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Enhancing Tomato (*Solanum lycopersicum* L.) Fruit Yield and Quality and Blossom End Rot Control Using Different Biological Calcium Sources

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Abstract

Cultivated for its richness in nutrients, tomato culture is demanding fertilizer, especially in calcium. Calcium deficiencies and physiological disorders cause serious diseases in tomatoes. Blossom end rot (BER), in susceptible cultivars, may cause severe economic losses. The goal of this study is to determine the effect of three organic calcium sources on the growth and quality of fruit production of tomatoes. Egg, snail and sea shell powders and extracts have been used as biological fertilizers. The experiment was conducted in a block factorial trial with three replications. The trials comprised two factors: calcium sources and calcium source form (powder and extract). The results showed that the growth parameters and yield were improved by the calcium source, whatever the form. Also, BER was lower in plants treated with calcium contrary to the control. However, plants treated with eggshells showed the best growth (mean) and the lowest rate (0.40%) of BER than the snail and sea shell.

Keywords

Tomatoes, Blossom End Rot, Eggshells, Snail Shells, Seashells

1. Introduction

Blossom end rot in tomatoes has been described as a physical disorder [1] [2]

[3]. Although low calcium content has generally been reported to be the cause of blossom end rot in tomatoes, various factors including acidic growing media, high N content, high soil salinity, low soil moisture and soil dryness have also been reported to affect the development of blossom end rot [1] [3]-[10]. Tomato is widely cultivated for its fruits rich in lycopene and other valuable antioxidant compounds [11] [12]. In Côte d'Ivoire, annual production was estimated at 40,000 tons [13], against a need of 100,000 tons per year [14]. Its cultivation occupies a significant portion of the Ivorian population, mainly women (60%) and youth in rural and peri-urban areas [15]. As a result, tomato culture can contribute efficiently to the development and well-being of populations. Unfortunately, like all Vegetable production, tomato is challenged by a range of biotic and abiotic factors, often resulting in a substantial loss of the produce in each growing cycle. As the population is growing, the world is facing increasing demands for a stable food supply grown on agricultural lands worldwide. Abiotic stresses are becoming increasingly more prevalent, especially considering climate change. According to [3] [16], blossom end rot is one of the most devastating physiological disorders that affect various crops, such as pepper (*Capsicum annuum* L.), watermelon (*Citrullus lanatus* Thunb.) and particularly tomato (*Solanum lycopersicum* L.).

Blossom end rot of tomato was first identified as a physiological disorder [4]. In susceptible cultivars, it may cause severe economic losses in some seasons and under certain environmental conditions. Several works [17] [18] found a correlation between the occurrence of blossom end rot and Ca^{2+} nutrition. This physiological disorder is generally attributed to inadequacy of Ca^{2+} in the fruits and it is, therefore, called a calcium-related disorder [19] [20] [21], specified that blossom end rot is a local deficiency of Ca^{2+} in tomato fruit, or in the distal end of tomato fruit, respectively. However, it is not possible to predict the occurrence of blossom end rot on this basis. In fact, Ca^{2+} plays an essential role in plant growth and development where it fulfills three main functions. Calcium serves several functions in plants, including cation-anion balance, transport processes of cell membranes and assisting with extension of primary root systems. For vegetable producers, calcium's most important function during the crop fruiting stage is its role in cell wall/cell membrane stability [3]. Calcium deficiency is usually induced in plants because calcium is not a highly mobile element [22]. Moreover, favorable calcium nutrition is important for the prevention of blossom end rot and cracking in tomatoes [23].

In response to this physiological disorder, various control strategies have been developed. Among these methods, chemical control based on the intensive use of high-calcium chemical fertilizers in plantations has proven to be the most effective [1] [24].

However, inorganic fertilizers are known for their high cost and their negative environmental effects if managed poorly. Thus, to reduce and eliminate the adverse effects of synthetic fertilizers on human health and environment, nowadays, a new agricultural practice has been developed called as sustainable agriculture or ecological agriculture.

This work fits into this context of sustainable development and aims to test the effect of different biological calcium sources on the blossom end rot. To this end, three types of biological calcium were tested to assess their impact on growth and physiological disorder in tomatoes.

2. Materials and Methods

2.1. Experimental Site

The study was conducted on the experimental plot of Nangui Abrogoua University (UNA). Geographically the experimental field was located at: 5˚17'N and 5˚31"N latitude and 3˚45'W and 4˚31'W longitude. The site was characterized by moderately and high temperature (24.51˚C to 27.67˚C) and relative humidity of 80% during the experiment.

2.2. Materials

The variety Lindo F1 was used as plant material. F1 was chosen because of its resistance to Bacterial Wilt caused by Ralstonia solanacearum and Fusarium wilt. In addition, it adapts well to these climate conditions.

2.3. Methods

Tomato seedlings were grown from seed in coco peat and watered twice a week. Seedlings were transplanted at the three-leaf stage to individual plastic pots containing disinfected topsoil.

This topsoil was a sandy-clay type with a good water retention capacity. Before its use, it was disinfected by heating in a metallic barrel of 100 L. Then, once cooled, culture pots of 4 L were filled to 3/4 of their volume. Uniformly sized plants were selected to provide three replicates per treatment. Three biological sources of calcium were tested (eggshells, snail shells and seashells). These shells, after collection were washed, air-dried, and then powdered with a silver crest blender.

From this powder, calcium extract was obtained by the technic of vinegar alcohol extraction [25]. Then, 100 ml of extract were diluted in 10 L of water for application. Ten days after transplanting, the plants are either treated with calcium powder, or treated with calcium extracts. Each seedling was treated with 5 g of calcium powder and as soon as flower buds appeared, 75 g of powder were applied around each seedling. Concerning calcium extracts, 1 L of diluted extract was watered to each plant once a week.

The experiment was arranged in a factorial block with three replicates. Each block consists of seven sub-plots and each sub plot represents one treatment. The total number of treatments is 21. Each sub-plot consists of 15 crop pots spaced 0.5 m apart on the row and 0.8 m from one row to another.

2.3.1. Data Collection

Data was collected on several parameters including vegetative, phenological, fruiting and yield parameters. Traits such as: height growth, collar diameter of plants, the number of leaves, branches, flowers, and fruit were assessed regularly by counting. 50% flowering fruiting and mature fruit time were also evaluated. Concerning production parameters, flower abortion rate (FAR), blossom end rot (BER), spoiled fruit rate (SFR), fresh fruit mass (FFM) and net yield were assessed. These parameters were evaluated according to the formulas described by Jean *et al.* [26].

$$\text{NFR} = \frac{\text{NFN}}{\text{TNF}} \times 100;\ \text{FLAR} = \frac{\text{Nf} - \text{NF}}{\text{Nf}} \times 100;\ \text{SFR} = \frac{\text{NFS}}{\text{NTF}} \times 100;$$

with NFN: number of fruit necrotic; NF: number of fruit; Nf: number of flowers; NFR: necrotic fruit rate; TNF: total number of fruit; NFS: number of fruit rate.

The mass of fresh fruit in the production was assessed by subplot, by weighing the fruit in each subplot using a Force brand needle scale.

Yield was assessed by treatment. At each harvest, total fruit weight was assessed to determine total yield using the following formula:

$$\text{Yield net}\left(\text{kg/ha}\right) = \frac{\text{Mass of healty fruit}\left(\text{kg}\right)}{\text{Area of cultivated space}\left(\text{ha}\right)} \times 10000.$$

2.3.2. Data Analysis

Combined multivariate analysis of variance (MANOVA) appropriate to two factors was performed to compare calcium source (eggshell, snail shell and seashell) and the form (extract and powder) as well as their interaction. This allowed the identification of significant factors based on a vector of dependent variables. When MANOVA revealed significant difference for a factor, one way analysis of variance (ANOVA1) was performed. Least significant difference (LSD) multiple range-tests were used to identify differences between means. Tests were performed using Xlstat 2016 software.

3. Results

3.1. Effect of Calcium Powders and Extracts on Growth Parameters

Calcium treatment greatly affected tomato growth parameters ($P < 0.001$). The greatest heights (95.93 cm and 95.83 cm) were obtained with plants treated with eggshell and snail powders respectively. Plants fertilized with eggshell powder gave the largest collar diameter (12.71 mm). Eggshell extract gave the highest average number of leaves (22.33) and branching (4.03). However, the lowest average values were obtained with control, without calcium (**Table 1**).

3.2. Effect of Biological Calcium on Tomato Phenological Parameters

Calcium sources have reduced the days required for 50 percent flowering, fructification, and fruit maturation. The days required for 50 percent flowering were 23 and 25 days after transplanting (DAT) with eggshell powder and extract.

Table 1. Effect of biological calcium on tomato plant growth and production.

Calcium sources	Height (cm)	Collar Diam. (mm)	Number of leave	Branching
EP	95.93 ± 1.85^{a}	12.71 ± 0.25^{a}	21.30 ± 0.46^{ab}	3.80 ± 0.14^{ab}
SSP	95.83 ± 1.85^{a}	12.38 ± 0.25^{ab}	20.13 ± 0.46^{b}	3.37 ± 0.14^{bc}
SeSP	85.80 ± 1.85^{c}	9.60 ± 0.25^{d}	19.27 ± 0.46^{c}	3.10 ± 0.14^{c}
ESE	93.90 ± 1.85^{ab}	11.02 ± 0.25^{c}	22.33 ± 0.46^{a}	4.03 ± 0.14^{a}
SSE	86.60 ± 1.85^{b}	11.52 ± 0.25^{b}	21.23 ± 0.46^{ab}	3.50 ± 0.14^{b}
SeSE	77.57 ± 1.85^{d}	10.68 ± 0.25^{c}	19.97 ± 0.46^{b}	3.63 ± 0.14^{b}
C	58.53 ± 1.85^{e}	8.60 ± 0.25^{d}	16.50 ± 0.46^{d}	2.57 ± 0.14^{d}
F	52.11	35.73	17.19	19.16
Pr > F	0.0001	0.0001	0.0001	0.0001

In each column, the values followed by the same letters do not differ significantly at the 5% level. EP: eggshell powder; SSP: snail shell powder; SeSP: sea shell powder; ESE: egg shell extract; SSE: snail shell extract; SeSE: sea shell extract; C: control; Diam.: diameter.

Endeed, eggshell, whatever its form (powder or extract) favorited all the parameters analyzed (Table 2). This calcium source induced fruiting and ripening 24 and 67 DAT for powder and 27 and 66 DAT for extract, respectively.

3.3. Effect of Biological Calcium on Tomato Fruit Production

Calcium sources affected significantly flowering and fruiting compared to controls (Table 3). Plants fertilized with eggshell powder produced the highest number of flowers (51.41) and fruits (49.03). This treatment had the lowest flower abortion rate and necrotic fruits. Fruits from these plants are less distorted (Figure 1). Indeed, control fruits are characterized by large brown to black, dry leathery areas on the blossom end rot (Figure 2).

3.4. Effect of Biological Calcium on Tomato Yield

Whatever calcium source, powder and extract form significantly affected the yield. The highest average value of mass fruit, healthy fruits, and net yield (12.53 kg, 11.75 kg and 13.81 T/ha, respectively) were obtained with plants treated with eggshell powder (Table 4). Concerning gross yield, the highest values were obtained with powder whatever the calcium source.

3.5. Effect of Calcium Source on Tomato Fruit Quality

The fruit firmness and diameter, brix degree and calcium content are influenced of the calcium source. The firmness and calcium content in the fruit varied according to the calcium form applied on the plants (Table 5). Indeed, firmest fruits (67.33) and the highest calcium content (6.4 kg/F) were obtained with plants treated with eggshell powder. Moreover, the mean values of the brix degree were lowest for sea shell powder and the untreated plants while the largest

Table 2. Impact of calcium sources (eggshell, snail shell, seashell) and form (powder and extract) on phenological parameters.

Calcium sources	AT50FL	AT50F	AT50R	DFR
EP	23.67 ± 0.76[c]	24.00 ± 0.58[c]	63.67 ± 0.78[d]	0.40 ± 1.52[b]
SSP	31.00 ± 0.76[b]	33.67 ± 0.58[b]	71.00 ± 0.78[c]	1.08 ± 1.52[b]
SeSP	35.33 ± 0.76[a]	38.67 ± 0.58[a]	75.33 ± 0.78[ab]	1.25 ± 1.52[b]
ESE	25.33 ± 0.76[c]	27.67 ± 0.58[c]	66.00 ± 0.78[d]	1.29 ± 1.52[b]
SSE	31.33 ± 0.76[b]	33.33 ± 0.58[b]	71.33 ± 0.78[c]	2.46 ± 1.52[b]
SeSE	33.67 ± 0.76[ab]	36.00 ± 0.58[ab]	73.67 ± 0.78[b]	2.76 ± 1.52[b]
C	37.33 ± 0.76[a]	40.33 ± 0.58[a]	77.33 ± 0.78[a]	82.89 ± 1.52[a]
F	44.315	42.813	39.965	410.156
Pr > F	0.0001	0.0001	0.0001	0.0001

In each column, the values followed by the same letters do not differ significantly at the 5% level. EP: eggshell powder; SSP: SNAIL shell powder; SeSP: sea shell powder; ESE: egg shell extract; SSE: snail shell extract; SeSE: sea shell extract; C: control; AT50FL: average time to 50% flowering; AT50F: average time to 50% fruiting; AT50R: average time to 50% ripening; FLAR: flower abortion rate; DFR: damaged fruit rate; SFR: stunted fruit rate.

Table 3. Impact of calcium sources (eggshell, snail shell, seashell) and form (powder and extract) on tomato production.

Calcium sources	Number of flowers	Number of fruits	FLAR	SFR	NFR
EP	51.43 ± 1.14[a]	49.03 ± 0.96[a]	0.64 ± 1.13[b]	1.00 ± 1.61[b]	0.40 ± 1.01[b]
SSP	34.07 ± 1.14[c]	29.80 ± 0.96[c]	1.62 ± 1.13[b]	5.00 ± 1.61[b]	2.2 ± 1.01[b]
SeSP	41.53 ± 1.14[b]	37.43 ± 0.96[d]	4.32 ± 1.13[b]	6.33 ± 1.61[b]	2.97 ± 1.01[b]
ESE	45.93 ± 1.1[b]	42.07 ± 0.96[b]	2.51 ± 1.13[b]	4.00 ± 1.61[b]	1.73 ± 1.01[b]
SSE	34.33 ± 1.14[c]	30.83 ± 0.96[de]	3.32 ± 1.13[b]	8.00 ± 1.61[b]	3.33 ± 1.01[b]
SeSE	41.50 ± 1.14[b]	34.67 ± 0.96[cd]	2.38 ± 1.13[b]	5.66 ± 1.61[b]	3.13 ± 1.01[b]
C	24.50 ± 1.14[d]	17.73 ± 0.96[e]	50.96 ± 1.13[a]	44.66 ± 1.61[a]	55.44 ± 1.01[a]
F	53.25	89.58	266.335	87.62	393.839
Pr > F	0.0001	0.0001	0.0001	0.0001	0.0001

In each column, the values followed by the same letters do not differ significantly at the 5% level. EP: eggshell powder; SSP: snail shell powder; SeSP: sea shell powder; ESE: egg shell extract; SSE: snail shell extract; SeSE: sea shell extract; C: control; SFR: stunted fruit rate.

fruit diameters were obtained with the eggshell (57.18 mm) and snail powders (57.02 mm).

Table 4. Impact of calcium sources (eggshell, snail shell, seashell) and form (powder and extract) on tomato yield.

Calcium sources	MF	GROSS YIELD	MHF	NET YIELD
EP	12.53 ± 0.21^{a}	13.68 ± 1.62^{a}	11.75 ± 0.09^{a}	13.81 ± 0.24^{a}
SSP	11.71 ± 0.21^{ab}	13.96 ± 1.62^{a}	10.10 ± 0.09^{bc}	13.62 ± 0.24^{b}
SeSP	11.33 ± 0.21^{b}	13.78 ± 1.62^{a}	9.38 ± 0.09^{c}	13.03 ± 0.24^{b}
ESE	11.28 ± 0.21^{b}	13.96 ± 1.62^{a}	10.30 ± 0.09^{b}	13.66 ± 0.24^{ab}
SSE	11.40 ± 0.21^{b}	13.22 ± 1.62^{b}	9.95 ± 0.09^{bc}	12.52 ± 0.24^{bc}
SeSE	11.14 ± 0.21^{b}	12.90 ± 1.62^{c}	9.68 ± 0.09^{c}	12.41 ± 0.24^{c}
C	6.88 ± 0.21^{c}	9.02 ± 1.62^{d}	3.71 ± 0.09^{d}	4.68 ± 0.24^{d}
F	77.190	326.084	831.669	144.393
Pr > F	0.0001	0.0001	0.0001	0.0001

In each column, the values followed by the same letters do not differ significantly at the 5% level. EP: eggshell powder; SSP: snail shell powder; SeSP: sea shell powder; ESE: egg shell extract; SSE: snail shell extract; SeSE: sea shell extract; C: control; MF: average mass of fruits; MHF: mass of healthy fruits.

Table 5. Impact of calcium sources (eggshell, snail shell, seashell) and form (powder and extract) on tomato fruit firmness and diameter, brix degree and calcium content.

Calcium sources	Firmness (Kg/F)	BRIX (˚)	Ca^{2+} CF (100 g/F)	DF (mm)
EP	6.40 ± 0.48^{a}	3.67 ± 0.30^{ab}	67.33 ± 0.28^{a}	57.18 ± 0.17^{a}
SSP	4.56 ± 0.48^{ab}	4.00 ± 0.30^{ab}	40.97 ± 0.28^{bc}	57.02 ± 0.17^{a}
SeSP	4.95 ± 0.48^{ab}	4.43 ± 0.30^{a}	23.88 ± 0.28^{c}	48.7 ± 0.17^{b}
ESE	4.94 ± 0.48^{ab}	3.83 ± 0.30^{ab}	41.15 ± 0.28^{b}	54.9 ± 0.17^{b}
SSE	4.62 ± 0.48^{ab}	3.83 ± 0.30^{ab}	40.51 ± 0.28^{b}	50.0 ± 0.17^{b}
SeSE	4.40 ± 0.48^{ab}	4.00 ± 0.30^{ab}	28.58 ± 0.28^{c}	49.7 ± 0.17^{b}
C	2.89 ± 0.48^{b}	5.20 ± 0.30^{a}	11.90 ± 0.28^{d}	38.2 ± 0.17^{c}
F	4.535	6.432	262.702	37.250
Pr > F	0.009	0.002	0.0001	0.001

Iin each column, the values followed by the same letters do not differ significantly at the 5% level. EP: eggshell powder; SSP: snail shell powder; SeSP: sea shell powder; ESE: egg shell extract; SSE: snail shell extract; SeSE: sea shell extract; C: control. Ca^{2+} CF: calcium content in fruits; DF: diameter of fruits.

4. Discussion

Calcium participates in myriad life processes and is involved in nearly all aspects of plant development [27]. The use of powders and extracts of eggshells, snails, and seashells as a source of biological calcium has significantly improved several growth parameters, development, and tomato fruit production. Results can be explained by the fact that these organic fertilizers are all easily assimilated by

Figure 1. Healthy fruits produced with plants treated with eggshell powder.

Figure 2. Control fruits with blossom end rot.

tomato plants. These biological calcium sources can constitute a real alternative to the use of synthetic calcium to struggle against the blossom end rot. Blossom end rot is characterized by large brown to black, dry leathery areas on the blossom end rot of tomato. These spots can enlarge and coalesce until the affect areas involve up to half of the surface of the fruit. The development of blossom end rot causes distortion of fruits.

Indeed, the eggshell consists of 94% calcium carbonate, 4% organic matter, 1% magnesium carbonate and 1% calcium phosphorus [28]. As for snail shells, it consists of 86% calcium and organic matter [29]. Seashells are also composed of calcium carbonate and organic matter [30]. The earliness of plants treated with eggshell shows a good growth and development of the plants fertilized, which is characterized by its high calcium content.

The highest mean values were obtained with biological calcium treatment, whatever the form, due to lowest rate of abortion flower and a lower incidence of blossom end rot in comparison to the control. [31] found similar results on tomato. Indeed, according to this author, calcium treatment with 80 ppm concentration showed the highest fresh fruit yield due to available concentration of calcium into soil solution. Highly available concentration of calcium has been known to increase the tolerance of plants to stress, and it is possible that this may have led to the higher production of fruit quality.

The reason for early maturity is that calcium binds to pectin and forms calcium pectate, which is very useful in increasing the stiffness of the middle lamella and resistance to degrading enzymes such as polygalacturanase [32].

One of the appreciable characteristics of the tomato is the rigidity of the fruits. The firmness, in addition to being an organoleptic quality, can play an important role in fruit conservation.

Fruit firmness could be due to the calcium accumulation in the cell walls, which facilitates the cross-linking of pectic polymers, increasing wall strength and cell cohesion [33].

Brix (total soluble solids) is a combination of sugar and soluble salt. The results showed that total soluble solids were higher in control fruits than those treated with calcium. This is the consequence of a faster ripening of the control fruits because of their lowest calcium content. Indeed, in the fruit, calcium binds to pectin by forming the salt bridge between Ca^{2+} and the COO group [34]. As a result, calcium pectate is formed which will reduce the degradation of the cell wall and the production of ethylene, which will, therefore, slow down the fruit ripening process.

5. Conclusion

The results showed that the treatment with egg, snail and sea shell powders and extracts was well assimilated by the tomato plants. This uptake increased the level of calcium in plants and fruits. Thus, the plants were in good health resulting in improved growth, yield and reduced fruit blossom end rot. Also, it appears from this study that eggshell powder is more assimilable by the studied variety than other sources of calcium. These results make it possible to improve production, the quality of the fruits and above all to reduce production costs while ensuring the protection of the soil.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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