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Athira N
ICAR-Indian Agricultural Research Institute, Pusa Campus, New Delhi, India

Prativa Anand
ICAR-Indian Agricultural Research Institute, Pusa Campus, New Delhi, India

MC Singh
ICAR-Indian Agricultural Research Institute, Pusa Campus, New Delhi, India

Sandeep Kumar Lal
ICAR-Indian Agricultural Research Institute, Pusa Campus, New Delhi, India

Prasenjit Ray
ICAR-Indian Agricultural Research Institute, Pusa Campus, New Delhi, India

Debasis Golui
ICAR-Indian Agricultural Research Institute, Pusa Campus, New Delhi, India

Mahesh Kumar
ICAR-Indian Agricultural Research Institute, Pusa Campus, New Delhi, India

Corresponding Author:
Prativa Anand
ICAR-Indian Agricultural Research Institute, Pusa Campus, New Delhi, India

Growth, flowering, root traits and seed yield response of marigold (*Tagetes erecta* L.) to nickel and zinc levels in irrigation water

Athira N, Prativa Anand, MC Singh, Sandeep Kumar Lal, Prasenjit Ray, Debasis Golui and Mahesh Kumar

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Abstract
Environmental pollution caused by heavy metals is a global concern due to their persistence and toxicity in soil and water ecosystems. The present study investigated the effects of varying concentrations of nickel (Ni) and zinc (Zn) in irrigation water on the growth, flowering, root morphology, and seed yield of marigold (*Tagetes erecta* L.). The experiment was conducted under controlled pot conditions with eight treatments (T_1-T_8) involving different concentrations of Ni (0.2-2 mg L^{-1}) and Zn (2-10 mg L^{-1}), individually and in combination. Growth, morphological, and reproductive parameters were recorded to assess metal tolerance and accumulation response. Results revealed that moderate Zn levels (2 mg L^{-1}; T_5) significantly enhanced plant height, leaf area, root length, and flower yield compared to control, whereas high combined metal concentrations (Ni 2 mg L^{-1} + Zn 10 mg L^{-1}; T_8) caused marked reductions in growth and biomass. Moderate metal stress stimulated root proliferation, facilitating higher metal uptake. Overall, *T. erecta* exhibited strong tolerance and maintained aesthetic quality under low to moderate contamination, indicating its suitability as an ornamental phytoremediator for marginal or wastewater-irrigated soils. These findings suggest that marigold can serve as an effective, eco-friendly crop for remediation of Ni-Zn-polluted environments while retaining commercial value.

Keywords: Marigold, phytoextraction, heavy metals, nickel, zinc, irrigation water

Introduction
Environmental pollution caused by heavy metals is a critical problem in many countries worldwide, stemming from both natural processes and human activities. The rapid pace of urbanization and industrial growth has led to large amounts of industrial effluents mixing with sewage and river water (Raj *et al.*, 2006) [20]. Due to the scarcity of irrigation water, marginal farmers are increasingly using such contaminated sewage water to irrigate their fields. This practice inadvertently introduces a significant number of heavy metals into the agricultural ecosystem (Kumar and Dhingra, 2005) [14]. Essential heavy metals, such as copper (Cu), zinc (Zn), manganese (Mn), nickel (Ni), and iron (Fe), are necessary for normal plant growth and development. However, an excess of these metals can negatively impact plant growth, photosynthesis, respiration, enzyme activity, DNA structure and function, and membrane stability (Goswami and Das, 2016) [11].

A variety of physical, chemical, and biological techniques have been utilized to clean up sites contaminated with heavy metals. However, conventional methods for remediating heavy metal-contaminated soil and water may not always be viable due to technical, environmental, or cost-related challenges (Lajayer *et al.*, 2017) [15]. Recently, plant-based remediation, known as phytoremediation, has gained attention as a cost-effective and environmentally sustainable approach for tackling heavy metal pollution in soils and water bodies (Wan *et al.*, 2016) [23]. Phytoremediation includes several strategies, such as phytoextraction, phytostabilization, photoevaporation, rhizofiltration, and rhizodegradation (Liu *et al.*, 2008; Mahar *et al.*, 2016) [16, 18]. Among these, phytoextraction has emerged as a promising remediation strategy, characterized by its simplicity, speed, and eco-friendly nature, enabling plants to absorb, transport, and accumulate hazardous contaminants from the environment into their tissues. Research by Salt *et al.* (1995) [21] has shown that the cost of phytoextraction could be ten times lower than traditional remediation methods. During current times, phytoextraction is considered the most vital phytoremediation technique due to its durability and potential for commercial application.

Using edible crops for phytoextraction is generally not recommended, as heavy metals can enter the food chain, posing risks to human and animal health (Gupta *et al.*, 2013) [12]. In contrast, ornamental plants offer a more feasible option due to their diversity and abundance; local ornamental plants can be tested for their potential to extract heavy metals in contaminated environments (Liu *et al.*, 2008 [16]; Wang and Liu, 2014 [24]). Marigold (*Tagetes erecta*) is a visually appealing and widely cultivated ornamental plant from the Asteraceae (Compositae) family (Lorenzi and Souza, 2001) [17]. The rapid growth and extensive root system of *Tagetes erecta*, along with its ability to establish itself in poor soils, indicate that it may be suitable for the remediation of areas contaminated by metal pollution. Therefore, the present study was undertaken to assess the growth, flowering, root traits and seed yield of *Tagetes erecta* under varying Ni and Zn concentrations in irrigation water.

Materials and Methods

The experiment was conducted at the Centre for Protected Cultivation Technology (CPCT), ICAR-Indian Agricultural Research Institute, New Delhi (77°16′ E; 28°62′ N; altitude 228 m amsl) during 2023-24. Seeds of Tagetes erecta (variety 'Pusa Bahar') were sown in October 2023 in seed-trays; seedlings were grown for one month to minimise mortality. Surface soil (0-15 cm) was collected from the IARI farm (28°38′6.3″ N, 77°08′56.3″ E), air-dried, ground and passed through a 2 mm sieve. Soil was mixed thoroughly and used for pot experiment. Four kg of prepared soil was placed in each plastic pot. A basal dose of fertilisers equivalent to 100:80:80 kg ha^{-1} (Urea 267 mg kg^{-1}, DAP 308 mg kg^{-1}, MOP 236 mg kg^{-1}) was applied in solution form. One-month-old seedlings were transplanted into pots, labelled and irrigated with solutions containing the specified Ni and Zn concentrations at regular intervals. A completely randomized design (CRD) was used with eight treatments (T_1 - Control: irrigation water; T_2 - Ni at 0.2 mg L^{-1}; T_3 - Ni at 1 mg L^{-1}; T_4 - Ni at 2 mg L^{-1}; T_5 - Zn at 2 mg L^{-1}; T_6 - Zn at 5 mg L^{-1};T_7 - Zn at 10 mg L^{-1}; T_8 - Ni at 2 mg L^{-1} + Zn at 10 mg L^{-1}) and three replications. Weeding was performed manually weekly. Pinching of main shoot for uniformity was done at 45 days after transplanting.

Observations recorded: A range of morphological, growth, reproductive and root-system parameters were recorded. Plant height (cm) was measured from soil base to apical shoot at flowering stage. Plant spread (cm) was measured in North-South and East-West directions; average taken. Number of primary and secondary branches per plant at full bloom were recorded. Number of leaves per plant and leaf area were measured on average-sized leaves. Shoot diameter (mm) at ~5 cm above ground was measured using digital vernier. For shoot length (cm), shoot fresh and dry weight (g) - whole shoot was removed, fresh weight was recorded, then oven-dried at 80 °C for 48 h for dry weight. Days taken for bud initiation, full bloom, number of flowers/plant, flower diameter (mm), fresh weight and dry weight of individual flower (g) were taken. senescence and flower shelf-life were recorded. Root parameters like root length (cm), root diameter (mm), root surface area (cm^2), root volume (cm^3), number of root tips were measured using Root Image Analyzer (WinRHIZO software). For root fresh weight and dry weight (g) roots were washed, blotted, weighed fresh, then dried at 80 °C for 48 h for dry weight. Seed parameters included 100 seed weight (g), seed yield per plant (g), seed germination (%) (rolled paper towel method at 25±2 °C; first count on day 3, final on day 14), seedling dry weight (mg) after drying at 50 °C for 48 h. Seedling vigour index -I and II were recorded as per the formula suggested by Abdul-Baki and Anderson (1973) [1] as given below:

Seedling vigour index-I (Length) = Germination percentage (%) × Seedling length (cm) seedling vigour index-II (Mass) = Germination% × seedling dry weight (mg).

Statistical analysis: Data were analysed using ANOVA (Completely Randomised Design) via Web-Based Agricultural Statistics Software Package 2.0 (WASP 2.0).

Results and Discussion

Growth and morphological response

The growth performance of *Tagetes erecta* was strongly influenced by varying concentrations of nickel (Ni) and zinc (Zn) in irrigation water. Plant height varied significantly among treatments, ranging from 42.67 cm to 54.00 cm. The maximum height (54.00 cm) was recorded in plants treated with Zn @ 2 mg/L (T_5), followed by Ni @ 0.2 mg/L (T_2) and Zn @ 5 mg/L (T_6), which produced plants of 53.33 cm and 52.33 cm, respectively. Conversely, the combination of Ni @ 2 mg/L + Zn @ 10 mg/L (T_8) resulted in the shortest plants (42.67 cm), suggesting that high combined levels of Ni and Zn induced phytotoxicity and suppressed vegetative growth. This results are in conformity with findings of Cakmak, 2008 [9]. who suggested that zinc at moderate concentrations appears to enhance auxin metabolism and enzymatic activity, promoting cell elongation and division. Plant spread also exhibited significant differences, ranging from 33.17 cm to 45.33 cm. The widest spread was observed in T_5 (Zn @ 2 mg/L), indicating that optimal Zn levels improve canopy expansion and photosynthetic surface area. Treatments T_1 (Control), T_2 (Ni @ 0.2 mg/L), and T_6 (Zn @ 5 mg/L) performed comparably, whereas T_8 recorded the smallest spread, reiterating the inhibitory impact of excessive heavy metal accumulation. Number of primary and secondary branches followed a similar pattern. The highest number of primary branches (15.67) and secondary branches (56.67) were recorded in T_5, while the lowest (9.00 and 35.33, respectively) occurred in T_8. Moderate Zn levels are known to stimulate meristematic activity and branching, whereas elevated heavy metal concentrations disrupt cytokinin synthesis and inhibit lateral bud formation (Broadley *et al.*, 2007) [6]. Leaf area varied significantly among treatments (12.33-28.67 cm^2). The maximum leaf area (28.67 cm^2) was obtained under Zn @ 2 mg/L (T_5), suggesting improved cell expansion and chlorophyll synthesis. In contrast, Ni @ 2 mg/L + Zn @ 10 mg/L (T_8) recorded the smallest leaves, likely due to heavy metal-induced chloroplast damage and impaired stomatal regulation (Gautam *et al.*, 2017) [10]. The number of leaves ranged from 207.00 to 322.33, with the highest count in T_5, followed by T_2. Shoot growth parameters such as length, diameter, and biomass also exhibited significant treatment effects. Maximum shoot length (37.00 cm), diameter (10.85 mm), and fresh weight (83.60 g) were recorded in T_5, closely followed by T_2. The lowest values were obtained in T_8 (23.33 cm, 9.09 mm, and 67.73 g, respectively). Similarly, shoot dry weight was highest in T_5

(21.53 g) and lowest in T_8 (19.40 g). The findings confirm that zinc at moderate concentration enhances marigold growth by stimulating enzymatic and hormonal activities, while low nickel levels contribute to nitrogen metabolism and chlorophyll synthesis (Brown *et al*., 1987; Gautam *et al*., 2017) [7, 10]. However, excessive accumulation of these metals disrupts nutrient uptake, reduces root growth, and causes oxidative stress, leading to growth inhibition.

Table 1: Growth and morphological response of marigold (*Tagetes erecta* L.) in response to nickel and zinc levels in irrigation water

Treatment	Plant Height(cm)	Plant Spread(cm)	No of primary branches	No of secondary branches	No. of leaves	Leaf Area (cm^2)	Shoot Length (cm)	Shoot Diameter (mm)	Shoot Fresh Weight (g)	Shoot Dry Weight (g)
T_1	48.00^{abcd}	42.50^{abc}	13.00^{abc}	45.67^{bcd}	249.00^{c}	23.33^{bc}	30.33^{c}	10.06^{cde}	69.40^{ef}	20.20^{c}
T_2	53.33^{ab}	43.83^{ab}	14.33^{ab}	52.00^{ab}	312.00^{a}	26.33^{ab}	35.67^{ab}	10.19^{ab}	81.27^{a}	21.30^{ab}
T_3	50.17^{abcd}	40.00^{abcd}	11.33^{bc}	48.00^{abc}	265.33^{b}	17.67^{de}	32.00^{bc}	9.99^{cd}	75.50^{bc}	21.00^{ab}
T_4	46.33^{bcd}	35.17^{cd}	9.33^{c}	42.67^{bcd}	224.67^{d}	14.00^{ef}	28.67^{c}	9.76^{ef}	71.80^{de}	20.57^{bc}
T_5	54.00^{a}	45.33^{a}	15.67^{a}	56.67^{a}	322.33^{a}	28.67^{a}	37.00^{a}	10.85^{a}	83.60^{a}	21.53^{a}
T_6	52.33^{abc}	41.83^{abc}	12.33^{abc}	50.67^{abc}	271.33^{b}	20.33^{cd}	33.00^{abc}	9.96^{bc}	77.50^{b}	21.17^{ab}
T_7	44.83^{cd}	36.50^{bcd}	10.00^{c}	40.67^{cd}	241.33^{c}	15.33^{ef}	29.67^{c}	9.45^{de}	73.07^{cd}	20.80^{c}
T_8	42.67^{d}	33.17^{d}	9.00^{c}	35.33^{d}	207.00^{e}	12.33^{f}	23.33^{d}	9.09^{f}	67.73^{f}	19.40^{d}
CD (0.05)	7.51	7.76	4.31	10.90	14.19	4.47	4.52	0.46	3.02	0.78

(T_1 - Control: irrigation water; T_2 - Ni at 0.2 mg L^{-1}; T_3 - Ni at 1 mg L^{-1}; T_4 - Ni at 2 mg L^{-1}; T_5 - Zn at 2 mg L^{-1}; T_6 - Zn at 5 mg L^{-1}; T_7 - Zn at 10 mg L^{-1}; T_8 - Ni at 2 mg L^{-1} + Zn at 10 mg L^{-1})

Flowering attributes

The data in Table 2 revealed that the treatment with Ni @ 0.2 mg/L (T_2), followed by Zn @ 2 mg/L (T_5), recorded the highest values for key flowering parameters, including flower fresh weight, flower dry weight, flower stalk diameter, flower stalk length, flower diameter. These results clearly indicate that the application of nickel and zinc at lower concentrations positively influenced floral development and morphology in marigold. Comparable findings were reported by Sobati-Nasab *et al*. (2021) [22], who observed that the foliar application of Ni at 0.156 mg/L enhanced the fresh and dry weight of flowers and increased peduncle diameter in calendula (*Calendula officinalis*). The beneficial effects of low nickel levels can be attributed to its role as a micronutrient involved in nitrogen metabolism, enzyme activation, and urea hydrolysis, which support growth and floral differentiation. In contrast, the Ni @ 2 mg/L + Zn @ 10 mg/L (T_8) treatment resulted in the lowest values for most flowering parameters. Plants under this treatment exhibited delayed bud initiation, flower color development, flower opening, and full bloom. Such delays suggest that high concentrations of Ni and Zn induce physiological stress or nutrient imbalances, interfering with normal hormonal signaling and flowering processes. Elevated heavy metal concentrations are known to disrupt photosynthetic efficiency and reduce assimilate translocation to reproductive organs, ultimately affecting flower formation and quality (Aravindhan *et al*., 2019) [4]. Conversely, Ni @ 0.2 mg/L (T_2) treatment promoted earlier flowering and shorter durations for bud initiation and bloom, suggesting that moderate nickel concentration creates a favorable physiological environment for floral induction. This treatment also showed prolonged days to senescence and longer shelf life, indicating delayed floral aging and improved post-harvest longevity. The enhancement of these traits may be due to improved metabolic efficiency and antioxidant defense mechanisms that reduce oxidative stress in floral tissues.

These results are consistent with those of Atanassova and Zapryanova (2009) [5], who reported that heavy metal stress delays flowering and shortens bloom longevity in several ornamental species. Similarly, Sobati-Nasab *et al*. (2021) [22] found that low nickel concentrations positively influenced phytochemical quality and flower performance in pot marigold, whereas excessive Ni application exerted toxic effects. Overall, the findings demonstrate that low concentrations of Ni (0.2 mg/L) and Zn (2 mg/L) enhance flowering behavior, while their higher combined concentrations (Ni @ 2 mg/L + Zn @ 10 mg/L) impair floral development and longevity. This highlights the importance of maintaining optimal micronutrient balance to achieve superior flower yield and post-harvest quality in *Tagetes erecta* cultivated under heavy-metal-influenced conditions.

Table 2: Flowering attributes of marigold (*Tagetes erecta* L.) in response to nickel and zinc levels in irrigation water

Treatment	Days to bud initiation	Days to full bloom	Days to senescence	Shelf life	No. of flowers/plant	Flower diameter (mm)	Flower fresh weight (g)	Flower dry weight (g)
T_1	54.00^{cd}	75.33^{bcd}	9.00^{e}	3.00^{e}	11.67^{abc}	50.71^{abcd}	5.52^{bcd}	0.89^{a}
T_2	49.00^{g}	71.00^{e}	11.97^{a}	4.10^{a}	12.33^{ab}	60.09^{a}	6.30^{a}	0.93^{a}
T_3	51.33^{ef}	73.67^{cde}	10.30^{c}	3.40^{c}	9.33^{bcd}	53.67^{abcd}	5.74^{abc}	0.84^{ab}
T_4	55.00^{bc}	76.67^{bc}	8.30^{f}	2.70^{f}	7.33^{d}	48.95^{bcd}	5.37^{cd}	0.77^{bc}
T_5	50.67^{fg}	73.00^{de}	11.40^{b}	3.80^{b}	13.33^{a}	58.21^{ab}	6.13^{ab}	0.92^{a}
T_6	52.67^{de}	74.33^{cd}	9.80^{d}	3.20^{d}	10.33^{abcd}	55.49^{abc}	5.97^{abc}	0.87^{a}
T_7	56.67^{ab}	78.33^{ab}	7.70^{g}	2.40^{g}	8.33^{cd}	47.24^{cd}	5.22^{cd}	0.74^{c}
T_8	58.00^{a}	80.33^{a}	6.30^{h}	2.00^{h}	6.67^{d}	45.30^{d}	4.96^{d}	0.70^{c}
CD (0.05)	1.77	3.06	0.37	0.14	3.71	9.61	0.76	0.09

(T_1 - Control: irrigation water; T_2 - Ni at 0.2 mg L^{-1}; T_3 - Ni at 1 mg L^{-1}; T_4 - Ni at 2 mg L^{-1}; T_5 - Zn at 2 mg L^{-1}; T_6 - Zn at 5 mg L^{-1}; T_7 - Zn at 10 mg L^{-1}; T_8 - Ni at 2 mg L^{-1} + Zn at 10 mg L^{-1})

Root traits

Root growth parameters— root length, surface area, volume, and number of root tips—were markedly influenced by the metal treatments (Table 3). The maximum root length and surface area were observed in T_5 (Zn 2 mg L^{-1}), while the lowest values occurred in T_8. Roots of plants grown under moderate Zn appeared more fibrous and extensive, reflecting healthy rhizosphere development, whereas roots under high Ni + Zn stress were shorter, thinner, and exhibited browning near the tips, indicative of oxidative injury. The stimulation of root growth under moderate Zn supply may be attributed to Zn's role in auxin metabolism, which promotes root initiation and elongation (Ali *et al*., 2013) [2]. In addition, Zn stabilizes cellular membranes and protects against lipid peroxidation, maintaining root integrity under mild stress (Antoniadis *et al*., 2017) [3]. Conversely, excessive metal exposure likely impaired root-cell division and caused thickening of cortical layers, resulting in restricted elongation. Similar results were reported by Brune and Dietz (1995) [8], who observed a decrease in dry matter production and root elongation in maize when exposed to elevated nickel levels. Root fresh weight ranged from 10.17 g to 19.67 g, and root dry weight from 3.15 g to 9.22 g, both attaining maximum values under T_5 (Zn @ 2 mg/L) and minimum under T_8 (Ni @ 2 mg/L + Zn @ 10 mg/L). These results indicate that moderate zinc concentration supports better biomass accumulation, while excessive metal exposure causes metabolic stress and inhibits dry matter production. The reduction in root biomass under high-metal stress has also been observed in *Tagetes patula* and *Pelargonium zonale*, where elevated heavy-metal concentrations caused significant reductions in root dry matter and increased electrolyte leakage (Wang & Liu, 2014) [24].

These findings confirm that controlled application of essential micronutrients, especially zinc, is vital for promoting healthy root architecture and mitigating the adverse impacts of heavy metals in contaminated soils.

Table 3: Root traits of marigold (*Tagetes erecta* L.) in response to nickel and zinc levels in irrigation water

Treatment	Root length	Root diameter	Root surface area (cm^2)	Root volume (cm^3)	Number of root tips	Root fresh weight (g)	Root dry weight (g)
T_1	738.15^{abc}	1.52	324.12^{ab}	11.79^{ab}	1224.67^{c}	16.99^{c}	7.43^{c}
T_2	846.08^{ab}	1.64	349.66^{a}	12.45^{ab}	1353.00^{b}	18.69^{b}	7.78^{b}
T_3	570.84^{cd}	1.22	264.63^{abc}	10.16^{ab}	1036.67^{e}	14.36^{e}	5.51^{e}
T_4	486.96^{cd}	1.13	221.30^{bc}	8.43^{bc}	953.00^{f}	11.28^{g}	3.84^{g}
T_5	970.29^{a}	1.94	369.17^{a}	13.25^{a}	1451.67^{a}	19.67^{a}	9.22^{a}
T_6	624.93^{bcd}	1.39	299.17^{abc}	10.77^{ab}	1141.34^{d}	15.51^{d}	6.37^{d}
T_7	492.81^{cd}	1.14	235.38^{bc}	9.41^{abc}	880.67^{g}	13.53^{f}	4.34^{f}
T_8	399.74^{d}	1.04	190.47^{c}	6.05^{c}	780.00^{h}	10.17^{h}	3.15^{h}
CD (0.05)	252.46	N/A	113.90	4.05	50.10	0.74	0.30

(T_1 - Control: irrigation water; T_2 - Ni at 0.2 mg L^{-1}; T_3 - Ni at 1 mg L^{-1}; T_4 - Ni at 2 mg L^{-1}; T_5 - Zn at 2 mg L^{-1}; T_6 - Zn at 5 mg L^{-1}; T_7 - Zn at 10 mg L^{-1}; T_8 - Ni at 2 mg L^{-1} + Zn at 10 mg L^{-1})

Seed yield and quality attributes

The influence of Ni and Zn on seed yield and quality traits of marigold is presented in Table 4. All parameters—seed weight, seed yield, germination, seedling length, dry weight and vigour indices—varied significantly among treatments. The 100-seed weight ranged from 0.14 g to 0.22 g, with the highest recorded in T_5 (Zn @ 2 mg/L) and T_2 (Ni @ 0.2 mg/L). Similarly, seed yield per plant ranged from 4.42 g to 14.87 g, with T_5 (Zn @ 2 mg/L) yielding the highest output, followed by T_2 (Ni @ 0.2 mg/L). The improved yield under moderate Zn and Ni concentrations could be attributed to enhanced photosynthetic activity, carbohydrate translocation, and improved reproductive efficiency (Cakmak, 2008) [9]. Conversely, T_8 (Ni @ 2 mg/L + Zn @ 10 mg/L) produced the lowest seed weight and yield, implying metal toxicity at higher concentrations that interfered with pollen viability and nutrient translocation. Similar results were reported by Atanassova & Zapryanova (2009) [25], who observed delayed flowering and reduced yield in ornamentals under elevated heavy metal stress. Seedling length varied between 7.63 cm and 11.19 cm, with the longest seedlings observed in T_5 (Zn @ 2 mg/L), followed by T_2 (Ni @ 0.2 mg/L). Correspondingly, seedling dry weight ranged from 4.37 g to 8.70 g, showing a similar pattern. The enhancement under moderate Zn levels may be due to improved enzymatic activation and protein synthesis necessary for early seedling vigour (Marschner, 2012) [19]. However, T_8 (Ni @ 2 mg/L + Zn @ 10 mg/L) recorded the lowest growth, reflecting inhibited metabolic function and oxidative stress. Seed germination percentage ranged from 83.00% to 95.67%, with T_5 and T_2 showing maximum germination, while T_8 exhibited the lowest. Vigour indices (SVI I and II) followed the same trend, with T_5 (Zn @ 2 mg/L) recording the highest SVI I (1069.79) and SVI II (832.50). These results suggest that moderate zinc levels facilitate enzyme activation and cell division during germination, leading to more vigorous seedlings. The decline under higher concentrations may result from disruptions in energy metabolism and membrane integrity (Kiokias *et al*., 2016) [13].

Table 4: Seed yield and quality attributes marigold (*Tagetes erecta* L.) in response to nickel and zinc levels in irrigation water

Treatment	100 seed weight	Seed yield/plant	Seed germination (%)	Seedling length (cm)	Seedling dry weight (cm)	Seedling Vigour Index-I	Seedling Vigour Index- II
T_1	0.16^{bcd}	8.57^{cde}	91.67^{bc}	9.71^{ab}	7.47^{c}	890.60^{c}	684.30^{c}
T_2	0.21^{a}	13.73^{ab}	94.33^{ab}	10.64^{a}	8.17^{b}	1003.03^{b}	769.90^{b}
T_3	0.18^{abc}	10.07^{bcd}	88.00^{de}	9.21^{ab}	6.27^{e}	810.63^{d}	551.60^{e}
T_4	0.15^{cd}	5.77^{de}	85.00^{ef}	8.34^{b}	4.97^{g}	709.00^{e}	421.97^{g}
T_5	0.22^{a}	14.87^{a}	95.67^{a}	11.19^{a}	8.70^{a}	1069.79^{a}	832.50^{a}
T_6	0.19^{ab}	11.21^{abc}	89.33^{cd}	9.52^{ab}	6.73^{d}	850.28^{cd}	601.60^{d}
T_7	0.15^{bcd}	7.61^{cde}	86.00^{def}	8.45^{b}	5.43^{f}	727.54^{e}	467.53^{f}
T_8	0.14^{d}	4.42^{e}	83.00^{f}	7.63^{b}	4.37^{h}	632.97^{f}	362.33^{h}
CD (0.05)	0.04	4.75	3.48	2.12	0.42	51.72	41.84

(T_1 - Control: irrigation water; T_2 - Ni at 0.2 mg L^{-1}; T_3 - Ni at 1 mg L^{-1}; T_4 - Ni at 2 mg L^{-1}; T_5 - Zn at 2 mg L^{-1}; T_6 - Zn at 5 mg L^{-1}; T_7 - Zn at 10 mg L^{-1}; T_8 - Ni at 2 mg L^{-1} + Zn at 10 mg L^{-1})

Conclusion
Overall, *Tagetes erecta* responded positively to moderate Zn and low Ni levels, while high combined concentrations proved detrimental. The results indicate that marigold possesses a considerable degree of tolerance to Zn and Ni stress and can survive and produce substantial biomass even under sub-optimal irrigation conditions. The ability of marigold to maintain morphological integrity under mild stress suggests an efficient physiological adaptation of this crop.

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