

Vegetative Growth Response of Robusta Coffee Seedlings (*Coffea canephora* Pierre ex A. Froehner) to Various Concentrations of Atonic Growth Regulators

Novi Yulanda Sari^{1*}, Nursamsi², Muhammad Syahfitra³, Novfirman⁴, Dyah Puspita Sari⁵

^{1,2,3,4,5} Program Studi Pengelolaan Perkebunan, Jurusan Bisnis Pertanian, Politeknik Pertanian Negeri Payakumbuh, Lima Puluh Kota, Indonesia

*Corresponding author: noviyulandas@yahoo.com

Article History

Received: 14 February 2026

Approved: 10 March 2026

Published: 15 March 2026

Keywords

atonik concentration, foliar application, robusta coffee seedlings, vegetative growth

ABSTRACT

Seedling quality is a critical determinant of the long-term productivity of robusta coffee. Under nursery conditions, seedlings often exhibit slow and uneven growth, which may limit canopy development and photosynthetic efficiency. Therefore, strategies that enhance physiological processes are needed to improve seedling performance. Atonik, a plant growth regulator (PGR) containing nitrophenolate compounds, has been reported to stimulate metabolic activity and enhance plant growth. However, information regarding the optimal concentration of Atonik for seed-propagated robusta coffee seedlings remains limited. This study aimed to evaluate the vegetative growth response of robusta coffee seedlings to different concentrations of Atonik and to determine the most effective rate during the nursery stage. The experiment was arranged in a completely randomized design (CRD) with a single factor consisting of five Atonik concentrations (0, 10, 15, 20, and 25 ml/L) and three replications. Observed variables included plant height, leaf number, stem diameter, leaf length, leaf width, total fresh weight, and total dry weight. Data were analyzed using ANOVA followed by Duncan's Multiple Range Test at 5%. The results showed that Atonik application significantly increased plant height, stem diameter, leaf width, total fresh weight, and total dry weight. The 15 ml/L concentration significantly increased plant height and leaf width, whereas the 20 ml/L concentration significantly improved stem diameter and biomass accumulation. Overall, the 20 ml/L treatment was the most effective in enhancing seedling vigor during the nursery stage.

© 2026 The Authors. Published by Christian University of Indonesia.
Licensed under CC BY-SA 4.0: <https://creativecommons.org/licenses/by-sa/4.0/>

INTRODUCTION

Robusta coffee (*Coffea canephora* Pierre ex A. Froehner) is one of the main plantation commodities, playing an important role in supporting the national economy. In Indonesia, coffee is mostly

produced by smallholder plantations (Badan Pusat Statistik, 2022; Haryono et al., 2024). However, productivity gains at the farmer level still show a gap between actual yields and the genetic potential of plants. This condition indicates that efforts to increase

coffee production should not rely solely on improving cultivation techniques in the field, but must also be supported by the use of high-quality planting materials. Vigorous and uniform seedlings typically develop stronger root systems and crowns, allowing them to adapt more rapidly after transplanting (Nugroho et al, 2023; Ali et al., 2024; Khairunnisa et al., 2025).

The nursery phase is a crucial stage because it is during this period that the root system and initial crown begin to form, determining the plant's subsequent photosynthetic capacity. In practice, the vegetative growth of coffee seedlings at the age of the first 2–4 months often takes place relatively slowly and is less uniform; Crown development that is not optimal can limit leaf formation and the plant's ability to utilize light, so that the assimilate formation process is not optimal (Taiz et al., 2015). This shows that efforts to improve seedling quality through nutrient addition alone are not sufficient; it is also necessary to consider how plant physiological processes can function efficiently (Purba et al., 2022; Wahyuni et al, 2018; Ningsih et al., 2024; Yanty et al., 2025).

Physiologically, the vegetative growth of coffee seedlings is determined by hormonal balance and cellular metabolic activity. Cell division and elongation in shoot meristems contribute to height increase and the formation of new organs,

while photosynthesis and respiration provide energy for plant growth (Davies, 2010). If this physiological activity is not optimal, growth can be stunted even when environmental conditions are relatively supportive. Therefore, an approach directed at improving the physiological efficiency of plants through the application of growth regulators (ZPT) is important to improve the quality of seedlings so that they are more vigorous and responsive to the environment (Yuliatin & Faizah, 2023).

Atonic is one of the synthetic ZPTs that contain sodium nitrophenolate compounds, which can improve respiration, photosynthesis efficiency, and nutrient absorption and translocation. This increase in metabolic activity can support cell division and elongation and accelerate biomass accumulation. Some studies suggest that the application of Atonic at certain concentrations can enhance plant vegetative growth. However, the plant's response to ZPT is strongly influenced by the concentration and does not always show a linear pattern (Parađiković et al., 2019; Brata et al., 2020; Wahyuni et al., 2018; Tavallali & Darvishzadeh, 2025; Purba et al., 2022; Badaria et al; 2025).

In coffee plants, the use of ZPT has been more focused on synthetic auxins, such as IBA, to stimulate root formation during cuttings propagation (Hartmann et al., 2011). This approach generally focuses on

the rooting phase, whereas research on crown growth in coffee seedlings is still relatively limited. In fact, in a generative nursery system, the development of the crown has an important role in determining the capacity of photosynthesis as well as the direction of subsequent vegetative growth.

However, information on the effect of Atonic on vegetative growth in the crown component and the accumulation of total biomass of coffee seeds derived from beans is still relatively limited. In addition, the response patterns of each growth component to variations in Atonic concentration have also not been studied in depth. Therefore, this study was conducted to determine the effect of several Atonic concentrations on vegetative growth of coffee seedlings and to identify the most appropriate dose to support the formation of vigorous, high-quality seeds during the seedling phase. Thus, the study of seedlings' physiological responses to ZPT applications is an important part of developing a strategy to improve the quality of sustainable coffee planting material.

RESEARCH METHODS

Study Design

This experiment was designed using a Completely Randomized Design (*Rancangan Acak Lengkap*, RAL) with one treatment factor: atonic concentration, with five levels: 0 ml/L (control), 10 ml/L, 15 ml/L, 20 ml/L, and 25 ml/L. Each treatment

was repeated three times, yielding 15 experimental units. Each experimental unit consisted of five plants, so the total number of seedlings used was 75.

Location

This research was carried out at the nursery of the Payakumbuh State Agricultural Polytechnic, Harau District, Lima Puluh Kota Regency, West Sumatra, from April to June 2025.

Tools and Materials

The tools used in the study include measuring cups, hand sprayers, rulers, calipers, analytical scales, and drying ovens. The ingredients used are 12-week-old robusta coffee seeds and ZPT Atonic.

Procedure

The robusta coffee seeds used in this study are local seeds from smallholder plantations in Baso District, Agam Regency, West Sumatra. The seeds are propagated generatively to produce seeds ready for treatment. All seedlings came from the same source and were selected for high uniformity to obtain a relatively homogeneous experimental unit. The treatment is in the form of an Atonic growth regulator (ZPT) at concentrations of 0, 10, 15, 20, and 25 ml/L.

The solution is prepared by measuring Atonic using a measuring cup to the required volume, then dissolving it in clean water and stirring until evenly mixed. Next, water is added to reach a final volume of 1 liter, and the mixture is stirred until evenly

distributed. The 0 m/L treatment was prepared using water without Atonic, serving as a control.

The Atonic solution is applied by spraying it onto the leaves of coffee seedlings until it reaches spray saturation (run-off). The treatment was given once weekly for 6 consecutive weeks. Spraying is carried out in the morning (\pm 07.00-09.00 WIB) to minimize solution loss due to evaporation and enhance plant absorption. During the study, all seedlings were maintained under the same watering, weeding, and other maintenance treatments to minimize the influence of factors outside the treatment on plant growth response.

Data Collection

The variables observed included plant height, number of leaves, stem diameter, leaf length, leaf width, total fresh weight, and total dry weight. The height of the plant is measured from the surface of the medium to the highest shoot. The number of leaves is calculated on the leaves that have fully developed. The stem diameter is measured with a caliper at a position \pm 2 cm above the surface of the planting medium. Observations of leaf length and width were carried out on the same leaf each week, i.e., leaves that had been fully developed and were assigned as a fixed sample during the study period. At the end of the 6th week, the plants are harvested and separated into the crown and roots for fresh weight

determination. Next, the sample is dried in the oven at 70°C for about 48 hours until it reaches a constant weight, which serves as the basis for determining the dry weight.

Data Analyze

The observation data were analyzed through a variety-based fingerprint test (ANOVA) at a significance level of 5% after first testing the assumptions of normality and homogeneity of the variety. The data on the number of leaves that do not meet the assumption are transformed using \sqrt{x} the square root (x) before analysis. If there is a significant difference between treatments, the analysis is followed by Duncan's Multiple Range Test (DMRT) at the 5% level. The entire analysis was carried out using SAS software.

RESULTS AND DISCUSSION

Plant Height

The results of the analysis showed that the administration of Atonic had a significant effect on the height of coffee seedlings ($p < 0.05$). The highest average height was observed at a concentration of 15 ml/L (25.33 cm) and was significantly higher than the control (15.57 cm). However, the growth response does not increase linearly with increased concentration. At 20 and 25 ml/L, height decreased compared to 15 ml/L. The data on plant height are shown in **Figure 1**.

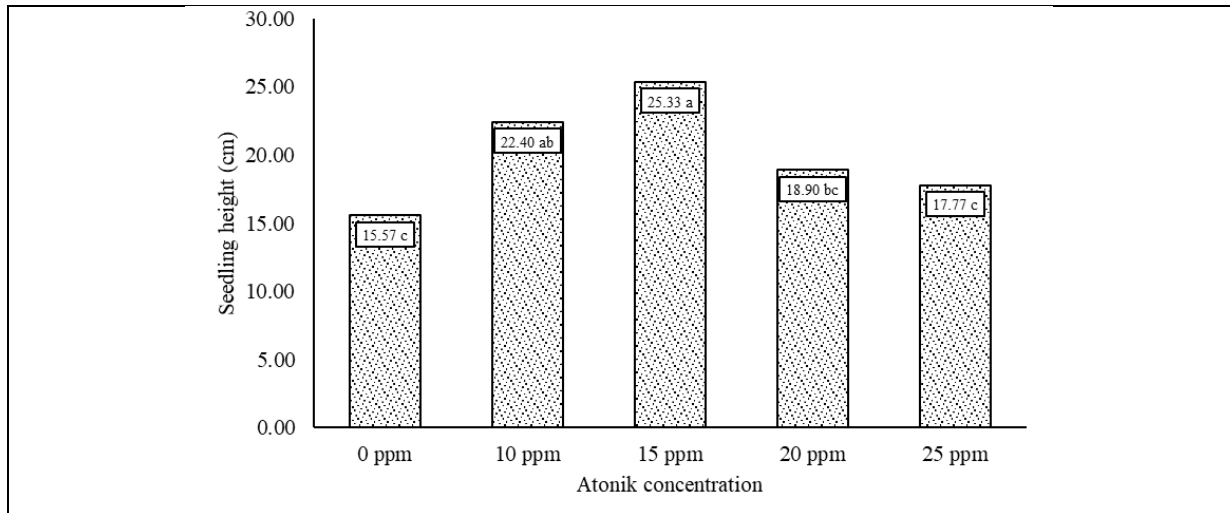


Figure 1. Coffee seedling height at some concentration of Atonic ZPT

Remarks: The numbers in the subimage, followed by different letters, show a significant difference according to the DMRT test at the 5% level.

Physiologically, the increase in plant height is a manifestation of the activity of the meristem of shoots that involves the process of cell division and elongation. Nitrophenolate compounds, as active components of Atonic, function as biostimulants that can increase cellular respiration and enzymatic activity, so that the availability of energy in the form of ATP for cell wall synthesis and tissue expansion is more optimal. At a concentration of 15 ml/L, the metabolic activity of coffee seeds is thought to be more efficient, allowing optimal cell lengthening and significantly increasing plant height (Przybysz et al., 2014; Parađiković et al., 2019).

In addition to playing a role in improving energy metabolism, nitrophenolate compounds are also reported to be able to increase the efficiency of nutrient absorption and nitrogen translocation in plants (Tavallali &

Darvishzadeh, 2025; Rouphael & Colla, 2020). Nitrogen functions as an important component in the synthesis of structural proteins and growth hormones, including auxin, which play a direct role in the process of stem elongation (Taiz et al., 2015). In the coffee nursery phase, which naturally exhibits a relatively slow growth rate, this increase in metabolic efficiency is an important factor because it accelerates the formation of the initial crown and the seedlings' readiness to enter the transplanting phase (Tavallali & Darvishzadeh, 2025; Rouphael & Colla, 2020).

Conversely, a decrease in plant height at 20-25 ml/L indicates that excessive ZPT concentrations can disrupt the plant's growth balance. This is in line with the concept of hormesis, where low to moderate doses are stimulating, while higher doses actually decrease biological responses. At higher

concentrations, increased metabolic activity in plant cells and tissues can shift photosynthetic allocation toward the formation of other vegetative organs, such as leaves or stem thickening, resulting in suboptimal stem elongation.

Based on the observed physiological response, the 15 ml/L concentration is the most effective application rate for increasing the height of coffee seedlings without disrupting growth regulation. This concentration optimizes stem elongation while maintaining vegetative growth stability during the nursery phase (Calabrese & Baldwin, 2002; Erofeeva, 2024).

Stem Diameter

Atonic administration has a very noticeable effect on the diameter of coffee seedlings ($p < 0.05$). The maximum response is obtained at 20 ml/L, whereas plant height reaches its optimum at 15 ml/L

(**Figure 2**). This difference suggests that apical growth and radial growth do not necessarily require the same level of stimulation, as different physiological processes control them.

Physiologically, stem thickening is related to the activity of the vascular cambium, which produces secondary xylem and phloem. This process involves cell division and tissue strengthening through cell wall formation and lignification, requiring sufficient energy and photosynthate supply (Taiz et al., 2015).

Nitrophenolate in Atonic is known to enhance plant respiration and metabolic activity, thereby increasing energy availability for structural tissue formation. At a concentration of 20 ml/L, the stimulation appears optimal for plant growth, promoting cambial activity without disturbing physiological balance.

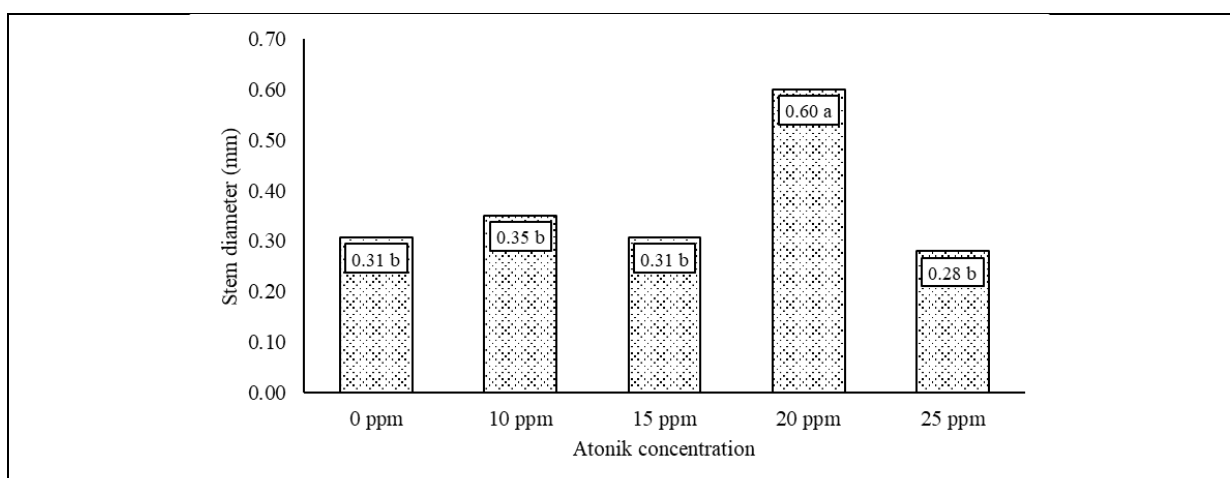


Figure 2. Stem diameter of coffee seeds at some concentrations of Atonic ZPT

Remarks: The numbers in the subimage, followed by different letters, show a significant difference according to the DMRT test at the 5% level

At this appropriate dose, metabolic processes and photosynthate distribution occur more efficiently, supporting stronger stem development. In contrast, excessive doses may disrupt growth balance and alter assimilate allocation to other organs, thereby inhibiting stem thickening (Beam et al., 2023; Parađiković et al., 2019; Yakhin et al., 2017).

Number of Leaves

The analysis showed that applying Atonic did not have a significant effect on the number of coffee seedling leaves ($p > 0.05$). Numerically, the 25 mL/L concentration produced the highest number of leaves, although the difference was not statistically significant. This indicates that leaf formation during the nursery phase is relatively stable and less responsive to Atonic concentration.

Physiologically, the number of leaves is determined by the activity of the shoot's meristem as well as the balance of growth hormones, especially auxins and cytokinins (Taiz et al., 2015). Although nitrophenolates in Atonic increase metabolic activity and nutrient absorption efficiency, the formation of new leaves in 3–4-month-old coffee seedlings is more influenced by the plant's internal regulation and physiological age. Data on the number of leaves are presented in **Table 1**.

Table 1. Number of leaves and leaf length of robusta coffee seedlings at some Atonic concentration

| Concentration (m1/L) | Number of leaves (leaves) | Leaf length (cm) |
|----------------------|---------------------------|------------------|
| 0 | 13 to | 13.67 to |
| 10 | 14 to | 11.83 to |
| 15 | 16 to | 15.33 A |
| 20 | 15 to | 14.67 A |
| 25 | 20 to | 11.57 to |

Remarks: Numbers followed by the same letter in the same column show no significant difference based on the DMRT test of 5%.

The leaf growth pattern at this stage tends to follow a consistent natural rhythm. Thus, the improvement in the physiological condition of the plant due to the administration of Atonic has not been followed by a noticeable increase in the number of leaves (Parađiković et al., 2019; Rouphael & Colla, 2020; Damatta et al., 2007).

Leaf Length

The analysis showed that Atonic administration did not have a significant effect on coffee seedling leaf length ($p > 0.05$), although there was a numerical tendency to increase at 15–20 mL/L (Table 1). This condition suggests that leaf length growth in the nursery phase is relatively stable and is not very responsive to variations in Atonic concentration. Physiologically, leaf length is determined by cell growth, which is strongly influenced by turgor pressure, the nature of the cell wall, and the balance of growth hormones such as auxin and gibberellin (Taiz et al., 2015). Although nitrophenolate in Atonic improves

respiration and photosynthesis efficiency, the increase in leaf area and size in coffee seedlings aged 3–4 months still follows the plant's internal regulation. The stable length of the leaves throughout the treatment also suggests that the application of Atonic does not trigger excessive leaf growth.

Leaf Width

The results showed that Atonic administration significantly affected leaf width in coffee seedlings ($p < 0.05$), with the best response at 15 ml/L (**Figure 3**). This concentration differs from the optimal point at the stem's height and diameter, confirming that each part of the plant responds differently to ZPT stimulation. For leaf width, a moderate dose yields the most effective results.

Physiologically, the width of the leaf is determined by the process of cell enlargement after the division phase is

complete. This process is influenced by turgor pressure, cell wall flexibility, and growth hormone balance (Taiz et al., 2015). The nitrophenolate present in Atonics can increase respiratory activity and photosynthetic efficiency, thereby providing energy for the formation of new tissues. At a concentration of 15 ml/L, an increase in metabolism is sufficient to support optimal leaf dilation without disturbing the physiological balance of the plant (Parađiković et al., 2019; Roupael & Colla, 2020).

Leaf width decreasing at a concentration of 20–25 ml/L indicates that the increase in leaf size has a tolerance limit to stimulation. When the dose of Atonic exceeds physiological needs, the metabolic and hormonal balance of the plant becomes disturbed so that the process of leaf widening becomes less optimal.

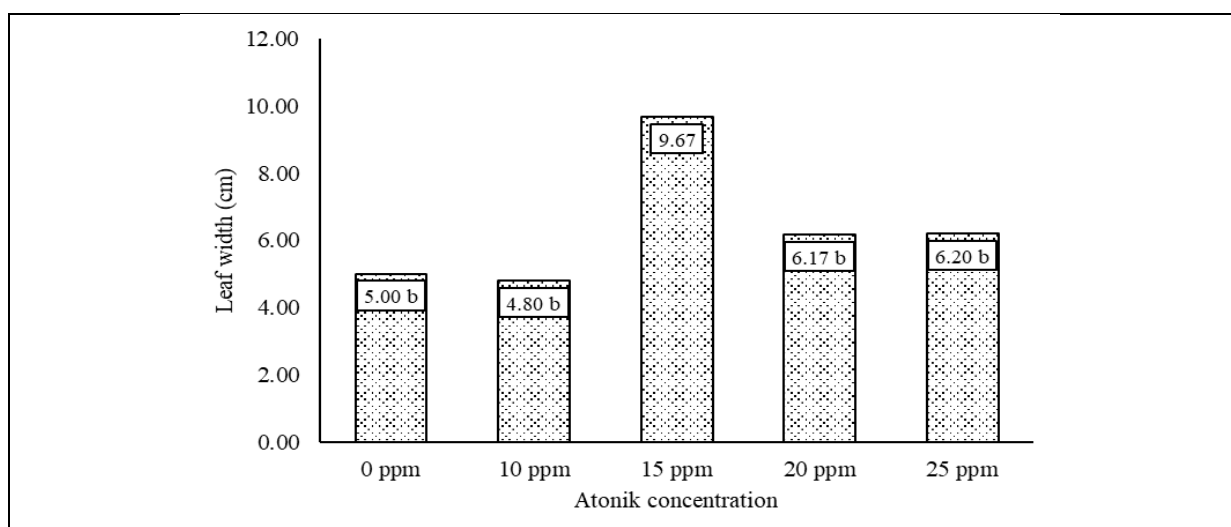


Figure 3. Leaf width of coffee seedlings at some concentration of Atonic ZPT

Remarks: The numbers in the subimage, followed by different letters, show a significant difference according to the DMRT test at the 5% level.

Too high a concentration of ZPT can trigger an imbalance in endogenous hormones, particularly between auxin, cytokinin, and gibberellin, which play roles in cell growth. This condition can limit the enlargement of epidermal cells and mesophyll tissue, thereby reducing the surface area of the leaves (Taiz et al., 2015; Erofeeva, 2024). In addition, increased metabolic activity due to nitrophenolates can increase the rate of respiration and the energy requirements of cells, diverting some of the energy to maintain metabolic balance

rather than to form new tissues (Rouphael & Colla, 2020). This pattern is consistent with the principle of hormesis, in which the growth response increases to an optimal point, then decreases at higher doses (Calabrese & Baldwin, 2002).

Fresh Weight and Dry Weight

Atonic administration significantly affected the fresh and dry weights of coffee seedlings ($p < 0.05$), with the highest values observed at 20 ml/L. The fresh weight and dry weight data are shown in **Figure 4**.

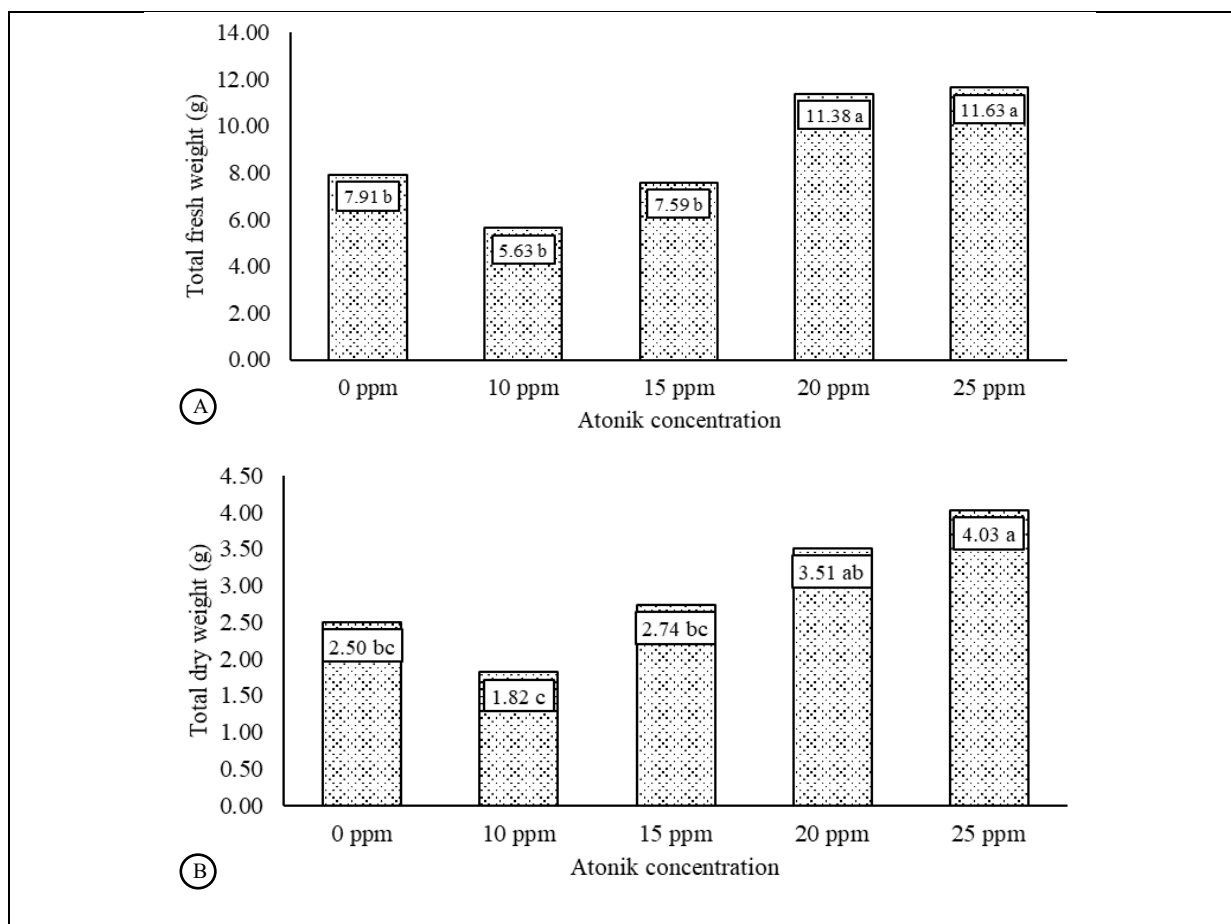


Figure 4. The fresh weight and dry weight of coffee seeds at some concentration of Atonic ZPT. A. Total fresh weight; B. Total dry weight

Remarks: The numbers in the subimage, followed by different letters, show a significant difference according to the DMRT test at the 5% level.

An increase in these two parameters showed that the plant's response was not only evident in morphological changes but also reflected higher biomass accumulation. In contrast to some growth parameters, which reach an optimum at lower concentrations, biomass formation is actually maximum at 20 ml/L. It shows that the accumulation of dry matter requires a higher level of metabolic stimulation than other vegetative growth processes.

Physiologically, fresh weight reflects the total mass of the plant, including water content, while dry weight represents the results of photosynthesis that have been converted into structural tissue (Taiz et al., 2015). The increase in dry weight, in line with fresh weight, at a concentration of 20 ml/L, suggests that the increase in plant weight is not solely due to increased water content but reflects the efficiency of photosynthate conversion into biomass. Nitrophenolates in Atonics are known to increase respiratory activity, photosynthetic efficiency, and nutrient absorption and translocation, so that, at these concentrations, the production and distribution of assimilates seem to occur more effectively.

In contrast, the loss of fresh weight and dry weight at a concentration of 25 ml/L suggests that the increase in dose is not always directly proportional to biomass accumulation. This pattern is in line with the

principle of hormesis, in which the physiological response increases until it reaches an optimum dose, then decreases when it exceeds a certain tolerance threshold. At higher doses, some of the energy is allocated to maintaining the cell's metabolic balance, thereby decreasing the efficiency of new tissue formation (Calabrese & Baldwin, 2002).

Overall, the response of coffee seeds to Atonic application shows that each growth parameter has a different optimum concentration. A concentration of 15 ml/L is more effective in promoting leaf elongation and widening, while 20 ml/L provides the most stable response to stem diameter and biomass accumulation. This pattern illustrates a shift in growth direction as the dose increases, from dominance of elongation to strengthening of the structure and the accumulation of dry matter. Meanwhile, the insignificance of the number and length of leaves shows that the formation of new organs in the nursery phase is still more influenced by regulation within the plant body than by stimulation from outside. Thus, the 20 ml/L concentration is the most balanced dose for supporting the growth and development of coffee seedlings during the nursery phase.

However, this research still has some limitations. Observations were only made in the nursery phase at 3–4 months of age, so it was not possible to describe the impact of

Atonic application on continued growth after the seedlings were transferred to the field or on the generative phase of the plant. In addition, the observed parameters remain limited to morphological and biomass traits, so the physiological mechanisms underlying plant responses have not been directly observed.

Further research is suggested to evaluate the consistency of coffee seed responses after the transplanting phase and to measure physiological parameters, such as photosynthesis rate, chlorophyll content, and enzymatic activity, to gain a more comprehensive understanding of the mechanism of action of Atonics. Testing under different environmental conditions and across diverse coffee genotypes is also needed to obtain more precise and applicable dosage recommendations for field cultivation conditions.

CONCLUSION

The administration of Atonic ZPT has a real effect on the vegetative growth of robusta coffee seedlings (*C. canephora*). The concentration of 15 ml/L has a significant effect on the increase in plant height and leaf width, while the concentration of 20 ml/L has a significant effect on the stem diameter, fresh weight, and dry weight of the plant. These differences in responses suggest that each growth component requires a different level

of stimulation. Thus, a concentration of 20 ml/L is more appropriate for the nursery phase to achieve better seedling growth and higher biomass accumulation.

REFERENCES

- Ali, F. Y., Rosdiana, E., Rohman, H. F., & Kusumaningtyas, R. N. (2024). Increasing the growth of robusta coffee seedlings (*Coffea canephora*) through application of KNO₃ and shallot extract. *Jurnal Kridatama Sains dan Teknologi*, 6(2), 585–594.
- Badan Pusat Statistik. (2022). *Statistik Indonesia 2022*. Badan Pusat Statistik.
- Badaria, Rustiana, W. O., & Anggia. (2025). Response of different doses of Atonik on the growth of California papaya seedlings. *Jurnal Agriyan: Jurnal Agroteknologi Unidayan*, 11(2).
- Balk, M., Sofia, P., Neffe, A. T., & Tirelli, N. (2023). Lignin, the lignification process, and advanced lignin-based materials. *International Journal of Molecular Sciences*, 24(14), 11668. <https://doi.org/10.3390/ijms241411668>
- Brata, I. K., Sutedja, I. N., & Arimbawa, I. W. P. (2020). Pertumbuhan kopi robusta. *Jurnal Agroekoteknologi Tropika*, 9(1).
- Calabrese, E. J., & Baldwin, L. A. (2002). Defining hormesis. *Human & Experimental Toxicology*, 21(2), 91–97. <https://doi.org/10.1191/0960327102ht2170a>
- DaMatta, F. M., Ronchi, C. P., Maestri, M., & Barros, R. S. (2007). Ecophysiology of coffee growth and production. *Brazilian Journal of Plant Physiology*, 19(4).
- Davies, P. J. (2010). Plant hormones: Biosynthesis, signal transduction, action! In *Plant hormones: Biosynthesis, signal transduction, action!* Springer. <https://doi.org/10.1007/978-1-4020-2686-7>

- Erofeeva, E. A. (2024). Plant hormesis: The energy aspect of low and high-dose stresses. *Plant Stress*, *14*, 100628. <https://doi.org/10.1016/j.stress.2024.100628>
- Hartmann, H. T., Kester, D. E., Davies, F. T., Jr., & Geneve, R. L. (2010). *Plant propagation: Principles and practices* (8th ed.). Prentice Hall.
- Haryono, A., Juniarti, I., Matajat, K., Suroso, A. I., & Soesilo, M. (2024). Partnership development of smallholder coffee cultivation: A model for social capital in the global value chain. *Economies*, *12*(12). <https://doi.org/10.3390/economies12120349>
- Khairunnisa, A., Anjarsari, I. R. D., & Ariyanti, M. (2025). Effectiveness of humic acid and nitrogen-fixing bacteria in the growth of robusta coffee seedlings. *Jurnal Agrotek Tropika*, *13*(4), 1015–1027. <https://doi.org/10.23960/jat.v13i4.10395>
- Ningsih, M. S., Syafrison, F., Fardedi, Oktabriana, G., Rahmah, M., Jailani, H. Y., Bungaini, Nurpiati, & Kurniawan, R. (2024). Effect of natural growth regulators on the growth of coffee seedlings in the cotyledon phase. *Jurnal Riset Perkebunan*, *5*(2), 65–75. <https://doi.org/10.25077/jrp.5.2.65-75.2024>
- Nugroho, S. A., Setyoko, U., Safitiri, A. K. N., & Arthamurti, T. T. (2023). Pengaruh ZPT alami dan pupuk kandang sapi terhadap pertumbuhan bibit kopi robusta (*Coffea canephora* L.). *Jurnal Ilmu Pertanian*, *2*(1), 17–24.
- Parađiković, N., Teklić, T., Zeljković, S., Lisjak, M., & Špoljarević, M. (2019). Biostimulants research in some horticultural plant species: A review. *Food and Energy Security*, *8*(2). <https://doi.org/10.1002/fes3.162>
- Przybysz, A., Gawrońska, H., & Gajc-Wolska, J. (2014). Biological mode of action of a nitrophenolates-based biostimulant: Case study. *Frontiers in Plant Science*, *5*, 713. <https://doi.org/10.3389/fpls.2014.00713>
- Purba, K., Hartawan, R., & Marpaung, R. (2022). Uji efektivitas natrium nitrofenol dalam menunjang pertumbuhan setek kopi robusta (*Coffea canephora* L.). *Jurnal Media Pertanian*, *7*(1), 1–7. <https://doi.org/10.33087/jagro.v7i1.138>
- Rouphael, Y., & Colla, G. (2020). Toward a sustainable agriculture through plant biostimulants: From experimental data to practical applications. *Agronomy*, *10*(10). <https://doi.org/10.3390/agronomy10101461>
- Taiz, L., Zeiger, E., Møller, I. M., & Murphy, A. (2015). *Plant physiology and development* (6th ed.). Sinauer Associates.
- Tavallali, V., & Darvishzadeh, M. D. (2025). Synergistic effects of Fe nanocomplex and nitrophenolate-based biostimulant on growth and physiological performance of tomato seedlings. *BMC Plant Biology*, *25*(1). <https://doi.org/10.1186/s12870-025-06930-y>
- Wahyuni, S. P., Suarsana, M., & Mardana, I. W. E. (2018). Pengaruh jenis media organik dan konsentrasi Atonik terhadap pertumbuhan bibit kakao (*Theobroma cacao* L.). *Agricultural Journal*, *1*(2).
- Yakhin, O. I., Lubyantov, A. A., Yakhin, I. A., & Brown, P. H. (2017). Biostimulants in plant science: A global perspective. *Frontiers in Plant Science*, *7*, 2049. <https://doi.org/10.3389/fpls.2016.02049>
- Yanty, D. P., Syafruddin, & Wahyuni, N. (2025). The effect of concentration and frequency of application of shallot extract as a natural growth regulator (PGR) on the growth of robusta coffee seedlings (*Coffea canephora*). *Journal of Tropical Agricultural Innovation*, *1*(1), 7–13.

- Yuliatin, E., & Faizah, M. (2023). Karakteristik dan potensi bakteri rhizosfer penghasil indole acetic acid yang berasosiasi dengan tanaman kopi (*Coffea* spp.). *Jurnal Pro-Life*, 10(2), 804–816. <https://doi.org/10.33541/pro-life.v10i2.4899>