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The Effectiveness of Pruning and Atonic in Improving the Reproductive Development of Coffee Plants

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Abstract
The Decline in Arabica coffee productivity in the Kintamani highlands indicates agronomic constraints affecting the plant's reproductive phase. Pruning and the application of growth regulators are two essential approaches to improving the physiological balance that supports flower and fruit formation. This study aims to assess the effectiveness of pruning and Atonic application in promoting shoot, leaf, flower, and fruit bud development in Arabica coffee plants. The study was conducted over 12 weeks using a factorial design with a combination of pruning treatments and several Atonic dosage levels. Data were analysed using ANOVA and post hoc tests tests to determine the differences between treatments. The results showed that pruning consistently increased shoot regeneration and improved canopy structure, thereby optimising light capture efficiency and photosynthetic product distribution. The Atonic application strengthened the plants' physiological response by increasing meristem activity and nutrient absorption. The combination of both treatments produced the highest number of flowers and fruit buds compared to either treatment alone. Scientifically, these findings indicate that the enhancement of the generative phase is highly dependent on vegetative conditions, which are strengthened by canopy management and hormonal stimulation. This study makes an essential contribution to the development of coffee cultivation strategies that integrate pruning practices and hormone regulation to sustainably increase productivity.

Keywords:
Coffee, pruning, plant growth regulator, Atonic, reproductive development

1. Introduction

Arabica coffee production plays a vital role in Indonesia's agricultural sector, as it is a leading commodity that supports farmers' livelihoods and the processing industry. Bangli Regency, as the centre of Arabica coffee in Bali, contributes significantly to the province's total production. Catur Village in Kintamani District is an up-and-coming area because it has the altitude, climate, and soil characteristics suitable for coffee growth. The trend in Arabica coffee production in this region has fluctuated, leading to a decline over the past five years. Data from the relevant agency records production in 2024 at 2,164 tons, in 2023 at 1,960 tons, in 2022 at 2,082 tons, in 2021 at 2,173 tons, and in 2020 at 2,249 tons (BPS). This decline illustrates unresolved agronomic issues that have not been addressed with Optimal, particularly in aspects of crop management related to canopy structure, plant hormonal balance, and plant physiological quality [1].

Coffee (*Coffea* spp.) is a perennial plant of global economic and social importance. Achieving high and stable yields while maintaining quality and sustainability requires careful management of the plant canopy and the physiological processes that regulate the distribution of photosynthates (assimilates). Targeted canopy management and strategic pruning are key to achieving these goals, as both shape plant architecture, influence the microclimate, and regulate the efficiency of photosynthetic carbon allocation to productive organs (fruit and seeds) (Gokavi et al., 2021). This practice improves air circulation, enhances leaf lighting, and reduces the incidence of unproductive or diseased branches. Pruning also regulates the proportion of vegetative and generative branches, ensuring that plants produce productive shoots that support flower formation. These productive shoots determine the success of the generative phase because they are where the series of flowers and fruit buds appear. Coffee plants with neat and balanced canopies are capable of producing higher quantities of fruit with better quality. Uncontrolled canopy conditions often lead to competition for energy between organs, thereby reducing the efficiency of flower formation [2].

Growth regulators help optimise coffee growth, especially in strengthening the metabolic processes plants require. Atonic is one of the widely used growth regulators to increase plant physiological activity. The Atonic formula consists of ortho-nitrophenol, para-nitrophenol, and sodium nitroguaiacolate compounds, as well as micronutrients such as calcium, sulfur, boron, zinc, manganese, copper, molybdenum, and iron [3]. These compounds accelerate cellular processes and promote the synthesis of organic compounds needed for the initiation of buds and leaves, which are crucial in preparing plants for reproductive growth. Strong vegetative development determines the plant's readiness to form flowers and fruit buds, as these phases require substantial photosynthate reserves. Similar effects have been reported in studies where biostimulants enhanced leaf development, chlorophyll content, and vigor in Arabica coffee seedlings and other horticultural crops [4], [5]. In addition, growth regulators may increase the plant's tolerance to less favourable environmental conditions, enabling continued allocation of energy to reproductive processes.

Scientific information on pruning and the use of growth regulators has been widely reported, but most studies evaluate each treatment independently. Research on how pruning interacts with Atonic to influence the sequential development of shoots, leaves, flowers, and fruit buds remains limited. This lack of integrated understanding restricts the development of precise cultivation strategies for highland Arabica coffee plantations such as those in Bangli. Irregular pruning can hinder the formation of productive branches, while excessive Atonic doses may disrupt physiological processes, increasing the risk of flowering failure. A deeper understanding of how these two treatments interact is necessary to improve cultivation outcomes. Previous studies have emphasized the importance of examining vegetative–reproductive relationships in coffee, especially concerning carbon allocation and canopy efficiency [6], [7]. The present study aims to fill this gap by systematically observing the development of shoots, leaves, flowers, and fruit buds in Arabica coffee under combined pruning and Atonic treatments at varying concentrations.

2. Material and Methods

2.1 Research Location and Time

The research was conducted in Catur Village, Kintamani District, Bangli Regency, Q66R+6HX, at an altitude of ±1,200 meters above sea level. Observations began after treatment was applied and lasted for 12 weeks, with periodic measurements every 2 weeks.

2.2 Research Design and Treatment

The study used a 2 × 4 factorial design (pruning × Atonic) with three replicates per treatment. Each treatment combination consisted of three test plants, resulting in a total of 24 experimental units (8 combinations × 3 replicates). Observations are conducted every two weeks over 12 weeks, with measurements taken at six points: T1 at Week 2, T2 at Week 4, T3 at Week 6, T4 at Week 8, T5 at Week 10, and T6 at Week 12, allowing systematic monitoring of vegetative and reproductive development.

2.3 Material and Equipment

The experimental materials included productive Arabica coffee plants from UPP Catur Paramitha, Catur Village. The chemical treatment consisted of the growth regulator Atonic dissolved in water as the application medium. The tools used included pruning shears, hoes, bamboo supports, 500 mL measuring cups, buckets, and hand sprayers (SPRAYER SWAN SA).

2.4 Treatment Implementation

Productive coffee plants with uniform growth conditions were selected as test plants, with each experimental unit consisting of one plant. Observations were conducted on productive branches one year after pruning to ensure comparable physiological conditions among treatments. Pruning was performed following local cultivation standards, which included the removal of old, diseased, wild, and unproductive branches to maintain the desired canopy structure. The timing of pruning adhered to recommended practices, namely two to three months after harvest.

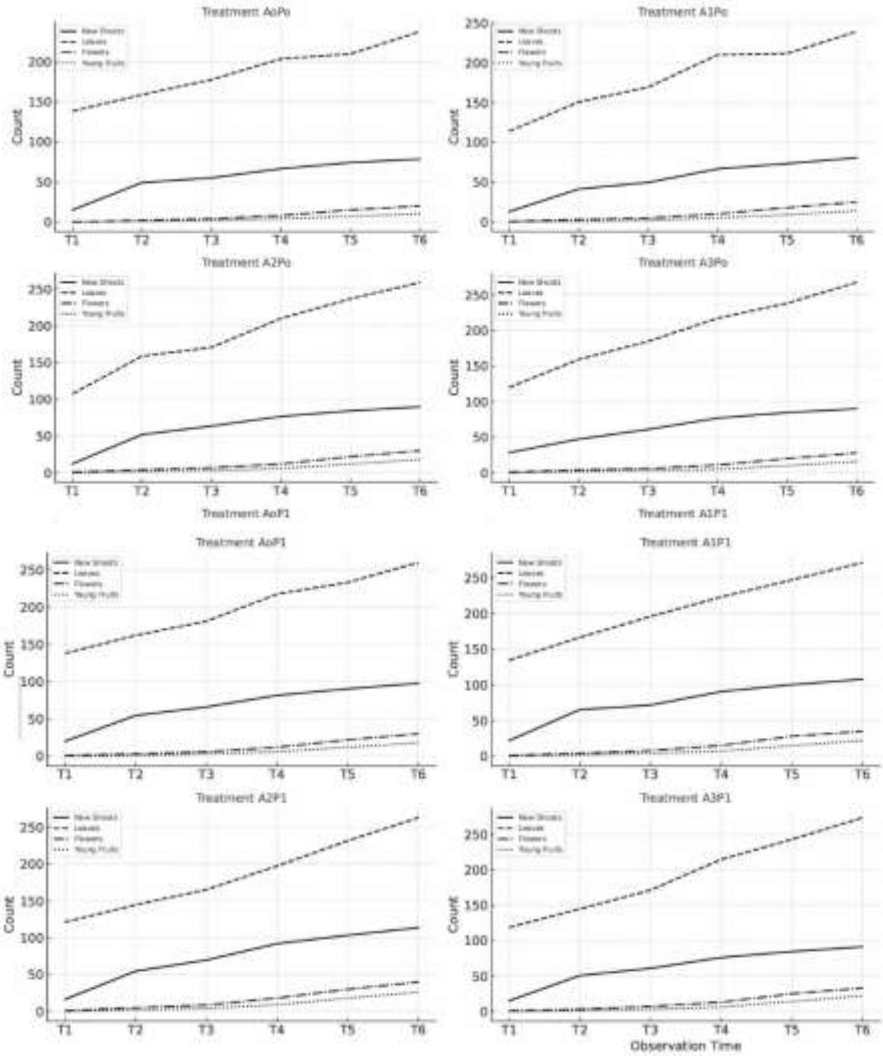
Atonic was dissolved in water at concentrations of 1, 2, and 3 mL L^{-1} according to the respective treatments. The solution was applied foliarly using a hand sprayer, ensuring even coverage of both the upper and lower leaf surfaces until wet without excessive runoff. The frequency of application followed the experimental protocol, either as an initial application followed by repeated applications according to the experimental schedule or once a month as specified in the field design. Control plants (A0) functioned as a solvent control, receiving only distilled water without atonic to ensure that any observed effects were attributable solely to the active compound rather than the solvent. All plants were grown under uniform environmental and agronomic conditions (irrigation regime, nutrient management, light intensity, and pest control), with the treatment factor being the only variable applied.

2.5 Data Analysis Procedure

The data collected for each variable was statistically analysed. Analysis of variance (ANOVA) was used to test the effect of the factors Atonic, pruning, and the interaction A × P on the observed variables. Duncan's Multiple Range Test at a 5 per cent significance level (DMRT, $\alpha = 0.05$) was used to compare treatment means when ANOVA showed significant differences. Statistical prerequisite tests included checking the normality of residuals (e.g., Shapiro-Wilk test) and homogeneity of variances (e.g., Levene's test). Data transformation was performed when necessary to meet the ANOVA assumptions.

3. Results and Discussion

The growth dynamics of Arabica coffee across the six observation periods (T1–T6) show clear and consistent differences among treatments. In all treatments, the number of new shoots and leaves increased steadily over time, indicating continuous vegetative development. Treatments that combined pruning with Atonic, particularly those using medium and higher doses, demonstrated the most accelerated vegetative response. These treatments produced noticeably more new shoots compared with non-pruned treatments, confirming that pruning effectively stimulates dormant bud activation and enhances canopy renewal.



Note:

- A0P0 = Without Atonic and without pruning
- A1P0 = Atonic 1 mL L⁻¹ without pruning
- A2P0 = Atonic 2 mL L⁻¹ without pruning
- A3P0 = Atonic 3 mL L⁻¹ without pruning
- A0P1 = Without Atonic with pruning
- A1P1 = Atonic 1 mL L⁻¹ with pruning
- A2P1 = Atonic 2 mL L⁻¹ with pruning
- A3P1 = Atonic 3 mL L⁻¹ with pruning
- T1 = Week 2
- T2 = Week 4
- T3 = Week 6
- T4 = Week 8
- T5 = Week 10
- T6 = Week 12

Figure 1. The effect of atonic dose treatment with and without pruning

3.1 New Shoot Development

The number of new shoots increased across all treatments from T1 to T6. The control plants produced the fewest shoots, while the combination of pruning and Atonic, especially treatment A2P1, produced the most significant increase in shoots at the end of the observation period. This increase occurred because pruning triggered the reactivation of dormant buds and improved the distribution of photosynthates, as explained by Ghosh et al. [8], who found that pruning Arabica coffee stimulated shoot regeneration in improving canopy architecture. Similar findings have been reported in studies on multi-stem coffee systems, where strategic pruning led to significant improvements in shoot regeneration, canopy uniformity, and vegetative renewal [7], [9].

The application of Atonic further enhanced shoot development by increasing meristematic activity, as its nitrophenolic compounds are known to accelerate cell division and regulate enzymatic processes. Phenolic-based PGRs stimulate metabolic pathways that promote vegetative organ formation in several perennial crops. Comparable results were also observed in biostimulant studies on coffee seedlings, where enhanced vegetative vigor, taller plant height, and increased bud formation were attributed to improved nutrient assimilation under PGR application [5], [10].
The present study aligns with these findings, demonstrating that shoot proliferation increases not only under independent treatments but also more effectively through the strong interaction between pruning and Atonic, which enhances physiological responses linked to endogenous hormone activity. This interaction reflects broader evidence on source–sink strengthening and canopy activation in perennial crops [11], [12].

3.2 Leaf Development

Pruning and Atonic treatment resulted in a higher leaf count than other treatments. Leaves are the primary organs that support the accumulation of photosynthates for reproductive processes. The increase in leaf number in the A1P1 and A2P1 treatments indicates that pruning creates optimal conditions for light penetration (Fig.1). This is supported by the findings of Baitelle [6], who reported that canopy management through pruning increases photosynthetic efficiency by creating a more open canopy.

Growth regulators such as Atonic amplify these physiological effects by improving nutrient absorption and increasing chlorophyll accumulation, both of which are necessary for photosynthetic activity. PGRs can slow leaf senescence and maintain photosynthetic capacity through endogenous hormone regulation. Thus, the combination of treatments in this study provides ideal physiological conditions for sustained leaf growth [13], [14].

3.3 Flower Development

The number of flowers increased more significantly in the pruning treatment combined with Atonic. The A2P1 treatment produced the highest number of flowers compared to the other treatments (Fig.1). This development shows that the generative phase is greatly influenced by the vegetative strength formed in the previous stage. Coffee flowering is highly dependent on canopy quality, light distribution, and carbohydrate reserves produced during the vegetative phase [11], [15], [16].

Growth regulators also strengthen the flowering response by activating physiological pathways that promote flower differentiation. PGRs increase flower formation in oil crops by strengthening nutrient accumulation and increasing photosynthetic activity. Similar results were observed in this study, where 2 mL Atonic solution per plant of Atonic provided a balance between hormonal stimulation and vegetative readiness, maximising flowering [13].

3.4 Fruit Development

The A2P1 treatment also showed the highest number of fruit primordia (Fig.1). This finding reinforces the principle that fruit primordium formation is closely related to the availability of photosynthates produced by healthy leaves and shoots. Stable isotope analysis, that the dynamics of carbon allocation between sources and sinks are a determining factor in the successful transition from flower to fruit in coffee. When source capacity is high, fruit formation becomes more efficient [17-19].

Pruning creates a balance in the distribution of energy to the generative organs. Canopy management through pruning improves the quality of physiological resources for fruit formation [20,21]. The results of this study are very consistent with the literature because A2P1 not only increases the number of flowers but also converts them into the highest number of fruit buds.

4. Conclusion

This study shows that the generative processes of coffee plants is strongly influenced by the quality of vegetative growth, which is developed through pruning and hormonal stimulation from Atonic. The combination of pruning with 2 mL Atonic solution per plant proved to be the most effective in increasing the number of flowers and fruit buds, followed by a dose of one millilitre. These results indicate that proper canopy management, when combined with growth regulation, can significantly strengthen the generative processes of coffee plants. These findings fill a knowledge gap in the relationship between vegetative and generative processes and provide a strong scientific basis for developing more precise and productive coffee cultivation practices.

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