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Trichome Morphology and Biotic Stress in Cayenne Pepper Under Organic Fertilizer Treatments

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Abstract: Trichomes play a role in protecting plants from herbivores and pathogens, and their formation can be influenced by nutrient availability and environmental factors. This study examined the effect of liquid organic fertilizer (POC) on the development of leaf trichomes in cayenne pepper (*Capsicum frutescens*) grown on ultisol soil in Tarakan, Indonesia. The experiment used a completely randomized design with seven fertilization treatments: control (P0), NPK (P1), and POC at concentrations of 5–15 g/L (P2–P6), each replicated four times. Leaf samples collected 45 days after transplanting were cleared, stained, and observed microscopically. Several types of trichomes were identified, with non-glandular forms observed more frequently than glandular ones, mainly located along the abaxial midrib and veins. Variation in trichome number and form appeared to increase in plants treated with higher POC concentrations (10–15 g/L). Occasional fungal structures were noted on some leaf surfaces, coinciding with the presence of glandular trichomes. These observations suggest that POC application may influence trichome development in cayenne pepper under field conditions, providing preliminary morphological information relevant to organic fertilization practices on marginal soils.

Keywords: Biotic stress response; *Capsicum frutescens*; liquid organic fertilizer; trichome density; trichome morphology

Introduction

Red cayenne pepper (*Capsicum frutescens*) is a key vegetable commodity in Indonesia, valued for its popularity, nutritional content, and versatile culinary applications. Beyond household use, it is widely utilized in the food industry as a natural additive, flavor enhancer, and preservative (Olatunji & Afolayan, 2019; Rezazadeh et al., 2023; Zeiner et al., 2023; Knazicka et al., 2025). Its economic importance is reflected in increasing production in Tarakan City, a rapidly urbanizing island city in North Kalimantan (BPS Kalimantan Utara, 2021). With limited arable land, Tarakan relies on efficient and sustainable farming systems to secure local food supply and reduce import dependence. Enhancing cayenne pepper productivity is therefore critical for urban food security and smallholder livelihoods.

Fertilization strongly influences cayenne pepper growth, yield, and quality. Liquid organic fertilizer (POC) is increasingly adopted for its ability to improve soil fertility, support nutrient cycling, and minimize the negative impacts of synthetic inputs (Martínez-Alcántara et al., 2016; Stan et al., 2021; Brown et al., 2022; Zhou et al., 2022; Gao et al., 2023; Liu et al., 2024; Ren et al., 2024). POC, derived from manure, plant residues, and organic waste, supplies essential nutrients while enhancing soil organic matter and microbial activity. In urban contexts such as Tarakan, POC use also recycles

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local organic residues, reduces waste disposal pressure, and creates a circular nutrient flow that benefits smallholder farming.

Despite yield improvements, biotic stress remains a major constraint to pepper production. *Colletotrichum* spp. (anthracnose) and *Cercospora capsici* can cause up to 80% and 50% yield losses, respectively, if unmanaged (Moekasan & Prabaningrum, 2012; Isnawan & Mubarok, 2014; Herwidyarti et al., 2013; Mursyidin & Mulyaningsih, 2024). Heavy reliance on synthetic pesticides and fungicides raises concerns over residues, environmental contamination, and resistance development, highlighting the need for integrated approaches that strengthen plant self-defense mechanisms alongside nutrient management.

Trichomes, specialized epidermal outgrowths on leaves, stems, and reproductive organs, are among the most important morphological defenses in plants. They vary in type (glandular and non-glandular), shape, and function, acting as mechanical barriers, secreting secondary metabolites, and enhancing tolerance to herbivores and pathogens (Engene et al., 2012; Glas et al., 2012; Kortbeek et al., 2016). The shape and type of trichomes are very diverse in Solanaceae family, including non-glandular and glandular types, each of which has a different protective function (Dewi et al., 2015). Trichome density and morphology are plastic traits influenced by nutrient status and environmental stimuli. Nitrogen supplementation, for example, has been shown to increase trichome density in *Artemisia annua* (Bilkova et al., 2016). However, trichome responses to organic fertilization remain inconsistent across crops and environments, likely due to differences in species physiology, fertilizer composition, and climatic conditions (Vaičiulytė et al., 2022; Rodolfi et al., 2021; Talebi et al., 2017).

Most studies examining the effects of POC on trichomes have been conducted under greenhouse or temperate conditions, where pest pressure is minimal. This limits understanding of trichome responses in tropical field systems, where high temperature, humidity, and endemic pest loads may amplify trichome induction or interact with nutrient-driven changes. Few studies have simultaneously assessed nutrient input and naturally occurring biotic stress, despite evidence that trichomes act as physical and chemical barriers against fungal pathogens (Karabourniotis et al., 2020; Celedon et al., 2020). Understanding these interactions is therefore essential for developing low-input strategies that reduce pesticide dependence while maintaining productivity (Hochmuth et al., 2022; Kim et al., 2012; Dupont et al., 2015; Gao et al., 2023).

The novelty of this study lies in evaluating the dual role of POC under natural tropical field conditions—both as a nutrient source and as a potential inducer of structural defense through trichome formation. Unlike previous studies conducted in controlled environments, this research was performed on ultisol soils in Tarakan, characterized by low fertility and high pest pressure, using locally produced POC to reflect smallholder practices. Additionally, it documents the occurrence of fungal structures as indicators of natural biotic stress, allowing a contextual understanding of how POC influences trichome morphology and abundance under real field conditions.

Clarifying these relationships is important for three reasons: (1) it provides empirical evidence linking organic fertilization with plant defense expression, supporting the development of integrated nutrient and pest management strategies; (2) it promotes the sustainable use of locally available organic resources while reducing dependence on synthetic pesticides; and (3) it contributes to understanding plant morphological adaptation to tropical environments. Therefore, this study investigates the effects of varying POC concentrations on trichome type, distribution, and abundance in *C. frutescens*, and explores their relationship with naturally occurring biotic stress to support more resilient, sustainable pepper production systems in tropical urban agriculture.

Method

Study Area

This research was conducted on cultivation land located on Jalan Bumi Perkemahan Binalatung, Pantai Amal Village, East Tarakan District, Tarakan City, North Kalimantan. Microscopic observations were carried out in the Plant Science and Biotechnology Laboratories, Faculty of Agriculture, Borneo Tarakan University (Figure 1).

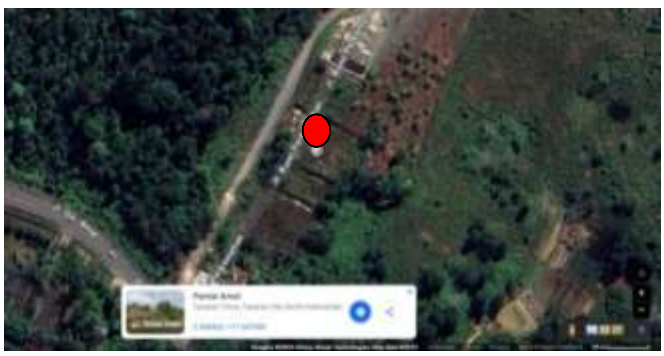


Figure 1. Field research location (red plot)

Field Research Procedures

Cayenne pepper (*Capsicum frutescens*) seedlings were raised in seedling trays containing a standard soil medium and watered as needed during the nursery phase. Seedlings were transplanted at one month of age, when plants had developed six uniform leaves. Raised beds (40 cm high) were prepared, with a total of 20 beds. Each treatment plot consisted of four plants per replication, with four replications, resulting in 16 plants per treatment and a total of 112 plants across all treatments. Fertilization was applied twice: first, one week after transplanting, and again 30 days later. Routine watering was performed daily to maintain adequate soil moisture (Figure 2).

Research Design

A completely randomized design (CRD) was employed with seven fertilization treatments and four replications per treatment. The treatments included: control without fertilizer (P0), 2.5 g NPK (P1), and liquid organic fertilizer (POC) at concentrations of 5 g/L (P2), 7.5 g/L (P3), 10 g/L (P4), 12.5 g/L (P5), and 15 g/L (P6). The POC used in this study was a farmer-prepared formulation produced by fermenting livestock manure and plant residues, with vegetable waste serving as the primary feedstock. Direct chemical analysis of the applied POC was not conducted due to equipment limitations; therefore, published reference values for vegetable-waste-based POC were used as a compositional proxy, typically containing 21.05% organic matter, 0.08% nitrogen (N), 0.09% phosphorus (P), and 3.18% organic carbon (C) (Ji et al., 2017; Haryanta et al., 2022). This limitation is acknowledged and further discussed in the Discussion section (Figure 2).

Biotic Stress Consideration

Direct quantitative measurement of biotic stress (e.g., insect population counts or pathogen incidence) was not performed. Instead, biotic stress was qualitatively inferred from the visual presence of fungal spores and hyphae in cleared leaf tissues during microscopic examination. These observations were interpreted in the context of published reports of common cayenne pepper pathogens in the region, such as *Colletotrichum* spp. and *Cercospora capsici* (Moekasan & Prabaningrum, 2012; Mursyidin & Mulyaningsih, 2024) (Figure 2).

Microscopic Preparation and Imaging

Microscopic observations were conducted on 1 × 1 cm leaf tissue samples collected from the middle third of the fully expanded leaves. Samples were cleared using a modified clearing method (Chairiyah et al., 2023). Leaf tissues were treated with 5% NaOH to remove chlorophyll, followed by immersion in 50% sodium hypochlorite for one hour. Cleared samples were thoroughly rinsed, then dehydrated through a graded ethanol series (30%, 50%, 70%, 80%, and 100%). Staining was performed with methylene blue prior to mounting on glass slides. Observations were made under an Olympus CX31 light microscope at magnifications of 40×, 100×, and 400×. Images were captured using a mounted digital camera, and scale bars (50–100 μm) were calibrated using ImageJ software (Figure 2).

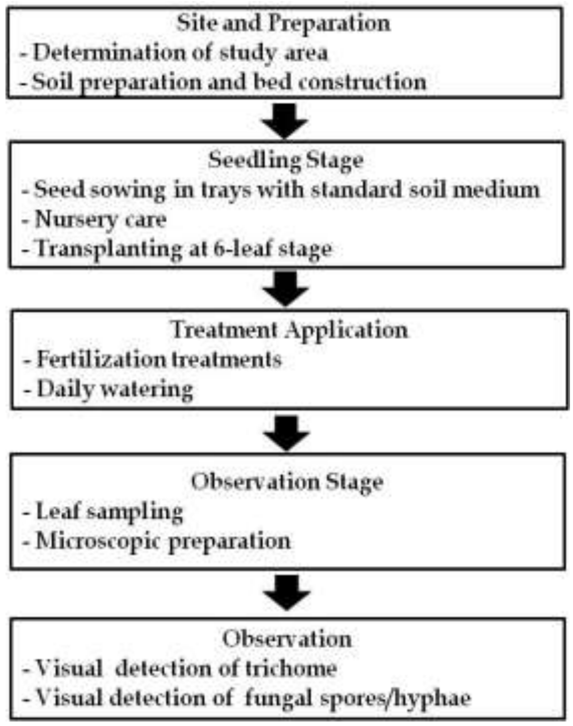


Figure 2. Research procedures stages

Trichome Assessment

Trichome density was scored visually in midrib and lamina regions using an ordinal scale: low (<25% coverage), medium (25–50%), and high (>50%). Trichome types were classified following Watts et al. (2021). Observations focused on distribution patterns, morphological diversity, and relative abundance across treatments rather than absolute counts, given equipment limitations (Figure 2).

Data Analysis

The anatomical data were descriptive and qualitative. Results were presented as distributions of trichome types and density scores across treatments. No inferential statistical analyses were performed because the primary objective was to document and compare morphological diversity under different fertilization regimes.

Result and Discussion

Microscopic examination identified 16 non-glandular and one glandular trichome type on cayenne pepper leaves grown under different POC concentrations (Figure 3). The observed trichomes included unicellular and multicellular subulate, basilate, round-tipped, and hooked forms, following the classification by Watts et al. (2021) (Table 1). Non-glandular trichomes were predominant across treatments. Observations showed that most trichomes found on cayenne pepper (*Capsicum frutescens*) leaves have a simple hair-like appearance with hooked tips. This finding aligns with that of Dewi et al. (2015), who also reported simple hair-like non-glandular trichomes in the same species.

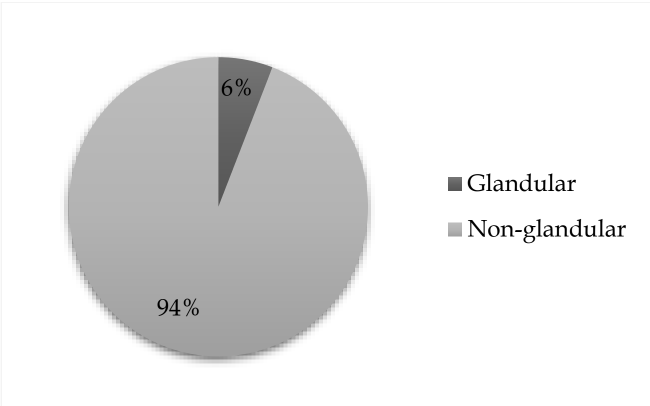


Figure 3. Percentage of variation in trichome types

Trichome variation was observed among treatments (Table 2). Plants treated with POC (P2–P6) showed a tendency for higher trichome occurrence compared to the control (P0), although differences varied in magnitude. These results indicate that POC application may influence epidermal differentiation, consistent with the role of nutrients, particularly nitrogen and potassium, in trichome formation (Bilkova et al., 2016; Wei et al., 2025).

The application of liquid organic fertilizer (POC) enhances plant growth by improving nutrient availability and stimulating metabolic activity through bioactive compounds that are easily absorbed by plant tissues. This physiological stimulation promotes vigorous vegetative growth, as demonstrated by Rusdiyana et al. (2022), who reported that POC derived from peanut shells and banana peels increased plant height and leaf number in spinach. Similarly, Mappanganro et al. (2023) found that POC from water spinach waste enhanced the vegetative performance of chili peppers, while Rosadi et al. (2022) and Pane et al. (2023) observed that POC made from fish waste, coconut water, and cassava peels (Abdullah et al., 2025) improved nutrient uptake and natural hormone activity, resulting in better growth. The growth-promoting effect of POC has also been verified in mustard greens, where a 6% concentration increased leaf number and pest resistance (Hapsari & Suparno, 2023). In addition, Nasirudin et al. (2023) and Mumtazah et al. (2025) reported that POC derived from leachate and Samanea saman leaves enhanced overall plant biomass and vigor.

Increased metabolic activity and optimal vegetative development contribute to the formation of robust leaf tissues, including the differentiation of epidermal cells into protective structures such as trichomes. Various formulations and concentrations of POC have proven effective in stimulating leaf physiology in different crops. For example, POC with nanobubble technology enhances nitrogen and potassium absorption efficiency (Asri et al., 2025), while NASA POC improves plant height and yield in sweet corn (Sitorus et al., 2024). Similarly, GDM POC has been shown to increase vegetative growth and tomato fruit yield through the optimization of N, P, and K utilization (Riwu Kaho et al., 2025). Collectively, these studies demonstrate that nutrient enrichment through POC not only enhances photosynthetic performance and epidermal activity but also supports trichome initiation as a form of structural defense.

Trichomes are specialized epidermal outgrowths that function as both mechanical and chemical barriers against biotic stress. Nutrient-driven enhancement of epidermal differentiation through POC can therefore strengthen plant defense capacity. Febriyani et al. (2022) reported that glandular trichomes in several Annona species produce essential oils and bioactive compounds with antibacterial and antifungal properties, while Herjayanti et al. (2022) found that both glandular and non-glandular trichomes in Biophytum are involved in metabolite secretion and protection. Within the Solanaceae family, including Capsicum frutescens, trichomes serve a dual role in mechanical and chemical defense against herbivores and pathogens (Yusuf et al., 2025). Similarly, Yuliany et al. (2022) observed that various shade plants possess glandular and non-glandular trichomes that act as protective barriers and environmental bioindicators. These findings collectively support that POC application promotes leaf development and epidermal differentiation into trichomes, thereby enhancing structural and biochemical defense mechanisms in plants, including cayenne pepper.

Plant hormones such as auxin, gibberellin, and cytokinins regulate trichome initiation and epidermal cell fate (Matías-Hernández et al., 2016; Traw & Bergelson, 2010). Likewise, jasmonic acid and ethylene enhance trichome development under biotic stress (Li et al., 2021; Tian et al., 2017). The occasional appearance of glandular trichomes may reflect local physiological or environmental responses rather than a direct effect of POC concentration.

The higher proportion of non-glandular trichomes suggests that physical protection remains the main epidermal defense mechanism, while glandular trichomes may contribute to chemical protection through secondary metabolite secretion (Saini et al., 2015). Another study also showed that the presence of glandular trichomes is often associated with the plant's ability to produce secondary metabolites such as flavonoids and alkaloids that function as natural defenses (Astiti et al., 2021). These results indicate that the increase in the number of glandular trichomes may be related to the activity of secondary metabolite secretion, as reported by Tanzerina et al. (2025) in *Hodgsonia macrocarpa*, where trichomes act as a secretory tissue for storing bioactive compounds. Similar nutrient-related trichome responses have been reported in Capsicum annuum, tomato, and eggplant under organic fertilization or stress conditions (Kamala et al., 2018; Zhang et al., 2020; Chen et al., 2021; Rodríguez et al., 2024). Overall, POC treatment appears to influence trichome morphology in cayenne pepper, supporting previous studies linking nutrient management with epidermal development (Hochmuth et al., 2022; Kim et al., 2012; Dupont et al., 2015; Gao et al., 2023). Further investigation is required to determine whether these structural changes contribute to physiological or defensive functions.

Table 1. Classification and Number of Trichomes Found in the Leaf Tissue of Cayenne Pepper Plants (*Capsicum frutescens*)

Trichome type	Number of cells	Form	Surface	Base	Tip
Glandular	Multicellular	Straight	Slim	Regular	Globular
Non-glandular	Multicellular	Straight	Atenuatte	Pedestal	Subulate
					Blunt
				Pedestal	Subulate
					Blunt
			Pustulate	Regular	Subulate
					Blunt
				Pedestal	Subulate
					Blunt
		Hooked	Atenuatte	Regular	Subulate
					Blunt
				Pedestal	Subulate
					Blunt
			Pustulate	Regular	Subulate
					Blunt
				Pedestal	Subulate
					Blunt

In the context of urban agriculture in Tarakan City, the use of POC represents a potential strategy for improving nutrient management within integrated crop systems. POC application may influence physiological processes related to photosynthesis and the biosynthesis of phytohormones such as auxin, gibberellin, cytokinin, ethylene, and jasmonic acid, which are known to regulate trichome initiation and epidermal differentiation. Although this study did not include quantitative measurements of trichome density, microscopic observations indicated noticeable morphological variation among treatments. These findings suggest that POC could contribute to improved leaf surface structure through nutrient-mediated physiological regulation. Further studies using calibrated microscopy and statistical analysis are recommended to quantify these responses and clarify the relationship between POC application and trichome development in cayenne pepper.

Trichomes display considerable morphological diversity across plant species, classified by cell number, glandular function, and branching (Werker, 2000; Kennedy, 2003; Kang et al., 2014; Liu et al., 2021). In Capsicum, six main trichome types are reported, three non-glandular (II, III, V) and three glandular (I, IV, VII), with types II, III, V, and VII most frequent in this study (Kim et al., 2012). Epidermal differentiation varied by leaf region, with glandular trichomes dominating the abaxial lamina and non-glandular trichomes concentrated along the adaxial midrib (Table 3). This pattern is similar to the findings of Julianti et al. (2024) who stated that the density of trichomes in the abaxial leaf is higher as a protective mechanism against water loss and excess radiation.

Tambaru et al. (2019) also identified glandular trichomes on both abaxial and adaxial surfaces of *Clinacanthus nutans* (Acanthaceae) leaves, which secrete secondary metabolites such as terpenoids, flavonoids, and alkaloids that function in biotic stress defense. Similarly, Febriyani et al. (2022) reported species-specific variation in trichome distribution among *Annona*, with *A. muricata* exhibiting trichomes only on the abaxial epidermis, *A. cherimola* on both surfaces, and *A. squamosa* lacking trichomes entirely. These findings suggest that trichome distribution across leaf surfaces is species-dependent and closely related to plant protective strategies. These patterns are consistent with previous reports that trichome distribution is shaped by genetic factors, leaf developmental stage, and stress exposure (Kalicharan et al., 2018; Ning et al., 2016; Baird et al., 2024; Kabir et al., 2024; Xiao et al., 2017). Other studies also reported that Glandular trichome abundance is likewise regulated by genetic, environmental, and hormonal cues, particularly gibberellins, cytokinins, and jasmonic acid, which coordinate initiation and density under both normal and stress conditions (Dalin et al., 2008; Fambrini & Pugliesi, 2019; Khan et al., 2021; Li et al., 2021; Han et al., 2022).

Table 2. Qualitative Comparison of Trichome Abundance, Diversity, and Distribution in Cayenne Pepper Leaves Under Different Fertilization Treatments

Treatment	Trichome Abundance*	Trichome Diversity**	Predominant Trichome Type	Distribution Pattern
P0 (Control)	Few	Low	Non-glandular	Observed mainly near midrib
P1 (NPK 2.50 g)	Several	Moderate	Non-glandular, few glandular	Visible along midrib and leaf surface
P2 (POC 5.00 g/L)	Several	Moderate	Non-glandular	Spread across leaf surface
P3 (POC 7.50 g/L)	Numerous	Moderate	Non-glandular, glandular present	Found along midrib and lamina areas
P4 (POC 10.00 g/L)	Numerous	Moderate–High	Non-glandular	Observed along midrib and veins
P5 (POC 12.50 g/L)	Abundant	Moderate–High	Non-glandular, few glandular	Distributed across leaf surface
P6 (POC 15.00 g/L)	Abundant	High	Non-glandular, few glandular	Distributed across leaf surface

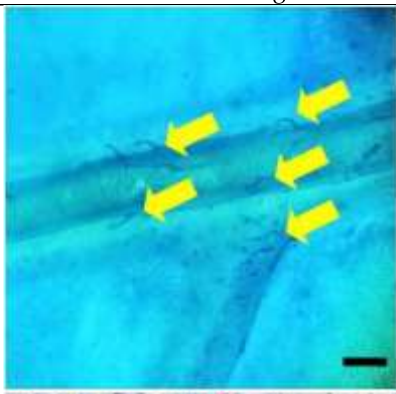
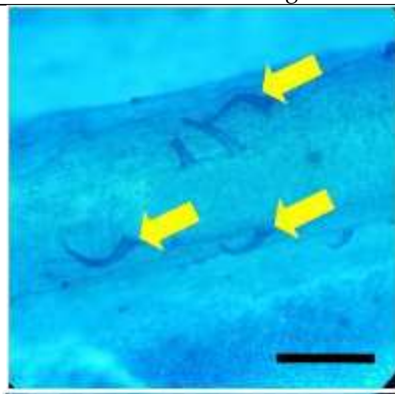
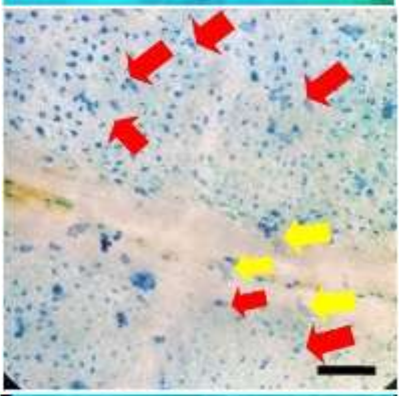
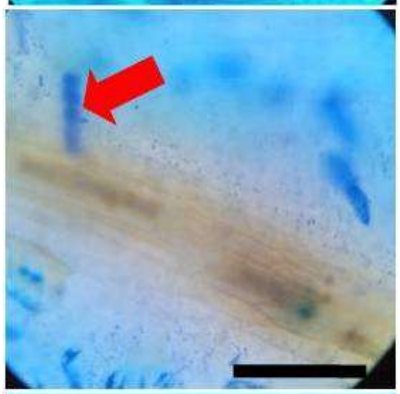
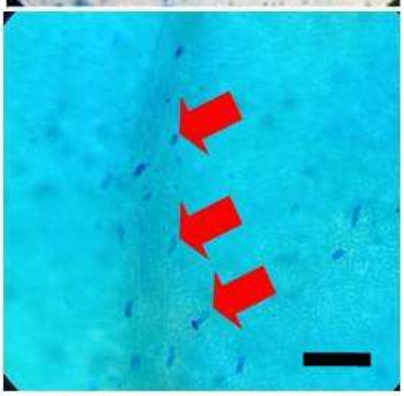
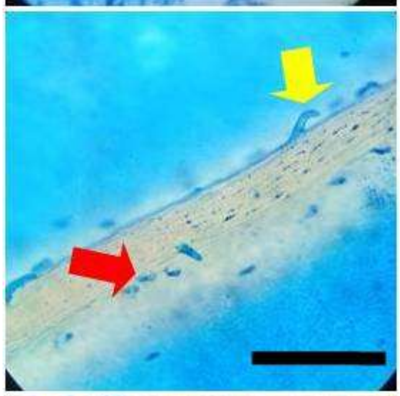
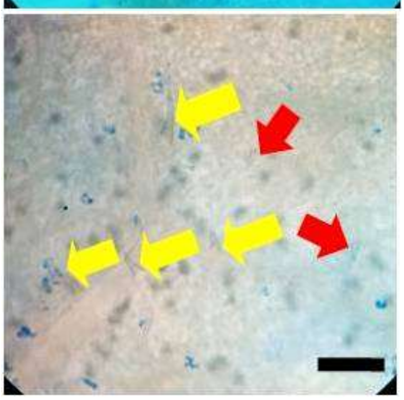
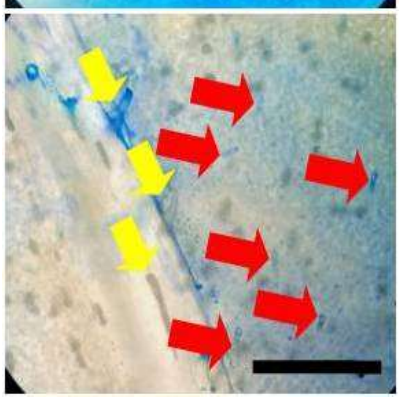
* Qualitative observation under 40×–100× magnification
** Based on visible morphological variation (low ≤ 5 forms, moderate 6–10, high ≥ 11)

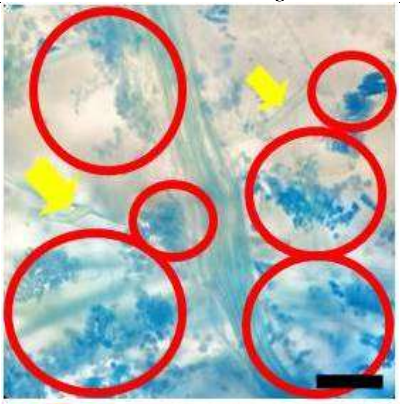
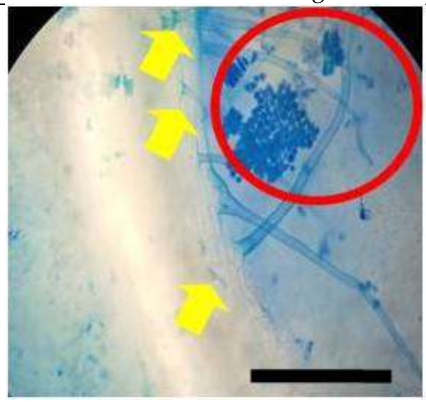
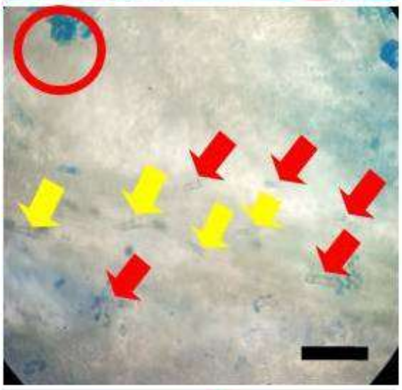
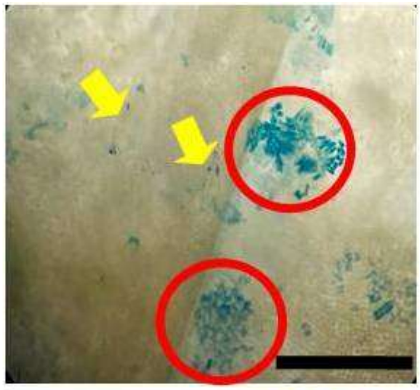
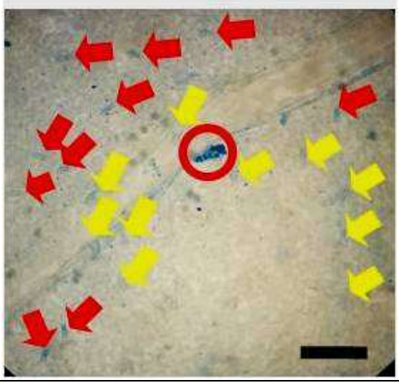
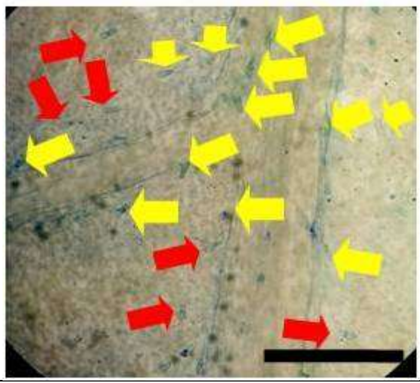
Fertilizer application likely promoted epidermal differentiation by enhancing photosynthesis, pigment accumulation, and growth (Choudhary et al., 2022; Jama-Rodzeńska et al., 2022; Khourchi et al., 2022; Lv et al., 2022; Balázs et al., 2023; El-Desouki et al., 2024; Mthiyane et al., 2024). Increased photosynthesis drives phytohormone biosynthesis, as glucose provides both energy and carbon skeletons for auxin, cytokinin, gibberellin, ethylene, ABA, brassinosteroid, salicylic acid, and jasmonic acid production (Fanciullino et al., 2014; Hashimoto et al., 2016; Eckert et al., 2014; D’Alessandro & Havaux, 2019; Mandal & Dutta, 2020; Swapnil et al., 2021; Machín et al., 2023; Choi, 2024; He et al., 2020; Hedden, 2020; Seo & Marion-Poll, 2019; Hayat et al., 2007; Liu et al., 2019; Havko et al., 2016; Nguyen et al., 2022; Gao et al., 2024). Glucose-derived carbon fuels tryptophan-dependent auxin synthesis (Mroue et al., 2018; Blakeslee et al., 2019; Pérez-Llorca et al., 2019; Fàbregas & Fernie, 2021; Mishra et al., 2022), supports cytokinin and gibberellin biosynthesis (Kieber & Schaller, 2014; Kiba et al., 2019; Bergman et al., 2024), and provides precursors for ABA, ethylene, brassinosteroids, salicylic acid, and jasmonic acid (Fanciullino et al., 2014; Seo & Marion-Poll, 2019; Sun et al., 2022; Bajguz et al., 2020; Hayat et al., 2007; Liu et al., 2019; Havko et al., 2016; Nguyen et al., 2022). These hormones collectively regulate trichome initiation, epidermal morphogenesis, and defense signaling (Fàbregas & Fernie, 2021). The marked increase in trichome density and diversity under higher POC concentrations suggests POC enhances photosynthesis and activates hormone-mediated structural defenses against herbivores and pathogens.

Plant hormone signaling is central to trichome initiation and patterning, coordinating epidermal cell differentiation, gene expression, and defense responses (Wang et al., 2021). Auxin regulates epidermal cell fate and interacts with cytokinin and gibberellin to control trichome distribution and number (Yang & Ye, 2013; Matías-Hernández et al., 2016; Li et al., 2021; Yuan et al., 2021). Gibberellins and cytokinins act synergistically in adaxial trichome induction, while ethylene promotes epidermal cell division, endoreduplication, and branching, often acting with auxin and cytokinin under stress (Matías-Hernández et al., 2016; Zhang et al., 2020; Li et al., 2021). Jasmonic acid directly regulates glandular trichome formation and defense metabolite production, typically synergizing with gibberellins but sometimes antagonized by salicylic acid (Campos et al., 2009; Saini et al., 2015; Lv et al., 2021; Li et al., 2022; Silva et al., 2024). Crosstalk among kinetin, salicylic acid, and jasmonic acid modifies glandular trichome protein profiles, affecting cuticle biosynthesis, plastid function, and secondary metabolism (Dimopoulos et al., 2025). Brassinosteroids interact antagonistically with jasmonic acid, with brassinosteroid deficiency enhancing and jasmonic acid deficiency suppressing trichome-mediated defenses (Campos et al., 2009; Saini et al., 2015;

Silva et al., 2024). Collectively, these pathways indicate that jasmonic acid is a key regulator of trichome development and plant defense, integrating with gibberellin and brassinosteroid signaling to optimize structural and chemical defenses (Li et al., 2022).

Table 3. Anatomical Review of Leaf Tissue of Cayenne Pepper Plants (*Capsicum frutescens*) with Different Fertilizer Concentration Variations

Cayenne Pepper Tissue	Microscope Observation		Description
	100x Magnification	400x Magnification	
P0 (Control)			The trichomes formed were fewer than the other treatments. Most of the trichomes were found in the midrib and were classified as non-glandular trichomes
P1(2.50 g NPK)			Trichomes formed were more abundant than it was found on the negative control treatment. The abundance of trichomes was not only in the midrib but also in the leaf tissue. The trichomes found were non-glandular and glandular types
P2 (POC 5.00 g/L)			The trichomes formed were concentrated in the midrib and surrounding areas. The trichomes formed were of the non-glandular and glandular types
P3 (POC 7.50 g/L)			Glandular and non-glandular trichomes were mostly formed in the abaxial part. Glandular trichomes dominated leaf tissue, while non-glandular trichomes dominated the midrib

Cayenne Pepper Tissue	Microscope Observation		Description
	100x Magnification	400x Magnification	
P4 (POC 10.00 g/L)			There was a pathogenic fungal infection that caused damage to the leaf tissue. The trichomes formed tend to be the non-glandular type that are concentrated in the midrib
P5 (POC 12.50 g/L)			Non-glandular and glandular trichomes were formed, concentrated in the midrib. In addition, there were spores of pathogenic fungi in the leaf tissue
P6 (POC 15.00 g/L)			Non-glandular trichomes were abundant in the midrib, while glandular trichomes were very few in number in the adaxial part of the leaf

Note: yellow arrows indicate non-glandular trichomes; red arrows indicate glandular trichomes; red circles indicate the presence of pathogen spores. Bar= 10 mm.

The effect of biotic stress on trichome formation was also reported by Kim et al. (2011). It is known that there is a relationship between the phenotype of trichome-forming and various resistances to biotic stress in cayenne plants. Furthermore, it is also known that there is a relationship between the phenotype of trichome-forming and resistance to cayenne spot virus. This is known from the density of trichomes on the main stem, which is closely related to resistance to viruses in cayenne plants. According to Grishkan (2024), soil, which is commonly known as a planting medium, is a complex environment consisting of various organisms. Fungi are one type of organism that can be found in soil. These organisms are known to be able to secrete enzymes, organic acids, and play an important role in the process of decomposition, aggregation, and soil stabilization. Although they have an important role, fungi can also act as pathogenic agents in agricultural cultivation. It is also reported from other reports that soilborne plant diseases are generally caused by infection from soil pathogenic fungi through the root system. These fungi reside in the soil for a long period. During this time, the pathogenic fungus forms chlamydospores, penetrates the root system, expands the tissue, colonizes, and metastasizes in the xylem. It also causes systemic damage, chlorosis, and death in plants (Arie, 2019). Huchhellman et al. (2017) also described that glandular trichomes can be found in about 30% of vascular plant species. Their function is to secrete or store secondary metabolites, which contribute to the plant's defense system against the environment.

Study Limitations and Considerations

This study did not include direct nutrient composition analysis of the locally produced liquid organic fertilizer (POC) due to the unavailability of certain laboratory facilities in the study area. Instead, the POC was prepared following the standard farmer formulation in Tarakan City, consisting of fermented livestock manure and plant residues. Although precise nutrient data were not obtained, the composition is supported by published reference values describing similar organic formulations. Similarly, quantitative measurements of trichome density could not be performed due to the lack of automated imaging and counting equipment. Instead, observations focused on morphological diversity, distribution patterns, and qualitative abundance across treatments.

Future studies could address these gaps by using portable nutrient testing kits or simple colorimetric assays for NPK determination, which are accessible and low-cost for field settings. For trichome quantification, smartphone-based photomicrography combined with open-source image analysis software (e.g., ImageJ) could provide reliable, low-cost trichome density counts, increase reproducibility, and allow basic statistical comparisons even in resource-limited laboratories.

Conclusion

Observations in this study indicated that non-glandular trichomes were more commonly found on cayenne pepper (Capsicum frutescens) leaves, mostly along the abaxial midrib and veins. Variation in trichome number and form appeared to increase in plants receiving liquid organic fertilizer (POC), particularly at concentrations of 10–15 g/L. These observations suggest that POC may influence trichome development under field conditions on ultisol soils. Although further quantitative analysis is needed, the present findings provide preliminary information on the morphological responses of cayenne pepper to organic fertilization in tropical cultivation systems.

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Author Contributions

Conceptualization, N.C. and A.M.; methodology, N.C. and N.J.; software, —; validation, A.M. and N.J.; formal analysis, N.J. and M.A.; investigation, N.C., N.J., M.A., S.A.L., and M.; resources, A.M.; data curation, N.J. and M.A.; writing—original draft preparation, N.C.; writing—review and editing, A.M. and S.A.L.; visualization, M.A. and M.; supervision, A.M.; project administration, N.C.; funding acquisition, N.C. All authors have read and approved the published version of the manuscript.

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Conflicts of Interest

The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

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