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THE EFFECTS OF ZINC AND BORON ON SEED QUALITY OF EARLY CAULIFLOWER (*BRASSICA OLERACEA* VAR. *B OTRYTIS* L.) CV. SABOUR AGRIM

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ABSTRACT

The present study investigated the effects of zinc and boron on the seed quality traits of early cauliflower (*Brassica oleracea* var. *botrytis* L.) cv. Sabour Agrim during the Rabi season of 2022-23. The experiment was conducted at Hi-Tech Horticulture, Dr. RPCAU, Pusa, Samastipur, employing a factorial randomized block design with four levels of zinc (0, 2.5, 5, and 7.5 kg ha^{-1}) and boron (0, 1.0, 1.5, and 2.0 kg ha^{-1}). Results showed that the combined application of 2.5 kg zinc ha^{-1} and 2.0 kg boron ha^{-1} ($Zn_{2.5}B_{2.0}$) significantly improved seed quality parameters, including 1000 seed weight (5.0 g), seed germination (98.3%), vigor index-1 (1316.6), vigour index-2 (9.0), and seed viability (98%). This research demonstrates that appropriate zinc and boron supplementation can enhance seed quality in early cauliflower production, addressing micronutrient deficiencies commonly observed in agricultural soils.

Key words: cauliflower, seed quality, micronutrients, germination, vigor index, seed viability

Introduction

Cauliflower (*Brassica oleracea* var. *botrytis* L.), possessing a chromosome number of 2n=18, is an important cool-season vegetable crop, estimated for its nutritional value, palatable taste, and specific soil and climatic requirements (Thakur *et al*., 2019). It belongs to the family Cruciferae.The edible portion, known as the curd, comprises approximately 45 percent of the total mass of the plant (Rai and Yadav, 2005).It is a crucial dietary component owing to its cost-effectiveness, consumer demand, and year-round availability (Thakur *et al*., 2019). On a global scale, India ranks as the second-largest producer of cauliflower, with cultivation extending over 479.29 thousand hectares, yielding a production of 9436.69 thousand tonnes and a productivity rate of 19.69 tonnes per hectare. Within India, Bihar holds the third position in cauliflower production, with an output of 1031.47 thousand tons per hectare (Indiastat, 2024).

Cauliflower occupies a significant position among vegetable crops, with a consistent demand throughout the year. However, its production is hindered by a lack of high-quality seeds from the recommended varieties.

Superior seed availability is crucial for ensuring robust crop establishment across various field crops. A primary challenge observed in the field is the inadequate establishment of seedlings, which is affected by seed quality, adverse climatic conditions, and suboptimal field management (Khulbe *et al.*, 2010). Nutritional deficiencies, particularly of zinc and boron, are the predominant factors contributing to soil health deterioration and yield stagnation (Yadav *et al.*, 2015). Zinc is a vital micronutrient necessary for optimal plant growth and development, and plays a critical role in various metabolic processes, including enzyme activity, cell wall development, respiration, photosynthesis, chlorophyll formation, and other biochemical functions (Alloway and Brain, 2008). It is an essential component of numerous enzymes such as carbonic anhydrase, alcohol dehydrogenase, superoxide dismutase, and RNA polymerase, and is involved in nitrogen metabolism. Zinc deficiency in plants disrupts these processes, leading to diminished growth, yield and quality (Vijayreddy *et al.*, 2005a; Singh *et al.*, 2005). The extent of zinc deficiency varies significantly with soil type, while the application rate is contingent upon crop type, soil characteristics, and climatic conditions. Zinc deficiency is prevalent in soils that are coarse textured, calcareous, or alkaline in pH, with low organic carbon content and high erosion. In India, zinc deficiency was observed in 46% of soils (Vijayreddy *et al.*, 2025b; Murthy, 1988). In zinc-deficient plants, the middle leaves exhibit golden yellow or orange coloration in the interveinal areas. Young leaves remain small and are often referred to as "little leaf" or "rosetting" (Marschner, 1995).

Boron has emerged as the third most deficient nutrient in Indian soils, following zinc and sulfur, with recent data indicating a deficiency level of 23.2 percent (Shukla and Behera, 2017). Boron is essential for various physiological processes, including flowering, fertilization, curd quality, yield, and seed yield, in cauliflower, a crop that is highly sensitive to boron deficiency (Kumar *et al.*, 2022). Additionally, boron is involved in calcium metabolism, auxin synthesis, sugar metabolism, solute translocation, and protein synthesis (Narayanamma *et al.*, 2007). Deficiency symptoms such as 'Hollow Heart' and 'Browning of Curd' in cauliflower have been attributed to boron deficiency by numerous researchers (Raja, 2007; Sarker *et al.*, 2019). An inadequate boron supply significantly impaired the enzymatic activities responsible for potassium uptake. The intensification of agriculture, combined with the use of boron-free inputs and insufficient organic matter, has exacerbated boron deficiency in soils. The margin between boron deficiency and toxicity is narrow, necessitating the precise calibration of boron doses (Narayanamma *et al.*, 2007). Furthermore, limited research has been conducted on the effects of Zinc and boron on seed quality during early cauliflower production. Consequently, the present study aimed to evaluate the effects of varying doses of zinc and boron on seed quality in early cauliflower. Addressing micronutrient deficiencies has been shown to results in high yields.

Table 1: Treatment details used in the experiment.

S. No.	Treatment	Details
1.	T_1-Zn_0B_0	0 kg ha^{-1} + 0 kg ha^{-1}
2.	T_2-$Zn_0B_{1.0}$	0 kg ha^{-1} + 1.0 kg ha^{-1}
3.	T_3-$Zn_0B_{1.5}$	0 kg ha^{-1} + 1.5 kg ha^{-1}
4.	T_4-Zn_0B_2	0 kg ha^{-1} + 2.0 kg ha^{-1}
5.	T_5-$Zn_{2.5}B_0$	2.5 kg ha^{-1} + 0 kg ha^{-1}
6.	T_6-$Zn_{2.5}B_{1.0}$	2.5 kg ha^{-1} + 1.0 kg ha^{-1}
7.	T_7-$Zn_{2.5}B_{1.5}$	2.5 kg ha^{-1} + 1.5 kg ha^{-1}
8.	T_8-$Zn_{2.5}B_{2.0}$	2.5 kg ha^{-1} + 2.0 kg ha^{-1}
9.	T_9-$Zn_{5.0}B_0$	5.0 kg ha^{-1} + 0 kg ha^{-1}
10.	T_{10}-$Zn_{5.0}B_{1.0}$	5.0 kg ha^{-1} + 1.0 kg ha^{-1}
11.	T_{11}-$Zn_{5.0}B_{1.5}$	5.0 kg ha^{-1} + 1.5 kg ha^{-1}
12.	T_{12}-$Zn_{5.0}B_{2.0}$	5.0 kg ha^{-1} + 2.0 kg ha^{-1}
13.	T_{13}-$Zn_{7.5}B_0$	7.5 kg ha^{-1} + 0 kg ha^{-1}
14.	T_{14}-$Zn_{7.5}B_{1.0}$	7.5 kg ha^{-1} + 1.0 kg ha^{-1}
15.	T_{15}-$Zn_{7.5}B_{1.5}$	7.5 kg ha^{-1} + 1.5 kg ha^{-1}
16.	T_{16}-$Zn_{7.5}B_{2.0}$	7.5 kg ha^{-1} + 2.0 kg ha^{-1}

Methods and Materials

A field experiment was conducted to investigate the effects of the interaction between Zinc and boron on the growth characteristics, seed yield, and quality attributes of Early Cauliflower (*Brassica oleracea* var. *botrytis* L.) cv. Sabour Agrim during the Rabi season of 2022–23. This study was carried out at the Hi-Tech Horticulture Facility within the Department of Horticulture, PG College of Agriculture, Dr. RPCAU, Pusa, Samastipur. The experimental site predominantly features loamy to sandy loamy soil, with a temperature range of 8.6°C to 35.7°C and relative humidity between 31% and 99% during the crop period of 2022–23. As detailed in Table 1, the experiment was a factorial randomized block design with three replications. Seedlings were transplanted at a spacing of 60 × 45 cm, and fertilizers were applied according to the recommended dosage: 125 kg of nitrogen (N), 80 kg of phosphorus (P), and 60 kg of potassium (K), and 20 tons per hectare of farmyard manure (FYM) at the time of planting. Five plants from each treatment combination and replicate were randomly selected and tagged for observation. The recorded observations for these five plants were averaged to determine the mean values for various parameters, including 1000 seed weight, germination percentage, seedling length (cm), seedling

Table 2: Individual and Interaction effects of Zn and B on 1000 seed weight (test weight), germination percentage and Seed vigour index (VI-1), Vigour index (VI-2), Seed viability test based on TZ test, seedling length (cm) and seedling dry weight (g) of early cauliflower.

Treatments	SW	SG	SL	VI-1	SDW	VI-2	SVB
Zn_0	$3.1^{c} \pm 0.85$	$80.4^{c} \pm 8.1$	$11.2^{a} \pm 0.8$	$899.4^{c} \pm 118.7$	0.46c ± 0.09	5.1d ± 1.11	85.6c ± 7.7
$Zn_{2.5}$	$3.5^{b} \pm 1.00$	$85.7^{b} \pm 8.3$	$11.4^{a} \pm 1.4$	$972.8^{b} \pm 169.0$	0.55b ± 0.11	6.1c ± 1.47	90.5b ± 7.0
$Zn_{5.0}$	$3.7^{a} \pm 1.12$	$84.3^{b} \pm 9.1$	$11.8^{a} \pm 1.1$	$1000.9^{b} \pm 178.9$	0.54b ± 0.08	6.4b ± 1.43	91.2ab ± 6.3
$Zn_{7.5}$	$3.8^{a} \pm 0.90$	$89.5^{a} \pm 7.4$	$11.4^{a} \pm 0.9$	$1041.8^{a} \pm 187.6$	0.57a ± 0.07	6.8a ± 1.55	93.3a ± 5.0
S Em (±)	0.1	1.6	0.17	12.4	0.008	0.1	0.9
CD(P<0.05)	0.2	4.8	0.5	35.8	0.023	0.2	2.5
B_0	$2.2^{d} \pm 0.28$	$75.7^{d} \pm 4.6$	$10.4^{c} \pm 0.5$	$788.4^{d} \pm 46.7$	0.42d ± 0.05	4.4d ± 0.48	82.1d ± 4.2
$B_{1.0}$	$3.2^{c} \pm 0.40$	$81.2^{c} \pm 4.9$	$11.2^{b} \pm 0.7$	$907.5^{c} \pm 39.1$	0.49c ± 0.06	5.5c ± 0.73	88.6c ± 3.7
$B_{1.5}$	$4.2^{b} \pm 0.33$	$87.8^{b} \pm 5.0$	$11.7^{b} \pm 0.6$	$1023.0^{b} \pm 51.7$	0.57b ± 0.07	6.6b ± 0.62	93.5b ± 6.0
$B_{2.0}$	$4.4^{a} \pm 0.59$	$95.2^{a} \pm 4.1$	$12.5^{a} \pm 1.0$	$1195.9^{a} \pm 129.0$	0.63a ± 0.04	7.9a ± 0.96	96.4a ± 3.5
S Em (±)	0.1	0.8	0.17	12.4	0.008	0.1	0.9
CD(P<0.05)	0.2	2.4	0.5	35.8	0.023	0.2	2.5
T_1-Zn_0B_0	$1.9^{k} \pm 0.12$	$70.3^{k} \pm 3.6$	$10.5^{de} \pm 0.8$	$740.0^{i} \pm 26.4$	0.373i ± 0.03	3.9k ± 0.17	77.0d ± 2.0
T_2-$Zn_0B_{1.0}$	$2.7^{i} \pm 0.06$	$78.6^{hij} \pm 2.2$	$10.9^{de} \pm 0.7$	$860.4^{gh} \pm 22.4$	0.407hi ± 0.03	4.4g ± 0.15	85.4bc ± 1.9
T_3-$Zn_0B_{1.5}$	$4.1^{de} \pm 0.10$	$82.1^{fgh} \pm 2.5$	$12.0^{bc} \pm 0.1$	$986.7^{cde} \pm 30.1$	0.473g ± 0.01	5.7ef ± 0.36	85.3a ± 3.2
T_4-Zn_0B_2	$3.5^{g} \pm 0.10$	$90.7^{bcd} \pm 1.7$	$11.1^{cde} \pm 0.7$	$1010.3^{cd} \pm 20.4$	0.583cd ± 0.04	6.5c ± 0.00	94.8a ± 2.1
T_5-$Zn_{2.5}B_0$	$2.0^{jk} \pm 0.10$	$74.5^{jk} \pm 4.1$	$10.3^{e} \pm 0.6$	$768.7^{i} \pm 2.9$	0.403hi ± 0.02	4.1jk ± 0.40	81.2cd ± 2.1
T_6-$Zn_{2.5}B_{1.0}$	$3.1^{h} \pm 0.15$	$84.2^{fg} \pm 2.9$	$10.6^{de} \pm 0.7$	$893.6^{fg} \pm 21.6$	0.527ef ± 0.04	5.6g ± 0.27	87.4b ± 1.5
T_7-$Zn_{2.5}B_{1.5}$	$4.4^{c} \pm 0.21$	$89.4^{cde} \pm 3.5$	$11.5^{cd} \pm 1.0$	$1026.4^{cd} \pm 8.3$	0.58cd ± 0.05	6.6de ± 0.10	96.2a ± 2.1
T_8-$Zn_{2.5}B_{2.0}$	$5.0^{a} \pm 0.20$	$98.3^{a} \pm 1.1$	$13.4^{a} \pm 0.5$	$1316.6^{a} \pm 9.2$	0.673a ± 0.03	9.0a ± 0.17	98.0a ± 3.1
T_9-$Zn_{5.0}B_0$	$2.2^{j} \pm 0.06$	$77.4^{hij} \pm 1.1$	$10.3^{e} \pm 0.5$	$797.7^{hi} \pm 52.2$	0.447gh ± 0.02	4.6ij ± 0.17	83.6bc ± 5.5
T_{10}-$Zn_{5.0}B_{1.0}$	$3.2^{h} \pm 0.17$	$76.2^{ij} \pm 3.1$	$12.0^{bc} \pm 0.6$	$916.8^{efg} \pm 27.5$	0.487fg ± 0.03	5.9fg ± 0.25	88.1b ± 2.5
T_{11}-$Zn_{5.0}B_{1.5}$	$4.6^{b} \pm 0.21$	$86.3^{def} \pm 0.6$	$12.0^{bc} \pm 0.6$	$1035.1^{c} \pm 47.5$	0.57de ± 0.03	6.8d ± 0.15	97.3a ± 2.0
T_{12}-$Zn_{5.0}B_{2.0}$	$4.8^{ab} \pm 0.10$	$97.3^{a} \pm 4.4$	$12.9^{ab} \pm 0.6$	$1254.1^{ab} \pm 78.1$	0.643ab ± 0.03	8.3b ± 0.51	95.7a ± 4.4
T_{13}-$Zn_{7.5}B_0$	$2.6^{i} \pm 0.15$	$80.7^{ghi} \pm 3.2$	$10.5^{e} \pm 0.6$	$847.4^{gh} \pm 61.1$	0.473g ± 0.02	5.0hi ± 0.31	86.7b ± 6.8
T_{14}-$Zn_{7.5}B_{1.0}$	$3.7^{fg} \pm 0.15$	$85.7^{ef} \pm 4.9$	$11.2^{cde} \pm 0.3$	$959.3^{def} \pm 4.1$	0.553de ± 0.02	6.2ef ± 0.06	93.7a ± 1.1
T_{15}-$Zn_{7.5}B_{1.5}$	$3.9^{ef} \pm 0.10$	$93.5^{abc} \pm 2.4$	$11.2^{cde} \pm 0.2$	$1043.8^{c} \pm 48.5$	0.64ab ± 0.01	7.1cd ± 0.30	95.0a ± 2.4
T_{16}-$Zn_{7.5}B_{2.0}$	$4.3^{cd} \pm 0.10$	$94.5^{ab} \pm 1.4$	$12.7^{ab} \pm 0.4$	$1202.4^{b} \pm 82.1$	0.62bc ± 0.02	7.9b ± 0.10	96.2a ± 1.7
S Em (±)	0.1	1.6	0.35	24.8	0.016	0.1	1.7
CD(P<0.05)	0.2	4.8	1.00	71.9	0.046	0.4	5.0

Values in the column with same letters are not significantly different; **SW: 1000 seed weight (g); **SG:** Seed germination (%); **SL:** Seedling length (cm); **VI-1:** Vigour Index (VI-1), **SDW:** Seedling dry weight; **VI-2:** Vigour Index (VI-2); **SVB:** Seed Viability based on TZ test (%)

dry weight (g), Vigour Index-1 (VI-1), Vigour Index-2 (VI-2), and seed viability based on tetrazolium test (tz).

1000 seed weight (Test weight)

A sample of 1000 seeds randomly selected from the net plot produce was counted and subsequently weighed using an electronic balance to determine the 1000-seed weight (test weight) in grams.

Seed Germination Percentage (ISTA, 2011)

Each plot yielded 100 seeds, which were then used in germination tests. The seeds were placed on blotter paper inside petri dishes and kept in a seed germinator set to 21°C. After a period of 10 days, the germination rate was determined using a specific formula.

Seedling length (cm)

To assess seedling length, ten seedlings were randomly chosen, and their average length was recorded in cm during the initial measurement. Each seedling's length was gauged from the tip of the root to the tip of the shoot using a scale.

Seedling dry weight (g)

To assess the dry weight of seedlings, ten were chosen based on their length. These seedlings were then dried in an oven set at 60°C for a duration of 48 h, after which their weight was recorded. The average weight is reported in grams.

Vigour Index (VI-1): (germination percentage X seedling length) (Abdul-Baki and Anderson, 1973)

Seedling length was measured in cmon a meter scale, and the vigour index (VI-1) was determined based on the germination percentage and seedling length.

Vigour Index (VI-2): Germination percentage X seedling dry weight (Abdul-Baki and Anderson, 1973)

Ten plants were randomly selected and their dry weights were measured.Seedlings were dried at 60°C for 48 h, and weights were recorded using a device that measured in grams. The vigour index (VI-2) was calculated using germination percentage and seedling dry weight**.**

Seed Viability Based on Tetrazolium Test (TZ)

The seeds were split longitudinally and soaked in water overnight or placed on wet paper for 18h. Seeds were immersed in an aqueous solution containing 1.0% 2,3,5-triphenyl tetrazolium chloride at 30°C in the dark for 8–10 h. In dicot seeds, the tetrazolium solution drains off and the cotyledons turn crimson. The viability of each seed was assessed after washing it three to four times with distilled water. To interpret this, the seed coatings must be removed**.**

Statistical Analysis

The experiment was conducted with three replicates in a factorial randomized block design, and the obtained data were subjected to analysis of variance (ANOVA). Duncan's Multiple Range Test was employed to determine significant differences between means at a 5% probability level. The analysis was performed using GRAPES software (version 10.0) (Gopinath *et al*., 2021). The results are presented as means accompanied by their corresponding standard deviations**.**

Results and Discussion

The quality of early cauliflower seeds is influenced by the soil nutrient content and management practices. Specifically, deficiencies in zinc (Zn) and boron (B) can be mitigated by supplementation with these nutrients, thereby enhancing seed quality. This improvement is reflected in parameters such as the weight of 1000 seeds, germination percentage, vigour index (VI-1 and VI-2), seedling dry weight, seedling length and seed viability based on TZ test. Optimal plant growth requires both macronutrients and micronutrients. The availability of essential micronutrients has diminished since the advent of the Green Revolution. This decline is attributed to the cultivation of high-yielding plant varieties, use of nutrient-rich fertilizers, intensive cropping, particularly in irrigated regions, and reduced application of organic matter. The rapid depletion of these nutrients from the soil has constrained the productivity of vegetable crops. The results highlight the positive impact of zinc and boron supplementation on crop performance. The data depicted in Table 2.0 and Figure 1.0 demonstrate the effects of zinc and boron, both separately and in combination, on the seedling vigour index (VI-2) of early cauliflower.

Effect of Zinc

Zinc application significantly influenced 1000-seed weight, seed germination, vigour indices (VI-1 and VI-2), seedling dry weight, and seed viability, whereas seedling length was not significantly affected ($p > 0.05$), as shown in Table 2 and Fig. 1 and 2. The highest 1000-seed weight (3.8 g) was recorded in Zn7.5, which was statistically similar to $Zn_{5.0}$ (3.7 g) but significantly higher than $Zn_{2.5}$ (3.5 g) and the control Zn_0 (3.1 g). Germination percentage increased from 80.4 % in Zn_0 to 89.5 % in $Zn_{7.5}$ (+11.3 %). Vigour index (VI-1) rose from 899.4 (Zn_0) to 1041.8 ($Zn_{7.5}$) (+15.8 %). Seedling dry weight improved from 0.46 g (Zn_0) to 0.57 g ($Zn_{7.5}$), while vigour index (VI-2) increased from 5.1 to 6.8. Seed viability (TZ test) also rose from 85.6 % (Zn_0) to 93.3 % ($Zn_{7.5}$), representing a 9.0 % increase. The influence of zinc and boron on seed quality attributes was investigated, focusing on parameters such as 1000 seed weight (test weight), seed germination percentage, vigour index (VI-1), vigour index (VI-2), and seed viability as determined by the tetrazolium (TZ) test. The application of boron and zinc to the soil significantly enhanced these seed quality traits. Zinc plays a pivotal role in auxin biosynthesis, enzyme activation, and membrane stability, all of which contribute to improved seed development and germination (Alloway 2008). Increased 1000-seed weight in Zn-treated plots suggests improved carbohydrate metabolism and translocation during seed-filling. Higher germination and vigour index under Zn application aligns with findings in mustard (Halim *et al*., 2023) and faba bean (Roy *et al*., 2022), where zinc enhanced hydrolytic enzyme activity, leading to better reserve mobilization during germination (Chaudhari *et al*., 2017).

Effect of Boron

Boron significantly enhanced all the measured seed quality traits ($p < 0.05$), as shown in Table 2 and Fig. 1 and 2. The highest 1000-seed weight was recorded for $B_{2.0}$ (4.4 g), which was 100 % greater than the control B_0 (2.2 g). Germination improved from 75.7 % in B_0 to 95.2 % in B_2 treatment.B_0 (+25.7 %). Seedling length increased from 10.4 cm (B_0) to 12.5 cm ($B_{2.0}$), and VI-1 from 788.4 to 1195.9 (+51.7 %). Seedling dry weight ranges from 0.42 g (B_0) to 0.63 g ($B_{2.0}$), while VI-2 nearly doubled from 4.4 to 7.9. Seed viability improved from 82.1 % (B_0) to 96.4 % ($B_{2.0}$) (+17.4 %). Boron's effect on seed weight, germination, and viability can be attributed to its role in cell wall structural integrity, sugar transport, and pollen tube elongation [24]. Substantial increases in seed viability and vigour index with $B_{2.0}$ indicate enhanced membrane integrity and reduced oxidative stress during seed development. Similar improvements with boron supplementation have been reported for *Raphanus sativus* (Deepika and Pitagi, 2015) and *Daucus carota* (Mohanta *et al*., 2013).

Interaction of Zinc and Boron

The Zn × B interaction was highly significant ($P < 0.05$), as shown in Table 2 and Fig. 1 and 2. The combination $Zn_{2.5}$+ $B_{2.0}$ (T8) yielded the maximum 1000-seed weight (5.0 g), germination (98.3 %), seedling length (13.4 cm), VI-1 (1316.6), seedling dry weight (0.673 g), VI-2 (9.0), and seed viability (98.0 %). This represented improvements of +163.2 % in seed weight, +39.7 % in germination, +27.6 % in seedling length, +77.9 % in VI-1, +80.4 % in seedling dry weight, +130.8 % in VI-2, and +27.3 % in seed viability compared to the control Zn_0 B_0 (T1). Other high-performing combinations included $Zn_{5.0}$+ $B_{2.0}$ (T12) and $Zn_{7.5}$+ $B_{2.0}$ (T16), which were statistically on par with T8 for most traits. Synergistic effect of $Zn_{7.5}$+

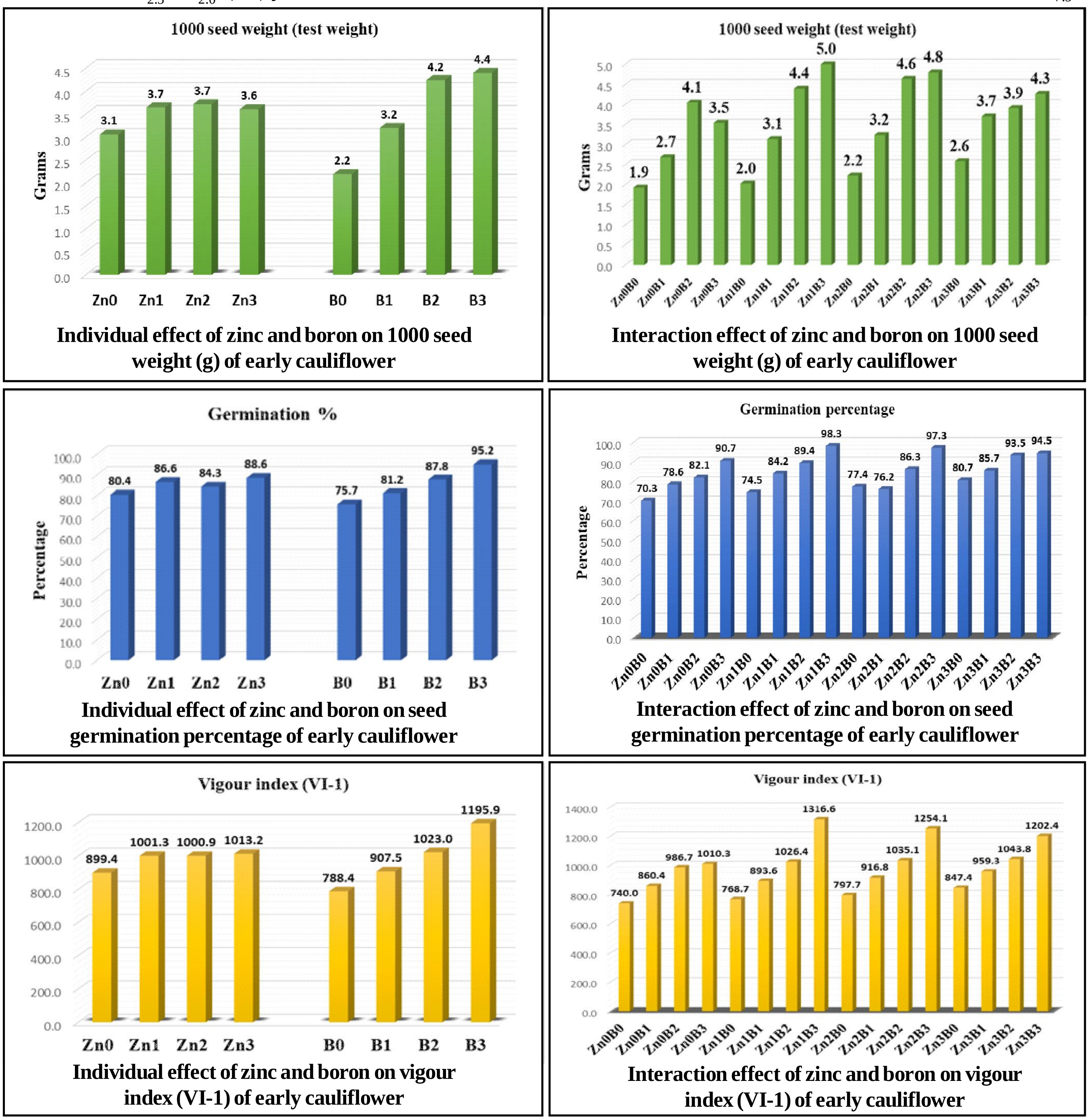

Fig. 1: Individual and Interaction effect of Zinc and Boron on 1000 seed weight (test weight), germination percentage and Seed vigour index (VI-1) of early cauliflower.

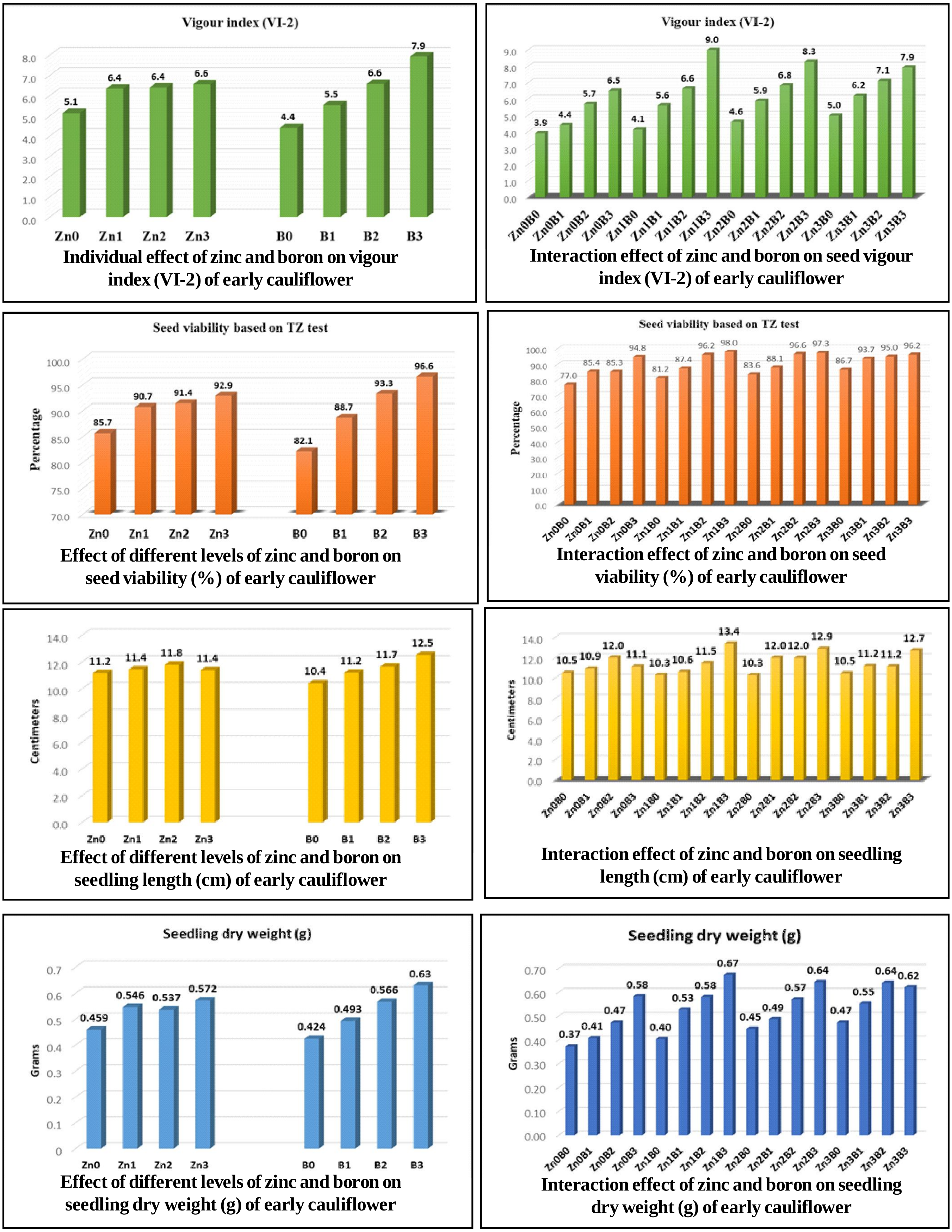

Fig. 2: Individual and Interaction effect of Zinc and Boron on Vigour index (VI-2), Seed viability test based on TZ test, seedling length (cm), seedling dry weight (g) of early cauliflower.

$B_{2.0}$ The superior performance of $Zn_{2.5}$+ $B_{2.0}$ suggests a strong synergistic interaction. Zinc enhances metabolic enzyme systems, whereas boron ensures structural and transport functions (Kumar *et al*. 2013). Together, they likely optimize nutrient partitioning to seeds, resulting in a higher mass, improved germination uniformity, and greater seedling vigour. Comparable synergistic effects have been documented in *Raphanus sativus* (Deepika and Pitagi 2015) and *Daucus carota* (Mohanta *et al*., 2013).

Implications for Seed Production The results indicate that the combined application of moderate zinc (2.5–5.0 kg ha^{-1}) with high boron (2.0 kg ha^{-1}) can substantially improve seed quality traits in early cauliflower. This has direct implications for the seed industry standards, as higher germination and vigour are critical for market acceptance and field performance. The adoption of such micronutrient regimes can be particularly beneficial in zinc and borondeficient soils, enhancing both seed yield and quality in intensive cropping systems.

Conclusion

The findings highlighted that among the boron levels tested, $B_{2.0}$ was the most effective in enhancing seed quality, followed by $B_{1.5}$ and $B_{1.0}$. In terms of zinc application, $Zn_{7.5}$ yielded the highest seed quality, followed by Zn_5 and $Zn_{2.5}$. The combined application of zinc and boron, 2.5 kg ha^{-1} of zinc with 2.0 kg ha^{-1} of boron significantly enhanced seed quality traits includes 1000-seed weight, germination percentage, seedling length, vigour index (VI-1 and VI-2), seedling dry weight and seed viability based on TZ test in early cauliflower. For practical applications, it is recommended to apply 2.5 kg of zinc and 2 kg of boron per hectare to achieve optimal seed quality in early cauliflower production. This micronutrient supplementation strategy is particularly advantageous in intensive cropping systems and regions with zinc and borondeficient soils, potentially leading to enhanced seed industry standards and field performance.

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