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RESPONSE OF COCOA (*THEOBROMA CACAO* L.) PRODUCTIVITY TO BIOCHAR AND ACTINOMYCETES SPP.

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SUMMARY

The study investigates the use of biochar as a soil improver to address various crop cultivation challenges by utilizing actinomycetes to enhance the available nutrients for plants. It aimed to examine the response of cocoa plants to different types of biochar and concentrations of actinomycetes for growth and productivity. This research began in Watu Toa Village, Marioriwawo District, Soppeng Regency, using 3-year-old MCC 02 plants. The research employed a split-plot design with main plots as the types of biochar (rice husk, coconut shell, and corn cob biochars). The subplots comprised various concentrations of actinomycetes, i.e., 0, 30, 60, and 90 mL L^{-1}. The results revealed significant interaction effects between the types of biochar and actinomycetes concentration on stomatal opening area (83.04 μm^2), number of cocoa pods formed (43.11 pods), percentage of fallen flower cluster (32.39%), and 100 dry beans' weight (171.68 g). However, the individual application of actinomycetes enunciated the most pronounced effects, particularly in the number of pods created (126.52 pods), the percentage of fallen cocoa pods (16.77%), the number of harvested fruits (15.67 fruits), and the production yield (618.84 g/tree and 687.53 kg/ha).

Keywords: Cocoa (*T. cacao* L.), biochar, actinomycetes, interaction effects, growth and physiological traits, productivity

Key findings: The combination of corn cob biochar and the highest concentration of actinomycetes (90 mL L^{-1}) provided the best effects on cocoa (*T. cacao* L.) for the stomatal openings, the lowest percentage of fallen flowers, and the maximum 100 dry seeds' weight.

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INTRODUCTION

The agriculture sector has an important economic role in Indonesia, as seen by its contribution to the gross domestic product (GDP). Its contribution to GDP seemed large (12.40%) in 2022, following the processing industry sector with the share of 18.34%. Plantation is one of the subsectors with considerable potential. The plantation subsector contribution in 2022 was 3.76% of the total GDP and 30.30% of the agriculture, forestry, and fisheries sector, which has a leading position in this sector (Central Bureau of Statistics, 2023). One of plantation commodities with a high economic value is the cocoa plant (*Theobroma cacao* L.). The large contribution made by Indonesia through the development of the cocoa plant mostly comes from the island of Sulawesi. South Sulawesi is one of the third-largest cocoa-producing centers after Central Sulawesi and Southeast Sulawesi, with an area of 175.5 ha and a production of 82.5 tons (Central Bureau of Statistics, 2024). For the last five years, the productivity of cocoa plants in South Sulawesi has continually declined. In 2018, the cocoa plant productivity in South Sulawesi was 807 kg/ha, decreasing in 2019 to 756 kg/ha (Central Bureau of Statistics, 2020). In 2020, it was 776 kg/ha, in 2021, at 753 kg/ha (Central Bureau of Statistics, 2022), and by 2022, at 725 kg/ha (Central Bureau of Statistics, 2023).

The low productivity of cocoa plants results from erosion, climate change, improper land management practices, and postharvest nutrient exploitation. Land degradation in cocoa plantation areas causes fertilization to be ineffective even though the fertilization treatment follows recommendations, wherein the fertilizer will only saturate the soil and not properly absorbed by the plants (Utomo et al., 2010). Infertile land conditions will indirectly affect cocoa production (Nurqadri et al., 2020).

Improving the quality of damaged soil can proceed by adding organic materials, such as, biochar. Biochar is a carbon-rich organic material produced through the pyrolysis of biomass, i.e., wood, plant residues, or manure. The manufacture of biochar by pyrolysis (incomplete combustion) takes place using a combustion tool or pyrolyzer to obtain charcoal containing high carbon and can be effective as a soil conditioner (Agricultural Research and Development Agency, 2012; Situmeang, 2020). Biochar can increase soil fertility, carbon absorption, and microbial activity. Biochar has several benefits in crop management, including its potential to increase soil carbon and mitigate climate change. Moreover, biochar can reduce the soil organic carbon mineralization and stabilize the unstable fresh organic substrates, thereby increasing soil carbon storage. Additionally, it can improve the efficiency of microbial carbon utilization and promote the formation of stable microbial residues from the labile substrate added into the soil (Kalu *et al.,* 2024). Biochar can also protect exogenous organic substrates and their microbial derivatives from decomposition, thus promoting strong organo-mineral bonds and boosting the soil carbon (Pan *et al*., 2021). Hence, biochar has the potential to enrich soil fertility and contribute to sustainable crop production practices.

Soil microbes' actinomycetes play an essential role by increasing the availability of nutrients for crop plants. The microbes have metabolic machinery to depolymerize and release specific major elements, such as, nitrogen, phosphorus, and sulfur, bound together in organic molecules and have little bioavailability to plants (Jacoby *et al*., 2017). The interaction between plants and soil microbes is crucial for nutrient uptake and the overall performance of crop plants. Therefore, it is necessary to combine soil microbes, such as actinomycete microbes, with biochar to improve and increase cocoa plant productivity.

Actinomycetes microorganisms have various advantages, including their ability to produce antibiotics, as biological pathogens, and produce bioactive compounds with antiviral, anticancer, herbicide, insecticide, and antiparasitic activities (Rabah *et al*., 2007). These microorganisms also inhibit the growth of gram-positive bacteria, making them valuable in the agriculture sector and medicines (Ambarwati and Purwani, 2010). Furthermore, actinomycetes have distinct morphologies, found both in soil and aquatic environments, contributing to managing the ecological and nutrient cycles. Their ability to produce antibiotics and bioactive compounds makes them valuable for various applications in agriculture, medicine, and environmental management (Saryono *et al*., 2019). Based on the above discussion, the presented study planned to investigate the response of cocoa plants for growth and productivity to different types of biochar and actinomycetes concentrations.

MATERIALS AND METHODS

Experimental site and procedure

This research ran from February to August 2023 at the traditional plantation, Watu Toa Village, Mario Riwawo District, Soppeng Regency, South Sulawesi Province, Indonesia (4°27′43.4″ S – 119°53′32.2″ E). This study used the cacao-cutting MCC 02 clones, with a distance of 3 m × 3 m. Materials include drums, thermometers, scopes, rulers, CCM-200 plus, hoes, machetes, analytical scales, cameras, stationery, actinomycetes, water, labels, and biochar comprising rice husk, corn cob, and coconut shell. The soil analysis before and after application of experimental factors in the cocoa appears in Table 1.

Experimental design

The said study had a split plot design with two factors and three replications. The first factor was the types of biochar (B) used in the main plots, comprising three levels, i.e., rice husk biochar t ha^{-1} (B0), coconut shell biochar 5 t ha^{-1} (B1), and corn cob biochar 5 t ha^{-1} (B2). The second factor was the concentrations of microbial actinomycetes (M) used in subplots, consisting of four levels, viz., without actinomycetes (M0), actinomycetes 30 mL L^{-1} (M1), actinomycetes 60 mL L^{-1} (M2), and actinomycetes 90 mL L^{-1} (M3). Each treatment had three replicates, with 108 cocoa subplots managed with three trees per plot.

Biochar preparation

Making biochar started with drying rice husks, coconut shells, and corn cobs. Before burning, chopping of the coconut shells and corn cobs occurred. Combustion took place using drums and a gas stove with a temperature of 300 °C–400 °C, following the methodology of Hossain *et al*. (2011). The combustion transpired under anaerobic conditions for 4 to 6 hours, depending on what base material to burn. The charcoal formed underwent cooling, pulverizing, and keeping ready for application. The biochar analysis is available in Table 2.

Actinomycetes preparation

The solution preparation comprised calculating the need for actinomycetes solution using a measuring cup according to each concentration. The volume of actinomycetes applied per plant was 2,000 mL. The number of plants for each concentration with three experimental units was 27 plants; thus, the total solution required in one treatment was: m_1 = 30 mL × 27 plants × 2 L/plant = 1,620 mL, m_2 = 60 mL × 27 plants × 2 L/plant = 3,240 mL, and m_3 = 90 mL × 27 plants × 2 L/plant = 4,860 mL. The needed total amount of actinomycete solution was 9,720 mL. The solution application continued by taking the solution according to each treatment level, then dissolved using air into a measuring cup until it reached 2,000 L and finally stirred to obtain a homogeneous solution.

Parameters observed

Parameters studied consisted of the stomatal opening area (μm^2), number of flower clusters formed, percentage of fallen flower clusters, number of cocoa pods produced, and the percentage of fallen cocoa pods, as observed in the 2nd to 20th week after application. The parameters number of cocoa pods harvested, number of seeds per ripe fruit, 100 dry beans' weight (g), cocoa production per tree (g/tree),

Table 1. Soil analysis before and after application of experimental factors in the cocoa.

Treatment	pH	Organic Material			Bray Olsen P_2O_5 (ppm)	Cation Exchange Rate (cmol[+] kg^{-1})	
		Walkley & Black C (%)	Kjeldahl N (%)	C/N		K	CEC
Before							
Composites	6.25	1.79	0.12	15	10.39	0.33	21.66
After							
Rice Husk Biochar 5 t ha^{-1} Without Actinomycetes	6.28	2.34	0.10	24	9.68	0.29	16.42
Rice Husk Biochar 5 t ha^{-1} + Actinomycetes 30 mL L^{-1}	6.33	2.61	0.11	23	12.79	0.30	20.76
Rice Husk Biochar 5 t ha^{-1} + Actinomycetes 60 mL L^{-1}	6.29	2.63	0.17	15	11.71	0.27	21.27
Rice Husk Biochar 5 t ha^{-1} + Actinomycetes 90 mL L^{-1}	6.42	2.81	0.18	16	10.86	0.33	22.48
Coconut Shell Biochar 5 t ha^{-1} Without Actinomycetes	6.48	2.45	0.20	12	11.06	0.18	22.07
Coconut Shell Biochar 5 t ha^{-1} + Actinomycetes 30 mL L^{-1}	6.62	2.87	0.22	13	12.99	0.36	20.60
Coconut Shell Biochar 5 t ha^{-1} + Actinomycetes 60 mL L^{-1}	6.55	2.99	0.24	13	15.54	0.41	23.35
Coconut Shell Biochar 5 t ha^{-1} + Actinomycetes 90 mL L^{-1}	6.69	3.18	0.24	13	14.72	0.46	24.19
Corn Cob Biochar 5 t ha^{-1} Without Actinomycetes	6.57	2.77	0.26	11	12.75	0.32	21.75
Corn Cob Biochar 5 t ha^{-1} + Actinomycetes 30 mL L^{-1}	6.68	2.86	0.28	10	14.95	0.42	23.76
Corn Cob Biochar 5 t ha^{-1} + Actinomycetes 60 mL L^{-1}	6.62	3.20	0.31	10	16.87	0.36	25.90
Corn Cob Biochar 5 t ha^{-1} + Actinomycetes 90 mL L^{-1}	6.74	3.24	0.28	12	15.38	0.38	24.37

Source: Soil Chemistry and Fertility Laboratory, Hasanuddin University, 2023.

Table 2. Biochar analysis.

Treatment	Organic Material			CEC (cmol[+] kg^{-1})	NHO_3 : $HClO_4$	
	Walkley & Black C (%)	Kjeldahl N (%)	C/N		P (ppm)	K (cmol[+] kg^{-1})
Rice Husk Biochar	17.79	0.78	23	52.15	0.05	0.11
Coconut Shell Biochar	15.41	2.45	6	43.25	0.13	0.84
Corn Cob Biochar	20.09	3.05	7	56.35	0.18	0.83

Source: Soil Chemistry and Fertility Laboratory, Hasanuddin University, 2023.

and cocoa production per hectare (kg ha^{-1}) reached observation at the end of the study. Calculating the percentage of fallen flowers and fallen cocoa pods and production per hectare used the following equations.

$$\text{Percentage of fallen flowers} = \frac{Number\ of\ fallen\ flowers}{Number\ of\ formed\ flowers} \times 100\%$$

$$\text{Percentage of fallen cocoa pods} = \frac{Number\ of\ fallen\ pods}{Number\ of\ formed\ pods} \times 100\%$$

Production per hectare = Total population per hectare × production per tree

Data analysis

The data comprising various parameters, as arranged in a tabular form and analyzed, used the analysis of variance (ANOVA) (Sawyer, 2007). After getting the means with significant differences, the least significant difference ($LSD_{0.05}$) test helped further compare and separate the means of different categories. All the data analysis continued processing with the Microsoft Excel 2021 software.

RESULTS AND DISCUSSION

The results revealed significant interaction effects between the types of biochar and actinomycetes concentration on the stomatal opening area, number of cocoa pods formed, percentage of fallen flower cluster, and 100 dry beans' weight (Table 3). However, the individual application of actinomycetes enunciated the most pronounced effects, particularly in the number of pods formed, the percentage of fallen cocoa pods, the number of harvested fruits, and the production per tree and production per hectare. The outcomes of physiological observations of plants showed the provision of corn cob biochar with actinomycetes microbes at 90 mL L^{-1} gave the highest values on the area of stomata openings (83.04 μm^2). This aligns with the results of the previously carried out soil analysis, namely, the corn cob biochar and 90 mL actinomycetes giving high organic matter compared to other treatments. This occurs because corn cob biochar has high porosity, which helps in better water and nutrient retention, thus creating more optimal soil conditions to support plant physiological functions. Actinomycetes microbes also help in mobilizing nutrients and supporting the decomposition of organic matter, which can increase the availability of essential nutrients for plants. Plants getting enough nutrients and water will affect the opening and closing of stomata, hence increasing photosynthesis and more efficient gas exchange. Fitriyah *et al.* (2017) stated the availability of sufficient water causes the opening of plant stomata to increase, helping enhance photosynthesis to form optimal plant biomass. Previous research also revealed applying biochar can substantially regulate the stomatal opening in cabbage (Chen *et al*., 2023).

The observations on the flower cluster formed showed the highest average flower cluster produced (126.52 cluster) appeared in the treatment of corn cob biochar with the topmost concentration of actinomycetes (90 mL L^{-1}). It significantly differed from the treatments of actinomycetes concentrations of 0 mL L^{-1} and 30 mL L^{-1}; however, it was nonsignificantly different from the corn biochar and actinomycetes at 60 mL L^{-1} (Table 4). The application of actinomycetes can considerably enhance plant growth and productivity. Previous research showed actinomycetes could interact with plants to increase flower growth and production by producing growth hormones that can affect flower growth and development (Suloi *et al*., 2022).

Table 3. Effect of different types of biochar and actinomycetes concentrations on the average stomatal opening area (μm^2) in cocoa.

Biochar Type	Actinomycetes (mL L^{-1})				$LSD_{0.05}$
	0 (m0)	30 (m1)	60 (m2)	90 (m3)	
Rice Husk Biochar (b0)	57.52^{a}_{q}	67.34^{a}_{p}	68.33^{a}_{p}	51.95^{c}_{q}	10.57
Coconut Shell Biochar (b1)	58.61^{a}_{q}	66.64^{a}_{pq}	74.44^{ab}_{p}	70.58^{b}_{p}	
Corn Cob Biochar (b2)	60.92^{a}_{r}	72.57^{a}_{q}	79.76^{a}_{pq}	83.04^{a}_{p}	
$LSD_{0.05}$	9.45				

Numbers followed by the same letter in column (a, b) and row (p, q, r) mean not significantly different in the $LSD_{0.05}$.

Table 4. Effect of different types of biochar and actinomycetes concentrations on the average number of flower clusters, fallen cocoa pods, fruit harvest, production/tree, and production/hectare in cocoa.

Treatment	Parameters				
	FCF	FCP	NHF	Production tree^{-1}	Production ha^{-1}
			Biochar Type		
Rice Husk Biochar	100.78	27.55	12.75	457.43	508.20
Coconut Shell Biochar	114.50	20.38	13.08	502.93	558.75
Corn Cob Biochar	117.81	22.00	12.95	535.51	594.95
$LSD_{0.05}$	NS	NS	NS	NS	NS
			Actinomycetes		
Without Actinomycetes	86.41r	33.54q	10.59q	382.22r	424.64q
Actinomycetes 30 mL L^{-1}	105.11q	22.74p	11.63q	444.15qr	493.46q
Actinomycetes 60 mL L^{-1}	126.08p	16.77p	15.67p	618.84p	687.53p
Actinomycetes 90 mL L^{-1}	126.52p	20.18p	13.81pq	549.28pq	610.25pq
$LSD_{0.05}$	13.00	7.84	3.61	143.15	159.28

Numbers followed by the same letter in the row (p, q, and r) mean not significantly different in the LSD test α 0.05. FCF = Flower Clusters Formed (flowers), FCP = Fallen Cocoa Pods (%), NHF = Number Harvested Fruits (fruits).

The assessment on the percentage of fallen cocoa pods indicated the lowest average percentage of fallen cocoa pods (16.77%) resulted in the treatment of actinomycetes microbes at 60 mL L^{-1}), which was notably different from the actinomycetes at 0 mL L^{-1}. However, it had a nonsignificant difference from the actinomycetes (30 mL L^{-1} and 90 mL L^{-1}) (Table 4). Actinomycetes can produce compounds that strengthen the plant's defense system against biotic and abiotic stress conditions, which can further reduce the possibility of fruiting in pentil fall. Chukwuneme *et al*. (2020) explored the inoculation of drought-tolerant strains of *Streptomyces pseudovenezuelae* and *Arthrobacter arilaitensis,* which enhanced plant growth and development and reduced the undesirable effects of drought stress in maize.

In cocoa, the highest average number of harvested fruit (15.67) was evident in the treatment of actinomycetes at 60 mL L^{-1} (Table 4). The said treatment was considerably different from other actinomycetes (0 mL L^{-1} and 30 mL L^{-1}); however, it was nonsignificantly different from the actinomycetes at 90 mL L^{-1}. Actinomycetes can produce plant growth hormones, such as auxin, cytokinin, and gibberellin, stimulating the growth and development of flowers, in turn increasing the fertilization in cocoa plants. Swarnalakshmi *et al*. (2016) reported actinobacteria types of actinomycetes directly help crop plants to obtain nutrients through fixation of atmospheric nitrogen, producing photohormones, i.e., auxins, gibberellins, and cytokinins that can directly enhance plant growth.

The results further revealed the highest average production per tree (618.84 g) was in the treatment of actinomycetes, 60 mL L^{-1}, which was notably different from other actinomycetes (0 and 30 mL L^{-1}). However, it nonsignificantly differed from the actinomycetes at 90 mL L^{-1} (Table 4). The maximum average production per hectare (687.53 kg/ha) emerged in the actinomycetes at 60 mL L^{-1}, remarkably varying from other actinomycetes (0 and 30 mL L^{-1}), but nonsignificantly different from the actinomycetes at 90 mL L^{-1} (Table 4). This may be due to the influence of the plant growth hormones auxin, cytokinin, and gibberellin produced by actinomycetes, stimulating the flower growth and development. In turn, it increases the fertilization rate in cocoa plants. Swarnalakshmi *et al*. (2016) revealed in their findings that actinomycetes help plants obtain nutrients through atmospheric nitrogen fixation and produce photohormones, i.e., auxins, gibberellins, and cytokinins, enhancing plant growth. Actinomycetes can also improve the

Table 5. Effect of different types of biochar and actinomycetes concentrations on the average percentage of fallen flowers clusters (%) in cocoa.

Biochar Type	Actinomycetes (mL L^{-1})				$LSD_{0.05}$
	0 (m0)	30 (m1)	60 (m2)	90 (m3)	
Rice Husk Biochar (b0)	66.59 a q	69.46 b q	45.70 a q	62.60 b q	
Coconut Shell Biochar (b1)	64.95 a q	56.70 b q	43.68 a p	42.23 a p	13.11
Corn Cob Biochar (b2)	56.62 a q	43.21 a p	40.27 a p	32.39 a p	
$LSD_{0.05}$	11.08				

Numbers followed by the same letter in column (a, b) and row (p, q, r) mean not significantly different in the $LSD_{0.05}$.

Table 6. Effect of different types of biochar and actinomycetes concentrations on the average number of cocoa pods formed (pods) in cocoa.

Biochar Type	Actinomycetes (mL L^{-1})				$LSD_{0.05}$
	0 (m0)	30 (m1)	60 (m2)	90 (m3)	
Rice Husk Biochar (b0)	20.00 b p	26.00 a p	22.22 b p	25.45 a p	
Coconut Shell Biochar (b1)	31.89 a pq	25.11 a q	38.33 a p	25.45 a q	9.09
Corn Cob Biochar (b2)	20.22 b r	25.89 a qr	43.11 a p	31.78 a q	
$LSD_{0.05}$	7.45				

Numbers followed by the same letter in column (a, b) and row (p, q, r) mean not significantly different in the $LSD_{0.05}$.

soil quality, reduce diseases' impact, and increase cocoa productivity. Valois *et al*. (1996) reported actinomycetes inhibit the growth of Phytophthora spp. by producing fungal metabolites and secreting glucanase, which also occurred active on Phytophthora spp. cell walls.

The observations on the percentage of fallen flower clusters provided their lowest average percentage appeared in the treatment of corn cob biochar with actinomycetes microbe (90 mL L^{-1}), which was 32.39% (Table 5). The said promising combination was significantly different from the rice husk biochar with actinomycetes at 90 mL L^{-1}; however, it showed nonsignificantly different from the coconut shell biochar with actinomycetes at 90 mL L^{-1}. The use of biochar and microbial actinomycetes can reduce the loss of cocoa flowers and can better develop them into pods. Biochar can also improve the soil structure, increase water retention, and soil cation exchange capacity (CEC), which improve the absorption of nutrients by cocoa plants and reduce the flower loss in the plants (Shalsabila *et al*., 2017). Actinomycetes can increase plant resistance to various types of abiotic and biotic stresses, such as drought, salinity, and pest attacks, which can help cocoa plants stay healthy and prevent flower loss (Airlangga *et al*., 2021). The actinomycetes microbes can also aid cocoa plants to overcome environmental stresses, often manifested in the plant's flower loss (Andina and Zulkifli, 2023).

The results further revealed the highest average number of cocoas formed (43.11) in the treatment of corn cob biochar with actinomycetes microbes (60 mL L^{-1}) (Table 6). The said promising interaction was considerably different from the treatment of rice husk biochar with actinomycetes microbes of 60 mL L^{-1} but was nonsignificantly different from the coconut shell biochar with actinomycetes of the same dose (60 mL L^{-1}). This may occur due to the complete fulfillment of the nutrients needed by plants. Arif *et al*. (2021) reported the considerable role of corn cob biochar in increasing the formation of cocoa pods and also improving soil structure,

Table 7. Effect of different types of biochar and actinomycetes concentrations on the average number of beans per fruit in cocoa.

Treatment	Number of Beans per Fruit
Biochar Type	
Rice Husk Biochar	23.25
Coconut Shell Biochar	23.67
Corn Cob Biochar	24.51
$LSD_{0.05}$	NS
Actinomycetes	
0 mL L^{-1}	23.66
30 mL L^{-1}	23.52
60 mL L^{-1}	23.76
90 mL L^{-1}	24.29
$LSD_{0.05}$	NS

Table 8. Effect of different types of biochar and actinomycetes concentrations on the average 100 dry beans weight (g) in cocoa.

Biochar Type	Actinomycetes (mL L^{-1})				$LSD_{0.05}$
	0 (m0)	30 (m1)	60 (m2)	90 (m3)	
Rice Husk Biochar (b0)	$\overset{a}{149.08q}$	$\overset{b}{154.93q}$	$\overset{a}{162.30p}$	$\overset{b}{149.64q}$	8.65
Coconut Shell Biochar (b1)	$\overset{a}{152.06q}$	$\overset{a}{164.15q}$	$\overset{a}{164.57p}$	$\overset{a}{166.56p}$	
Corn Cob Biochar (b2)	$\overset{a}{157.64q}$	$\overset{a}{169.25p}$	$\overset{a}{170.22p}$	$\overset{a}{171.68p}$	
$LSD_{0.05}$	6.82				

Numbers followed by the same letter in column (a, b) and row (p, q) mean not significantly different in the $LSD_{0.05}$.

increasing nutrient retention, encouraging the growth of microorganisms, and raising nutrient uptake. Applying biochar to soil creates a favorable environment for plant growth and nutrient uptake by improving soil physicochemical and biological properties, such as porosity, water infiltration, WHC, aggregate stability, bulk density, soil hardness, pH, cation exchange capacity, and nutrient cycling (Kavitha *et al*., 2018). The interaction between biochar and actinomycetes can increase water absorption capacity and nutrient availability for crop plants and protect them from diseases. Bhatti *et al*. (2017) mentioned the actinomycetes chiefly contribute to environmental organic recycling by producing hydrolytic enzymes, enriching the availability of nutrients and minerals, and synthesizing growth regulators. In particular, microbes were able to inhibit the phytopathogens.

Outcomes on the number of seeds per ripe cocoa pod enunciated the coconut shell biochar with actinomycetes at 90 mL L^{-1} tends to produce the most seeds per ripe cocoa pod (24.29) (Table 7). However, the fewest seeds per ripe cocoa pod (23.25) was evident in the rice husk biochar with actinomycetes at 30 mL L^{-1}. Microbial actinomycetes and biochar type did not significantly affect the average number of seeds per ripe cocoa pod, and it could have influences from the altitude and environmental conditions. Ilham *et al*. (2017) mentioned that altitude in the study location alters the production and fat content of cocoa beans, and the higher the altitude, the lower the temperature and lower the cocoa production.

Findings on the 100 dry beans' weight showed the maximum average 100 dry seeds' weight (171.68 g) resulted in the corn cob biochar with actinomycetes at 90 mL L^{-1}, which was remarkably different from the rice husk biochar with actinomycetes at 90 mL L^{-1}. However, it was nonsignificantly different from the coconut shell biochar with actinomycetes at

90 mL L^{-1} (Table 8). Plant dry weight sustained influences from several factors, such as drying, fermentation, and the nutrients absorbed by fresh seeds in crop plants. The most important determinants for assessing cocoa yield potential include light interception, photosynthesis and photoassimilate delivery capacity, respiration rate for pod morphology, and seed fermentation (Zuidema, 2005; Nasaruddin *et al*., 2021). Ifmalinda *et al.* (2023) reported the drying process is critical to making wet cocoa beans into dry quality and suitable for consumption. Fermentation of cocoa beans will develop flavor, aroma, and color that will affect the dry weight of cocoa beans (Hayati *et al*., 2012; Farid *et al*., 2021). Fresh beans consist of two main components—pulp and cotyledons—which can alter the cocoa beans' formation (Tarigan *et al*., 2021; Sabahannur and Syam, 2023).

CONCLUSIONS

The results revealed the cocoa productivity received more dominant influences from actinomycetes treatment individually. The actinomycetes alone affect the flower cluster formed, the percentage of fallen cocoa pods, the number of harvested fruits, and cocoa productivity. The combined application of biochar and actinomycetes has better effects on the area of stomatal openings, the percentage of fallen flower clusters, the number of cocoa pods produced, and the 100 dry beans' weight.

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