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# EFFECT OF PRE-SOWING SEED TREATMENTS WITH SILICON NANOPARTICLES ON GERMINABILITY OF SUNFLOWER (*HELIANTHUS ANNUUS*)

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**Abstract**

Janmohammadi M., Sabaghnia N., 2015: Effect of pre-sowing seed treatments with silicon nanoparticles on germinability of sunflower (*Helianthus annuus*) [Silicio nanodalelių įtaka tikrosios saulėgrąžos (*Helianthus annuus*) daigumui, sėklas apdorojant prieš sėją]. – Bot. Lith., 21(1):13–21.

Silicon is one of the most widespread macro elements that have beneficial effects on plant growth. Although its positive effects on plant growth and development have been widely considered, little information is available about possibility of nano-silicon utilization in seed invigoration treatments. Enhanced seed germination may lead to improved stand establishment and it can play important role in successful crop production. Partial *hydration* of the seeds followed by *dehydration* in a *controlled* environment often results in rapid seed germination and more uniform seedling emergence compared to untreated seeds. In the present study, the effect of seed soaking in different *concentration nano-silicon solutions* (0, 0.2, 0.4, 0.6, 0.8, 1 and 1.2 mM for 8 h) on germination characteristics of sunflower was investigated. Seed soaking in low concentration *nano-silicon solutions (*0.2 and 0.4 mM*) significantly* reduced days to 50% germination and mean germination time and improved root length, mean daily germination, seedling vigour index and final germination percentage. These results suggest that the incorporation of nano-silicon in priming solution, in an appropriate concentration, remarkably enhances germination performance and causes an effective invigoration of the seedling. These results underline the importance of pre-sowing seed soaking in diluted *nano-silicon* solutions for improving the germinability of sunflower.

**Keywords:** germination rate, nano-sized, seed priming, seedling vigour.

## INTRODUCTION

Sunflower (*Helianthus annuus* L.) is a major source of vegetable oil in the world. The main producing countries or areas are the Ukraine (Kirovograd, Xar'kov and Dnepropetrovsk regions), Russia, Argentina, China, Romania, Hungary, Bulgaria and France. However, Turkey, Morocco, Pakistan, Iran, Iraq and Sudan are the principal producers of the oil *type sunflower seeds* in semiarid region of West Asia and North Africa (WANA). It has been estimated that world production of sunflower seeds exceeds 37 *million tons* from an area of 25 *million* ha land (Faostat, 2012). The annual production of the oil *type sunflower* seeds in Iran are near to 90.000 tons, which is achieved from 68.000 ha (Faostat, 2012). Under dryland farming of WANA, sunflower frequently experience terminal drought and heat stress due to low and uncertain rainfall as well as high temperatures resulting in low and unstable yields. In semiarid region the invigorated and prompt germination is fundamental for achieving a satisfactory crop establishment and better productivity, but several environmental restrictions are great barriers. *In WANA* rainfed *areas*, particularly in the dominant *Mediterranean*-type *climate*, early sowing, rapid seedling establishment and vigorous development can considerably hasten plant growth and may avoid the facing of critical periods/*stages* of *development* with terminal drought and high temperature stress (Janmohammadi et al., 2013).

Poor crop establishment was identified as a major constraint on rainfed crop production (Harris et al., 1999). In this context, it seems that seed priming as one of the seed invigoration strategies would improve seed germination, plant growth, and crop yield (Ashraf & Foolad, 2005). Pre-sowing seed treatments or seed priming performed by various approaches and methods enhances pre- and post-germination activities. Priming is adjusting the hydration level within seeds to permit seedlings to emerge more rapidly and to facilitate the *uniform seedling* stand (Basra et al., 2006; Hu et al., 2005). The main principle of pre-sowing seed treatments is a controlled seed hydration to a point, where germination processes are started, but not fulfilled. Most priming treatments involve imbibing seed with constrained amounts of water to allow adequate hydration and progress of biochemical processes, but preventing the protuberance of the radicle (Ashraf & Foolad, 2005). In respect of the pre-sowing seed treatments effect, Wahid et al. (2008) concluded that priming of sunflower achenes with hydrogen peroxide ($H_2O_2$), salicylic acid, thiourea, gibberellic acid was the best for vigour enhancement compared to other salts and simple hardening.

In recent years, nanomaterials are becoming an increasingly important issue in agriculture, particularly as additives, growth stimulators, agents in fertilizers and plant protection products. It appears that the utilization of *nano-sized particles* in agriculture could increase efficiency and lead to more environmentally sound applications. Previous studies showed the potential of nanomaterials in improving seed germination and seedling early growth (Zheng et al., 2005; Siddiqui & Al-whaibi, 2014; Sabaghnia & Janmohammadi, 2014; Sabaghnia & Janmohammadi, 2015).

Agricultural utilization of nanoparticles is currently an attractive area of interest. Nanoparticles can easily enter into plant system by overcoming the cell wall barrier in comparison with bulk materials. They have achieved greater consideration because of their highly reactive surface-to-volume ratio property. However, behaviour of nanoparticles inside the plant system is really unpredictable (Nair et al., 2011). Recently, between the various nanomaterials there were lots of interests in effect of nano-silicon on plant growth. It is probably due to its beneficial effects on plant growth and production. Silicon is the second most abundant mineral element in the soil and has been recognized as a beneficial nutrient for plant growth and development (Liang et al., 2007). Silicon also can activate some defence mechanisms. It appears that silicon has an important function in plant protection, because it is deposited on the walls of epidermis and vascular tissues and it plays an important role as a physicomechanical barrier (Ma & Yamaji, 2008), and also regulate some physiological processes related to defence mechanisms in plants (Bao-shan et al., 2004).

Given the beneficial effects of the silicon on germination and seedling growth, seed prehydration in *solution* of *nano-silicon* can be considered as a seed vigour enhancement treatment. Although the earlier works revealed that some advantages are associated with priming treatments for seed vigour improvement, there is dearth of information about the germination performance of primed achenes of sunflower with nanomaterials. Therefore, it was essential to evaluate the application of *nano-silicon* in order to improve sunflower seed germination capability. The purpose of this investigation was to evaluate the effect of seed priming in *nano-silicon* solution on seed germination performance of sunflower to find out the most promising concentration.

## MATERIALS AND METHODS

Achenes of sunflower (*Helianthus annuus* L., cv. Azargol) were purchased from Dryland Agricultural Research Institute (DARI), Iran. Seeds were kept in a dry place in the dark at room temperature before use. Before germination, the achenes were immersed in a 5% sodium hypochlorite solution for 10 min to ensure surface sterility, then washed with distilled water for three times.

Pre-hydration treatments were including control (non-primed seeds) and achenes soaking in *solutions* containing different *concentrations* of *nano-silicon* (0.2, 0.4, 0.6, 0.8, 1 and 1.2 mM for 8 h). *Nano-*

*silicon* ($nSiO_2$) was purchased from the Pishgaman Nano, Iran. Specific surface area of *nano-silicon* was 180–600 $m^2 \cdot g^{-1}$ and purity was 99.7%. The result of X-ray analysis and the high-resolution transmission electron microscopy (HRTEM) image of the $SiO_2$ (Fig. 1), provided by the Pishgaman Nano, testified that the particle sizes are in the range of nano. According to the manufacturer, the particle sizes of $SiO_2$ ranged from 20 to 30 nm.

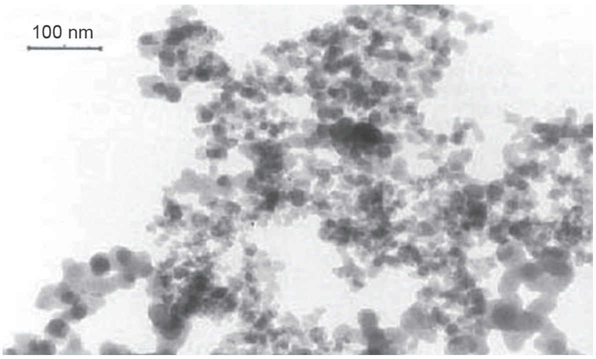


Fig. 1. Large area TEM image of silica nanoparticles

After pre-soaking, both primed and non-primed (control) seeds were washed with distilled water, then allowed to air dry for 48 h at 25ºC (Iqbal & Ashraf, 2007). A completely randomized experimental design was used for the germination test, with three replications and 90 seeds per replication (30 seeds in each Petri dish as an experimental unit (subsample). Primed achenes were placed on 9 cm Petri dishes between sheets of paper (two sheets under and one on the seeds) and wetted with 10 ml sterilized distilled water. Germination and seedling growth performed in a dark incubator at 20 ± 1°C and germinated seeds were recorded daily for eight days. Germination was considered to have occurred when the seed developed at least 2 mm long radicle. The final germination percentage was calculated based on total number of germinated seeds at the end of tenth day. The all evaluations were executed as described in Seedling Evaluation Handbook (Aosa, 1991). Mean germination time (MGT) was computed after Ellis & Roberts (1981) as $MGT = \Sigma T_i N_i / \Sigma N_i$, where $N_i$ is the number of newly germinated seeds at time $T_i$. Germination index was calculated as follows: $GI = \Sigma (G_t/T_t)$, where $G_t$ is the number of seeds germinated on day t and $T_t$ is the number of days from the beginning of germination test (Hu et al., 2005). The seed lot having greater germination index is considered to be more vigorous.

Mean daily germination (MDG) was calculated as the cumulative percentage of full seed germination at the end of the test and divided by the number of days from sowing to the end of the test. The time to 50% germination ($T_{50}$) was calculated according to the formula of Farooq et al. (2005) as follows: $T_{50} = t_i + (t_j - t_i) \times (N/2 - n_i) / (n_j - n_i)$, where N is the final number of germination and $n_i$, $n_j$ – cumulative number of seeds germinated by adjacent counts at times $t_i$ and $t_j$, when $ni < N/2 < nj$. Seedling vigour index based on the length (SVIL) was calculated following modified formula of Abdual-Baki & Anderson (1973); SVIL = seedling length (cm) × germination percentage. Seedling vigour index based on the weight was computed as SVIW = SDM × G%, where SDM is seedling dry mass at the end of test and G% is the final germination percentage. Energy of germination (EG) was calculated four days after the start of the experiment. It is the percentage of germinating seeds four days after planting relative to the total number of seeds tested (Ruan et al., 2002). The fresh weight of seedling roots and shoots was determined by weighing the roots and the shoots separately on electric balance. After the fresh weight was taken, the seedlings were kept in a hot air oven at 60°C for 48 h and then the weight of dry matter was recorded. Data were subjected to the analysis of variance (ANOVA) procedures, and the LSD test was applied at 5% probability level to compare the differences between treatment means.

## RESULTS

A significant ($p < 0.01$) effect of achene pre-hydration treatments was seen on the final germination percentage (GP). Mean comparison revealed that pre-hydration in solutions containing 0.2, 0.4 and 0.6 mM *nano-silicon* cause a slight increase in final germinal percentage, while high concentrations of *nano-silicon* noticeably reduced the germination percentage (Table 1). Evaluation of mean daily germination (MDG) showed that priming treatments have significant effect on this trait. The response of MDG against pre-hydration treatments was relatively similar to GP, so the best performance was recorded for achenes pre-hydrated in solutions at low concentrations of *nano-silicon*. High germination index (GI) shows the *vigorous germination*. Statistical analysis showed that achene pre-hydration in *nano-silicon* solution could considerably affect the GI. The highest value of this trait was recorded in achenes primed in 0.2 mM *nano-silicon* solution. However, priming at higher concentration of *nano-silicon* could not improve this parameter and even achenes primed at 1.0 mM concentration showed the lowest value of GI (Table 1). Assessment of mean germination time (MGT) revealed that achene priming in 0.2, 0.4 and 0.8 mM *nano-silicon* solutions could appreciably reduce the MGT as compared to intact achenes. However, the highest value of MGT was related to priming at 1.0 mM concentration. This trend also was recognizable by examining the $T_{50}$. Generally, achenes primed in low concentration *nano-silicon* solution could finish their germination in a closer spread of times. Variance analysis showed a significant effect of priming treatments on energy of germination (EG). Mean comparison revealed that priming of achenes in high concentration *nano-silicon* solution reduced the EG compared to control achenes (Table 1).

The results showed that pre-hydration treatment of achenes before germination significantly influenced performance of seedling growth by improving root length, shoot length, shoot dry mass, root dry

Table 1. Effect of seed priming in *colloid solution* of silica *nanoparticles* on seed germination characteristics of sunflower (*Helianthus annuus* L.)

| Nano-silica Concentration (mM) | GP | MDG | GI | MGT | $T_{50}$ | EG |
|---|---|---|---|---|---|---|
| Control | 80.33$^{ab}$ | 13.05$^{ab}$ | 8.56$^{c}$ | 2.52$^{bc}$ | 1.71$^{b}$ | 73.33$^{a}$ |
| 0.2 | 91.67$^{a}$ | 15.27$^{a}$ | 12.55$^{a}$ | 2.13$^{c}$ | 0.38$^{c}$ | 78.33$^{a}$ |
| 0.4 | 90.00$^{a}$ | 15.00$^{a}$ | 11.24$^{ab}$ | 2.49$^{cb}$ | 0.57$^{c}$ | 78.33$^{a}$ |
| 0.6 | 85.00$^{a}$ | 14.17$^{ab}$ | 8.74$^{cb}$ | 2.92$^{b}$ | 1.80$^{ab}$ | 78.33$^{a}$ |
| 0.8 | 78.33$^{ab}$ | 13.05$^{ab}$ | 8.32$^{c}$ | 2.80$^{cb}$ | 1.85$^{ab}$ | 58.33$^{a}$ |
| 1.00 | 33.33$^{c}$ | 5.55$^{c}$ | 2.19$^{d}$ | 3.99$^{a}$ | 2.18$^{a}$ | 20.00$^{b}$ |
| 1.2 | 65.00$^{b}$ | 10.83$^{b}$ | 8.26$^{c}$ | 2.23$^{bc}$ | 2.09$^{ab}$ | 58.33$^{a}$ |
| Level of significance | ** | ** | ** | ** | ** | ** |
| CV% | 16.49 | 16.51 | 17.30 | 15.71 | 17.06 | 18.32 |

GP: germination percentage, MDG: mean daily germination (%), GI: germination index (number of seeds germinated. day$^{-1}$), MGT: mean germination time (day), $T_{50}$: days to 50% germination, EG: energy of germination (%). In a column, figures with the same letter (s) do not differ significantly, whereas figures with dissimilar letter are statistically different. * = Significant at 5% level of probability, ** = Significant at 1% level of probability. CV: Coefficient of Variation

Table 2. Impact of pre-sowing seed treatment via the *solution* of silica *nanoparticles* on seedling growth of sunflower (*Helianthus annuus* L.)

| Nano-silica concentration (mM) | RL | SL | SDM | RDM | SVIL | SVIW |
|---|---|---|---|---|---|---|
| Control | 1.08$^{c}$ | 7.58$^{c}$ | 57.00$^{cd}$ | 16.00$^{b}$ | 6881$^{bcd}$ | 5718$^{bc}$ |
| 0.2 | 3.15$^{ab}$ | 13.37$^{a}$ | 86.67$^{a}$ | 27.66$^{a}$ | 15185$^{a}$ | 10562$^{a}$ |
| 0.4 | 3.36$^{a}$ | 10.55$^{ab}$ | 82.33$^{ab}$ | 30.00$^{a}$ | 12527$^{ab}$ | 10110$^{a}$ |
| 0.6 | 2.08b$^{c}$ | 8.01$^{abc}$ | 63.33$^{bc}$ | 16.32$^{b}$ | 9021$^{abc}$ | 6808$^{b}$ |
| 0.8 | 1.99$^{c}$ | 6.35$^{cb}$ | 60.66$^{dc}$ | 11.00$^{b}$ | 6806$^{bcd}$ | 5558$^{bc}$ |
| 1.00 | 1.58$^{c}$ | 3.80$^{c}$ | 47.00$^{cd}$ | 13.66$^{b}$ | 1759$^{d}$ | 1947$^{d}$ |
| 1.2 | 1.43$^{c}$ | 4.80$^{c}$ | 42.66$^{d}$ | 9.33$^{b}$ | 4375$^{cd}$ | 3320$^{cd}$ |
| Level of significance | ** | * | ** | ** | ** | ** |
| CV% | 21.89 | 30.39 | 17.49 | 27.48 | 24.85 | 22.93 |

RL: root length (cm), SL: shoot length (cm), SDW: shoot dry mass (mg), RDW: root dry mass (mg), SVIL: seedling vigour index based on length (cm × %), SVIW: seedling vigour index based on weight (mg × %). In a column, figures with the same letter (s) do not differ significantly, whereas figures with dissimilar letter are statistically different. * = Significant at 5% level of probability, ** = Significant at 1% level of probability mass and seedling vigour index (Table 2). The investigation of root length indicated that achene priming in low concentration *nano-silicon* solution could create the longest roots. However, the shortest roots were related to un-primed and primed achenes in high concentration *nano-silicon* solution (Table 2). Also a significant ($p < 0.05$) effect of achene pre-hydration treatments was seen on the shoot length and response trend was similar to the status described for the root length. Shoot dry mass (SDM) was significantly affected by priming treatments ($p < 0.01$). Increasing *nano-silicon* concentration resulted in a decrease of SDW (Table 2). However, the evaluation of root dry mass (RDM) indicated that significant differences were only recorded for achenes primed in low concentration *nano-silicon solution* (0.2 and 0.4 mM). Mean comparison of both seedling vigour indices suggested that the best performance was related to achenes primed in 0.2 mM solution of *nano-silicon*. This status was more evident in SVIL.

Principle component analysis (PCA) described a suitable amount of the total variation; the correlation coefficient between any two traits is approximated by the cosine of the angle between their vectors. In Fig. 2, the most prominent relations are: a strong positive association between mean daily germination, germination index, energy of germination and germination percentage; between shoot length; between shoot dry mass, root dry mass and root length as indicated by the small obtuse angles between their vectors (r = cos 0° = +1). There was a negative correlation between root length, root dry mass, shoot dry weight and $T_{50}$ (Fig. 2) as indicated by the near perpendicular vectors (r = cos180° = -1). However, an insignificant correlation was found between these traits and mean germination time as indicated by the near perpendicular vectors (r = cos90° = 0). Relationship between different germination characters was studied through Pearson's correlation coefficients (Table 3). A significant positive correlation was found between mean daily germination, germination percentage and

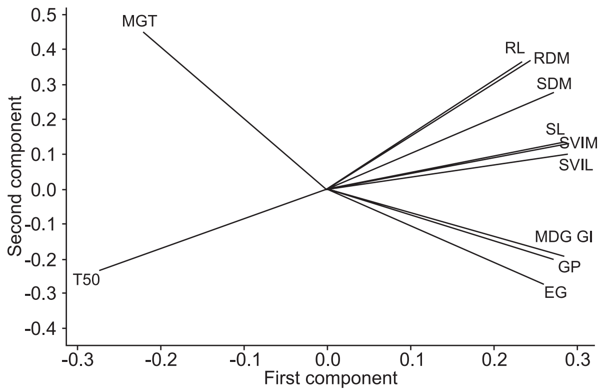


Fig. 2. The principle component analysis (PCA) for germination traits of sunflower after priming with *silica nanoparticles solution*. GP: germination percentage, MDG: mean daily germination, GI: germination index, MGT: mean germination time, $T_{50}$: days to 50% germination, EG: energy of germination, RL: root length, SL: shoot length, SDW: shoot dry mass, RDW: root dry mass, SVIL: seedling vigour index based on length, SVIW: seedling vigour index based on weight

Table 3. Pearson's correlation coefficients between different germination and seedling growth characteristics of sunflower

| | GP | MDG | GI | MGT | T50 | RL | SL | EG | SDM | RDM | SVIL |
|---|---|---|---|---|---|---|---|---|---|---|---|
| MDG | 0.99 | | | | | | | | | | |
| GI | 0.95 | 0.95 | | | | | | | | | |
| MGT | -0.79 | -0.79 | -0.89 | | | | | | | | |
| $T_{50}$ | -0.70 | -0.70 | -0.81 | 0.55 | | | | | | | |
| RL | 0.58 | 0.58 | 0.66 | -0.32 | -0.89 | | | | | | |
| SL | 0.81 | 0.81 | 0.87 | -0.61 | -0.95 | 0.80 | | | | | |
| EG | 0.97 | 0.97 | 0.92 | -0.81 | -0.63 | 0.46 | 0.76 | | | | |
| SDM | 0.76 | 0.76 | 0.79 | -0.44 | -0.96 | 0.90 | 0.96 | 0.66 | | | |
| RDM | 0.57 | 0.57 | 0.65 | -0.34 | -0.95 | 0.87 | 0.88 | 0.53 | 0.92 | | |
| SVIL | 0.87 | 0.87 | 0.91 | -0.64 | -0.94 | 0.84 | 0.99 | 0.81 | 0.96 | 0.86 | |
| SVIW | 0.87 | 0.87 | 0.89 | -0.61 | -0.95 | 0.86 | 0.97 | 0.81 | 0.97 | 0.89 | 0.99 |

GP: germination percentage, MDG: mean daily germination, GI: germination index, MGT: mean germination time, $T_{50}$: days to 50% germination, EG: energy of germination, RL: root length, SL: shoot length, SDW: shoot dry mass, RDW: root dry mass, SVIL: seedling vigour index based on length, SVIW: seedling vigour index based on weight. Critical values of correlation $p < 0.05$ and $p < 0.01$ (D.F. 5) are 0.75 and 0.87, respectively energy of germination (r ≥ 0.90; $p < 0.01$). MGT and $T_{50}$ negatively correlated with other evaluated traits. There was a significant positive correlation between SVIL and SVIW.

## DISCUSSION

The current study revealed that achenes soaking in *nano-silicon* solution resulted in vigour enhancement. The fastest and most uniform germination was observed in achenes primed in 0.2 and 0.4 mM *nano-silicon solution*. Lower $T_{50}$ and MGT indicated earlier and fast germination, while higher GI and EG demonstrated more vigorous germination. These results confirm the earlier study on improved percent seed germination, mean germination time, seed germination index, seed vigour index, seedling fresh weight and dry mass by utilization of *nano-silicon* in germination medium of tomato (Siddiqui & Al-Whaibi, 2014).

The results of this experiment showed that proper implementation of priming treatment could significantly *invigorate and* accelerate seed germination and seedling growth. However, all priming treatments are not always effective. Water uptake by a dry seed identifies three major phases of germination: phase 1 is characterized by the imbibition of water into seeds according to the difference in water potential; phase 2 is a lag phase in which there is little water uptake, but considerable metabolic activity, and is characterized by enzyme synthesis and activation; phase 3 is noticeable by an enhance in water content coinciding with root growth and emergence (Ashraf & Foolad, 2005). The improvement of germination in primed seeds might be the consequence of optimal pre-hydration and passing the first and second stages. Our results revealed that achenes soaking in high concentration *nano-silicon* solutions (0.8, 1 and 1.2 mM) not only could not improve germination, but also resulted in the reduction of seedling growth compared to untreated seeds. This suggests that the mentioned two steps are not well performed at high concentrations. The present findings seem to be consistent with other research, which found that the beneficial influences of the *nano-silicon* are more pronounced at low concentrations (Sabaghnia & Janmohammadi, 2014; Haghighi et al., 2012). However, contrary trend has been reported by Siddiqui & Al-Whaibi (2014), who indicated that parameters of seed germination increase with the increasing of the levels of *nano-silicon* up to 8 $g \cdot l^{-1}$. These differences may be due to differences in the environmental factors such as temperature, different nanoparticle size and difference in the seed structures of the various plant species. It has been suggested that by increasing of silicon concentration at the around of the seed it is accumulated in the epidermal tissues, and a layer of cellulose membrane-Si is created when calcium and pectin ions are present, which can increase sustainability of cell wall by forming a layer (Sahebi et al., 2015), and it can partly delay radicle emergence. However, the application of an appropriate concentration of silicon could facilitate cell wall loosening and increase cell extension by formatting complexes of Si-polyphenol or substitution of Si and lignin (Dragišić Maksimović et al., 2007). Our results suggested that response of sunflower germination to pre-hydration at various concentrations of nano-silicon solution were very different. It shows that the influences of the nanoparticles on early seedling growth of plants are almost unpredictable and an absolute comprehension of the role of nano-sized engineered materials on plant physiology at the molecular level is still lacking (Khodakovskaya et al., 2011). However, between the effective concentrations of bulk and nano-silicon there are significant differences. Although it has been shown that exogenous application of bulk silicon ($Na_{2-}SiO_3$) at high concentration (1.5 mM) considerably improved germination percentage and germination index of borage seeds (Torabi et al., 2012), our findings emphasized that the best result could be obtained at very low concentration of nano-silicon. From the physiological stand point, silicon is able to increase the plasma membrane integrity by providing more stable lipids involved in their cell membrane (Sahebi et al., 2015), and it has been revealed that silicon has an important role in plant protection against biotic and abiotic stress (Ma, 2004). Previous studies have suggested that nano-silicon application may alleviate the adverse effects of salinity stress on seed germination (Haghighi et al., 2012; Sabaghnia & Janmohammadi, 2015) and increase water-use efficiency and photosynthesis rate in plants (Ma, 2004). It has been suggested that exogenous silicon may improve seed germination and seedling growth by enhancing antioxidant defence and improvement in Fe nutrition (Shi et al., 2014). In the present study, we found that pre-sowing treatment with nano-silicon could invigorate the germination of sunflower. However, to the present, very low is understood about physiological roles of nano-silicon in improvement of seed germination. However, further research should be done to investigate the interaction between nano-silica and seed at cellular and molecular levels. Overall, the quick seed germination after pre-sowing treatments is resulted from enhanced metabolic activities in the primed achenes (Wahid et al., 2008). In summary, the results showed that pre-hydration treatments in diluted solutions of nano-silicon not only improved the germination characteristics, but also enhanced the seedling growth parameters.

## CONCLUSION

The results of the current study reiterated that controlled imbibition of sunflower achene in *nano-silicon* solution followed by dehydration could significantly enhance seed germination. Achenes priming in low concentration *nano-silicon* solution enhanced percent seed germination, seed germination index, seedling vigour index, seedling fresh weight and dry weight as well as decreased mean germination time and $T_{50}$. These positive effects of nano-silicon observed in primed seeds may suggest that they would exhibit more acceptable agronomic and physiological performance. Vigour enhancement by the incorporation of nano-silicon in priming solution might be due to increased cell division within the apical meristem of seedling. Based on our study, we suggest a potential use of nano-silicon in priming treatments to invigorate and accelerate seed germination and produce stronger seedlings in semiarid regions. In this experiment, we did not study the physiological mechanisms of seed germination, therefore, it still remains to be investigated how nano-silicon stimulates the physiological activities of seed germination to produce strong and vigorous seedling.

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## SILICIO NANODALELIŲ ĮTAKA TIKROSIOS SAULĖGRĄŽOS (*HELIANTHUS ANNUUS*) DAIGUMUI, SĖKLAS APDOROJANT PRIEŠ SĖJĄ

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### Santrauka

Silicis yra vienas iš labiausiai paplitusių augalams naudingų makroelementų. Nors jo teigiamas poveikis augalų augimui ir vystymuisi plačiai nagrinėjamas, tačiau apie silicio nanodalelių panaudojimo galimybę sėklų gyvybingumui padidinti informacijos yra mažai. Didesnis sėklų daigumas gali pagerinti pasėlio įsitvirtinimą ir tokiu būdu nulemti gausesnį derlių. Kontroliuojamoje aplinkoje sėklas dalinai išmirkius, po to – išdžiovinus, sėklos dažnai dygsta greičiau ir tolygiau, lyginant su neapdorotomis sėklomis. Šiame darbe buvo tiriamas sėklų mirkymo skirtingos koncentracijos nano silicio tirpaluose (0; 0,2; 0,4; 0,6; 0,8 1 ir 1,2 mM 8 val.) poveikis saulėgrąžų daigumo savybėms. Sėklų mirkymas mažos koncentracijos (0,2 ir 0,4 mM) nano silicio tirpaluose žymiai sumažino laiką iki 50 % daigų pasirodymo ir vidutinį dygimo laiką, padidino šaknų ilgį, vidutinį paros daigumą, daigų stiprumo indeksą ir galutinį daigumo procentą. Rezultatai rodo, kad tinkamos koncentracijos nano silicio tirpalo panaudojimas mirkymui žymiai pagerina dygimo procesą ir daigų stiprumą. Šie rezultatai taip pat pabrėžia sėklų mirkymo atskiestuose nano silicio tirpaluose prieš sėją svarbą saulėgrąžų daigumo pagerinimui.