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Phenotypic Performance of Pakisan Bird's Eye Chili Landrace (*Capsicum frutescens* L.) under Various Application Rates of Soil Amendments

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ABSTRACT

Pakisan bird's eye chili is a local landrace whose phenotypic performance requires improvement, particularly through the application of soil amendments such as biochar and animal manure. This study aimed to evaluate the phenotypic performance of the Pakisan landrace under various application rates of soil amendments. The experiment was conducted at the Experimental Field of the Faculty of Agriculture and Engineering, Panji Sakti University, Singaraja. The experiment was designed by Randomized Complete Block Design (RCBD) with two factors. The first factor was the application rate of cashew nut shell biochar (CNSB) at four levels (0, 10, 20, and 30 t ha^{-1}). The second factor was the application rate of goat manure compost (GMC) at three levels (0, 10, and 20 t ha^{-1}). Plant phenotypic parameters, including plant height, leaf number, leaf area, root length, root fresh weight, shoot fresh weight, total plant fresh weight, root dry weight, shoot dry weight, total plant dry weight, and fruit yield per plant, were observed. The results indicated that increasing the CNSB rate up to 30 t ha^{-1} consistently enhanced the fruit yield per plant. Each additional 10 t ha^{-1} of CNSB increased the fruit yield by 6.71 g $plant^{-1}$. Similarly, increasing the GMC rate up to 20 t ha^{1} led to a higher fruit yield, with each 10 t ha^{-1} increment increasing the yield by 7.58 g $plant^{-1}$. The interaction between CNSB and GMC application rates significantly influenced fruit yield per plant ($P < 0.01$). The combination of 30 t ha^{-1} CNSB and 10 t ha^{-1} GMC produced the highest fruit yield per plant at the first harvest, reaching 84.00 g $plant^{-1}$. Consequently, the application of cashew nut shell biochar and goat manure compost, both individually and in combination, effectively enhances the phenotypic performance of the Pakisan bird's eye chili landrace.

Keywords: *application rate, bird's eye chili, performance, phenotype, soil amendment*

INTRODUCTION

Chili, particularly bird's eye chili (*Capsicum frutescens* L.) is recognized as one of the nine essential staple commodities with high demand in Bali, thereby significantly impacting regional inflation. Nevertheless, the marketing of bird's eye chili adheres to an open market system, where prices typically decrease during production surpluses and rise when production levels drop or market availability becomes constrained.

The population of Bali Province cumulatively requires bird’s eye chili at an average rate of 23.14 t day^{-1}or approximately 8,446.1 t year^{-1}. From the production perspective, based on data from BPS Bali Province (2022), the province is currently only able to produce between 2,052.3 and 3,533.13 t year^{-1}, resulting in a substantial supply deficit of 4,912.97 to 6,393.8 t year^{-1}. The low production of bird’s eye chili in Bali is attributed to various factors, such as weather conditions, pest and disease infestations, and declining soil fertility (Muliantari, 2023). Consequently, various efforts must be undertaken to enhance chili yields. One such strategy is the development of local bird’s eye chili cultivars (landraces) found in Bali. According to Demirboga et al. (2024), Kirana et al. (2025), and Ramadhani et al. (2025), local cultivars are generally more adaptive to their environment, thereby enabling them to maintain sustainable productivity.

Pakisan chili is one of the local bird’s eye chili cultivars found in Bali. Cultivated by farmers in Pakisan Village, this landrace is characterized by fruits that are longer than those of other bird’s eye chilies, measuring 10 - 12 cm, and thicker fruit flesh which contributes to a longer shelf life. Ready-to-harvest Pakisan chili exhibits a vibrant and more striking color compared to other varieties. However, Pakisan chili currently only achieves optimal production when developed in its area of origin in Pakisan Village (Dina, 2017).

Pakisan bird’s eye chili remains relatively unknown to the general public, as its cultivation is largely confined to its area of origin. Efforts to expand the planting area have been initiated by the Buleleng District Agriculture Office through Good Agriculture Practice (GAP) field schools in several farmer groups outside Pakisan Village; however, the results have only reached an average of 60% of the yield potential. Therefore, studies on the application of appropriate technologies must be continuously conducted to improve the performance of Pakisan chili.

The application of organic materials and soil amendments such as biochar, either applied alone or in combination with animal manure, may enhance the availability of nutrients and positively influence the soil’s physical, chemical, and biological conditions. Therefore, it represents a sustainable soil management strategy to increase the productivity of horticultural crops in tropical marginal soils (Nabila et al., 2026; Safitri et al., 2018). Biochar is a carbon-rich material produced from the thermal decomposition of organic waste under limited oxygen conditions (pyrolysis). It exhibits high resistance to mineralization and decomposition due to the presence of stable carbon compounds (Bawamenemi et al., 2025; Evizal & Pramastiwi, 2023). Biochar functions to enhance nutrient retention over extended periods, improve soil fertility, and increase water availability for plant uptake by up to 61.9%. In addition, it enhances phosphorus and nitrogen uptake by plant roots, promotes increases in shoot dry weight and root-to-shoot ratio, and can be utilized as a coating material for slow-release fertilizers (Karimah et al., 2024; Safitri et al., 2018; Sarwono, 2016; Supriyadi et al., 2025).

Cashew nutshells are a by-product of cashew nut processing that have traditionally been underutilized, commonly used as a substitute for firewood, in roof tile industries, or simply discarded, leading to undesirable waste accumulation. This issue is primarily attributed to the recalcitrant nature of cashew nutshells, which makes them resistant to decomposition. To enhance their value, cashew nutshell waste can be converted into biochar; however, its effectiveness as a soil amendment requires further evaluation.

The application rates of biochar in bird’s eye chili cultivation vary considerably. Safitri et al. (2018) reported that the biochar application at rate of 0.77 g mm^{-1} improved soil physical, chemical, and biological properties, enhanced plant growth and yield, and increased water use efficiency. However, the optimal application rates of cashew nut shell biochar and goat manure compost, particularly their interactive effects for Pakisan bird's eye chili cultivation, remain unclear and have not yet been established.

Organic fertilizers are derived from agricultural residues, including plant biomass (e.g., leaf litter) and animal waste. One important source of organic fertilizer is goat manure compost. Goat manure compost contains essential nutrients required for plant growth, such as nitrogen (N), phosphorus (P), and potassium (K). Its application has been shown to improve soil fertility, enhance the growth of bird's eye chili, and help maintain soil ecosystem balance while reducing reliance on synthetic fertilizers. This is attributed to its relatively high organic C/N ratio (27.49%), as well as its nutrient content, including 1.21% N, 0.14 mg 100 g^{-1} P, and 0.92 cmol kg^{-1} K, making it suitable for improving the growth and yield of bird's eye chili (Kahar, 2019).

This study aimed to determine the optimal application rates of cashew nut shell biochar (CNSB) and goat manure compost, as well as their combined effects, on the phenotypic performance of Pakisan bird's eye chili.

MATERIALS AND METHODS

The experiment was conducted at the Experimental Farm of the Faculty of Agriculture and Engineering, Universitas Panji Sakti, located at Jl. Bisma No. 22, Banjar Tegal, Singaraja, Bali, at an altitude of approximately 39 m above sea level, from March to June 2024.

The equipment used in this study included a hoe, watering can, buckets, digital caliper, knife, digital balance, camera, measuring tape, and writing materials. The experimental materials comprised Pakisan bird's eye chili seedlings, cashew nut shell derived biochar, goat manure compost, compound fertilizers (NPK Phonska and NPK Mutiara), pesticides, polybags, and labeling boards.

The experiment was arranged in a factorial Randomized Complete Block Design (RCBD) with two factors. The first factor consisted of four application rates of cashew nut shell biochar (B): 0 t ha^{-1} (B_0), 10 t ha^{-1} (B_1), 20 t ha^{-1} (B_2), and 30 t ha^{-1} (B_3). The second factor consisted of three application rates of goat manure compost (K): 0 t ha^{-1} (K_0), 10 t ha^{-1} (K_1), and 20 t ha^{-1} (K_2). The treatments were arranged in all possible combinations, resulting in 12 treatment combinations. Each treatment was replicated three times, for a total of 36 experimental units.

Phenotypic performance parameters observed in this study included plant height, stem base diameter, number of leaves per plant, leaf area, number of primary branches, number of secondary branches, root length, root fresh weight, shoot fresh weight, total plant fresh weight, root dry weight, shoot dry weight, total plant dry weight, and fruit weight at first harvest only. The observed data were subjected to analysis of variance (ANOVA). When treatment effects were found to be significant ($P < 0.05$ or $P < 0.01$) mean separation was performed using Duncan's Multiple Range Test (DMRT) at the 5% significance level. In addition, regression analysis was conducted to evaluate the relationship between the application rates of soil amendments and fruit weight per plant.

RESULTS AND DISCUSSION

The application of cashew nut shell biochar and goat manure compost significantly influenced the phenotypic traits of Pakisan bird's eye chili. Cashew nut shell biochar promoted early vegetative vigor, significantly affecting plant height (at 14 and 21 dat), leaf area (at 14 dat), and stem diameter. Conversely, goat manure compost showed stronger delayed effects on plant structural development and yield components, particularly leaf number (at 35 dat), total dry biomass, and fruit weight. Notably, a highly significant interaction ($P < 0.01$) was detected for fruit weight per plant, indicating a clear synergistic effect between biochar application and organic fertilization.

Plant Height

The results of Duncan's Multiple Range Test (DMRT) indicated that the application of cashew nut shell biochar at 20 t ha^{-1} (B_2) resulted in the highest plant height at 14 days after transplanting (12.08 cm), which was significantly different from the application rates of 10 t ha^{-1} (10.58 cm) and 30 t ha^{-1} (11.24 cm). Similarly, at 21 days after transplanting, the application of 20 t ha^{-1} (B_2) produced the highest plant height (14.63 cm), which was significantly higher than that observed at 10 t ha^{-1} (12.55 cm) and 30 t ha^{-1} (13.86 cm) (Table 1).

The application of biochar did not consistently result in a significant increase in plant height, which may be attributed to the fact that biochar does not directly supply nutrients to plants. Instead, biochar functions by retaining and enhancing the availability of nutrients in the soil. This is consistent with the findings of Elviwirda (2020), who reported that biochar cannot be classified as an organic fertilizer since it does not directly contribute nutrients; however, its high cation exchange capacity (CEC) enables it to adsorb soil cations and retain added nutrients, thereby making them more available for plant uptake. This was further supported by the plant height observations, which indicated that cashew nut shell biochar exhibited an optimal threshold at an application rate of 20 t ha^{-1} (B_2) in promoting stem elongation during the early vegetative stage.

Interestingly, the application of biochar at a lower rate (10 t ha^{-1}), B_1 resulted in more inhibited plant growth compared to the control (B_0). This phenomenon is most likely associated with transient nitrogen immobilization, whereby biochar with a high C/N ratio, particularly at limited application rates, tends to adsorb nitrogen from the soil solution to support microbial activity, thereby creating nutrient competition for plants during the early growth stage (Jelita et al., 2026; Zhang and Shen, 2022).

In contrast, goat manure compost application showed no significant effect on plant height across all observation periods (14 - 35 days after transplanting). The absence of an immediate vertical growth response reflects the slow-release characteristics of goat manure compost, in which the mineralization of nitrogen and phosphorus requires a longer period before becoming available to plants compared to conventional inorganic fertilizers (Nugroho et al., 2022).

This lack of significance also suggests that the primary contribution of goat manure compost in this system lies not in accelerating stem elongation, but rather in enhancing plant structural development and fruit productivity during subsequent growth stages.

Leaf Number

The results of Duncan's Multiple Range Test (DMRT) indicated that the application of cashew nut shell biochar at 30 t ha^{-1} (B_3) produced the highest number of leaves at 21 days after transplanting (5.30 leaves), which was significantly different from the application rate of 10 t ha^{-1} (B_1) (4.44 leaves). Similarly, the application of goat manure compost at 20 t ha^{-1} (K_2) resulted in the highest leaf number at 21 days after transplanting (5.39 leaves), which was significantly different from 0 t ha^{-1} (K_0) (4.58 leaves) and 10 t ha^{-1} (K_1) (4.83 leaves).

Furthermore, the application of goat manure compost at 20 t ha^{-1} continued to produce the highest number of leaves at 35 days after transplanting (10.94 leaves), which was significantly higher than that observed at 10 t ha^{-1} (10.08 leaves) (Table 2).

Table 1. Effects of cashew nut shell biochar and goat manure compost application rates on plant height performance

Treatment	Plant Height (cm)			
	14 dat	21 dat	28 dat	35 dat
Biochar (B)				
B_0 (control)	11.94a	13.89ab	20.51	28.56
B_1 (10 t ha^{-1})	10.58b	12.55b	17.72	25.67
B_2 (20 t ha^{-1})	12.08a	14.63a	20.93	29.44
B_3 (30 t ha^{-1})	11.24ab	13.86ab	19.80	28.55
DMRT 5%	**1.02**	**1.45**	**ns**	**ns**
Compost (K)				
K_0 (control)	11.28	13.24	19.04	26.55
K_1 (10 t ha^{-1})	11.23	13.53	19.91	28.45
K_2 (20 t ha^{-1})	11.87	14.43	20.27	29.17
DMRT 5%	**ns**	**ns**	**ns**	**ns**

Note: Values marked with the same letter within a column do not differ significantly based on Duncan's Multiple Range Test (DMRT) at the 5% significance level. "ns" indicates non-significant effects

Table 2. Effects of cashew nut shell biochar and goat manure compost application rates on the number of leaves per plant

Treatment	Leaf Number (leaves)			
	14 dat	21 dat	28 dat	35 dat
Biochar (B)				
B_0 (control)	3.78	4.81ab	6.44	9.63
B_1 (10 t ha^{-1})	3.07	4.44b	6.78	9.52
B_2 (20 t ha^{-1})	3.59	5.19a	6.96	11.19
B_3 (30 t ha^{-1})	3.44	5.30a	7.48	10.22
DMRT 5%	**ns**	**0.53**	**ns**	**ns**
Compost (K)				
K_0 (control)	3.33	4.58b	6.58	9.39b
K_1 (10 t ha^{-1})	3.50	4.83b	6.94	10.08ab
K_2 (20 t ha^{-1})	3.58	5.39a	7.22	10.94a
DMRT 5%	**ns**	**0.45**	**ns**	**1.28**

Note: Values marked with the same letter within a column do not differ significantly based on Duncan's Multiple Range Test (DMRT) at 5% significance level. "ns" indicates non-significant effects

Based on the statistical analysis, biochar application had a significant effect on leaf number at 21 days after transplanting. This response may indicate that a greater volume of biochar creates a more stable root-zone environment by maintaining soil moisture and aeration, which directly stimulates leaf primordia initiation. The increase in soil specific surface area due to the porous structure of biochar enhances water retention capacity, thereby maintaining cell turgor to support cell division in the apical meristem (Safitri et al., 2018).

The vital role of goat manure compost became more evident in the leaf number parameter, where the application rate of 20 t ha^{-1} (K_2) produced the highest number of leaves, with significant differences observed at 21 days after transplanting (5.39 leaves) and sustained up to 35 days after transplanting (10.94 leaves). This significance suggests that, upon entering the active vegetative phase, the decomposition process of goat manure compost reaches a stage at which the release of nutrients particularly nitrogen (N), which is abundant in goat manure compost becomes synchronized with plant demand. The effectiveness of the K_2 treatment in maintaining a higher leaf number up to 35 days after transplanting represents an important physiological advantage for Pakisan bird's eye chili, providing sufficient assimilate reserves to support the transition into the generative phase (Kahar, 2019).

Leaf Area

The results of Duncan's Multiple Range Test (DMRT) showed that the application of cashew nut shell biochar had a significant effect on the leaf area of Pakisan bird's eye chili at the early observation stage (14 days after transplanting), but this effect became non-significant at 21, 28, and 35 days after transplanting (Table 3). At 14 days after transplanting, the highest leaf area was recorded under the B_3 treatment (30 t ha^{-1}), with a mean value of 7.46 cm^2, which was statistically comparable to the control (B_0; 7.30 cm^2) and the B_2 treatment (20 t ha^{-1}; 7.26 cm^2). In contrast, the lowest leaf area was observed under the B_1 treatment (10 t ha^{-1}), with a value of 5.45 cm^2, which was significantly lower than those of the other treatments (Table 3).

Table 3. Effects of cashew nut shell biochar and goat manure compost application rates on leaf area per plant

Treatment	Leaf Area (cm^2)			
	14 dat	21 dat	28 dat	35 dat
Biochar (B)				
B_0 (control)	7.30 a	14.59	17.57	36.31
B_1 (10 t ha^{-1})	5.45 b	11.64	19.81	36.12
B_2 (20 t ha^{-1})	7.26 a	15.20	19.52	38.05
B_3 (30 t ha^{-1})	7.46 a	15.15	24.25	42.93
DMRT 5%	**1.65**	**ns**	**ns**	**ns**
Compost (K)				
K_0 (control)	6.05	12.86	19.56	34.85
K_1 (10 t ha^{-1})	7.08	14.56	21.40	40.62
K_2 (20 t ha^{-1})	7.47	15.01	19.90	39.59
DMRT 5%	**ns**	**ns**	**ns**	**ns**

Note: Values marked with the same letter within a column do not differ significantly based on Duncan's Multiple Range Test (DMRT) at the 5% significance level. "ns" indicates non-significant effects

These findings suggest that cashew nut shell biochar does not function as a continuous primary nutrient source, but rather acts as a soil amendment that retains and conserves nutrients supplied from goat manure compost application. The inherent properties of biochar, including its high specific surface area and nutrient retention capacity, enable the adsorption of nutrient ions and reduce leaching losses, thereby maintaining their availability for plant uptake over a longer period in the soil (Lehmann and Joseph, 2015). The application of goat manure compost did not exhibit a significant effect on leaf area across all observation periods, from 14 to 35 days after transplanting. Likewise, no significant interaction was observed between the application rates of cashew nut shell biochar and goat manure compost on leaf area expansion throughout the experimental period.

Root Length, Root Fresh Weight, and Root Dry Weight

The analysis of variance (ANOVA) indicated that the application rates of cashew nut shell biochar (B), goat manure compost (K), and their interaction (B × K) had no significant effect on root length (Table 4). However, the results of Duncan's Multiple Range Test (DMRT) showed that the application of cashew nut shell biochar at 20 t ha^{-1} (B_2) resulted in the highest root fresh weight (24.17 g plant^{-1}), which was significantly higher than the control (13.89 g plant^{-1}).

The application of cashew nut shell biochar at 20 t ha^{-1} (B_2) also produced the highest root dry weight (3.85 g plant^{-1}), which was significantly higher than those observed at 10 t ha^{-1} (2.57 g plant^{-1}), 0 t ha^{-1} (2.44 g plant^{-1}), and 30 t ha^{-1} (2.81 g plant^{-1}) (Table 4).

Table 4. Effects of cashew nut shell biochar and goat manure compost application rates on root length, root fresh weight, and root dry weight

Treatment	Root Length (cm)	Root Fresh Weight (gram)	Root Dry Weight (gram)
Biochar (B)			
B_0 (control)	40.09	13.89b	2.44bc
B_1 (10 t ha^{-1})	37.04	18.61ab	2.57c
B_2 (20 t ha^{-1})	42.03	24.17a	3.85a
B_3 (30 t ha^{-1})	40.88	20.56ab	2.81bc
DMRT 5%	**ns**	**6.27**	**0.37**
Compost (K)			
K_0 (control)	37.01	16.25	2.53
K_1 (10 t ha^{-1})	41.40	21.04	3.01
K_2 (20 t ha^{-1})	41.62	20.63	3.20
DMRT 5%	**ns**	**ns**	**ns**

Note: Values marked with the same letter within a column do not differ significantly based on Duncan's Multiple Range Test (DMRT) at the 5% significance level. "ns" indicates non-significant effects

The significant increase in root fresh and dry weight following the application of cashew nut shell biochar at 20 t ha^{-1} (B_2) indicates a fundamental improvement in the root architecture of Pakisan bird's eye chili. Although root length did not show a statistically significant difference, the increase in root biomass suggests that biochar plays a greater role in stimulating lateral root branching and root hair density rather than elongation of the primary root. The porous structure of biochar creates an ideal microhabitat within the soil, which not only enhances aeration but also provides niches for the proliferation of mycorrhizal fungi and phosphate-solubilizing bacteria that synergistically interact with the root system (Lehmann and Joseph, 2015).

The optimal response observed at 20 t ha^{-1} (B_2), along with the decline in root biomass at a higher rate (30 t ha^{-1}, B_3), suggests the presence of a physical and chemical threshold in soil tolerance. The reduction in root dry weight at the B_3 level may be attributed to excessive alterations in soil pH or increased macroporosity, which can disrupt the stability of the root–soil interface. Furthermore, high biochar application rates, particularly under suboptimal moisture conditions, may induce temporary hydrophobicity, thereby limiting adequate hydration within the early root-zone environment (Edeh and Masek, 2021).

On the other hand, the absence of a significant effect of goat manure compost on root related parameters suggests that, at this growth stage, root development is more strongly governed by the physical structure of the growing medium (biochar effect) rather than by chemical nutrient availability (fertilizer effect). This observation is consistent with the nature of organic fertilizers, which require a longer mineralization period before nutrients become available for plant uptake. Nevertheless, the greater root biomass observed under the moderate biochar application rate provides a critical physiological foundation. A more structurally developed root system enhances the plant's capacity for nutrient uptake once nutrients from goat manure compost are fully released during the generative phase, ultimately contributing to increased fruit weight (Nabila et al., 2026).

Shoot Dry Weight and Total Plant Dry Weight

The analysis of variance (ANOVA) indicated that the application rate of cashew nut shell biochar (B) had no significant effect on shoot dry weight and total plant dry weight. In contrast, the application rate of goat manure compost (K) had a significant effect on both variables, with the highest values observed at 20 t ha^{-1} (K_2), resulting in a shoot dry weight of 22.21 g $plant^{-1}$ and a total plant dry weight of 25.42 g $plant^{-1}$. The lowest values were recorded under the control treatment (0 t ha^{-1}, K_0), with a shoot dry weight of 16.45 g $plant^{-1}$ and a total plant dry weight of 18.98 g $plant^{-1}$. Furthermore, the interaction between cashew nut shell biochar and goat manure compost (B × K) showed no significant effect on both parameters (Table 5).

The accumulation of shoot dry weight and total plant dry weight represents a fundamental indicator of the physiological efficiency of plants in converting light energy and nutrients into organic biomass. In this study, the dominant significant effect of goat manure compost compared to biochar on dry biomass production (Table 5) highlights that the availability of macronutrients (N, P, and K) is the primary limiting factor in the formation of structural tissues in Pakisan bird's eye chili. The increase in total plant dry weight under the K_2 treatment (25.42 g) indicates that nitrogen mineralization from goat manure compost had reached a sufficient level to support protein and chlorophyll biosynthesis, which is crucial for expanding the plant's metabolic sink capacity. This finding is consistent with Kahar (2019), who reported that a consistent supply of nutrients from organic manure directly enhances net assimilation rate and dry matter accumulation in chili plants.

The non-significant effect of biochar alone on shoot dry weight provides an important perspective on assimilate partitioning within the plant system. Although biochar was previously shown to significantly enhance root biomass, this improvement was not directly translated into a proportional increase in aboveground biomass. This phenomenon suggests that the role of biochar in this study is primarily associated with moderating the rhizosphere environment and strengthening root system development, whereas aboveground biomass accumulation remains largely dependent on the direct nutrient supply from goat manure compost mineralization. As described by Lehmann and Joseph (2015), the primary function of biochar is to enhance nutrient use efficiency through retention mechanisms; however, in the absence of sufficient external nutrient inputs, biochar alone is unable to meet the metabolic energy demands required for vigorous vegetative growth.

The absence of a significant interaction effect on dry biomass parameters indicates that both biochar and goat manure compost operate through different yet complementary mechanisms. The more robust root system resulting from biochar application has created a more efficient nutrient uptake pathway for nutrients gradually released from goat manure compost. This latent synergy, although not statistically evident in total dry weight, represents a critical precondition for Pakisan bird's eye chili before entering the reproductive phase, during which assimilate reserves in the shoot are mobilized to support fruit formation and filling (Nugroho et al., 2022).

Table 5. Effects of cashew nuts shell biochar and goat manure compost application rates on shoot dry weight and total plant dry weight

Treatment	Shoot Dry Weight (gram)	Total Plant Dry Weight (gram)
Biochar (B)		
B_0 (control)	17.27	19.71
B_1 (10 t ha^{-1})	18.74	21.31
B_2 (20 t ha^{-1})	23.19	27.04
B_3 (30 t ha^{-1})	19.74	22.54
DMRT 5%	**ns**	**ns**
Compost (K)		
K_0 (control)	16.45b	18.98b
K_1 (10 t ha^{-1})	20.55ab	23.57ab
K_2 (20 t ha^{-1})	22.21a	25.42a
DMRT 5%	**4,84**	**5,67**

Note: Values marked with the same letter within a column do not differ significantly based on Duncan's Multiple Range Test (DMRT) at the 5% significance level. "ns" indicates non-significant effects

Fruit Weight per Plant at First Harvest

The analysis of variance (ANOVA) indicated that both cashew nut shell biochar (B) and goat manure compost (K) had a highly significant effect on fruit weight per plant at first harvest ($P < 0.01$). A highly significant interaction effect between cashew nut shell biochar and goat manure compost was also observed for fruit yield. The interaction treatment B_3K_1 produced the highest fruit weight per plant, with a yield of 84 g plant^{-1}, whereas the lowest yield was obtained from the B_0K_1 interaction, which produced 29.67 g plant^{-1} in the first harvest (Table 6).

The highly significant interaction between cashew nut shell biochar and goat manure compost on fruit weight demonstrates a synergistic effect in optimizing the generative phase of Pakisan bird's eye chili. The superior performance of the B_3K_1 combination (84.00 g) compared to other treatments is attributed to the synchronization between macronutrient supply and the improvement of rhizosphere quality.

Based on the chemical analysis of cashew nut shell biochar conducted at the Soil Laboratory, Faculty of Agriculture, Udayana University (Table 7), the biochar exhibited low total nitrogen content (0.150%), very high organic carbon content (11.690%), and very high levels of phosphorus and potassium, with total P at 9,802.701 ppm and total K at 71.027 meq/100 g. These characteristics suggest that the application of biochar at 30 t ha^{-1} (B_3) functions as a reservoir for phosphorus and potassium, while also enhancing the retention of nitrogen supplied by goat manure compost (K_1). This finding is consistent with Sarbaina et al. (2021), who reported that the combined application of biochar and organic fertilizer significantly increases phosphorus availability to a very high level, which is a key element in flower and fruit formation.

Table 6. Interaction effects of cashew nut shell biochar and goat manure compost application rates on fruit weight per plant at first harvest (g plant^{-1})

Treatment			
cashew nut shell biochar	goat manure compost K_0 (control)	K_1 (10 t ha^{-1})	K_2 (20 t ha^{-1})
B_0 (control)	44.33 b A	29.67 a A	66.67 c B
B_1 (10 t ha^{-1})	41.33 a A	66.00 c C	51.00 b A
B_2 (20 t ha^{-1})	54.67 a B	53.00 a B	67.00 b B
B_3 (30 t ha^{-1})	51.00 a B	84.00 c D	67.33 b B
DMRT 5 %		5.01	

Note: Values marked lowercase letters indicate horizontal comparisons (manure effects), while the uppercase letters in parentheses indicate vertical comparisons (biochar effects). Means with the same letter do not differ significantly at the 5% level by DMRT.

Table 7. Chemical properties of cashew nutshell biochar

No	Variabel	Kandungan
1	pH	8.880
2	Moisture Content	5.600 %
3	C- Organik	11.690 %
4	N Total	0.150 %
5	P Total	9802.701 ppm
6	K Total	71.027 (meq/100g)

Note: Data obtained from laboratory analysis conducted at the Soil Science Laboratory, Faculty of Agriculture, Udayana University (2024).

The B_0K_1 treatment recorded the lowest fruit weight (29.67 g), confirming that in the absence of biochar, goat manure compost alone is unable to function optimally. Without a biochar matrix to retain nutrients, a substantial proportion of nutrients from the manure is likely lost through leaching or remains unavailable for efficient uptake due to a poorly developed root system. The nearly threefold increase in yield observed in the B_3K_1 treatment compared to B_0K_1 reinforces the concept proposed by Lehmann and Joseph (2015), that biochar is not merely a soil amendment but a catalyst capable of enhancing the efficiency of organic fertilization.

The regression analysis for fruit weight under cashew nut shell biochar application showed a linear response pattern. The regression results also revealed that each incremental increase of 10 t ha^{-1} biochar application was associated with an increase in fruit weight at first harvest of 6.71 g plant^{-1} (R^2= 0.984) (Figure 1).

The regression analysis for fruit weight at first harvest under goat manure compost application showed a linear response pattern. The regression curve also indicates that each incremental increase of 10 t ha^{-1} goat manure compost was associated with an increase in fruit weight of 7.58 g plant^{-1} (R^2=0.958) (Figure 2).

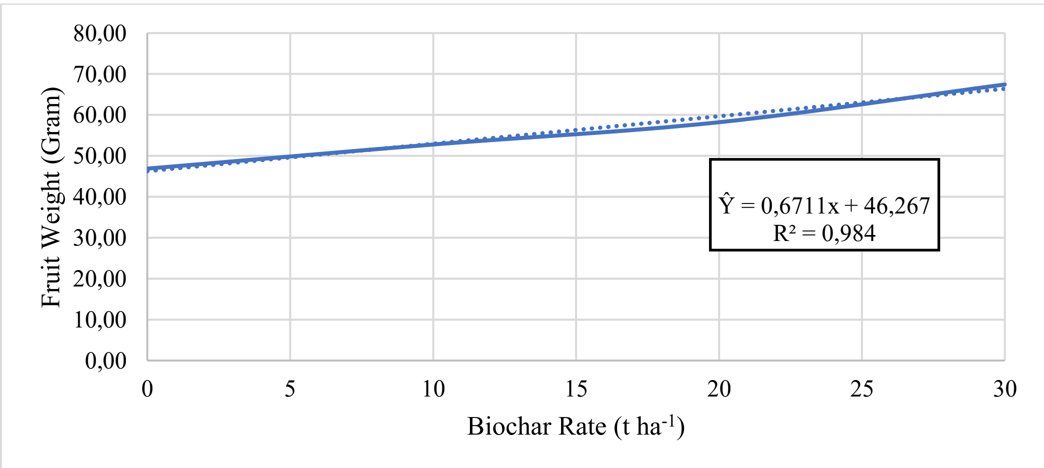

Figure 1. Relationship between cashew nut shell biochar application rates and fruit weight per plant at first harvest

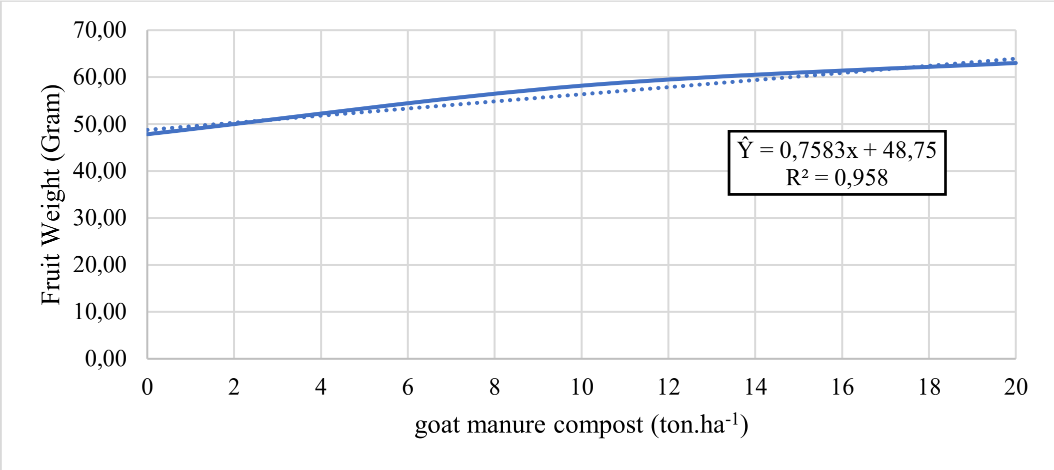

Figure 2. Relationship between goat manure compost application rates and fruit weight per plant at first harvest

CONCLUSION

The sole application of cashew nut shell biochar showed a positive linear correlation with plant productivity up to an application rate of 30 t ha^{-1}, where each incremental increase of 10 t ha^{-1} biochar was associated with an average increase in fruit weight of 6.71 g plant^{-1}. The sole application of goat manure compost was effective in enhancing plant growth and yield up to a dosage of 20 t ha^{-1}, with an estimated increase in fruit weight of 7.58 g plant^{-1} for every 10 t ha^{-1} increment at this level. A highly significant interaction was observed between cashew nut shell biochar and goat manure compost application rates. The combination of 30 t ha^{-1} biochar and 10 t ha^{-1} goat manure compost produced the highest fruit weight per plant at the first harvest, reaching 84.00 g plant^{-1}. Further research is needed on the agronomic characterization of Pakisan chilies using fruit morphology parameters and accumulated yields throughout the productive life of the plant.

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