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Effectiveness of Biochar application on the growth of red chili plants during the vegetative stage under waterlogging

Efektivitas aplikasi Biochar terhadap pertumbuhan tanaman cabai merah fase vegetatif pada kondisi stres jenuh air

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ABSTRAK

Lahan basah riparian mempunyai potensi besar dimanfaatkan untuk budidaya tanaman sayuran yang salah satu diantaranya yaitu budidaya tanaman cabai. Salah satu faktor penting yang perlu diperhatikan adalah teknik budidaya dan pemanfaatan bahan organik untuk memperbaiki sifat fisik, kimia, dan biologi tanah khususnya untuk menghadapi kondisi jenuh air pada musim penghujan. Tujuan penelitian ini adalah untuk menguji pengaruh aplikasi biochar terhadap pertumbuhan tanaman cabai (*Capsicum annuum* L.) pada fase vegetatif pada saat perakaran mengalami kondisi jenuh air. Penelitian ini menggunakan rancangan acak lengkap faktorial yang terdiri dari dua faktor. Faktor pertama yaitu stres *waterlogging* yang terdiri atas kontrol (C) dan stres *waterlogging* (W). Faktor kedua (N) yaitu aplikasi biochar yang terdiri atas perlakuan tanpa bichar (N0), biochar sekam padi (N1) dan biochar tempurung kelapa (N2) dengan dosis masing-masing 200g polybag^{-1}. Hasil penelitian menunjukkan bahwa kondisi waterlogging (W) dan pemberian biochar (B) menunjukkan hasil berbeda nyata terhadap panjang tajuk, panjang akar, jumlah daun, dan berat kering total tanaman cabai, sedangkan interaksinya (WxN) menunjukkan hasil berbeda tidak nyata pada tinggi dan panjang akar tanaman. Pemberian perlakuan tanpa biochar (N0) pada kondisi jenuh air total justru memberikan panjang tajuk, panjang akar, jumlah daun, dan berat kering total tanaman berbeda nyata lebih tinggi dibandingkan dengan pemberian biochar tempurung kelapa (N1) maupun sekam padi (N2).

Kata kunci: biochar, cabai, jenuh air, stress abiotik

ABSTRACT

The riparian wetland offers potential for horticultural crop cultivation, such as chili peppers. It is important to consider cultivation techniques and the use of organic matter to improve soil properties, particularly to combat waterlogging during the rainy season. This study aimed to assess the impact of biochar application on the growth of chili peppers (*Capsicum annuum* L.) during the vegetative stage under waterlogging conditions. This research employed a complete randomized design factorial with two factors. The first factor involved waterlogging stress, including control (C) and waterlogging stress (W). The second factor (N) encompassed the application of biochar, namely without biochar (N0), rice husk biochar (N1), and coconut shell biochar (N2) at a dose of 200 g plant^{-1}. The results showed that waterlogging conditions (W) and biochar application (N) showed significantly different results in shoot length, root length, number of leaves, and total dry weight of chili plants, while the interaction (WxN) showed significant differences in shoot length and root length of plants. Treatment without biochar (N0) in waterlogging conditions showed shoot length, root length, number of leaves, and total dry weight of plants that were significantly higher than treatment coconut shell biochar (N1) and rice husk applications (N2).

Keywords: abiotic stress, biochar, chili pepper, waterlogging

INTRODUCTION

Suboptimal land refers to land naturally characterized by low productivity due to internal factors such as soil and parent materials, or external factors like extreme climate (Lakitan et al., 2018). This also includes degraded land resulting from unwise exploitation. In Indonesia, the estimated area of suboptimal land encompasses 121.1 million hectares of dry land and 33.4 million hectares of wetland, which includes riparian wetland/ lowland swamp land and tidal land spread across Sumatra, Kalimantan, and Irian Jaya (Alwi et al., 2017).

The potential of riparian wetlands in South Sumatra is approximately 2.28 million hectares, constituting 27% of the area of South Sumatra. However, only 368 thousand hectares of the riparian wetland has been utilized for cultivation, leaving around 2.60 million hectares of unused lowland swamp area in South Sumatra. Recent agricultural development has resulted in suboptimal land use, such as converting swampy land to replace fertile land for non-agricultural purposes (Prabowo et al., 2020).

Developing lowland swamp land for agriculture requires land and water management technology, as well as appropriate cultivation methods to achieve optimal results. Adequate socio-economic conditions of the community, institutions, and infrastructure are also essential. The riparian wetland is flooded during certain periods, influenced by rainwater and floods from upstream rivers and underground sources (Siaga et al., 2019a). Based on the height and duration of standing water, swamp land is divided into three categories: shallow basin, middle basin, and deep basin (Effendi et al., 2014).

The lowland swamp land's productivity and intensity still fall below their potential, typically allowing only one harvest per year due to two main issues: puddles in the rainy season and unpredictable puddle heights, as well as drought during the dry season. Riparian wetland holds significant potential for agricultural development, including the ability to cultivate crops year-round, even during the dry season. Considering the agro-hydrological conditions, riparian wetland offers opportunities for cultivating horticultural commodities, particularly high-value chili plants by employing suitable technological innovations tailored to the land's conditions, such floating culture during flooding period (Siaga et al., 2018; 2019a). Therefore, cultivating chili on riparian wetlands is feasible (Simatupang & Rina, 2019).

Planting chili plants in areas with standing water is risky as they cannot tolerate continuous waterlogging. Excessive water stagnation in swampy areas can lead to leaf loss and root disease. The presence of root factors can significantly impact plant growth. It is important to provide appropriate and optimal water to ensure good plant growth and achieve maximum agricultural production results (Kumala, 2020).

Efforts to cultivate chili plants in waterlogged conditions should focus on using appropriate cultivation techniques to optimize plant growth. Adding organic matter can improve soil properties and provide essential nutrients. Biochar is commonly used to improve soil, and increase main cations, phosphorus, total N, and CEC, ultimately leading to higher yields (Justang et al., 2021).

Previous studies have shown the positive impact of biochar on soil and plants in optimal conditions, but its effect on plant survival in flooded conditions is not well-documented. Research on the impact of biochar application on the morphological characteristics of chili plants (*Capsicum annuum* L.) in the vegetative phase under waterlogging stress conditions is therefore important. The purpose of this research was to assess the impact of biochar application on the growth of chili peppers (*Capsicum annuum* L.) during the vegetative stage under waterlogging conditions.

MATERIALS AND METHODS

Location and Materials

This research was conducted at the experimental land of the Agrotechnology Department, Faculty of Plant and Animal Sciences, Universitas Bina Insan, Lubuklinggau from January to February 2023. The equipment used included tubs/containers (measuring 100 cm x 50 cm), seedling trays, meters, rulers, cameras, analytical scales, and ovens. The materials used in this research comprised polybags, topsoil, rice husks, cow manure, rice husk biochar, coconut shell biochar (powdered), hot variety chili seeds, NPK fertilizer (16:16:16), foliar fertilizer (*Gandasil D*), fungicides (*Decoprima and Dithane*), bactericide (*Agrept*), and insecticide (*Furadan*).

Research Method

This study utilized a factorial completely randomized design (CRD) with 2 (two) factors. The first factor was waterlogging stress (P) consisting of control (P0) and waterlogging stress (P1). The second factor was biochar application (N) consisting of without biochar (N0), rice husk biochar (B1), and coconut shell biochar (N2). There were 6 treatment combinations created, each combination repeated 3 times with 5 plants in each repetition, resulting in 90 plant units.

Waterlogging treatment lasted for 3 days, starting 3 weeks after transplanting, followed by a 7-day recovery period. The water level was maintained at 0.5 cm above the ground surface (by increasing the decreased water due to evaporation and removing the excessive water due to rain).

Data Analysis

Data was analyzed using the SAS System 9 For Windows application, and significant differences were further tested using the LSD (least significant difference) at α= 5% significance level.

RESULTS

Impact of waterlogging conditions and biochar application on the growth characteristics of chili plants

The ANOVA analysis results for the impact of waterlogging conditions and biochar application on the growth characteristics of chili plants in the vegetative phase are presented in Table 1. Shoot length, root length, number of leaves, and total dry weight of chili plants displayed significant differences under waterlogging conditions (W) and biochar application (B). Meanwhile, the interaction of waterlogging stress treatment and biochar application (WxN) gave an effect that was not significantly different from the parameters of Shoot length and root length (Table 1).

Shoot length, root length, number of leaves, and total dry weight of chili pepper plants under waterlogging and biochar application

Based on the results of further tests, it was found that waterlogging stress conditions (W) showed significantly different effect on the parameters of shoot length, number of leaves and dry weight of plants but were not significantly different from the parameters of root length. Biochar application treatment gave significantly different effect between the control treatment (N0), rice husk biochar (N1), and coconut shell biochar (N2), but not significantly different between rice husk biochar treatment (N1) and coconut shell biochar (N2) on all variables observed. The treatment without biochar application showed significantly higher shoot length, root length, number of leaves, and dry weight of chili plants compared to the biochar treatment (Table 2).

Tabel 1. Results of analysis of variance (ANOVA) recapitulation

	Source of Variation		
	Waterlogging (W)	Biochar (N)	W X N
Shoot length (cm)	**	**	ns
Root Length (cm)	*	**	ns
Number of Leaves	**	**	**
Total Dry Weight (g)	**	**	*

Note: **= significantly different (α = 0.01) ; *= significantly different (α = 0.05); ns = no significantly different

Tabel 2. Shoot length, root length, number of leaves, and total dry weight of chili pepper plants under waterlogging and biochar application

Treatments	Shoot Length (cm)	Root Length (cm)	Number of Leaves	Total Dry Weight (g)
Waterlogging (W)				
Control (W0)	20.61_a	20.22_a	41.55_a	2.56_a
Waterlogging (W1)	13.77_b	16.61_a	15.22_b	0.74_b
Biochar (N)				
Control (N0)	22.33_a	23.16_a	47.66_a	3.08_a
Rice Husk Biochar (N1)	16.33_b	16.66_b	21.00_b	1.10_b
Coconut Shell Biochar (N3)	12.91_b	15.41_b	16.50_b	0.78_b

Note: B0= Control; B1= Rice Husk Biochar, B2= Coconut Shell Biochar. Means followed by the same letter in the same column indicate that they are not significantly different based on LSD at the α = 5% level

Comparison root length, shoot length and number of leaves of chili pepper between control and waterlogging in biochar application

Figure 1A showed that root length without biochar application (N0), there is a significant difference between control conditions (morning and evening watering) and waterlogging conditions with an average of 27.33 cm and 17.33 cm, but chili plants applied with rice husk biochar (N1) and coconut shell biochar (N2) can survive in waterlogging conditions, this is evidenced by the fact that there are results that are not significantly different between control conditions and waterlogging conditions. The root length in the rice husk biochar treatment in control and waterlogging conditions is 20.33 cm and 11.33 cm and in the coconut shell biochar treatment in control and waterlogging conditions with an average of 14.16 cm and 11.66 cm..

In the parameter of shoot length treatment without biochar application (N0) there is a very significant difference between control conditions and waterlogging conditions with the highest average of 27.66 cm in control conditions and 18.66 in waterlogging conditions. The treatment of rice husk biochar (N1) obtained results that were not significantly different with the highest average of 17.66 cm in control conditions and waterlogging conditions obtained an average of 15.66 cm. In the treatment of coconut shell biochar (N2) there is an unreal difference between the control and waterlogging treatments with the highest average in waterlogging conditions which is 15.50 cm compared to the control condition of 15.33 cm (Figure 1.B).

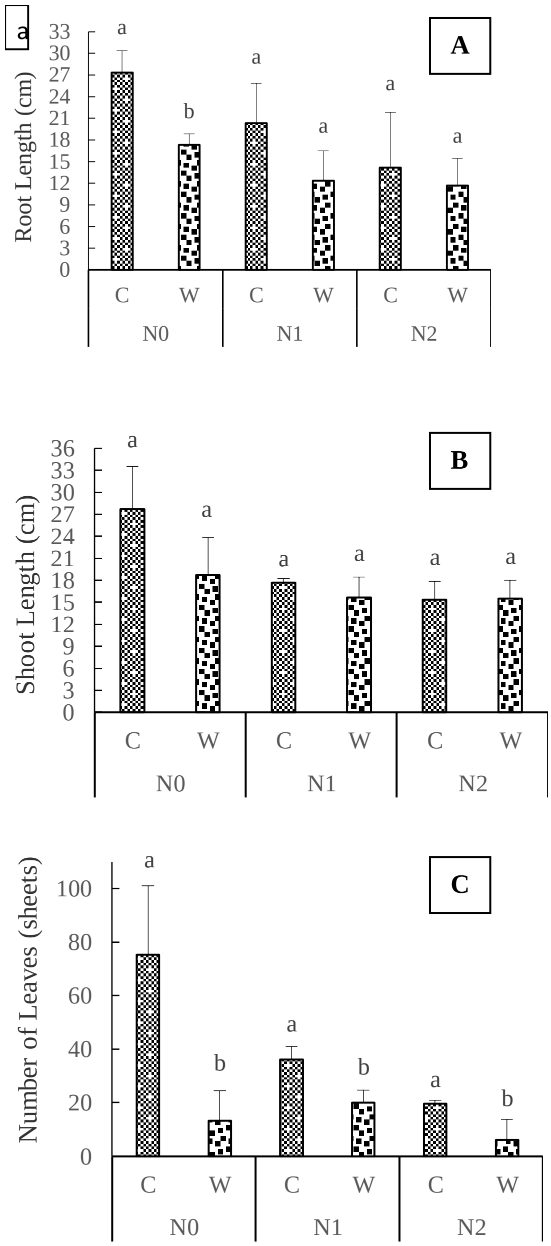

Figure 1. Root length, shoot length and number of leaves of chili Pepper under Control (C) and Waterlogging (W) after recovery. N0= Control; N1= Rice Husk Biochar, N2= Coconut Shell Biochar. Means followed by the same letter in the same diagram in each B treatment indicate that they are not significantly different based on LSD at the α = 5% level.

Based on Figure 1.C on the parameter of the number of leaves of all treatments there was a very significant difference between the control and waterlogging conditions. Treatment without biochar application (N0) there was a very significant difference between the control and waterlogging conditions with an average difference of 62.00 strands.

In the treatment of rice husk biochar (N1) there was a difference of 16.00 strands between the control treatment and waterlogging. In the treatment of coconut shell biochar (N2) the average in control conditions with waterlogging conditions had a difference of 13.66 strands.

Comparison Leaf area of chili pepper between control and waterlogging in biochar application

In Figure 2, the B1 control treatment continued to increase from the 0th day of observation to the last day of observation, the N2 control treatment experienced a decrease in leaf area on the 1st day of observation and then increased to the last day of observation. In the submerged N1 treatment, the leaf area decreased on the 2nd day of observation and then increased on the 3rd day, the submerged N2 treatment decreased from the 1st day of observation to the last day of observation.

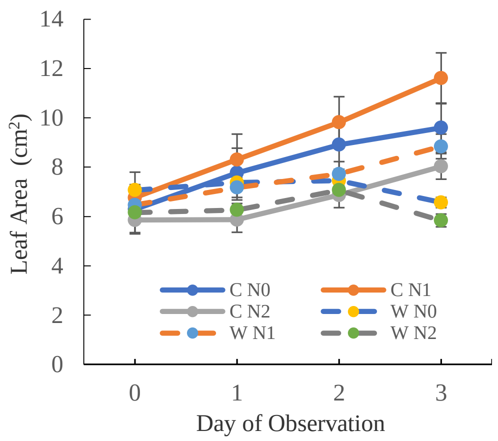

Figure 2. Comparison of Leaf Area of Chili Pepper under Control (C) and Waterlogging (W) after recovery. N0= Control; N1= Rice Husk Biochar, N2= Coconut Shell Biochar. Means followed by the same letter in the same diagram in each B treatment indicate that they are not significantly different based on LSD at the α = 5% level.

Based on the results of observations on the parameters of plant dry weight, treatment without biochar (N0) gave a significantly different effect between the control and waterlogging treatments with an average control of 5.23 g and waterlogging 0.93 g.

The dry weight of the plants in the N1 condition was significantly different from the control condition. The treatment of rice husk biochar (N1) obtained results that were not significantly different with the highest average of 1.33 g in control conditions and in waterlogging conditions obtained an average of 0.86 g. In the treatment of rice husk biochar (N1), the highest average of 1.33 g was obtained in control conditions. In the coconut shell biochar treatment (N2) the highest average was also found in the control condition with an average of 1.13 g compared to the waterlogging condition of 0.42 g (Figure 3).

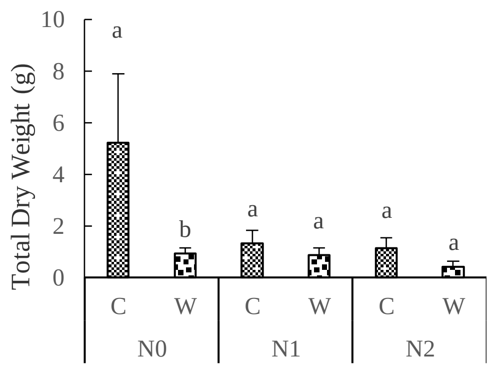

Figure 3. Total Dry Weight of Chili Pepper under Control (C) and Waterlogging (W) after recovery. N0= Control; N1= Rice Husk Biochar, N2= Coconut Shell Biochar. Means followed by the same letter in the same diagram in each B treatment indicate that they are not significantly different based on LSD at the α = 5% level.

Comparison dry weight of chili pepper between control and waterlogging in biochar application

The dry weight of the roots of chili plants in the treatment without biochar (N0) and coconut shell biochar treatment in control and waterlogging conditions obtained very significantly different results with an average difference in the treatment without biochar (N0) of 1.06g and the treatment of coconut shell biochar (N2) by 0.14g, while in the treatment of rice husk biochar (N1) in control and waterlogging conditions obtained results that were not significantly different (Table 3). Shoot dry weight without biochar application (N0) in control and waterlogging conditions displayed very significantly different results, while the treatment of rice husk biochar (N1) and coconut shell biochar (N2) in control and waterlogging conditions with results that are not significantly different.

Furthermore, leaves dry weight showed that the dry weight of chili plant leaves in the treatment without biochar (N0) and coconut shell biochar (N2) obtained results that were significantly different in control and waterlogging conditions, while the rice husk biochar treatment (N1) showed results that were not significantly different in control and waterlogging conditions (Table 3).

Table 3. Comparison of root, stem and leaves dry weight of chili pepper plants among control and waterlogging in each biochar application

Treatments		Dry Weight (g)		
		Root	Stem	Leaves
N0	C	1.233 a	1.400 a	2.600 a
	W	0.167 b	0.433 b	0.500 b
N1	C	0.200 a	0.367 a	0.767 a
	W	0.200 a	0.333 a	0.333 b
N2	C	0.233 a	0.367 a	0.533 a
	W	0.087 b	0.233 a	0.107 b

Note. N0= Control; N1= Rice Husk Biochar, N2= Coconut Shell Biochar; C= control; W= waterlogging. Means followed by the same letter in the same column in each N treatment indicate that they are not significantly different based on LSD at the α = 5% level.

The interesting in this study is that under waterlogging conditions the rice husk charcoal biochar treatment (N1) has higher growth than the treatment without biochar (N0) and the coconut shell biochar treatment (N1) for several parameters such as the number of leaves (Figure 1.C), leaf area (Figure 2) and root dry weight (Table 3).

DISCUSSION

Susilawati et al. (2012) research revealed that flooding of chili plant roots led to tissue damage, rotting, and hindered water and nutrient absorption due to lack of oxygen and low energy production. Zainul et al. (2022) found that soil water levels of 70-130% inhibited cayenne pepper plant growth, decreased oxygen concentration, and caused hypoxia, disrupting osmotic pressure, nutrient transport, and photosynthesis. Waterlogging at full WSR reduced root length and biomass due to anoxia or hypoxia, inhibiting root growth and energy production (Siaga et al., 2023). Waterlogging stress negatively impacted soil aeration, root respiration, and aerobic microbial activity, disrupting nutrient absorption and causing leaf yellowing (Kumala, 2020). Under waterlogging stress, the number of plant leaves decreased due to environmental and internal factors (Siaga et al, 2019b).

The decrease in leaf area is suspected to be due to plant stress from waterlogging, causing wilting and leaf shedding in chili plants. Meihana et al. (2022) research indicates that shallow groundwater at 3 cm below the base surface and waterlogging dampens the relative leaf expansion rate. Plants located at a groundwater depth of 3 cm below the surface have a lower leaf expansion rate compared to the control. This suggests that hypoxia stress significantly affects plant leaves. Leaves are the most sensitive plant organs to hypoxia stress. Hypoxia conditions force plants to undergo morphological changes, such as reduced leaf spread rate and decreased leaf area (Aldana et al., 2014; Meihana et al., 2023b). According to Siaga et al. (2019b) study, the total leaf area significantly decreases due to old leaves shedding, but the fallen leaves are replaced by new shoots.

The reduction in leaf area due to waterlogging leads to a decrease in the photosynthesis rate in plants and impacts the growth of plant vegetative organs. This can be observed in the morphological changes in plants such as plant height, root length, and decreased plant dry weight (Barickman et al., 2019; Tian et al., 2021; Huang et al., 2022).

Based on research results, the application of biochar under control conditions (morning and evening watering) and waterlogging stress conditions shows no significant difference (Figure 1). Biochar application to the soil causes the soil to become loose and crumbly. If the soil is waterlogged, it causes plant roots to not be bound to the soil so that the roots decay faster. Unlike the soil that is not given biochar if experiencing waterlogging, the roots of the plant are still bound to the soil so that the roots are relatively more durable. Nurida et al. (2017) research proves that the application of rice husk biochar can increase the organic C content, followed by an increase in the total pore space percentage in the soil. Rice husk biochar has the highest ability to provide K at around 0.90%, as well as providing the highest Cation Exchange Capacity (CEC) value of 29.27 me/100 g. The soil's organic C content increases from 0.90% to 1.02% - 1.07% after the application of rice husk and coconut shell biochar as soil amendments.

This research indicates that the application of rice husk biochar results in the highest leaf count, the largest leaf area, and the highest dry root weight. This suggests that during the recovery period, the application of rice husk biochar can enhance the media's ability to retain water, significantly influencing leaf expansion rates and ensuring smooth nutrient absorption by plant roots (Meihana et al., 2023a).

According to the Agricultural Research and Development Agency (2013), rice husk biochar has a high cation exchange capacity, allowing it to bind cations in the soil, which can be utilized for plant growth. Herman and Resigia (2018) reports that apart from improving soil chemistry, one of the functions of biochar is its ability to enhance fertilization by locking in nutrients when they are in excess and releasing them when the plant is under stress. Slow-release nutrients require micronutrients and nutrients to prevent deficiencies.

Based on Ndruru et al. (2018) research findings, the application of rice husk biochar resulted in the highest average plant height compared to other treatments. Biochar can enhance nutrient availability for plants, improve plant metabolism and physiology, and promote plant growth, including maximum plant count and productivity. The application of biochar can increase the uptake of N nutrients in the soil by rice plants. The combination of rice husk biochar with inorganic fertilizers resulted in the highest total N soil uptake at 0.33%.

CONCLUSION

The research results indicate that the use of two types of biochar affects shoot length, root length, number of leaves, leaf area, and dry weight of chili plants under waterlogging stress. There was a significant difference between the treatment without biochar and the two biochar application treatments in both control and waterlogging conditions. The use of rice husk biochar shows potential for growing chili plants in waterlogged conditions.

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