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RESEARCH PAPER

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Effects of various calcium sources and application methods on the growth, yield, and fruit quality of tomato (*Solanum lycopersicum* L.)

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ABSTRACT

For millions of farmers around the world, growing tomatoes presents financial potential. Nevertheless, the sector still faces several production constraints, such as the century-old issue of blossom end rot caused by a calcium deficiency. Notably, there is a lack of locally available scientific research on how to mitigate this physiological disorder using biological calcium sources and comparing its efficacy to commercially available calcium, specifically in the Philippines. The study was conducted from February 2025 to May 2025 at SEAIT Agricultural Research Center (SARC), Tupi, South Cotabato, to determine the effect of different calcium sources (calcium nitrate, eggshell, & snail shell) and the method of application (powder and extract) on the growth, production, yield, quality, and profitability of tomato. A 4×2 factorial experiment using a Randomized Complete Block Design (RCBD) and three replications was used for the study. Results of the study revealed that different calcium sources, whatever the method of application, significantly affected the plant height at 60 DAT, number of days to 50% flowering, number of flowers, number of fruits, flower abscission rate, blossom end rot rate, firmness, total soluble solids, weight of fruits, weight of marketable and non-marketable fruits, fruit diameter, and yield attributes of tomato. Furthermore, blossom end rot was less observed on tomatoes applied with organic calcium sources, specifically eggshell and snail shell, improving fruit quality and yield. The result suggests that utilizing these biological calcium sources improves tomato production outcomes and attains economic return by up to 323.97%.

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INTRODUCTION

Globally, tomato production is a significant contributor to the agricultural industry, providing substantial economic benefits to farmers. The industry, though, is impacted by an enormous limitation with abiotic factors exerting a negative influence on fruit yield and quality. Blossom end rot (BER), dating back over a century, is one of such limitations. To address this physiological disorder, producers are increasingly turning to synthetic fertilizers, which can degrade soil and contaminate water.

Tomato is an extensively cultivated commodity because of its broad adaptability and popularity in fast food, increased value, and many processed products (Wang *et al.*, 2023). As the second most popular vegetable after potatoes (Rao and Agarwal, 1999; Quinet *et al.*, 2019), tomatoes are known to contain a substantial number of carotenoids, lycopene, and antioxidants that may help prevent diseases like cancer and heart disease (Bertin and Génard, 2018). Moreover, tomato is also considered to be a potent horticultural crop that plays a significant role in the human diet (Sharma *et al.*, 2021).

As one of the most extensively farmed and prized crops in the world, tomatoes are grown for their nutritional content and culinary diversity in the Philippines. In the SOCCSKSARGEN region, tomato production dropped by 15.1 percent in the first quarter of the previous year (PSA, 2024). The productivity of tomatoes in the region is significantly lower than in other regions, and farmers are facing an ongoing challenge in finding ways to enhance the quality of tomato fruits despite the challenges of both biotic and abiotic factors. Furthermore, growers are having trouble with Blossom-end rot (BER), a physiological disorder that frequently affects tomato fruits. It is initially identified by a water-soaked lesion at the blossom end of the fruit. This lesion rapidly progresses, resulting in a blackened, dry, and sunken leathery area (Taylor and Locascio, 2004).

Blossom end rot (BER) is reported to be a disease related to calcium deficiency, considering that it was determined to be generally associated with under-accumulation of calcium inside the fruits (Shear, 1975; Taylor and Locascio, 2004; Watanabe *et al.*, 2021). Increased cell expansion during fruiting and reduced calcium transport to the distal fruit regions contribute to the development of blossom-end rot (Sethi *et al.*, 2024). This nutrient is considered the single most vital nutrient for plants, with three functions of particular importance: cation/anion balance, facilitation of cellular transport, and promotion of root growth.

In response to this physiological disorder, control measures have been developed and comprise several approaches. Some of these include the implementation of chemical control, an aspect where high-calcium fertilizers have been widely applied in agriculture to correct this disorder (Shao *et al.*, 2013; Haleema *et al.*, 2024). However, this method of inorganic fertilizer has a negative environmental effect, especially if it is applied improperly, and it tends to be costly. Sustainable agriculture brought a new way to reduce and remove the adverse impacts of synthetic fertilizers on human health as well as the environment.

So far, there is limited scientific literature that systematically compares the effects of various sources of calcium on tomato yield and fruit quality, as well as their efficacy in minimizing blossom end rot (BER). This study falls into the principles of sustainable development and aims to assess the impact of different biological sources of calcium on blossom end rot. Thus, the study was conducted to determine the effects of calcium sources and application methods on the growth, production, quality, yield, and BER incidence in tomatoes.

MATERIALS AND METHODS

Experimental area

The study was conducted at SEAIT Agricultural Research Center (SARC) with the coordinates of 6°22'41"N 124°56'07"E at an elevation of 182 meters above mean sea level. The site was characterized by a sandy loam texture with moderate levels of Nitrogen, Phosphorus, and Potassium. The experimental area also experienced very high humidity at 95% with low rainfall of 2.4 inches during the study duration.

Seed procurement

The tomato seeds (Diamante Max F1) were obtained from an authorized dealer of East-West Seed Company (Lim, 2024). Riboldi *et al.* (2018) mentioned that more BERs were observed in varieties of tomatoes with long fruit lengths, most probably due to factors that would interfere with the transportation of calcium to the distal end.

Soil sampling and analysis

A random collection of soil samples from the experimental area was done using a spade. The soil samples were laid out on a clean basin to facilitate air drying for seven days. A soil sample weighing one kilogram was carefully prepared and pulverized into a fine powder to eliminate any foreign materials (Lim, 2024). The collected samples were sent to the Bureau of Soil and Water Management (BSWM) for soil analysis, located in General Santos City, South Cotabato. The fertilizer recommendation of (80-75-60) for the study was determined based on the measured nitrogen, phosphorus, and potassium (NPK) content of the soil. The soil exhibited a sandy loam texture and a nearly neutral pH of 6.8, with medium levels of organic matter (3.5), available nitrogen, phosphorus, and potassium (Fig. 1).

Land preparation

The field was prepared for two (2) weeks before transplanting using different tillage equipment so that the stubble and weeds from earlier crops would have enough time to decompose. Weeds and other vegetation in the area were eradicated. Plowing was done to extensively pulverize the area (DA RFO-O2, 2017).

Lay-outing and staking

The experiment utilized a factorial block design with three replicates. Each block contained eight sub-plots, with each sub-plot assigned a distinct treatment (Coulibaly *et al.*, 2023). The experimental area was laid out one week before planting using steel tape and twine. Staking was done using bamboo sticks.

Fig. 1. Documentation of (A) soil sample preparation (B) Field layout of the study (C) Collection of snail shells and eggshells (D) Fertilizer application (E) application of powdered calcium source (F) Application of calcium extracts (G) BER occurrence in control plants (H) BER occurrence in tomato treated with calcium nitrate (I) Fruit production of tomatoes treated with biological calcium

Seedling production

A 1:1 mixture of garden soil and vermicompost was used as growing media. The garden soil was sterilized by a sun-drying method. The tomato cultivar Diamante F1 was used in the research. A single seed was sown in each cell. Seedlings received irrigation according to their specific water requirements. Two weeks after sowing, the seedlings were applied with 50 grams of urea (46-0-0) per seedling tray. Until they are prepared for transplantation, the seedlings were kept in partial shade (DA RFO-O2, 2017).

Hardening

One week before permanently moving the plants onto the field, the seedlings were hardened by progressively exposing them to sunlight. The seedlings were exposed until ten in the morning on the first day, and the amount of time was increased each day until the seedlings could tolerate the heat of the sun all day. To avoid transplant shock and to acclimate developing seedlings to field conditions, watering was decreased at 2-day intervals (DA RFO-O2, 2017).

Treatment preparation

Three different calcium sources were tested (eggshells, snail shells, and calcium nitrate). Calcium powder was prepared by collecting eggshells from different egg and balut vendors, local bakery and pastries shop, and food houses, while snail shells were gathered from nearby rice fields of Tupi, Polomolok, Koronadal, and Norala, South Cotabato. The shells were cleansed, air-dried, and then pulverized using a stainless-steel blade blender (Coulibaly *et al.*, 2023).

For calcium extract (Water-Soluble Calcium) preparation, shells were crushed into small pieces, then it was lightly roasted to remove any organic substances that may rot and deteriorate during the process. Three (3) tablespoons of roasted shells were put in a container filled with one (1) liter of brown rice vinegar (BRV). The eggshells were moved up and down, emitting bubbles, and melted to become a neutralized liquid. The process was done if there were no more movements or bubbles. Calcium extracts were fermented for three days (Reddy, 2011). Subsequently, 25 milliliters of extract were diluted in 2.5 liters of water before application.

YaraLiva Nitrabor, containing 15% nitrogen, 18.3% calcium (Ca), and 0.3% boron (B), served as the calcium nitrate source in this study. This was procured from a local agricultural supply store (Lim, 2024).

Transplanting

Seedlings were transplanted 30 days after sowing (DAS), with one seedling placed in each hill. To maintain a complete crop stand, replacement plants were introduced five days after the initial transplanting (Lim, 2024).

Fertilizer application

The fertilizer reference for this study was the recommended nitrogen-phosphorus-potassium (NPK) rate of 80-75-60 kilograms per hectare of inorganic fertilizer, as determined by soil analysis. The application rate was calculated for each planting hill. The needed NPK fertilizers were applied at basal, at 15 DAT, and at 30 DAT, respectively (Department of Agriculture, 2017).

Treatment application

Treatments were applied in four different stages of tomato. The first treatment application was done at the seedling establishment stage (10 DAT) (Coulibaly *et al.*, 2023). The second, third, and fourth applications were administered at the vegetative stage (20 DAT), early flowering stage (30 DAT), and early fruiting stage (40 DAT), respectively (Lim, 2024). Each seedling received 75 grams of powder applied around the base of the plant (Coulibaly *et al.*, 2023). In addition, 250 milliliters of diluted calcium extract was administered to each plant at the same interval (Coulibaly *et al.*, 2023). YaraLiva Nitrabor was the source of Calcium nitrate in the study and was purchased from a local agricultural supply store. This was applied through granular and foliar application according to the suggested dosage of the product (150g/ 16L of water at a rate of 150mL per hill) for foliar application, and (5g per plant) for granular application (Yara Fertilizers Philippines Inc., 2024).

Trellising

To ensure the growth of tomatoes, a trellis was provided at 15 DAT. This was done using locally available materials such as twine, string, and poles. The main branches of the plants were tied to the stakes to secure them in place, helping them thrive despite the weather conditions (DA RFO-O2, 2017).

Care and management

Watering was done whenever necessary to supply a sufficient amount of water, which is needed for optimum plant growth. More so, weeding was done as often as necessary when unwanted plants and vegetation appeared. Pests and diseases were monitored daily. The occurrence of insect pests and diseases such as Leaf Curling, Septoria, Early blight, and Late blight was rapidly managed using chemical control, pruning, and complete eradication (Lim, 2024).

Harvesting

Harvesting was done 60 days after transplanting. This was performed following three (3) cycles of harvesting with three (3) days' intervals. Fruits were harvested at the breaker stage when the blossom end turns pinkish or reddish (DA RFO-O2, 2017).

Data gathered

Growth parameters

Plant height at 60 DAT (cm): Plant height was recorded 60 days after transplanting by measuring from the base to the tip of the primary stem of the sample plants (Lim, 2024).

Number of days to 50% flowering: The days to 50% flowering were determined by recording the interval from transplanting until five out of ten sample plants per plot exhibited their first open flower. Results were expressed in days (Coulibaly *et al.*, 2023).

Production parameters

Number of flowers: The number of flowers on each plant was counted and recorded. The total number of flowers from all sampled plants was divided by ten to calculate the average per plant (Coulibaly *et al.*, 2023).

Number of fruits: The number of fruits per plant was counted and recorded at each harvest. The total fruit count from all harvest cycles was summed and divided by ten to calculate the average number of fruits per plant (Lim, 2024).

Flower abscission rate: The flower abscission rate for tomato was calculated as follows: the difference between the number of flowers (nf) and the number of fruits (NF) was divided by the number of flowers (nf), and the result was multiplied by 100. This was computed using the formula below (Jean *et al.*, 2015).

$$FLAR = \frac{nf - NF}{nf} \times 100$$

Blossom end rot rate: The incidence rate of Blossom End Rot (BER) per plant was calculated as the number of BER-affected fruits divided by the total number of fruits per plant, then multiplied by 100, as shown in the following formula (Lim, 2024).

$$Rate\ of\ BER = \frac{number\ of\ fruits\ with\ BER}{total\ number\ of\ fruits} \times 100$$

Fruit quality parameters

Ten freshly harvested tomato *var. Diamante Max* fruits at the breaker stage produced in each subplot in the study were used in gathering fruit quality parameters. These fruits were chosen for their size uniformity, color, and being free from defects and diseases (Acedo and Benetiz, 2021). Samples were brought to SEAIT Integrated Laboratory. The researcher washed the fruits with tap water and allowed them to air-dry before data collection. Two agriculturists were invited to evaluate all the quality parameters.

Visual quality rating (VQR): The external characteristics of each tomato fruit were evaluated according to a standardized visual quality rating (VQR) system (Subere,1997). Fruits rated 3 or below were considered unmarketable.

Fruit firmness: Tomato firmness can be improved by an adequate calcium supply. Firm tomatoes have a longer shelf life in stores, which facilitates storage and transportation (Dodgson *et al.*, 2023). Firmness was measured using a Fruit Hardness Tester (GY-3-Penetrometer). For each tomato, two readings were taken from opposite sides of the fruit, and the average of these values was calculated to represent the firmness of the sample.

Total soluble solids (TSS): Supplementing with calcium significantly improves the quality parameters of tomato, especially total soluble sugar (Lim, 2024). Total soluble solids (TSS) were measured for ten tomato fruits per subplot using juice extracted from each sample. A hand refractometer, with a range of 0 to 32 °Brix and a resolution of 0.2 °Brix, was used by applying 1 to 2 drops of clear juice to the prism (Iglesia *et al.*, 2013).

Yield parameters

Weight (kg) of fruits per plant: Fresh fruits were weighed and recorded at each harvest cycle. After the final cycle, the total fruit weights were summed and divided by ten to calculate the average fresh fruit weight per plant (Lim, 2024).

Weight (kg) of marketable fruits per plant: The weight of marketable fruits was determined by weighing all classified marketable fruits harvested from the ten sample plants that met the criteria set by the Philippine National Standards (2006). The total weight of all classified marketable fruits from every cycle of harvest was recorded. The results were expressed in kilograms (kg) (Coulibaly *et al.*, 2023).

Weight (kg) of non-marketable fruits: Researchers determined the weight of non-marketable fruits by weighing all fruits classified as non-marketable from the ten sample plants that failed to meet the criteria. The total weight of all classified non-marketable fruits from every cycle of harvest will be recorded. The results were expressed in kilograms (kg) (Coulibaly *et al.*, 2023).

Fruit diameter (cm): A vernier caliper was used to collect the fruit diameter data. The total fruit size was summed and divided by ten to determine the average fruit diameter (Lim, 2024).

Number of locules per fruit: The researcher determined the number of locules per fruit by counting each chamber in ten sample fruits from each subplot. The average was calculated by summing the counts and dividing by ten (Roohanitaziani, 2019)

Yield (ton/ha): The yield (ton/ha) was gathered by weighing all the harvested fruits from the ten (10) sample plants per plot in all harvest cycles (Lim, 2024). The yield was computed using the formula provided below (Amarullah, 2021):

$$Yield\ (ton\ per\ hectare) = \frac{yield\ per\ plot(kg) x\ 10{,}000\ m^2}{(net\ plot\ size) x\ 1000(kg\ per\ ton)}$$

Net return analysis: Return on Investment (ROI) was calculated through an economic analysis. Production costs were determined using current local prices for farm inputs and labor. Gross income was calculated using the prevailing market price per kilogram of tomatoes. ROI was then calculated as net income divided by production cost, multiplied by 100 (Lim, 2024).

$$ROI = \frac{Net\ income}{Total\ cost\ of\ production} x\ 100$$

Statistical data analysis

The collected data were analyzed using Analysis of Variance (ANOVA), appropriate for a Randomized Complete Block Design, implemented with the Statistical Tool for Agricultural Research (STAR). Treatments that exhibited statistically significant differences were further compared using Least Significant Difference (LSD) test to identify specific differences among treatment means (Lim, 2024).

RESULTS AND DISCUSSION

Plant height (cm) at 60 days after transplanting (DAT)

Table 1 presents the tomato plant height at 60 days after transplanting (DAT) as affected by various calcium sources and application methods. Based on the analysis, Factor A (calcium sources) had a significant effect on tomato plant height ($p < 0.05$). This result reveals that tomato plant height responded significantly to different calcium sources, regardless of the methods of application, with snail shell, eggshell, and calcium nitrate treatments outperforming the control. Furthermore, all calcium-treated plants, including snail shell, yielded the tallest plant height (96.23 cm), comparable with the application of eggshell (95.33 cm) and calcium nitrate (93.22 cm). Meanwhile, the control (no calcium application) had the shortest height (86.60 cm). The findings of

Coulibaly *et al.* (2023) corroborate this result, who mentioned that the application of eggshell and snail shell whenever the form significantly boosted the plant height of tomato. They also emphasized that the plants can easily absorb these organic fertilizers. Moreover, plant height is mostly determined by cell elongation in growing tissues and cell division in meristematic areas. During mitosis, calcium maintains spindle fiber production and chromosomal integrity, ensuring proper cell division (Tuna *et al.*, 2007; Abdur and Ihsan, 2012). A recent study by Weng *et al.* (2022) found that calcium improves the development of root systems, which enhances the uptake of essential macronutrients, mainly nitrogen, phosphorus, and potassium, all of which are necessary for shoot elongation and biomass production.

Plant height variation across treatments could be explained by differences in calcium bioavailability from each source and their potential effects on nutrient uptake efficiency, which influences vegetative development. According to Polese (2007), snail shells are composed of 86% calcium and organic materials. By comparison, Valera *et al.* (2003) report that eggshells contain 94% calcium carbonate, 4% organic matter, and 1% each of magnesium carbonate and calcium phosphorus. The early application of these calcium sources promotes robust growth and development in fertilized plants, as evidenced by increased calcium accumulation in plant tissues (Feagley and Fenn, 2024). This statement is supported by several authors, including Coulibaly *et al.* (2023), who found that the application of both eggshell and snail shell significantly enhanced the plant height of tomato. Moreover, Bhargaw *et al.* (2024) mentioned that calcium derived from eggshell produced a significant improvement in tomato growth. Furthermore, Yao *et al.* (2024) reported that the addition of powdered apple snail (*Pomacea canaliculata*) shells to acidic soils significantly enhanced maize growth performance and yield. Plant height, biomass accumulation, and grain yield were among the important agronomic parameters that were improved by the addition of this amendment.

Table 1. Plant height (cm) of tomato at 60 days after transplanting (DAT) as affected by various calcium sources and application methods, Sultan Kudarat State University, May 2025

Different calcium sources	Methods of application		Mean
	Powder	Extract	
A1. Control (No application)	86.60	86.60	86.60^{b}
A2. Calcium nitrate	93.07	93.37	93.22^{a}
A3. Snail shell	94.80	97.67	96.23^{a}
A4. Egg shell	93.47	97.20	95.33^{a}
Mean ^{ns}	91.99^{ns}	93.71^{ns}	92.85

CV = 2.51%; Means that share the same letter superscripts do not differ significantly at the 5% significance level according to the least significant difference (LSD) test; ^{ns} = not significant

Number of days to 50% flowering

Different calcium sources significantly affected the time required for 50% of tomato plants to flower, as presented in Table 2. Statistical analysis revealed that plants treated with calcium nitrate, snail shell, and eggshell flowered earlier, averaging 28 to 28.17 days, compared to those in the control group, which received no calcium supplementation. The control plants consistently took 31.00 days to reach 50% flowering, regardless of the method of application. This result implies that calcium supplementation, regardless of sources and methods of application, can significantly accelerate the reproductive development of the tomato plant as exhibited by its early flower initiation. Cell walls and membranes at the shoot apical meristem are strengthened by calcium. Faster progression to bloom is made possible by this structural reinforcement, which promotes earlier floral bud differentiation (Janeclare *et al.*, 2021).

This result conforms with Coulibaly *et al.* (2023), who found that the application of biological calcium sources, including egg shell and snail shell, significantly increased the flower initiation of tomato. They emphasized that snail and eggshells contain bioavailable calcium (about 86% calcium and 94% $CaCO_3$) that plants can effectively absorb. This increase in calcium absorption speeds up physiological processes like flowering. In addition, Vu *et al.* (2022) found that supplementation of calcium derived from eggshells promotes early flowering of groundnuts. Taufique *et al.* (2014) also observed the early flowering of tomato when applied with eggshell powder under potted conditions. Furthermore, it has been demonstrated that using calcium nitrate $Ca(NO_3)_2$, typically improves flowering performance in roses by increasing stem elongation, flower number, and quality, all of which prolong vase life. Calcium nitrate, a readily accessible source of calcium and nitrogen, facilitates effective nutrient uptake and physiological activity, both of which aid in the earlier and more vigorous development of flowers. More so, Watane *et al.* (2022) mentioned that foliar spraying of calcium nitrate significantly reduced the days to the flowering stage of China aster.

Table 2. Days to flowering of tomato at 31 days after transplanting (DAT) as affected by various calcium sources and application methods, Sultan Kudarat State University, May 2025

Different calcium sources	Methods of application		Mean
	Powder	Extract	
A1. Control (No application)	31.00	31.00	31.00^{b}
A2. Calcium nitrate	28.33	28.00	28.17^{a}
A3. Snail shell	27.67	28.33	28.00^{a}
A4. Egg shell	28.67	27.33	28.00^{a}
Mean ^{ns}	28.92 ^{ns}	28.67^{ns}	28.80

CV = 3.22%; Means that share the same letter superscripts do not differ significantly at the 5% significance level according to the least significant difference (LSD) test; ^{ns} = not significant

Table 3. Number of flowers of tomato per plant at 35 to 50 days after transplanting (DAT) as affected by various calcium sources and application methods, Sultan Kudarat State University, May 2025

Different calcium sources	Methods of application		Mean
	Powder	Extract	
A1. Control (No application)	26.06^{c}	26.07^{c}	26.07^{c}
A2. Calcium nitrate	31.93^{b}	34.00^{b}	32.97^{b}
A3. Snail shell	37.93^{a}	33.07^{b}	35.50^{ab}
A4. Egg shell	32.67^{b}	39.60^{a}	36.14^{ab}
Mean ^{ns}	32.15^{ns}	33.19^{ns}	34.87

CV = 6.10%; Means that share the same letter superscripts do not differ significantly at the 5% significance level according to the least significant difference (LSD) test; ^{ns} = not significant

Number of flowers per plant

Table 3 presents the number of tomato flowers at 35 to 50 days after transplanting (DAT) resulting from the application of different calcium sources using multiple application methods. The interaction between calcium sources and methods of application also showed significant differences in specific treatment combinations. Notably, the eggshell applied as an extract resulted in the highest individual mean (39.60), significantly outperforming other combinations. This result is also comparable with snail shell applied through the powdered form, which exhibited an average of 37.93 flowers per plant. This suggests that not only the source of calcium but also its mode of application plays a critical role in determining its effectiveness. Calcium has a significant role in cell wall growth, membrane integrity, and signal transmission, all important for flower formation and fruit development in tomatoes. Eggshell extract and snail shell powder give calcium in a more accessible ionic form (Ca^{2+}) than raw or less processed calcium sources. Their processing into extracts or fine powders boosts solubility and uptake by plants, promoting earlier and more abundant flowering (Coulibaly *et al.*, 2023).

Eggshells are rich in calcium carbonate, but they are relatively insoluble in water. However, calcium becomes more solubilized in an available form (Ca+2) when processed into extracts (Rosnah *et al.*, 2021). In contrast, snail shell, when applied through the powdered form, degrades slowly and serves as a long-term calcium source. This slow release helps maintain a consistent calcium supply critical for cellular processes (Ngouoko *et al.*, 2022).

Number of fruits (pcs.)

Table 4 shows the number of tomato fruits at 65 to 80 days after transplanting (DAT) produced under various calcium sources and application methods. The analysis of variance revealed that the application of different calcium sources significantly influenced the number of fruits produced by tomato plants. Among the four treatments, plants that received no calcium application consistently produced the lowest mean fruit count (23.20). In contrast, those treated with calcium nitrate (30.47 fruits), snail shell (32.87 fruits), and eggshell (32.53 fruits) recorded significantly higher fruit numbers. These findings indicate that calcium is essential for floral growth because it promotes hormonal balance, structural integrity, and successful reproduction. It is necessary for pollen viability and tube growth, stabilizes cell walls during the production of floral organs, and serves as a secondary messenger in the transduction of flowering signals. Furthermore, calcium preserves cellular stability in reproductive tissues, which reduces flower and fruit abortion. The importance of calcium for agricultural productivity and reproductive development is highlighted by these functions, which together improve fruit set and flower retention (Hepler, 2005; Yang *et al.*, 2021; Nizam *et al.*, 2019). This implies that integrating calcium into tomato could substantially increase yield outcomes. This agrees with the findings of Dong *et al.* (2025), who found an increase in fruit load and enhanced yield of citrus when applied with calcium supplementation. Similarly, Lim (2023) reported that the application of calcium nitrate in conjunction with standard fertilization protocols significantly increased tomato fruit yield. Coulibaly *et al.* (2023) also noticed that supplementation of biological calcium sources, such as eggshell, enhances the number of fruits of tomato. Moreover, Bhargaw *et al.* (2024) confirmed that foliar application of eggshell-derived calcium significantly increases the fruit yield of tomato compared with untreated plants.

Table 4. Number of tomato fruits per plant at 65 to 80 days after transplanting (DAT) as affected by various calcium sources and application methods, Sultan Kudarat State University, May 2025

Different calcium sources	Methods of application		Mean
	Powder	Extract	
A1. Control (No application)	23.20	23.20	23.20^{b}
A2. Calcium nitrate	29.47	31.47	30.47^{a}
A3. Snail shell	35.20	30.53	32.87^{a}
A4. Egg shell	30.40	34.67	32.53^{a}
Mean ^{ns}	29.57^{ns}	29.97^{ns}	28.80

CV = 9.18%; Means that share the same letter superscripts do not differ significantly at the 5% significance level according to the least significant difference (LSD) test; ^{ns} = not significant

Flower abscission rate (%)

Table 5 presents the tomato flower abscission rate at 50 days after transplanting (DAT) under various calcium sources and application methods. Analysis of variance reveals that the sources of calcium significantly influenced the flower abscission rate in tomato plants. The control group, which received no calcium supplementation, exhibited the highest abscission rate (11.23). In contrast, plants treated with calcium from calcium nitrate, eggshell, and snail shells recorded a notably comparable mean of (7.61), (7.00), and (7.42) abscission rate. This finding suggests that calcium supplementation aids in reducing the premature dropping of tomato flowers.

Calcium plays a crucial role in reducing flower abscission in tomato by acting as a signal modulator that mitigates ethylene biosynthesis while simultaneously enhancing auxin transport, both of which are well-documented inhibitors of flower drop (Tao, 2009; Xu *et al.*, 2010, 2012). Among all tested sources, eggshell and snail shell led to the lowest abscission rate, highlighting their potential as a sustainable calcium source for tomato cultivation. This finding aligns with the results of Coulibaly *et al.* (2023), who observed that biological calcium sources, such as eggshells, snail shells, and seashells, significantly reduce the flower abscission rate of tomatoes compared with untreated control groups.

Table 5. Flower abscission rate of tomato at 50 days after transplanting (DAT) as affected by various calcium sources and application methods, Sultan Kudarat State University, May 2025

Different calcium sources	Methods of application		Mean
	Powder	Extract	
A1. Control (No application)	11.22	11.23	11.23[a]
A2. Calcium nitrate	7.77	7.46	7.61[b]
A3. Snail shell	7.18	7.66	7.42[b]
A4. Egg shell	6.94	7.06	7.00[b]
Mean [ns]	8.28 [ns]	8.35[ns]	8.32

CV = 5.17%; Means that share the same letter superscripts do not differ significantly at the 5% significance level according to the least significant difference (LSD) test; [ns] = not significant

Table 6. Blossom end rot rate (%) of tomato at 65 to 80 days after transplanting (DAT) as affected by various calcium sources and application methods, Sultan Kudarat State University, May 2025

Different calcium sources	Methods of application		Mean
	Powder	Extract	
A1. Control (No application)	10.92	10.92	10.92[a]
A2. Calcium nitrate	10.23	10.17	10.20[a]
A3. Snail shell	7.86	8.08	7.97[b]
A4. Egg shell	7.61	7.02	7.32[b]
Mean [ns]	9.16[ns]	9.05[ns]	9.10

CV = 4.81%; Means that share the same letter superscripts do not differ significantly at the 5% significance level according to the least significant difference (LSD) test; [ns] = not significant

Blossom end rot rate (%)

The application of different calcium sources significantly affected the rate of blossom end rot in tomato plants at 65 to 80 days after transplanting (DAT), as presented in Table 6. Statistical analysis indicated that calcium sources significantly affected the rate of BER incidence in tomato. Among these treatments, the control group, with no calcium application, exhibited the highest BER occurrence of 10.92%, indicating that the absence of supplemental calcium triggers this physiological disorder in tomato (Saure, 2014; Shear, 1975; Adams and Ho, 1993; de Freitas *et al.,* 2021; Taylor and Locascio, 2004; Watanabe *et al.,* 2021). Calcium is critical for cell integrity and membrane stability. When calcium is deficient, particularly in the rapidly expanding cells at the blossom end, cell membranes become compromised, leading to the development of the disorder (Ho and White, 2005; Westerfield *et al.*, 2022). This result is in contrast with the findings of Saure (2014), who mentioned that calcium depletion in affected tissues is not the initiating factor in the occurrence of BER but rather the secondary cellular damage. He also insisted that abiotic stressors such as drought, salinity, excessive light, and ammonium toxicity are attributed to the mentioned physiological disorder.

Furthermore, calcium supplementation from various sources differed significantly from each other. Calcium nitrate showed the highest BER rate of 10.20% comparable to the control. This was followed by the application of snail shell with a BER incidence rate of 7.97%, while the lowest occurrence rate was recorded from eggshell treatment. These finding suggests that biological calcium source, specifically egg shell, can effectively reduce blossom end rot. This conforms with the results of (Coulibaly, 2023; Bhargaw *et al.*, 2024; Vergara *et al.*, 2024), who found that calcium supplementation through eggshells significantly reduced the BER rate in tomato.

Meanwhile, it is worth noting that the application of calcium nitrate, among other calcium sources, resulted in a higher incidence of BER. This result may be due to excessive nitrogen application since this treatment has 15% nitrate content. This finding is supported by Gebremariam and Tesfay (2019); Abdelkader *et al.* (2024), who found that excessive nitrogen fertilization significantly increases the incidence of BER by disrupting calcium uptake within the developing fruit due to rapid vegetative growth and nitrogen-induced nutrient imbalances.

Visual quality rating (VQR)

Table 7 shows the tomato's Visual Quality Rating (VQR) at 65 days after transplanting as influenced by various calcium sources and application methods. Based on statistical analysis, the interaction between calcium sources and application methods on tomato's VQR did not indicate a significant difference with a mean value across all combinations ranged from 7.38 to 8.02 (mean overall 7.70), This shows that the visual quality results are not significantly affected by the particular calcium source or the application method when combined, indicating that the quality of tomato fruit remains unchanged across the investigated treatments.

Table 7. Visual quality rating of tomato fruit at 65 days after transplanting (DAT) as affected by various calcium sources and application methods, Sultan Kudarat State University, May 2025

Different calcium sources	Methods of application		Mean ^{ns}
	Powder	Extract	
A1. Control (No application)	7.67	7.67	7.67
A2. Calcium nitrate	7.81	7.62	7.72
A3. Snail shell	7.78	7.59	7.69
A4. Egg shell	7.38	8.02	7.70
Mean ^{ns}	7.66^{ns}	7.73^{ns}	7.70

CV = 4.04%; ^{ns} = not significant

Table 8. Firmness (kg/cm3) of tomato fruit at 65 days after transplanting (DAT) as affected by various calcium sources and application methods, Sultan Kudarat State University, May 2025

Different calcium sources	Methods of Application		Mean
	Powder	Extract	
A1. Control (No application)	7.05	7.05	7.05^{b}
A2. Calcium nitrate	8.06	8.19	8.12^{a}
A3. Snail shell	7.93	7.95	7.94^{a}
A4. Egg shell	8.17	8.58	8.38^{a}
Mean ^{ns}	7.80^{ns}	7.94^{ns}	7.87

CV = 5.16%; Means that share the same letter superscripts do not differ significantly at the 5% significance level according to the least significant difference (LSD) test; ^{ns} = not significant

Moreover, the study also found no statistically significant variations in VQR between the various sources, including calcium nitrate, snail shell, egg shell, and control (no application), on the influence of calcium sources alone, numerically ranging from 7.67 to 7.72, an indicator that harvested tomato fruits are considered good with minor defects (Subere, 1997). This is in line with earlier studies that show that while basic calcium sufficiency may not necessarily result in noticeable changes in visual evaluations (Rivera *et al.*, 2023). In addition, Adekiya *et al.* (2025) confirmed that various calcium sources strengthened cell walls, increased nutrient uptake, prolonged shelf life, and decreased postharvest weight loss. However, it did not demonstrate that calcium had a direct impact on aspects of visual quality, such as fruit color or appearance.

Fruit firmness (kg/cm3)

Table 8 presents the effects of various calcium sources and application methods on tomato fruit firmness at 65 days after transplanting (DAT). Based on the analysis, calcium sources significantly influenced tomato's firmness ($p < 0.05$). This result reveals that the firmness of tomato fruit responded significantly to different calcium sources, with snail shell, eggshell, and calcium nitrate treatments outperforming the control. Among these, eggshell yielded the highest numerical mean of (8.38 kg/cm3), comparable with the application of calcium nitrate (8.12 kg/cm3) and snail shell (7.94 kg/cm3). Meanwhile, the control (no calcium application) had the lowest firmness of 7.05 kg/cm3. This is consistent with the scientific notion that calcium increases cell cohesion and resistance to softening by cross-linking pectic molecules in the fruit's cell walls (Coulibaly *et al.*, 2023; Dodgson *et al.*, 2023). Moreover, calcium plays a critical role in preserving the firmness of fruit by preventing the activity of enzymes that break down cell walls, such as polygalacturonase and pectin methyl esterase, and stabilizing cell wall structure through calcium-pectate cross-linking. Furthermore, it delays softening during ripening and postharvest storage by maintaining membrane integrity and reducing oxidative stress (Gao *et al.*, 2019).

Similar findings were observed in the study of El-Tantawy and Mahmoud (2016), who documented an increased firmness in tomato fruit under calcareous soil when applying certain calcium sources, specifically, calcium nitrate at the right growth phases. Adekaya *et al.* (2025) also identified that calcium nitrate is one of the most effective calcium sources in maintaining fruit firmness of tomato. Furthermore, an enhanced tomato fruit firmness was also noted by Coulibaly *et al.* (2023), with the application of natural calcium sources such as eggshell and snail shell. Also, Thakur *et al.* (2019) and Bhargaw *et al.* (2024) demonstrated that calcium chloride and PRANAM-Ca, both derived from eggshell, are effective in enhancing the fruit firmness of tomato.

Table 9. Total soluble solids (°Brix) of tomato fruit at 65 days after transplanting (DAT) as affected by various calcium sources and application methods, Sultan Kudarat State University, May 2025

Different calcium sources	Methods of application		Mean
	Powder	Extract	
A1. Control (No application)	9.10^{a}	9.10^{a}	9.10^{a}
A2. Calcium nitrate	8.33^{b}	8.47^{b}	8.40^{b}
A3. Snail shell	8.13^{b}	8.53^{ab}	8.33^{b}
A4. Egg shell	9.27^{a}	8.40^{b}	8.83^{b}
Mean ^{ns}	8.71^{ns}	8.62^{ns}	8.67

CV = 4.04%; Means that share the same letter superscripts do not differ significantly at the 5% significance level according to the least significant difference (LSD) test; ^{ns} = not significant

Total soluble solids (°Brix)

Table 9 presents the total soluble solids (TSS) content in tomato fruit at 65 days after transplanting (DAT) resulting from the application of different calcium sources using different application methods. The interaction between calcium sources and methods of application showed significant differences in specific treatment combinations. Notably, the eggshell applied as powder resulted in the highest individual mean (9.27), statistically comparable to the control group (9.10), and snail shell applied through extract (8.53), respectively. Meanwhile, the lowest TSS value was attributed to the application of snail shell powder (8.13) with no significant difference from calcium nitrate in powder form (8.33), calcium nitrate in extract form (8.47), and eggshell extract (8.40). This discovery supports the findings of Santos *et al.* (2023), who highlighted that the chemical form and mode of application affect calcium bioavailability and assimilation, which can change downstream metabolic pathways and nutrient uptake efficiency. The method of calcium application, according to Dong *et al.* (2005), has a considerable impact on the overall amount of calcium accumulated and its chemical forms in tomato fruits. Soil calcium application increases structurally bound calcium, while foliar treatment enhances exchangeable and water-soluble calcium, allowing growing tissues to access nutrients more quickly.

Weight of fruits (g)

Table 10 presents the effects of various calcium sources on tomato fruit weight at 65-80 days after transplanting (DAT) and their interaction with application methods. Based on the analysis, calcium sources had a significant influence on tomato fruit weight ($p < 0.05$). This result reveals that the weight of tomato fruits responded significantly to different calcium sources, with treatments using snail shell, eggshell, and calcium nitrate outperforming the control. Among these, eggshell yielded the heaviest fruit weight (1000.10g), comparable with the application of snail shell (931.47g). Moreover, plants treated with calcium nitrate were statistically different from plants treated with snail shell and eggshell with (878.67g). Meanwhile, the control produced the lightest-weight tomato fruit (580.47g) per plant. The results indicate that calcium supplementation significantly improves tomato fruit development, likely due to calcium's function in cell wall stability, enzyme regulation, and overall fruit quality, thereby supporting established findings regarding calcium's beneficial physiological effects on tomato fruit growth and weight development (Tongali *et al.,* 2024; Polwaththa and Amarasinghe, 2024).

Furthermore, the application of eggshell and snail shell, whatever the form, produced the heaviest tomato fruit. These biological calcium sources resulted in an increased number of flowers and fruits while consequently reducing the flower abscission rate and blossom end rot occurrence, similar to the findings of Coulibaly *et al.* (2023). Polese (2007) states that snail shells consist of 86% calcium and organic matter, whereas eggshells comprise 94% calcium carbonate, 4% organic matter, 1% magnesium carbonate, and 1% calcium phosphorus (Valera *et al.*, 2003). The early application of eggshells to plants enhances growth and development, as indicated by increased calcium concentrations in the treated plants. Moreover, it is worth noting that control (no calcium application) and calcium nitrate application led to a reduced fruit weight per plant. This can be attributed to a higher blossom end rot rate of (10.20% to 10. 92%) from these treatments, which resulted in distorted fruits, supporting the findings of Lim (2023).

Table 10. Weight (g) of tomato fruits per plant at 65 to 80 days after transplanting (DAT) as affected by various calcium sources and application methods, Sultan Kudarat State University, May 2025

Different calcium sources	Methods of application		Mean
	Powder	Extract	
A1. Control (No application)	580.46	580.47	580.47^{c}
A2. Calcium nitrate	927.40	829.93	878.67^{b}
A3. Snail shell	1013.67	849.27	931.47^{a}
A4. Egg shell	934.80	1065.40	1000.10^{a}
Mean ^{ns}	864.08^{ns}	831.27^{ns}	847.68

CV = 11.33%; Means that share the same letter superscripts do not differ significantly at the 5% significance level according to the least significant difference (LSD) test; ^{ns} = not significant

Weight of marketable fruits (g)

Table 11 presents the effects of various calcium sources and application methods on the weight of marketable tomato fruits at 65-80 days after transplanting (DAT). The varying mean values among the treatments in the study showed that the type of calcium source had a significant effect on the measured parameter. Plants that received no calcium application consistently exhibited the lowest weight of marketable fruits of 464.00g, suggesting that a reduction in marketable yield was due to the absence of supplemental calcium. In contrast, tomatoes applied with eggshell-derived calcium achieved the heaviest weight of (818.33g), outperforming the control (464.00g) and calcium nitrate treatment (695.97g), and statistically comparable to the application of snail shell, which produced an average weight of 767.33g of marketable fruits, respectively. According to Kabir and Díaz-Pérez (2025), calcium enhances cell wall integrity and membrane stability, which promotes consistent fruit development and lowers losses from rotting, softening, and breaking. Because of these enhancements, a greater number of fruits meet marketable requirements for both size and quality, which increases the total marketable yield.

More so, the heaviest tomato fruit was obtained through the utilization of eggshells and snail shells, in any form. Similar to the findings of Coulibaly *et al.* (2023), these biological calcium sources boosted the quantity of flowers and fruits while lowering the rate of floral abscission and the occurrence of blossom end rot. In addition, applying calcium improves fruit integrity and lowers physiological problems, increasing the weight of marketable tomato fruits. Chelated calcium enhances nutrient supply and foliar absorption (El-Tantawy and Mahmoud, 2016; Adekiya *et al.*, 2025).

In contrast, it is noteworthy that both the calcium nitrate administration and the control resulted in a lower marketable fruit weight per plant. This is explained by the fact that these treatments had a higher blossom end rot rate (10.20% to 10.92%), which led to deformed fruits similar to the findings of Lim (2023).

Table 11. Weight (g) of marketable tomato fruits per plant at 65 to 80 days after transplanting (DAT) as affected by various calcium sources and application methods, Sultan Kudarat State University, May 2025

Different calcium sources	Methods of application		Mean
	Powder	Extract	
A1. Control (No application)	464.00	464.00	464.00^{c}
A2. Calcium nitrate	766.53	625.40	695.97^{b}
A3. Snail shell	835.60	699.07	767.33^{a}
A4. Egg shell	765.73	870.93	818.33^{a}
Mean ^{ns}	707.97^{ns}	664.85^{ns}	686.41

CV = 12.78%; Means that share the same letter superscripts do not differ significantly at the 5% significance level according to the least significant difference (LSD) test; ^{ns} = not significant

Table 12. Weight (g) of non-marketable tomato fruits per plant at 65 to 80 days after transplanting (DAT) as affected by various calcium sources and application methods, Sultan Kudarat State University, May 2025

Different calcium sources	Methods of Application		Mean
	Powder	Extract	
A1. Control (No application)	122.40^{c}	122.40^{b}	122.40^{b}
A2. Calcium nitrate	130.67^{bc}	204.53^{a}	167.60^{a}
A3. Snail shell	178.40^{a}	150.20^{b}	164.30^{a}
A4. Egg shell	169.07^{ab}	161.13^{ab}	165.10^{a}
Mean ^{ns}	150.14^{ns}	159.57^{ns}	154.85

CV= 16.32%; Means that share the same letter superscripts do not differ significantly at the 5% significance level according to the least significant difference (LSD) test; ^{ns} = not significant

Weight of non-marketable fruits (g)

Table 12 presents the weight of non-marketable tomato fruits at 65-80 days after transplanting (DAT) as affected by various calcium sources and application methods. The interaction between calcium sources and methods of application showed significant differences in specific treatment combinations. This implies that the effectiveness of a calcium source was not consistent across application methods and vice versa. Notably, the calcium nitrate applied as an extract resulted in the heaviest weight of non-marketable fruit (204.53g), statistically comparable to eggshell extract (161.13g). This could be due to the rapid availability of calcium and nitrate in extract form, which may have accelerated the vegetative growth but limits the distribution of calcium to individual fruits, resulting in localized calcium deficiency (Ho and White, 2005). Similarly, snail shells and eggshells, applied in powdered form, also produced the highest non-marketable yield of 178.40g and 169. 07g with no statistical variation. This can be attributed to the slow release of calcium from these treatments that may not meet the required rate during cell expansion, making it vulnerable to structural failure and leading to BER occurrence (Indeche *et al.*, 2020).

Fruit diameter (mm)

Table 13 presents the effects of various calcium sources and application methods on tomato fruit diameter at 65 days after transplanting (DAT). Based on the analysis, calcium sources significantly influenced tomato fruit diameter. This result reveals that tomato fruit diameter responded significantly to different calcium sources, with snail shell, eggshell, and calcium nitrate treatments outperforming the control. Among these, eggshell yielded the widest diameter (45.23 mm), comparable with the application of calcium nitrate (44.30 mm) and snail shell (43.95 mm). Meanwhile, the control had the narrowest fruit diameter (38.29 mm). The results indicate that calcium supplementation significantly improves tomato fruit development by enhancing cellular integrity and maintaining cell walls through its interaction with pectin. Calcium encourages cell expansion and water retention in tomato fruits, increasing fruit weight and diameter (Polwaththa and Amarasinghe, 2024; Hocking *et al.*, 2016).

The findings are consistent with those of Coulibaly *et al.* (2023), who reported that the application of eggshell, regardless of its form, significantly increased tomato fruit diameter. Eggshells contain 94% calcium carbonate, 4% organic matter, 1% magnesium carbonate, and 1% calcium phosphorus (Valera *et al.*, 2003). This high calcium carbonate content has been shown to increase crop diameter. Lim (2023) also found that supplying calcium nitrate to tomato plants significantly enhances the fruit diameter. Commercially available calcium sources, including calcium nitrate, can supply 15% nitrate that can be easily assimilated by plants. This nutrient, according to Lu *et al.* (2009), can stimulate cytokinin accumulation, which generally supports cell expansion.

Table 13. Fruit diameter (mm) of tomato at 65 days after transplanting (DAT) as affected by various calcium sources and application methods, Sultan Kudarat State University, May 2025

Different calcium sources	Methods of application		Mean
	Powder	Extract	
A1. Control (No application)	38.29	38.29	38.29[b]
A2. Calcium nitrate	44.14	44.47	44.30[a]
A3. Snail shell	43.55	44.35	43.95[a]
A4. Egg shell	44.32	46.14	45.23[a]
Mean [ns]	42.58 [ns]	43.31[ns]	42.94

CV = 2.19%; Means that share the same letter superscripts do not differ significantly at the 5% significance level according to the least significant difference (LSD) test; [ns] = not significant

Number of locules per fruit (pcs.)

Table 14 shows the number of tomato fruit locules at 65 days after transplanting (DAT) as affected by various calcium sources and application methods. Based on the analysis, the effect of calcium sources did not reach a statistically significant result in terms of the locule counts of the tomato. The number of locules did not differ significantly among the calcium treatments. Control, snail shell, eggshell, and calcium nitrate applications produced statistically identical results. Numerically, the control group yielded the highest numerical mean (2.37), comparable with all other treatments, including the application of calcium nitrate (2.28), egg shell (2.27), and snail shell, with an average of 2.27 locules per fruit. This implies that the locule count of tomato fruit was not influenced by calcium application, whatever the source.

More so, the powder and extract forms of calcium application did not significantly differ in terms of the method of application, with numerical means of 2.32 and 2.28, respectively. Based on this finding, the number of locules per fruit is not significantly impacted by the method of calcium supplementation.

Similarly, analysis of variance revealed that there was no significant difference in the interaction between calcium sources and application methods on the locule count of tomato fruit, with mean values ranging from 2.17 to 2.37 for all combinations. This demonstrates that neither the specific calcium source nor the application technique, when combined, significantly alters the measured parameter, suggesting that the number of locules is constant throughout the examined treatments.

These findings indicate that calcium supplementation does not affect the number of locules per tomato fruit. Instead, this trait is primarily governed by genetic determinants. According to Muños *et al.* (2011), the fasciated (*fas*) and locule number (*lc*) loci determine tomato fruit size and shape. Two SNPs around WUSCHEL in *lc* appear before *fas* mutations, and their interaction results in the numerous locules observed in contemporary cultivars. Moreover, the SlWUS gene plays a crucial function in controlling carpel formation and locule development; in tomato, silencing it significantly reduced the quantity of fruit locules from 6–8 in wild-type plants to 3–4 (Li *et al.*, 2017).

Table 14. Number of locules per tomato fruit at 65 days after transplanting (DAT) as affected by various calcium sources and application methods, Sultan Kudarat State University, May 2025

Different calcium sources	Methods of application		Mean ^{ns}
	Powder	Extract	
A1. Control (No application)	2.37	2.37	2.37
A2. Calcium nitrate	2.23	2.33	2.28
A3. Snail shell	2.37	2.17	2.27
A4. Egg shell	2.30	2.23	2.27
Mean ^{ns}	2.32^{ns}	2.28^{ns}	2.30

CV = 7.45%; ^{ns} = not significant

Table 15. Yield (ton/ha) of tomato at 65 to 80 days after transplanting (DAT) as affected by various calcium sources and application methods, Sultan Kudarat State University, May 2025

Different calcium sources	Methods of application		Mean
	Powder	Extract	
A1. Control (No application)	5.53	5.53	5.53^{c}
A2. Calcium nitrate	8.83	7.90	8.37^{b}
A3. Snail shell	9.66	8.09	8.88^{a}
A4. Egg shell	8.90	10.16	9.53^{a}
Mean ^{ns}	8.23^{ns}	7.92^{ns}	8.08

CV = 11.31%; Means that share the same letter superscripts do not differ significantly at the 5% significance level according to the least significant difference (LSD) test; ^{ns} = not significant

Yield (ton/ha)

The application of different calcium sources notably affected the yield per hectare of tomato plants at 65 to 80 days after transplanting (DAT), as shown in Table 15. Statistical analysis revealed that plants treated with snail shell and eggshell produced the highest yield, averaging 8.88 and 9.53 tons, compared to those in the control group, which received no calcium supplementation, resulting in the lowest yield of 5.53 tons. This result implies that calcium supplementation, particularly from biological sources, can significantly increase the overall yield of the tomato plant. This increased yield may be attributed to the role of calcium in cell elongation and nutrient uptake, which increases the photosynthetic rate of the plants and therefore results in enhanced yield (Sajid *et al.*, 2019).

This finding conforms with Coulibaly *et al.* (2023), who found that the application of biological calcium sources, including egg shell and snail shell, significantly increased the fruit yield of tomato. They emphasized that snail and eggshells contain bioavailable calcium (about 86% calcium and 94%

$CaCO_3$) that plants can effectively absorb. Bee (2011) also mentioned that eggshells is the best natural calcium source in which is 90% absorbable, where one teaspoon contains 700 to 800 mg of calcium. In addition, snail shells are composed of 86% calcium and organic matter (Polese, 2007).

Moreover, the yield improvement observed from the application of organic calcium sources could also be linked to calcium's role in increasing the fruit count and reducing the incidence of blossom end rot. Based on the study's findings, a notable increase in the BER rate was observed in the control group and plants treated with calcium nitrate, which resulted in significantly lower yield. This result is consistent with the findings of Lim (2023), who noted a yield reduction in those plants with a high BER rate.

Net return analysis

Table 16 presents the net return analysis for tomato production under various calcium sources and application methods. In ascending order, control (no application) recorded the lowest ROI of 155.79 percent. This was followed by calcium nitrate applied in extract form with 239.65 percent, snail shell extract with 242.01 percent, calcium nitrate applied in powder form with 292.52 percent, eggshell powder with 295.35 percent, snail shell powder with 317.77 percent, and eggshell extract with 330.16 percent, respectively.

Table 16. Analysis of net returns (%) in tomato production affected by various calcium sources and application methods, Sultan Kudarat State University, May 2025

Treatments	Yield per 300 square meter	Total production cost (₱)	Gross income sold at ₱40.00 per kg.	Net income (₱)	Return on investment (%)
Control- No application	165.90kg	2,594.32	6,636.00	4041.68	155.79
Calcium nitrate applied as powder	264.97kg	2,700.16	10,598.80	7898.64	292.52
Calcium nitrate applied as an extract	237.12kg	2,792.56	9,484.80	6692.24	239.65
Snail shell applied as powder	289.62kg	2,773.00	11,584.80	8811.8	317.77
Snail shell applied as an extract	242.74kg	2,838.95	9,709.60	6870.65	242.01
Eggshell applied as powder	267.09kg	2,702.32	10,683.60	7981.28	295.35
Eggshell applied as an extract	304.59kg	2,832.32	12,183.60	9351.28	330.16

Note: Production costs were calculated using the prevailing market prices for agricultural inputs and local labor. Gross income was estimated using the current market price per kilogram of tomatoes.

The results suggest that calcium fertilization is a financially feasible investment because it significantly increases economic returns when compared to the control, regardless of the source or form. Significantly, inexpensive, locally accessible sources like eggshell and snail shell—especially in powder or extract form—outperformed commercial calcium nitrate in terms of return on investment, indicating their potential as sustainable, cost-effective substitutes for farmers.

CONCLUSION

The study concludes that the application of different calcium sources, whatever the method of application, significantly affected the growth, production, quality, and yield attributes of tomato. Also, eggshells and snail shells as a biological calcium source constantly resulted in improved fruit yield and quality by significantly reducing the occurrence of blossom end rot, thus resulting in higher profitability. Furthermore, these materials are readily available and low-cost, which can be a cost-effective substitute for commercially available calcium sources.

RECOMMENDATIONS

The following recommendations are proposed in accordance with the study's findings and conclusions.

The use of biological calcium sources, such as eggshell and snail shell, is highly recommended in tomato cultivation with similar agro-climatic conditions, as it effectively reduces the BER occurrence, thus improving the yield and quality of tomato.

It is recommended that tomato growers utilize locally available calcium sources, particularly eggshells and snail shells, as a cost-effective and sustainable substitute to synthetic calcium sources, hence increasing their return on investments.

Further study is recommended to determine the effectiveness of these treatments on other tomato varieties.

Future research should be conducted on determining the effects of excessive nitrogen application on the occurrence of BER.

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