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Effect of Paclobutrazol and α-naphthaleneacetic acid on Growth and Yield of Zucchini (*Cucurbita pepo* L.) In Tropical Regions

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***Abstract*— *Zucchini is one of Cucurbitaceae family with a lot of vitamins and benefical for boosting immune system, preventing cancer risk and preventing inflammation. In Indonesia cultivation zucchini less than optimal so that it is necessary to apply cultivation techniques that can increase production zucchini. This Research to study effect of α-naphthaleneacetic acid (NAA) and various concentrations of paclobutrazol (PBZ) on growth and yield zucchini. The Experiments was a factorial experiment using split plot design with two factor, first factor was NAA with 2 treatment levels (with and without apply NAA) and the second factor was the concentration with 5 treatment levels (0, 50, 100, 150, and 200 ppm). The observation data results were analysis of variance (ANOVA) and continued least significant difference (LSD) at 5% error level. The results showed that significant effect of NAA and PBZ on growth and yield of zucchini. There was can inhibit the vegetative organs like plant length, leaf area and stem length. Beside that, there were increasing the generative organs in the parameters number of fruits, fruit length, diameter fruit, fresh fruit weight and fruit weight per plant, harvest index and partition biomass. Effect of PBZ especially at higher concentrations can inhibited plant growth while enhancing fruit quality, where was NAA demonstrated potential in optimizing fruit development through hormonal regulation. In conclusion, the interaction of PBZ and NAA was found to influence not only zucchini fruit morphology but providing into the regulation of growth and quality in horticultural crops.*

Keywords*— *Paclobutrazol, A-Naphthaleneacetic acid, Zucchini, Quality of fruit, Biomassa partition and Harvest index

I. INTRODUCTION

Zucchini (*Cucurbita pepo* L.) contain B-complex vitamins (B1, B2, B3, B6, folate, and choline) and dietary fiber, which are beneficial in regulating blood sugar levels and preventing cancer risk, as well as helping to reduce the risk of heart problems and stroke (Rizky et al. 2021). Zucchini is very high in vitamin C, which is important for preventing premature aging, boosting the immune system and preventing inflammation. In addition, zucchini are also high in zinc, protein, iron, calcium, vitamin K, vitamin A and lutein important for eye problems (Bannayan et al. 2017).

The domestic demand for zucchini continues to grow due to the increase in Japanese and Korean restaurants. In addition, the need for vegetable imports in Japan from Indonesia rose significantly from 2014 to 2019 by 11.5% year^{-1} and in 2020 it increased by 24.2%, so zucchini farmers have a great opportunity to export zucchini (Tokoro et al. 2020). Data on zucchini production from 2015 to 2018 experienced a fairly low increase in production of 10,253 t ha^{-1}, 10,190 t ha^{-1},10,673 t ha^{-1} and 10,961 t ha^{-1} (BPS, 2018). So that zucchini production in Indonesia has not met the needs of local and international markets. Indonesia only meets international market demand of less than 2,000 t year^{-1}. Meanwhile, the average Japanese market demand for zucchini is more than 50,000 t year^{-1} (Binardi et al. 2017).

Various factors can affect plant growth which causes plant growth and yield to be less than optimal so that it is necessary to apply cultivation techniques that can increase production of zucchini fruit, one of which is the use of growth regulators such as paclobutrazol (PBZ) and α-naphthaleneacetic acid (NAA). PBZ inhibits gibberellin biosynthesis so that stem and leaf growth is inhibited, but stimulates flower induction and increases fruit production (Syahputra et al. 2021). PBZ also increases leaf chlorophyll content, to supports photosynthesis and flowering (Franca et al. 2017).

Increasing the production yield and quality of zucchini fruit can be done by cultivation techniques, one of which is by applying growth regulators. Based on the nature of growth regulators is divided into two, namely there are those that spur and inhibit growth (Asgarian et al. 2013). Paclobutrazol (PBZ) functions to inhibit gibberellin biosynthesis, thereby inhibiting stem and leaf elongation and stimulating flower induction, causing plants to become shorter as photosynthetic activity is allocated to increase fruit production (Franca et al. 2017) in their experiments. Optimization of photosynthetic products into generative organs can also be done with NAA which includes auxins so that it can stimulate fruit formation. The hormone auxin has an important role in fruit formation in plants. this study was done. The objectives of this study were therefore to evaluate the effects interaction relationship between NAA and PBZ concentrations in controlling growth, increased fruit formation and quality of fruit zucchini. The objective of our study was to evaluate the effects interaction relationship between NAA and PBZ concentrations in controlling growth, increased fruit formation and quality of fruit zucchini.

II. MATERIALS AND METHODS

2.1. Research Site

The research was conducted from Mei to June 2024 in Dresel, Oro-Oro Ombo, Batu, East Java. Located at 7°54'-37 "S 122°31'34 "E with an altitude between 1010 meters above sea level with a minimum temperature of 18-24°C and a maximum temperature of 28-32°C (BPS, 2021).

2.2. Experimental Design and Treatments

The experimental design used was Split Plots Design with 3 replications. The first factor as the main plot is the provision of NAA consisting of 2 levels, without and with applying NAA. The second factor as a subplot with PBZ concentration consists of 5 levels, concentrations PBZ 0, 50, 100, 150 and 200 ppm.

Growth regulator was applied at 06.30-08.00 AM, apply PBZ with the concentration according to the treatment by spraying on all parts of the plant at the age of 14 DAT before the flowers bloom, and consentration NAA 100 ppm at the age of 26 DAT by spraying on flowers and fruits The preparation of growth regulator solution is done by making a 1 liter water stock solution with growth regulator concentration according to calculation on the basis of (Flores et al., 2018).

$$M1 \times V1 = M2 \times V2$$

Legend: M1 – Pure growth regulator concentration before dilution (ppm), V1 – Volume of growth regulator stock solution before dilution (ml), M2 – Treatment growth regulator concentration after dilution (ppm), and V2 – Volume of treatment stock solution after dilution (ml)

Fig. 1: PBZ and NAA application

Growth observations at 14, 21, 28, and 35 DAT by observed plant length, number of leave, leaf area, stem length, female flower bloming, number of male flowers, number of female flowers, and flower ratio. Yield Observations by Fruit length, fruit diameter, fruit number, fruit set, fruit weight, fruit weight per plant, harvest index and biomassa partition,

Leaf area observations were using the ALA method (Average Leaf Area). Calculation of plant leaf area with the ALA method using the formula showed below Widaryanto et al. (2019):

$$LA\ (cm^2\ plant^{-1}) = ALA\ (cm^2\ leaf^{-1}) \times \sum \text{Number of leaf}\ (leaf\ plant^{-1})$$

The Harvest Index (HI**)** observations is a measure of the efficiency of a plant in converting its biomass into economically valuable parts, usually grains or fruits. The formula is as follows (Donald, 2962):

$$HI = \frac{\text{Economic Yield}}{\text{Total Aboveground Biomass}}$$

Legend: Economic Yield: The yield of the portion of the plant that is harvested for economic purposes and Total Aboveground Biomass: The total biomass produced by the plant

Biomass Partitioning observation describes how the total biomass of a plant is distributed among different plant organs (roots, stems, leaves, fruits, etc.). It is calculated as a ratio (Poorter and Nagel, 2000):

$$\text{Biomass Partitioning} = \frac{\text{Biomass of Specific Organ}}{\text{Total Biomass of the Plant}}$$

Legend: Biomass of Specific Organ: Biomass of a particular organ like roots, stems, or fruits. And Total Biomass of the Plant: Total mass (dry or fresh weight) of the plant, including all aboveground and underground organs.

2.3. Data Collection and Analysis

The observation results were analyzed using ANOVA test at the 5% level. If the test results show a real effect, then the Least Significant Difference (LSD) test is continued at the 5% level and polynomial regression test to determine relationship between the two variable

III. RESULTS

3.1. Effect of NAA and Various Concentrations of PBZ on Zucchini Plant Growth

The results of the analysis of variance of plant length observations. There is no interaction between the provision of NAA and PBZ concentration. The provision of NAA showed no significant difference at 7, 14, 21, 28 and 35 DAT on the increase in plant length. Meanwhile, the provision of PBZ concentration was able to give a significant difference to plant length of zucchini at 21, 28 and 35 DAT (Table 1).

Table 1: The Effect of NAA and Various Concentrations of PBZ on the Plant Length of Zucchini

NAA	Plant Length (cm) at DAT				
	7	14	21	28	35
Without NAA	17,64	29,36	43,94	49,47	51,32
With NAA	16,67	29,00	44,86	50,79	52,72
LSD-N (5%)	ns	ns	ns	ns	ns
CoV-N(%)	10,07	12,00	14,98	13,55	13,24
Consentration of PBZ (ppm)	Plant Length (cm) at DAT				
	7	14	21	28	35
0	17,47	29,64	54,11 b	60,65 c	64,22 c
50	16,70	28,78	44,04 a	52,13 b	53,57 b
100	17,40	28,95	43,56 a	48,74 ab	50,50 ab
150	17,10	29,42	40,69 a	45,43 a	46,73 ab
200	17,11	29,13	39,60 a	43,71 a	45,06 a
LSD- P (5%)	ns	ns	4,638	5,650	6,936
CoV-P (%)	11,15	8,29	8,53	9,21	10,89

Legend: means followed by different letters are significantly different by a LSD test at α = 0.05, ns = not significantly different, CoV= Coefisien of Varians

NAA application had no significant effect on zucchini plant length growth at all observation times. Beside that, PBZ application especially at high concentrations have significantly inhibited plant length growth. The decrease in plant length was increasingly evident with increasing plant age with a noticeable effect occurring at the highest PBZ concentration which consistently caused plant shortening compared to treatments without PBZ and lower concentrations.

The results of the analysis of variance of the observation number of leaves in there is no interaction between the provision of NAA and PBZ concentration. The provision of NAA showed no significant difference at 7, 14, 21, 28 and 35 DAT on the addition of the number of leaves. Meanwhile, the provision of PBZ concentration was able to give a significant difference to the number of zucchini leaves at 21, 28 and 35 DAT (Table 2).

Table 2: The of NAA and Various Concentrations of PBZ on the Number of Leaves

NAA	Number of Leave (leaf plant^{-1}) at DAT				
	7	14	21	28	35
Without NAA	1,86	6,35	12,27	15,28	18,44
With NAA	1,88	6,41	12,34	14,50	17,44
LSD-N (5%)	ns	ns	ns	ns	ns
CoV-N(%)	10,46	11,73	12,91	12,86	14,73
Consentration of PBZ (ppm)	Number of Leave (leaf plant^{-1}) at DAT				
	7	14	21	28	35
0	1,85	6,53	11,07 a	13,38 a	15,09 a
50	1,88	6,20	11,73 ab	13,71 ab	16,38 a
100	1,86	6,36	12,37 ab	15,07 abc	16,51 a
150	1,89	6,43	13,08 b	15,55 bc	19,87 b
200	1,86	6,38	13,27 b	16,73 c	21,85 b
LSD- P (5%)	ns	ns	1,552	1,944	3,221
CoV-P (%)	12,43	12,61	10,31	10,67	14,67

Legend: means followed by different letters are significantly different by a LSD test at α = 0.05, ns = not significantly different, CoV= Coefisien of Varians

The results showed that the application of NAA showed no significant effect on the number of leaves of zucchini plants at all observation times. Beside that, PBZ application at higher concentrations consistently increased the number of leaves significantly, especially at the highest concentration. The increase in leaf number was most prominent at older plant ages, with a more pronounced effect at higher PBZ concentrations compared with other treatments.

The results of the analysis of variance the leaf area observations in there is no interaction between the provision of NAA and PBZ concentration. The provision of NAA showed no significant difference at 7, 14, 21, 28 and 35 DAT on the addition of leaf area. Meanwhile, the provision of PBZ concentration was able to give a significant difference to the area of zucchini leaves at of 21, 28 and 35 DAT (Table 3).

Table 3: The Effect of NAA and Various Concentrations of PBZ on Leaf Area of Zukini NAA Leaf area (cm^2 plant^{-1}) at DAT

NAA	Leaf Area (cm^2 plant^{-1}) at DAT				
	7	14	21	28	35
Without NAA	51,56	363	1034	1556	2198
With NAA	51,78	362	1091	1758	2480
LSD-N (5%)	ns	ns	ns	ns	ns
CoV-N(%)	10,45	12,50	11,16	11,32	9,671
Consentration of PBZ (ppm)	Leaf Area (cm^2 plant^{-1}) at DAT				
	7	14	21	28	35
0	50,12	365,9	1217 c	2192 d	2823 c
50	52,55	363,0	1153 bc	1650 c	2567 bc
100	51,55	364,5	1044 ab	1608 bc	2299 ab
150	52,62	359,6	1003 ab	1448 ab	2024 a
200	51,53	357,6	894,7 a	1388 a	1983 a

LSD- P (5%)	ns	ns	171,9	183,2	373,1
CoV-P (%)	13,47	9,210	13,22	9,040	13,03

Legend: means followed by different letters are significantly different by a LSD test at α = 0.05, ns = not significantly different, CoV= Coefisien of Varians

The result NAA application showed no significant impact on the leaf area of zucchini plants at all observation times. Beside that, PBZ application especially at high concentrations had significantly reduced leaf area. This reduction in leaf area became more pronounced at higher PBZ concentrations especially at older plant ages, compared to treatments without PBZ or with lower PBZ concentrations. The leaf area reduction effect was most pronounced at the highest PBZ concentration.

Table 4: The Effect of NAA and Various Concentrations of PBZ on Flowering, Number of Female and Male Flowers, Female Flower Ratio, Number of Fruits and Fruit Set in zucchini Plants

NAA	Flower Blooming (DAT)	Number of Male Flower (flower plant^{-1})	Number of Female Flower (flower plant^{-1})	Flower Ratio	Number of Fruits (fruit plant^{-1})	Fruit Set (%)
Without NAA	23,24	14,00 A	13,70	1,061	8,730	65,17
With NAA	23,28	16,33 B	14,50	1,169	9,510	58,25
LSD-N (5%)	ns	2,254	ns	ns	ns	ns
CoV-N(%)	4,041	9,460	10,70	9,222	9,980	9,440
Consentration of PBZ (ppm)	Flower Blooming (DAT)	Number of Male Flower (flower plant^{-1})	Number of Female Flower (flower plant^{-1})	Flower Ratio	Number of Fruits (fruit plant^{-1})	Fruit Set (%)
0	22,76	11,50 a	16,17 c	0,705 a	7,001 a	65,50
50	23,42	14,25 b	15,08 c	0,952 b	8,120 ab	58,58
100	23,45	15,67 bc	14,58 bc	1,082 bc	9,330 bc	61,53
150	23,34	17,08 c	13,25 b	1,304 cd	10,25 cd	59,84
200	23,36	17,33 c	11,42 a	1,533 d	10,91 d	62,92
LSD- P (5%)	ns	2,443	1,782	0,236	1,495	ns
CoV-P (%)	1,750	13,16	10,32	17,32	13,39	19,77

Legend: means followed by different letters are significantly different by a LSD test at α = 0.05, ns = not significantly different, CoV= Coefisien of Varians

There is no interaction between the provision of NAA and PBZ concentration. On Table 4 in the provision of NAA showed significantly different in the observation of the number of female flowers, but not significantly different in the observation of flowering age, number of male flowers, female flower ratio, number of fruits and fruit set. Meanwhile, the provision of PBZ concentration is able to provide significantly different on the observation of flowering age, the number of female and male flowers, the ratio of female flowers, the number of fruits but not significantly different on the observation of fruit set NAA did not accelerate flowering age but significantly increased the number of female flowers.

PBZ application, especially at concentrations of 150 and 200 ppm, also increased the number of female flowers, while the number of male flowers was reduced at the highest PBZ concentration. PBZ application at 200 ppm increased the ratio of female flowers, and NAA application had no significant effect on the ratio. In addition, PBZ at high concentrations increased fruit set, although NAA had no significant effect on fruit set.

3.2. Effect of NAA and Various Concentrations of PBZ on Zucchini Harvest

The results of analysis of variance of fruit length observations in there is an interaction between the provision of NAA and PBZ concentration. Separately, the administration of NAA showed significantly different on fruit length. In addition, the concentration of PNZ showed significantly different on fruit length (Table 5).

Table 5: Interaction between NAA and Various Concentrations of PBZ on Zucchini Fruit Length

NAA	Fruit Length (cm)				
	Consentration of PBZ (ppm)				
	0	50	100	150	200
Without NAA	25,33 a A	26,89 ab A	28,78 ab A	30,22 b A	26,67 ab A
With NAA	21,67 a A	28,42 b A	29,18 b A	30,71 b A	31,69 b B
LSD (%)	3,659				
CoV-N (%)	9,161				
CoV-P (%)	7,560				

Legend: Numbers accompanied by the same uppercase letter in the same column and the same lowercase letter in the same row show no significant difference based on 5% LSD test, ns = not significantly different

The application of PBZ at a high concentration (200 ppm) without NAA significantly reduced the length of zucchinifruit, while the application of NAA at the same PBZ concentration reduced the impact of the reduction. An increase in PBZ concentration generally affected fruit length, whether in treatments with or without NAA. At a concentration of 150 ppm without NAA, fruits showed a significant increase in length compared to the treatment without PBZ. In addition, application of PBZ at various concentrations with NAA resulted in longer fruits, with the highest increase in length at 200 ppm PBZ concentration.

The results of the analysis of variance of fruit diameter observations in there is no interaction between the administration of NAA and PBZ concentration. Separately, the provision of NAA showed significantly different on the addition of fruit diameter. Meanwhile, the provision of PBZ concentration is able to give a significant difference to the diameter of zucchini fruit (Table 6).

Table 6: The Effect of NAA and Various Concentrations of PBZ on fruit diameter of zucchini

NAA	Fruit Diameter (mm)
Without NAA	61,60 A
With NAA	69,58 B
LSD-N (5%)	ns
CoV-N(%)	7,600
Consentration of PBZ (ppm)	Fruit Diameter (mm)
0	61,63 a
50	63,63 ab
100	66,51 abc
150	69,07 bc
200	67,20 c
LSD- P (5%)	4,886
CoV-P (%)	6,090

Legend: Means followed by different letters are significantly different by a LSD test at α = 0.05, ns = not significantly different, CoV= Coefisien of Varians

Fruit diameter was significantly different between NAA and PBZ concentrations. NAA increased fruit diameter more, while PBZ at 200 ppm concentration also showed a significant increase compared to several treatments, but there was no significant difference at 100 and 150 ppm concentrations.

The results of analysis of variance of observations of fresh fruit weight and fruit weight per plant in there is an interaction between the provision of NAA and PBZ concentration. Separately, the provision of NAA showed significantly different to the weight of fresh fruit and large fruit per plant. In addition, the application of PBZ concentration showed significantly different on fresh fruit weight and fruit wight per plant (Table 7).

Table 7: Interaction between NAA and Various Concentrations of PBZ on Zucchini Fresh fruit weight and fruit weight per plant

	Fresh fruit weight (g fruit^{-1})				
NAA	Consentration of PBZ (ppm)				
	0	50	100	150	200
Without NAA	430,4 a A	570,2 b A	572,8 b A	735,7 c A	543,0 b A
With NAA	740,4 bc B	684,3 a B	721,0 ab B	749,0 bc A	778,6 c B
LSD (%)	77,24				
CoV-N (%)	6,34				
CoV-P (%)	6,84				
	Fruit Weight (g plant^{-1})				
NAA	Consentration of PBZ (ppm)				
	0	50	100	150	200
Without NAA	3013 a A	4656 b A	4964 bc A	6989 d A	5610 c A
With NAA	5182 a B	5520 a B	7210 b B	8239 c B	8953 d B
LSD (%)	673,9				
CoV-N (%)	6,060				
CoV-P (%)	6,450				

Legend: Numbers accompanied by the same uppercase letter in the same column and the same lowercase letter in the same row show no significant difference based on 5% LSD test, ns = not significantly different

Fresh fruit weight and fruit weight per plant are significantly different between the treatment without NAA and with NAA application at various PBZ concentrations. The treatment without NAA showed heavier weight than the treatment with NAA at most PBZ concentrations. PBZ concentrations of 150 ppm in the treatment without NAA and 200 ppm in the treatment with NAA also showed a significant increase in weight compared to other treatments, while there were no significant differences at certain concentrations.

Table 8: Interaction between NAA and Various Concentrations of PBZ on Zucchini harvest index

	Harvest Index (%)				
NAA	Consentration of PBZ (ppm)				
	0	50	100	150	200

Without NAA	0,966 a	0,972 b	0,979 c	0,987 e	0,983 d
	A	A	A	A	A
With NAA	0,976 a	0,979 a	0,983 b	0,988 c	0,989 c
	B	B	B	A	B
LSD (%)			0,003		
CoV-N (%)			0,166		
CoV-P (%)			0,158		

Legend: Numbers accompanied by the same uppercase letter in the same column and the same lowercase letter in the same row show no significant difference based on 5% LSD test, ns = not significantly different

The results of the analysis of variance of harvest index observations in there is an interaction between the provision of NAA and PBZ concentration. Separately, the application of NAA showed significantly different to the harvest index of zucchini. In addition, the PBZ concentration showed significantly different on the harvest index of zucchini (Table 8).

Application of NAA and PBZ at various concentrations significantly affected the harvest index of zucchini. Increasing PBZ concentration showed significant differences in harvest index both with and without NAA. In the treatment without NAA, 150 ppm PBZ concentration produced the highest harvest index with a significant increase compared to other concentrations. Meanwhile, when NAA was applied, PBZ concentrations of 150 and 200 ppm showed a higher harvest index and were significantly different from PBZ concentrations of 0, 50, and 100 ppm.

IV. DISCUSSION

The results showed that the application of NAA and various concentrations of PBZ had a significant effect on the growth and yield of zucchini plants. There was a significant effect on plant length, number and area of leaves, stem length, number of female and male flowers, female flower ratio, and number of fruits. Meanwhile, the application of NAA with 100 ppm PBZ affected the age of female flowering, although it did not have a significant impact on fruit set. In the weight.

The study showed that the application of NAA had no significant effect on the length of zucchini plants at the age of 35 DAT, with the average length without NAA (51.32 cm) and with NAA (52.72 cm). In contrast, the application of PBZ with a concentration of 200 ppm showed a significant decrease in plant length compared to the control without PBZ, from 64.22 cm to 45.06 cm, which means a decrease of 42.52%. Paclobutrazol (PBZ) inhibits the biosynthesis of gibberellin, a hormone responsible for cell elongation and division, thus slowing the growth of zucchini plants (Degarajan, 2014). PBZ increases the activity of cellulase and pectinase enzymes, which break down cell walls and stems to become shorter but fuller. Pectinase enzymes hydrolyze pectin, making the cell wall more flexible, while cellulase decomposes cellulose, improving nutrient access and accelerating nutrient translocation to other organs, as well as producing carbohydrates as an energy source. As a result, plants grow fuller with more flexible but shorter stems (Seleim et al., 2015).

The decrease in plant length is also caused the absorption of PBZ which affects the plant canopy, so that the growth of new shoots is inhibited, The effect of PBZ in inhibiting similar growth was found in the research on potato plants with a concentration of 150 ppm. which recorded a 23.4% decrease in zucchini plant height upon PBZ application.) also found that PBZ can inhibit gibberellin biosynthesis in rice plants, resulting in significantly inhibited growth (Zhang et al., 2020)

The study also showed that the application of NAA had no significant effect on the number of zucchini leaves at the age of 35 DAT, with the average number of leaves without NAA (18.44) and with NAA (17.44). However, the application of PBZ at concentrations 200 ppm and 150 ppm showed a significant effect, with the number of leaves 21.85 and 19.87 respectively, while the control without PBZ had 64.22 leaves. This decrease in the number of leaves amounted to 24.06% and 30.94%. PBZ works by inhibiting the production of gibberellin, a hormone responsible for cell elongation, thus slowing stem growth and directing energy to leaf formation (Yuliadi et al., 2012). This mechanism is also supported an increase in the activity of cellulase and pectinase enzymes, which break down cell walls and improve nutrient translocation, and convert cellulose into carbohydrates that become a source of energy for plants, helping to increase the number of leaves (Putri et al., 2023; Gusmawan et al., 2018). PBZ inhibits gibberellin biosynthesis by suppressing the enzyme kaurene synthase, which prevents the formation of kaurenoate, thus inhibiting cell elongation and stem internodes. This diverts plant resources to increase the number of leaves, as also found in the research of Anggraeni et al. (2015), which reported a significant increase in leaf number at various PBZ concentrations, including 2.71 additional leaves at 20 ppm PBZ. However, the increase in leaf number decreased at PBZ concentrations higher than 500 ppm (Yuliadi et al., 2012).

The application of NAA has no significant effect on the leaf area of zucchini plants at the age of 35 DAT with an average leaf area without NAA (2198 cm^2) and with NAA (1983 cm^2). However, the application of PBZ at a concentration of 200 ppm showed a significant effect, with a leaf area reaching 2823 cm^2, which decreased by 42.38% compared to the control without PBZ. PBZ works by inhibiting gibberellin biosynthesis through inhibition of the enzyme ent-kaurene oxidase, which reduces active gibberellin levels in plants. This reduction in gibberellin impacts growth patterns, including a decrease in leaf area and an increase in leaf thickness (Hedden et al., 2021). Smaller and thicker leaves reduce total photosynthetic capacity, although water use efficiency increases due to thicker leaf morphology (Al-Munqedhi et al., 2021).

The reduction in leaf area is mainly due to a decrease in cell size, not cell number. This results in a decrease in light penetration and overall photosynthetic capacity, although leaf thickness increases with more chloroplasts per unit area. Research by Kumar et al. (2021) also showed that PBZ significantly reduced leaf area in tomato and chili plants, with changes in leaf morphology to become thicker and darker green.

Zucchini stem length have decreased significantly due to PBZ application, especially at concentrations of 100 and 150 ppm. At 28 DAT, the stem length decreased by 25.97% and 51.93% without NAA. However, NAA application can reduce this decrease, especially at 100 and 150 ppm PBZ. At 35 DAT, a decrease in stem length was also seen at PBZ concentrations of 0 and 50 ppm, with a decrease of 18.66% and 6.22%, but the effect of NAA helped maintain stem length. NAA increases amino acid and protein synthesis, and stimulates cell division, while also working with cytokinin hormones for stem growth. Activation of signal transduction pathways by NAA induces the expression of cell growth-related genes, facilitating plant stem elongation through expansin and hydrolytic enzymes (Rademacher, 2020). PBZ at concentration of 200 ppm showed a significant effect in inhibiting stem elongation, both the treatment with and without applying NAA, with a reduction of 100.7% and 130.3% at 28 DAT, and 118.32% and 111.1% at 35 DAT, respectively. This study shows that PBZ, as an inhibitor of gibberellin synthesis, slows down and inhibit stem growth, while this effect can be slightly reduced by NAA application .

PBZ inhibits the biosynthesis of gibberellin, an important hormone in stem elongation and flowering. Through the inhibition of key enzymes such as Copalyl Diphosphate Synthase (CDS), Kaurene Synthase (KS), and Kaurene Oxidase (KO), PBZ prevents the conversion of isoprenoid precursors to active gibberellins, inhibiting vegetative growth (Al-Munqedhi et al., 2021).

Fig 2 Relationship between the Application of NAA and Various Concentrations of PBZ on the Stem Length of Zucchini at A. 28 DAT and B. 35 DAT. The higher the concentration of PBZ with combination to the treatment without NAA and the application NAA then showed a significant decreased in the value of the stem length of zucchini plants. However, the treatment without NAA showed a shorter stem length value than the treatment with application NAA.

Based on the results of the regression test showed that the treatment had a significant effect on the stem length of zucchini plants. The following below is the relationship between the application of NAA with various concentrations of PBZ on the stem length of zucchini plants.

NAA and PBZ have an antagonistic relationship, NAA functions as a growth stimulator, while PBZ functions as a growth inhibitor. NAA can increased zucchini stem length by affecting protein synthesis and root development. This hormone also plays a role in activating enzymes that play a role in the synthesis of important compounds such as amino acids. Meanwhile, increased the concentration of PBZ can decrese the zucchini stem length by inhibiting protein synthesis and reducing enzyme activity. This hormone also plays a role in inhibiting root and stem development, and reduces the production of other hormones such as NAA (Hedden, 2021).

The study showed that the application of NAA did not significantly affect the flowering age of zucchini plants, either without NAA (23.24 DAT) or with NAA (23.28 DAT). However, the application of PBZ at a concentration of 200 ppm showed a longer flowering age (23.36 DAT) than without PBZ (22.76 DAT). PBZ inhibits the biosynthesis of gibberellin, a hormone that plays a role in the transition from the vegetative phase to the generative phase, thus extending the flowering time (Flores et al., 2018). The higher the concentration of PBZ, the greater the effect on delaying flowering age, as lower gibberellins cause a delay in the transition to flower formation.

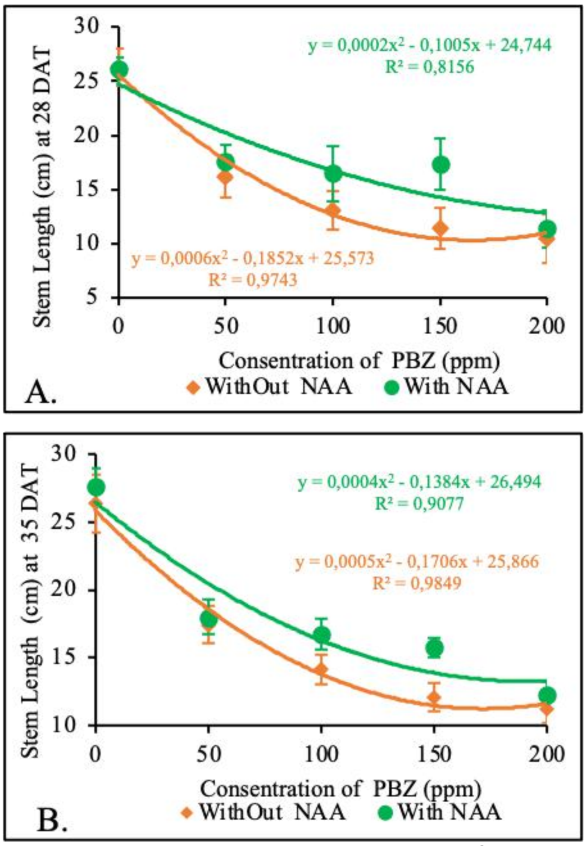


Fig. 2 Relationship between the Application of NAA and Various Concentrations of PBZ on the Stem Length of Zucchini at A. 28 DAT and B. 35 DAT

The results showed that the application of NAA increased the number of female flowers from 14.00 flowers plant^{-1} without NAA to 16.33 flowers plant^{-1} with NAA, with an increase of 14.27%. Synthetic auxins, such as NAA to stimulate female flower formation by modulating the expression of genes involved in flower development and cell differentiation (Singh et al., 2021). In addition, the interaction of NAA with ethylene accelerates the development of female flowers and inhibits the formation of male flowers (Rahmawati et al., 2020). The application of PBZ at a concentration of 200 ppm also significantly increased the number of female flowers (17.33 flowers plant^{-1}), which showed an increase of 33.64%. PBZ reduces gibberellin levels that usually promote male flowers, so more female flowers are formed (Zhang et al., 2021).

NAA application showed no significant effect on the number of male flowers at Table 4 either without NAA (13.70 flowers plant^{-1}) or with NAA (14.50 flowers plant^{-1}). However, PBZ had a significant effect, reducing the number of male flowers from 16.17 flowers plant^{-1} (without PBZ) to 11.42 flowers plant^{-1} (with PBZ), showing a decrease of 41.52%. PBZ works as a gibberellin inhibitor that usually stimulates male flower formation. By reducing gibberellin levels, PBZ inhibits the formation of male flowers and increases the number of female flowers (Wang et al., 2021). This study found that the ratio of female flowers was not significantly different in the treatments without NAA (1.061) and with NAA (1.169). Although NAA has the potential to increase auxins that stimulate the formation of female flowers, in this case, the administration of NAA did not have a significant effect, possibly due to the inappropriate timing of NAA administration (Lee et al., 2020). In contrast, the administration of PBZ at a concentration of 200 ppm increased the ratio of female flowers to 1.533 compared to the treatment without PBZ (0.705), with an increase of 54.02%. This is because PBZ suppresses gibberellin levels, which encourage the formation of male flowers, thus increasing the proportion of female flowers (Aghaalikhani et al., 2012).

NAA application did not have a significant effect on the number of fruits at Table 4, with an average without NAA (8.73 fruits plant^{-1}) and with NAA (9.51 fruits plant^{-1}). In theory, NAA can extend the life span of female flowers, increasing the chances of pollination success (Li et al., 2019), but in this study, environmental factors such as suboptimal temperature or humidity might limit the effect of NAA on fruit set (Zhang et al., 2021). On the other hand, PBZ showed a more pronounced effect on fruit number. PBZ application is able to inhibit gibberellins so that more resources are allocated to fruit formation, increasing the number of fruits formed (Rahimi et al., 2018). PBZ inhibits the enzymes ent-kaurene oxidase and Gibberellin 20-oxidase in the gibberellin biosynthesis pathway, which decreases the production of active gibberellin. With reduced gibberellin levels, PBZ not only slows vegetative growth but also promotes the differentiation of female flowers over male flowers (Chen et al., 2020). This gibberellin inhibition also affects the transition from vegetative to generative phase, making zucchini plants more efficient in using energy for fruit production rather than excessive vegetative growth. Auxins, such as NAA, interact with ethylene to stimulate the formation of female flowers and inhibit male flowers. Ethylene is known to accelerate the maturation of female flowers, while auxin regulates hormonal balance by increasing the expression of genes involved in female flower differentiation (Singh et al., 2021).

The increase in ethylene after NAA application leads to a decrease in male flowers, thus increasing the proportion of female flowers. Research shows that too high a dose of PBZ can cause phytotoxic effects, which reduce plant productivity and damage plant physiology (Kim et al., 2022). Therefore, it is necessary to select the right dose and application time to obtain optimal benefits from PBZ without harming plant productivity. PBZ increases carbohydrate accumulation in leaves and reduces vegetative growth, which allows zucchini plants to allocate more resources to female flower formation and development (Rahimi et al., 2018). PBZ helps improve the efficiency of nutrient transportation through the vessel network, supporting increased production of fruits and female flowers, which may ultimately increase the economic potential of zucchini plants (Zhang et al., 2021).

Based on the results in Table 6, it was found that the interaction between NAA and PBZ affected the fruit length of zucchini. Application of 200 ppm PBZ without NAA produced fruit length of 26.67 cm, while the addition of NAA at the same PBZ concentration increased the fruit length to 31.69 cm, with an increase of 18.82%. PBZ inhibits the biosynthesis of gibberellin, an important hormone in cell elongation, while NAA stimulates growth by increase cell division and elongation (Kurepin et al., 2019). This study also showed that in the treatment without NAA, PBZ 150 ppm produced the longest fruit length (30.22 cm), an increase of 23.38% compared to the control (25.33 cm). In contrast, in the treatment with NAA, the highest fruit length was achieved at 200 ppm PBZ, with an increase of 31.62% compared to the control. These results suggest that NAA can compensate for the inhibition of gibberellin by PBZ, resulting in optimal fruit length at higher PBZ concentrations (Thomas et al., 2018). NAA and PBZ also affect enzymatic activity, PBZ inhibits enzymes involved in gibberellin synthesis, while NAA increases the activity of enzymes that trigger cell elongation (Taiz et al., 2018). This interaction creates balanced hormonal conditions, favoring optimal fruit growth. At 200 ppm PBZ, NAA is able to neutralize the inhibitory effect of PBZ, so that the fruit can grow longer. addition, the effect of PBZ and NAA on fruit length is related to the increase in secondary metabolites, such as flavonoids and phenolics, which play a role in plant resistance and fruit quality (Abebie et al., 2020). The optimal interaction of PBZ and NAA produces the best fruit length, with 150 ppm PBZ concentration without NAA and 200 ppm PBZ with NAA showing maximum results. Adjustment of PBZ and NAA dosage is important to optimize agricultural yield and quality of zucchini fruit.

Based on the results in Table 6, the diameter of zucchini fruit did not show a significant interaction, but the application of NAA increased the diameter to 69.58 mm, an increase of 11.47% compared to without NAA (61.60 mm). NAA, as an auxin, stimulates cell division and expansion in the pericarp, allowing cells to absorb more water and nutrients, thus increasing cell size. NAA application also increases the efficiency of nutrient transportation to the fruit (Hasanuzzaman et al., 2020) and contributes to fruit quality by strengthening cell walls (Wang et al., 2019). NAA interacts with other hormones, such as gibberellins and cytokinins, to create synergistic effects in fruit growth, Application of PBZ at a concentration of 200 ppm resulted in a diameter of 67.20 mm, an increase of 8.29% compared to 61.63 mm in the absence of PBZ. PBZ also increases water use efficiency and nutrient distribution to the fruit and affects cytokinin levels that support cell division (Smith et al., 2020). Overall, PBZ directs nutrient distribution to the fruit, increasing their size and quality, with a 16% increase in diameter in Rademacher's (2020) study. Further research is needed to understand the interaction between PBZ and environmental factors and optimize PBZ concentration.

Based on Fig. 3, the treatment of naphthalenacetic acid (NAA) and paclobutrazol (PBZ) on the harvest index of zucchinis, the results showed that this combination had a significant effect in increasing yield.

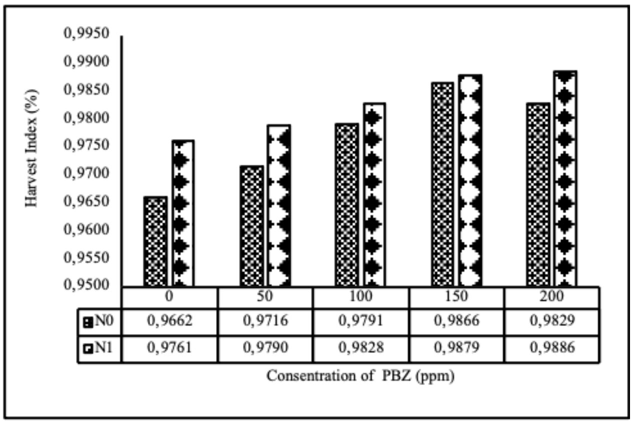


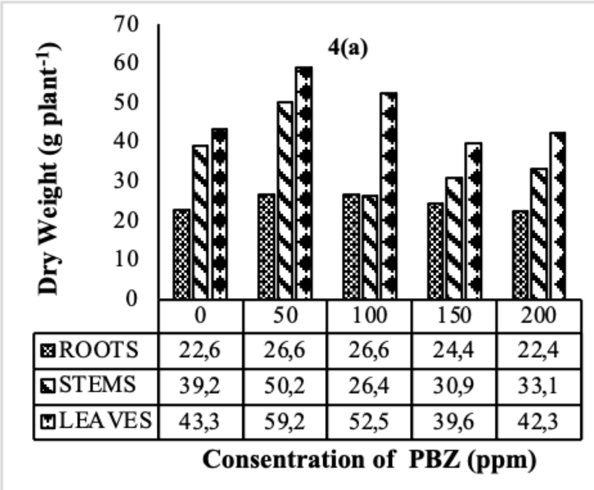
Fig 3. Relationship between the Application of NAA and Various Concentrations of PBZ on the fruit fresh weight and fruit weight per plant of Zucchini

The application of PBZ without NAA resulted in significant variations in harvest index at different PBZ concentrations. Without NAA, the harvest index increased from 0.966 at 0 ppm PBZ to 0.987 at 150 ppm, indicating an increase in photosynthetic efficiency with increasing PBZ concentration. However, at 200 ppm, there was a slight decrease in harvest index to 0.983. This suggests that too high a concentration of PBZ might have a saturating effect or inhibit some aspects of plant metabolism, resulting in a slight decrease in photosynthetic efficiency at the highest level. Beside that, the treatment with NAA, the harvest index at 0 ppm PBZ concentration reached 0.976 and continued to increase to 0.989 at 200 ppm concentration. These results indicate that the combination of NAA and PBZ at various concentrations has a synergistic effect that increases the efficiency of photosynthetic yield utilization by plants, resulting in a higher harvest index than without NAA.

The application of NAA and PBZ had a significant impact on harvest index in zucchini plants. A higher harvest index in PBZ and NAA treatments indicates a better efficiency of photosynthesis yield utilization for fruit formation. an increase in harvest index is generally caused a change in the allocation of assimilate from vegetative growth to generative organs, which in this case are zucchini fruits. This effect was apparent at 150 ppm PBZ concentration without NAA and 200 ppm PBZ concentration with NAA, which produced the highest harvest index. PBZ as an inhibitor of gibberellin biosynthesis, inhibits plant vegetative growth by reducing stem elongation and increasing stress resistance (Fletcher et al., 2015). In this study, the application of PBZ without NAA resulted in an increased harvest index at a concentration of 150 ppm, indicating that at this concentration, vegetative growth was optimally reduced, so that more energy was used for fruit formation. However, at 200 ppm PBZ concentration, the harvest index slightly decreased. Sharma et al. (2017) noted that too high a dose of PBZ can excessively inhibit plant metabolism, causing a reduction in photosynthetic efficiency and assimilate distribution, thereby lowering the harvest index.

A higher harvest index indicates that zucchini plants are more efficient in utilizing photosynthetic products for fruit production, which in turn increases the economic value of the plants. Based on the table, the combination of NAA and PBZ, especially at higher concentrations of PBZ, significantly increased plant efficiency. This means that in cultivation practices, the application of growth regulators such as NAA and PBZ can be an effective strategy to economically increase zucchini yield. The results of this study are in line with previous findings stating that PBZ is able to reduce plant height, increase harvest index, and stimulate fruit formation through regulating assimilate distribution (Rademacher, 2015). In addition, the use of NAA has been shown to play an important role in increasing photosynthetic efficiency through regulating cell division and fruit elongation, which also increases yield (Taiz & Zeiger, 2018). From the results shown in Table 8, it is clear that the interaction between NAA and PBZ significantly affected the harvest index of zucchini plants. Application of NAA together with PBZ resulted in a higher harvest index, which means that the plants were able to utilize photosynthetic products more efficiently for fruit production. This increase in harvest index indicates that the combination of NAA and PBZ can significantly increase the yield of zucchini plants, improve photosynthetic efficiency, and ultimately contribute to an increase in the economic value of the plants.

The application of NAA and PBZ with various concentrations affects biomass partitioning in zucchini plants, especially in the dry weight of roots, stems, and leaves. In this study, it was found that the treatment without NAA with 50 ppm. PBZ produced dry weight of roots, stems, and leaves of 26.6 g, 50.2 g, and 59.2 g, respectively. Meanwhile, at 100 ppm PBZ concentration, the root dry weight remained 26.6 g, but the stem and leaf weight decreased to 26.4 g and 52.5 g, respectively. A more significant decrease in stem and leaf dry weight occurred at 200 ppm PBZ concentration, where root dry weight dropped to 22.4 g, while at 150 ppm PBZ, stem and leaf weight dropped to 30.9 g and 39.6 g, respectively.



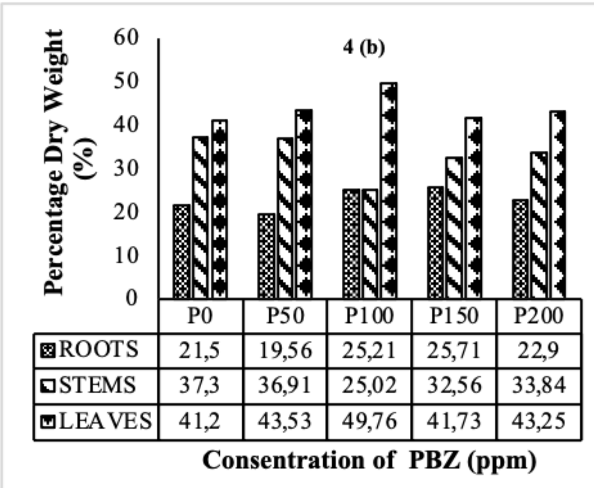


Fig 4. Dry weight (4a), percentage dry weight (4b) of roots, stems, and leaves treated with out NAA and applying various concentrations of PBZ

Consentration PBZ of 50 ppm have the highest dry weight of roots, stems, and leaves, while the lowest dry weight for all plant parts (roots, stems and leaves) is obtained in plants given 150 ppm PBZ concentration. However, the percentage of biomass between plant parts or organs (4b), the partition of biomass obtained is not always in line with the quantity of dry weight. The results showed that the percentage of root dry weight in plants treated with 150 ppm PBZ concentration was higher than that treated with 50 ppm PBZ concentration.

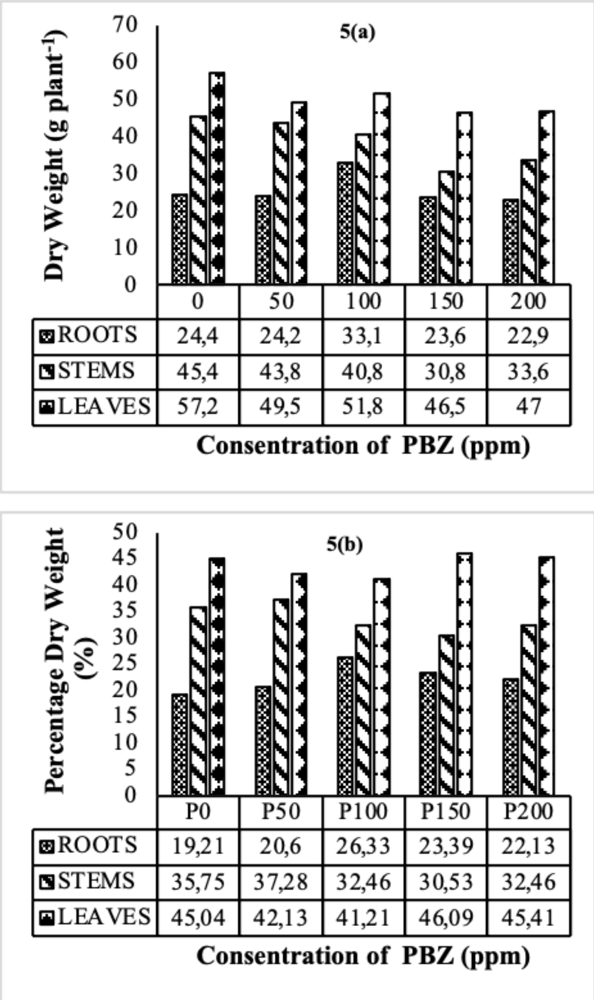


Fig 5. Dry weight (5a), percentage dry weight (5b) of roots, stems, and leaves treated with applying NAA and various concentrations of PBZ

The provision of NAA and PBZ concentration of 0 ppm gave the highest dry weight of roots, stems, and leaves, while the lowest dry weight for all parts of the plant (roots, stems and leaves) was obtained in plants given at the provision of NAA and PBZ concentration of 150 ppm. Fig. 5(a) shows the effect of NAA application at various concentrations of PBZ on plant dry weight. At 0 ppm PBZ, the dry weight of roots, stems, and leaves were 24.4 g, 45.4 g, and 57.2 g, respectively. However, at 200 ppm PBZ, stem and leaf dry weight decreased to 33.6 g and 47 g, while root weight increased at 100 ppm PBZ before decreasing again at 150 and 200 ppm PBZ.

However, when analyzed based on the percentage of biomass between plant parts or organs (5b), the partition of biomass obtained is not always in line with the quantity of dry weight. The results showed that the percentage of root dry weight in plants given NAA and 100 ppm PBZ concentration was actually higher than those given NAA and 0 ppm PBZ concentration.

The decrease in stem weight was caused by the inhibition of gibberellin biosynthesis by PBZ, a hormone important in plant cell elongation. This resulted in shorter and more compact plants. At 100 ppm PBZ, the percentage of leaf weight increased to 49.76%, which was due to a greater allocation of resources to the leaves than the stems, resulting in the leaves having a greater proportion in the biomass. Recent studies have also confirmed that PBZ not only inhibits the vertical growth of plants, but also helps plants adapt to environmental stress. According to Zhang et al. (2023), PBZ increases water use efficiency and plant resistance to abiotic stress. In addition, PBZ reduced gibberellin (GA) levels and increased abscisic acid (ABA) levels, which enhanced root biomass stability and plant resistance to unfavorable environmental conditions.

V. CONCLUSION

Applying NAA had no significant impact on zucchini growth, but increased the number of female flowers and fruit size, while PBZ effectively inhibited vegetative growth by reducing stem length and leaf area, and increased fruit production by diverting resources to female flower formation. The combination of NAA and PBZ exerted a synergistic effect, NAA helped mitigate PBZ inhibition of stem growth. In addition, this study also showed PBZ affected biomass partitioning by directing more resources to the roots and leaves, while NAA helped improve nutrient distribution to the stem and fruit. In addition, the combination of NAA and PBZ was shown to increase harvest index, with PBZ concentration the 150 ppm providing a significant increase in plant yield. Further research is needed to understand the interaction of these hormones and their impact on plant resilience and long-term productivity and to optimize combination of these two hormones to achieve maximum yield without compromising long-term productivity.

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