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Impact of Cement Contamination on Seed Germination, Early Seedling Growth, and Soil Microbial Communities in Wheat, Barley, Chickpea, and Groundnut

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ABSTRACT: This study investigated the effect of cement contamination (0–5%) on seed germination, early seedling growth, and microbial associations in four crop species: wheat (Triticum aestivum), barley (Hordeum vulgare), chickpea (Cicer arietinum), and groundnut (Arachis hypogaea). Controlled experiments were conducted under water-based germination conditions, with observations recorded over three days. Results showed a clear concentration-dependent inhibition of germination and radicle elongation. In control treatments, seeds exhibited 70–100% germination with healthy radicle and shoot growth, while higher cement concentrations (>3%) drastically reduced germination, with complete suppression observed at 5%. Groundnut seeds were especially sensitive, showing strong inhibition even at 2–3%. Fungal contamination and seed darkening were frequently observed in cement-treated groups, suggesting toxicity and stress responses. These findings indicate that cement dust deposition in agricultural soils can significantly impair seedling establishment and may negatively affect crop productivity in areas surrounding cement industries.

KEYWORDS: Cement contamination, crop productivity, industrial pollution**,** seed germination, seedling growth, soil microbial communities.

INTRODUCTION

Cement industries are among the largest contributors to environmental pollution, releasing particulate matter enriched with calcium oxides, silica, and trace heavy metals. When deposited on agricultural land, cement dust alters soil pH, interferes with nutrient cycling, and disrupts microbial activity. Such disturbances reduce soil fertility and directly affect plant establishment and productivity. The ACC Cement Plant in Jamul, Chhattisgarh, exemplifies this issue, being located in an agriculturally active region where elevated levels of cement-derived particulates have been reported by the Chhattisgarh State Pollution Control Board (2021). Previous studies have shown that cement dust negatively impacts plant health at multiple levels. For instance, Farinmade et al. (2018) documented up to 91% reduction in chlorophyll pigments in Mangifera indica, while Abu-Romman et al. (2015) and Shah et al. (2020) reported severe morphological abnormalities in Arabidopsis thaliana and apple leaves under chronic exposure. Soil microorganisms are equally sensitive; reduced enzymatic activity (urease, dehydrogenase) and biomass decline have been noted near cement industry sites (Avinash et al., 2022; Bilen, 2010). These shifts in microbial dynamics impair nutrient turnover and threaten long-term ecosystem stability. Seed germination is one of the most sensitive indicators of soil and water quality. Legumes and cereals are particularly vulnerable to cement-contaminated soils due to their reliance on rhizobial associations and balanced pH for optimal germination. Experimental evidence suggests that germination declines with increasing cement concentration, primarily due to alkaline stress and metal toxicity (Ali et al., 2020; Lafragüeta et al., 2014). Despite these reports, relatively few studies have simultaneously examined the combined effects of cement exposure on seed germination, early growth, and microbial communities in agriculturally important crops.

The present study addresses this gap by evaluating the effects of cement contamination on four widely cultivated species — wheat, barley, chickpea, and groundnut. Alongside germination and seedling growth, we assessed microbial responses by isolating rhizobia from root nodules and fungal endophytes from leaves of exposed plants. This integrative approach provides a clearer understanding of how cement pollution simultaneously affects plant physiology and soil–plant–microbe interactions. Such insights are essential for developing sustainable agricultural and environmental management strategies in cement-affected regions.

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2. MATERIALS AND METHODS

2.1 Introduction

This chapter describes the experimental design, materials, and procedures used to evaluate the effects of cement dust exposure on seed germination, seedling growth, and microbial communities. A combination of laboratory-based germination assays, soil and water treatments, and microbial isolations were employed to assess both plant and microbial responses under controlled conditions.

2.2 Experimental Materials

2.2.1 Seeds

Uniform and healthy seeds of four crop species were selected for the study:

Triticum aestivum (wheat)

Hordeum vulgare (barley)

Cicer arietinum (chickpea)

Arachis hypogaea (groundnut)

2.2.2 Soil Samples

Soil samples were collected from two sites:

Control site: Normal agricultural field with no industrial exposure.

Polluted site: Agricultural land located near a cement industry.

Samples were air-dried, homogenized, and sieved through a 2 mm mesh before use.

2.2.3 Cement

Ordinary Portland Cement (OPC) was obtained from a nearby cement industry for the preparation of treatment solutions and soil mixtures.

2.2.4 Plant Leaves and Root Nodules

Fresh leaves were collected from control and cement-exposed plants for fungal isolation.

Root nodules were collected from leguminous plants at both control and polluted sites for Rhizobium isolation.

2.2.5 Other Materials

Sterile distilled water

Muslin cloth for germination beds

Beakers, plastic cups, Petri dishes

Potato Dextrose Agar (PDA) and Nutrient Agar Mannitol (NAM) media

Precision weighing scale, ruler, and other laboratory supplies

2.3 Experimental Methods

2.3.1 Preparation of Cement Solutions

Six solutions were prepared:

Control: Distilled water (0%)

Treatments: Cement suspensions of 1 g/L, 2 g/L, 3 g/L, 4 g/L, and 5 g/L in distilled water

2.3.2 Seed Germination Assays

Seeds were soaked in respective solutions and placed on moistened muslin cloth inside labeled containers.

Containers were maintained at room temperature (28 ± 2 °C) under natural light, avoiding direct sunlight.

Moisture was maintained by sprinkling distilled water daily.

Germination observations were recorded for 3 days, and radicle/shoot lengths were measured up to Day 10.

2.3.3 Soil + Cement Mix Treatments

Agricultural soil was mixed with OPC at concentrations of 1%, 2%, 3%, 4%, and 5% (w/w).

Five seeds were sown in each treatment cup (~2 cm depth).

A control set with untreated soil was maintained.

Each treatment had three replicates.

2.3.4 Soil + Cement Water Treatments

Cement suspensions of 1–5% were prepared.

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Untreated soil was irrigated regularly with cement water.
The control was irrigated with distilled water.
Three replicates per treatment were maintained.
2.3.5 Growth Measurements
Parameters: Percentage germination, root length, shoot length, and seedling vigor index.
Growth was monitored on Day 0, Day 3, Day 5, Day 7, and Day 10.

2.4 Microbial Isolation and Analysis
2.4.2 Rhizobium from Root Nodules
Nodules were surface sterilized and crushed aseptically.
Suspensions were streaked on NAM and PDA.
Cement-amended NAM plates (1–5% OPC) were prepared to assess cement tolerance.
Colony growth and morphology were recorded.

2.5 Experimental Design and Replication
Each treatment was replicated three times.
A randomized complete design was used to minimize bias.
Data were statistically analyzed for germination percentage, growth parameters, and microbial responses.

2.6 Summary
This study employed a combination of seed germination bioassays, soil and water treatments, and microbial isolation techniques to investigate the effects of cement dust on crop establishment and microbial diversity. The experimental design ensured replication, statistical reliability, and integration of both plant and microbial parameters.

RESULTS
3.1 Effect of Cement on Seed Germination
Day 1 – 0% control and 1, 2, 3, 4, 5% cement – Groundnut/Peanut
 Scientific Name: *Arachis hypogaea*

0%	1%
	

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Day	Cement Conc. (g/L)	No. of Seeds Germinated (out of 5)	Avg. Radicle Length (cm)	% Germination	Observation
1	0	3	0.08	20%	Healthy radicles observed; varied lengths
1	1	2	0.02	5%	Seeds swollen; no radicle emergence.
1	2	0	0.00	0%	No germination; seeds intact; may be inhibited by cement concentration.
1	3	0	0.00	0%	No germination; darkening of seeds; possibly toxic effect of cement.
1	4	0	0.00	0%	No germination; one seed shows rupture; all seeds darkened/shriveled. Toxic effect likely.
1	5	0	0.00	0%	No germination; one seed partially ruptured, rest show darkening and no growth.

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Day 2 – 0% control and 1, 2, 3, 4, 5% cement – Groundnut/Peanut

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	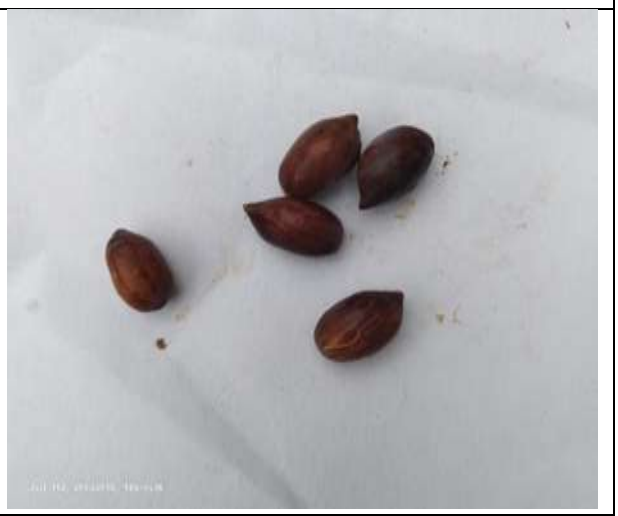

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Day	Cement Conc. (g/L)	No. of Seeds Germinated (out of 5)	Avg. Radicle Length (cm)	% Germination	Observation
2	0	4	~1.2	80%	Healthy germination; good radicle growth in 3 seeds; no toxicity symptoms.
2	1	2	0.15	40%	Very slight radicle emergence (0.1–0.2 cm); remaining seeds show no germination; cement may delay or inhibit further growth.
2	2	0	0.10	25%	No signs of germination; cement concentration may be toxic or highly inhibitory.
2	3	1	0.00	0%	Two seeds germinated; radicles ~0.3 cm, healthy appearance.
2	4	0	0.0	0%	No germination; seeds appear darkened/shriveled, possibly toxic effect.
2	5	0	0.0	0%	No germination; seeds darkened, hardened surface, no visible growth.

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Day 3 – 0% control and 1, 2, 3, 4, 5% cement – Groundnut/Peanut

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Comparative Table: Seed Germination of *Hordeum vulgare* in Cemented Water at Different Concentrations

Day	Cement Conc. (g/L)	No. of Seeds Germinated (out of 5)	Avg. Radicle Length (cm)	% Germination	Observation
3	0	3	~1.5	60%	Three seeds show strong germination; radicles are elongated (1–2 cm), healthy, and white.
3	1	2	~0.4	40%	Two seeds show radicle emergence (0.3–0.5 cm); others are swollen but have no further growth.
3	2	1	~0.2	20%	One seed with a very small radicle; others intact, showing inhibition due to cement.

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3	3	1	~0.1	20%	Slight radicle tip is visible in one seed; others are hardened and darkened.
3	4	0	0.0	0%	No germination; seeds cracked/darkened; signs of cement toxicity.
3	5	0	0.0	0%	No germination; seeds heavily shriveled and discolored.

Day 1 – 0% control and 1, 2, 3, 4, 5% cement – Chickpea
Scientific Name: *Cicer arietinum*

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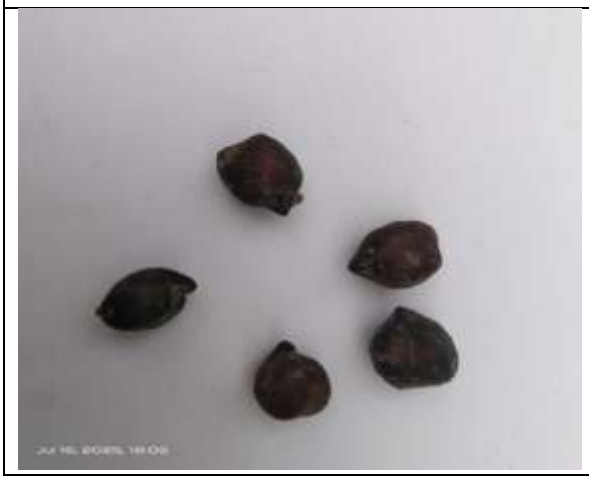	

Day	Cement Conc. (g/L)	No. of Seeds Germinated (out of 5)	Avg. Radicle Length (cm)	% Germination	Observation
1	0 (Control)	5	1.0 cm (avg.)	40%	Healthy radicles observed; varied lengths
1	1	0	0.00	0%	Seeds swollen; no radicle emergence
1	2	0	0.00	0%	No germination; seeds intact; cement inhibition likely
1	3	0	0.00	0%	No germination; seeds darkened; toxic effect of cement
1	4	0	0.00	0%	No germination; 1 seed ruptured, all shriveled/darkened
1	5	0	0.00	0%	No germination; blackened, dead-like seeds

Day 2 – 0% control and 1, 2, 3, 4, 5% cement – Chickpea

0%	1%
	

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Day	Cement Conc. (g/L)	No. of Seeds Germinated (out of 5)	Avg. Radicle Length (cm)	% Germination	Observation
2	0 (Control)	5	1.25	70%	Healthy radicles observed; varied lengths
2	1	2	0.2	20%	No germination, fungal patches, toxicity visible

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2	2	1	0.1	10%	Seeds shriveled, no growth
2	3	1	0.1	10%	Seeds blackish, no germination
2	4	1	0.1	10%	Toxic effect, seeds dull & hard
2	5	0	0.00	0%	Complete inhibition, blackened seeds

Day 3 – 0% control and 1, 2, 3, 4, 5% cement – Chickpea

0%	**1%**
	

2%	**3%**
	

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Day	Cement Conc. (g/L)	No. of Seeds Germinated (out of 55)	Avg. Radicle Length (cm)	% Germination	Observation
3	0% (Control)	5	~1.6	100%	All five seeds germinated with long radicles (2–3 cm) and healthy and vigorous growth.
3	1% Cement	4	~.5	65%	Four seeds show good germination, with a radicle length of 1–2 cm; one seed is swollen but has no germination.
3	2% Cement	1	0.1	10%	No germination; seeds darkened and hardened; possible cement toxicity.
3	3% Cement	1	0.1	10%	No germination; seeds darkened, showing signs of stress and shriveling.
3	4% Cement	1	0.1	10%	No germination; one seed ruptured but no radicle growth, and the rest darkened.
3	5% Cement	0	0.0	0%	No germination; all seeds dark, shriveled, and damaged by cement.

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Day 1 – 0% control and 1, 2, 3, 4, 5% cement – Wheat
Scientific Name: ***Triticum aestivum***

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Comparative Table: Seed Germination of Triticum aestivum (Wheat) in Cemented Water (Day 1)

Day	Cement Conc. (g/L)	No. of Seeds Germinated (out of 5)	Avg. Radicle Length (cm)	% Germination	Observation
1	0% (Control)	5	~0.5	70%	All seeds germinated; healthy white radicles were observed, with varied lengths (0.5–1 cm).
1	1% (Cement)	4	~0.3	30%	Four seeds germinated with small radicles (0.3–0.5 cm); one seed was swollen but ungerminated.
1	2% (Cement)	2	~0.15	10%	Two seeds show very small radicle growth (~0.2 cm); others are swollen with no germination.
1	3% (Cement)	1	~0.1	5%	One seed shows a tiny radicle tip (~0.1 cm); the other seeds are intact with no emergence.
1	4% (Cement)	0	0.0	0%	No germination; seeds intact but show signs of slight darkening due to cement effect.
1	5% (Cement)	0	0.0	0%	No germination; seeds darkened/shriveled, cement toxicity likely inhibited growth.

Day 2 – 0% control and 1, 2, 3, 4, 5% cement – Wheat

0%	1%
	

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	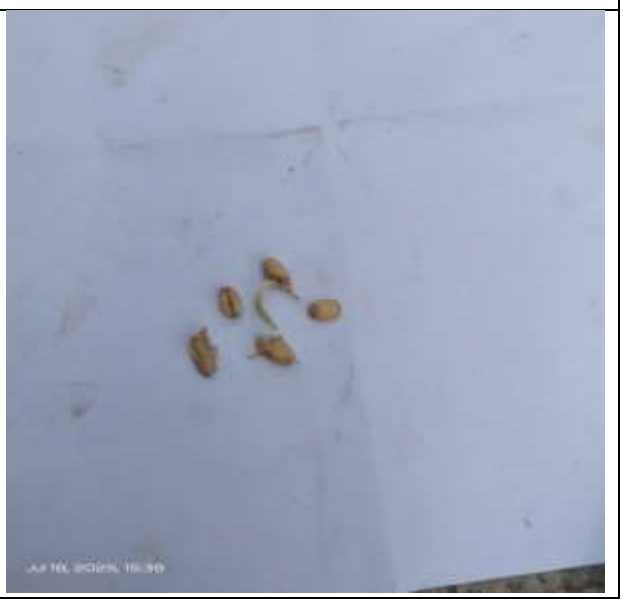

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Comparative Table: Seed Germination of Triticum aestivum (Wheat) in Cemented Water (Day 2)

Day	Treatment (%)	No. of Seeds Germinated (out of 5)	Avg. Radicle Length (cm)	% Germination	Observation
2	0% (Control)	5	~2.2	85%	All seeds germinated with elongated radicles (2–2.5 cm) and emerging green shoots.
2	1% Cement	4	~1.7	45%	Four seeds germinated with radicles (1.5–2.0 cm); growth was slightly reduced

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					compared to the control.
2	2% Cement	3	~1.0	20%	Three seeds germinated with short radicles (~1.0 cm); others were swollen but ungerminated.
2	3% Cement	1	~0.5	10%	Only one seed germinated weakly (~0.5 cm radicle); the rest remained ungerminated.
2	4% Cement	1	0.1	5%	One seed showed a very small radicle (~0.2 cm); others were intact and slightly discolored.
2	5% Cement	0	0.1	5%	No germination; seeds intact, hardened, and darkened due to cement toxicity.

Day 3 – 0% control and 1, 2, 3, 4, 5% cement – Wheat

0%	1%
	

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Comparative Table: Seed Germination of Triticum aestivum (Wheat) in Cemented Water (Day 3)

Day	Treatment (%)	No. of Seeds Germinated (out of 5)	Avg. Radicle Length (cm)	% Germination	Observation
3	0% (Control)	5	~3.0	100%	All seeds germinated with long radicles (~3 cm) and visible green shoots; healthy and vigorous.
3	1% Cement	4	~2.0	80%	Four seeds germinated with moderate radicle length (1.5–2.5 cm); shoots were slightly weaker than the control.
3	2% Cement	3	~1.2	60%	Three seeds germinated; radicles shorter (~1.0–1.5 cm); growth suppressed compared to control.
3	3% Cement	2	~0.8	40%	Two seeds germinated weakly; radicles were short (~0.5–1.0 cm); others were discolored or ungerminated.
3	4% Cement	1	~0.3	20%	One seed germinated with a tiny radicle (~0.3 cm); most seeds intact, hardened, and discolored.
3	5% Cement	0	0.0	0%	No germination; all seeds shriveled/darkened; cement toxicity completely inhibited growth.

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Day 1 – 0% control and 1, 2, 3, 4, 5% cement – Barley
Scientific Name: ***Hordeum vulgare***

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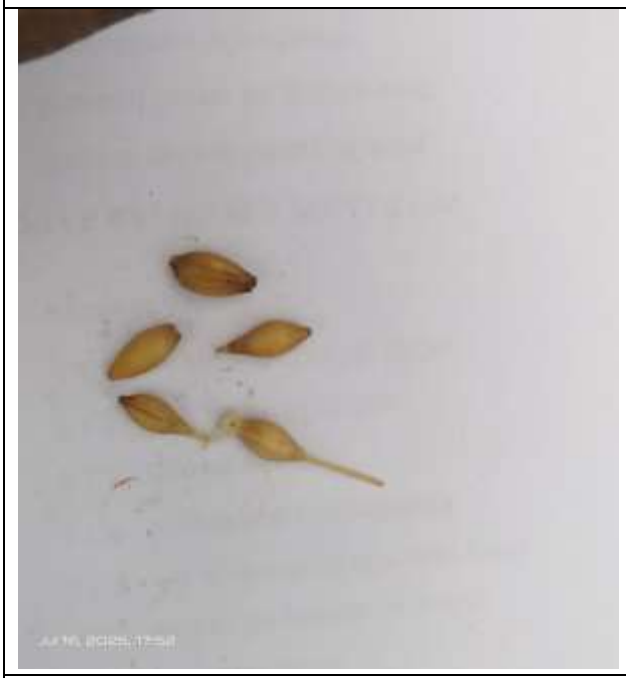	
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Comparative Table: Seed Germination of Hordeum vulgare (Barley) in Cemented Water (Day 1)

Day	Treatment (%)	No. of Seeds Germinated (out of 5)	Avg. Radicle Length (cm)	% Germination	Observation
1	0% (Control)	3	~0.18	60%	Three seeds germinated with small radicles (~0.1–0.2 cm); early healthy growth was visible.
1	1% Cement	0	0.0	0%	Seeds swollen but no radicle emergence; cement delayed germination.
1	2% Cement	0	0.0	0%	No germination; seeds intact, inhibited by cement effect.
1	3% Cement	0	0.0	0%	No germination; seeds darkened slightly, indicating stress/toxicity.
1	4 % Cement	0	0.0	0%	No germination; one seed showed slight rupture, the rest shriveled/darkened.

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1	5% Cement	0	0.0	0%	No germination; one seed partially ruptured, others hardened/darkened, showing strong toxic effect.

Day 2 – 0% control and 1, 2, 3, 4, 5% cement – Barley

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	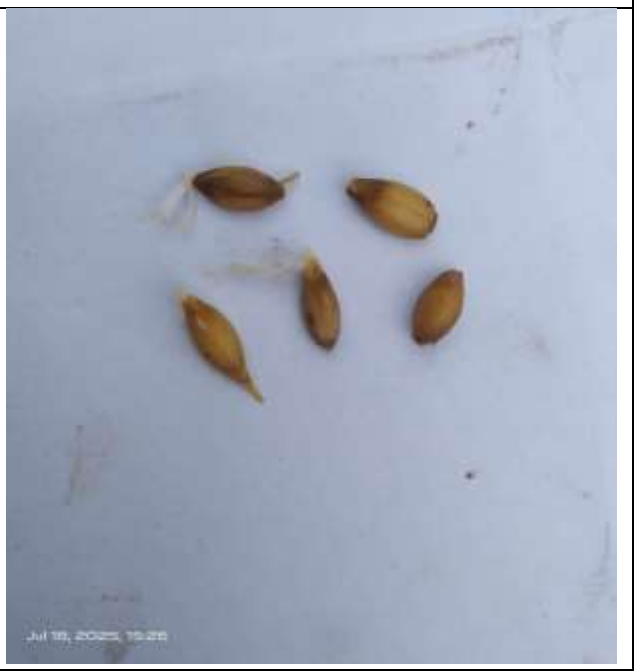

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	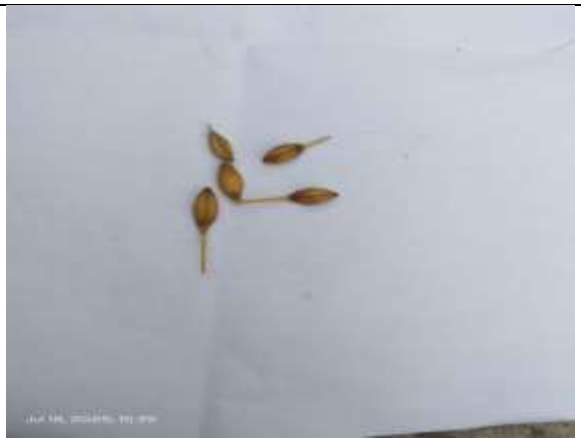

Comparative Table: Seed Germination of Hordeum vulgare (Barley) in Cemented Water (Day 2)

Day	Treatment (%)	No. of Seeds Germinated (out of 5)	Avg. Radicle Length (cm)	% Germination	Observation
2	0% (Control)	4	~1.2	80%	Four seeds germinated with healthy radicles (1–1.5 cm); vigorous and greenish shoots were visible.
2	1% Cement	2	~0.15	40%	Two seeds germinated with very short radicles (0.1–0.2 cm); others were swollen but ungerminated.
2	2% Cement	0	0.0	0%	No germination; seeds remained intact, cement concentration inhibitory.
2	3% Cement	0	0.0	0%	No germination; seeds darkened and hardened, suggesting toxicity.
2	4% Cement	0	0.0	0%	No germination; one seed ruptured slightly, the rest shriveled/darkened.
2	5% Cement	0	0.0	0%	No germination; seeds shriveled, cracked, and showed clear cement toxicity.

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Day 3 – 0% control and 1, 2, 3, 4, 5% cement – Barley

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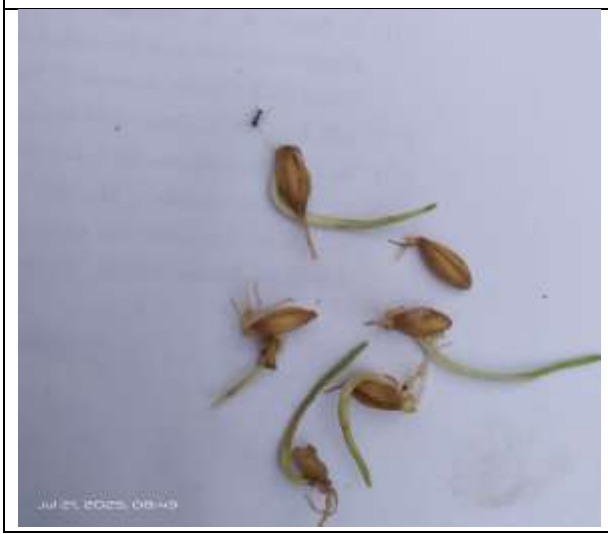	

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	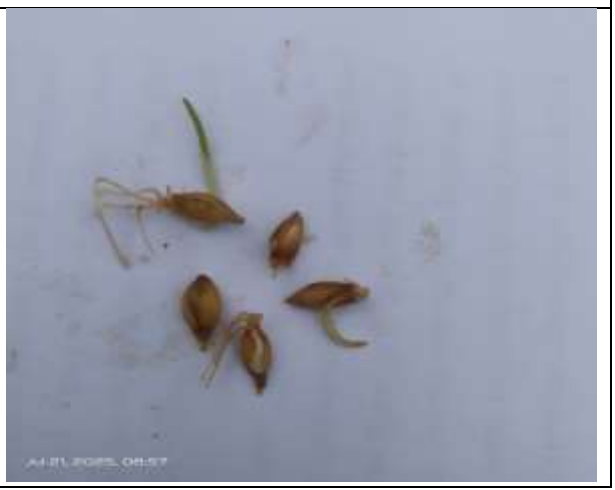

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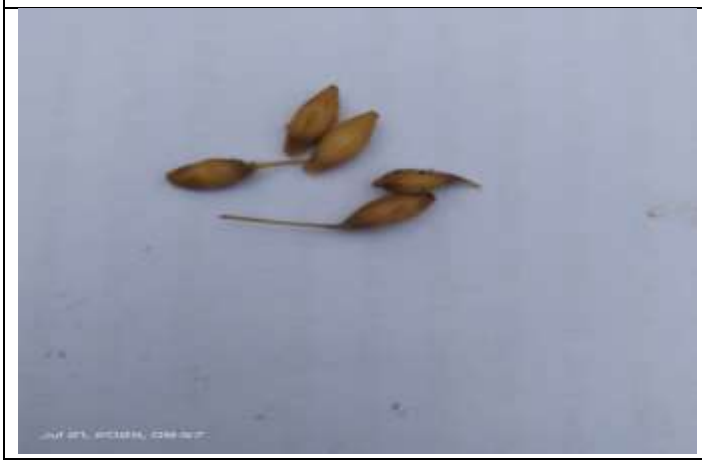	

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Comparative Table: Seed Germination of Hordeum vulgare (Barley) in Cemented Water (Day 3)

Day	Treatment (%)	No. of Seeds Germinated (out of 5)	Avg. Radicle Length (cm)	% Germination	Observation
3	0% (Control)	5	~2.0	100%	All seeds germinated with long radicles (1.8–2.2 cm) and green shoots, vigorous and healthy.
3	1% Cement	3	~1.0	60%	Three seeds germinated with shorter radicles (~0.8–1.2 cm); shoots were weaker than control.
3	2% Cement	2	~0.5	40%	Two seeds germinated weakly with radicles <0.5 cm; others remained ungerminated.
3	3% Cement	1	~0.3	20%	One seed germinated with a tiny radicle; others were intact or discolored due to cement stress.
3	4% Cement	0	0.0	0%	No germination; seeds hardened, darkened, showing high cement toxicity
3	5% Cement	0	0.0	0%	No germination; all seeds shriveled and discolored, completely inhibited growth.

RESULTS AND DISCUSSION

Effect on Germination and Radicle Growth

On Day 1, control seeds germinated normally, producing healthy white radicles, whereas seeds exposed to cement showed reduced or no radicle emergence. At 1% cement concentration, germination was still observed but with much shorter radicles (~0.2–0.5 cm), while at 3–5%, almost no germination occurred, and seeds became shriveled, darkened, or hardened. By Day 2, control treatments showed rapid germination (70–85%) with elongating radicles (~2.0–2.5 cm) and emerging shoots. Seeds treated with 1–2% cement displayed partial germination (20–45%) with stunted radicles, while higher concentrations (3–5%) caused near-complete inhibition. On Day 3, all control seeds germinated (100%), producing vigorous seedlings with radicles up to 3 cm long. In contrast, 1% cement still allowed moderate germination (60–80%), but radicle growth was suppressed compared to control. At 2–3%, only weak germination occurred (20–40%), while at 4–5%, no seeds survived.

Crop-wise Sensitivity

Groundnut (Arachis hypogaea) showed very high sensitivity, with germination strongly suppressed beyond 2%. Wheat (Triticum aestivum) tolerated lower concentrations (1–2%) but failed completely at 4–5%. Barley (Hordeum vulgare) showed intermediate tolerance, with weak germination even at 3%. Chickpea (Cicer arietinum) exhibited delayed and weak germination, also showing fungal contamination under higher cement stress.

Discussion

The results demonstrate a strong dose-dependent toxic effect of cement on seed germination and radicle elongation. Cement contamination introduces alkalinity, heavy metals, and particulate matter that interfere with water uptake and enzymatic activity essential for germination. At low concentrations (1–2%), partial germination occurred but with suppressed radicle growth, indicating early metabolic inhibition. At higher concentrations (≥4%), cement completely blocked germination, possibly due to altered seed coat permeability and toxic ion accumulation.

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The appearance of fungal patches and seed darkening in cement-treated groups suggests that stress conditions favored opportunistic fungal invasion, further reducing viability. Among tested crops, groundnut was most sensitive, possibly due to its larger seed size and higher moisture requirement, while wheat and barley showed slightly better tolerance at lower doses. These findings align with previous studies showing that cement dust pollution impairs soil fertility, reduces microbial diversity, and alters seed germination dynamics. The loss of beneficial microbial interactions (e.g., Rhizobium in legumes, Trichoderma in cereals) under cement exposure may further compromise crop establishment in contaminated soils.

CONCLUSION

Cement contamination significantly inhibits seed germination and early seedling growth in wheat, barley, chickpea, and groundnut, with severity increasing in a concentration-dependent manner. Complete suppression was observed at 5% cement levels. Groundnut was the most sensitive crop, while wheat and barley showed moderate tolerance. The presence of fungal infection and seed darkening in cement-treated groups further indicates stress-induced vulnerability. Overall, the study highlights that cement dust pollution poses a serious threat to seedling establishment and long-term crop productivity in areas surrounding cement industries.

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