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Increasing Three Soybean Varieties' Growth and Production by Soaking Using Paclobutrazol

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Abstract

Soybeans represent an economically viable source of plant-based protein. This study aimed to assess the impact of paclobutrazol soaking on the growth and yield of three distinct soybean varieties. The investigation was conducted in Sampecita Village, located in the Kutalimbaru District of Deli Serdang Regency, North Sumatra, from January to May 2024. An experimental approach was employed, utilizing a factorial Randomized Block Design (RAK) that included two main treatments: soybean varieties (Dering 1, Dega 1, and Devon 1) and varying concentrations of paclobutrazol soaking (0 ppm, 25 ppm, 50 ppm, and 75 ppm), with each treatment replicated three times. The collected data were analyzed, followed by Duncan's Multiple Range Test (DMRT). The findings indicated that paclobutrazol soaking significantly influenced the growth and yield of soybean plants, particularly affecting plant height, the number of pods per plot, and the weight of 100 seeds. However, parameters such as root length, flowering age, number of productive branches, and number of pods per sample did not exhibit significant changes. The variety treatment had a notable effect on root length, number of productive branches, number of pods per sample, number of pods per plot, and weight of 100 seeds while flowering age and plant height remained unaffected. Notably, the 0 ppm concentration and the Devon 1 variety positively impacted the growth and yield of soybean plants.

Keywords: Increase, Paclobutrazol, Soaking, Soybeans, Variety

1. Introduction

The soybean plant (*Glycine max* L. Merr) is a significant food crop cultivated for an extended period by the Indonesian population (Zamriyetti et al., 2021; Luta et al., 2024). This crop plays a crucial role in fulfilling food requirements and enhancing community nutrition, as it serves as an affordable source of vegetable protein (Harahap & Siregar, 2023) when compared to other protein sources such as meat, milk, and fish (Maimunah, 2015; Najla et al., 2022).

The average annual demand for soybeans is approximately 2.3 million tons; however, domestic production is limited to around 800,000 to 900,000 tons (Karim et al., 2019). In 2023, the area dedicated to soybean cultivation reached 218.74 thousand hectares, reflecting an increase of 37.81 thousand hectares or 20.90 percent from the 2022 harvest area of 180.92 thousand hectares. Furthermore, soybean production in 2023 amounted to 349.09 thousand tons, which represents an increase of 47.58 thousand tons or 15.78 percent compared to the 2022 production figure of 301.51 thousand tons (Direktorat Jendral Tamanan Pangan, 2024).

The optimization of soybean planting can be achieved by selecting superior varieties and applying growth regulators. Multiple breeding organizations have completed the development of 78 high-quality soybean varieties that have significantly impacted productivity, particularly in the agricultural sector (Balitbangtan, 2016). These superior varieties exhibit diverse potential yields, harvest ages, seed sizes, seed colors, and adaptation areas. The variability in the attributes of these elite cultivars is crucial in the advancement of soybean cultivation, considering the growing region's varied conditions and consumer demands. The issue in the cultivation of soybeans lies in the fact that soybean plants exhibit a high degree of sensitivity to fluctuations in their growing environment, leading to

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potential reductions in crop yields. Farmers typically opt for high-quality indigenous national varieties such as Kipas Putih and Kipas Merah and superior national varieties like Orba, Wilis, and Anjasmoro (Nilahayati & Putri, 2015).

One of the advancements in agricultural cultivation involves the application of plant growth regulators. The primary objective of utilizing these regulators is to enhance plant productivity. Additionally, the study has demonstrated that plant growth regulators can effectively suppress vegetative growth, improve the quality of fruits (including pods and seeds), and boost overall plant production and productivity (Yusran, 2024).

Paclobutrazol is a synthetic growth retardant that inhibits the elongation of plant cells by suppressing gibberellin biosynthesis (Kurniawati et al., 2021). The application of paclobutrazol can effectively rest the plant's growing points and promote flowering, leading to earlier flowering and accelerated fruit development, which is anticipated to enhance plant production when treated with paclobutrazol (Harpitaningrum et al., 2014). The mechanism by which paclobutrazol operates involves the inhibition of gibberellin production by blocking the oxidation of kaurene to kaurenic acid, resulting in a decrease in cell division rates and a reduction in vegetative growth (Marshel et al., 2015). This study evaluates three soybean varieties' development and production enhancement by applying paclobutrazol soaking.

2. Material and Methods

The study was carried out in Sampecita Village, located within the Kutalimbaru District of Deli Serdang Regency, North Sumatra, at geographical coordinates 3° 0' 27.800"N and 98° 0' 30.840"E, with an elevation of 25 meters above sea level. The study period spanned from January to May 2024. The plant materials utilized included soybean seeds from the Dering 1, Devon 1, and Dega 1 varieties, along with paclobutrazol, topsoil, manure, and 18 cm x 25 cm polybags. The tools employed in this investigation comprised hoes, measuring tapes, watering cans, stationery, and other necessary equipment.

An experimental design was implemented, specifically a factorial Randomized Block Design (RAK), which incorporated two treatments: the soybean varieties (Dering 1, Dega 1, and Devon 1) and varying concentrations of paclobutrazol immersion (0 ppm, 25 ppm, 50 ppm, and 75 ppm), each replicated three times. The data collected from the study were analyzed, followed by a mean difference test using Duncan's Multiple Range Test (DMRT) via the Statistical Tool for Agricultural study (STAR) version 2.0.1. The parameters observed for the soybean plants included plant height (cm), root length (cm), number of productive branches, number of pods per sample, number of pods per plot, seed weight per sample (g), seed weight per plot (g), and weight of 100 seeds per plot (g).

The study was conducted by preparing the land, filling polybags, arranging polybags, soaking soybean seeds, planting, determining sample plants, and maintaining plant crops by watering, weeding, inserting, fertilizing, controlling pests and diseases, and harvesting. The flow diagram of the study implementation can be seen in Figure 1.

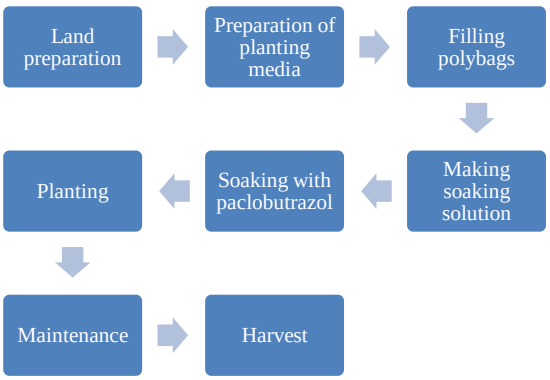

Figure 1. Research flow diagram

3. Results and Discussion

3.1. Plant Height (Soybeans)

The study's findings indicate that the application of the paclobutrazol soaking treatment significantly affected the height parameters of soybean plants. In contrast, the variety treatment and the interaction between variety and soaking treatment demonstrated no significant impact on these parameters (see Table 1 for details).

Table 1. Average Plant Height (cm) in Paclobutrazol Soaking Treatment

Varieties	Paclobutrazol				Average
	0 ppm	25 ppm	50 ppm	75 ppm	
Ring 1	37.80 ± 1.07	31.43 ± 0.57	29.20 ± 2.80	30.80 ± 1.05	32.31 ± 1.89 a
Devon 1	35.00 ± 2.04	31.33 ± 0.52	29.10 ± 2.93	21.77 ± 3.50	29.30 ± 2.79 a
Dega 1	35.10 ± 4.20	33.23 ± 2.28	30.57 ± 0.47	21.90 ± 1.56	30.20 ± 2.92 a
Average	35.97 ± 0.92 a	32.00 ± 0.62 b	29.62 ± 0.47 b	24.82 ± 2.99 b	

Description: Numbers followed by the same letter in the column indicate no significant effect at the 5% level using the DMRT test.

Table 1 illustrates that the immersion treatment with paclobutrazol results in the highest plant height at a concentration of 0 ppm, measuring 35.97 cm. A notable decrease is observed at 25 ppm, where the height is 32.00 cm, followed by 50 ppm at 26.62 cm, and the lowest height recorded at 75 ppm, 24.82 cm. This trend indicates that paclobutrazol effectively inhibits plant height growth compared to the control treatment at 0 ppm, which did not

involve paclobutrazol immersion. According to Ardigusa & Sukma (2015), paclobutrazol was found to reduce the growth of Sanseviera plants by an average of 19.4% at 15 MST compared to control specimens.

Furthermore, Table 1 reveals that among the soybean varieties, the Dering 1 variety exhibits the greatest plant height at 32.31 cm, while the Dega 1 variety measures 30.20 cm, showing no significant difference. The Devon 1 variety has the lowest height at 29.30 cm. These variations can be attributed to genetic differences among the Dering 1, Devon 1, and Dega 1 varieties. Sari et al. (2014) noted that the Anjosmoro variety demonstrates a superior capacity for height increase compared to Wilis, Detam 1, and Detam 2, highlighting the genetic diversity in the tested varieties. Additionally, Bakhtiar et al. (2014) emphasized that the interplay between genetic factors and environmental conditions significantly influences the growth of soybean plants.

3.2. Root Length (cm)

The results of the variance analysis demonstrated that the root length parameter of soybean plants exhibited a significant effect on the variety treatment. Conversely, the soaking treatment with paclobutrazol and the interaction between the two had no significant impact, as illustrated in Table 2.

Table 2. Average Root Length (cm) in Paclobutrazol Soaking Treatment

Varieties	Paclobutrazol				Average
	0 ppm	25 ppm	50 ppm	75 ppm	
Ring 1	38.74 ± 4.13	35.37 ± 2.54	34.23 ± 4.23	38.77 ± 5.49	36.71 ± 1.13 a
Devon 1	45.57 ± 7.08	41.47 ± 2.73	38.33 ± 0.95	28.67 ± 1.66	38.51 ± 3.60 a
Dega 1	23.00 ± 3.50	20.23 ± 3.27	22.00 ± 1.53	27.43 ± 4.59	23.17 ± 1.53 b
Average	35.77 ± 6.68 a	32.36 ± 6.31 a	31.52 ± 4.90 a	31.62 ± 3.59 a	

Description: Numbers followed by the same letter in the column indicate no significant effect at the 5% level using the DMRT test.

The length of soybean plant roots against paclobutrazol immersion at a concentration of 0 ppm showed the highest root length of 12.43 cm, no significant effect at a concentration of 50 ppm of 11.83 cm, a concentration of 25 ppm of 11.82 cm, and the lowest at a concentration of 50 ppm of 50.90 cm (Table 2). As a growth inhibitor, Paclobutrazol works on plants' sub-meristem by inhibiting gibberellin biosynthesis. This process involves inhibiting the oxidation of kaurene to kaurenic acid, which in turn inhibits the elongation and enlargement of plant cells (Mahgoub et al ., 2006)

Table 2 shows that the soybean variety treatment that had the highest root length was in the Devon 1 variety of 9.64 cm, which had a significant effect on the Devon 1 variety of 38.51 cm, a substantial impact on the Dering 1 variety of 36.71 cm and the lowest in the Dega 1 variety of 23.17 cm. This is due to the differences in each variety. Aulia et al. (2014) stated that all varieties tested, namely Mallika, Detam 1, Detam 2, and Cikuray, showed different genotype and phenotype properties. The growth and development of an organism are supported by the interaction of genes and the environment that influences it. The interaction of plant genetics with the growing climate affects the variation of plant morphological characteristics (Rahmat et al., 2018).

3.3. Number of Productive Branches (branches)

According to the findings of the variance analysis, it has been demonstrated that the parameter of the number of productive branches exerts no significant effect on the variety treatment, soaking with paclobutrazol, and the interaction of both on soybean plants. These results can be observed in Table 3.

Table 3. Average Number of Productive Branches (branches) in Paclobutrazol Soaking Treatment

Varieties	Paclobutrazol				Average
	0 ppm	25 ppm	50 ppm	75 ppm	
Ring 1	13.69 ± 0.50	12.66 ± 0.51	12.78 ± 0.59	12.32 ± 0.77	12.86 ± 0.29 a
Devon 1	12.99 ± 0.52	13.32 ± 0.69	12.45 ± 0.22	11.76 ± 0.54	12.63 ± 0.34 a
Dega 1	8.53 ± 0.23	8.32 ± 0.19	7.20 ± 0.49	7.34 ± 0.33	7.85 ± 0.34 b
Average	11.74 ± 1.62 a	11.43 ± 1.57 a	10.81 ± 1.81 a	10.47 ± 1.57 a	

Description: Numbers followed by the same letter in the column indicate no significant effect at the 5% level using the DMRT test.

Statistically, the parameter of the number of productive branches at a concentration of 0 ppm has the highest number of productive branches, namely 17.74 branches, which does not significantly affect the concentration of 25 ppm, namely 11.43 branches, the concentration of 50 ppm, namely 10.81 branches and the lowest at a concentration of 75 ppm, namely 10.47 ppm. Paclobutrazol inhibits cell division, resulting in plants' rest point growth, and plants' photosynthesis will be shifted to the generative phase for pod and seed filling (Zulfaniah et al. 2020). Stem elongation in corn plants decreased with increasing concentration of paclobutrazol given. Stem elongation of corn plants every week for four weeks in the 50 ppm paclobutrazol treatment was higher than the 100 ppm paclobutrazol treatment (Latifa & Indriyatmoko, 2022).

Table 3 shows that the soybean variety treatment that has the highest number of productive branches is in the Dering 1 variety of 12.83 branches, which has a significant

effect on the Devon 1 variety of 12.63 branches and the lowest in the Dega 1 variety of 7.85 branches. The difference in the number of productive branches between the varieties studied is caused by differences in the nature or advantages of each variety according to its genotype in certain environmental conditions. Hence, each array displays its properties and benefits. Environmental factors influence the varying number of branches. Rahmat et al. (2018) stated that the interaction of plant genetics with the growing environment affects the variation in plant morphological characteristics. The greater the number of branches in one variety, the more leaves there are, so photosynthate increases and will be transported to fill the pods (Sa'diyah et al ., 2016).

3.4. Flowering Age (days)

The study's findings demonstrated that the flowering age parameter exerted no substantial influence on the variety treatment, the soaking process with paclobutrazol, or the interaction between both parameters on soybean plants. These outcomes are elucidated in Table 4.

Table 4. Average Flowering Age (days) in Paclobutrazol Soaking Treatment

Varieties	Paclobutrazol				Average
	0 ppm	25 ppm	50 ppm	75 ppm	
Ring 1	47.00 ± 1.00	49.00 ± 0.00	48.67 ± 0.33	48.33 ± 0.67	48.25 ± 0.44 a
Devon 1	55.00 ± 0.58	56.33 ± 0.33	55.67 ± 0.33	56.00 ± 0.00	55.75 ± 0.28 a
Dega 1	40.67 ± 0.88	41.33 ± 0.67	41.67 ± 0.33	42.00 ± 0.00	41.42 ± 0.28 a
Average	47.56 ± 4.15 a	48.89 ± 4.33 a	48.67 ± 4.04 a	48.78 ± 4.05 a	

Description: Numbers followed by the same letter in the column indicate no significant effect at the 5% level using the DMRT test.

Table 4 shows that the soaking treatment with paclobutrazol on soybeans experienced a reasonably long flowering time, namely at a concentration of 25 ppm of 48.89 days, no significant effect at a concentration of 75 ppm of 48.78 days, a concentration of 50 ppm of 48.67 days, and the fastest at a concentration of 0 ppm of 47.56 days. Long flowering age can cause the formation of reproductive organs, especially pod formation and seed filling, to be delayed. Giving paclobutrazol with an inappropriate concentration can cause flower loss, and this will cause no pods to form, so the pods formed will be relatively few (Sambeka et al ., 2012).

Table 4 shows that the soybean variety treatment with the fastest flowering age is the Dega 1 variety at 41.42 days, which has no significant effect on the Dering 1 variety at 48.25 days. The longest is the Devon 1 variety at 55.75 days. Basically, the flowering age of soybean plants depends on the variety, growing environment (soil fertility), and duration of irradiation. Soybean plants in Indonesia generally start flowering at 30-50 HST. The duration of irradiation and temperature greatly influences flowering. The optimum temperature required by soybean plants is 30^0 C; soybean plants are short-day plants, which means that the plants will not flower if the duration of irradiation exceeds the critical limit, which is around 15 hours. Bakhtiar et al . (2014) stated that the varieties that flower the fastest are Burangrang and Detam varieties, which are around 33 days after planting, while the varieties that bloom the longest are Gema, Tanggamus, and Orba, which are 44 days after planting. Varieties that flower the fastest will have the opportunity to be harvested faster, too. This will benefit farmers if they plant early-maturing plants to avoid the danger of water shortages if a drought occurs.

3.5. Number of Pods (pods)

The results of the variance analysis demonstrated that the number of pods exhibited a significant effect on the variety treatment but no significant effect on the soaking treatment with paclobutrazol or the interaction between the two treatments on soybean plants. These findings are elucidated in Table 5.

Table 5. Average Number of Pods per Sample (g) in Paclobutrazol Soaking Treatment

Varieties	Paclobutrazol				Average
	0 ppm	25 ppm	50 ppm	75 ppm	
Ring 1	189.33 ± 51.68	138.33 ± 44.98	94.77 ± 30.72	43.63 ± 1.33	116.52 ± 31.04 b
Devon 1	193.63 ± 3.48	120.77 ± 27.35	128.47 ± 2.32	161.67 ± 19.53	137.63 ± 8.90 a
Dega 1	35.27 ± 4.02	29.77 ± 6.46	35.33 ± 12.89	29.03 ± 6.87	32.40 ± 1.74 c
Average	139.41 ± 52.08 a	96.29 ± 33.64 a	86.19 ± 27.23 a	78.11 ± 41.99 a	

Description: Numbers followed by the same letter in the column indicate no significant effect at the 5% level using the DMRT test.

The results of the study showed that at a concentration of 0 ppm, paclobutrazol had the highest number of pods per sample of 139.41 pods, which had no significant effect at a concentration of 25 ppm of 96.29 pods, a concentration of 50 ppm of 86.19 pods and the lowest at a concentration of 75 ppm of 78.11 pods. Harpitaningrum et al . (2014) stated that paclobutrazol is a growth inhibitor that functions to inhibit the synthesis of gibberellin, which stimulates cell division in the growth phase so that the presence of paclobutrazol will rest the plant's growth points, thus inhibiting pod formation.

Table 5 illustrates that among the soybean varieties examined, the Dering 1 variety exhibited the highest average number of pods per sample at 116.52, while the

Devon 1 variety followed closely with 137.63 pods. In contrast, the Dega 1 variety recorded the lowest average, with only 32.40 pods. As noted by Widiastuti & Latifah (2016), the variation in seed sizes across different soybean varieties is influenced by genetic factors and the seed filling process. Although the maximum potential seed size is genetically predetermined, the actual size achieved is contingent upon environmental conditions during the seed-filling phase. Furthermore, pod weight is significantly affected by the accumulation of photosynthetic products, which can be optimized through adequate water and nutrient availability. The weight of the seeds is a critical determinant of soybean yield (Suwitono et al., 2021). Genetic factors predominantly govern the characteristics of the number of complete pods and total pods. The Sinabung variety demonstrated the highest count of full pods, showing no significant difference compared to the Kipas Merah Bireuen and Kaba varieties. Conversely, the Grobogan and Burangrang varieties exhibited the lowest counts of full pods. The Sinabung, Kipas Merah Bireuen, and Kaba varieties were the most prolific in terms of both full and total pod counts. Consequently, a higher pod count will likely correlate with increased seed production, enhancing overall yield (Bakhtiar et al., 2014).

3.6. Wet Weight (g)

The research findings indicate that the wet weight parameter (g) substantially impacted variety treatment while demonstrating an insignificant effect on soaking with paclobutrazol and the interaction between the two factors on soybean plants. These observations are elucidated in Table 6.

Table 6. Average Wet Weight (g) in Paclobutrazol Soaking Treatment

Varieties	Paclobutrazol				Average
	0 ppm	25 ppm	50 ppm	75 ppm	
Ring 1	107.92 ± 9.47	77.67 ± 17.56	75.00 ± 3.70	60.93 ± 9.27	80.38 ± 9.89 b
Devon 1	131.27 ± 11.77	114.75 ± 5.67	107.17 ± 25.81	104.17 ± 12.49	114.34 ± 6.07 a
Dega 1	60.52 ± 13.99	67.58 ± 12.38	76.52 ± 24.30	60.67 ± 21.55	66.32 ± 3.78 c
Average	99.00 ± 20.81 a	86.67 ± 14.34 a	86.23 ± 10.48 a	75.26 ± 14.46 a	

Description: Numbers followed by the same letter in the column indicate no significant effect at the 5% level using the DMRT test.

Table 6 shows that the highest wet weight (g) was at a concentration of 0 ppm of 99.00 g, which had no significant effect on a concentration of 25 ppm of 86.67 g, a concentration of 50 ppm of 86.23 g, and the lowest at a concentration of 75 ppm of 75.26 g. (Sugianto et al ., 2022) the administration of too high concentrations of paclobutrazol causes the growth of shoots and buds, inhibits the growth of female flowers, and reduces the number of fruits. Paclobutrazol can inhibit the enzyme ent-kaurene oxidase into ent-kaurenoic acid, which is the main biosynthesis pathway of gibberellin, with the inhibition of gibberellin biosynthesis resulting in inhibited plant growth and photosynthesis, which results in low total dry weight of plants (.

Table 6 shows that the soybean variety treatment that has the number of pods per plot is in the Devon 1 variety of 513.92 g, which has a significant effect on the Dering 1 variety of 368.08 g, and the lowest is in the Dega 1 variety of 129.75 g. Superior varieties are expected to meet several criteria, including increased production, increased production stability, meeting quality standards, following farmers' planting patterns, and different consumer demands in each region. In addition to genetic factors, the number and size of plant seeds are determined by the conditions experienced by the seeds during their filling period, such as extreme environmental conditions such as low soil fertility, lack of water or flooding can also affect. The performance of seed weight per plant shows that the superior Sinabung variety can grow and produce results comparable to the Kipas Merah Bireuen variety. Meanwhile, the Tanggamus and Grobongan varieties have lower seed weights per plant than Kipas Merah Bireuen. Thus, the Kipas Merah Bireuen and Sinabung varieties can be planted for high production. This shows that the Sinabung variety is more adaptive than other superior varieties (Bakhtiar et al ., 2014).

3.7. Weight of 100 Seeds (g)

The study's findings demonstrated that the parameter of 100 seed weight substantially impacted variety treatment, while its interaction with soaking with paclobutrazol was non-significant. These observations are elucidated in Table 7.

Table 7. Average Weight of 100 Seeds (g) in Gibberellin Soaking Treatment

Varieties	Paclobutrazol				Average
	0 ppm	25 ppm	50 ppm	75 ppm	
Ring 1	11.30 ± 0.06	10.83 ± 0.12	10.83 ± 0.41	10.30 ± 0.06	10.82 ± 0.20 c
Devon 1	14.83 ± 0.09	14.27 ± 0.09	13.67 ± 0.12	12.17 ± 0.24	13.73 ± 0.57 b
Dega 1	25.73 ± 0.57	21.73 ± 0.19	21.53 ± 1.54	21.50 ± 0.31	22.63 ± 1.04 a
Average	17.29 ± 4.34 a	15.61 ± 3.22 b	15.34 ± 3.20 b	14.66 ± 3.46 c	

Description: Numbers followed by the same letter in the column indicate no significant effect at the 5% level using the DMRT test.

Table 7 indicates that the maximum weight of 100 seeds was recorded at a concentration of 0 ppm, measuring 17.29 g. This weight exhibited a significant effect when compared to the 25-ppm concentration, which yielded a

weight of 15.34 g, and the 50 ppm concentration, also at 15.34 g. The lowest weight was observed at a concentration of 75 ppm, 14.66 g. The chlorophyll content plays a crucial role in the seed filling process within pods. An increase in chlorophyll content can enhance the production of assimilates through photosynthesis, thereby potentially increasing the content of the pods and decreasing the occurrence of empty pods. This hypothesis may increase the average number of total pods and the average number of filled pods (Zulfaniah et al., 2020).

Furthermore, Table 7 reveals that among the soybean varieties, the Dega 1 variety exhibited the highest seed weight per plot at 24.67 g, significantly affecting the Devon 1 variety, which weighed 17.08 g, while the Dering 1 variety recorded the lowest weight at 12.33 g. The observed differences in seed size—large, medium, and small—are likely attributed to variations in food reserve content among the different seed sizes (Kilkoda, 2015). Each variety's size is influenced by its genetic makeup and the environmental conditions in which it is cultivated. According to Sari et al. (2014), the Wilis variety produced a dry weight of 100 seeds at 11.2 g. Although this result is statistically the lowest among the four varieties, it is noteworthy that the dry weight of 100 seeds in the Wilis variety has reached and even surpassed the expected potential yield of approximately 10 g.

4. Conclusion

According to the investigation, it can be inferred that the 0 ppm concentration and the Devon 1 variety exhibited a relatively positive impact on the growth and yield of soybean plants. The greater the amount of paclobutrazol administered, the greater the plant growth and yield inhibition.

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