RESEARCH ARTICLE Legume Research- An International Journal, Volume 48 Issue 5: 773-779 (May 2025)

Evaluating the Impact of Selenium on Germination and Early Growth Stages of *Phaseolus vulgaris*: A Comprehensive Study

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10.18805/LRF-852

ABSTRACT

Background: Selenium is an essential micronutrient for plants, playing a critical role in various physiological processes. However, its effects on plant growth can be dual, acting as both a beneficial nutrient and a potential toxin depending on its concentration. This study investigates the impact of selenium on the germination and early growth stages of *Phaseolus vulgaris* (common bean), a crop of significant agricultural importance.

Methods: The experiment was conducted under controlled laboratory conditions at Kahramanmaras Sutcu Imam University (Kahramanmaras/Turkey) in 2022 year. *Phaseolus vulgaris* seeds were subjected to different selenium concentrations: 0, 1, 2, 4, 8, 16, 32, 64, 128, 256, 512 and 1024 mg/l. The seeds were incubated in Petri dishes and monitored for various parameters including plumula length, radicle length, germination ratio, germination index and seed vigor index.

Result: It is indicated that both genotype and selenium dose had significant effects on the evaluated parameters. Lower selenium doses (0,1,2,4,8 and 16 mg/l) generally promoted germination and growth, while higher doses (32 mg/l and above) had inhibitory effects. The germination ratio, germination index and seed vigor index were significantly higher at lower selenium concentrations, indicating an optimal dose for enhancing seedling vigor and growth. The findings highlight the dual role of selenium as both a nutrient and a potential toxin, depending on its concentration. This study provides valuable insights into optimizing selenium application for improving the growth and productivity of common bean plants. Understanding the optimal selenium levels for different genotypes can aid in developing better fertilization strategies for sustainable agriculture.

Key words: Germination, *Phaseolus vulgaris*, Seed vigor, Selenium.

INTRODUCTION

Selenium is not classified as a heavy metal; rather, it is considered a *non-metal* or *metalloid* among chemical elements. Although selenium can be toxic at high doses, it is essential for the body in small amounts and is classified as a trace element (WHO, 2020). It plays an important role in the function of certain enzymes and antioxidant systems (Feng *et al.,* 2013; dos Reis *et al.,* 2017; Andrade *et al.,* 2018; Silva *et al.,* 2020). Therefore, selenium falls into a different category than heavy metals and has distinct biological effects. On the other hand negative effects of heavy metals on various living organisms have been reported in numerous studies (Olgunoglu and Olgunoglu, 2016; Olgunoglu *et al.,* 2021; Artar *et al.,* 2024).

Selenium (Se) is an essential micronutrient that plays a crucial role in various physiological processes in plants (Gupta and Gupta, 2017; Xia *et al.,* 2021; Gui *et al.,* 2022; Titov *et al.,* 2022; Zesmin *et al.,* 2023). It is known for its dual role as both a nutrient and a potential toxin, depending on its concentration in the environment (Damalas *et al.,* 2019). Selenium is taken up by plants primarily in the form of selenate (SeO_2^{-4}) and selenite (SeO_2^{-3}) and its accumulation and distribution within the plant can significantly influence plant growth and development (Pyrzyñska, 2002; Smoleñ *et al.,* 2016; Wen *et al.,* 2024).

Selenium's impact on plant growth has been extensively studied (Chao, 2022; Khan *et al.* 2023; Samynathan *et al.* 2023). At low concentrations, selenium can promote plant growth by enhancing antioxidant capacity, improving stress resistance and stimulating growth hormones (Hawrylak-Nowak, 2008; Hasanuzzaman *et al.,* 2014).

However, at higher concentrations, selenium can become toxic, leading to oxidative stress, membrane damage and inhibition of growth (Bodnar *et al.,* 2012; Wen

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How to cite this article: Cokkizgin, A., Girgel, U., Kara, Z. and Cokkizgin, H. (2025). Evaluating the Impact of Selenium on Germination and Early Growth Stages of *Phaseolus vulgaris*: A Comprehensive Study. Legume Research. 48(5): 773-779. doi: 10.18805/LRF-852.

Submitted: 15-01-2025 **Accepted:** 07-02-2025 **Online:** 12-03-2025

et al., 2018). This dual role makes it essential to understand the optimal selenium levels for different plant species and cultivars (Gupta and Gupta, 2017).

Phaseolus vulgaris (common bean) is an important legume crop with significant nutritional and economic value (Girgel *et al*., 2023). The common bean is known for its high protein content and essential nutrients, making it a staple food in many parts of the world. The germination and early growth stages of common bean plants are critical for determining overall plant health and productivity. Previous studies have shown that selenium supplementation can influence germination rates, seed vigor and seedling growth in common bean and other legume species (Bal *et al.,* 2021; Karaman *et al.,* 2023).

Selenium's effects on germination and seed vigor have been a focus of research due to its potential to improve crop yields and stress resilience. For instance, studies have reported that selenium application can enhance germination rates and seedling growth in selenium-deficient soils, providing a strategy for improving crop productivity under challenging environmental conditions (Smoleñ *et al.,* 2016; Damalas *et al.,* 2019). Additionally, selenium has been shown to mitigate the negative effects of abiotic stresses such as drought, salinity and extreme temperatures in various crops, including common bean (Terry *et al.,* 2000; Bodnar *et al.,* 2012; Mohajeri *et al.,* 2016; Huang *et al.,* 2018; Pereira *et al.,* 2018; Elkelish *et al.,* 2019; Mata-Ramírez *et al.,* 2019; Sattar *et al.,* 2019). The objective of this study was to investigate the effects of selenium on the germination and early growth stages of *Phaseolus vulgaris* (common bean) plants. Specifically, the study aimed to evaluate the impact of different selenium concentrations on parameters such as plumula length, radicle length, germination ratio, germination index and seed vigor index. By understanding these effects, the research seeks to provide insights into optimizing selenium application for enhancing the growth and productivity of common bean plants under controlled environmental conditions.

Materials and Methods

Experimental design

This experiment was conducted at the Kahramanmaras Sutcu Imam University, University-Industry-Public Collaboration, Development, Application and Research Center (Kahramanmaras/Turkey) under controlled laboratory conditions between June and September 2022. The study aimed to investigate the effects of selenium (SeO2-4) on various parameters (plumula length, radicle length, germination ratio, germination index and seed vigor index) of *Phaseolus vulgaris* (common bean) plants.

Plant material and treatments

Phaseolus vulgaris

seeds were used as the plant material. The seeds were subjected to different selenium (SeO_2^{-4}) treatments with varying concentrations: 0, 1, 2, 4, 8, 16, 32, 64, 128, 256, 512 and 1024 mg/l. The seeds were placed in Petri dishes containing filter paper moistened with selenium solutions of the respective concentrations. Each treatment was replicated three times.

Experimental setup

The seeds were incubated in a growth chamber under controlled environmental conditions:

a) Temperature: 25±1°C.
b) Relative humidity: 70%.
c) Photoperiod: 16 hours light/8 hours dark (Karaman *et al.,* 2023).

Parameters evaluated

Plumula length

The length of the shoot was measured using a digital caliper after a specified growth period (Bal *et al.,* 2021).

Radicle length

The length of the root was measured using a digital caliper (Smoleñ *et al.,* 2016).

Germination ratio

The percentage of seeds that successfully germinated was recorded (Damalas *et al.,* 2019).

Germination index

According to Damalas *et al.* (2019), the germination index was determined by evaluating the speed and efficiency of seed germination over time. Daily germination counts were recorded to calculate the overall germination performance (Wen *et al.,* 2018).

Seed vigor index

As described by Finch-Savage and Bassel (2016), the seed vigor index was assessed by combining the germination percentage with the lengths of the plumula and radicle. This index reflects the overall health and growth potential of the seeds (Cokkizgin and Colkesen, 2012; Cokkizgin, 2012).

Statistical analysis

The data obtained from the experiment were subjected to ANOVA to determine the significance of differences between treatments with SAS program (SAS, 2006). Tukey's HSD test was used for multiple comparisons to identify specific differences between treatment groups (Tukey, 1941; Tukey, 1949; Mohajeri *et al.,* 2016).

Results and Discussion

Plumula length

The ANOVA results indicate that both genotype and selenium dose have significant effects on plumula length in bean plants (Fisher, 1925; Kirk, 2012) (Table 1). However, the interaction between genotype and dose was not significant ($p = 0.3748$) (Whanger, 2002; Lyons, 2010).

Genotype

The genotype had a significant effect on plumula length ($F(1, 48) = 9.64$, $p = 0.0032$) (Kirk, 2012). Aydintepe had a higher mean plumula length (1.33556) compared to Ispir, which had a mean of 1.05694. This suggests that Aydintepe is more resilient or responsive to selenium, possibly due to inherent genetic differences (Whanger, 2002) (Table 2).

Selenium dose

Selenium dose had a highly significant effect on plumula length ($F(11, 48) = 35.32$, $p<0.0001$) (Hawrylak-Nowak, 2008) (Table 3). Lower doses of selenium (0 and 1 mg/l) resulted in higher plumula lengths:

0 mg/l: Mean plumula length = 2.6683

1 mg/l: Mean plumula length = 2.7033

As the selenium dose increased, the plumula length decreased dramatically:

32 mg/l: Mean plumula length = 1.3667

64 mg/l: Mean plumula length = 0.8500

256 mg/l and above: Mean plumula length = 0

These results indicate that lower doses of selenium are optimal for promoting plumula growth, suggesting that selenium is beneficial in small amounts but detrimental at higher concentrations. This aligns with previous studies indicating that selenium can act as both a micronutrient and a toxin, depending on its concentration (Fisher, 1925; Kirk, 2012; Lyons, 2010).

The findings of this study are supported by previous research showing that selenium supplementation can significantly affect plant growth and development. For instance, Whanger (2002) and Hawrylak-Nowak (2008) found that selenium can enhance plant growth at low concentrations, but higher concentrations can be toxic. Similarly, Lyons (2010) demonstrated that the efficiency of selenium biofortification in cereals depends on the concentration used, with low doses being beneficial.

These findings are crucial for agricultural practices, especially in selenium-rich or deficient soils. Understanding the optimal selenium concentrations for different genotypes can help in formulating better fertilization strategies to maximize crop yield and quality (Hawrylak-Nowak, 2008). Furthermore, the significant performance of Aydintepe over Ispir suggests that specific genotypes may have inherent advantages in terms of resilience to environmental stressors, making them more suitable for selenium-enriched soils (Lyons, 2010).

Radicle length

The ANOVA results indicate that both genotype and selenium dose have significant effects on radicle length in bean plants (Fisher, 1925; Kirk, 2012). Additionally, the interaction between genotype and dose was found to be significant ($p<0.0001$) (Whanger, 2002; Lyons, 2010) (Table 1).

Genotype

The analysis shows that genotype significantly impacts radicle length [$F(1, 48) = 13.69$, $p = 0.0006$] (Kirk, 2012). Aydintepe exhibited a higher mean radicle length (1.255) compared to Ispir, which averaged 0.9375. These results suggest Aydintepe's greater resilience or responsiveness to selenium, likely due to inherent genetic traits (Recek *et al.,* 2021) (Table 2).

Selenium dose

Selenium dose had a profound effect on radicle length ($F(11, 48) = 36.67$, $p<0.0001$) (Baalbaki *et al.,* 2018) (Table 3). Lower selenium doses (0 and 1 mg/l) led to longer radicles:

0 mg/l: Mean radicle length = 3.0383

1 mg/l: Mean radicle length = 1.9000

Higher doses of selenium resulted in a significant reduction in radicle length:

2 mg/l: Mean radicle length = 1.6167

Table 1: Summary of variance analysis for the examined parameters.

Source of variation	df	Mean square				
		Plumule length	Radicle length	Germination rate	Germination index	Seed vigor index
Genotype	1	1.39723**	1.81451**	7001.388**	9.07712**	2999.251
Se Conc.	11	5.11881**	4.86001**	7392.803**	6.97581**	144828.49**
Genot. × Se Conc.	11	0.16077	0.65908**	266.540**	0.37602**	5913.504*
Error	48	0.14490	0.13252	71.527	0.05610	2318.187
Corrected total	71					
Coeff var	31.82180	33.20791	16.77503	16.49128	29.07095	
R-square	0.89529	0.90765	0.96374	0.97092	0.93722	

Table 2: Mean values and formed tukey groups for the examined parameters by varieties*.

Genotypes	Plumule length	Radicle length	Germination rate	Germination index	Seed vigor index
Aydintepe	1.33556[a]	1.25500[a]	40.556[b]	1.08126[b]	159.17[a]
Ispir	1.05694[b]	0.93750[b]	60.278[a]	1.79139[a]	172.08[a]
Mean	1.196	1.096	50.417	1.436	165.621

*Means with the same letter are not significantly different.

8 mg/l: Mean radicle length = 1.5167
32 mg/l: Mean radicle length = 1.0500
64 mg/l: Mean radicle length = 0.7167
128 mg/l: Mean radicle length = 0.5500
256 mg/l: Mean radicle length = 0.0833
512 mg/l and 1024 mg/l: Mean radicle length = 0

These findings suggest that lower selenium doses are optimal for enhancing radicle growth, confirming that selenium can be beneficial in small amounts but harmful at higher concentrations. This observation aligns with earlier studies demonstrating selenium's dual role as a nutrient and toxin, depending on the dosage (Paul *et al.,* 2024; Baalbaki *et al.,* 2018).

The results of this study are corroborated by past research indicating that selenium supplementation can significantly influence plant growth and development. Whanger (2002) and Hawrylak-Nowak (2008) found that selenium could promote plant growth at low levels, while high levels proved toxic. Similarly, Lyons (2010) showed that selenium biofortification's efficiency in cereals is dependent on the concentration, with low doses providing benefits.

Understanding the optimal selenium levels for different genotypes is vital for agricultural practices, particularly in selenium-abundant or deficient soils. These insights can help develop better fertilization strategies to maximize crop yield and quality (Recek *et al.,* 2021). The superior performance of Aydintepe over Ispir also indicates that certain genotypes may possess inherent advantages in dealing with environmental stresses, making them more suitable for selenium-enriched soils (Paul *et al.,* 2024).

Germination rate

The ANOVA analysis reveals that both genotype and selenium dose significantly influence germination ratio in bean plants (Fisher, 1925; Kirk, 2012). Furthermore, a significant interaction between genotype and dose was detected (p = 0.0007) (Table 1).

Genotype

The results indicate that the germination ratio is markedly affected by genotype (F (1, 48) = 97.88, p < 0.0001) (Kirk, 2012). Ispir showed a higher mean germination ratio (60.278) compared to Aydintepe, which averaged 40.556. These findings suggest that Ispir's genetic traits may confer greater resilience or responsiveness to selenium (Recek *et al.,* 2021) (Table 2).

Selenium dose

The dose of selenium had a profound impact on the germination ratio (F (11, 48) = 103.36, p < 0.0001) (Baalbaki *et al.,* 2018) (Table 3). Lower selenium doses (0, 1, 2, 4, 8 and 16 mg/l) were associated with higher germination ratios:
0 mg/l: Mean germination ratio = 86.667
1 mg/l: Mean germination ratio = 80.000
2 mg/l: Mean germination ratio = 78.333
4 mg/l: Mean germination ratio = 75.000
8 mg/l: Mean germination ratio = 78.333
16 mg/l: Mean germination ratio = 73.333
Conversely, higher doses of selenium significantly reduced the germination ratio:
32 mg/l: Mean germination ratio = 67.500
64 mg/l: Mean germination ratio = 42.500
128 mg/l: Mean germination ratio = 22.500
256 mg/l: Mean germination ratio = 0.833
512 mg/l and 1024 mg/l: Mean germination ratio = 0

These results highlight that optimal germination is achieved with lower selenium doses, emphasizing selenium's role as both beneficial in small amounts and harmful at higher concentrations. This observation is consistent with previous research indicating selenium's dual role depending on its dosage (Baalbaki *et al.,* 2018; Kong *et al.,* 2022).

Further studies have supported these findings, showing selenium supplementation can significantly influence plant germination and development. For example,

Table 3: Mean values and statistical groups formed from different selenium doses for the examined parameters*.

Se Conc.	Plumule length	Radicle length	Germination rate	Germination index	Seed vigor index
0	2.6683^{a}	3.0383^{a}	86.667^{a}	3.1447^{a}	478.45^{a}
1	2.7033^{a}	1.9000^{b}	80.000^{ab}	2.5263^{b}	364.78^{b}
2	1.7317^{b}	1.6167^{bc}	78.333^{ab}	2.1745^{bc}	262.51^{c}
4	1.5133^{bc}	1.5167^{bc}	78.333^{ab}	2.1394^{bcd}	221.55^{cd}
8	1.3833^{bcd}	1.5000^{bc}	75.000^{ab}	2.0478^{cd}	220.66^{cd}
16	1.3717^{bcd}	1.1833^{bcd}	73.333^{ab}	1.8485^{cd}	184.75^{cd}
32	1.3667^{bcd}	1.0500^{cd}	67.500^{b}	1.6997^{d}	164.33^{d}
64	0.8500^{cde}	0.7167^{de}	42.500^{c}	1.0787^{e}	65.08^{e}
128	0.6667^{def}	0.5500^{de}	22.500^{d}	0.5526^{f}	25.33^{e}
256	0.1000^{ef}	0.0833^{e}	0.833^{e}	0.0238^{g}	0.00^{e}
512	0.0000^{f}	0.0000^{e}	0.000^{e}	0.0000^{g}	0.00^{e}
1024	0.0000^{f}	0.0000^{e}	0.000^{e}	0.0000^{g}	0.00^{e}
Mean	1.196	1.096	50.417	1.436	165.621

*Means with the same letter are not significantly different.

Whanger (2002) and Hawrylak-Nowak (2008) found that selenium promotes germination at low levels but becomes toxic at higher levels. Similarly, Lyons (2010) demonstrated the effectiveness of selenium biofortification in cereals, noting the benefits of low doses.

Understanding the appropriate selenium levels for different genotypes is crucial for agricultural practices, especially in selenium-rich or deficient soils. These insights can aid in developing better fertilization strategies to optimize crop yield and quality (Recek *et al.,* 2021). The superior performance of Ispir over Aydintepe also suggests that specific genotypes may have inherent advantages in managing environmental stresses, making them more suitable for selenium-enriched soils (Baalbaki *et al.,* 2018).

Germination index

The ANOVA results clearly demonstrate that both genotype and selenium dose significantly impact the germination index in bean plants. Moreover, a significant interaction between genotype and selenium dose was observed ($p<0.0001$) (Karaman and Turkay, 2023) (Table 1).

Genotype

Our analysis indicates that the genotype has a substantial impact on the germination index ($F(1, 48) = 161.78$, $p< 0.0001$). Ispir presented a higher mean germination index (1.79139) compared to Aydintepe, which averaged 1.08126. These results highlight that Ispir's genetic attributes may provide greater adaptability or responsiveness to selenium (Recek *et al.,* 2021) (Table 2).

Selenium dose

The selenium dose significantly affected the germination index ($F(11, 48) = 124.33$, $p<0.0001$) (Damalas *et al.,* 2019) (Table 3). Lower selenium doses (0, 1, 2, 4, 8 and 16 mg/l) resulted in higher germination indices:
0 mg/l: Mean germination index = 3.1447
1 mg/l: Mean germination index = 2.5263
2 mg/l: Mean germination index = 2.1745
4 mg/l: Mean germination index = 2.0478
8 mg/l: Mean germination index = 2.1394
16 mg/l: Mean germination index = 1.8485
Conversely, higher selenium doses led to a marked reduction in the germination index:
32 mg/l: Mean germination index = 1.6997
64 mg/l: Mean germination index = 1.0787
128 mg/l: Mean germination index = 0.5526
256 mg/l: Mean germination index = 0.0238
512 mg/l and 1024 mg/l: Mean germination index = 0

These findings underline that optimal germination is achieved with lower selenium doses, emphasizing selenium's dual role as both beneficial in small amounts and detrimental at higher concentrations. This is consistent with previous studies indicating selenium's role as both a nutrient and a toxin, depending on its dosage (Mohajeri *et al.,* 2016; Damalas *et al.,* 2019).

Supporting literature shows that selenium supplementation can significantly influence plant germination and development. Whanger (2002) and Hawrylak-Nowak (2008) demonstrated that selenium promotes germination at low levels, while high levels are toxic. Similarly, Karaman *et al.* (2023) highlighted the effectiveness of selenium biofortification in cereals, noting the benefits of low doses.

Understanding the optimal selenium levels for different genotypes is critical for agricultural practices, particularly in selenium-rich or deficient soils. These insights can aid in developing better fertilization strategies to optimize crop yield and quality (Recek *et al.,* 2021). The superior performance of Ispir over Aydintepe also suggests that specific genotypes may possess inherent advantages in managing environmental stresses, making them more suitable for selenium-enriched soils (Karaman *et al.,* 2023).

Seed vigor index

The ANOVA analysis reveals that both genotype and selenium dose significantly influence the Seed Vigor Index in bean plants. Additionally, the interaction between genotype and selenium dose was found to be significant ($p = 0.0125$) (Bal *et al.,* 2021) (Table 1).

Genotype

Our analysis indicates that genotype does not significantly impact the Seed Vigor Index ($F(1, 48) = 1.29$, $p = 0.2610$). Both Ispir and Aydintepe showed similar mean Seed Vigor Indices, suggesting that genetic differences may not play a crucial role in this aspect under the conditions studied (Recek *et al.,* 2021) (Table 2).

Selenium dose

The selenium dose had a substantial effect on the Seed Vigor Index ($F(11, 48) = 62.47$, $p < 0.0001$) (Smoleñ *et al.,* 2016) (Table 3). Lower selenium doses (0, 1, 2, 4, 8 and 16 mg/l) were associated with higher Seed Vigor Indices:
0 mg/l: Mean seed vigor index = 478.45
1 mg/l: Mean seed vigor index = 364.78
2 mg/l: Mean seed vigor index = 262.51
4 mg/l: Mean seed vigor index = 221.55
8 mg/l: Mean seed vigor index = 220.66
16 mg/l: Mean seed vigor index = 184.75
In contrast, higher selenium doses led to a marked reduction in the seed vigor index:
32 mg/l: Mean seed vigor index = 164.33
64 mg/l: Mean seed vigor index = 65.08
128 mg/l: Mean seed vigor index = 25.33
256 mg/l: Mean seed vigor index = 0.00
512 mg/l and 1024 mg/l: Mean seed vigor index = 0

These results emphasize that optimal seed vigor is achieved with lower selenium doses, underscoring selenium's dual role as both beneficial in small amounts and detrimental at higher concentrations. This aligns with previous studies indicating selenium's dual role as a nutrient and a toxin, depending on its dosage (Bal *et al.,* 2021; Smoleñ *et al.,* 2016).

The literature supports these findings, showing that selenium supplementation can significantly influence seed

vigor and overall plant development. Whanger (2002) and Smoleñ *et al.* (2016) demonstrated that selenium promotes seed vigor at low levels, while high levels are toxic. Similarly, Karaman *et al.* (2023) highlighted the effectiveness of selenium biofortification in cereals, noting the benefits of low doses.

Understanding the optimal selenium levels for different genotypes is crucial for agricultural practices, particularly in selenium-rich or deficient soils (Zhou *et al.,* 2023). These insights can aid in developing better fertilization strategies to optimize crop yield and quality (Recek *et al.,* 2021). The similar performance of Ispir and Aydintepe suggests that other factors beyond genetic differences may influence seed vigor under varying selenium doses (Karaman *et al.,* 2023).

CONCLUSION

In conclusion, lower selenium doses were found to enhance germination and seedling growth, indicating selenium's beneficial role as a micronutrient at optimal concentrations. Conversely, higher selenium doses (32 mg/l and above) inhibited growth, highlighting selenium's potential toxicity when present in excess. These findings underscore the dual nature of selenium as both an essential nutrient and a potential toxin, depending on its concentration.

ACKNOWLEDGEMENT

No financial support from any institution or organization was received for this study. The authors independently funded the entirety of this research.

Disclaimers

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Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this article. No funding or sponsorship influenced the design of the study, data collection, analysis, decision to publish, or preparation of the manuscript.

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