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Canopy Management and Supplemental Fertilization Improve Cayenne Pepper (*Capsicum frutescens* L.) Yield in Sandy Dryland Conditions

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Abstract

Cayenne pepper cultivation in sandy dryland areas often faces suboptimal conditions that limit productivity. This study aimed to assess the impact of canopy management through pruning of lateral branches, combined with supplemental fertilization, on the growth and yield of cayenne pepper. A field experiment was conducted in Gumantar Village, North Lombok Regency, Indonesia, utilizing a factorial randomized complete block design with three replications. Pruning treatments included: no pruning, complete pruning, pruning at three weeks after planting, and pruning at five weeks. Fertilization treatments included: no supplemental fertilizer, monopotassium phosphate (MKP), and potassium-silicate-humic acid. Results showed significant interaction effects of pruning and supplemental fertilization on yield and its components, including fruit weight per plant, number of fruits per plant, and fruit-set percentage. The highest yield, 5.2 kg per plot (approximately 6.9 t/ha), was achieved with complete pruning combined with MKP treatment, while the lowest yield, approximately 5.2 t/ha, occurred in the control. Both pruning and fertilization treatments significantly affected vegetative growth parameters, including plant height, leaf number, and stem diameter. Plants without pruning produced the shortest plants but had the highest leaf number and stem diameter. Meanwhile, plants treated with MKP showed the greatest improvement in vegetative growth. The findings highlight that canopy management, combined with MKP supplementation, is strongly recommended for maximizing cayenne pepper yield in sandy, dryland environments.

Keywords: branch pruning, dichotomous branch, fruit set, phosphate, potassium, total fruit weight per leaf ratio

Introduction

The cayenne pepper (*Capsicum frutescens* L.), a chili species, plays a crucial role in people's lives, especially in Indonesia. Almost all adults in Indonesia consume food containing cayenne pepper daily. The preference for cayenne pepper stems from its spiciness, which is attributed to its relatively high capsaicin content. In addition to its spicy flavor, cayenne pepper is popular for its vibrant color, which adds variety to dishes; some fruits are red, while others are green. The nutritional content of cayenne pepper is notable, as this fruit-vegetable is rich in beta-carotene and vitamins. Various studies have indicated that cayenne pepper fruit contains beta carotene ranging from 12.35 to 14.18 ppm, vitamin E from 328.6 to 486.8 ppm (Sudjaroen, 2014), vitamin C from 430 to 2470 ppm (Olatunji & Afolayan, 2018), crude fiber from 1.60 to 3.03%, protein from 3.41% to 4.20%, and carbohydrates from 9.00% to 21.25% (Temitayo et al., 2023), depending on the variety and growing location. A comprehensive review of the nutritional values and other functional properties of pepper has been published previously (Duranova et al., 2022).

From the farmers' perspective, producing cayenne pepper can be a profitable endeavor. This is mainly due to the steadily increasing demand that accompanies population growth. Consequently, cayenne pepper cultivation has expanded, with the harvested area continuing

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to rise. Suboptimal lands, such as dry, sandy soils, are increasingly being used for cayenne pepper cultivation. In 2019, the harvested area of cayenne pepper in Indonesia was 166,943 hectares, increasing to 193,423 hectares by 2023. Unfortunately, the productivity of cayenne pepper crops declined from 8.23 to 7.79 tons/ha during this period (Satu-Data, 2024). Since cayenne pepper farming is generally practiced intensively in rural areas, this decline in productivity directly affects farmers' incomes. If this situation persists, the economic condition of cayenne pepper farmers will worsen further, significantly affecting their livelihoods (Yang et al., 2022).

One factor contributing to the low productivity of cayenne pepper plants is low soil fertility, particularly in dry sandy soils. The dry, sandy land in North Lombok Regency (NLR) not only has low fertility but also a relatively low cation exchange capacity (CEC) (Jaya, 2021). In low-CEC conditions, fertilization must be applied carefully to minimize fertilizer loss after application. Generally, the fertilizer used to meet the nutritional needs of cayenne pepper plants on NRL's dry, sandy land is the government-subsidized compound fertilizer NPK Phonska (15-15-15). If water availability is limited, as in dry areas, a higher dose of phosphate fertilizer is necessary to achieve greater yields in fruit-bearing vegetables (Lopes Sobrinho et al., 2024). The efficiency of phosphate fertilization can be enhanced with the additional application of humic acid (Xiong et al., 2023). Furthermore, humic acid has been shown to increase chili plant yields (Zamljen et al., 2024). In chili cultivation, the dosage of potassium fertilizer plays a crucial role in determining optimal yields (Lorenzoni et al., 2016). Previous research has demonstrated that chili plant growth and yields are enhanced when compound fertilizers are applied at optimal rates, in conjunction with additional micronutrient-containing fertilizers (Ahmed & Abdelkader, 2020). Micronutrients such as silicon (Si) have been reported to enhance chili plant growth (Lob et al., 2023).

Apart from low soil fertility, chili productivity can also decline due to climate change (Rais et al., 2023). Climate change has caused various impacts, including droughts, floods, rising air temperatures, and outbreaks of pests and plant diseases (Bhutia et al., 2018; Schneider et al., 2022). In dry sandy soils, water availability and high sunlight intensity limit plant growth. These conditions are exacerbated by climate change, including unpredictable rainfall and rising air temperatures, which affect nearly all aspects of human life (Abbas, 2022; Trenberth, 2011). Therefore, several approaches are needed to ensure high crop yields under limited water conditions (Burridge et al., 2022), one of which is canopy management.

Canopy management through pruning unproductive branches can maximize sunlight absorption by plant leaves (Ramanjineyulu et al., 2024) and enhance yield and fruit quality, as seen in tomato plants (Goda et al., 2014). Unproductive branches are those basal lateral branches under a dichotomous branch that remain largely vegetative, receive insufficient sunlight, divert assimilates away from developing fruits, and increase canopy humidity. Pruning these branches has also been noted to decrease pest attacks on chili plants (Setiawati et al., 2021). Pruning unproductive branches during the vegetative phase is anticipated to reduce water use before anthesis, freeing up more water for use after anthesis. This form of canopy management has been shown to help maintain plant greenness during the reproductive phase (George-Jaeggli et al., 2017), thereby increasing crop yield.

Despite theoretical and experimental evidence showing that pruning unproductive branches can improve vegetative balance, fruit set, and yield in chili pepper, farmers rarely adopt this practice. Limited knowledge, labor constraints, and the absence of locally validated evidence have contributed to consistently low yields that fall short of the crop's genetic potential. However, empirical studies assessing the agronomic performance and economic feasibility of pruning under real smallholder dryland conditions remain scarce. This lack of field-based evidence constrains the development of practical recommendations to improve chili productivity in dryland areas.

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This study aimed to investigate the effects of supplemental fertilizer applications containing phosphate, potassium, silicate, and humic acid, along with canopy management through pruning at various times, on the growth and yield of cayenne pepper plants in sandy dryland conditions. Integrating the pruning of unproductive branches with specific supplemental macronutrients, silicates, and humic acid can enhance total fruit weight per leaf ratio, leading to a significantly higher yield.

Materials and Methods

Site Description and Experimental Design

A field experiment was conducted in a dryland area of Gumantar Village, Kayangan District, North Lombok Regency (NLR), Indonesia (latitude -8.253194, longitude 116.288619) from April to August 2024. The workflow of the experiment is presented in Figure 1. The climate type in most parts of NRL's dryland is classified as D3 and D4 according to the Oldeman classification system (As-Syakur et al., 2012), indicating a rainfall period of only three to four months per year. The soil is classified as an Entisol, characterized by a sandy loam texture. Selected chemical properties of the soil at the experimental site measured just before the experiment are shown in Table 1, and the criteria were provided by the Indonesian Soil Research Institute.

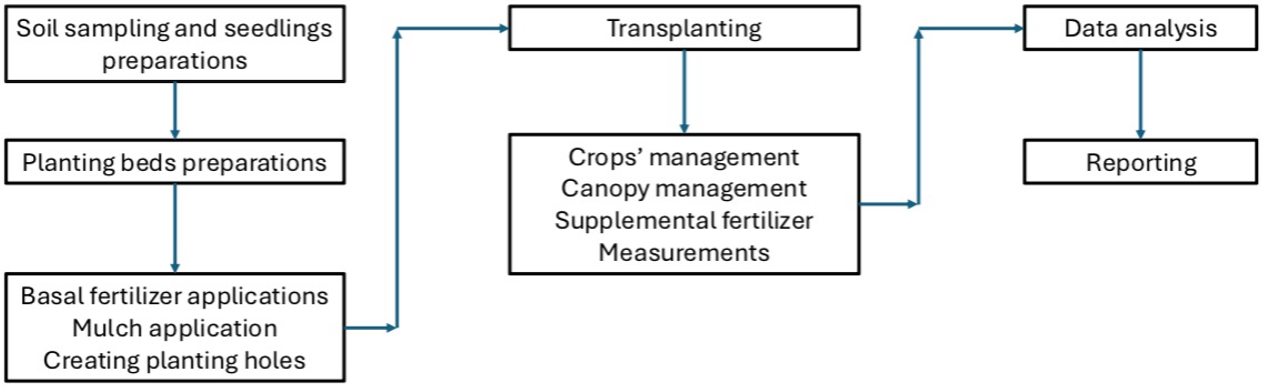
The experiment employed a factorial design with two treatment factors: supplemental fertilization and pruning of branches below the dichotomous shoot, as illustrated in Figure 4. The fertilization factor comprised three levels: no supplemental fertilization (f0), application of MKP or monopotassium phosphate, containing 52% P_2O_5 and 34% K_2O (f1), and application of foliar fertilizer (f2), containing 60% potassium (K), 40% silicate (Si), and 90% humic acid (HA), hereafter referred to as K-Si-HA. The pruning factor included four levels: no pruning (p0), complete pruning of all branches below the dichotomous branch (p1), pruning only at three weeks after planting (WAP) (p2), and pruning only at 5 WAP (p3). All treatments were arranged factorially using a randomized complete block design (RCBD) with three replications.

Experiment Materials and Preparations

Seeds of the cayenne pepper cultivar 'Dewata 43' (F1), produced by PT East West Seeds were sown in seed trays for 28 days until they developed four true leaves. Before transplanting, 36 experimental plots were prepared to match the number of treatments. Each plot measured 600 cm in length, 120 cm in width at the base, 100 cm in width at the top, and 30 cm in height, for a total area of 7.2 m^2. The spacing between treatment plots was 50 cm, while that between replications (blocks) was 75 cm. All plots were arranged in an east–west

Figure 1

Worksflow from Soil Sampling to Reporting



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Table 1

Soil Chemical Properties at the Experimental Site Before the Experiment

No.	Parameter	Method	Unit	Value	Category
1.	pH	H_2O		6.9	Neutral
2.	Organic C	Walkey&Black	%	1.19	Low
3.	Total N	Kjeldahl	%	0.09	Very low
4.	Olsen P	Spectro	ppm	37.73	Medium
5.	Total K	Percolation	cmol/kg	0.77	High
6.	Cation exchange capacity	Percolation	cmol/kg	9.99	Low

orientation.

A compound NPK fertilizer (16-16-16) was applied at a rate of 360 g per plot (equivalent to 600 kg/ha) as a basal dose. The total compound fertilizer dose applied in this experiment was 1,200 kg/ha. This rate was based on farmers' practices in the area surrounding the experimental site. The fertilizer was evenly spread across each plot's surface and thoroughly mixed into the topsoil. Next, black polyethylene plastic mulch was installed to cover the entire surface of each plot. Planting holes were created in each plot with an inter-row spacing of 60 cm and an intra-row spacing of 50 cm, resulting in 20 planting holes per plot.

After transplanting, bamboo stakes measuring 150 cm in length and 4 cm in width were inserted 30 cm deep into the soil. Each stake was placed approximately 15 cm away from the cayenne pepper plant. The purpose of staking was to support the plants during the fruiting phase by tying them to the bamboo stakes.

Irrigation was conducted by channeling water into the furrows between the experimental plots to a depth of about 10 cm, saturating the plots for approximately 30 min. The irrigation frequency varied from once every five to seven days, depending on plant conditions. Water for irrigation was obtained from a deep-well pump near the experimental site.

In addition to irrigation, routine supplemental fertilization using the rest of the dose (600 kg/ha) was conducted every two weeks with the same fertilizer as the basal application. The fertilizer was applied two or three days after irrigation to ensure enough time for the crops to absorb the nutrients. The first supplemental fertilization began at 2 WAP and continued until 14 WAP. The application rate was 60 g per plot, equivalent to 100 kg/ha. In each treatment plot, fertilizer was applied by dissolving 60 g of NPK in 5 liters of water, with each plant receiving 250 ml of the resulting solution.

Pesticides with active ingredients spiropidion (30%) and acetamiprid (24%) were applied weekly, starting at transplanting, to prevent virus transmission by thrips and aphids. Pesticide applications ceased at 9 WAP. To avert fruit fly infestations during the fruit ripening stage, pesticides containing metomyl (40%) and profenofos (500 g/L) were applied weekly. Fungal disease management, particularly for anthracnose on cayenne pepper fruit, used fungicides containing the active ingredients xemium and pyraclostrobin. Weed control consisted of regularly hand-pulling weeds that emerged in planting holes to keep plots free of weed interference.

Treatment Application

Supplemental fertilization was conducted fortnightly, starting at 3 WAP, and continued until just before the fifth harvest. MKP fertilizer was applied by drenching each plant with 200 ml of a 2 g/L solution. In contrast, K-Si-HA was applied via foliar spraying at a volume of 100–150 ml per plant (100 ml during the vegetative phase and 150 ml during the generative phase), using a solution concentration of 3 ml/L. The application frequency for K-Si-HA matched that of MKP.

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Pruning of branches below the dichotomous shoot was carried out according to the designated treatments: no pruning, pruning each time a branch emerged, pruning only at 3 WAP, and pruning only at 5 WAP. Pruning was performed with sterilized, sharp scissors soaked in 60% alcohol. Pruning was discontinued after the first harvest.

Measurements and Data Analysis

Environmental variables, including daily maximum and minimum air temperatures and relative humidity, were recorded at the experimental site using a portable thermohygrometer. Plant growth parameters, including plant height, stem diameter, and leaf number, were observed at 9 WAP, before the first harvest.

The percentage of flowers that developed into fruit (fruit set) was calculated by dividing the number of fruits formed by the total number of flowers recorded over three weeks from the onset of flowering (indicated with raffia ties) and multiplying the result by 100.

Data on the number of fruits and their weight per plant were collected from six harvests of three sample plants per treatment. Meanwhile, fruit yield per plot was calculated by summing the total fruit weight from 20 plants per plot across six harvests. Fruit weight per leaf ratio was calculated using the ratio of total fruit weight and total leaf number per plants.

All observational data were analyzed using analysis of variance (ANOVA) at the 95% confidence level. Significant differences among treatments were further evaluated using Duncan's multiple range test (DMRT) at the 5% significance level. A simple correlation analysis was performed to evaluate the relationships between fruit set and the number of fruits per plant, and between fruit weight per plant and fruit weight per plot.

Results and Discussion

Yield (fruit weight per plot), yield components, and total fruit weight per leaf ratio were affected by the interaction between supplemental fertilizer and unproductive branch pruning. The growth parameters, such as plant height, number of leaves, and stem diameter, were affected by the main effects of both supplemental fertilization and unproductive branch pruning. Time to first flower was not affected by the two treatments.

As presented in Table 1, the soil at the experimental site had very low total nitrogen (N), low organic carbon (C), and low CEC. Earlier studies have confirmed that soil with low organic C content usually has low CEC (Bi et al., 2023) and often reduces fertilization efficiency (Ćirić et al., 2023). The very low total N, low organic C, and low CEC in the soil at the experimental site were due to a soil texture primarily composed of sand (70% sand, 15% clay, and 15% silt), with large particle sizes. Consequently, vegetable crops such as tomatoes and chilies grown near the study area are typically fertilized at high rates (Jaya et al., 2022; Safta et al., 2025). In addition to the common NPK (15-15-15) compound fertilizer, additional fertilizers are often added to boost crop yields, especially in fruit-bearing vegetable crops such as cayenne pepper (Jaya et al., 2022). The medium and high levels of phosphorus (P) and potassium (K) were mainly due to residual fertilization from previous crops.

Cayenne pepper grows and yields best within a temperature range of 21-33 ^{0}C (Pagamas & Nawata, 2007). As shown in Figure 2, maximum air temperatures at the experimental site often exceeded 33 ^{0}C, indicating a high risk of flower abscission. Previous studies have shown that air temperatures above 32 ^{0}C can cause flower drop in chili plants (Olatunji & Afolayan, 2018). However, the average temperature during the generative phase (from June 10 onward), recorded at 28.8 ± 0.86 ^{0}C during the day and 23.4 ± 1.12 ^{0}C at night, remained within a favorable range for fruit development, especially for chili cultivars that tolerate higher temperatures (Srivastava et al., 2022). The cultivar tested in this study, 'Dewata 43', is locally produced in Indonesia and is considered well adapted to the environmental variability of its growing region.

The average relative humidity during the

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experimental period was 65.0 ± 4.45%, with fluctuations shown in Figure 2. This humidity level is still considered optimal for cayenne pepper plant growth. Growth may be negatively affected when relative humidity drops below 45% or rises above 85% (Wu & Guo, 2025). However, the most suitable relative humidity for optimal growth, development, and yield in chili plants is around 50% (Ahmed et al., 2023).

Canopy management by pruning all branches below the dichotomous branch significantly increased cayenne pepper plant height. The complete pruning treatment showed a more pronounced effect than the others, and plants pruned only at 3 and 5 WAP showed similar heights (Table 2). This suggests that continuous canopy management, which involves removing basal lateral branches, promotes apical shoot growth and leads to taller plants. Previous studies have demonstrated that lateral branch pruning can increase indoleacetic acid (IAA) levels in the roots, thereby enhancing the upward transport of water and nutrients (Xu et al., 2020) and promoting plant growth.

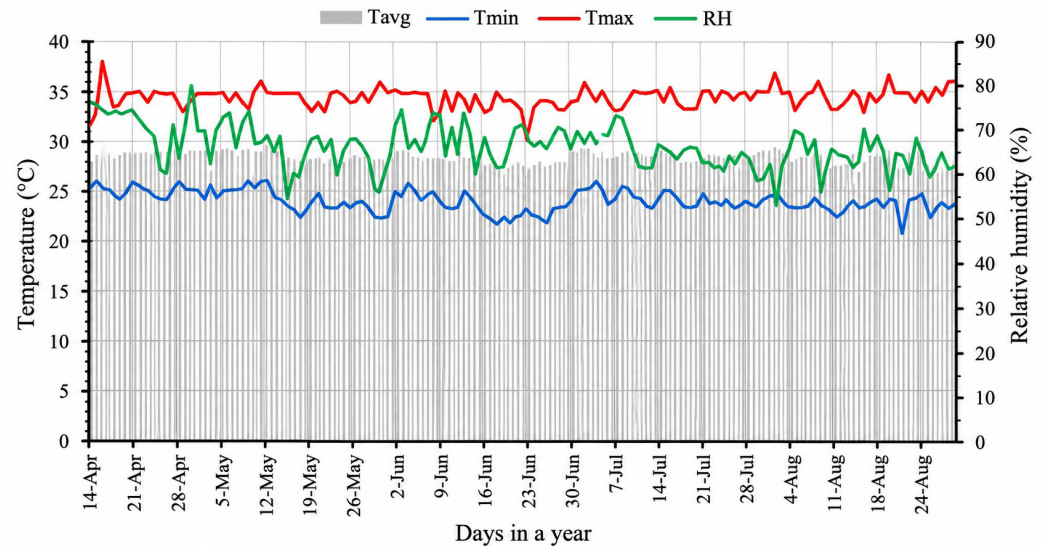
Conversely, plants that were left unpruned or pruned early (3 WAP) produced more leaves than those subjected to continuous pruning or pruning at 5 WAP (Table 2). Canopy management through the removal of basal lateral branches is essential in horticultural crops to prevent carbohydrate allocation imbalances between vegetative and reproductive stages. Excessive branching results in dense foliage, which can cause self-shading or create suboptimal microclimatic conditions within the canopy (Liu et al., 2024). Dense foliage in chili plants reduces light penetration, weakening shaded leaves as photosynthetic sources. Weak sources produce fewer photosynthates, weakening sink organs and potentially leading to flower abscission or impaired fruit development (Koper et al., 2021).

Short-statured chili plants with dense foliage need sturdy stems to stay upright. This was evident in the larger stem diameter of unpruned plants. Interestingly, plants pruned at 3 WAP had a larger stem diameter than those pruned at five weeks or complete pruning (Table 2). Stem diameter is positively linked to leaf number or leaf biomass. As leaf production increases, stem diameter tends to increase, and thicker stems are usually associated with greater leaf mass (Sun et al., 2019).

Flowering time, defined as the point at which 50% of the plants in a plot have open flowers, was not significantly affected by

Figure 2

Daily Temperature Maximum (Tmax), Minimum (Tmin), Average (Tavg), and Relative Humidity (RH) Recorded During the Experiment



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pruning (Table 2). This is likely because chili plants typically initiate their first flowers at the dichotomous branching point, and the timing of this developmental stage was relatively consistent across the tested plants.

Supplemental fertilization improved plant growth parameters, including height, leaf number, and stem diameter, compared to the control (no supplement), but did not affect flowering time (Table 2). Among the fertilizers tested, MKP (monopotassium phosphate) showed a more pronounced effect than K-Si-HA across all observed growth parameters. MKP contains a high concentration of phosphorus, which is absent from K-Si-HA. The role of phosphorus in enhancing growth in horticultural crops, particularly within the Solanaceae family, is well documented (Abobatta & Abd Alla, 2023). Additionally, phosphorus helps improve plant resilience under suboptimal conditions, such as elevated air temperatures beyond the crop's optimal range (Khan et al., 2023). While the roles of phosphorus and potassium in enhancing flower quantity and strength have been widely reported (Lopes Sobrinho et al., 2024; Salehi Molkabadi & Ghasemi, 2022), specific literature addressing their influence on flowering time in chili plants remains scarce.

The interaction between canopy management by lateral branch pruning and supplemental fertilization significantly influenced yield, yield components, and total fruit weight per leaf ratio (Table 3). The highest flower-to-fruit conversion rate was observed in plants that underwent continuous pruning of lateral branches below the dichotomous branch, combined with MKP supplementation. Conversely, unpruned plants showed the lowest conversion rate across all fertilizer treatments.

As previously mentioned, continuous pruning reduced the number of leaves (Table 2). 'Dewata 43', the chili cultivar used in this study, is a short-statured, bushy plant (Figure 3), as stated in the variety description according to the Indonesian Ministry of Agriculture Decree No. 345/Kpts/SR.120/9/2005. This growth habit shaded the lower canopy leaves, limiting their exposure to sunlight. Leaves that lack sufficient light typically show reduced photosynthetic capacity (Cutolo et al., 2023) and decreased nutrient uptake efficiency (Wang et al., 2020). As a result, unpruned plants, regardless of fertilizer treatment, had the lowest fruit-set percentage (Table 3). These results align with previous research showing that weakened source strength leads to increased flower drop (Marcelis

Table 2

Plant Growth Parameters with the Treatments of Pruning and Supplemental Fertilizer

Treatments	Parameter measured			
	Plant height (cm)	Leaf number	Stem diameter (mm)	Time to flowering (DAP)
Pruning				
No pruning	59.3 c*	521.2 a	12.0 a	28.1
Complete pruning	61.4 a	462.1 d	10.8 d	28.2
Pruning 3 WAP	60.8 b	496.4 b	11.6 b	27.8
Pruning 5 WAP	60.5 b	470.3 c	11.2 c	27.9
Fertilizer				
No supplement	59.6 c	481.3 b	11.2 b	28.1
Monopotassium phosphate (MKP)	61.3 a	491.1 a	11.6 a	27.9
K-Si-HA	60.6 b	490.1 a	11.4 ab	28.0

*Notes. *Values in the column for the same treatment, followed by different letters, indicate significant differences based on DMRT at a 5% level. K-Si-HA is potassium, silicate, and humic acid. DAP: days after planting.*

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et al., 2004).

In addition to encouraging vertical growth, lateral branch pruning changed the canopy structure (Figure 4). Canopy manipulation enhances light penetration, thereby boosting photosynthetic activity (Sarlikioti et al., 2011). Increased photosynthesis positively affects source−sink partitioning (Bennett et al., 2012). As a result, plants that underwent continuous pruning and received supplemental fertilizer showed higher fruit set than unpruned plants under all supplemental fertilizer treatments (Table 3). MKP supplementation consistently achieved the highest fruit set across all pruning treatments, with the greatest significant effect under continuous pruning.

MKP fertilizer outperformed K-Si-HA across most pruning treatments, except at 5 WAP (Table 3). Previous studies show that cayenne pepper plants respond differently to different fertilizer types (Stan et al., 2021). Although K-Si-HA contains higher calcium levels than MKP,

Figure 3

Performance of Cayenne pepper 'Dewata 43' at the Late Vegetative Phase (Left) and Generative Phase (Right)



Figure 4

Illustration of Cayenne Pepper Dichotomous Branch (Left), Plant Performance with Continuous Pruning (Center), and Pruned at 5 WAP (Right)



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Table 3

Cayenne Pepper Fruit Set, Yield and Yield Components Efficiency with Pruning and Supplemental Fertilizer Treatments

Pruning	Fertilizer	Parameter measured				
		Fruit set (%)	Fruit number per plant	Fruit weight per plant (g)	Fruit weight per plot (kg)	Total fruit weight per leaf ratio
No pruning	No supplement	84.1 e*	97.6 e	205.2 d	3.9 d	0.40 d
	MKP	84.8 e	102.2 e	222.8 cd	4.4 cd	0.42 d
	K-Si-HA	84.0 e	101.4 e	218.8 d	4.3 cd	0.42 d
Complete pruning	No supplement	86.5 d	121.3 d	236.5 c	4.5 c	0.52 c
	MKP	91.1 a	144.3 a	291.3 a	5.2 a	0.62 a
	K-Si-HA	89.5 b	141.8 ab	283.4 ab	4.9 b	0.61 ab
Pruning 3 WAP	No supplement	85.8 d	118.2 d	227.8 cd	4.2 d	0.47 cd
	MKP	89.8 b	137.7 b	282.7 ab	5.0 b	0.56 bc
	K-Si-HA	88.3 c	133.6 bc	274.7 b	4.8 b	0.55 bc
Pruning 5 WAP	No supplement	85.6 de	118.0 d	229.9 cd	4.2 d	0.49 c
	MKP	89.0 bc	134.5 bc	276.5 b	5.1 ab	0.59 ab
	K-Si-HA	87.8 c	130.2 c	269.1 b	4.9 b	0.57 b

Notes. *Values in the same column, followed by different letters, indicate significant differences based on DMRT at a 5% level. MKP is monopotassium phosphate, and K-Si-HA is potassium, silicate, and humic acid.

and calcium is known to strengthen source tissues under shaded leaf conditions (Zhu et al., 2025), the 'Dewata 43' chili cultivar in this study performed better with MKP supplementation.

Other research has also shown that combining phosphorus (P) and potassium (K) provides better results than applying either nutrient alone (Akram et al., 2017). Meanwhile, the 90% humic acid content in K-Si-HA did not significantly affect plant performance, likely because the plants had already received essential nutrients from the basal NPK fertilizer. This conclusion aligns with earlier findings that 100% humic acid had no significant effect on crops already fertilized with NPK (Ichwan et al., 2022). Similarly, although potassium silicate has been shown to positively affect chili growth (El-Gazzar et al., 2020), its impact in this study was less noticeable than that of MKP.

A higher fruit set was linked to an increased number of fruits per plant (Table 3). There was a strong positive correlation (r = 0.94) between fruit set and the number of fruits per plant. Similarly, fruit weight per plant and per plot were heavily influenced by fruit number (r = 0.93 and 0.86, respectively). The consistent effects of pruning and supplemental fertilization on yield (fruit weight per plot) and yield components were apparent, especially under continuous pruning combined with MKP supplementation. Plants that were pruned and treated with either MKP or K-Si-HA consistently produced higher yields than unpruned plants, regardless of supplemental fertilizer treatment. This result was supported by the higher total fruit weight per leaf ratio seen in pruned plants receiving supplemental fertilizer, compared to unpruned plants with or without supplemental fertilization (Table 3).

Supplemental fertilizers such as MKP, potassium silicate, and humic acid boost yields in fruit-bearing vegetables such as cayenne pepper by enhancing nutrient absorption, strengthening physiological functions, and increasing stress resilience. MKP provides readily available phosphorus and potassium, which support root development, energy metabolism, and nutrient transport, thereby improving reproductive growth (Sassine et al., 2021). Sufficient potassium

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improves stomatal control and photosynthesis, which boosts carbohydrate transfer to fruits (Luo et al., 2021). Silicate strengthens cell walls and improves water-use efficiency, helping plants tolerate heat and drought stress (Verma et al., 2022; Wang et al., 2021). Humic acid improves soil structure and nutrient availability, resulting in higher chlorophyll levels and better fruit quality (Ampong et al., 2022; Ichwan et al., 2022; Nabi et al., 2025). Collectively, these inputs foster improved flowering, fruit set, and yield, even under difficult agroecological conditions.

As previously discussed, removing lateral branches below the dichotomous branch effectively decreases the number of leaves receiving limited sunlight. Leaves that lack sufficient light become a weak source, reducing overall crop productivity (Chavan et al., 2020). Pruning lower canopy leaves improves photosynthetic capacity by enhancing carbon and nitrogen metabolism, thereby strengthening the source–sink relationship (Iqbal et al., 2012). As a result, pruned plants with fewer leaves showed greater efficiency in converting photosynthates into fruit. Fertilizers high in phosphorus (P) and potassium (K) are crucial for vegetable crops, such as cayenne pepper (Batool et al., 2015; Botella et al., 2017). Supplemental fertilization is essential for cayenne pepper grown in sandy dryland soils, where nutrient leaching can significantly decrease fertilization efficiency. These findings highlight that supplemental fertilization and pruning basal lateral branches can significantly enhance yield, offering scalable, evidence-based strategies to improve cayenne pepper production in sandy dryland soils worldwide.

Conclusions

Canopy management and supplemental fertilizer application significantly interacted to affect the yield and yield components of cayenne pepper grown in sandy dryland conditions. Continuous pruning combined with MKP fertilizer, which is rich in phosphorus and potassium, produced the highest yield. No significant interaction was observed between canopy management and supplemental fertilization for vegetative growth parameters. Unpruned plants exhibited shorter height, more leaves, and larger stem diameters compared to pruned plants. Meanwhile, plants supplied with supplemental MKP fertilizer showed better growth performance than those without it. The cost-effectiveness of canopy management in cayenne pepper, including pruning branches below the dichotomous branching point and applying MKP fertilizer, warrants further research. Additionally, a physiological study is needed to examinate leaf area productivity to determine efficiency in converting photosynthetic products into fruit biomass.

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Conflict of Interest

The authors declare no conflict of interest.

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