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Laboratory Based Assessment of Sunflower (*Helianthus Annuus* L.) Genotypes Through Seed Priming by Water and Nutrient Solution

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ABSTRACT

The purpose of this study was to establish that how sunflower genotypes respond to hydropriming and nutripriming. In this regard, four priming treatments, no priming, seed priming with canal water, 1.0% urea, and 0.2% zinc sulphate were experienced to four sunflower genotypes: HO-1, Charnika, Hysun-33, and NK-278. Different seed priming sources, genotypes, and their interactions had a substantial ($P<0.05$) impact on seed germination and other growth parameters according to the statistical analysis of the data. Seed priming with 0.2% $ZnSO_4$ produced the highest seed germination (92.30%), seedling vigor index (1499), root length seedling^{-1} (6.07 cm), shoot length seedling^{-1} (16.82 cm), root fresh weight seedling^{-1} (16.82 g), shoot fresh weight seedling^{-1} (5.02 g), root dry weight seedling^{-1} (0.14 g), and shoot dry weight seedling^{-1} (0.31 g). All the values were superior to 1.0% urea while no priming gave the lowest results. Whereas, HO-1 performed superior to other genotypes in every parameter, including seed germination (83.80%), seedling vigor index (1316), root length seedling^{-1} (5.40 cm), shoot length seedling^{-1} (16.20 cm), root fresh weight seedling^{-1} (16.20 g), shoot fresh weight seedling^{-1} (3.89 g), root dry weight seedling^{-1} (0.11 g), and shoot dry weight seedling^{-1} (0.29 g), while Hysun-33 ranked second among the tested genotypes. The best results were obtained when 0.2% $ZnSO_4$ × genotype HO-1 was combined. Therefore, it is determined that priming with 0.2% $ZnSO_4$ performed superior.

Introduction

Sunflower (Helianthus annuus L.2n=34) belonging to the Asteraceae family, originated from eastern north America (Naseem *et al.,* 2015). It is one of the key oil seed crop plants (Ahmed *et al.,* 2022), grown primarily for seed which contain 40–50% oil and 17–20% protein with higher polyunsaturated fatty acids and lower levels of cholesterol (Nasralla et al., 2014). Globally it is cultivated on 29.3 million ha and producing 54.3 million tons with the seed yield of 2040 kg ha^{-1} (FAO STAT, 2023). Annually around 20 million tons of vegetable oil is obtained from sunflower worldwide, sunflower ranks fourth after palm, soybean, and rapeseed in vegetable oil production (USDA, 2024). In Pakistan, sunflower is grown on an area of 62483.00 ha with a total production of 98302.00 tons (GoP, 2023-24). While Pakistan requires annually 4.5-4.8 million MT edible oil (Ajmal et al., 2022). Because oilseed crop productivity in Pakistan is still low when compared to global production. Thus, edible oil is the major food

import in Pakistan. During the year 2023-24 Pakistan imported 3140.3 thousand tons, amounting to Rs.831667.2 million. It is expected that, the Per capita edible oil consumption in Pakistan will reach up to 22 kg in 2028 (Rana et al., 2022). It is needed to introduce advanced agronomic practices to increase the yield per acre of oilseed crops (Bin Mustafa et al., 2024).

As a consequence of climate change, crops are facing stresses during their physiological growth. Among these stresses factors, salt stress is an important (Ali et al., 2021) because that affects negatively on seedling growth as well as osmotic stress and ion toxicity which restrain the crop production. (Granaz et al., 2022; Akhter et al., 2022). For consistent germination and early seedling establishment seed priming is an accepted strategy for improving germination and yield potential (Parisa Ahmadi et al., 2026).

In the sustainable agricultural systems, to initiate early metabolic processes while preventing radicle protrusion, seed priming is a pre-sowing treatment that partially hydrates the seed (Habibi et al., 2025). Amongst the different priming methods (Habibi et al., 2024), hydro-priming followed by re-drying is the simplest, cost-effective and farmer-friendly approaches (Catiempo et al., 2021, Adhikari et al., 2021). According to the findings of (Al-Salhi, 2019), use of hydroprimng shown significant effect on the seed germination. (Yadav et al., 2023) also reported that, hydro-priming enhances the germination, seedling growth and field emergence in a number of crops.

Including other seed priming methods, nutripriming is an essential for various physiological processes. It is performed by soaking of seed in micro- or macro nutrient solutions (Farooq et al., 2012). There are many nutrients are used, either individually or in combinations, during the nutripriming (Thakur et al., 2022). For example, Urea, Mg, Zn, and B have been applied to various crops (Sharma et al., 2022). However, Zn and urea considered most frequently. Nitrogen is a main element of several imperative plant substances (Abdelaal, 2015.; Hafez and Abdelaal, 2015). It is considered as a key component in the building blocks of proteins (Rosenblueth et al., 2018). Zn is a fundamental nutrient and plays a crucial role in cellular functions, metabolism and physiological activities of plant body (Yang et al., 2020). It is a major component of photosynthesis by acting in chlorophyll synthesis (Dang et al., 2024) Zn also decreases the plant stresses like, salinity, drought, and extreme temperatures (Rahman., et al., 2024). Numerous studies have reported better germination following Zn seed priming (Sadeghizadeh and Zarea 2022; Imran et al., 2021; Rehman et al., 2015). Additionally, Seed priming with Zn, leading to a 27% increase in grain yield (Harris et al., 2007). Overall, Zn priming treatments, mainly at optimal concentrations in sunflower seeds, considerably boost seedling growth, yield and yield components of crop and making them a capable cost-effective agronomic tool for improving production efficiency.

Therefore, the present study was conducted to assess systematically, the effect of hydro-priming and nutripriming on seed germination, growth of seedling, seedling vigour, physiological and metabolic activity of seedlings compared to non-primed seeds.

MATERIALS AND METHODS

To evaluate the effects of seed priming treatments on sunflower genotypes, a laboratory experiment was executed at the Department of Agronomy, Sindh Agriculture University, Tandojam. The trial followed a two-factor Completely Randomized Design (CRD), with three replications. The experimental variables were arranged as under:

Factor A (Four priming sources): No priming, canal water, 1.0% Urea and 0.2% $ZnSO_4$

Factor B (Four Genotypes): HO-1, Charnika, Hysun-33 and NK-278.

Method of seed priming: All the required equipments were sterilized on 121 °C for 20 min in the autoclave. The seed was disinfected with 2% sodium hypochlorite for five minutes before priming. Then seed was rinsed several times in distilled water and primed accordingly. The nutrient solutions of Urea and $ZnSO_4$ were prepared appropriately. For preparing 1.0% Urea solution, 1.0 g of commercial Urea fertilizer was dissolved in 100 ml of distilled water. Similarly, 0.2% zinc sulphate concentration was achieved by dissolving 200 mg of $ZnSO_4$ fertilizer per 100 ml of distilled water. Seeds were then immersed in the prepared solutions. After priming, seed was dried in the room at normal temperature for one hour and sown in the prepared media.

Sowing of seed: Sunflower seeds were sown by using, dibbling method in the aluminum trays measuring (30 x 15 cm). These trays were filled with 5 kg of sand and saturated with canal water. Each tray accommodated 20 seeds of a specific genotype arranged in a grid of four rows with five seeds per row. Moisture requirement for germination of seed was replenished as needed using a manual sprinkler. The seedlings were uprooted after 20 days. The different parameters were investigated as below.

Germination (%): As plants attained the age of 10 days, the germination% was recorded and calculated through the specified formula:

$$\text{Germination (\%)} = \frac{\text{Total number of germinated seeds}}{\text{Total number of seeds}} \times 100$$

Seedling vigour index: The formula used for calculation of seedling vigour index is as under

Seedling vigour index = Seed germination (%) × Seedling length (cm)

Root length (cm) seedling^{-1}

Five seedlings from each treatment were uprooted and seedlings were washed with tap water. Each seedling measured from the seed to the root tip by scale in centimeters (cm) and average was calculated.

Shoot length (cm) seedling^{-1}

The five seedlings were selected at random from treatments and length of each seedling from seed up to the tip of leaf blade were recorded in (cm) and expressed in average.

Root fresh weight (g) seedling^{-1}

Five seedlings were randomly selected from each treatment, roots were separated from each other, then root fresh weight (g) weighed by digital balance. Values were expressed in average.

Shoot fresh weight (g) seedling^{-1}

From each treatment, five seedlings were selected randomly, then shoots and roots were separated. After that, fresh weight (g) was measured through digital balance and average was intended.

Root dry weight (g) seedling^{-1}

The roots of five seedlings were taken randomly from each treatment and dried in oven at 70^{o}C for 48 hour according to Ahmadvand et al., (2012) in drying vacuum oven (Model: No: Mino 3055 Gen lab Thermal eng). and weighed with digital balance.

Shoot dry weight (g) seedling^{-1}

The five seedlings were taken randomly from each treatment and dried in oven at 70^{o}C for 48 hour according to Ahmadvand et al., (2012) and weighed with digital balance.

Statistical analysis

The collected data was analyzed through Statistic software 8.1. While, the treatments mean (LSD) were evaluated by least significant difference test (P = 0.05) (Statistix, 2006).

Results

Germination (%): Data regarding the growth characteristics indicated that seed priming remained significant (P<0.05%) statistically. As germination (%) is most important indicator for seedling numbers to estimate final grow. Results of the data indicated that, the germination (%) of genotypes were influenced significantly (p<0.05) by seed priming sources (Figure-1a). The highest germination (92.30 %) was achieved by using 0.25% $ZnSo_4$ whereas unprimed seed noted lowest germination (66.33 %). Among the genotypes (Figure-1b), HO-1 demonstrated the maximum germination (83.80%), whereas minimum germination (76.30 %) was observed in NK-278. Regarding the treatment interactive effects, 0.2% $ZnSO_4$×HO-1 noted the maximum germination response (95.0%), closely followed by seed germination of 94.00% with 0.2% $ZnSO_4$ × Hysun-33 (Figure-1c), conversely, the least germination (60.0%) was observed in the unprimed NK-278 genotype.

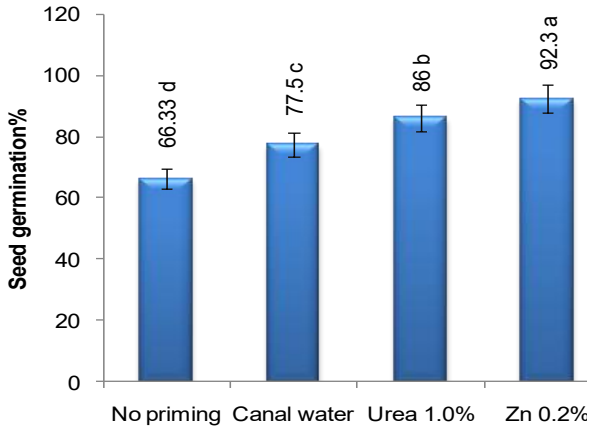


Figure. 1a. Effect of seed priming on seed germination (%) of sunflower

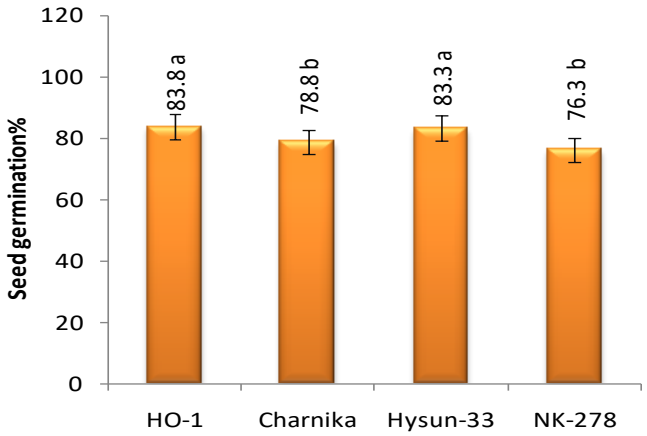


Figure. 1b. Response of genotypes on seed germination (%) of sunflower

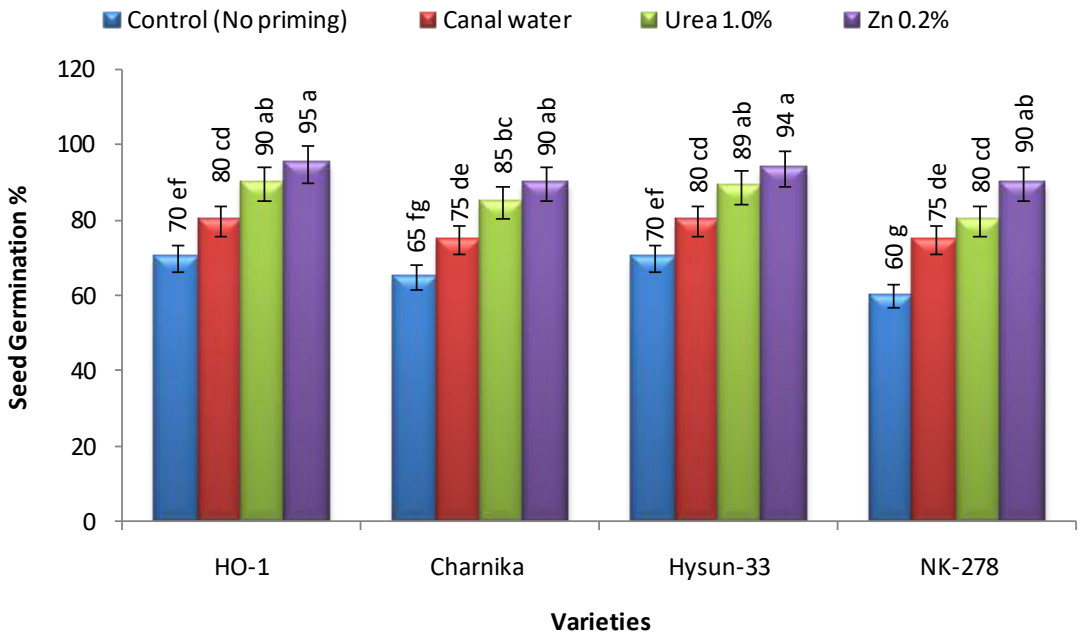
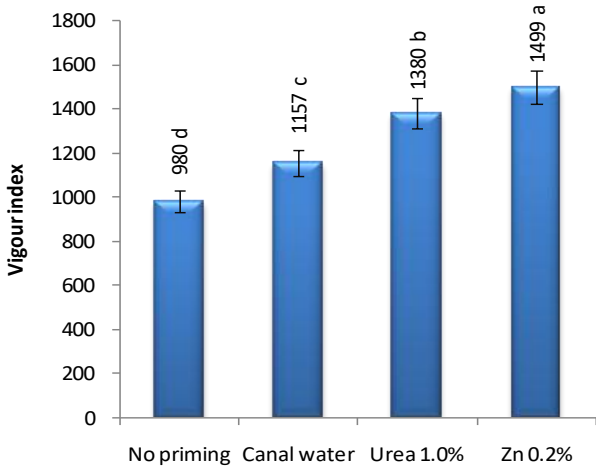


Figure. 1c. Interactive effect of seed priming on seed germination (%) of sunflower genotypes

Seedling vigour index: The assessment of seedling vigour indices exposed significant effect for both seed priming strategies and sunflower genotypes, alongside a prominent interaction effect between the two factors. In case of seed priming treatments (Figure-2a), the profound enhancement was noted by 0.2% $ZnSO_4$, which recorded a vigour index of 1499. This was followed by the 1.0% Urea treatment (1380), while priming with canal water ranked third at 1157. The lowest performance was recorded in the unprimed seed which produced an index of only 980. In parallel, genetic variations across the sunflower genotypes significantly influenced seedling development (Figure-2b). Cultivar HO-1 established a maximum vigour index of 1316. Hysun-33 followed as the second most vigorous genotype at 1270, whereas NK-278 exhibited the minimum index of 1184. Over the course of the study, HO-1 constantly established superiority over Hysun-33, Charnika, and NK-278. The interaction between seed priming treatments and genotypes also noted significant variation (Figure 2c). The integration of 0.2% $ZnSO_4$ with the HO-1 genotype maximized seedling vigor 1550. This response was close by the 0.2% $ZnSO_4$ × Hysun-33 which attained an index of 1520. In contrast, the poorest performance was observed under the unprimed NK-278 with a minimum index of 947.



a. Effect of seed priming on seedling vigour index of sunflower

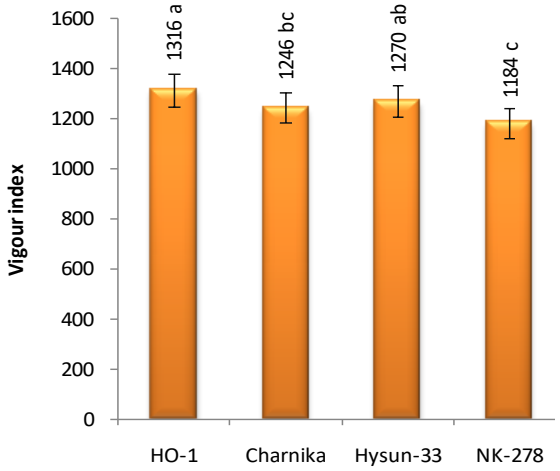


Figure. 2b. Response of genotypes on seedling vigour index of sunflower

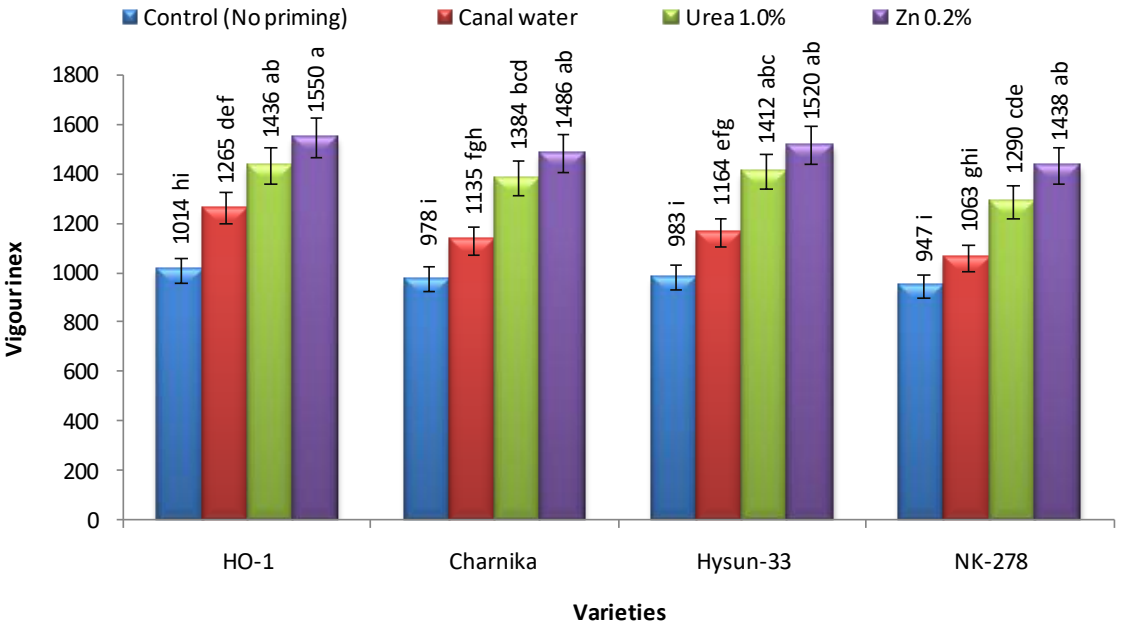


Figure. 2c. Interactive effect of seed priming on seedling vigour index of sunflower genotypes

Root length (cm) seedling^{-1}: The data of (Figure-3a) revealed that, different chemical composition of the seed priming media produced distinct variations in root length seedling^{-1}. Nutripriming proved as a highly effective approach, for accelerating root elongation when compared to hydropriming and unprimed treatments. The application of a 0.2% $ZnSO_4$ solution recorded the longest 6.07 cm roots; this is a significant increase over the secondary treatment 1.0% Urea, which recorded the root length of 4.82 cm seedling^{-1}. Hydropriming with traditional canal water proved less effective and ranked third with 4.30 cm root length. The lowest root development seedling^{-1} was observed in the control (No Priming), with a minimum value of 3.70 cm. With respect to genotypes (Figure-3b), HO-1 demonstrated maximum root length of 5.40 cm, whereas genotype Hysun-33 placed close with the root length of 4.77 cm. However NK-278 genotype exhibited the lowest root elongation with 4.22 cm. The combination of 0.2% $ZnSO_4$ and HO-1 genotype observed the highest root length, reaching 8.00 cm seedling^{-1}. The next best interaction was observed in the Hysun-33 genotype primed with 0.2% $ZnSO_4$, with root length of 6.00 cm. The shortest roots (3.20 cm seedling^{-1}) noted in NK-278 genotype which was unprimed.

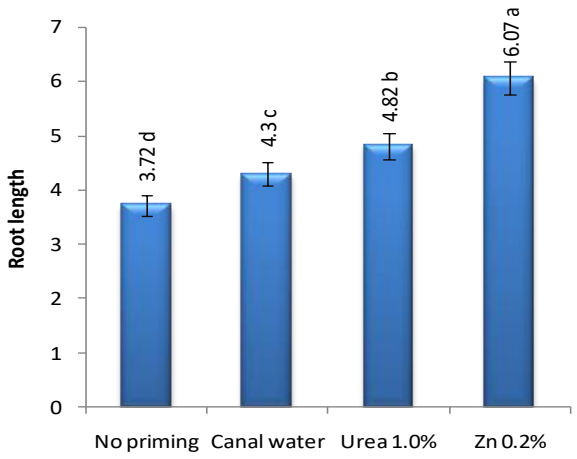


Figure. 3a. Effect of seed priming on root length (cm) of sunflower

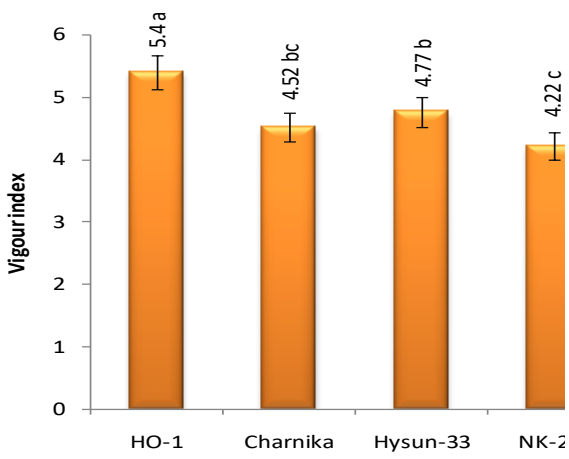


Figure. 3b. Response of genotypes on root length (cm) of sunflower

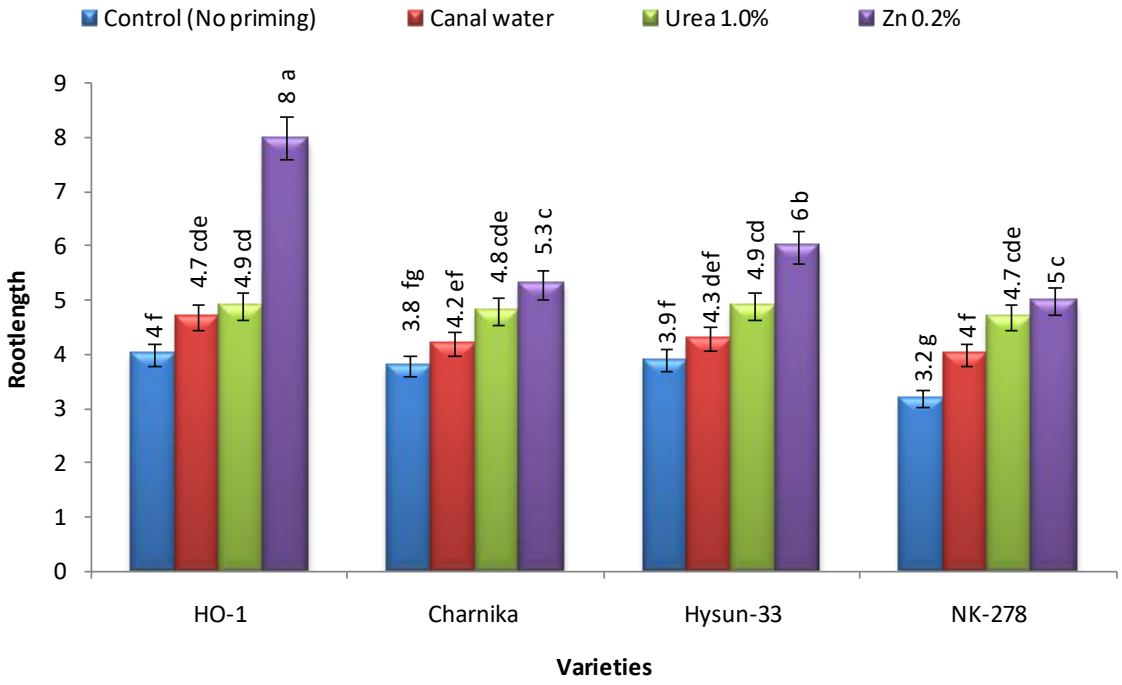
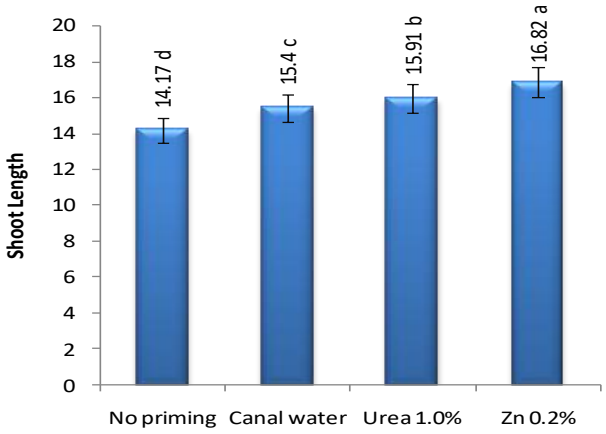


Figure. 3c. Inter active effect of seed priming on root length (cm) of sunflower genotypes

Shoot length (cm) seedling^{-1}: In case of seed priming sources (Figure-4a), the most substantial shoot growth was induced by 0.2% ZnSO4, which achieved 16.82 cm seedling length. This was followed closely by the 1.0% Urea treatment at 15.91 cm, while canal water ranked third with producing a lower shoot length of 15.40 cm. However the lowest shoot length (14.17 cm) seedling^{-1} was observed in the unprimed control treatment. Among genotypes (Figure-4b), greatest shoot length (16.20) cm seedling^{-1} was recorded in genotype HO-1. The Hysun-33 noted in parallel with the shoot length of (15.57) cm seedling^{-1}, in contrast, genotype NK-278 exhibited (15.15 cm) seedling^{-1} the lowest shoot length.

Analysis of the interaction effects (Figure 4c) revealed that, combining a 0.2% ZnSO4 treatment with the HO-1 genotype optimized seedling development upto18.00 cm. The next most effective 0.2% ZnSO4 x Hysun-33g produced a shoot length of 16.50 cm. on the other hand, the least outcome occurred in the unprimed NK-278 where shoot growth stalled at a minimum of 13.50 cm.



a. Effect of seed priming on shoot length(cm) of sunflower

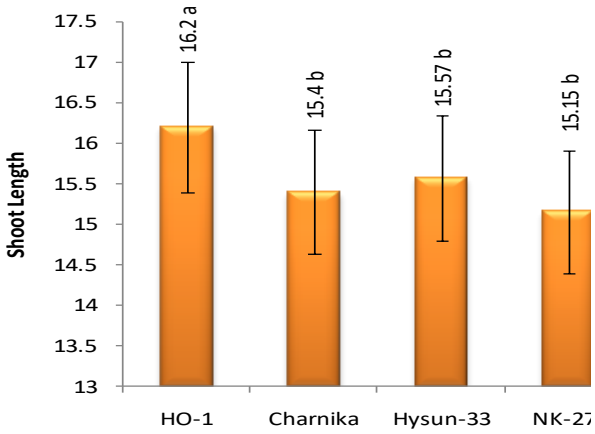


Figure. 4b. Response of genotypes on shoot length(cm) of sunflower

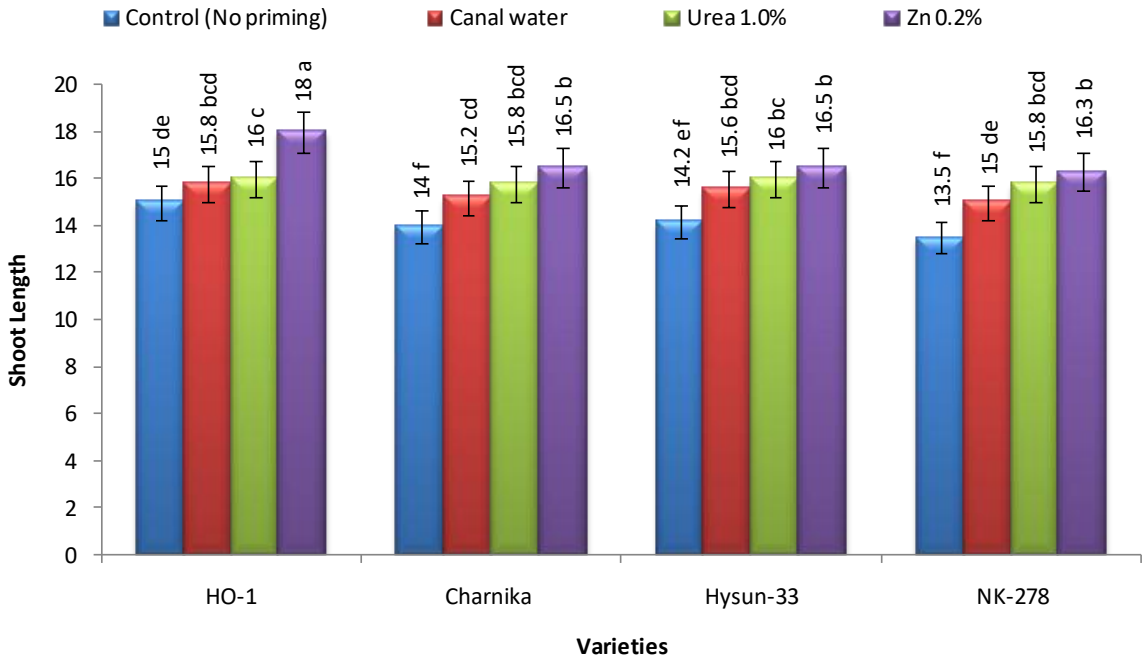


Figure. 4c. Interactive effect of seed priming on shoot length (cm) of sunflower genotypes

Root fresh weight seedling^{-1} (g): Results presented in (Figure-5a) signify that highest root fresh weight 16.82 g seedling^{-1} was noted when seed was primed with 0.2% $ZnSO_4$, followed by 15.91 g seedling^{-1} with 1.0% Urea. However the close value 15.40 g of root fresh weight was noted under canal water treatment. In comparison, unprimed seed produced lowest root fresh weight of 14.17 g seedling^{-1}. Difference amongst the genotypes (Figure 5b) also evident that, genotype HO-1 recorded maximum root fresh weight of (16.20) g, followed by (15.57) g by genotype Hysun-33. Whereas minimum (15.15) g root fresh weight seedling^{-1} was recorded in NK-278 genotype. Regarding the interactive effects (Figure-5c), highest 18.00 g root fresh weight seedling^{-1} was recorded under the interaction of 0.2% Zinc × HO-1, followed by 16.50 g seedling^{-1} under interaction of 0.2% $ZnSO_4$ x Hysun-33. Whereas, the minimum 13.50 g root fresh weight seedling^{-1} was recorded with the interaction of No priming × NK-278.

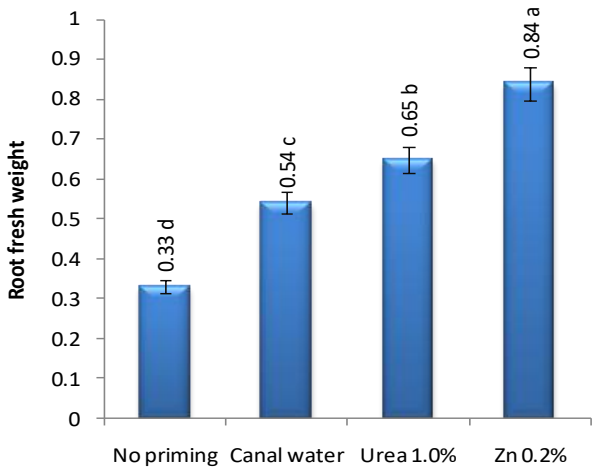
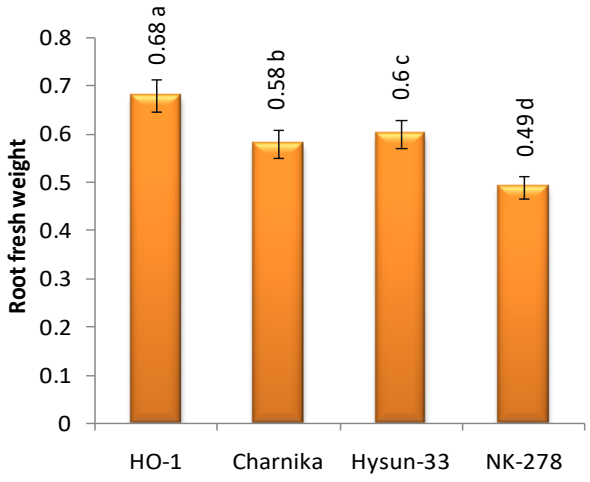


Figure. 5a. Effect of seed priming on root fresh weight seedling^{-1} (g) of sunflower



b. Response of genotypes on root fresh weight seedling^{-1} (g) of sunflower

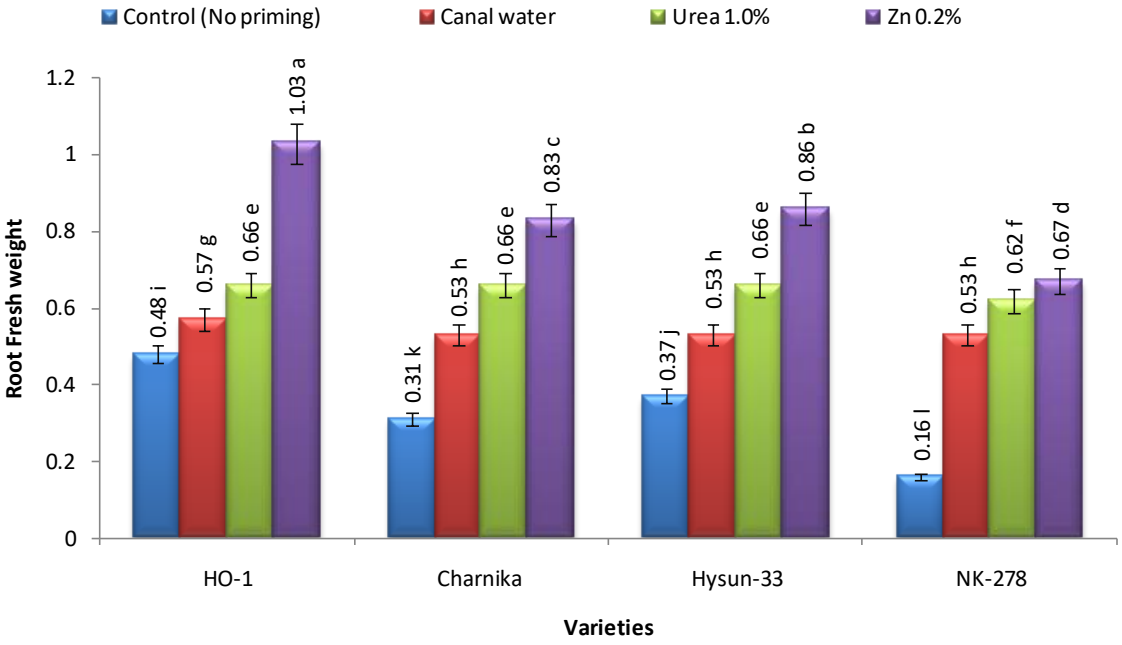


Figure. 5c. Interactive effect of seed priming on root fresh weight (g) of sunflower genotypes

Shoot fresh weight (g) seedling^{-1}: Regarding the priming sources (Figure 6a), 0.2% $ZnSO_4$ emerged as significant and recorded the maximum shoot fresh weight to 5.02 g seedling^{-1}, which distinctly exceeded the 1.0% urea (3.52 g) and canal water (3.04 g) treatments. While the unprimed seed recorded minimum of 2.75 g seedling^{-1}. Parallel to these findings, the genotype HO-1 established as the top performer with 3.89 g fresh weight seedling^{-1}, closely trailed by Hysun-33 at 3.81 g, whereas NK-278 confirmed the lowest shoot fresh weight seedling^{-1} by producing only 3.11 g. As per combined interactive effects, the pairing of a 0.2% $ZnSO_4$ treatment with the HO-1 genotype achieved the maximum shoot fresh weight at 5.70 g seedling^{-1}, closely matched by the same 0.2% $ZnSO_4$ treatment applied to Hysun-33 at 5.62 g. In contrast the absolute minimum biomass accumulation occurred when the NK-278 genotype was left unprimed and recorded meager 2.39 g value. It is evident that these interactive treatments set the fact that, nutrient-rich priming with zinc sulfate delivers a growth-promoting advantage than traditional priming with urea or canal water. In this study noteworthy increase in shoot fresh weight (g) seedling^{-1}was recorded when sunflower seed was primed with 0.2% $ZnSO_4$. These findings are in harmony with (Rouhi et al., 2011) who concluded

that Zinc induced better growth and seedling establishment due to its enzymatic activities. Furthermore, Zinc serves as a crucial structural element and enzymatic cofactor, playing a key role in the efficiency of growth regulation (Rudani et al., 2018). Mallikarjuna et al., (2020) also specified direct relation of zinc accessibility with regulation of growth regulators.

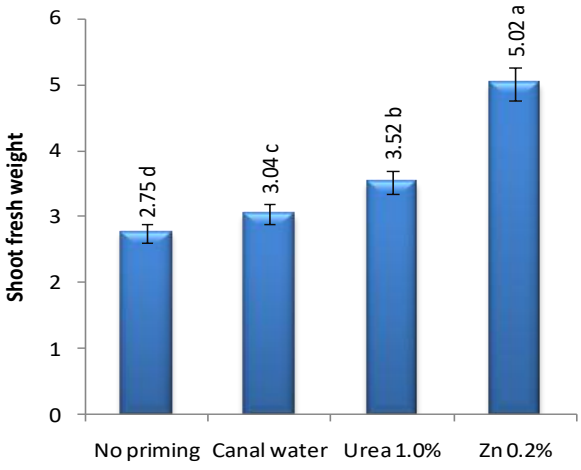


Figure. 6a. Effect of seed priming on shoot Fresh weight seedling^{-1} (g) of sunflower

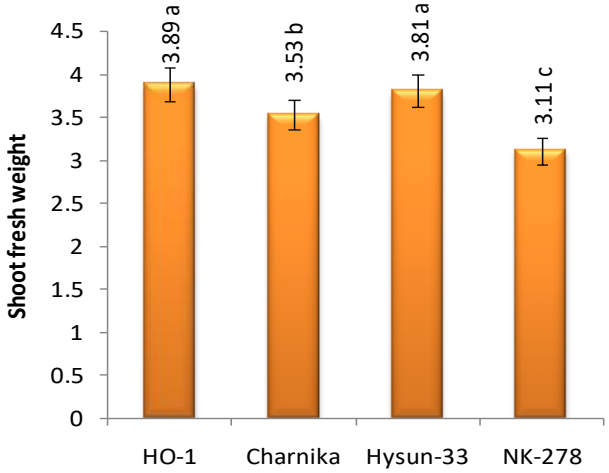


Figure. 6b. Response of genotypes on shoot fresh weight seedling^{-1} (g) of sunflower

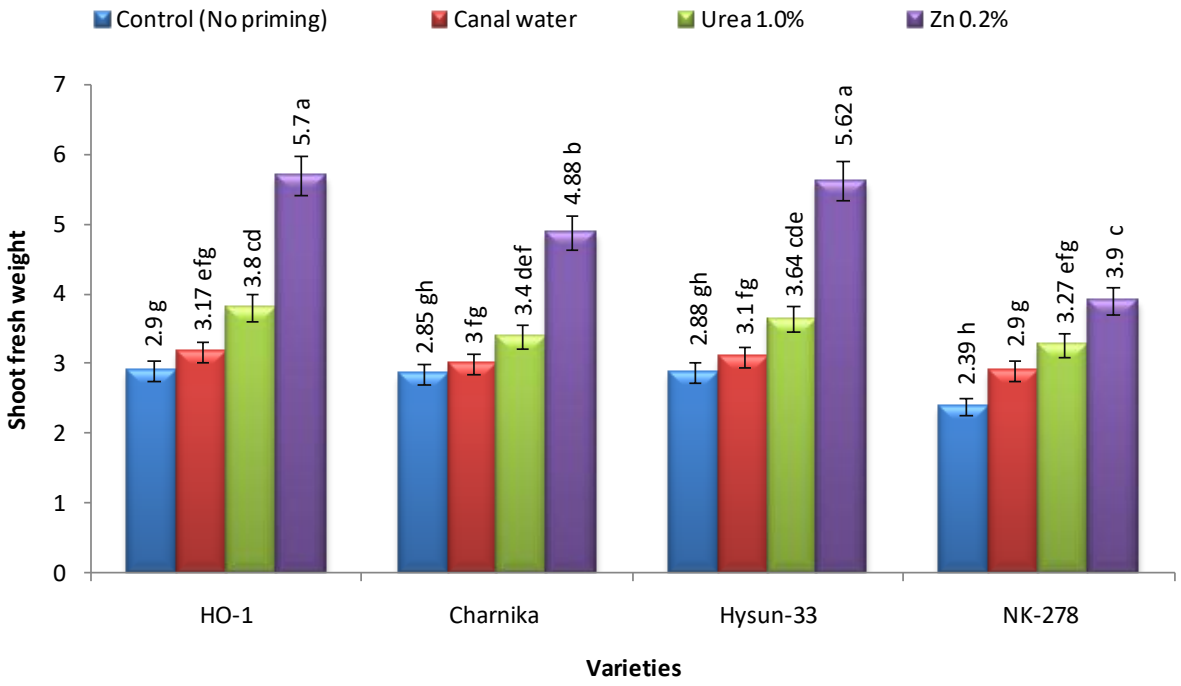


Figure. 6c. Interactive effect of seed priming on shoot fresh weight seedling^{-1} (g) of sunflower genotypes

Root dry weight seedling^{-1} (g): Looking at the priming sources (Figure 7a), 0.2% $ZnSO_4$ maximized the root dry weight of 0.14 g seedling^{-1}, followed by the 1.0% urea (0.10 g) and canal water (0.07 g). While the unprimed seed recorded the lowest weight of 0.05 g. Alongside, the genotypic screening (Figure 7b) recognized the HO-1 as superior genotype with a maximum 0.11 g root dry weight seedling^{-1} which was closely followed by Hysun-33 at 0.09 g. Whereas NK-278 demonstrated the lowest 0.08 g value. However, the interactive effect of treatments and genotypes was recorded at significant level and presented in (Figure 7c), the greatest root dry weight (0.11 g) seedling^{-1} was recorded by 0.2% $ZnSO_4$ × genotype HO-1 interaction, a comparable response was observed in genotype Hysun-33 under the same priming treatment, which produced a root dry weight of 0.13 g seedling^{-1}. In contrast lowest (0.04 g) root dry weight seedling^{-1}was recorded in the interaction between the non-primed seed of genotype NK-278.

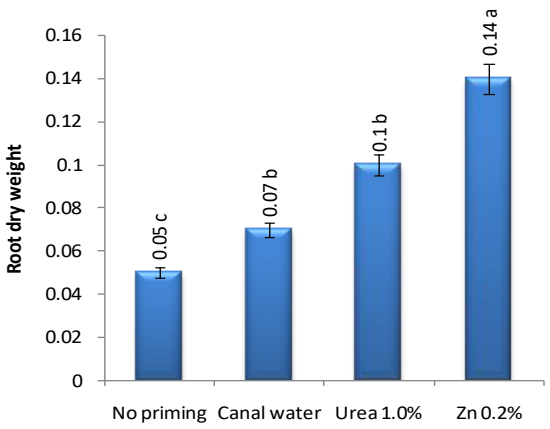


Figure. 7a. Effect of seed priming on root dry weight seedling^{-1} (g) of sunflower

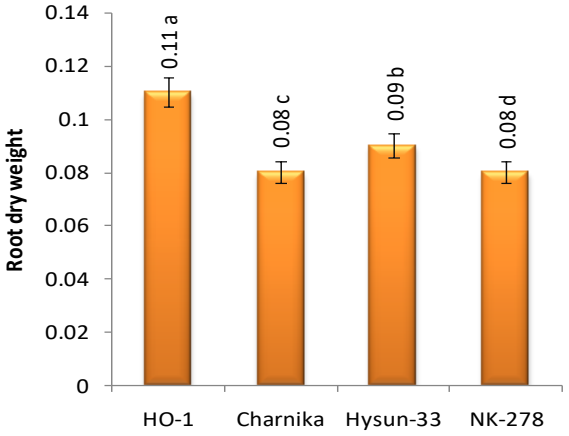


Figure. 7b. Response of genotypes on root dry weight seedling^{-1} (g) of sunflower

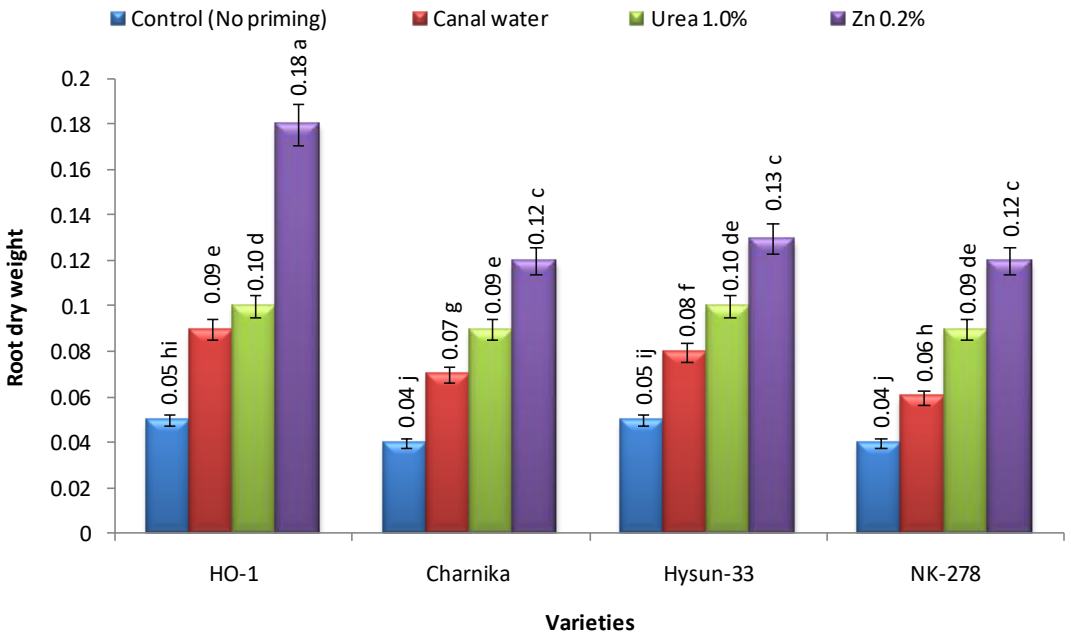


Figure. 7c. Inter active effect of seed priming on root dry weight seedling^{-1} (g) of sunflower genotypes

Shoot dry weight seedling^{-1} (g): The results shown in (Figure 8a) confirmed that nutrient priming significantly enhanced shoot dry matter accumulation. Among the seed priming treatments, seeds treated with 0.2% $ZnSO_4$ recorded the highest shoot dry weight (0.31 g) seedling^{-1}although priming with 1.0% urea resulted in 0.28 g shoot dry weight seedling^{-1}. However Canal water priming produced an intermediate response with 0.26 g seedling^{-1} in comparison, the untreated seed exhibited the lowest shoot dry weight (0.22 g) seedling^{-1}. In terms of shoot biomass (Figure-8b), HO-1 achieved the utmost shoot dry weight of 0.29 g seedling^{-1}. While Hysun-33 produced 0.28 g shoot dry weight, while NK-278 recorded the minimum weight of 0.25 g seedling^{-1}. The interactive effects (Figure-8c) depicted the highest (0.34 g) shoot dry weight seedling^{-1} under the interaction of 0.2% Zinc × HO-1, The interaction between 0.2% $ZnSO_4$ priming and Hysun-33 ranked second by producing 0.33 g shoot dry weight seedling^{-1}. However, the non-primed genotype NK-278 performed at lower level, where shoot dry weight declined to 0.18 g seedling^{-1}.

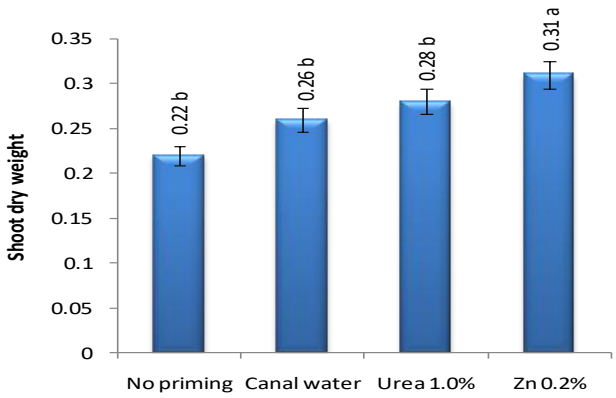


Figure. 8a. Effect of seed priming on shoot dry weight seedling^{-1} (g) of sunflower

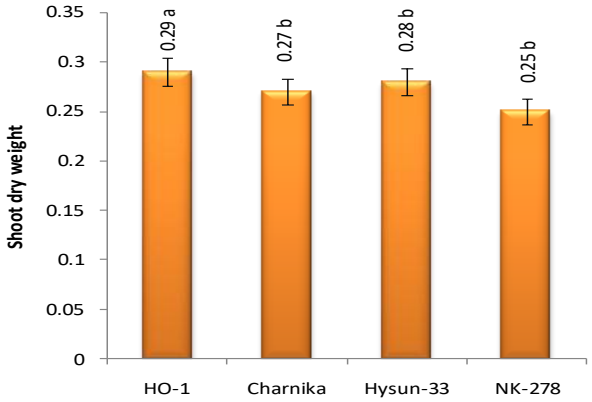


Figure. 8b. Response of genotypes on shoot dry weight seedling^{-1} (g) of sunflower

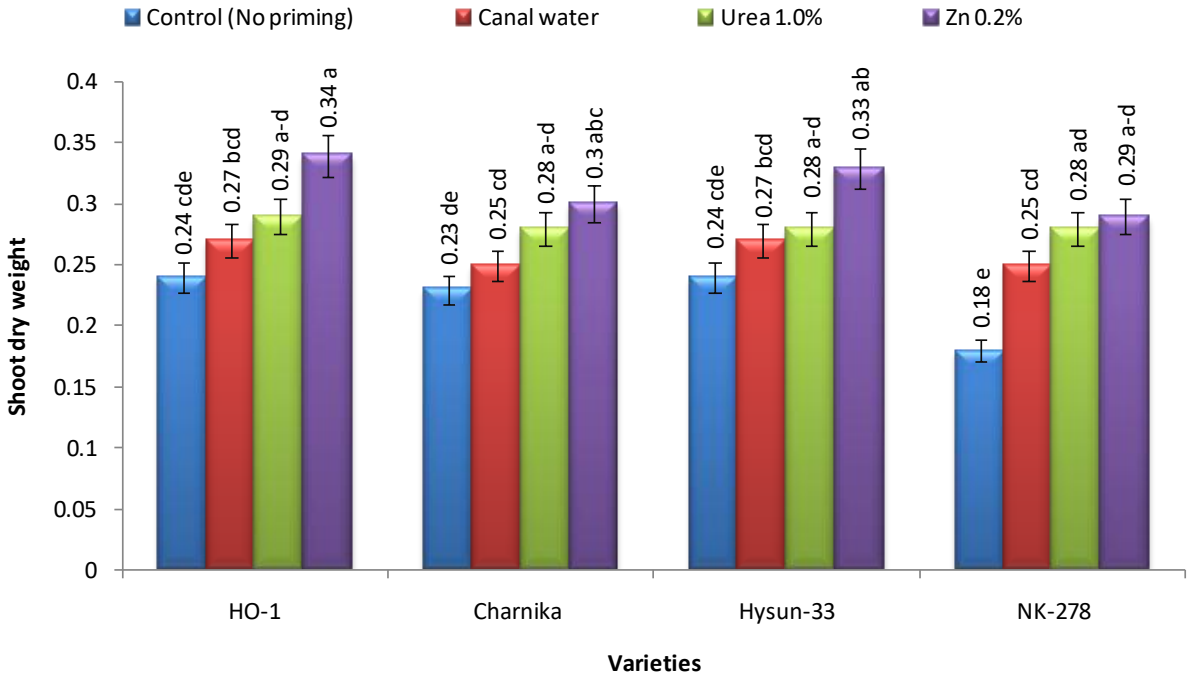


Figure. 8c. Inter active effect of seed priming on shoot dry weight seedling^{-1} (g) of sunflower genotypes

Discussion

According to the findings our study, the seed priming with 0.2% $ZnSO_4$ recorded the highest seed germination (%). The increase in germination % in zinc treated seeds may be attributed to the hydrolysis of cotyledon reserved material. As highlighted by (Yang et al., 2020), Zn is essential for cellular functions like, metabolic and physiological activities. This diverse functionality of zinc makes it a highly promising seed priming agent. According to the recent studies Zn seed priming significantly enhanced the germination% in rice, wheat, and spinach (Sadeghizadeh and Zarea, 2022; Imran et al., 2021). Zinc is a vital nutrient for photosynthesis and enzyme activity (Natasha et al., 2022; Saleem et al., 2022). Furthermore, the significant varietal variation was established in studied traits of sunflower. The genotype HO-1 surpassed all other genotypes followed by Hysun-33, Charnika and NK-278, respectively. The resulting difference among the genotypes may be due to the difference in their genetic makeup, which is reflected in the varied germination rate due to disparity among genotypes (Habib, 2017). Our results are in agreement with the conclusion of (Gursoy, 2022), who confirmed that there are significant differences between sunflower varieties in seed

viability and seedling growth activity. The superiority of 0.2% $ZnSO_4$ seed priming over 1.0% urea might be due to the fact that, 1.0% urea concentration hinders the germination rather than increasing, because when urea enters the seed, it is rapidly broken down by the plant enzyme urease, this reaction releases free ammonia, which is highly toxic to embryonic tissues and can burn the emerging radicle before it protrudes. However Zinc stabilizes cell membranes, preventing cellular leaking and ensuring seamless metabolic activation.

The significant results have been observed in seedling vigour index through the seed 0.2% $ZnSO_4$ priming. The considerable increase in seedling vigour of sunflower genotypes with 0.2% Zinc Sulfate priming, compared to 1.0% Urea, canal water, and unprimed seeds, is due to the unique biochemical and hormonal role of zinc during the earliest stages. However the Canal water initiates simple hydration but lacks enzymatic catalysts. This improvement in seedling vigor index also accredited to the collective effect of better germination and amplified length of seedlings (Damalas et al., 2019). Furthermore, Zn contributes in hormonal activity and reduces the time of germination (Abdelaziz and Taha; Hussain et al., 2024). The considerable increase in seedling vigour of sunflower genotypes with 0.2% Zinc Sulfate priming, compared to 1.0% Urea, canal water, and unprimed seeds, is due to the unique biochemical and hormonal role of zinc during the earliest stages. However the Canal water initiates simple hydration but lacks enzymatic catalysts. This improvement in seedling vigor index also accredited to the collective effect of better germination and amplified length of seedlings (Damalas et al., 2019). Furthermore, Zn contributes in hormonal activity and reduces the time of germination (Abdelaziz and Taha; Hussain et al., 2024).

As per results of our study, seed priming with 0.2% $ZnSO_4$ significantly improved root length compared with other treatments. The reason of enhancement in root length through nutripriming is the early cell division and metabolic movement in the seed (Oliveira et al., 2019). Moreover Elsahookie and Cheyed (2023) as well as Majeed and Cheyed (2022) also observed the differences in radical length across various sunflower cultivars. Our findings are in line with (Khaleghi, 2024) who concluded that seed priming enhanced overall root length. Conversely, 1.0% Urea hinders growth because it breaks down into toxic free ammonia that stunts weak emerging root tips, while unprimed seeds provide only basic hydration without vital hormones which are needed to accelerate early seedling establishment.

Further investigation demonstrated that the application of 0.2% $ZnSO_4$ shoot length (cm) was increased notably as compared to other treatments. This increase in shoot length might be due to Zn seed priming, because it promoted physiological activities during the germination and growth phases of seedlings (Hassan et al., 2022; Rizan et al., 2018). In contrast, 1.0% Urea causes osmotic stress and localized ammonia toxicity that stunts early growth, while canal water and unprimed seeds lack the specialized nutritional and hormonal activity required to exceed baseline shoot extension. Additionally, the difference among genotypes in shoot length may be due to structural difference in genes, which resulted in distinct phenotypic behavior among genotypes (Habib, 2017). Ahmad et al., (2019) also reported genotypic differences and noted that the FH 687 genotype showed better root length than the hybrid FH 674.

These results suggest that nutrient-based seed priming, particularly with $ZnSO_4$, markedly enhanced root fresh weight compared with urea priming and hydropriming (canal water). Among the tested sunflower genotypes, HO-1 constantly exhibited better performance, which indicates its greater capacity for vigorous root development. In our study the data for root fresh weight (g) was significantly affected by the application of 0.2% $ZnSO_4$ as compared to rest of the treatments. This increase in the root fresh weight might be due to the optimal concentrations $ZnSO_4$, which extensively boosted the seedling growth consequently root fresh weight increased drastically. In contrast, 1.0% Urea burns the root tips, limiting their biomass and water-holding capacity. While, canal water and unprimed seed lacks the micronutrients, resulting in less developed root systems that naturally carry the less fresh weight. According to Iqbal et al., (2015) micronutrients increase the root fresh weight by activating vital plant enzymes.

The application of 0.2% $ZnSO_4$ caused a major increase in root dry weight (g). Because seed priming enhances seedling dry matter (Damalas et al., 2019). The primed seed exposed the mobilization of seed reserves, promoted better embryo growth and improved the germination and related traits. Consequently, physiological process allowed seedlings to utilize water and nutrients more efficiently. As a result, the dry weight of roots increased in primed seeds (Ansari et al., 2013). Whereas 1.0% Urea causes osmotic stress, whereas canal water and unprimed seeds lack key metabolic catalysts, resulting in slower growth and less accumulated shoot dry weight. Our results establishes the findings of (Dashab & Omidi 2021) who reported that, only hydropriming decreases the root dry weight.

Overall these findings obviously indicate that nutripriming with $ZnSO_4$ improved shoot dry matter production effectively than priming with urea, canal water or no priming. In the present study it was also observed that seed nutripriming increased shoot dry weight (g) considerably because of faster and stronger root establishment. This physiological process allows seedlings to consume water and nutrients properly, ultimately drives a major increase in the shoot biomass (Ansari et al., 2013). Regarding shoot dry weight Seedling[1], the genotype HO-1 exhibited a clear superiority over Hysun-33, Charnika, and NK-278. The reason

for this difference among the genotypes is of course due to the genetic diversity of the genotypes. Furthermore, the enhancement in shoot dry weight was proportional to the increase in root and plumule length within the same genotype as (Qandil and Al-Sharif 2012) reported that different genetic behavior of varieties results differences in performance during germination and other subsequent characteristics. Additionally, the concentration of 0.2% $ZnSO_4$ was significantly superior to the rest of concentrations and gave the highest shoot dry weight, whereas the compared treatments resulted the lowest values.

Conclusion

These results clearly establish that seed priming is a successful, cost-effective and economical strategy for improving sunflower seedling performance. Particularly Nutripriming with 0.2% $ZnSO_4$ resulted in the highest germination and seedling growth. Genotypes HO-1 and Hysun-33 were found to be promising under laboratory conditions and were screened out for further studies. Therefore, it is strongly recommended that growers should be prime the sunflower seed before sowing preferably with 0.2% $ZnSO_4$ to achieve maximum germination and vigorous crop stand.

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The authors declare that they have no conflict of interest.

Authors' Contribution Z.A.A, Conducted the research work and wrote the manuscript. M.N.K, supervised the work, M.M.R.J, revised the manuscript, M.B.A and M.H.T, analyzed the data.

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