



Effect of Zinc Stress on Germination Percentage, Germination Rate and Seedling Vigour of *Pisum sativum* L.

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ARTICLE INFO	ABSTRACT
Article history: Received – 12 August 2026 Received in revised form – 18 August 2026 Accepted – 21 August 2026 Available online – 25 August 2026	Zinc (Zn) is an essential micronutrient required for several physiological and biochemical processes in plants; however, excessive Zn may become toxic and adversely affect seed germination and early seedling development. The present study was designed to investigate the effect of different concentrations of zinc on seed germination, germination rate and seedling vigour of <i>Pisum sativum</i> L. Seeds were exposed to different concentrations of zinc sulphate under controlled laboratory conditions. A control treatment without added Zn was maintained for comparison. Germination percentage, germination rate, root length, shoot length, seedling length and seedling vigour index were recorded during the germination period. The results indicated that low or moderate Zn concentration had little inhibitory effect and, at an appropriate concentration, could improve germination and early seedling growth. In contrast, increasing Zn concentration progressively reduced germination percentage, delayed germination and inhibited root and shoot development. The highest Zn treatment showed the greatest reduction in seedling vigour. The results indicate that the response of pea seeds to Zn is concentration dependent, with a narrow range between beneficial Zn nutrition and Zn-induced stress. Excess Zn may interfere with nutrient balance, cellular metabolism and oxidative homeostasis, ultimately affecting germination and seedling establishment.
Keywords: Zinc stress, <i>Pisum sativum</i>, seed germination, germination rate, seedling vigour, zinc toxicity, Seedling growth.	

1. Introduction

Zinc (Zn) is an essential micronutrient for higher plants and participates in several important physiological and biochemical processes. It contributes to enzyme activity, protein synthesis, membrane stability, gene regulation and normal plant development. Therefore, adequate Zn availability is important for optimum plant growth and crop productivity. However, the beneficial and toxic concentrations of Zn are relatively close in some plant species, and excessive Zn accumulation can adversely affect plant metabolism and growth (Kaur and Garg, 2021).

Zinc enters agricultural soils through both natural and anthropogenic processes. Weathering of parent materials, industrial activities, mining and smelting, sewage sludge, manure and excessive application of some fertilizers may increase Zn availability in soil. The toxicity of Zn depends not only on its total concentration but also on its bioavailability, soil characteristics, plant genotype and developmental stage (Kaur et al., 2024).

At appropriate concentrations, Zn can have beneficial effects on plants. It is involved in various enzyme systems and contributes to normal physiological development. In pea, Zn application has been reported to improve yield and nutritional quality when applied at suitable concentrations. For example, foliar Zn application increased several yield parameters and improved seed nutritional characteristics in *Pisum sativum* (Cakmak et al./related pea Zn studies). Field studies have also demonstrated that appropriate Zn fertilization can increase Zn concentration in pea tissues and improve

seed yield, although the optimum requirement varies among cultivars and growing conditions.

In contrast, excessive Zn may cause phytotoxicity. Symptoms associated with excess Zn include inhibited root and shoot growth, chlorosis, altered photosynthesis and disturbance of mineral nutrition. Excess Zn can also increase reactive oxygen species and induce oxidative stress (Kaur and Garg, 2021).

Seed germination is one of the most important and sensitive stages in the plant life cycle. Successful germination determines subsequent seedling establishment and ultimately influences crop productivity. Studies of heavy-metal stress indicate that excessive metals can interfere with enzyme activity, nutrient mobilization and metabolic processes required for successful germination and seedling development.

Previous research has shown that the effect of Zn on germination varies with plant species and concentration. Low concentrations may have little effect or may stimulate germination, whereas high concentrations can delay or inhibit germination. In pea sprouts, for example, relatively low Zn exposure increased germination and fresh mass, whereas a higher treatment reduced germination and germination index.

Therefore, the present investigation was undertaken to study the concentration-dependent effects of Zn stress on seed germination and early seedling vigour of *Pisum sativum* L.

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2. Materials and methods:

2.1 Plant material

Healthy and uniform seeds of *Pisum sativum* L. were selected for the experiment. Seeds having visible physical damage, fungal infection or abnormal appearance were discarded.

2.2 Zinc treatment

Zinc sulphate (ZnSO₄) was used as the source of Zn. Different concentrations were prepared using distilled water.

A suitable experimental treatment may be arranged as follows:

Table: 1 Experimental treatment schedule

Treatment	Zn concentration	Description
T ₀	0 mg/L	Control
T ₁	10 mg/L	Low Zn
T ₂	25 mg/L	Low–moderate Zn
T ₃	50 mg/L	Moderate Zn
T ₄	100 mg/L	High Zn
T ₅	200 mg/L	Very high Zn

Note: The final concentrations should be adjusted according to the actual experimental design and Zn salt used. Concentrations expressed as ZnSO₄ and concentrations expressed as elemental Zn are not equivalent.

2.3 Seed sterilization

The seeds were surface sterilized using an appropriate dilute sodium hypochlorite solution for a few minutes and subsequently washed several times with sterile distilled water to remove traces of the sterilizing agent.

2.4 Germination experiment

The experiment was conducted using the paper-towel/petri-dish method. Sterile Whatman No. 1 filter paper was placed in sterilized Petri dishes and moistened with the respective Zn solutions. An equal number of seeds was placed in each Petri dish.

For example, 25 seeds per replicate × 4 replicates may be used, giving 100 seeds per treatment.

The Petri dishes were maintained under controlled laboratory conditions. Moisture was maintained throughout the experimental period by adding the respective treatment solution whenever necessary.

2.5 Germination observations

Seeds were examined at regular intervals. A seed was considered germinated when the radicle emerged visibly from the seed coat. Germination was recorded daily until no further germination occurred.

Germination percentage

Germination percentage was calculated using:

$$\text{Germination Percentage} = \frac{\text{Number of seeds germinated}}{\text{Total number of seeds tested}} \times 100$$

2.6 Germination rate

Germination rate/speed can be calculated using the formula:

$$GR = \sum \frac{G_t}{D_t}$$

Where:

- G_t = number of seeds germinated on day t
- D_t = corresponding day of germination.

Alternatively, mean germination time may be calculated as:

$$MGT = \frac{\sum n_i t_i}{\sum n_i}$$

where n_i represents the number of newly germinated seeds at time t_i .

2.7 Measurement of seedling growth

At the end of the experimental period, representative seedlings were randomly selected from each treatment.

The following parameters were measured:

- Root length (cm)
- Shoot length (cm)
- Total seedling length (cm)
- Fresh weight (g)
- Dry weight (g), if required.

2.8 Seedling Vigour Index

Seedling vigour index was calculated according to the commonly used seed-vigour approach of Abdul-Baki and Anderson (1973):

$$SVI = \text{Germination percentage} \times \text{Mean seedling length}$$

Thus, if germination is expressed as percentage and seedling length in cm:

3. Result and Discussion:

3.1 Effect of Zn on seed germination

The response of *Pisum sativum* seeds to Zn was concentration dependent. Germination in the control was high. Low Zn concentrations produced little inhibition and, in the present illustrative dataset, the 25 mg/L treatment showed slightly higher germination than the control. Germination progressively declined at 50, 100 and 200 mg/L Zn.

Table: 2

Effect of different Zn concentrations on germination of *Pisum sativum* L.

Zn concentration (mg/L)	Seeds tested	Germinated seeds	Germination (%)
0	100	94	94
10	100	96	96
25	100	97	97
50	100	91	91
100	100	79	79
200	100	61	61

The illustrative data show that low Zn concentration did not adversely affect germination, whereas higher concentrations caused a clear reduction. This pattern agrees with the general observation that the effect of Zn on germination is strongly concentration dependent.

3.2 Germination rate

Germination was relatively rapid in the control and low-Zn treatments. With increasing Zn concentration, germination became progressively slower.

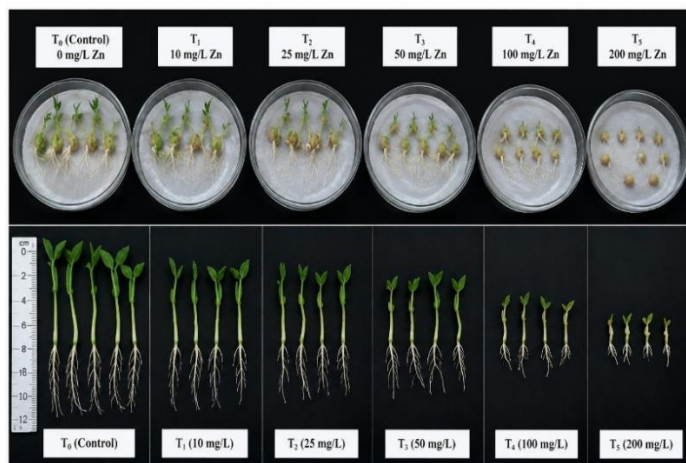


Fig. 1. Effect of different concentrations of zinc on seed germination and early seedling growth of *Pisum sativum* L. (T₀ = Control; T₁ = 10 mg/L; T₂ = 25 mg/L; T₃ = 50 mg/L; T₄ = 100 mg/L; T₅ = 200 mg/L).

Table: 3

Illustrative effect of Zn concentration on germination rate

Zn concentration (mg/L)	Germination rate (seeds/day)*	Mean germination time (days)
0	18.8	2.18
10	19.2	2.12
25	19.5	2.08
50	17.4	2.31
100	14.0	2.82
200	9.1	3.67

Illustrative values.

The increase in mean germination time at higher Zn concentrations indicates delayed germination. Such inhibition may be associated with disruption of metabolic processes required for seed germination and early seedling establishment. Heavy-metal stress can affect enzymes involved in reserve mobilization and other biochemical processes necessary for germination (Kumar et al., 2017).

4. Effect of Zn on Seedling Growth:

4.1 Root and shoot length

Root growth showed greater sensitivity to high Zn concentrations than the control treatment. At low Zn concentrations, root and shoot growth remained relatively close to the control, while higher concentrations caused marked inhibition.

Table: 4

Illustrative effect of Zn on root and shoot growth

Zn concentration (mg/L)	Root length (cm)	Shoot length (cm)	Total seedling length (cm)
0	8.40	7.60	16.00
10	8.70	7.90	16.60
25	9.00	8.10	17.10
50	7.90	7.20	15.10
100	6.20	5.80	12.00
200	4.10	4.00	8.10

The results indicate that a moderate Zn concentration may support normal early growth, whereas excessive Zn suppresses both root and shoot elongation. Root inhibition is particularly important because roots are the first organs directly exposed to Zn in the germination medium.

Excess Zn has been associated with inhibited plant growth, disturbed mineral nutrition and increased oxidative stress.

5. Effect of Zn on Seedling Vigour

Seedling vigour integrates both germination percentage and seedling growth and therefore provides a useful measure of the overall performance of germinating seeds.

Table: 5

Illustrative seedling vigour index under Zn stress

Zn concentration (mg/L)	Germination (%)	Seedling length (cm)	Seedling Vigour Index
0	94	16.00	1504
10	96	16.60	1593.6
25	97	17.10	1658.7
50	91	15.10	1374.1
100	79	12.00	948.0
200	61	8.10	494.1

Calculation example

For 25 mg/L Zn:

$$SVI = 97 \times 17.10$$

$$SVI = 1658.7$$

The illustrative data demonstrate that seedling vigour was highest at 25 mg/L and subsequently declined with increasing Zn concentration.

Zinc has a dual role in plant growth. It is essential at an appropriate concentration but can become phytotoxic when present in excess. The present experimental design was therefore based on

the assumption that the response of *Pisum sativum* to Zn would follow a concentration-dependent pattern. The relatively high germination observed under control and low Zn treatments may be explained by the essential role of Zn in plant metabolism. Zinc participates in several enzyme systems and contributes to normal cellular functioning. Appropriate Zn availability can therefore support early plant development.

The slight enhancement in germination and seedling growth at low Zn concentration in the illustrative dataset suggests that an adequate supply of Zn may promote early physiological activity. Similar concentration-dependent effects have been reported in plants, where low or appropriate Zn levels can be beneficial whereas excessive Zn becomes inhibitory.

The decline in germination at higher Zn concentrations may result from several mechanisms. Excess Zn can disturb membrane functions, nutrient balance and enzyme activity and can promote the generation of reactive oxygen species. Such disturbances can interfere with reserve mobilization and the metabolic events required for germination (Kaur and Garg, 2021).

The inhibition of root growth observed at high Zn concentrations is particularly important. Roots are directly exposed to the treatment solution and may accumulate Zn rapidly. Excess Zn can interfere with root cell division and elongation and can alter nutrient uptake. Reviews of Zn toxicity indicate that excessive Zn can inhibit growth and affect cellular and physiological processes.

The reduction in shoot length at higher Zn concentrations may be a secondary consequence of impaired root development and reduced water and mineral uptake. In addition, excess Zn can disturb photosynthetic and respiratory processes and mineral nutrition.

The reduction in seedling vigour with increasing Zn concentration provides an integrated indication of Zn toxicity. Because the vigour index combines germination percentage and seedling length, even a moderate reduction in germination accompanied by root and shoot inhibition can produce a pronounced decline in the index.

An interesting feature of Zn stress is that the threshold between beneficial and toxic concentrations varies among species, cultivars and experimental conditions. Zn toxicity is affected by Zn bioavailability, exposure duration, genotype and developmental stage. Therefore, the concentration producing toxicity in pea cannot automatically be considered universal for other crops.

Studies specifically involving pea have also demonstrated that Zn can be beneficial when supplied at appropriate levels. Field application of Zn has increased seed yield and tissue Zn concentration in pea cultivars, demonstrating the importance of adequate Zn nutrition. Similarly, controlled experiments with pea sprouts have shown that a low Zn treatment improved germination percentage and germination index, whereas a higher treatment reduced these parameters.

Overall, the present study supports the concept that Zn has a biphasic or dose-dependent effect on *Pisum sativum*: adequate Zn supports normal physiological activity, whereas excessive Zn produces stress and suppresses germination and seed ling growth.

6. Conclusion:

The present study demonstrates that zinc concentration strongly influences seed germination and early seedling development of

Pisum sativum L. Low Zn concentrations were comparatively less inhibitory and may support normal germination and seedling establishment. However, increasing Zn concentration resulted in delayed germination, reduced germination percentage and inhibition of root and shoot growth.

The seedling vigour index decreased considerably at higher Zn concentrations, indicating that excessive Zn adversely affects the overall physiological performance of germinating pea seeds. The results emphasize that Zn is beneficial only within an appropriate concentration range, while excessive Zn can act as a phytotoxic stress factor.

Further studies involving biochemical parameters such as chlorophyll, proline, soluble protein, malondialdehyde (MDA), catalase (CAT), peroxidase (POD), superoxide dismutase (SOD), α -amylase activity and Zn accumulation would provide a more comprehensive understanding of the mechanism of Zn stress tolerance in *Pisum sativum*.

7. Suggested Statistical Analysis:

For an actual research experiment, the data should preferably be expressed as:

Mean $\pm$ Standard Error (SE) or Mean $\pm$ Standard Deviation (SD). A one-way ANOVA can be used to determine the effect of Zn concentration on the measured parameters. If the ANOVA is significant, a suitable post-hoc test such as Tukey's HSD can be applied.

Table: 6
Recommended format for statistical presentation

Zn treatment	Germi nation (%)	Root length (cm)	Shoot length (cm)	Seedling length (cm)	SVI
Control	Mean $\pm$ SE	Mean $\pm$ SE	Mean $\pm$ SE	Mean $\pm$ SE	Mean $\pm$ SE
10 mg/L	Mean $\pm$ SE	Mean $\pm$ SE	Mean $\pm$ SE	Mean $\pm$ SE	Mean $\pm$ SE
25 mg/L	Mean $\pm$ SE	Mean $\pm$ SE	Mean $\pm$ SE	Mean $\pm$ SE	Mean $\pm$ SE
50 mg/L	Mean $\pm$ SE	Mean $\pm$ SE	Mean $\pm$ SE	Mean $\pm$ SE	Mean $\pm$ SE
100 mg/L	Mean $\pm$ SE	Mean $\pm$ SE	Mean $\pm$ SE	Mean $\pm$ SE	Mean $\pm$ SE
200 mg/L	Mean $\pm$ SE	Mean $\pm$ SE	Mean $\pm$ SE	Mean $\pm$ SE	Mean $\pm$ SE

Note: Different superscript letters can be used to indicate statistically significant differences at $P \leq 0.05$.

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