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Response of Seed Production and Pollen Viability in Cucumber (*Cucumis sativus* L.) to Potassium and Boron Fertilizer Application

Leli Kurniasari [a,*], Putri Santika [a], M Rosyadi Adnan [a]

[a] Politeknik Negeri Jember, Jember, Indonesia

Abstract. *The improvement of cucumber cultivation practices, such as proper seed selection and appropriate fertilization, has the potential to enhance seed production and quality. Therefore, this study aimed to evaluate the most effective combination of potassium and boron fertilizer doses to improve seed production and pollen viability in cucumber. A randomized block design (RCBD) with two treatment factors was used. The first factor was potassium dose, applied at three levels: 100 kg/ha, 200 kg/ha, and 300 kg/ha. The second factor was boron dose, applied at four levels: 0 kg/ha, 1 kg/ha, 2 kg/ha, and 3 kg/ha. Data were analyzed using ANOVA, with a comprehensive set of observation parameters. In conclusion, no significant interaction was observed between potassium and boron treatments across all observed parameters. The treatment of 300 kg/ha potassium had a highly significant effect on the number of seeds per fruit (342.53), the number of filled seeds per fruit (289.93), seed weight per fruit (7.13 g), filled seed weight per fruit (8.24 g), and seed production per hectare (253.64 kg). Boron fertilizer treatment at a dose of 1 kg/ha had a highly significant effect on the time to emergence of male flowers (23.44 DAP), the time to emergence of female flowers (26.33 DAP), filled seed weight per fruit (7.86 g), and seed production per hectare (241.72 kg).*

Keywords: *potassium; boron; cucumber; pollen viability; seed production.*

Type of the Paper: Regular Article.

1. Introduction

Cucumber production in Indonesia has declined in recent years, decreasing from approximately 471,941 tons in 2021 to 444,057 tons in 2022 and further to 416,728 tons in 2023 [1]. The decrease may attribute to low crop productivity. This finding is consistent with Kurniasari et al. [2], who stated that low cucumber productivity is caused by genetic factors, suboptimal cultivation practices, unsuitable environmental conditions in the planting area, inadequate pest and disease management, and climate change.

Seed quality is a key factor that determines the productivity and overall performance of horticultural crops, including cucumber (*Cucumis sativus* L.). High-quality seed is influenced not only by its genetic characteristics but also by production processes, including planting techniques, harvesting methods, and post-harvest handling. All of these stages directly affect seed content, dormancy status, and germination ability. However, commercial-scale cucumber seed production often faces various challenges. Common issues include incomplete or poorly developed seed formation, significant variation in germination capacity among seeds originating from different

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* Corresponding author
Email: kurniasari@polije.ac.id

ovule positions within the fruit, and sensitivity of the seeds to environmental conditions during seed development and maturation processes [3].

The reliability of seed production depends largely on the proper progression of the plant's reproductive processes, particularly pollen development and viability, fertilization, and seed formation. All of these important processes are highly sensitive to the adequacy of nutrients—both micro- and macronutrients—available within the plant [4,5]. Pollen viability plays a crucial role in ensuring successful pollination and in producing uniform, fully developed seeds [6]. Reduced pollen viability or non-viable pollen limits seed formation, resulting in lower-quality seeds [7,8].

Potassium (K) is the primary cation responsible for regulating various crucial physiological processes in plants, including carbohydrate translocation, water balance (osmosis), enzyme activation, and the formation and maintenance of reproductive organs [9]. Therefore, potassium greatly influences flower quality, fertilization processes, and final yield outcomes, including the total amount and quality of seeds produced [10,11]. Insufficient potassium supply is commonly associated with reduced flower and fruit formation, as well as a decline in seed quality [12]. Boron (B) is an essential element in plant reproductive physiology due to its critical functions. It is required for maintaining cell wall stability in reproductive meristem tissues, facilitating anther maturation, promoting pollen germination, and supporting pollen tube growth. Conversely, an imbalanced supply of boron, whether in deficiency or excess (toxicity), can negatively affect reproductive success by reducing pollen viability, inhibiting pollen tube elongation, and ultimately hindering seed formation [13-15]. Adıgüzel et al. [16] reported that boron application can increase the number of seeds per fruit, as well as improve seed germination and vigor in melon plants.

Studies on cucumber and other Cucurbitaceae species show that boron (B) application during the flowering stage enhances traits related to flowering and yield, including time to first flowering, fruit length, fruit weight, number of fruits per plant, yield per plant, and yield per hectare [17]. The combination of potassium and boron fertilizers in the study of Sayed et al. [18] increased chlorophyll content, tissue water content in leaves and fruits, fresh and dry weight, fruit length and diameter, nutrient content (N, P, and K) in fruits, both in the first and second harvests. The combined application of potassium and boron is important, as potassium can mitigate the toxic effects of excessive boron, and their interaction enhances growth and yield compared with single-nutrient applications [18,19]. A study conducted by Meena et al. [20] found that boron is essential for the formation of viable pollen, while potassium (K), often referred to as a "quality nutrient," plays an important role in yield and seed quality. Therefore, the combination of these treatments is highly effective in producing high-quality seeds.

Based on the above background, this study was carried out to evaluate and analyze the response of seed production and pollen viability of cucumber (*Cucumis sativus* L.) to the application of potassium and boron fertilizers. This study is expected to offer a deeper understanding of how these two nutrients contribute to plant physiological processes, specifically those associated with time to male flower emergence and time to female flower emergence (DAP), pollen viability, seeds per fruit, filled seeds per fruit, seed weight per fruit, filled seed weight per fruit, seed production per hectare. Furthermore, the results are intended to serve as a scientific basis for developing more efficient fertilization strategies in commercial cucumber seed production.

2. Materials and Methods

2.1. Time and Place

This study was carried out from September 2022 to January 2023 in Bintoro Village, Patrang District, Jember Regency, East Java, where the soil pH was approximately 7.

2.2. Experimental Design

The experimental design used was a factorial randomized block design (RCBD) with three replications and consisting of two factors, and each factor consisting of four levels. The first factor was the dose of KCl fertilizer (P), consisting of P1 = 100 kg/ha, P2 = 200 kg/ha, and P3 = 300 kg/ha. The second factor was the dose of boron fertilizer (R), consisting of R0 = without boron fertilizer (control), R1 = 1 kg/ha, R2 = 2 kg/ha, and R3 = 3 kg/ha. Data were analyzed using analysis of variance (ANOVA) with the factorial RBCD method. When analysis of variance results showed significant (*) or highly significant (**) differences, further tests were carried out using the Duncan Multiple Range Test (DMRT).

2.3. Materials

The cucumber seeds used in this study were stock seeds from the PMS Variety. Prior to the experiment, a soil analysis was performed to assess potassium and boron levels. The seedbeds were 200 cm long, 100 cm wide, and 30 cm high, with 30 cm spacing between plots and 50 cm spacing between blocks, with 10 plants per bed.

2.4. Procedures

The planting media used was cocopeat and soil with a ratio of 1: 1 then placed in a tray. The prepared seeds were soaked in warm water for 1-2 hours and drained. The seeds were then incubated for 24 hours or until germination before being sown in the tray media. Basic fertilization aimed to maintain the balance of nutrients in the soil and provide initial growth nutrients to plants in the form of ZA at 8 g/plant and SP-36 at 24 g/plant. Follow-up fertilization used ZA at a dose of 14 g/plant. KCl fertilizer was applied in four split doses (7, 25, 40, 50 DAP by digging) alternating between soil drenching and dibbling, accumulating to total doses of 100, 200, and 300 kg/ha. Boron was applied once via soil drenching at 15 DAP comprising four levels: 0 (control), 1, 2, and 3 kg/ha.

Roguing activities were carried out during the vegetative phase, when plants were three weeks old, and during the generative phase, at four weeks after planting and before harvest. Control measures were implemented by spraying the plants with appropriate fungicides or insecticides. Whiteflies were controlled using insecticides with the active ingredient *imidacloprid* 100g/l, fruit flies were controlled using fungicides with the active ingredient *metalaxyl* 25% and *pyraclostrobin* 250g/l. Harvesting was conducted when the cucumber fruits reached the physiological ripe stage, as shown by approximately 80% yellowing of the fruit, softening of the flesh, and seeds that had begun to separate from the fruit tissue.

2.5. The observation parameters

The parameters observed in this study include time of male flower emergence (DAP), time to female flower emergence (DAP), and pollen viability. Time to male flower emergence was recorded when 75% of the male flowers had bloomed in each experimental plot. Time to female flower emergence was recorded when 75% of the female flowers had bloomed in each experimental plot. Pollen viability was assessed by collecting flowers at the anthesis stage and the pollen was incubated in *pollen germination medium* (PGM) solution. Observations were carried out across four fields of view per glass slide using a compound microscope at 10x magnification following a two-hour incubation period. According to Warid and Palupi [21], pollen germination was calculated using the following Eq. (1).

$$Germination\ Percentages = \frac{\sum Germinated\ Pollen}{\sum Total\ number\ of\ pollen} \times 100\% \tag{1}$$

Seeds per fruit was determined by counting the total seeds in each fruit from the sample plants, followed by calculating the average. Filled seeds per fruit was determined by counting the filled seeds in each fruit from the sample plants, followed by calculating the average. This calculation was performed after the seeds had undergone the extraction and sorting processes for each treatment. Seed weight per fruit was determined by weighing the total seeds from each fruit using an analytical balance. Filled seed weight per fruit was determined by counting the number of filled seeds per fruit and subsequently weighing them using an analytical balance. Seed production per hectare was determined by multiplying the weight of filled seeds per plant by the plant population per hectare, expressed in kilograms (kg). The yield was calculated using Eq. (2).

$$Seed\ Yield\ \left(\frac{kg}{ha}\right) = Seed\ Weight\ per\ Plant\ (kg) x\ Plant\ Population\ \left(\frac{plants}{ha}\right) \tag{2}$$

3. Results and Discussion

This study showed no significant interaction between potassium and boron treatments across all observed parameters; therefore, the results are presented and discussed based only on the main effects (single-factor treatments). The absence of an interaction between potassium and boron on pollen viability and seed production is likely because these two nutrients operate through different and relatively independent physiological mechanisms [22]. Boron plays a direct role in plant reproductive processes, particularly in pollen viability and germination, whereas potassium is more involved in general metabolic processes such as photosynthesis and assimilate translocation [13,15,23]. Furthermore, under adequate nutrient conditions, the effects of each nutrient tend to be additive (main effects) and do not result in a statistically significant interaction.

This study showed that the flowering occured earlier that the variety description (Table 1). Specifically, the 1 kg/ha boron treatment resulted in the emergence of male flowers at 23.44 - 26.44 DAP, while the variety description has a flowering age of approximately 25 - 27 DAP. Meanwhile, the average time to female flower emergence, which appeared at 26-27 DAP, almost equaled the variety description of 25-27 DAP. These results showed that boron can accelerated the emergence of male flower in cucumber plants. These results were in line with the study conducted by Susanto et al. [24], who reported that the application of boron 1.0 kg/ha accelerated the emergence of male and female flowers in watermelon plants.

Table 1. The Effect of Boron Fertilizer Dose Treatment (R) on Flowering Age (DAP).

Treatment	Average Time to Male Flower Emergence (DAP)	Average Time to Female Flower Emergence (DAP)
R1 (1 kg/ha)	23.4 ± 1.53 a	26.3 ±1.0 a
R0 (0 kg/ha)	24.0 ± 1.00 b	27.0 ± 1.0 b
R2 (2 kg/ha)	24.1 ± 1.15 b	27.1± 1.15 bc
R3 (3 kg/ha)	24.4 ± 0.58 b	27.6 ± 0.58 c

Notes: Numbers followed by letters (notations) in the same column show no significant difference in the DMRT test at the 5% level.

The results of this study contradict those of Utomo et al. [25], whos stated that boron reduces male flower production. Meanwhile, according to Li et al. [26], boron not only supports reproduction but is also directly related to accelerating flowering and plant maturity. This is thought to be because the boron transporter gene plays an important role in controlling flowering time.

Table 2 shows that the application of boron fertilizer significantly affected the pollen viability parameters. The 1 kg/ha boron treatment was significantly different from the 2 kg/ha and 3 kg/ha boron treatments. However, the 1 kg/ha boron treatment was not significantly different from the control. The application of boron fertilizer is believed to enhance pollen viability. This effect is attributed to the role of boron as a micronutrient that supports pollen tube formation. The development of the pollen tube serves as an indicator that the produced pollen is viable. This process is crucial for fruit and seed formation. A study conducted by Sotomayor et al. [27] reported that boron application enhances pollen viability and germination. The application of boron increased pollen germination by 67.5–73.5% compared to untreated controls and also promoted pollen tube elongation up to 66.7 nm. Furthermore, Adhikari et al. [28] explained that the pollen tube functions as a conduit for transporting sperm cells to the ovule during fertilization. The longer and more optimal the pollen tube growth, the greater the likelihood of successful fertilization and subsequent seed formation. According to Kumari et al. [29], boron can increase pollen germination percentage and pollen tube elongation. Susanto et al. [24] reported that application of 1 kg/ha boron produced a relatively high average number of pollen grains per anther and increased the fruit set percentage to as high as 94.44% in watermelon plants. According to Rodríguez et al. [30], boron application can increase the division of tapetum cells during the microsporogenesis process, thereby increasing the viability of the resulting pollen. The tapetum plays a role in providing nutrients for pollen development. Therefore, Aasim et al. [15] reported that boron is an essential element that plays a crucial role in preventing disruptions in pollen development from the early stages of microsporogenesis.

Table 2. Effect of Boron Fertilizer Dose Treatment (R) on Pollen Viability Parameters (%).

Treatment	26 DAP	33 DAP	40 DAP	47 DAP
R3 (3 kg/ha)	35.59 ± 3.91 a	35.07 ± 9.95 a	36.68 ± 8.59 a	36.06 ± 18.45a
R2 (2 kg/ha)	35.84 ± 10.48 a	36.72 ± 33.37a	37.33 ± 15.69a	37.96 ± 5.82a
R0 (0 kg/ha)	39.30 ± 18.34 ab	39.70 ± 13.33ab	38.42 ± 7.04 ab	39.68 ± 18.09ab
R1 (1 kg/ha)	45.58 ± 7.77b	45.77 ±5.35 b	45.62 ± 2.34b	45.02 ± 4.73 b

Notes: Numbers followed by letters (notations) in the same column show no significant difference in the DMRT test at the 5% level.

The application of potassium fertilizer significantly affected the number of seeds per fruit, seed weight per fruit, number of filled seeds per fruit, filled seed weight per fruit, and seed production per hectare (Table 3). The application of 300 kg/ha potassium had a significantly different effect on the number of seeds per fruit, with a mean of 342.53 ± 18.9. At the same dose, potassium produced a significantly different effect compared to 100 kg/ha but did not differ significantly from 200 kg/ha. Meanwhile, the application of 300 kg/ha potassium also had a significantly different effect on the number of filled seeds per fruit, filled seed weight per fruit, and seed production per hectare. Budak and Güneş [31] reported a significant increase in seed yield at a potassium application dose of 200 kg/ha compared to the control. Azab et al. [32] reported that potassium-based treatment increased almost all growth and productivity parameters, including yield parameters in pumpkin plants.

The significant effect of potassium fertilizer is thought to be due to its ability to improve photosynthesis and carbohydrate production. According to Budak and Güneş [31] and Sulfa et al.

[33], potassium (K) acts as an important cofactor or activator for many enzymes involved in key processes such as photosynthesis, protein synthesis, and carbon metabolism. With an adequate supply of potassium (K), plants can synthesize higher amounts of carbohydrates in the leaves. This increase in carbohydrates automatically increases the total amount of "energy" and raw materials available for transport and use by the fruit or seed. According to Song et al. [11] and Corrêa et al. [34], potassium plays a crucial role in improving seed yield components by enhancing photosynthesis and facilitating the translocation of assimilates to reproductive organs. Potassium application has been shown to enhance fruit number, fruit weight, and nutrient accumulation, indirectly leading to a higher number of seeds per fruit, increased seed weight, more filled seeds, and greater overall seed yield per hectare.

Table 3. Effect of Potassium (K) Fertilizer Dose Treatment on the Number of Seed per Fruit (Grains), Seed Weight per Fruit (Grams), Number of Fully Filled Seed per Fruit (Grains), Weight of Fully Filled Seed per Fruit (Grams), Seed Production per Hectare (kg).

Potassium Dosage (kg/ha)	Number of Seed per Fruit (Grain)	Seed Weight per Fruit (Gram)	Number of Filled Seed per Fruit (Grain)	Weight of Full Seed per Fruit (Gram)	Seed Production per Hectare (kg)
K1 (100 kg/ha)	299.53 ± 54.1a	6.21 ± 1.2a	229.35 ± 22.2a	6.49 ± 0.78a	199.56 ± 23.89a
K2 (200 kg/ha)	317.92 ± 39.0a	6.70 ± 0.8ab	274.47 ± 46.0b	7.56 ± 1.25 b	232.56 ± 38.70b
K3 (300 kg/ha)	342.53 ± 18.9b	7.13 ± 1.3b	289.93 ± 48.8c	8.24 ± 1.21c	253.64 ±39.67c

Notes: Numbers followed by letters (notations) in the same column show no significant difference in the DMRT test at the 5% level.

Boron fertilizer had a significantly different effect on filled seed weight per fruit and seed production per hectare (Table 4). Boron application at a dose of 1 kg/ha produced the highest filled seed weight per fruit, with a mean of 7.86 ± 2.35 g, but was not significantly different from the control. These results showed that a boron dose of 1 kg/ha is sufficient to increase filled seed weight per fruit. According to Li et al. [35], boron is well known for its critical role in maintaining phloem integrity, thereby facilitating sugar transport. Sufficient boron ensures smooth sugar transport, promoting seed filling and the production of fully developed seed. Goldbach et al. [36] reported that boron can increase seed filling, seed size, and reduce the percentage of empty or non-filled seeds.

Table 4. Effect of boron fertilizer dose treatment (R) on parameters of filled seed weight per fruit and parameters of seed production per hectare.

Treatment	Filled seed weight per fruit (g)	Seed production per hectare (kg)
R3 (3 kg/ha)	7,07 ± 3.07a	216.21 ± 12.65 a
R2 (2 kg/ha)	7.25 ± 2.84ab	224.31± 14.91ab
R0 (0 kg/ha)	7.54 ± 2.42bc	232.09 ± 17.53 ab
R1 (1 kg/ha)	7.86 ± 2.35c	241.72 ± 15.77b

Notes: Numbers followed by letters (notations) in the same column show no significant difference in the DMRT test at the 5% level.

Seed production per hectare also increased to 241.72 ± 15.77 kg/ha under the 1 kg/ha boron treatment, although it was not significantly different from the control and the 2 kg/ha boron treatment. This increase in seed production per hectare is correlated with filled seed weight per hectare, where a dose of 1 kg/ha is sufficient to increase filled seed weight per fruit. An increase in the number of fully developed seeds per fruit, combined with an adequate energy supply, directly enhances total seed production per hectare. Boron plays a very important role in the transport and utilization of assimilates (carbohydrates or energy produced through photosynthesis). This function ensures that more carbohydrates and energy are transferred to the seeds during the filling stage, increasing seed weight and overall seed production. Dordas et al. [37] reported that Boron treatment can increase yields in cucumber because it can increase the ability to absorb micronutrients. Giri et al. [38] also reported that boron fertilization can increase seed production per hectare in cucumber. Therefore, boron application has been shown to exert a significant effect on seed weight and seed yield per hectare. Boron plays a key role in enhancing seed filling by promoting the translocation of photosynthates to reproductive organs, thereby producing well-filled seeds and significantly increasing seed yield compared to conditions without boron application [36, 39, 40].

4. Conclusion

In conclusion, no significant interaction was observed between potassium and boron treatments across all observed parameters. The treatment of 300 kg/ha of potassium had a highly significant effect on the number of seeds per fruit (342.53), the number of filled seeds per fruit (289.93), seed weight per fruit (7.13 g), filled seed weight per fruit (8.24 g), and seed production per hectare (253.64 kg). Boron fertilizer treatment at a dose of 1 kg/ha had a highly significant effect on the time to emergence of male flowers (23.44 DAP), the time to emergence of female flowers (26.33 DAP), filled seed weight per fruit (7.86 g), and seed production per hectare (241.72 kg).

Abbreviations

RCBD	*Completely Randomized Block Design*
ANOVA	Analysis Of Variance
DMRT	*Duncan's Multiple Range Test*
DAP	Day After Planting

Data Availability Statement

Data will be made available on request.

CRediT Authorship Contribution Statement

Leli Kurniasari: Conceptualization, Data curation, Formal analysis, Methodology, Supervision, Resources, Validation, Writing – original draft, Writing – review and editing, Project

Administration, Funding Acquisition. **Putri Santika:** Methodology, Validation, Formal Analysis, Investigation, Resources, Data Curation, Writing-Original Draft, Writing,Review & Editing, Visualization. **M Rosyadi Adnan:** Methodology, Validation, Formal Analysis, Investigation, Resources, Data Curation, Writing-Original Draft, Writing,Review & Editing, Visualization.

Declaration of Competing Interest

The authors declare no competing interests.

Declaration of Use of AI in the Writing Process

Nothing to disclose.

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