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Assessing the Agricultural Viability of Textile Printing Wastewater: Dose-Dependent Effects on Germination and Early Growth of *Vigna radiata L.*

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ABSTRACT

Textile industrial activities generate substantial wastewater that may threaten aquatic and terrestrial ecosystems when inadequately managed. This study evaluated the phytotoxic effects of textile printing effluent from Sanganer, Jaipur, India, on seed germination and early seedling growth of *Vigna radiata L.* Effluent samples were characterized for selected physicochemical parameters using standard APHA methods. Germination bioassays were performed with five effluent concentrations. A clear concentration-dependent response was observed. At 25% effluent (T1), germination (95.67%) and shoot length (4.93 cm) were close to the control values (96.00% and 5.47 cm, respectively). At 100% effluent (T4), germination declined to 74.00%, while shoot and root lengths decreased to 3.93 and 3.10 cm, respectively ($p < 0.05$). The raw effluent was alkaline (pH 8.5) and contained elevated TDS (680 mg/L), COD (740 mg/L), and sodium (340 mg/L), conditions consistent with osmotic and ionic stress. The results indicate that undiluted textile effluent is unsuitable for direct agricultural use, whereas substantial dilution and/or appropriate treatment should be considered before reuse for irrigation.

Introduction

Water scarcity is a major constraint on agriculture, particularly in arid and semi-arid regions. Consequently, the reuse of municipal and industrial wastewater for irrigation is increasing. Industrial effluents may supply nutrients, but untreated wastewater can also introduce salts, alkalinity, organic loads, and other contaminants that adversely affect soil and plant development [Khan, *et,al*, 2025]. Textile printing and dyeing are water-intensive processes, reportedly requiring 150–200 L of water per kilogram of textile processed, and generate wastewater containing a complex mixture of dissolved and suspended constituents [Chavan, 2001, Bharadwaj, 1999]. In Rajasthan, textile-producing areas such as Sanganer and Jodhpur have a long history of wastewater-related environmental concerns, and contaminated water may be used for irrigation where freshwater is limited [Rastogi and Gautam 1999, Verma and Sharma 2012]. Although low concentrations of some organic and mineral constituents may not inhibit plant growth, excessive salinity, alkalinity, and chemical oxygen demand can impair water uptake, nutrient availability, and plant physiological processes [Radosevich *et.al*.1997, Nagda , *et.al*. 2006].

Seed germination is a sensitive developmental stage and provides a useful bioassay for evaluating the phytotoxicity of industrial effluents [APHA, 1998, ISTA, 2004]. Therefore, this study assessed the effects of graded concentrations of textile printing wastewater from Sanganer, Jaipur, on germination and early root and shoot development of *Vigna radiata L.*

Materials and Methods

Effluent collection and physicochemical characterization

Industrial effluent samples were collected from discharge outlets of textile printing units in Sanganer, Jaipur, India, using clean HDPE containers. Samples were transported to the laboratory and maintained below 50°C to minimize biochemical changes before analysis. pH, electrical conductivity (EC), total dissolved solids (TDS), biochemical oxygen demand (BOD), chemical oxygen demand (COD), dissolved oxygen (DO), and the major ions Na+, K+, Ca^2+, and Mg^2+ were determined according to APHA standard methods [APHA,1998,].

2.2 Preparation of experimental treatments

Raw effluent was diluted with double-distilled water to prepare five treatments: T0, 0% effluent (control); T1, 25% effluent (25 mL effluent + 75 mL distilled water); T2, 50% effluent (50 mL + 50 mL); T3, 75% effluent (75 mL + 25 mL); and T4, 100% raw effluent (100 mL).

Table 1 Composition of the working effluent treatments.

Treatment	Effluent Concentration (%)	Volume of Effluent (mL)	Volume of Distilled Water (mL)
T0	0 (Control)	0	100
T1	25	25	75
T2	50	50	50
T3	75	75	25
T4	100	100	0

Germination and seedling growth bioassay

Healthy and uniform *Vigna radiata L.* seeds were surface-sterilized with 0.1% (w/v) $HgCl_2$ for 5 min and rinsed repeatedly with sterile distilled water. For each treatment, 25 seeds were placed uniformly in Petri dishes lined with two layers of Whatman No. 1 filter paper, with three biological replicates per treatment. Each dish initially received 5 mL of the respective treatment solution. Plates were incubated in darkness for 48 h and subsequently maintained under a 12 h light/12 h dark cycle. On day 3, 15 mL of the standard nutrient solution specified for the experimental dilution gradient was added to sustain seedling growth. Germination percentage and root and shoot lengths were recorded on day 7 following ISTA procedures [ISTA 2004].

Statistical analysis

Data were expressed as mean ± standard deviation (SD) of the biological replicates. Treatment effects were evaluated using one-way analysis of variance (ANOVA), with $p < 0.05$ considered statistically significant.

Results and Discussion

Physicochemical characteristics of the effluent

The raw textile effluent was dark brown, had an unpleasant odour, and was alkaline (pH 8.5). It showed elevated COD (740 mg/L), TDS (680 mg/L), total alkalinity (330 mg/L), and relatively low DO (3.0 mg/L). Sodium was the dominant measured cation (340 mg/L), followed by calcium (250 mg/L), magnesium (60 mg/L), and potassium (15 mg/L).

Table 2 Physicochemical characteristics of the raw textile printing effluent.

S.No	Parameter	Value
1	Odour	Unpleasant
2	pH	8.5
3	Electrical Conductivity (EC, dS/m)	2.00
4	Chemical Oxygen Demand (COD, mg/L)	740
5	Biochemical Oxygen Demand (BOD, mg/L)	68.0
6	Dissolved Oxygen (DO, mg/L)	3.0
7	Total Solids (TS, mg/L)	850
8.	Total Suspended Solids (TSS, mg/L)	220
9.	Total Dissolved Solids (TDS, mg/L)	680
10.	Total Alkalinity (mg/L)	330
11.	Magnesium (Mg2+ mg/L)	60
12.	Potassium (K+, mg/L)	15
13.	Calcium (Ca2+, mg/L)	250
14.	Sodium (Na+, mg/L)	340

Effects on seed germination and seedling growth

Increasing effluent concentration was associated with reduced germination and seedling growth (Table 3). The control (T0) showed the highest germination (96.00%) and the greatest shoot and root lengths (5.47 and 4.80 cm, respectively). At 25% effluent (T1), germination remained 95.67%, with shoot and root lengths of 4.93 and 4.67 cm. At 50% (T2) and 75% (T3), germination decreased to 85.33% and 82.00%, respectively. The undiluted effluent (T4) produced the strongest inhibition, with germination of 74.00% and shoot and root lengths of 3.93 and 3.10 cm. Overall treatment differences were statistically significant ($p < 0.05$).

Table 3. Effect of textile printing effluent on *Vigna radiata L.* growth parameters on day 7 (mean ± SD).

Treatment	Effluent Conc. (%)	Shoot Length (cm) (Mean ± SD)	Root Length (cm) (Mean ± SD)	Seed Germination (%) (Mean ± SD)
T0	Control (0%)	5.47 ±0.15	4.80 ±0.20	96.00 ± 1.00
T1	25%	4.93 ±0.23	4.67 ±0.15	95.67 ± 1.15
T2	50%	4.60 ±0.26	4.43 ±0.21	85.33 ± 2.52
T3	75%	4.23 ±0.32	4.10 ±0.20	82.00 ±1.00
T4	100%	3.93 ±0.15	3.10 ±0.10	74.00 ±2.00

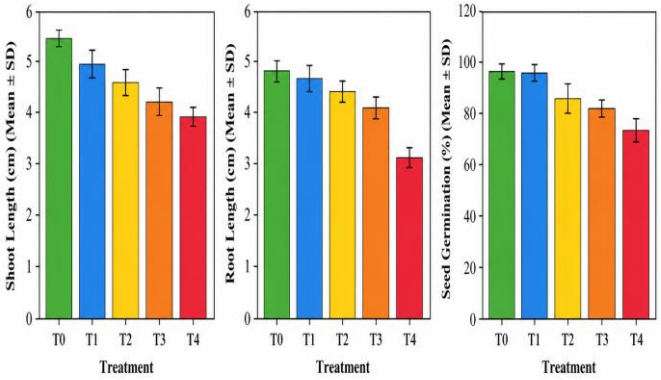

Fig-1 Effect of textile mill effluent on growth parameters of *Vigna radiate L.* (Day 7)

The concentration-dependent inhibition observed at higher effluent levels is consistent with osmotic stress and ion-associated toxicity. The elevated TDS and sodium concentration may increase external osmotic pressure and restrict water uptake during germination and early seedling development [Khan, and Sheikh, 1976, Sinha, and Paul 2013]. Textile effluents with high salt loads and organic content have similarly been reported to inhibit germination and early growth in crop species, including wheat, mustard, and peanut [Kurmi, *et al* 2023, Sinha and Paul 2013, Saravanamoorthy and Ranjitha Kumari 2007].

Alkalinity may additionally influence nutrient availability and root function, while the high COD indicates a substantial organic load. In the present experiment, the relatively small effect at 25% dilution suggests that dilution reduced the immediate phytotoxic pressure; however, the progressive decline at 50–100% demonstrates that reuse without adequate treatment or dilution may adversely affect crop establishment. Similar concerns have been reported for agricultural reuse of industrial wastewater, particularly with respect to salinity and soil degradation.

Conclusion

Raw textile printing effluent from Sanganer, Jaipur, exhibited clear phytotoxic effects on *Vigna radiata L.*, with inhibition increasing with effluent concentration. Undiluted effluent substantially reduced germination and early root and shoot growth. The results indicate that raw effluent should not be applied directly to agricultural soils. Dilution to lower concentrations and, preferably, suitable treatment should be evaluated before agricultural reuse, with particular attention to salinity, sodium, alkalinity, and organic load.

Declarations

Author contributions: Parul Sharma, Sapana Singhal and Komal Sharma contributed to the study conception and design, experimental work, data analysis, interpretation of results, and preparation and revision of the manuscript. Both authors approved the final manuscript.

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