCl          | 150 mM NaCl          |
| 0                               | 0,0182 <sup>a</sup>   | 0,0174 <sup>a</sup>  | 0,0100 <sup>a</sup>  | 0,0078 <sup>a</sup>  |
| 10                              | 0,0096 <sup>bc</sup>  | 0,0060 <sup>d</sup>  | 0,0077 <sup>bc</sup> | 0,0034 <sup>c</sup>  |
| 20                              | 0,0079 <sup>c</sup>   | 0,0068 <sup>cd</sup> | 0,0058 <sup>d</sup>  | 0,0030 <sup>c</sup>  |
| 40                              | 0,0082 <sup>c</sup>   | 0,0068 <sup>cd</sup> | 0,0062 <sup>c</sup>  | 0,0057 <sup>b</sup>  |
| 60                              | 0,0082 <sup>c</sup>   | 0,0083 <sup>c</sup>  | 0,0081 <sup>b</sup>  | 0,0046 <sup>bc</sup> |
| 80                              | 0,0118 <sup>b</sup>   | 0,0118 <sup>b</sup>  | 0,0077 <sup>bc</sup> | 0,0058 <sup>b</sup>  |
| 100                             | 0,0099 <sup>bc</sup>  | 0,0103 <sup>b</sup>  | 0,0080 <sup>b</sup>  | 0,0030 <sup>c</sup>  |

The shoot dry weigh of tomato seedlings was increased by 60 ppm of SiO<sub>2</sub> nanopriming up to 0,0057 g from 0,0041 g. On the other hand, 20 and 60 ppm of SiO<sub>2</sub> nanopriming application to tomato seeds, increased the shoot dry weight of tomato seedling developed under 100 mM of NaCl stress. The SiO<sub>2</sub> nanopriming decreased the shoot dry weight of tomato seedlings, grown under 150 mM of NaCl stress except from 80 ppm of SiO<sub>2</sub>. 80 ppm of SiO<sub>2</sub> did not change the shoot dry weight under 150 mM of NaCl stress condition (Table 4.73).

**Table 4.73.** Shoot dry weight (SDW) of tomato seedlings under salinity stress after SiO<sub>2</sub> nanopriming

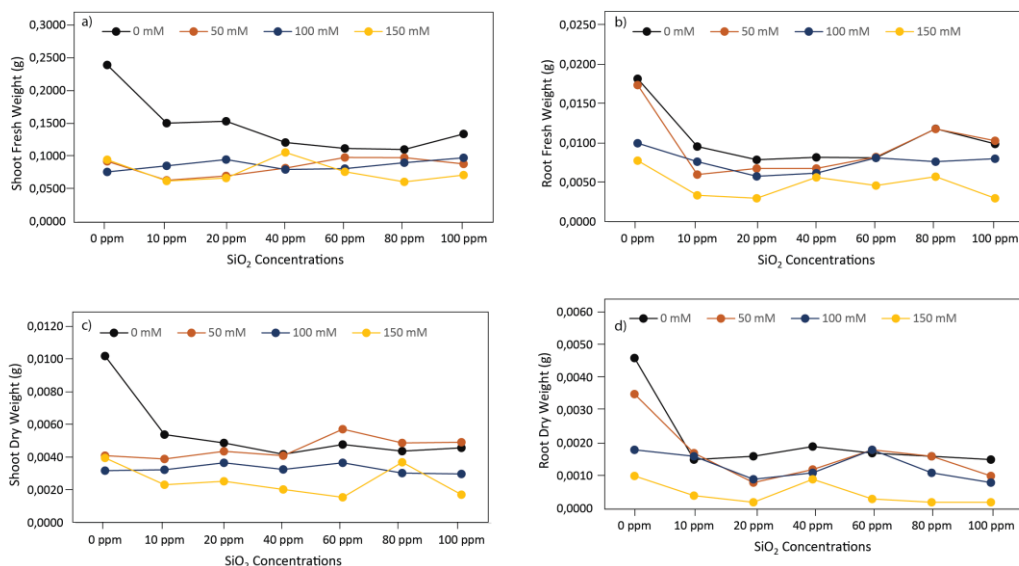
| SiO <sub>2</sub> Conc.<br>(ppm) | Shoot Dry Weight (g) |                      |                     |                      |
|---------------------------------|----------------------|----------------------|---------------------|----------------------|
|                                 | 0 mM NaCl            | 50 mM NaCl           | 100 mM NaCl         | 150 mM NaCl          |
| 0                               | 0,0102 <sup>a</sup>  | 0,0041 <sup>c</sup>  | 0,0032 <sup>b</sup> | 0,0040 <sup>a</sup>  |
| 10                              | 0,0054 <sup>b</sup>  | 0,0039 <sup>c</sup>  | 0,0033 <sup>b</sup> | 0,0023 <sup>b</sup>  |
| 20                              | 0,0049 <sup>bc</sup> | 0,0044 <sup>bc</sup> | 0,0037 <sup>a</sup> | 0,0026 <sup>b</sup>  |
| 40                              | 0,0042 <sup>c</sup>  | 0,0041 <sup>c</sup>  | 0,0033 <sup>b</sup> | 0,0021 <sup>bc</sup> |
| 60                              | 0,0048 <sup>bc</sup> | 0,0057 <sup>a</sup>  | 0,0037 <sup>a</sup> | 0,0016 <sup>c</sup>  |
| 80                              | 0,0044 <sup>c</sup>  | 0,0049 <sup>b</sup>  | 0,0031 <sup>b</sup> | 0,0037 <sup>a</sup>  |
| 100                             | 0,0046 <sup>bc</sup> | 0,0049 <sup>b</sup>  | 0,0030 <sup>b</sup> | 0,0017 <sup>c</sup>  |

The root dry weight of tomato seedlings, grown under salinity stress, decreased by SiO<sub>2</sub> nanopriming application (Table 4.74).

**Table 4.74.** Root dry weight (RDW) of tomato seedlings under salinity stress after SiO<sub>2</sub> nanopriming

| SiO <sub>2</sub> Conc.<br>(ppm) | Root Dry Weight (g) |                     |                     |                     |
|---------------------------------|---------------------|---------------------|---------------------|---------------------|
|                                 | 0 mM NaCl           | 50 mM NaCl          | 100 mM NaCl         | 150 mM NaCl         |
| 0                               | 0,0046 <sup>a</sup> | 0,0035 <sup>a</sup> | 0,0018 <sup>a</sup> | 0,0010 <sup>a</sup> |
| 10                              | 0,0015 <sup>b</sup> | 0,0017 <sup>b</sup> | 0,0016 <sup>a</sup> | 0,0004 <sup>b</sup> |
| 20                              | 0,0016 <sup>b</sup> | 0,0008 <sup>b</sup> | 0,0009 <sup>c</sup> | 0,0002 <sup>b</sup> |
| 40                              | 0,0019 <sup>b</sup> | 0,0012 <sup>b</sup> | 0,0011 <sup>b</sup> | 0,0009 <sup>a</sup> |
| 60                              | 0,0017 <sup>b</sup> | 0,0018 <sup>b</sup> | 0,0018 <sup>a</sup> | 0,0003 <sup>b</sup> |
| 80                              | 0,0016 <sup>b</sup> | 0,0016 <sup>b</sup> | 0,0011 <sup>b</sup> | 0,0002 <sup>b</sup> |
| 100                             | 0,0015 <sup>b</sup> | 0,0010 <sup>b</sup> | 0,0008 <sup>c</sup> | 0,0002 <sup>b</sup> |

Figure 4.147 presents the effect of salinity stress and SiO<sub>2</sub> nanopriming on tomato shoot and root fresh and dry weight of tomato seedlings.



**Figure 4.147.** Shoot fresh weight (a), root fresh weight (b), shoot dry weight (c) and root dry weight (d) of tomato seeds under salinity stress after SiO<sub>2</sub> nanopriming

The shoot length of maize seedling, developed under 50 mM of NaCl stress condition, was increased under all concentrations of SiO<sub>2</sub> nanopriming; but, 60 ppm of SiO<sub>2</sub> holds the first rank with 29,06 mm. 10 ppm of SiO<sub>2</sub> nanopriming increased the shoot length of maize seedlings, developed under 100 mM of NaCl condition, with 30,51 mm. However, SiO<sub>2</sub> nanopriming decreased the shoot length of maize seedlings, developed under 150 mM of NaCl condition (Table 4.75).

**Table 4.75.** Shoot length (SL) of maize seedlings under salinity stress after SiO<sub>2</sub> nanopriming

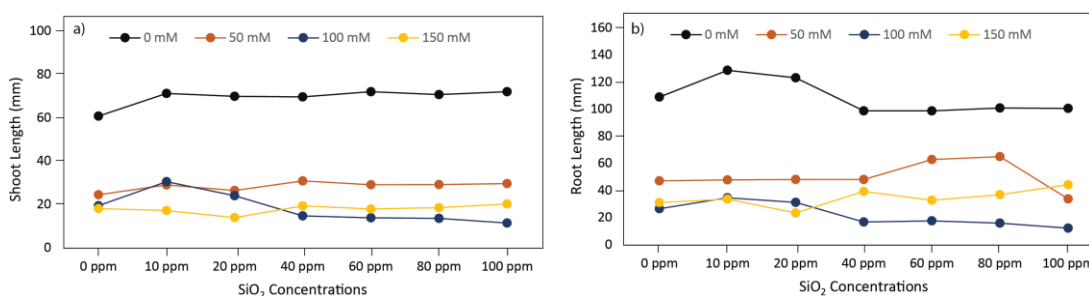
| SiO <sub>2</sub> Conc.<br>(ppm) | Shoot Length (mm)   |                     |                     |                     |
|---------------------------------|---------------------|---------------------|---------------------|---------------------|
|                                 | 0 mM NaCl           | 50 mM NaCl          | 100 mM NaCl         | 150 mM NaCl         |
| 0                               | 60,72 <sup>c</sup>  | 24,50 <sup>b</sup>  | 19,40 <sup>bc</sup> | 18,09 <sup>a</sup>  |
| 10                              | 71,19 <sup>ab</sup> | 28,94 <sup>ab</sup> | 30,51 <sup>a</sup>  | 17,24 <sup>ab</sup> |
| 20                              | 69,86 <sup>b</sup>  | 26,38 <sup>ab</sup> | 24,01 <sup>b</sup>  | 13,96 <sup>b</sup>  |
| 40                              | 69,54 <sup>b</sup>  | 30,81 <sup>ab</sup> | 14,76 <sup>cd</sup> | 19,31 <sup>a</sup>  |
| 60                              | 71,94 <sup>a</sup>  | 29,06 <sup>a</sup>  | 13,82 <sup>cd</sup> | 17,88 <sup>ab</sup> |
| 80                              | 70,59 <sup>ab</sup> | 29,17 <sup>ab</sup> | 13,54 <sup>d</sup>  | 18,57 <sup>ab</sup> |
| 100                             | 71,91 <sup>a</sup>  | 29,58 <sup>ab</sup> | 11,46 <sup>d</sup>  | 20,23 <sup>a</sup>  |

The root length of maize seedlings, developed under 50 mM of NaCl stress, was increased by 60 and 80 ppm of SiO<sub>2</sub> nanopriming. On the other hand, 10 ppm of SiO<sub>2</sub> treatment increased the root length of maize seedlings, developed under 100 mM of NaCl, up to 34,53 mm from 26,57 mm. 40 and 100 ppm SiO<sub>2</sub> application increased the root length of maize seedlings, developed under 150 mM of NaCl stress (Table 4.76).

**Table 4.76.** Root length (RL) of maize seedlings under salinity stress after SiO<sub>2</sub> nanopriming

| SiO <sub>2</sub> Conc.<br>(ppm) | Root Length (mm)    |                     |                     |                      |
|---------------------------------|---------------------|---------------------|---------------------|----------------------|
|                                 | 0 mM NaCl           | 50 mM NaCl          | 100 mM NaCl         | 150 mM NaCl          |
| 0                               | 108,88 <sup>b</sup> | 47,05 <sup>b</sup>  | 26,57 <sup>b</sup>  | 31,06 <sup>bc</sup>  |
| 10                              | 128,56 <sup>a</sup> | 47,74 <sup>b</sup>  | 34,53 <sup>a</sup>  | 33,59 <sup>abc</sup> |
| 20                              | 123,08 <sup>a</sup> | 48,00 <sup>ab</sup> | 31,24 <sup>ab</sup> | 23,38 <sup>c</sup>   |
| 40                              | 98,59 <sup>c</sup>  | 48,10 <sup>ab</sup> | 16,77 <sup>c</sup>  | 39,30 <sup>a</sup>   |
| 60                              | 98,60 <sup>c</sup>  | 62,74 <sup>a</sup>  | 17,51 <sup>c</sup>  | 32,76 <sup>abc</sup> |
| 80                              | 100,72 <sup>c</sup> | 64,85 <sup>a</sup>  | 15,85 <sup>c</sup>  | 36,81 <sup>ab</sup>  |
| 100                             | 100,43 <sup>c</sup> | 33,67 <sup>b</sup>  | 12,23 <sup>c</sup>  | 44,19 <sup>a</sup>   |

The effect of salinity stress and SiO<sub>2</sub> nanopriming on shoot and root length of maize seedlings is presented in Figure 4.148.



**Figure 4.148.** Shoot length (a) and root length (b) of maize seeds under salinity stress after SiO<sub>2</sub> nanopriming

The shoot fresh weigh of maize seedlings, developed under 50 MM of NaCl stress, was not affected by 10, 20, 40 and 60 ppm of SiO<sub>2</sub> nanopriming and decreased by 80 and 100 ppm of SiO<sub>2</sub> application. However, 10 and 40 ppm of SiO<sub>2</sub> application increased the shoot

fresh weight of maize seedlings developed under 100 and 150 mM of NaCl conditions respectively.

**Table 4.77.** Shoot fresh weight (SFW) of maize seedlings under salinity stress after SiO<sub>2</sub> nanopriming

| SiO <sub>2</sub> Conc.<br>(ppm) | Shoot Fresh Weight (g) |                       |                     |                       |
|---------------------------------|------------------------|-----------------------|---------------------|-----------------------|
|                                 | 0 mM NaCl              | 50 mM NaCl            | 100 mM NaCl         | 150 mM NaCl           |
| 0                               | 0,5612 <sup>d</sup>    | 0,2191 <sup>a</sup>   | 0,1168 <sup>b</sup> | 0,0676 <sup>c</sup>   |
| 10                              | 0,7733 <sup>b</sup>    | 0,1928 <sup>abc</sup> | 0,1415 <sup>a</sup> | 0,1018 <sup>ab</sup>  |
| 20                              | 0,8182 <sup>a</sup>    | 0,1800 <sup>abc</sup> | 0,1054 <sup>b</sup> | 0,0592 <sup>c</sup>   |
| 40                              | 0,6835 <sup>c</sup>    | 0,2607 <sup>a</sup>   | 0,0260 <sup>c</sup> | 0,1323 <sup>a</sup>   |
| 60                              | 0,6791 <sup>c</sup>    | 0,2155 <sup>ab</sup>  | 0,0410 <sup>c</sup> | 0,0833 <sup>bc</sup>  |
| 80                              | 0,6750 <sup>c</sup>    | 0,1632 <sup>bc</sup>  | 0,0305 <sup>c</sup> | 0,0973 <sup>abc</sup> |
| 100                             | 0,6786 <sup>c</sup>    | 0,1408 <sup>c</sup>   | 0,0184 <sup>c</sup> | 0,1078 <sup>ab</sup>  |

The root fresh weight of maize seedlings, developed under salinity stress, increased by SiO<sub>2</sub> as presented on Table 4.78. 10 and 20 ppm of SiO<sub>2</sub> nanopriming increased the root fresh weight of maize seedling, developed under 50 mM of NaCl stress, approximately three times. On the other hand, when the 80 ppm of SiO<sub>2</sub> increased the root fresh weight of maize seedlings, developed under 100 mM of NaCl condition, 40 ppm of SiO<sub>2</sub> increased the root fresh weight under 150 mM of NaCl condition.

**Table 4.78.** Root fresh weight (RFW) of maize seedlings under salinity stress after SiO<sub>2</sub> nanopriming

| SiO <sub>2</sub> Conc.<br>(ppm) | Root Fresh Weight (g) |                      |                      |                      |
|---------------------------------|-----------------------|----------------------|----------------------|----------------------|
|                                 | 0 mM NaCl             | 50 mM NaCl           | 100 mM NaCl          | 150 mM NaCl          |
| 0                               | 0,9272 <sup>c</sup>   | 0,3622 <sup>d</sup>  | 0,3273 <sup>c</sup>  | 0,3090 <sup>c</sup>  |
| 10                              | 1,2082 <sup>a</sup>   | 1,1390 <sup>a</sup>  | 0,6968 <sup>b</sup>  | 0,5832 <sup>ab</sup> |
| 20                              | 1,1398 <sup>b</sup>   | 1,0797 <sup>a</sup>  | 0,7393 <sup>ab</sup> | 0,5503 <sup>b</sup>  |
| 40                              | 0,9418 <sup>c</sup>   | 0,9060 <sup>bc</sup> | 0,7333 <sup>ab</sup> | 0,6561 <sup>a</sup>  |
| 60                              | 0,9219 <sup>c</sup>   | 0,9730 <sup>b</sup>  | 0,7917 <sup>ab</sup> | 0,6147 <sup>ab</sup> |
| 80                              | 0,9030 <sup>c</sup>   | 0,8475 <sup>c</sup>  | 0,8508 <sup>a</sup>  | 0,6042 <sup>ab</sup> |
| 100                             | 0,9148 <sup>c</sup>   | 0,8160 <sup>c</sup>  | 0,6830 <sup>b</sup>  | 0,5945 <sup>ab</sup> |

60 ppm of SiO<sub>2</sub> nanopriming increased the shoot dry weigh of maize seedlings developed under 50 and 100 mM of NaCl conditions approximately two times. On the other hand, the root length of maize seedlings, developed under 150 mM of NaCl stress, by 80 ppm of SiO<sub>2</sub> nanopriming (Table 4.79).

**Table 4.79.** Shoot dry weight (SDW) of maize seedlings under salinity stress after SiO<sub>2</sub> nanopriming

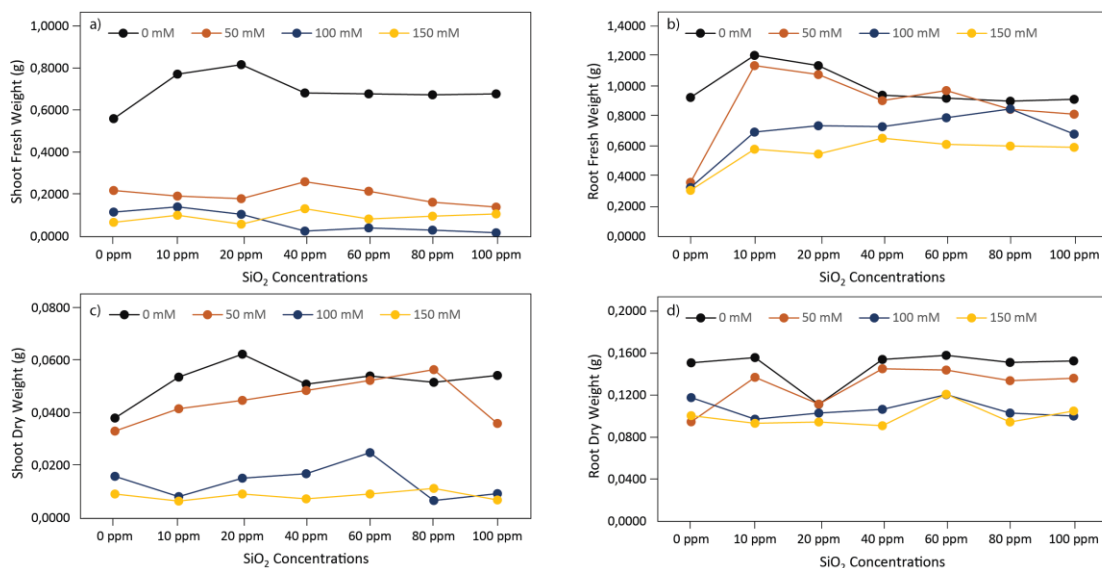
| SiO <sub>2</sub> Conc.<br>(ppm) | Shoot Dry Weight (g) |                      |                      |                      |
|---------------------------------|----------------------|----------------------|----------------------|----------------------|
|                                 | 0 mM NaCl            | 50 mM NaCl           | 100 mM NaCl          | 150 mM NaCl          |
| 0                               | 0,0381 <sup>d</sup>  | 0,0331 <sup>c</sup>  | 0,0159 <sup>b</sup>  | 0,0092 <sup>b</sup>  |
| 10                              | 0,0537 <sup>b</sup>  | 0,0416 <sup>bc</sup> | 0,0082 <sup>cd</sup> | 0,0065 <sup>c</sup>  |
| 20                              | 0,0624 <sup>a</sup>  | 0,0448 <sup>b</sup>  | 0,0152 <sup>b</sup>  | 0,0092 <sup>b</sup>  |
| 40                              | 0,0510 <sup>c</sup>  | 0,0486 <sup>b</sup>  | 0,0169 <sup>b</sup>  | 0,0073 <sup>bc</sup> |
| 60                              | 0,0541 <sup>b</sup>  | 0,0524 <sup>a</sup>  | 0,0249 <sup>a</sup>  | 0,0092 <sup>b</sup>  |
| 80                              | 0,0517 <sup>bc</sup> | 0,0565 <sup>a</sup>  | 0,0067 <sup>d</sup>  | 0,0113 <sup>a</sup>  |
| 100                             | 0,0543 <sup>b</sup>  | 0,0360 <sup>c</sup>  | 0,0093 <sup>c</sup>  | 0,0069 <sup>c</sup>  |

60 ppm of SiO<sub>2</sub> application to maize seeds increased the root dry weight of maize seedlings, developed under 50, 100 and 150 mM of NaCl stress conditions (Table 4.80).

**Table 4.80.** Root dry weight (RDW) of maize seedlings under salinity stress after SiO<sub>2</sub> nanopriming

| SiO <sub>2</sub> Conc.<br>(ppm) | Root Dry Weight (g) |                      |                     |                      |
|---------------------------------|---------------------|----------------------|---------------------|----------------------|
|                                 | 0 mM NaCl           | 50 mM NaCl           | 100 mM NaCl         | 150 mM NaCl          |
| 0                               | 0,1508 <sup>a</sup> | 0,0946 <sup>c</sup>  | 0,1178 <sup>b</sup> | 0,1005 <sup>b</sup>  |
| 10                              | 0,1559 <sup>a</sup> | 0,1370 <sup>b</sup>  | 0,0972 <sup>b</sup> | 0,0933 <sup>c</sup>  |
| 20                              | 0,1114 <sup>b</sup> | 0,1116 <sup>bc</sup> | 0,1030 <sup>b</sup> | 0,0946 <sup>bc</sup> |
| 40                              | 0,1540 <sup>a</sup> | 0,1453 <sup>a</sup>  | 0,1065 <sup>b</sup> | 0,0910 <sup>c</sup>  |
| 60                              | 0,1579 <sup>a</sup> | 0,1440 <sup>a</sup>  | 0,1206 <sup>a</sup> | 0,1209 <sup>a</sup>  |
| 80                              | 0,1512 <sup>a</sup> | 0,1338 <sup>b</sup>  | 0,1031 <sup>b</sup> | 0,0946 <sup>bc</sup> |
| 100                             | 0,1526 <sup>a</sup> | 0,1361 <sup>b</sup>  | 0,1002 <sup>b</sup> | 0,1050 <sup>b</sup>  |

Figure 4.149 presents the effect of salinity stress and SiO<sub>2</sub> nanopriming on shoot and root fresh and dry weight of maize seedlings.



**Figure 4.149.** Shoot fresh weight (a), root fresh weight (b), shoot dry weight (c) and root dry weight (d) of maize seeds under salinity stress after SiO<sub>2</sub> nanopriming

100 ppm of TiO<sub>2</sub> application to tomato seeds increased the shoot length of tomato seedlings, developed under 50 mM of NaCl stress conditions. On the other hand, TiO<sub>2</sub> nanopriming decreased the shoot length of tomato seedlings, developed under 100 mM of NaCl conditions, where 5 and 100 ppm of TiO<sub>2</sub> applications presented the lowest performance. Likewise, TiO<sub>2</sub> nanopriming decreased the shoot length of tomato seedlings, developed under 150 mM of NaCl stress condition (Table 4.81).

**Table 4.81.** Shoot length (SL) of tomato seedlings under salinity stress after TiO<sub>2</sub> nanopriming

| TiO <sub>2</sub> Conc.<br>(ppm) | Shoot Length (mm)   |                     |                     |                     |
|---------------------------------|---------------------|---------------------|---------------------|---------------------|
|                                 | 0 mM NaCl           | 50 mM NaCl          | 100 mM NaCl         | 150 mM NaCl         |
| 0                               | 75,40 <sup>ab</sup> | 43,17 <sup>b</sup>  | 40,57 <sup>a</sup>  | 38,49 <sup>a</sup>  |
| 5                               | 76,14 <sup>ab</sup> | 43,30 <sup>b</sup>  | 31,72 <sup>d</sup>  | 25,48 <sup>d</sup>  |
| 10                              | 78,28 <sup>a</sup>  | 40,51 <sup>c</sup>  | 37,45 <sup>b</sup>  | 31,45 <sup>bc</sup> |
| 50                              | 75,73 <sup>ab</sup> | 42,41 <sup>bc</sup> | 38,54 <sup>ab</sup> | 33,40 <sup>ab</sup> |
| 100                             | 72,54 <sup>b</sup>  | 47,67 <sup>a</sup>  | 33,85 <sup>d</sup>  | 26,24 <sup>cd</sup> |
| 250                             | 76,03 <sup>ab</sup> | 36,62 <sup>d</sup>  | 34,46 <sup>cd</sup> | 31,67 <sup>bc</sup> |
| 500                             | 66,37 <sup>c</sup>  | 47,71 <sup>a</sup>  | 36,67 <sup>bc</sup> | 37,12 <sup>a</sup>  |

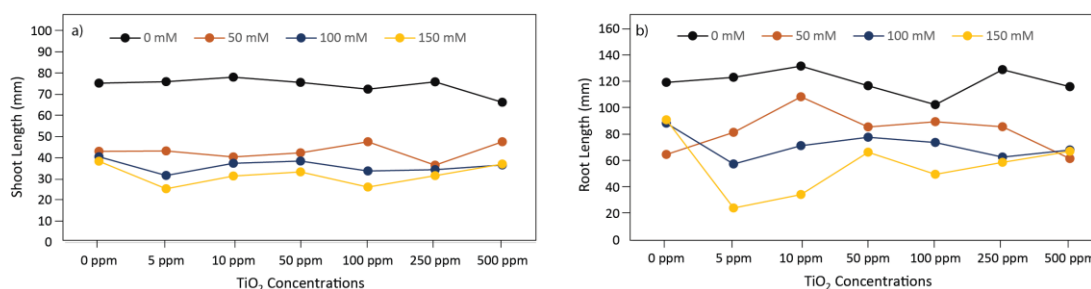
The root length of tomato seedlings, developed under 50 mM of NaCl conditions, was increased after nanopriming of tomato seeds by 10 ppm of TiO<sub>2</sub> suspension. However,

TiO<sub>2</sub> nanopriming decreased the root length of tomato seedlings, developed under 100 and 150 mM of NaCl stress conditions, where 5 ppm of TiO<sub>2</sub> decreased the root length the most (Table 4.82).

**Table 4.82.** Root length (RL) of tomato seedlings under salinity stress after TiO<sub>2</sub> nanopriming

| TiO <sub>2</sub> Conc.<br>(ppm) | Root Length (mm)      |                     |                     |                     |
|---------------------------------|-----------------------|---------------------|---------------------|---------------------|
|                                 | 0 mM NaCl             | 50 mM NaCl          | 100 mM NaCl         | 150 mM NaCl         |
| 0                               | 119,64 <sup>bc</sup>  | 65,07 <sup>d</sup>  | 88,76 <sup>a</sup>  | 91,33 <sup>a</sup>  |
| 5                               | 123,42 <sup>abc</sup> | 81,79 <sup>c</sup>  | 57,78 <sup>e</sup>  | 24,48 <sup>d</sup>  |
| 10                              | 132,02 <sup>a</sup>   | 108,76 <sup>a</sup> | 71,75 <sup>bc</sup> | 34,78 <sup>d</sup>  |
| 50                              | 117,09 <sup>bc</sup>  | 85,89 <sup>bc</sup> | 78,03 <sup>b</sup>  | 66,80 <sup>b</sup>  |
| 100                             | 102,72 <sup>d</sup>   | 89,84 <sup>b</sup>  | 74,17 <sup>bc</sup> | 49,98 <sup>c</sup>  |
| 250                             | 129,24 <sup>ab</sup>  | 86,07 <sup>bc</sup> | 63,08 <sup>de</sup> | 59,06 <sup>bc</sup> |
| 500                             | 116,43 <sup>c</sup>   | 61,90 <sup>d</sup>  | 68,44 <sup>cd</sup> | 67,53 <sup>b</sup>  |

The effect of salinity stress and TiO<sub>2</sub> nanopriming on shoot and root length of tomato seedlings was presented in Figure 4.150.



**Figure 4.150.** Shoot length (a) and root length (b) of tomato seeds under salinity stress after TiO<sub>2</sub> nanopriming

250 ppm of TiO<sub>2</sub> application increased the shoot fresh weight of tomato seedlings, developed under 50 mM of NaCl condition approximately 30%. On the other hand, 50ppm of TiO<sub>2</sub> nanopriming increased the shoot fresh weight of tomato seedlings up to 0,0866 g, developed under 100 mM of NaCl stress condition. However, the shoot fresh weight of tomato seedling decreased by TiO<sub>2</sub> nanopriming of tomato seeds except 250 ppm of TiO<sub>2</sub> application. 250 ppm of TiO<sub>2</sub> did not change the shoot fresh weight of tomato seedlings (Table 4.83).

**Table 4.83.** Shoot fresh weight (SFW) of tomato seedlings under salinity stress after TiO<sub>2</sub> nanopriming

| TiO <sub>2</sub> Conc.<br>(ppm) | Shoot Fresh Weight (g) |                      |                      |                     |
|---------------------------------|------------------------|----------------------|----------------------|---------------------|
|                                 | 0 mM NaCl              | 50 mM NaCl           | 100 mM NaCl          | 150 mM NaCl         |
| 0                               | 0,1328 <sup>b</sup>    | 0,0983 <sup>bc</sup> | 0,0762 <sup>b</sup>  | 0,0948 <sup>a</sup> |
| 5                               | 0,1470 <sup>ab</sup>   | 0,0933 <sup>c</sup>  | 0,0777 <sup>ab</sup> | 0,0560 <sup>b</sup> |
| 10                              | 0,1496 <sup>ab</sup>   | 0,0933 <sup>c</sup>  | 0,0783 <sup>ab</sup> | 0,0547 <sup>b</sup> |
| 50                              | 0,1561 <sup>a</sup>    | 0,1090 <sup>b</sup>  | 0,0866 <sup>a</sup>  | 0,0547 <sup>b</sup> |
| 100                             | 0,1434 <sup>ab</sup>   | 0,1219 <sup>a</sup>  | 0,0781 <sup>ab</sup> | 0,0335 <sup>d</sup> |
| 250                             | 0,1505 <sup>ab</sup>   | 0,1232 <sup>a</sup>  | 0,0771 <sup>ab</sup> | 0,0935 <sup>a</sup> |
| 500                             | 0,1574 <sup>a</sup>    | 0,1236 <sup>a</sup>  | 0,0749 <sup>b</sup>  | 0,0434 <sup>c</sup> |

The root fresh weight of tomato seedlings were decreased by TiO<sub>2</sub> nanopriming under salinity stress as presented on Table 4.84.

**Table 4.84.** Root fresh weight (RFW) of tomato seedlings under salinity stress after TiO<sub>2</sub> nanopriming

| TiO <sub>2</sub> Conc.<br>(ppm) | Root Fresh Weight (g) |                      |                      |                     |
|---------------------------------|-----------------------|----------------------|----------------------|---------------------|
|                                 | 0 mM NaCl             | 50 mM NaCl           | 100 mM NaCl          | 150 mM NaCl         |
| 0                               | 0,0088 <sup>c</sup>   | 0,0196 <sup>a</sup>  | 0,0100 <sup>a</sup>  | 0,0133 <sup>a</sup> |
| 5                               | 0,0128 <sup>ab</sup>  | 0,0109 <sup>b</sup>  | 0,0102 <sup>a</sup>  | 0,0025 <sup>c</sup> |
| 10                              | 0,0143 <sup>a</sup>   | 0,0062 <sup>de</sup> | 0,0067 <sup>c</sup>  | 0,0015 <sup>c</sup> |
| 50                              | 0,0109 <sup>abc</sup> | 0,0079 <sup>cd</sup> | 0,0068 <sup>c</sup>  | 0,0060 <sup>b</sup> |
| 100                             | 0,0093 <sup>bc</sup>  | 0,0082 <sup>c</sup>  | 0,0083 <sup>b</sup>  | 0,0015 <sup>c</sup> |
| 250                             | 0,0107 <sup>abc</sup> | 0,0098 <sup>b</sup>  | 0,0065 <sup>cd</sup> | 0,0010 <sup>c</sup> |
| 500                             | 0,0119 <sup>abc</sup> | 0,0061 <sup>e</sup>  | 0,0052 <sup>d</sup>  | 0,0015 <sup>c</sup> |

5 ppm of TiO<sub>2</sub> nanopriming increased the shoot dry weight of tomato seedlings, developed under 50 mM of NaCl stress conditions. On the other hand, the TiO<sub>2</sub> nanopriming decreased the shoot dry weight of tomato seedlings, developed under 100 and 150 mM of NaCl conditions and decreasing level increased by increasing in TiO<sub>2</sub> concentration (Table 4.85).

**Table 4.85.** Shoot dry weight (SDW) of tomato seedlings under salinity stress after TiO<sub>2</sub> nanopriming

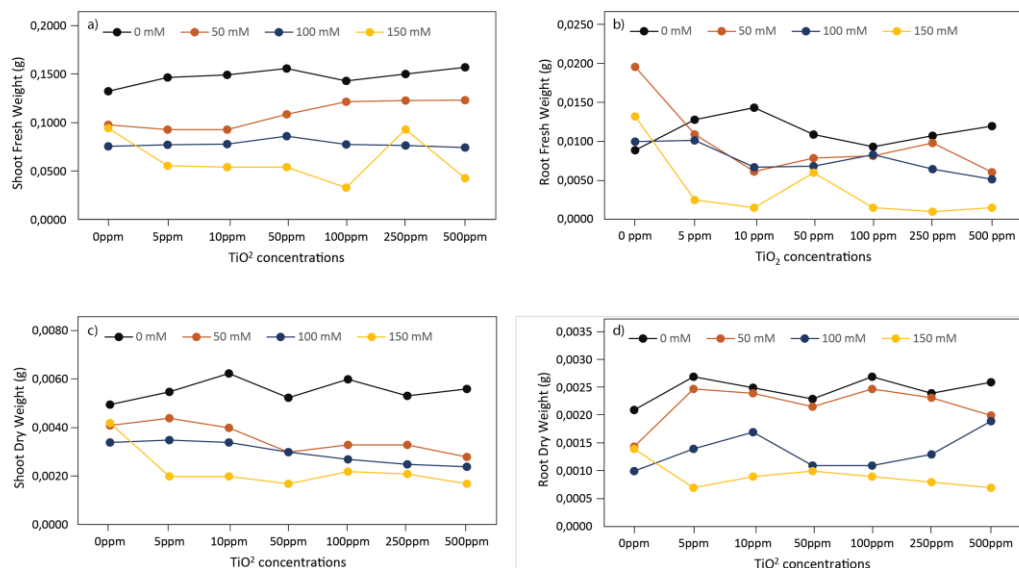
| TiO <sub>2</sub> Conc.<br>(ppm) | Shoot Dry Weight (g)  |                      |                      |                     |
|---------------------------------|-----------------------|----------------------|----------------------|---------------------|
|                                 | 0 mM NaCl             | 50 mM NaCl           | 100 mM NaCl          | 150 mM NaCl         |
| 0                               | 0,0050 <sup>c</sup>   | 0,0041 <sup>b</sup>  | 0,0034 <sup>a</sup>  | 0,0042 <sup>a</sup> |
| 5                               | 0,0055 <sup>abc</sup> | 0,0044 <sup>a</sup>  | 0,0035 <sup>a</sup>  | 0,0020 <sup>b</sup> |
| 10                              | 0,0062 <sup>a</sup>   | 0,0040 <sup>b</sup>  | 0,0034 <sup>a</sup>  | 0,0020 <sup>b</sup> |
| 50                              | 0,0052 <sup>bc</sup>  | 0,0030 <sup>cd</sup> | 0,0030 <sup>b</sup>  | 0,0017 <sup>b</sup> |
| 100                             | 0,0060 <sup>ab</sup>  | 0,0033 <sup>c</sup>  | 0,0027 <sup>bc</sup> | 0,0022 <sup>b</sup> |
| 250                             | 0,0053 <sup>bc</sup>  | 0,0033 <sup>c</sup>  | 0,0025 <sup>c</sup>  | 0,0021 <sup>b</sup> |
| 500                             | 0,0056 <sup>abc</sup> | 0,0028 <sup>d</sup>  | 0,0024 <sup>c</sup>  | 0,0017 <sup>b</sup> |

The root dry weight of tomato seedling was increased after TiO<sub>2</sub> nanopriming, developed under 50 mM of NaCl stress conditions. Besides, 500 ppm of TiO<sub>2</sub> nanopriming increased the root dry weight of tomato seeds approximately two times, developed under 100 mM of NaCl. However, TiO<sub>2</sub> nanopriming decreased the root dry weight of tomato seedlings, developed under 150 mM of NaCl (Table 4.86).

**Table 4.86.** Root dry weight (RDW) of tomato seeds under salinity stress after TiO<sub>2</sub> nanopriming

| TiO <sub>2</sub> Conc.<br>(ppm) | Root Dry Weight (g)  |                      |                     |                      |
|---------------------------------|----------------------|----------------------|---------------------|----------------------|
|                                 | 0 mM NaCl            | 50 mM NaCl           | 100 mM NaCl         | 150 mM NaCl          |
| 0                               | 0,0021 <sup>b</sup>  | 0,0014 <sup>c</sup>  | 0,0010 <sup>d</sup> | 0,0014 <sup>a</sup>  |
| 5                               | 0,0027 <sup>a</sup>  | 0,0025 <sup>a</sup>  | 0,0014 <sup>c</sup> | 0,0007 <sup>c</sup>  |
| 10                              | 0,0025 <sup>ab</sup> | 0,0024 <sup>a</sup>  | 0,0017 <sup>b</sup> | 0,0009 <sup>c</sup>  |
| 50                              | 0,0023 <sup>ab</sup> | 0,0022 <sup>b</sup>  | 0,0011 <sup>d</sup> | 0,0010 <sup>bc</sup> |
| 100                             | 0,0027 <sup>a</sup>  | 0,0025 <sup>a</sup>  | 0,0011 <sup>d</sup> | 0,0009 <sup>c</sup>  |
| 250                             | 0,0024 <sup>ab</sup> | 0,0023 <sup>ab</sup> | 0,0013 <sup>c</sup> | 0,0008 <sup>c</sup>  |
| 500                             | 0,0026 <sup>a</sup>  | 0,0020 <sup>b</sup>  | 0,0019 <sup>a</sup> | 0,0007 <sup>c</sup>  |

Figure 4.151 presents the effect of salinity stress and TiO<sub>2</sub> nanopriming on shoot and root fresh and dry weight of tomato seedlings.



**Figure 4.151.** Shoot fresh weight (a), root fresh weight (b), shoot dry weight (c) and root dry weight (d) of tomato seeds under salinity stress after TiO<sub>2</sub> nanopriming

TiO<sub>2</sub> nanopriming did not affect the shoot length of maize seedlings under 50 mM of NaCl stress condition. 10, 50 and 100 ppm of TiO<sub>2</sub> nanopriming had the same effect on the shoot length of maize seedlings, developed under 100 mM of NaCl condition and increased the shoot length to 26,18, 27,67 and 28,68 mm respectively. However, 5, 50 and 500 ppm pf TiO<sub>2</sub> nanopriming decreased the shoot length of maize seedlings, developed under 150 mM NaCl stress conditions, and rest of concentrations did not affect (Table 4.87).

**Table 4.87.** Shoot length (SL) of maize seedlings under salinity stress after TiO<sub>2</sub> nanopriming

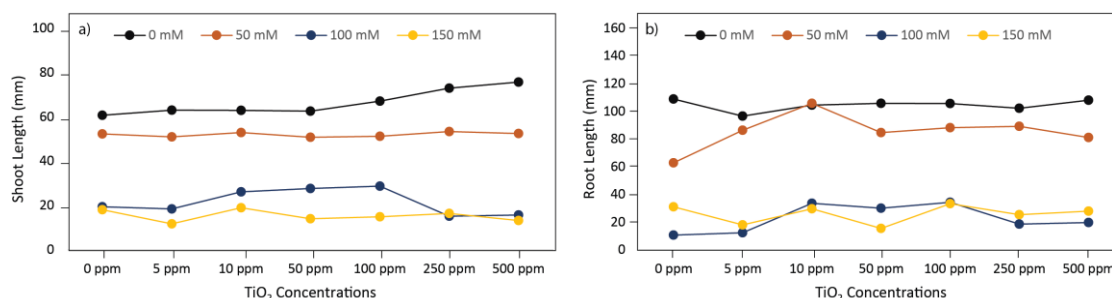
| TiO <sub>2</sub> Conc.<br>(ppm) | Shoot Length (mm)  |                    |                    |                      |
|---------------------------------|--------------------|--------------------|--------------------|----------------------|
|                                 | 0 mM NaCl          | 50 mM NaCl         | 100 mM NaCl        | 150 mM NaCl          |
| <b>0</b>                        | 60,72 <sup>d</sup> | 52,24 <sup>a</sup> | 19,40 <sup>b</sup> | 18,09 <sup>a</sup>   |
| <b>5</b>                        | 63,01 <sup>d</sup> | 50,99 <sup>a</sup> | 18,43 <sup>b</sup> | 11,70 <sup>c</sup>   |
| <b>10</b>                       | 62,92 <sup>d</sup> | 52,94 <sup>a</sup> | 26,18 <sup>a</sup> | 18,95 <sup>a</sup>   |
| <b>50</b>                       | 62,54 <sup>d</sup> | 50,75 <sup>a</sup> | 27,67 <sup>a</sup> | 13,97 <sup>bc</sup>  |
| <b>100</b>                      | 67,04 <sup>c</sup> | 51,25 <sup>a</sup> | 28,68 <sup>a</sup> | 14,92 <sup>abc</sup> |
| <b>250</b>                      | 72,92 <sup>b</sup> | 53,30 <sup>a</sup> | 15,13 <sup>b</sup> | 16,43 <sup>ab</sup>  |
| <b>500</b>                      | 75,71 <sup>a</sup> | 52,44 <sup>a</sup> | 15,71 <sup>b</sup> | 13,23 <sup>bc</sup>  |

The root length of maize seedling developed under 50 mM of NaCl condition, increased by TiO<sub>2</sub> nanopriming at all concentrations of TiO<sub>2</sub>. Likewise, all concentrations of TiO<sub>2</sub> application increased the root length of maize seedling, developed under 100 mM of NaCl condition and 10, 50 and 100 ppm of TiO<sub>2</sub> hold the first rank by more than 30 mm of root length. However, the TiO<sub>2</sub> nanopriming did not change the root length of maize seedling, developed under 150 mM of NaCl condition except 5 ppm, which decreases the root length of maize seedling (Table 4.88).

**Table 4.88.** Root length (RL) of maize seedlings under salinity stress after TiO<sub>2</sub> nanopriming

| TiO <sub>2</sub> Conc.<br>(ppm) | Root Length (mm)     |                     |                     |                     |
|---------------------------------|----------------------|---------------------|---------------------|---------------------|
|                                 | 0 mM NaCl            | 50 mM NaCl          | 100 mM NaCl         | 150 mM NaCl         |
| 0                               | 108,88 <sup>a</sup>  | 62,74 <sup>b</sup>  | 10,63 <sup>c</sup>  | 31,06 <sup>a</sup>  |
| 5                               | 96,47 <sup>b</sup>   | 86,30 <sup>ab</sup> | 12,35 <sup>bc</sup> | 17,98 <sup>b</sup>  |
| 10                              | 104,53 <sup>a</sup>  | 105,72 <sup>a</sup> | 33,60 <sup>a</sup>  | 29,56 <sup>a</sup>  |
| 50                              | 105,69 <sup>a</sup>  | 84,62 <sup>ab</sup> | 30,09 <sup>a</sup>  | 15,48 <sup>b</sup>  |
| 100                             | 105,63 <sup>a</sup>  | 88,16 <sup>ab</sup> | 34,33 <sup>a</sup>  | 33,33 <sup>a</sup>  |
| 250                             | 102,16 <sup>ab</sup> | 89,18 <sup>a</sup>  | 18,51 <sup>b</sup>  | 25,41 <sup>ab</sup> |
| 500                             | 107,96 <sup>a</sup>  | 81,13 <sup>ab</sup> | 19,75 <sup>b</sup>  | 27,92 <sup>ab</sup> |

Figure 4.152 presents the effect of salinity stress and TiO<sub>2</sub> nanopriming on maize shoot and root length.



**Figure 4.152.** Shoot length (a) and root length (b) of maize seeds under salinity stress after TiO<sub>2</sub> nanopriming

250 ppm of TiO<sub>2</sub> nanopriming increased the shoot fresh weight of maize seedlings, developed under 50 mM of NaCl concentration to 0,5678 g from 0,3895 g. However,

TiO<sub>2</sub> nanopriming decreased the shoot fresh weight of maize seedlings at 5 and 250 ppm, developed under 100 mM of NaCl and at 5, 50 and 250 ppm of TiO<sub>2</sub> developed under 150 mM of NaCl conditions. Rest of the concentrations did not affect the shoot fresh weight of maize seedlings, developed under 100 and 150 mM of NaCl stress conditions (Table 4.89).

**Table 4.89.** Shoot fresh weight (SFW) of maize seedlings under salinity stress after TiO<sub>2</sub> nanopriming

| TiO <sub>2</sub> Conc.<br>(ppm) | Shoot Fresh Weight (g) |                      |                      |                      |
|---------------------------------|------------------------|----------------------|----------------------|----------------------|
|                                 | 0 mM NaCl              | 50 mM NaCl           | 100 mM NaCl          | 150 mM NaCl          |
| <b>0</b>                        | 0,5612 <sup>c</sup>    | 0,3895 <sup>c</sup>  | 0,2335 <sup>a</sup>  | 0,1352 <sup>a</sup>  |
| <b>5</b>                        | 0,6008 <sup>bc</sup>   | 0,4646 <sup>b</sup>  | 0,1144 <sup>c</sup>  | 0,0902 <sup>b</sup>  |
| <b>10</b>                       | 0,5772 <sup>bc</sup>   | 0,4880 <sup>b</sup>  | 0,2074 <sup>ab</sup> | 0,1251 <sup>ab</sup> |
| <b>50</b>                       | 0,6084 <sup>bc</sup>   | 0,5099 <sup>ab</sup> | 0,2222 <sup>a</sup>  | 0,0962 <sup>b</sup>  |
| <b>100</b>                      | 0,6091 <sup>b</sup>    | 0,5093 <sup>ab</sup> | 0,3030 <sup>a</sup>  | 0,1123 <sup>ab</sup> |
| <b>250</b>                      | 0,6014 <sup>b</sup>    | 0,5678 <sup>a</sup>  | 0,0844 <sup>c</sup>  | 0,1413 <sup>a</sup>  |
| <b>500</b>                      | 0,6634 <sup>a</sup>    | 0,3895 <sup>c</sup>  | 0,1253 <sup>bc</sup> | 0,0940 <sup>b</sup>  |

50 and 250 ppm of TiO<sub>2</sub> nanopriming increased the root fresh weight of maize seedlings, developed under 50 mM of NaCl stress condition. 5 and 250 ppm of TiO<sub>2</sub> nanopriming decreased the root fresh weight of maize seedlings developed under 100 mM of NaCl condition and rest of the concentrations did not affect the root fresh weight of maize seedlings. Likewise, when the 5 ppm of TiO<sub>2</sub> nanopriming decreased the root fresh weight, rest of the concentrations did not affect the root fresh weight of maize seedlings developed under 150 mM of NaCl condition (Table 4.90).

**Table 4.90.** Root fresh weight (RFW) of maize seedlings under salinity stress after TiO<sub>2</sub> nanopriming

| TiO <sub>2</sub> Conc.<br>(ppm) | Root Fresh Weight (g) |                     |                       |                      |
|---------------------------------|-----------------------|---------------------|-----------------------|----------------------|
|                                 | 0 mM NaCl             | 50 mM NaCl          | 100 mM NaCl           | 150 mM NaCl          |
| 0                               | 0,9272 <sup>b</sup>   | 0,7273 <sup>d</sup> | 0,7243 <sup>a</sup>   | 0,6181 <sup>ab</sup> |
| 5                               | 1,0307 <sup>a</sup>   | 0,8465 <sup>c</sup> | 0,5929 <sup>bc</sup>  | 0,5691 <sup>b</sup>  |
| 10                              | 1,0710 <sup>a</sup>   | 0,8780 <sup>c</sup> | 0,7446 <sup>a</sup>   | 0,6896 <sup>a</sup>  |
| 50                              | 1,0488 <sup>a</sup>   | 1,0249 <sup>a</sup> | 0,6940 <sup>ab</sup>  | 0,5933 <sup>ab</sup> |
| 100                             | 0,9205 <sup>b</sup>   | 0,9746 <sup>b</sup> | 0,6670 <sup>abc</sup> | 0,6690 <sup>a</sup>  |
| 250                             | 0,9147 <sup>b</sup>   | 1,0667 <sup>a</sup> | 0,5336 <sup>c</sup>   | 0,6570 <sup>ab</sup> |
| 500                             | 1,0601 <sup>a</sup>   | 0,8894 <sup>c</sup> | 0,6470 <sup>abc</sup> | 0,6778 <sup>ab</sup> |

10 ppm of TiO<sub>2</sub> nanopriming increased the shoot dry weight of maize seedling developed under 50 mM of NaCl conditions. Besides, 5, 10 and 50 ppm of TiO<sub>2</sub> nanopriming increased the shoot dry weight of maize seedlings, developed under 100 mM of NaCl condition. All concentrations of TiO<sub>2</sub> increased the shoot dry weight of maize seedlings developed under 150 mM of NaCl and 50 ppm of TiO<sub>2</sub> holds the first rank with 0,0134 g (Table 4.91).

**Table 4.91.** Shoot dry weight (SDW) of maize seedlings under salinity stress after TiO<sub>2</sub> nanopriming

| TiO <sub>2</sub> Conc.<br>(ppm) | Shoot Dry Weight (g) |                      |                     |                      |
|---------------------------------|----------------------|----------------------|---------------------|----------------------|
|                                 | 0 mM NaCl            | 50 mM NaCl           | 100 mM NaCl         | 150 mM NaCl          |
| 0                               | 0,0381 <sup>d</sup>  | 0,0331 <sup>b</sup>  | 0,0127 <sup>c</sup> | 0,0046 <sup>d</sup>  |
| 5                               | 0,0430 <sup>c</sup>  | 0,0248 <sup>bc</sup> | 0,0235 <sup>a</sup> | 0,0096 <sup>bc</sup> |
| 10                              | 0,0424 <sup>c</sup>  | 0,0342 <sup>a</sup>  | 0,0231 <sup>a</sup> | 0,0095 <sup>bc</sup> |
| 50                              | 0,0464 <sup>b</sup>  | 0,0333 <sup>b</sup>  | 0,0228 <sup>a</sup> | 0,0134 <sup>a</sup>  |
| 100                             | 0,0501 <sup>a</sup>  | 0,0177 <sup>c</sup>  | 0,0152 <sup>b</sup> | 0,0074 <sup>c</sup>  |
| 250                             | 0,0479 <sup>ab</sup> | 0,0165 <sup>c</sup>  | 0,0155 <sup>b</sup> | 0,0079 <sup>c</sup>  |
| 500                             | 0,0490 <sup>ab</sup> | 0,0151 <sup>d</sup>  | 0,0131 <sup>c</sup> | 0,0123 <sup>b</sup>  |

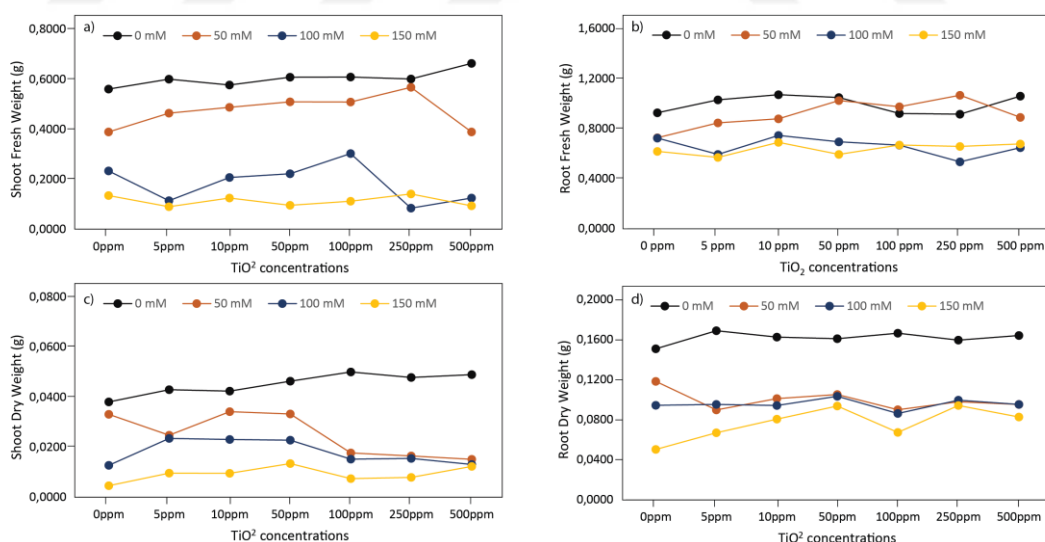
TiO<sub>2</sub> nanopriming decreased the root dry weight of maize seedlings developed under 50 mM of NaCl stress conditions. However, 50 and 250 ppm of TiO<sub>2</sub> nanopriming increased

the root fry weight of maize seedling developed under 100 and 150 mM of NaCl conditions (Table 4.92).

**Table 4.92.** Root dry weight (RDW) of maize seedlings under salinity stress after TiO<sub>2</sub> nanopriming

| TiO <sub>2</sub> Conc.<br>(ppm) | Root Dry Weight (g)  |                     |                     |                     |
|---------------------------------|----------------------|---------------------|---------------------|---------------------|
|                                 | 0 mM NaCl            | 50 mM NaCl          | 100 mM NaCl         | 150 mM NaCl         |
| 0                               | 0,1508 <sup>b</sup>  | 0,1183 <sup>a</sup> | 0,0943 <sup>b</sup> | 0,0503 <sup>d</sup> |
| 5                               | 0,1690 <sup>a</sup>  | 0,0897 <sup>c</sup> | 0,0953 <sup>b</sup> | 0,0669 <sup>c</sup> |
| 10                              | 0,1625 <sup>ab</sup> | 0,1011 <sup>b</sup> | 0,0942 <sup>b</sup> | 0,0805 <sup>b</sup> |
| 50                              | 0,1609 <sup>ab</sup> | 0,1051 <sup>b</sup> | 0,1034 <sup>a</sup> | 0,0937 <sup>a</sup> |
| 100                             | 0,1664 <sup>a</sup>  | 0,0899 <sup>c</sup> | 0,0862 <sup>c</sup> | 0,0672 <sup>c</sup> |
| 250                             | 0,1596 <sup>ab</sup> | 0,0979 <sup>c</sup> | 0,0994 <sup>a</sup> | 0,0941 <sup>a</sup> |
| 500                             | 0,1642 <sup>ab</sup> | 0,0952 <sup>c</sup> | 0,0952 <sup>b</sup> | 0,0827 <sup>b</sup> |

Figure 4.153 presents effect of salinity stress and TiO<sub>2</sub> nanopriming on shoot and root fresh and dry weight of maize seedlings.



**Figure 4.153.** Shoot fresh weight (a), root fresh weight (b), shoot dry weight (c) and root dry weight (d) of maize seeds under salinity stress after TiO<sub>2</sub> nanopriming

The seed germination rate of tomato seeds was increased by nanopriming application by all nanoparticle types, under severe salinity stress conditions. However, none of the nanoparticle type increased seed germination rate of maize seeds under salinity stress.

CNT nanopriming of tomato seeds increased the root growth of tomato seedling under salinity conditions. On the other hand, CNT nanopriming increased the biomass of maize seedlings under salt stress conditions. Pandey et al., indicated that CNT interacted with Na<sup>+</sup> ions and absorbs sodium ions, which resulted increasing in biomass of sorghum and switchgrass under salinity stress conditions (Pandey et. al., 2018). It is reported that, optimum concentration of CNT increased the salt stress tolerance of *Ocimum basilicum* L. by increased enzymatic and non-enzymatic antioxidant activity. However, increasing in concentration of CNT showed toxic effect (Gohari et. al., 2020).

SiO<sub>2</sub> nanopriming increased the tomato plant development under 100 mM of NaCl stress condition. On the other hand, SiO<sub>2</sub> nanopriming increased the maize seedlings growth under salinity stress. Almutairi reported that, SiO<sub>2</sub> nanoparticles could increase the salt tolerance level of tomato seeds by changing salt tolerance gene expression (Almutairi, 2016). The SiO<sub>2</sub> application to Fenugreek increased the salt tolerance of plants and 50 ppm of SiO<sub>2</sub> was more effective than 100 ppm (Ivani et. al., 2018). It is indicated that, nano-SiO<sub>2</sub> application to tomato plants increased the fresh and dry weights, root volume, and chlorophyll concentration under salt stress condition (Haghighi & Pessarakli, 2013).

TiO<sub>2</sub> nanopriming of tomato and maize seedlings improved the seedling growth under 50 mM of NaCl concentration. By increasing the salinity stress level, the effect of TiO<sub>2</sub> decreased in the current study. It is reported that, nano-TiO<sub>2</sub> application to barley under salt stress conditions, promoted the salt-tolerance of barley by increasing the biomass accumulation of barley and antioxidant enzyme activity (Karami and Sepehri, 2018). There is limited information on effect of TiO<sub>2</sub> nanoparticles on salinity stress in literature and in the current study showed that TiO<sub>2</sub> nanoparticle is more effective on drought stress compare to salinity stress.

#### **4.4.2.3 MDA content**

CNT nanopriming to tomato seeds decreased the MDA content of tomato seedling as presented in Table 4.93. MDA is produced by lipid peroxidation and used as indicator to determine the cellular injury (Marstin et. al., 2017). The decreasing in MDA even under salinity stress conditions showed that CNT application decreased the cellular damage of

tomato seedlings. On the other hand, increasing in CNT concentration increased the MDA level.

**Table 4.93.** MDA content of tomato seedlings after CNT nanopriming

| CNT Conc.<br>(ppm) | MDA ( $\mu\text{mol/g FW}$ ) |                   |                    |                   |
|--------------------|------------------------------|-------------------|--------------------|-------------------|
|                    | 0 mM NaCl                    | 50 mM NaCl        | 100 mM NaCl        | 150 mM NaCl       |
| 0                  | 1,56 <sup>a</sup>            | 2,23 <sup>a</sup> | 2,74 <sup>a</sup>  | 3,72 <sup>a</sup> |
| 50                 | 0,91 <sup>c</sup>            | 1,16 <sup>d</sup> | 1,30 <sup>c</sup>  | 1,47 <sup>c</sup> |
| 100                | 1,27 <sup>b</sup>            | 1,44 <sup>c</sup> | 1,57 <sup>bc</sup> | 1,75 <sup>b</sup> |
| 250                | 1,64 <sup>a</sup>            | 1,82 <sup>b</sup> | 1,76 <sup>b</sup>  | 1,84 <sup>b</sup> |

#### 4.4.2.1 Proline content

Proline content of tomato seedling were dramatically increased after CNT nanopriming, which was approximately 6 times more (Table 4.94). Proline has an important role on abiotic stress response mechanism on plants. Moukhtari et. al., indicated that exogenous application of proline increases the plant tolerance to abiotic stresses (Moukhtari et. al., 2020). It is concluded that, CNT nanopriming increased the stress tolerance of tomato seedlings by increased of proline content also in the current study.

**Table 4.94.** Proline content of tomato seedlings after CNT nanopriming

| CNT Conc.<br>(ppm) | Proline (nmol/g)   |                    |                    |                    |
|--------------------|--------------------|--------------------|--------------------|--------------------|
|                    | 0 mM NaCl          | 50 mM NaCl         | 100 mM NaCl        | 150 mM NaCl        |
| 0                  | 5,73 <sup>d</sup>  | 6,32 <sup>d</sup>  | 7,49 <sup>d</sup>  | 8,89 <sup>d</sup>  |
| 50                 | 12,66 <sup>c</sup> | 23,56 <sup>c</sup> | 28,33 <sup>c</sup> | 31,94 <sup>c</sup> |
| 100                | 22,18 <sup>b</sup> | 28,43 <sup>b</sup> | 30,55 <sup>b</sup> | 32,81 <sup>b</sup> |
| 250                | 33,02 <sup>a</sup> | 31,59 <sup>a</sup> | 37,29 <sup>a</sup> | 38,26 <sup>a</sup> |

#### 4.4.2.1 H<sub>2</sub>O<sub>2</sub> content

The H<sub>2</sub>O<sub>2</sub> content increased by CNT nanopriming correlated with CNT concentration (Table 4.95). Thus, CNT nanopriming increased the oxidative stress in tomato seedlings under salinity stress. Rahmani et. al., reported that CNT application to *Salvia verticillata*

L. also increased the H<sub>2</sub>O<sub>2</sub> content, which leded the antioxidant enzymes system activation (Rahmani et. al., 2020).

**Table 4.95.** H<sub>2</sub>O<sub>2</sub> content of tomato seedlings after CNT nanopriming

| CNT Conc.<br>(ppm) | H <sub>2</sub> O <sub>2</sub> (nmol/g) |                     |                     |                     |
|--------------------|--|---------------------|---------------------|---------------------|
|                    | 0 mM NaCl                              | 50 mM NaCl          | 100 mM NaCl         | 150 mM NaCl         |
| 0                  | 185,51 <sup>c</sup>                    | 198,61 <sup>d</sup> | 207,94 <sup>d</sup> | 224,86 <sup>d</sup> |
| 50                 | 214,49 <sup>b</sup>                    | 220,91 <sup>c</sup> | 230,54 <sup>c</sup> | 252,62 <sup>c</sup> |
| 100                | 226,55 <sup>a</sup>                    | 254,92 <sup>b</sup> | 258,62 <sup>b</sup> | 268,31 <sup>b</sup> |
| 250                | 218,63 <sup>b</sup>                    | 263,84 <sup>a</sup> | 275,66 <sup>a</sup> | 280,91 <sup>a</sup> |

## CHAPTER V

### CONCLUSION

In this Thesis, the using potential of three nanoparticles (CNT, SiO<sub>2</sub>, TiO<sub>2</sub>) as seed priming and coating agent in three crop species (tomato, maize, and dry bean) were investigated with four different experiments. In the first experiment, the effects of nanopriming on germination and seedling development of tomato, maize and dry bean under laboratory were tested *in vitro* conditions. Secondly, the effects of priming with different nanoparticles on growth, physiological traits, and yield of evaluated species were observed under *in vivo* (greenhouse) conditions. Then, the potential of different nanoparticles as seed coating agent was examined under *in vitro* conditions using the best concentrations determined in Experiment 2. Finally, the effects of nanopriming on seed germination and plant development were observed under drought and salinity conditions in pot experiments under greenhouse conditions. At the end of these experiments, the main conclusions derived from our results were listed below:

- TiO<sub>2</sub>, SiO<sub>2</sub> and CNT nanopriming increases the seed vigor index of tomato, bean and maize.
- Since the seeds already had high seed germination rate, the nanopriming application did not significantly change the germination rate of the seeds.
- While the TiO<sub>2</sub> increased the tomato seedling development, CNT increased the maize and bean seedling development compare to other nanoparticles.
- SiO<sub>2</sub> nanopriming application increased the yield of maize compared to control group.
- It was observed that, nanoparticles do not translocate through the other tissues of plant, especially edible parts, after nanopriming.
- CNT and SiO<sub>2</sub> addition to gelatin films increased the efficiency of gelatin on maize seedling development.
- CNT increased the seed germination rate of both tomato and maize seeds under drought stress.
- Low concentrations of CNT stimulates the response of plants against drought stress.

- $\text{TiO}_2$  nanoparticle was the most effective nanoparticle compare to  $\text{SiO}_2$  and CNT to increase the drought tolerance of plants.
- CNT increased the salinity tolerance of maize seedling under severe salinity stress conditions.
- Although  $\text{SiO}_2$  stimulated the response of maize against salinity stress, did not affect the tomato seedlings.
- Unlike the drought stress,  $\text{TiO}_2$  did not affect the response of plants against salinity stress.
- CNT nanopriming increased cell membrane stability of tomato under salinity stress by decreasing MDA content.

The translocation of nanoparticles was examined and any nanoparticle residues was observed, especially in edible parts. This thesis revealed novel findings regarding using possibilities of three nanoparticles as coating agent for different crop species with different seed size. Our findings clearly indicated that nanoparticles have potential to use for seed coating to promote early growth and development in crops. However, further studies are needed to develop efficient formulations and strategies in commercial usage.

## REFERENCES

- Accinelli C., Abbas H.K., Little N.S., Kotowicz, J. K., Mencarelli, M. and Shier, W. T., “A liquid bioplastic formulation for film coating of agronomic seeds.” *Crop Prot* 89, 123–128, 2016.
- Accinelli C., Abbas H.K. and Shier W.T., “A bioplastic-based seed coating improves seedling growth and reduces production of coated seed dust.” *J Crop Improv* 32, 318–330, 2018.
- Adak T., Kumar J., Shakil N. A., and Walia S. “Development of controlled release formulations of imidacloprid employing novel nano-ranged amphiphilic polymers.” *J Environ Sci Heal - Part B Pestic Food Contam Agric Wastes* 47, 217–225, 2012.
- Akbarimoghaddam H., Galavi M., Ghanbari A., and Panjehkeh N. “Salinity effects on seed germination and seedling growth of bread wheat cultivars.” *Trakia Journal of Sciences*, 9, 43-50,2011.
- Van Aken B. “Gene expression changes in plants and microorganisms exposed to nanomaterials.” *Curr Opin Biotechnol* 33, 206–219, 2015.
- Al-Degs Y.S., Al-Ghouti M.A. and El-Sheikh A.H. “Simultaneous determination of pesticides at trace levels in water using multiwalled carbon nanotubes as solid-phase extractant and multivariate calibration.” *J Hazard Mater* 169, 128–135, 2009.
- Ali M. M., Al-Ani A., Eamus D., and Tan, D. K. “Leaf nitrogen determination using non-destructive techniques–A review.” *J Plant Nutr* 40, 928–953, 2017.
- Ali S., Rizwan M., Hussain A., Rehman M. Z., Ali B., Yousaf B., and Ahmad P. “Silicon nanoparticles enhanced the growth and reduced the cadmium accumulation in grains of wheat (*Triticum aestivum* L.)” *Plant Physiol Biochem* 140, 1–8, 2019.
- Almansouri M., Kinet J., and Lutts S. “Effect of salt and osmotic stresses on germination in durum wheat ( *Triticum durum* Desf .)” *Plant and Soil*, 243–254, 2001.

Almutairi Z.M., “Effect of nano-silicon application on the expression of salt tolerance genes in germinating tomato (*Solanum lycopersicum* L.) seedlings under salt stress.” *Plant Omics* 9, 106–114, 2016.

Almutairi Z.M. and Amjad A., “Effect of Silver Nanoparticles on Seed Germination of Crop Plants.” *J Adv Chem* 4, 280–285, 2015.

Alsaedi A., El-Ramady H., Alshaal T. A., and Almohsen M., “Enhancing seed germination and seedlings development of common bean (*Phaseolus vulgaris*) by SiO<sub>2</sub> nanoparticles.” *Egypt J Soil Sci* 0, 0–0, 2017.

Amutha M., “Establishment of *Beauveria bassiana* (Balsamo) Vuillemin as an Endophyte in Cotton.” *Int J Curr Microbiol Appl Sci* 6, 2506–2513, 2017.

Anand A., Kumari A., Thakur M., and Koul A. “Hydrogen peroxide signaling integrates with phytohormones during the germination of magnetoprimed tomato seeds.” *Sci Rep* 9, 1–11, 2019.

Anand KV, Anugraha AR, Kannan M, , “Bio-engineered magnesium oxide nanoparticles as nano-priming agent for enhancing seed germination and seedling vigour of green gram (*Vigna radiata* L.).” *Mater Lett* 271, 127792, 2020.

Anand K. V., Anugraha A. R., Kannan M., Singaravelu G., and Govindaraju K. “Development of a Na-Alginate-based bioformulation and its use in the management of charcoal rot of sunflower (*Helianthus Annuus* L.).” *Pakistan J Bot* 44, 1167–1170, 2012.

Antonacci A., Arduini F., Moscone D., Palleschi G., and Scognamiglio V. “Nanostructured (Bio)sensors for smart agriculture.” *TrAC - Trends Anal Chem* 98, 95–103, 2018.

Arduini F., Cinti S., Scognamiglio V., and Moscone D. “Nanomaterials in electrochemical biosensors for pesticide detection advances and challenges in food analysis.” *Microchim Acta* 183, 2063–2083, 2016.

Aronne G., De Micco V., and Scala M. “Plant Reproductive Ecology for Conservation of Endangered Mediterranean Species.” *The Botanica* 54, 23-29 2004.

Aronne G., and Veronica D.M., “Hypocotyl features of *Myrtus communis* ( Myrtaceae ) a many-sided strategy for possible enhancement of seedling establishment in the Mediterranean environment.” *Bot J Linn* 145, 195–202, 2004.

Ashkavand P., Tabari M., Zarafshar M., Tomášková I., and Struve D. “Effect of SiO<sub>2</sub> nanoparticles on drought resistance in hawthorn seedlings.” *For Res Pap* 76, 350–359, 2015.

Avelar S. A. G., Sousa F. V. D., Fiss G., Baudet L., and Peske S. T. “The use of film coating on the performance of treated corn seed.” *Rev Bras Sementes* 34, 186–192, 2012.

Azimi R., Borzelabad M. J., Feizi H., & Azimi A. “Interaction of SiO<sub>2</sub> nanoparticles with seed prechilling on germination and early seedling growth of tall wheatgrass (*Agropyron elongatum* L.)” *Polish J Chem Technol* 16, 25–29, 2014.

Bailly C., “The signalling role of ROS in the regulation of seed germination and dormancy.” *Biochem J* 476, 3019–3032, 2019.

Bailly C., and Kranner I., “Analyses of reactive oxygen species and antioxidants in relation to seed longevity and germination.” *Methods Mol Biol* 773, 343–367, 2011.

Bakshi M., Liné C., Bedolla D. E., Stein R. J., Kaegi R., Sarret G., and Larue C. “Assessing the impacts of sewage sludge amendment containing nano-TiO<sub>2</sub> on tomato plants A life cycle study.” *J Hazard Mater* 369, 191–198, 2019.

Bayat N., Ghanbari A.A., and Bayramzade V., “Nanopriming a method for improving crop plants performance a case study of red beans.” *J Plant Nutr* 0, 1–10, 2020.

Behboudi F., Tahmasebi Sarvestani Z., Kassae M. Z., Modares Sanavi S. A. M., and Sorooshzadeh A. “Improving growth and yield of wheat under drought stress via application of SiO<sub>2</sub> nanoparticles.” *J Agric Sci Technol* 20, 1479–1492, 2018.

Berninger T., Mitter B. and Preininger C., “The smaller, the better? the size effect of alginate beads carrying plant growth-promoting bacteria for seed coating.” *J Microencapsul* 33, 127–136, 2016.

Bewley J.D., “Seed Germination and Dormancy.” *The Plant Cell* 9, 1997.

Bidlack J. and Jansky S., Introductory Plant Biology. *McGraw-Hill Higher Education*, 2003.

Bray E.A., “Response to abiotic stress.” *Biochem Adn Mol Biol Plants* 1158–1203, 2000.

Bybordi A., “The Influence of Salt Stress on Seed Germination , Growth and Yield of Canola Cultivars.” *Notulae Botanicae Horti Agrobotanici Cluj-Napoca* 38, 128–133, 2010.

Cañas J. E., Long M., Nations S., Vadan R., Dai L., Luo M., and Olszyk D. “Effects of functionalized and nonfunctionalized single-walled carbon nanotubes on root elongation of select crop species.” *Environ Toxicol Chem* 27, 1922–1931, 2008.

Carpıcı E.B., Celik N. and Bayram G., “Effects of salt stress on germination of some maize ( *Zea mays* L .) cultivars.” *African Journal of Biotechnology* 8, 4918–4922, 2009.

Carriger JF, Rand GM, Gardinali PR, , “Pesticides of potential ecological concern in sediment from south Florida canals An ecological risk prioritization for aquatic arthropods.” *Soil Sediment Contam* 15, 21–45, 2006.

Chandrasekaran U., Luo X., Wang Q., and Shu K. “Are There Unidenti fi ed Factors Involved in the Germination of Nanoprimered Seeds? ” *Frontiers in Plant Science* 11, 1–6, 2020.

Chhipa H., “Nanofertilizers and nanopesticides for agriculture.” *Environ Chem Lett* 15, 15–22, 2017.

Choi E. S., Sukweenadhi J., Kim Y. J., Jung K. H., Koh S. C., Hoang V. A., and Yang D.

C. “The effects of rice seed dressing with *Paenibacillus yonginensis* and silicon on crop development on South Korea’s reclaimed tidal land.” *F Crop Res* 188, 121–132, 2016.

Copeland L.O., and McDonald M.B., Seed Science and Thecnology. *Springer Science+Business Media*, New York, 1999.

Court M.N., Stephen C. and Waidj J.S. “Toxicity as a cause of the inefficiency of urea as a fertilizer. II. Experimental.” *Journal of Soil Science* 15, 1964.

Dağhan H., “Effects of TiO<sub>2</sub> nanoparticles on maize (*Zea mays* L.) growth, chlorophyll content and nutrient uptake.” *Appl Ecol Environ Res* 16, 6873–6883, 2018.

Dantas B.F., De Sá Ribeiro L. and Aragão C.A., “Germination, initial growth and cotyledon protein content of bean cultivars under salinity stress.” *Rev Bras Sementes* 29, 106–110, 2007.

Dawar S., Hayat S., Anis M., and Zaki M. J. “Effect of seed coating material in the efficacy of microbial antagonists for the control of root rot fungi on Okra and Sunflower.” *Pakistan J Bot* 40, 1269–1278, 2008.

DeRosa M. C., Monreal C., Schnitzer M., Walsh R., and Sultan Y. “Nanotechnology in fertilizers.” *Nat Nanotechnol* 5, 91, 2010.

Dhoke S. K., Mahajan P., Kamble R., and Khanna A. “Effect of nanoparticles suspension on the growth of mung (*Vigna radiata*) seedlings by foliar spray method.” *Nanotechnol Dev* 3, 1, 2013.

Dietz K.J., Mittler R., and Noctor G., “Recent progress in understanding the role of reactive oxygen species in plant cell signaling.” *Plant Physiol* 171, 1535–1539, 2016.

Ehsanfar S. and Modarres-Sanavy S.A., “Crop protection by seed coating.” *Commun Agric Appl Biol Sci* 70, 225–229, 2005.

El-Temsah Y.S. and Joner E.J., “Impact of Fe and Ag Nanoparticles on Seed

Germination and Differences in Bioavailability During Exposure in Aqueous Suspension and Soil.” *Environ Toxicol* 27, 42–49, 2010.

Evans L.T., “Is Crop Improvement Still Needed ?” *J Crop Improv* 14, 1–7, 2008.

FAO, “The future of food and agriculture trends and challenges.” *Futur Food Agric Trends Challenges* 4, 1951–1960, 2017.

Farooq M., Wahid A., Kobayashi N., Fujita D. B. S. M. A., and Basra S. M. A. “Plant Drought Stress Effects , Mechanisms and Management Review article.” *Sustainable Agriculture* 2009.

Fathi Z., Nejad R. A. K., Mahmoodzadeh H., and Satari T. N. “Investigating of a wide range of concentrations of multi-walled carbon nanotubes on germination and growth of castor seeds ( *Ricinus communis* L .).” *Journal of Plant Protection Research*, 57, 228-236, 2017.

Feizi H., Amirmoradi S., Abdollahi F., and Pour S. J. “Comparative Effects of Nanosized and Bulk Titanium Dioxide Concentrations on Medicinal Plant *Salvia officinalis* L.” *Annu Rev Res Biol Res Artic Annu Rev Res Biol* 3, 814–824, 2013a.

Feizi H., Kamali M., Jafari L., and Moghaddam P. R. “Phytotoxicity and stimulatory impacts of nanosized and bulk titanium dioxide on fennel (*Foeniculum vulgare* Mill).” *Chemosphere* 91, 506–511, 2013b.

Feng B.H., and Zhang Z.Y., “Carboxymethyl chitosan grafted ricinoleic acid group for nanopesticide carriers.” *Adv Mater Res* 236–238, 1783–1788, 2011.

Feynman R.P., “There’s Plenty of Room at the Bottom (reprint from speech given at annual meeting of the American Physical Society).” *Eng Sci* 23, 22–36, 1960.

Finch-savage W.E., and Bassel G.W., “Seed vigour and crop establishment extending performance beyond adaptation.” *J Exp Bot* 67, 567–591, 2016.

Finch-savage W.E. and Footitt S., “Seed dormancy cycling and the regulation of dormancy mechanisms to time germination in variable field environments.” *Journal of experimental botany* 2018.

Finch-savage W.E. and Leubner-metzger G., “Seed dormancy and the control of germination.” *New phytologist* 501–523, 2006.

Finch-savage W.E., Dent K.C. and Clark L.J., “Soak conditions and temperature following sowing influence the response of maize ( *Zea mays* L .) seeds to on-farm priming ( pre-sowing seed soak ).” *Field Crops Research* 90, 361–374, 2004.

Footitt S. and Finch-savage W.E., “Chapter 5 Production of Seed Samples for the Effective Molecular Analysis of Dormancy Cycling in Arabidopsis.” *Seed Dormancy*, 2015.

Footitt S., Douterelo-Soler I., Clay H., and Finch-Savage W. E. “Dormancy cycling in Arabidopsis seeds is controlled by seasonally distinct hormone-signaling pathways.” *Proceeding of the National Academy Science*, 108, 2011.

Galaktionova L. V., Lebedev S. V., Terekhova N. A., Voskobulova N. I., Korotkova A. M., and Vershinina I. A. “Evaluation of the effect of SiO<sub>2</sub> and Fe<sub>3</sub>O<sub>4</sub> nanoparticles on *Pisum sativum* seeds in laboratory and field experiments.” *BioRxiv Plant Biol* 2020.

Gao F., Hong F., Liu C., Zheng L., Su M., Wu X., and Yang P. “Mechanism of nano-anatase TiO<sub>2</sub> on promoting photosynthetic carbon reaction of spinach Inducing complex of Rubisco-Rubisco activase.” *Biol Trace Elem Res* 111, 239–253, 2006.

Gao F., Liu C., Qu C., Zheng L., Yang F., Su M., and Hong F. “Was improvement of spinach growth by nano-TiO<sub>2</sub> treatment related to the changes of Rubisco activase?” *BioMetals* 21, 211–217, 2008.

Garcia-fayos P., and Verdu M., “Soil seed bank , factors controlling germination and establishment of a Mediterranean shrub *Pistucia Zentiscus* L .” *Acta Oecologica* 19, 1998.

Ghoto K., Simon M., Shen Z. J., Gao G. F., Li P. F., Li H., and Zheng H. L. “Physiological and Root Exudation Response of Maize Seedlings to TiO<sub>2</sub> and SiO<sub>2</sub> Nanoparticles Exposure.” *Bionanoscience* 10, 473–485, 2020.

Giraldo J. P., Landry M. P., Faltermeier S. M., McNicholas T. P., Iverson N. M., Boghossian A. A., and Strano M. S. “Plant nanobionics approach to augment photosynthesis and biochemical sensing.” *Nature Materials* 13, 2014.

Giroto A. S., Guimarães G. G., Foschini M., and Ribeiro C. “Role of Slow-Release Nanocomposite Fertilizers on Nitrogen and Phosphate Availability in Soil.” *Sci Rep* 7, 2017.

Gleick P.H., “Water and energy.” *Annual Review of Energy and the environment*, 1994.

Gleick P.H., “Water in crisis Paths to sustainable water use.” *Ecol Appl* 8, 571–579, 1998.

Głodowska M., Husk B., Schwinghamer T., and Smith D. “Biochar is a growth-promoting alternative to peat moss for the inoculation of corn with a pseudomonad.” *Agron Sustain Dev* 36, 1–10, 2016.

Głodowska M., Schwinghamer T., Husk B., and Smith D. “Biochar Based Inoculants Improve Soybean Growth and Nodulation.” *Agric Sci* 08, 1048–1064, 2017.

Gogos A., Knauer K. and Bucheli T.D., “Nanomaterials in plant protection and fertilization Current state, foreseen applications, and research priorities.” *J Agric Food Chem* 60, 9781–9792, 2012.

Gomes-Filho E., Lima C. R. F. M., Costa J. H., da Silva A. C. M., Lima M. D. G. S., de Lacerda C. F., and Prisco J. T. “Cowpea ribonuclease Properties and effect of NaCl-salinity on its activation during seed germination and seedling establishment.” *Plant Cell Rep* 27, 147–157, 2008.

Graeber K. A. I., Nakabayashi K., Miatton E., Leubner-Metzger G. E. R. H. A. R. D., and

Soppe W. J.. “Molecular mechanisms of seed dormancy.” *Plant, Cell & Environment*, 2012.

Greenway H. and Rana M., “Mechanisms of Salt Tolerance in Nonhalophytes.” *Ann Rev Plant Physiol* 31, 149–190, 1980.

Gregg B. and Billups G., "Seed Conditioning". *CRC Press*, New York, 2016.

Gruber P., Marques M. P., Szita N., and Mayr T. “Integration and application of optical chemical sensors in microbioreactors.” *Lab Chip* 17, 2693–2712, 2017.

Guha T., Ravikumar K. V. G., Mukherjee A., Mukherjee A., & Kundu R. "Nanopriming with zero valent iron (nZVI) enhances germination and growth in aromatic rice cultivar (*Oryza sativa* cv. Gobindabhog L.)". *Plant Physiology and Biochemistry*, 127, 403-413, 2018. N

Guzman M., Dille J., & Godet S. “Synthesis and antibacterial activity of silver nanoparticles against gram-positive and gram-negative bacteria.” *Nanomedicine Nanotechnology, Biol Med* 8, 37–45, 2012.

Haghighi M., and da Silva J. A. T., “The effect of N-TiO<sub>2</sub> on tomato, onion, and radish seed germination.” *J Crop Sci Biotechnol* 17, 221–227, 2014.

Hall A.J.L., and Williams L.E., “Transition metal transporters in plants.” *Journal of experimental botany*, 54, 2601–2613, 2003.

Halmer P., Seed Technology and Its Biological Basis. ,Black and Bewley,. *CRC Press*, New York, 2000.

Halmer P, “Seed Technology and Seed Enhancement.” *XXVII International Horticultural Congress-IHC2006: International Symposium on Seed Enhancement and Seedling Production* 17–26, 2006.

Hameeda B., Harini G., Rupela O. P., Rao J. K., and Reddy G. “Biological Control of

Chickpea Collar Rot by Co-inoculation of Antagonistic Bacteria and Compatible Rhizobia.” *Indian J Microbiol* 50, 419–424, 2010.

Han C., and Yang P., “Studies on the molecular mechanisms of seed germination.” *Proteomics* 1–23, 2015.

Haynes C.L., and Duynes R.P. V., “Nanosphere Lithography A Versatile Nanofabrication Tool for Studies of Size-Dependent Nanoparticle Optics.” *J Phys Chem B* 105, 5599–5611, 2001.

Hellmann C., Greiner A., and Wendorff J.H., “Design of pheromone releasing nanofibers for plant protection.” *Polym Adv Technol* 22, 407–413, 2011.

Holdsworth M.J., and Soppe W.J.J., “Molecular networks regulating Arabidopsis seed maturation, after-ripening, dormancy and germination.” *New Phytologist*, 2008.

Hong F., Zhou J., Liu C., Yang F., Wu C., Zheng L., and Yang P., “Effect of Nano-TiO<sub>2</sub> on photochemical reaction of chloroplasts of spinach.” *Biol Trace Elem Res* 105, 269–279, 2005.

Hou Q., Ufer G., and Bartels D., “Lipid signalling in plant responses to abiotic stress.” *Plant, cell & environment*, 1029–1048, 2016.

Huang Z. M., Zhang Y. Z., Kotaki M., and Ramakrishna S., “A review on polymer nanofibers by electrospinning and their applications in nanocomposites.” *Compos Sci Technol* 63, 2223–2253, 2003.

Imran M., Mahmood A., Römheld V., and Neumann G.. “Nutrient seed priming improves seedling development of maize exposed to low root zone temperatures during early growth.” *Eur J Agron* 49, 141–148, 2013.

IPCC, “Climate Change 2007 The Physical Science Basis Summary for Policymakers.” 2007.

Jacob S. R., Kumar M. A., Varghese E., and Sinha S. N. “Hydrophilic polymer film coat as a micro-container of individual seed facilitates safe storage of tomato seeds.” *Sci Hort (Amsterdam)* 204, 116–122, 2016.

Janmohammadi M., Amanzadeh T., Sabaghnia N., and Dashti S. “Impact of foliar application of nano micronutrient fertilizers and titanium dioxide nanoparticles on the growth and yield components of barley under supplemental irrigation.” *Acta Agric Slov* 107, 265–276, 2016.

Joshi A., Kaur S., Dharamvir K., Nayyar H., and Verma G. “Multi-walled carbon nanotubes applied through seed-priming influence early germination, root hair, growth and yield of bread wheat (*Triticum aestivum* L.)” *J Sci Food Agric* 98, 3148–3160, 2018.

Kaewklin P., Siripatrawan U., Suwanagul A., and Lee Y. S., “Active packaging from chitosan-titanium dioxide nanocomposite film for prolonging storage life of tomato fruit.” *Int J Biol Macromol* 112, 523–529, 2018.

Kah M., and Hofmann T., “Nanopesticide research Current trends and future priorities.” *Environ Int* 63, 224–235, 2014.

Kah M, Beulke S, Tiede K, , “Nanopesticides State of knowledge, environmental fate, and exposure modeling.” *Crit Rev Environ Sci Technol* 43, 1823–1867, 2013.

Kah M., Beulke S., Tiede K., and Hofmann T. “A critical evaluation of nanopesticides and nanofertilizers against their conventional analogues.” *Nat Nanotechnol* 13, 677–684, 2018.

Kah M., Tufenkji N., and White J.C., “Nano-enabled strategies to enhance crop nutrition and protection.” *Nat Nanotechnol* 14, 532–540, 2019.

Kalacska M., Lalonde M., and Moore T.R., “Estimation of foliar chlorophyll and nitrogen content in an ombrotrophic bog from hyperspectral data Scaling from leaf to image.” *Remote Sens Environ* 169, 270–279, 2015.

Fenner, M. (Ed.). Seeds: the ecology of regeneration in plant communities. *Cabi*. 2000

Karunakaran G., Suriyaprabha R., Rajendran V., and Kannan N. “Influence of ZrO<sub>2</sub>, SiO<sub>2</sub>, Al<sub>2</sub>O<sub>3</sub> and TiO<sub>2</sub> nanoparticles on maize seed germination under different growth conditions.” *IET Nanobiotechnology* 10, 171–177, 2016.

Kaufman G., “Seed Coating A Tool for Stand Establishment a Stimulus to Seed Quality.” *Horttechnology* 1, 98–102, 1991.

Khajeh-Hosseini M., Powell A.A., and Bingham I.J., “The interaction between salinity stress and seed vigour during germination of soyabean seeds.” *Seed Sc Technol* 32, 715–725, 2003.

Khalaki M.A., Ghorbani A., and Ouri A.E., “*Thymus kotschyanus* L . submitted to potassium silicate nanoparticles , superabsorbent hydrogel , effective microorganisms and animal l.” *Biosci. J.*, 115–125, 2019.

Khalaki M. A., Moameri M., Lajayer B. A., and Astatkie T., “Influence of nano - priming on seed germination and plant growth of forage and medicinal plants.” *Plant Growth Regul* 2020.

Khan M.A., and Rizvi Y., “Effect of salinity, temperature, and growth regulators on the germination and early seedling growth of *Atriplex griffithii* var. *stocksii*.” *Can J Bot* 72, 475–479, 1994.

Khan M.A., Gul B. and Weber D.J., “Action of plant growth regulators and salinity on seed germination of *Ceratoides lanata*.” *Canadian Journal of Botany* 37–42, 2004.

Khater M.S., “Effect of Titanium Nanoparticles (TiO<sub>2</sub>) on Growth, Yield and Chemical Constituents of Coriander Plants.” *Arab J Nucl Sci Appl* 48, 187–194, 2015.

Khodakovskaya M., Dervishi E., Mahmood M., Xu Y., Li Z., Watanabe F., and Biris A. S.. “Carbon nanotubes are able to penetrate plant seed coat and dramatically affect seed germination and plant growth.” *ACS Nano* 3, 3221–3227, 2009.

Khodakovskaya M. V., de Silva K., Nedosekin D. A., Dervishi E., Biris A. S., Shashkov E. V., and Zharov V. P. “Complex genetic, photothermal, and photoacoustic analysis of nanoparticle-plant interactions.” *Proc Natl Acad Sci U S A* 108, 1028–1033, 2011.

Khodakovskaya M. V., De Silva K., Biris A. S., Dervishi E., and Villagarcia H. “Carbon nanotubes induce growth enhancement of tobacco cells.” *ACS Nano* 6, 2128–2135, 2012.

Khodarahmpour Z., and Motamedi M., “Effects of NaCl salinity on maize (*Zea mays* L.) at germination and early seedling stage.” *African Journal of Biotechnology* 11, 298–303, 2012.

Kumari M., Mukherjee A., and Chandrasekaran N., “Science of the Total Environment Genotoxicity of silver nanoparticles in *Allium cepa*.” *Sci Total Environ* 407, 5243–5246, 2009.

Kumpiene J., Lagerkvist A., and Maurice C., “Stabilization of As, Cr, Cu, Pb and Zn in soil using amendments - A review.” *Waste Manag* 28, 215–225, 2008.

Kurepa J., Paunesku T., Vogt S., Arora H., Rabatic B. M., Lu J., and Smalle J. A. “Uptake and Distribution of Ultrasmall Anatase TiO<sub>2</sub> Alizarin Red S Nanoconjugates in *Arabidopsis thaliana*.” *Nano Letters* 2010.

Laby R. J., Kincaid M. S., Kim D., and Gibson S. I., “The *Arabidopsis* sugar-insensitive mutants *sis4* and *sis5* are defective in abscisic acid synthesis and response.” *Plant J* 23, 587–596, 2000.

Lahiani M. H., Dervishi E., Chen J., Nima Z., Gaume A., Biris A. S., and Khodakovskaya M. V. “Impact of carbon nanotube exposure to seeds of valuable crops.” *ACS Appl Mater Interfaces* 5, 7965–7973, 2013.

Lally R. D., Galbally P., Moreira A. S., Spink J., Ryan D., Germaine K. J., and Dowling D. N. “Application of endophytic *Pseudomonas fluorescens* and a bacterial consortium to *Brassica napus* can increase plant height and biomass under greenhouse and field conditions.” *Front Plant Sci* 8, 1–10, 2017.

Lamsal K., Kim S. W., Jung J. H., Kim Y. S., Kim K. S., and Lee Y. S. “Application of silver nanoparticles for the control of Colletotrichum species in vitro and pepper anthracnose disease in field.” *Mycobiology* 39, 194–199, 2011.

Larue C, Laurette J, Herlin-Boime N, , “Accumulation, translocation and impact of TiO<sub>2</sub> nanoparticles in wheat (*Triticum aestivum* spp.) Influence of diameter and crystal phase.” *Sci Total Environ* 431, 197–208, 2012.

Li W., Roberts D. P., Dery P. D., Meyer S. L. F., Lohrke S., Lumsden R. D., and Hebbar K. P. “Broad spectrum anti-biotic activity and disease suppression by the potential biocontrol agent *Burkholderia ambifaria* BC-F.” *Crop Prot* 21, 129–135, 2002.

Li X., Schirmer K., Bernard L., Sigg L., Pillai S., and Behra R. “Silver nanoparticle toxicity and association with the alga *Euglena gracilis*.” *Environ Sci Nano* 2, 594–602, 2015.

Liu R., and Lal R., “Synthetic apatite nanoparticles as a phosphorus fertilizer for soybean (*Glycine max*).” *Sci Rep* 4, 2014.

Liu C., Liu Y., Lu Y., Liao Y., Nie J., Yuan X., and Chen F. “Use of a leaf chlorophyll content index to improve the prediction of above-ground biomass and productivity.” *PeerJ* 2019, 1–15, 2019.

Liu Q., Chen B., Wang Q., Shi X., Xiao Z., Lin J., and Fang X. “Carbon nanotubes as molecular transporters for walled plant cells.” *Nano Lett* 9, 1007–1010, 2009.

Lopisso D.T., Kühlmann V., and Siebold M., “Potential of soil-derived fungal biocontrol agents applied as a soil amendment and a seed coating to control *Verticillium* wilt of sugar beet.” *Biocontrol Sci Technol* 27, 1019–1037, 2017.

Lu M. M., De Silva D. M., Peralta E., Fajardo A., and Peralta M. “Effects of nanosilica powder from rice hull ash on seed germination of tomato (*Lycopersicon esculentum*).” *Philipp e-Journal Appl Res Dev* 5, 11–22, 2015.

Lucy J.A., and Glauert A.M., “Structure and assembly of macromolecular lipid complexes composed of globular micelles.” *J Mol Biol* 8, 727–748, 1964.

Ma X., Geiser-Lee J., Deng Y., and Kolmakov A. “Science of the Total Environment Interactions between engineered nanoparticles ( ENPs ) and plants Phytotoxicity , uptake and accumulation.” *Sci Total Environ* 408, 3053–3061, 2010.

Mahakham W., Theerakulpisut P., Maensiri S., Phumying S., and Sarmah A. K. “Science of the Total Environment Environmentally benign synthesis of phytochemicals-capped gold nanoparticles as nanoprimer agent for promoting maize seed germination.” *Sci Total Environ* 573, 1089–1102, 2016.

Mahakham W., Sarmah A. K., Maensiri S., and Theerakulpisut P. “Nanoprimer technology for enhancing germination and starch metabolism of aged rice seeds using phytosynthesized silver nanoparticles.” *Sci Rep* 7, 1–21, 2017.

Mahdavi S., Kafi M., Fallahi E., Shokrpour M., and Tabrizi L. “Water stress, nano silica, and digoxin effects on minerals, chlorophyll index, and growth in ryegrass.” *Int J Plant Prod* 10, 251–264, 2016.

Malnassy T.G., Physiological and biochemical studies on a treatment hastening the germination of seeds at low temperature, *Rutgers University*, p., 1971.

Man J., Yang Y., Zhang C., Zhang F., Wang Y., Gu M., and Wei C. “Morphology and structural characterization of high-amylose rice starch residues hydrolyzed by porcine pancreatic  $\alpha$ -amylase.” *Food Hydrocoll* 31, 195–203, 2013.

Manchanda G., and Garg E. N., “Salinity and its effects on the functional biology of legumes.” *Acta Phsiol Plant* 30, 595–618, 2008.

Manivannan P., Jaleel C.A., and Somasundaram R., “Osmoregulation and antioxidant metabolism in drought-stressed *Helianthus annuus* under triadimefon drenching.” *Comptens Rengus Biologies* 331, 418–425, 2008.

Mastronardi E., Tsae P., Zhang X., Monreal C., and DeRosa M. C. “Strategic Role of Nanotechnology in Fertilizers Potential and Limitations.” *Nanotechnologies Food Agric* 1–347, 2015.

Mehnert W., and Mader K., “Advances in the Cognitive Neuroscience of Neurodevelopmental Disorders Views from Child Psychiatry and Medical Genetics.” *Neurodev Disord* 47, 165–196, 2001.

Menard A., Drobne D., and Jemec A., “Ecotoxicity of nanosized TiO<sub>2</sub>. Review of in vivo data.” *Environ Pollut* 159, 677–684, 2011.

Mereddy R., “Solid Matrix Priming Improves Seedling Vigor of Okra Seeds.” *Proc Okla Acad Sci* 80, 33–37, 2000.

Mishra V., and Cherkauer K.A., “Agricultural and Forest Meteorology Retrospective droughts in the crop growing season Implications to corn and soybean yield in the Midwestern United States.” *Agric For Meteorol* 150, 1030–1045, 2010.

Moameri M., Alijafari E., and Ghorbani A., “ Effects of nanopriming and biopriming on growth characteristics of *Onobrychis sativa* Lam. under laboratory conditions.” *J Rangel* 12, 101–111, 2018.

Mohanraj V.J., and Chen Y., “Nanoparticles - A review.” *Trop J Pharm Res* 5, 561–573, 2006.

Mohsen Janmohammadi N.S., “Botanica lithuanica.” *Effect Pre-Sowing Sed Treat With Silican Nanoparticles Germination Sunflower (Helianthus Annu* 21, 13–21, 2015.

Moles A.T., and Westoby M., “Seedling survival and seed size a synthesis of the literature.” *Journal of Ecology* 372–383, 2004.

Mozafari M. R., Khosravi-Darani K., Borazan G. G., Cui J., Pardakhty A., and Yurdugul S. “Encapsulation of food ingredients using nanoliposome technology.” *Int J Food Prop* 11, 833–844, 2008.

Müller R.H., Mader K., and Gohla S., “Solid Lipid Nanoparticles (SLN) for Controlled Drug Delivery - a Review of the State of the Art.” *Eur J Pharm Biopharm* 50, 161–177, 2000.

Müller R. H., Petersen R. D., Hommoss A., and Pardeike J., “Nanostructured lipid carriers (NLC) in cosmetic dermal products.” *Adv Drug Deliv Rev* 59, 522–530, 2007.

Murphy B.R., Doohan F.M., and Hodkinson T.R., “A seed dressing combining fungal endophyte spores and fungicides improves seedling survival and early growth in barley and oat.” *Symbiosis* 71, 69–76, 2017.

Nair R., Varghese S. H., Nair B. G., Maekawa T., Yoshida Y., and Kumar D. S. “Nanoparticulate material delivery to plants.” *Plant Sci* 179, 154–163, 2010.

Nair R., Poulouse A. C., Nagaoka Y., Yoshida Y., Maekawa T., and Kumar D. S. “Uptake of FITC labeled silica nanoparticles and quantum dots by rice seedlings Effects on seed germination and their potential as biolabels for plants.” *J Fluoresc* 21, 2057–2068, 2011.

Nel A., Xia T., Mädler L., and Li N., “Toxic potential of materials at the nanolevel.” *Science (80-)* 311, 622–627, 2006.

Nonogaki H., Bassel G.W., and Bewley J.D., “Plant Science Germination — Still a mystery.” *Plant Science* 179, 574–581, 2010.

NTSC, “The National Nanotechnology Initiative strategic plan.” *Natl Sci Technol Counc* 46, 2007.

Nuruzzaman M. D., Rahman M. M., Liu Y., and Naidu R. “Nanoencapsulation, Nano-guard for Pesticides A New Window for Safe Application.” *J Agric Food Chem* 64, 1447–1483, 2016.

Ocsoy I., Paret M. L., Ocsoy M. A., Kunwar S., Chen T., You M., and Tan W. “Nanotechnology in plant disease management DNA-directed silver nanoparticles on graphene oxide as an antibacterial against *Xanthomonas perforans*.” *ACS Nano* 7, 8972–

8980, 2013.

Oloumi H., Mousavi E.A., and Nejad R.M., “Multi-Wall Carbon Nanotubes Effects on Plant Seedlings Growth and Cadmium/Lead Uptake In Vitro.” *Russ J Plant Physiol* 65, 260–268, 2018.

Olszewski M. W., Goldsmith R. S., Guthrie E. K., and Young C. A. “Use of sieved compost plus hydrogel for solid matrix priming of carrot seeds.” *Compost Sci Util* 20, 5–10, 2012.

Oracz K., and Karpiński S., “Phytohormones signaling pathways and ROS involvement in seed germination.” *Front Plant Sci* 7, 1–6, 2016.

Othman Y., Al-Karaki G., Al-Tawaha A. R., and Al-Horani A., “Variation in Germination and Ion Uptake in Barley Genotypes under Salinity Conditions.” *World Journal of Agricultural Sciences* 2006.

Ouda S.M., “ANTifungal Activity of Silver and Copper Nanoparticles on Two Plant Pathogens, *Alternaria alternata* and *Botrytis cinerea*.” *Res J Microbiolgy* 9, 34–42, 2014.

Owolade O.F., and Ogunleti D.O., “Effects of Titanium Dioxide on The Diseases, Development and Yield of Edible Cowpea.” *J Plant Prot Res* 48, 329–336, 2008.

Padhi P., and Pattanayak S.K., “Effect of Lime Coating and Molybdenum Seed Treatment on Nodulation, Growth and Yield of Different Pulses Grown in Alfisols.” *Int J Curr Microbiol Appl Sci* 7, 1417–1426, 2018.

Padilla, F. M., and Pugnaire, F. I. “Rooting depth and soil moisture control Mediterranean woody seedling survival during drought.” *Functional Ecology* 489–495, 2007.

Pandey A.C., Sanjay S.S. and Yadav R.S., “Application of ZnO nanoparticles in influencing the growth rate of *Cicer arietinum*.” *J Exp Nanosci* 5, 488–497, 2010.

Pandey J. K., Swarnkar R. K., Soumya K. K., Dwivedi P., Singh M. K., Sundaram S., and Gopal R., “Silver Nanoparticles Synthesized by Pulsed Laser Ablation as a Potent Antibacterial Agent for Human Enteropathogenic Gram-Positive and Gram-Negative Bacterial Strains.” *Appl Biochem Biotechnol* 174, 1021–1031, 2014.

Pandey, K., Lahiani, M. H., Hicks, V. K., Hudson, M. K., Green, M. J., & Khodakovskaya, M. “Effects of carbon-based nanomaterials on seed germination, biomass accumulation and salt stress response of bioenergy crops.” *PLoS One* 13, 1–17, 2018.

Parera C.A., and Cantliffe D.J., “Presowing Seed Priming.” *Hortic Rev (Am Soc Hortic Sci)* 109–141, 1994.

Parihar P., Singh S., and Singh R., “Effect of salinity stress on plants and its tolerance strategies a review.” *Science and Pollution* 4056–4075, 2015.

Parisi C., Vigani M., and Rodríguez-Cerezo E., “Agricultural nanotechnologies What are the current possibilities?” *Nano Today* 10, 124–127, 2015.

Park S., and Ahn Y.J., “Multi-walled carbon nanotubes and silver nanoparticles differentially affect seed germination, chlorophyll content, and hydrogen peroxide accumulation in carrot (*Daucus carota* L.).” *Biocatal Agric Biotechnol* 8, 257–262, 2016.

Pedrini S., Merritt D. J., Stevens J., and Dixon K. “Seed Coating Science or Marketing Spin ?” *Trends Plant Sci* 22, 106–116, 2016.

Peralta-Videa J. R., Zhao L., Lopez-Moreno M. L., de la Rosa G., Hong J., and Gardea-Torresdey J. L. “Nanomaterials and the environment A review for the biennium 2008-2010.” *J Hazard Mater* 186, 1–15, 2011.

Pereira D.M., Valentão P., and Andrade P.B., “Nano-and microdelivery systems for marine bioactive lipids.” *Mar Drugs* 12, 6014–6027, 2014.

Perlatti B., de Souza Bergo P. L., Fernandes J. B., and Forim M. R. “Polymeric

Nanoparticle-Based Insecticides A Controlled Release Purpose for Agrochemicals.” *Insectic - Dev Safer More Eff Technol* 2013.

Phu D., Du B. D., Van Tam H., and Hien N. Q. “Preparation and Foliar Application of Oligochitosan - Nanosilica on the Enhancement of Soybean Seed Yield.” *Int J Environ Agric Biotechnol* 2, 421–428, 2017.

Rafique R., Arshad M., Khokhar M. F., Qazi I. A., Hamza A., and Virk N. “Growth Response of Wheat to Titania Nanoparticles Application.” *NUST J Eng Sci* 7, 42–46, 2014.

Rafique R., Zahra Z., Virk N., Shahid M., Pinelli E., Park T. J., and Arshad M. “Dose-dependent physiological responses of *Triticum aestivum* L. to soil applied TiO<sub>2</sub> nanoparticles Alterations in chlorophyll content, H<sub>2</sub>O<sub>2</sub> production, and genotoxicity.” *Agric Ecosyst Environ* 255, 95–101, 2018.

Ragaei M. and Hassan Sabry A., “Nanotechnology for Insect Pest Control.” *Int J Sci Technol* 3, 2278–3687, 2014.

Rahimi A., “Seed priming improves the germination performance of cumin (*Cuminum syminum* L.) under temperature and water stress.” *Ind Crops Prod* 42, 454–460, 2013.

Rai M. and Ingle A., “Role of nanotechnology in agriculture with special reference to management of insect pests.” *Appl Microbiol Biotechnol* 94, 287–293, 2012.

Raikwar A., “Seed and seed technology introduction, definition and importance.” *Princ Seed Technol* 1975.

Rajjou L., Duval M., Gallardo K., Catusse J., Bally J., Job C., and Job D. “Seed germination and vigor.” *Annu Rev Plant Biol* 63, 507–533, 2012.

Raju B.B. and Rai P.K., “Studies on effect of polymer seed coating, nanoparticles and hydro priming on seedling characters of Pigeonpea (*Cajanus cajan* L.) seed.” *Journal of Pharmacognosy and Phytochemistry*, 6, 140–145, 2017.

Raliya R., Biswas P., and Tarafdar J.C., “TiO<sub>2</sub> nanoparticle biosynthesis and its physiological effect on mung bean (*Vigna radiata* L.)” *Biotechnol Reports* 5, 22–26, 2015.

Recillas S., García A., González E., Casals E., Puntos V., Sánchez A., and Font X. “Use of CeO<sub>2</sub>, TiO<sub>2</sub> and Fe<sub>3</sub>O<sub>4</sub> nanoparticles for the removal of lead from water. Toxicity of nanoparticles and derived compounds.” *Desalination* 277, 213–220, 2011.

Ren H., Yang L., and Liu N. “Nurse plant theory and its application in ecological restoration in lower subtropics of China.” *Progress in Natural Science* 2008.

Rico C. M., Majumdar S., Duarte-Gardea M., Peralta-Videa J. R., and Gardea-Torresdey J. L. “Interaction of nanoparticles with edible plants and their possible implications in the food chain.” *J Agric Food Chem* 59, 3485–3498, 2011.

Rocha I. D. S., Ma Y., Souza-Alonso P., Vosátka M., Freitas H., and Oliveira R. S. “Seed Coating A Tool for Delivering Beneficial Microbes to Agricultural Crops.” *Frontiers in plant science* 10, 2019.

Roohizadeh G., Majd A., and Arbabian S., “The effect of sodium silicate and silica nanoparticles on seed germination and growth in the *Vicia faba* L .” *Tropical Plant Research* 2, 85–89, 2015.

Ruiz-de-La-Cruz G., Aguirre-Mancilla C. L., Godínez-Garrido N. A., Osornio-Flores N. M., and Torres-Castillo J. A. “Chitosan mixed with beneficial fungal conidia or fungicide for bean (*Phaseolus vulgaris* L.) seed coating.” *Interciencia Rev Cienc y Tecnol América* 42, 307–312, 2017.

Saad A.I.M. and Elshahed A.M., “We are IntechOpen , the world ’ s leading publisher of Open Access books Built by scientists , for scientists TOP 1 %.” *Intech* i, 38, 2012.

Sabaghnia N., and Janmohammadi M., “Graphic Analysis of Nano-Silicon by Salinity Stress Interaction on Germination Properties of Lentil Using The Biplot Method.” *Agric For* 60, 29–40, 2014.

Sánchez-gómez D., Valladares F., and Zavala M.A., “Performance of seedlings of Mediterranean woody species under experimental gradients of irradiance and water availability trade-offs and evidence for niche differentiation.” *New phytologist* 795–806, 2005.

Saupe A., and Rades T., “Solid lipid nanoparticles.” *Nanocarrier Technol Front Nanotherapy* 9781402050, 41–50, 2006.

Schupp E.W., “Seed-Seedling Conflints, Habitat Choice, and Patterns of Plant Recruitment.” *Am J Bot* 82, 399–409, 1995.

Scognamiglio V., “Nanotechnology in glucose monitoring Advances and challenges in the last 10 years.” *Biosens Bioelectron* 47, 12–25, 2013.

Scott J.M., “Seed Coatings and Treatments and Their Effects on Plant Establishment.” *Adv Agron* 42, 43–83, 1989.

Sharma A.D., Rathore S.V.S., Srinivasan K., and Tyaki R.K., “Comparison of various seed priming methods for seed germination, seedling vigour and fruit yield in okra (*Abelmoschus esculentus* L. Moench).” *Sci Hortic (Amsterdam)* 165, 75–81, 2013.

Sharp R. E., Poroyko V., Hejlek L. G., Spollen W. G., Springer G. K., Bohnert H. J., and Nguyen H. T. “Root growth maintenance during water deficits physiology to functional genomics \*.” *Journal of experimental botany*, 55, 2343–2351, 2004.

Shen C. X., Zhang Q. F., Li J., Bi F. C., and Yao N. “Induction of programmed cell death in Arabidopsis and rice by single-wall carbon nanotubes.” *American Journal of Botany* 97, 1602–1609, 2010.

Siddique A., and Bose B., “Nitrate-hardened Seeds Increase Germination, Amylase Activity and Proline Content in Wheat Seedlings at Low Temperature.” *Physiol Mol Biol* 13, 199–207, 2007.

Siddiqui M.H., and Al-Wahaibi M.H., “Role of nano-SiO<sub>2</sub> in germination of tomato

(*Lycopersicum esculentum* seeds Mill.)” *Saudi J Biol Sci* 21, 13–17, 2014.

Siddiqui M.H., Firoz M.H.A. and Impact T., " Role of nano-SiO<sub>2</sub> in germination of tomato (*Lycopersicum esculentum* seeds Mill.) " *Nanotechnology and Plant Sciences*. 2015.

Singh A., Jain A., Sarma B. K., Upadhyay R. S., and Singh H. B. “Rhizosphere competent microbial consortium mediates rapid changes in phenolic profiles in chickpea during *Sclerotium rolfsii* infection.” *Microbiol Res* 169, 353–360, 2014.

Slomberg D.L., and Schoenfisch M.H., “Silica nanoparticle phytotoxicity to *Arabidopsis thaliana*.” *Environ Sci Technol* 46, 10247–10254, 2012.

Sobolev K., and Gutiérrez M.F., “How nanotechnology can change the concrete world.” *Am Ceram Soc Bull* 84, 14–18, 2005.

Song J., Zhou J., Zhao W., Xu H., Wang F., Xu Y., and Tian C. “Effects of salinity and nitrate on production and germination of dimorphic seeds applied both through the mother plant and exogenously during germination in *Suaeda salsa*.” *Plant Species Biol* 31, 19–28, 2016.

Song U., Jun H., Waldman B., Roh J., Kim Y., Yi J., and Lee E. J. “Functional analyses of nanoparticle toxicity A comparative study of the effects of TiO<sub>2</sub> and Ag on tomatoes (*Lycopersicon esculentum*).” *Ecotoxicol Environ Saf* 93, 60–67, 2013a.

Srivastava A., and Rao D.P., “Enhancement of plant growth using multiwalled carbon nanotubes "Enhancement Of Seed Germination And Plant Growth Of Wheat, Maize, Peanut And Garlic Using Multiwalled Carbon Nanotubes.” *Chem Bull* 3, 502–504, 2014.

Susu A. H., Lin K. F., Zhang W., Xu S. Y., Yang S. S., Zhang M., Zhang L. Y. Ai-hua, and Mei Z.L., “Effect of Nano-TiO<sub>2</sub> on the Germination and Growth of Rape Seed.” *J Agro-Environment Sci* 2009.

Sun D., Hussain H. I., Yi Z., Rookes J. E., Kong L., and Cahill D. M. “Mesoporous silica nanoparticles enhance seedling growth and photosynthesis in wheat and lupin.”

*Chemosphere* 152, 81–91, 2016.

Suriyaprabha R., Karunakaran G., Yuvakkumar R., Rajendran V., and Kannan N., “Silica Nanoparticles for Increased Silica Availability in Maize (*Zea mays*. L) Seeds Under Hydroponic Conditions.” *Curr Nanosci* 8, 902–908, 2012.

Szabolcs I., and Julius F., Salt affected soils in Europe. *The Hague* 1974.

Tamjidi F., Shahedi M., Varshosaz J., and Nasirpour A., “Nanostructured lipid carriers (NLC) A potential delivery system for bioactive food molecules.” *Innov Food Sci Emerg Technol* 19, 29–43, 2013.

Tan X., and Fugetsu B., “Multi-Walled Carbon Nanotubes Interact with Cultured Rice Cells Evidence of a Self-Defense Response.” *Journal of Biomedical nanotechnology*, 3, 285–288, 2007.

Tan X. M., Lin C., and Fugetsu B., “Studies on toxicity of multi-walled carbon nanotubes on suspension rice cells.” *Carbon N Y* 47, 3479–3487, 2009.

Tavili A., Zare S., Moosavi S. A., and Enayati A., “Effects of seed priming on germination characteristics of Bromus species under salt and drought conditions” *Am J Agric Environ Sci* 10, 163–168, 2011.

Taylor A., Klein D.E., and Whitlow T.H., “SMP Solid Matrix Priming of Seeds.” *Sci Hortic (Amsterdam)* 37, 1–11, 1988.

Tian F., Chen W., Cai E. W., Kou X., Fan G., Li T., and Wu Z., “Preservation of Ginkgo biloba seeds by coating with chitosan/nano-TiO<sub>2</sub> and chitosan/nano-SiO<sub>2</sub> films.” *Int J Biol Macromol* 126, 917–925, 2019.

Ugoji E.O., Laing M.D., and Hunter C.H., “An investigation of the shelf-life (storage) of Bacillus isolates on seeds.” *South African J Bot* 72, 28–33, 2006.

Usman M., Farooq M., Wakeel A., Nawaz A., Cheema S. A., Rehman H., and Sanaullah

M. “Science of the Total Environment Nanotechnology in agriculture Current status , challenges and future opportunities.” *Sci Total Environ* 721, 137778, 2020.

Vishal B., and Kumar P.P., “Regulation of Seed Germination and Abiotic Stresses by Gibberellins and Abscisic Acid.” *Frontiers in Plant Science* 9, 2018.

Wang W., Vinocur B., and Altman A., “Plant responses to drought , salinity and extreme temperatures towards genetic engineering for stress tolerance.” *Planta* 218, 1–14, 2003.

Wang X., Han H., Liu X., Gu X., Chen K., and Lu D. “Multi-walled carbon nanotubes can enhance root elongation of wheat (*Triticum aestivum*) plants.” *J Nanoparticle Res* 14, 2012.

Wang Y., Wang D., Shi P., and Omasa K., “Estimating rice chlorophyll content and leaf nitrogen concentration with a digital still color camera under natural light.” *Plant Methods* 10, 1–11, 2014.

Wanyika H., “Sustained release of fungicide metalaxyl by mesoporous silica nanospheres Nanotechnology for Sustainable Development.” *J Nanoparticle Res* 15, 2013.

Watanabe T., Misawa S., Hiradate S., and Osaki M., “Root mucilage enhances aluminum accumulation in *Melastoma malabathricum*, an aluminum accumulator.” *Plant Signaling and Behavior*, 7–10, 2008.

Wissing S.A., Kayser O., and Müller R.H., “Solid lipid nanoparticles for parenteral drug delivery.” *Adv Drug Deliv Rev* 56, 1257–1272, 2004.

Wu M. Y., Hao R. C., Tian X. H., Wang X. L., Ma G. H., and Tang H. T. “Effect of adding Nano-carbon in slow-released fertilizer on grain yield and nitrogen use efficiency of super hybrid rice.” *Hybrid Rice* 4, 2010.

Xie Y., Li B., Tao G., Zhang Q., and Zhang C. “Effects of nano-silicon dioxide on photosynthetic fluorescence characteristics of *Indocalamus barbatus* McClure.” *J Nanjing For Univ* 36, 59–63, 2012.

Xiong L., and Zhu J., “Molecular and genetic aspects of plant responses to osmotic stress.” *Plant, Cell & Environment* 2002.

Xu S., Hu B., He Z., Ma F., Feng J., Shen W., and Yang J., “Enhancement of Salinity Tolerance during Rice Seed Germination by Presoaking with Hemoglobin.” *International Journal of Molecular Sciences*, 2488–2501, 2011.

Yang F., Hong F., You W., Liu C., Gao F., Wu C., and Yang P. “Influences of nano-anatase TiO<sub>2</sub> on the nitrogen metabolism of growing spinach.” *Biol Trace Elem Res* 110, 179–190, 2006.

Yang F., Liu C., Gao F., Su M., Wu X., Zheng L., and Yang P. “The improvement of spinach growth by nano-anatase TiO<sub>2</sub> treatment is related to nitrogen photoreduction.” *Biol Trace Elem Res* 119, 77–88, 2007.

Yang Y., Qin Z., Zeng W., Yang T., Cao Y., Mei C., and Kuang Y. “Toxicity assessment of nanoparticles in various systems and organs.” *Nanotechnol Rev* 6, 279–289, 2017.

Young J.A., and Martens E., “Importance of hypocotyl hairs in germination of Artemisia seeds.” *Rangeland Ecology & Management/Journal of Range Management Archives* 44, 438–442, 1991.

Younis M.E., and Heikal Y.M., “South African Journal of Botany Nanoprimering technology enhances vigor and mitotic index of aged Vicia faba seeds using chemically synthesized silver nanoparticles.” *South African J Bot* 125, 393–401, 2019.

Zhang X., Zhang J., Quan J., Wang N., and Zhu Y. “Surface-enhanced Raman scattering activities of carbon nanotubes decorated with silver nanoparticles.” *Analyst* 141, 5527–5534, 2016.

Zheng L., Hong F., Lu S., and Liu C.. “Effect of nano-TiO<sub>2</sub> on strength of naturally aged seeds and growth of spinach.” *Biol Trace Elem Res* 104, 83–91, 2005.

Zhu J., “Plant salt tolerance.” *Trends Plant Sci* 6, 66–71, 2001.



## CURRICULUM VITEA

Ayten Kübra YAGIZ was born in Bolu, 1988. She completed higher education in Niğde Anadolu Öğretmen Lisesi in 2006. Later on, she completed her B.Sc. in İstanbul Technical University on Molecular Biology and Genetics in 2011 and M.Sc. On biomaterials in same university in 2014. She enrolled in Graduate School of Natural and Applied Sciences, Department of Agricultural Genetic Engineering at Niğde Ömer Halisdemir University to pursue her Ph.D. education under the supervision of Prof. Dr. Mehmet Emin ÇALIŞKAN in 2014. During her Ph.D. thesis she is working on nanoparticle applications on seed germination and seedling development. She is currently working as research assistant in same department since 2015.



