

EFFECTS OF TOMATO EXTRACT AND EGGSHELL POWDER ON PRE-NURSERY OIL PALM SEEDLINGS

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ABSTRACT

*This study evaluated the individual and interactive effects of eggshell powder and tomato extract on the early growth of oil palm seedlings (*Elaeis guineensis* Jacq.) in the pre-nursery stage. The experiment was conducted in Medan, North Sumatra, Indonesia, from December 2025 to March 2026 using a 4 x 4 factorial randomized complete block design with three replications. Eggshell powder was applied at 0, 5, 10, and 15 g per polybag, while tomato extract was applied at 0, 10, 20, and 60 mL L⁻¹. Plant height, stem diameter, leaf area, and leaf number were recorded from 5 to 12 weeks after planting (WAP). Data were analyzed by analysis of variance followed by Duncan's Multiple Range Test at the 5% level. Eggshell powder significantly affected stem diameter from 6 to 12 WAP and leaf area at 12 WAP; the 10 g treatment produced the greatest stem diameter (7.59 mm), whereas 15 g produced the greatest leaf area (21.62 cm²). Tomato extract significantly affected leaf number at 6 and 12 WAP, with 60 mL L⁻¹ producing 3.56 leaves at 12 WAP. Significant interactions were detected at 12 WAP for plant height (C3T3, 22.61 cm) and stem diameter (C2T1, 8.00 mm). These results indicate that the two organic inputs influenced different components of early seedling growth and that their benefits were dose- and time-dependent.*

*Keywords: eggshell powder; tomato extract; *Elaeis guineensis*; organic amendment; pre-nursery*

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INTRODUCTION

Oil palm (*Elaeis guineensis* Jacq.) is a strategic plantation crop in Indonesia, and the quality of planting material established during nursery management has important implications for subsequent field performance. National statistics continue to document the large scale of Indonesian oil-palm cultivation and production, reinforcing the need for efficient and sustainable nursery practices (Badan Pusat Statistik [BPS], 2024). In a two-stage nursery system, seedlings are first maintained in the pre-nursery before being transferred to the main nursery; therefore, early vegetative growth must be supported by suitable media, adequate nutrients, water, and appropriate microclimatic management (Pahan, 2012; Anhar et al., 2021).

Topsoil is commonly used as a nursery medium, but the repeated extraction of fertile topsoil creates practical and environmental constraints. Organic inputs that recycle locally available residues are therefore attractive as complementary amendments. Their effectiveness, however, depends on nutrient composition, decomposition rate, application dose, and the physiological demand of the crop. Studies in oil-palm pre-nursery systems have shown that organic fertilizers may produce significant responses for some growth traits but not others, indicating that nutrient release and treatment concentration are critical determinants of seedling response (Lidar & Muryanto, 2020; Setyorini et al., 2020; Anhar et al., 2021).

Eggshell waste is a potential calcium-rich amendment. Processed eggshell is dominated by calcium carbonate and can also contain smaller amounts of phosphorus, magnesium, and organic components (Mahreni et al., 2012; Laohavisuti et al., 2021). Experimental evidence indicates that finely ground eggshell can increase soil calcium and alter soil reaction, but the magnitude and timing of the response depend on dose, soil properties, and particle characteristics (Vu et al., 2022; Sebonela et al., 2024). Plant experiments have consequently produced mixed outcomes: eggshell application did not consistently improve all vegetative traits in mustard, while selected doses improved biomass or quality traits in lettuce and other crops (Ahlina & Supardi, 2023; Putri et al., 2023). A direct pre-nursery oil-palm study using eggshell and mycorrhiza also suggests that eggshell-based inputs can be evaluated as part of nutrient-management strategies under specific media conditions (Afrianti et al., 2020).

Tomato-derived material represents a different type of organic input. Rather than functioning primarily as a mineral amendment, tomato extract has been explored as a natural plant-growth-regulating input. In pre-nursery oil palm, natural and synthetic plant growth regulators have produced trait-specific responses, and a previous study reported that tomato extract at 10 mL L⁻¹ improved several seedling variables relative to other tested treatments (Ernita et al., 2023). More broadly, plant growth regulators influence cell division, elongation, differentiation, and source-sink relations, but their effects are strongly concentration-dependent and interact with plant nutritional status and developmental stage (Davies, 2010; Taiz et al., 2015).

The concentration-dependent nature of crop responses is also evident in recent experiments published in Algebra. Paclobutrazol concentration and application method produced different growth and production responses in beet (Hasibuan et al., 2024), while gibberellin and humic acid affected selected growth and yield variables of cherry tomato (Revina Azhari et al., 2025). These studies emphasize that an organic or growth-regulating input cannot be assumed to be beneficial at every dose; its performance must be tested experimentally under the target crop and production stage.

Combining eggshell powder with tomato extract may provide complementary functions: eggshell powder can act as a calcium-containing soil amendment, whereas tomato extract may act as a physiological stimulant. Nevertheless, plant mineral nutrition is governed by balanced nutrient supply; calcium cannot substitute for primary macronutrients, and a growth regulator cannot compensate for inadequate mineral nutrition (Marschner, 2012; Purba et al., 2021; Lakitan, 2019). This provides a rationale for testing both the individual factors and their interaction rather than presuming a synergistic response.

This study therefore aimed to determine (1) the effect of eggshell powder, (2) the effect of tomato extract, and (3) the interaction between eggshell powder and tomato extract on the growth of oil palm seedlings in the pre-nursery stage. The working hypothesis was that at least one dose of each input, or a specific combination of the two, would significantly alter plant height, stem diameter, leaf area, or leaf number during 5-12 WAP.

RESEARCH METHODS

The experiment was conducted from December 2025 to March 2026 at the agricultural field of the Faculty of Science and Technology, Tjut Nyak Dhien University, Medan, North Sumatra, Indonesia, at approximately 28 m above sea level. DxP Simalungun oil palm germinated seeds from the Indonesian Oil Palm Research Institute (PPKS) were used. The principal materials were topsoil, chicken eggshells, ripe tomatoes, and NPK fertilizer. The nursery was protected with approximately 55% shade.

A factorial randomized complete block design was used with two treatment factors and three replications. Eggshell powder (C) consisted of four levels: C0 = 0 g (control), C1 = 5 g per polybag, C2 = 10 g per polybag, and C3 = 15 g per polybag. Tomato extract (T) consisted of four concentrations: T0 = 0 mL L-1 (control), T1 = 10 mL L-1, T2 = 20 mL L-1, and T3 = 60 mL L-1. The 4 x 4 factorial arrangement generated 16 treatment combinations and 48 experimental plots. Each plot contained five seedlings, giving 240 seedlings in total; three seedlings per plot were used as observation samples.

For eggshell powder preparation, chicken eggshells were washed, sun-dried for approximately 3 h, ground using a blender, and sieved to obtain a fine and relatively uniform powder. The powder was weighed according to treatment and incorporated/applied to the polybag surface one week before planting. This preparation was standardized to improve particle uniformity because the agronomic behavior of eggshell-derived calcium is sensitive to particle size and dissolution conditions (Vu et al., 2022; Sebonela et al., 2024).

Tomato extract was prepared from 2 kg of soft ripe tomatoes. The tomatoes were washed, blended, filtered through gauze, mixed with 2 L of water, placed in a 3-L container, and allowed to stand for one week. Treatment concentrations were prepared in irrigation water. Root-zone application began at 1 WAP and was repeated weekly. The tested concentration range was selected to evaluate a wider response than the 10 mL L-1 level previously reported as effective for selected pre-nursery oil-palm traits (Ernita et al., 2023).

Plant height, stem diameter, leaf area, and leaf number were measured weekly from 5 to 12 WAP. Plant height was measured from the media surface to the tip of the youngest incompletely opened leaf. Stem diameter was measured with a digital caliper. Leaf area was estimated as leaf length x leaf width x 0.52. Leaf number was determined by counting developed leaves. Data were analyzed using factorial analysis of variance for a randomized complete block design. When the F-test indicated a significant treatment effect, means were separated using Duncan's Multiple Range Test (DMRT) at alpha = 0.05. Because the source dataset reports significance decisions and DMRT groupings rather than exact probability values, results are reported as significant or non-significant at the 5% level without inventing unreported p-values.

RESULTS AND DISCUSSION

Overall significance pattern

Treatment responses were trait- and time-specific. Eggshell powder did not significantly affect plant height or leaf number during 5-12 WAP, but it significantly affected stem diameter from 6 through 12 WAP and leaf area at 12 WAP. Tomato extract did not significantly affect plant height, stem diameter, or leaf area at the observed ages, but it significantly affected leaf number at 6 and 12 WAP. The interaction between the two factors was non-significant for most observations and became significant only for plant height and stem diameter at 12 WAP. Table 1 summarizes these significance patterns.

Table 1. Summary of treatment significance during 5-12 WAP

Growth variable	Eggshell powder (C)	Tomato extract (T)	C x T interaction
Plant height	NS, 5-12 WAP	NS, 5-12 WAP	Significant at 12 WAP only
Stem diameter	Significant, 6-12 WAP	NS, 5-12 WAP	Significant at 12 WAP only
Leaf area	Significant at 12 WAP only	NS, 5-12 WAP	NS, 5-12 WAP
Leaf number	NS, 5-12 WAP	Significant at 6 and 12 WAP	NS, 5-12 WAP

Note. WAP = weeks after planting; NS = non-significant at the 5% level.

Main effects at 12 WAP

At 12 WAP, the clearest main effect of eggshell powder was observed in stem diameter and leaf area. Stem diameter increased from 6.96 mm in the control to 7.59 mm at C2 (10 g per polybag), after which it was slightly lower at C3 (7.44 mm). Leaf area showed a stronger dose-related pattern,

increasing from 15.16 cm² at C0 to 21.62 cm² at C3. In contrast, the main effect of tomato extract at 12 WAP was significant only for leaf number, where T3 (60 mL L⁻¹) produced 3.56 leaves compared with 3.11 leaves in the untreated control. Main-factor means at 12 WAP are presented in Table 2.

Table 2. Main-factor means of oil palm seedling growth at 12 WAP

Treatment	Plant height (cm)	Stem diameter (mm)	Leaf area (cm ²)	Leaf number
C0	19.02	6.96 b	15.16 c	3.33
C1	19.71	7.35 ab	15.46 b	3.39
C2	20.40	7.59 a	18.10 ab	3.36
C3	20.09	7.44 a	21.62 a	3.36
T0	18.83	7.23	16.46	3.11 b
T1	19.63	7.46	20.23	3.39 ab
T2	20.23	7.26	15.99	3.39 ab
T3	20.52	7.40	17.57	3.56 a

Note. Within a factor and response variable, means followed by different letters differ according to DMRT at 5%. Means without letters belong to a non-significant main effect.

Interaction effects at 12 WAP

The interaction response was delayed until the end of the observation period. At 12 WAP, the highest plant height was recorded for C3T3 (15 g eggshell powder per polybag + 60 mL L⁻¹ tomato extract), reaching 22.61 cm. The lowest height was observed for C0T0 (17.28 cm). For stem diameter, the largest value occurred at C2T1 (10 g eggshell powder per polybag + 10 mL L⁻¹ tomato extract), reaching 8.00 mm, while C0T0 produced 6.42 mm. Importantly, the combination that maximized height differed from the combination that maximized stem diameter, demonstrating that the two traits did not respond identically to the same treatment intensity (Table 3).

Table 3. Interaction means for plant height and stem diameter at 12 WAP

Combination	Plant height (cm)	Stem diameter (mm)
C0T0	17.28 h	6.42 de
C0T1	19.29 de	7.27 abc
C0T2	20.42 bcd	6.97 e
C0T3	19.09 ef	7.17 abcd
C1T0	19.20 de	7.49 bcd
C1T1	18.34 g	7.23 abcd
C1T2	22.02 ab	7.40 abc
C1T3	19.28 de	7.28 ab
C2T0	20.24 cd	7.36 cd
C2T1	20.97 abc	8.00 a
C2T2	19.28 de	7.46 cd
C2T3	21.10 abc	7.56 cd
C3T0	18.59 fg	7.65 abc
C3T1	19.93 de	7.32 cd
C3T2	19.21 de	7.22 de
C3T3	22.61 a	7.59 bc

Note. Means within a column followed by different letters differ according to DMRT at 5%.

Effect of eggshell powder

The significant increase in stem diameter from 6 to 12 WAP, together with the leaf-area response at 12 WAP, suggests that eggshell powder contributed more strongly to structural growth than to rapid height elongation or leaf initiation. This interpretation is consistent with the chemical role of eggshell-derived calcium carbonate. Calcium contributes to cell-wall and membrane function, while eggshell materials may also modify the chemical environment of the rooting medium. However, calcium is not a substitute for the primary macronutrients required for rapid vegetative growth, which helps explain why plant height and leaf number did not respond significantly to eggshell powder alone (Marschner, 2012; Taiz et al., 2015).

The response also appears to be time-dependent. Ground eggshell is not an instantly soluble fertilizer; its agronomic effect depends on dissolution, particle size, medium acidity, and reaction time. Vu et al. (2022) demonstrated that eggshell powder can increase soil and plant calcium and improve groundnut performance at appropriate rates, while Sebonela et al. (2024) showed that eggshell application can increase soil pH and phosphorus availability. These mechanisms provide a plausible explanation for why differences in this study became clearer at later observations. The

pattern is also compatible with the variable crop responses reported by Ahlina and Supardi (2023) and Putri et al. (2023), where eggshell-based treatments did not uniformly enhance every measured trait.

Within the present experiment, C2 produced the largest stem diameter, whereas C3 produced the largest leaf area. This is agronomically important because it argues against describing a single eggshell dose as universally optimal. The effect should instead be interpreted by target trait. Previous work on oil-palm seedlings has similarly shown that organic nutrient sources can influence growth variables differently depending on dose and nutrient balance (Afrianti et al., 2020; Lidar & Muryanto, 2020; Setyorini et al., 2020).

Effect of tomato extract

Tomato extract significantly increased leaf number at 6 and 12 WAP but did not significantly change plant height, stem diameter, or leaf area as a main effect. The strongest response at 12 WAP occurred at T3 (60 mL L⁻¹), which produced 3.56 leaves. This result indicates that the tested extract functioned as a selective biostimulatory or growth-regulating input rather than as a complete fertilizer. Plant growth regulators operate at low concentrations and their effects depend on tissue sensitivity, developmental stage, endogenous hormone status, and mineral nutrition (Davies, 2010; Lakitan, 2019). Consequently, stimulation of leaf initiation can occur without proportional increases in all other vegetative variables.

The result partly agrees with Ernita et al. (2023), who reported beneficial responses of pre-nursery oil palm to tomato extract, although the most effective concentration and responsive traits were not identical. Such differences are expected because extraction procedure, application interval, seedling material, basal nutrition, and environmental conditions can change treatment performance. Concentration-dependent responses are also evident in experimental studies of plant growth regulators and organic stimulants in other crops (Hasibuan et al., 2024; Revina Azhari et al., 2025). The present finding therefore supports optimizing tomato extract specifically for the intended response instead of assuming that a concentration beneficial for one variable will maximize all growth traits.

Because tomato extract alone did not significantly increase stem diameter or leaf area, it should not be interpreted as a replacement for balanced mineral nutrition. Nutrient availability remains fundamental for chlorophyll formation, energy transfer, osmotic regulation, and structural biomass accumulation (Purba et al., 2021; Marschner, 2012). Related work with liquid organic fertilizers in oil-palm pre-nursery systems also shows that organic liquids may generate modest or non-significant responses unless nutrient concentration and dose match seedling requirements (Anhar et al., 2021).

Interaction between eggshell powder and tomato extract

Most interaction effects were non-significant, indicating that the two inputs generally acted independently during the first 11 weeks. A significant interaction emerged at 12 WAP for plant height and stem diameter. The late appearance of this interaction is biologically reasonable because a mineral amendment and a growth-regulating extract operate through different processes and time scales. Eggshell-derived calcium becomes available gradually, whereas physiologically active compounds in organic extracts may act more rapidly but can also be degraded or diluted in the rooting environment. The net response therefore depends on synchrony between nutrient availability and tissue responsiveness (Davies, 2010; Sebonela et al., 2024).

The highest plant height was obtained at the highest tested levels of both factors (C3T3), whereas the highest stem diameter occurred at an intermediate eggshell dose combined with the lowest non-zero tomato-extract concentration (C2T1). This contrast is important: it demonstrates that the interaction was not a simple linear dose-response. Similar complexity is commonly observed when organic fertilizers or biostimulants are combined, because each treatment may alter nutrient supply, medium chemistry, or plant metabolism in a different direction. Liquid organic fertilizer studies emphasize that nutrient composition and dilution strongly affect crop response (Phibunwatthanawong & Riddech, 2019), and compost containing tomato residues has recently been shown to improve selected pre-nursery oil-palm growth traits under specific dose and watering regimes (Ariyanti et al., 2025).

From a practical perspective, the results support using treatment objectives rather than a single blanket recommendation. If nursery management prioritizes stem robustness, C2 performed well as a main eggshell treatment and C2T1 produced the greatest stem diameter at 12 WAP. If leaf-area development is prioritized, C3 gave the greatest main-effect mean. If the objective is final plant height within the tested period, C3T3 was superior. Further research should test longer observation periods,

characterize media pH and exchangeable calcium before and after treatment, quantify the nutrient and active-compound composition of tomato extract, and compare eggshell powder with more soluble calcium forms. These measurements would help separate nutritional, liming, and growth-regulatory mechanisms.

CONCLUSIONS

Eggshell powder, tomato extract, and their interaction affected different components of oil palm seedling growth in the pre-nursery. Eggshell powder significantly increased stem diameter from 6 to 12 WAP and affected leaf area at 12 WAP; C2 (10 g per polybag) produced the largest stem diameter (7.59 mm), while C3 (15 g per polybag) produced the largest leaf area (21.62 cm²). Tomato extract significantly affected leaf number at 6 and 12 WAP, and T3 (60 mL L⁻¹) produced the highest mean at 12 WAP (3.56 leaves). Significant interactions occurred at 12 WAP for plant height and stem diameter: C3T3 produced the tallest seedlings (22.61 cm), while C2T1 produced the largest stem diameter (8.00 mm). The responses were therefore dose-, trait-, and time-dependent. Eggshell powder and tomato extract should be viewed as complementary inputs rather than complete substitutes for balanced nursery fertilization. Longer-term trials with soil chemical measurements and chemical characterization of the tomato extract are recommended before a generalized nursery recommendation is made.

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