Eggshell powder as calcium source on growth and yield of groundnut (Arachis hypogaea L.)

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ABSTRACT
The use of eggshells as an alternative source of calcium carbonate for groundnut can reduce the impact on the natural reserves of limestone, a non-renewable natural source. This study investigated the effects of eggshell powder application on the growth and yield of groundnut. The calcium treatments were lime application (A0) at 500 kg ha⁻¹ and four rates of eggshell powder application including A1 (200 kg ha⁻¹), A2 (300 kg ha⁻¹), A3 (400 kg ha⁻¹), and A4 (500 kg ha⁻¹). Two application times, T1 (applying 5-days before sowing) and T2 (applying 5-days after flowering) were employed. The results showed that eggshell powder could be a useful alternative source to supply Ca for groundnut. Application of eggshell powder before sowing resulted in significantly higher pod yield and total calcium uptake with better growth parameters than after flowering. Increasing eggshell powder application rates also increased soil pH and calcium contents, and plant calcium uptake. The application rate of eggshell powder before sowing at the rate of 300 kg ha⁻¹ produced the highest pod yield and was suggested to be optimum.

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Introduction
Groundnut (Arachis hypogaea L.) is an important global food and oil crop that underpins agriculture-dependent livelihood strategies meeting food, nutrition, and income security (Ojiewo et al., 2020). It has been grown in over 110 countries with a total harvested area of 31.6 million ha and a production of 53.6 million tonnes (“FAOSTAT,” 2020). In 2019, groundnut contributed to world trade with a total of 3.19 billion USD (OEC, https://oec.world). Vietnam is ranked in the top of 20 groundnut producers with a total area of 169,595 ha and annual total production of 425,371 tonnes. In Vietnam, groundnut production is aimed at replacing less profitable and unsustainable crops in almost all provinces.

Calcium (Ca) plays an important role in plant growth and yield because it is as a structural component of the cell wall, a regulator of cell homeostasis, an enzyme
activator, and participates in ion absorption (Marschner, 2012). Compared to other crops, groundnut has high Ca requirements for both vegetative growth and healthy pod development (Cheema et al., 1991; Gascho & Davis, 1994). The Ca deficiency possibly causes a lower yield in groundnut production and leads to a high percentage of aborted seeds (empty pods or pops) and improperly filled pods (Kamara, 2010; Ntare et al., 2008). Enough Ca around groundnut pods leads to increased yield, oil content, and protein content of the kernel (Gashí et al., 2012). However, Ca does not show improvements in the yield of groundnut when the soil has adequate Ca (Hartzog & Adams, 1973). Over-application of Ca even causes an imbalance in plant nutrients which leads to reduce the groundnut yield (Alva et al., 1989; Singh & Chaudhari, 2007; Walker & Keisling, 1978). Therefore, the appropriate supplement of Ca should be practiced to maintain a high yield in groundnut production.

In Vietnam, lime is popular for use as Ca supply for groundnut production with a recommendation rate of 500 kg ha\(^{-1}\) (Vietnam Ministry of Agricultural and Rural Development, 2011). However, lime is ineffective in neutral and alkaline soils (GRDC, 2017). Moreover, this Ca source currently causes environmental issues like the generation of CO\(_2\) from heating limestone up to 750\(^\circ\) C. These are also relatively soluble materials which subject to leaching by rainfall or exceeding irrigation.

The eggshell has been attracted as an alternative liming source in agricultural production (Arabhosseini & Faridi, 2018; Park et al., 2007). Eggshells present healthy, balanced Ca due to their trace amounts of other minerals and are probably the best natural source of Ca (King’ori, 2011). Eggshells contain up to 95% Ca carbonate and various macro and micro-nutrients such as magnesium, potassium, iron, and phosphorus. Therefore, eggshells are also good for plant growth, stimulate root development, and can be reused to make fertilizers. Application of eggshell powder on several crops (such as cowpea, red chili, tomato, etc.) showed better growth and yield (Taufique et al., 2014; Tri; Kurniastuti, 2018; Radha & Karthikeyan, 2019). In the development of Vietnam’s livestock, egg production and consumption continuously increase up to a total of 473,660 tonnes in 2020 ("FAOSTAT," 2020). It will bring out the huge potential to produce and use eggshell powder as an alternative Ca source for agricultural production.

The studies on the application of eggshell powder in agriculture as well as in groundnut production in Vietnam are still lacking. Moreover, to obtain good yields, groundnut plants require an adequate amount of Ca from soil from the early flowering stage up to the pod filling stage (Kamara, 2010). The first 20 days following entry of the peg in the soil is critical for pod development because 92% of the total Ca is taken up during that period (Pattee & Stalker, 1995). Therefore, in groundnut production, lime is often used before planting, and gypsum is usually applied at early flowering to enhance the Ca availability during the critical stages (GRDC, 2017). However, there have been no studies on the application of eggshells to groundnut. This study, hence, aimed to investigate whether eggshell powder is better than lime application and determine the optimum rates and appropriate time to supply eggshell powder for groundnut growth and yield.

**Materials and methods**

**Materials**

The commercial groundnut cultivar L27 provided by Legume Research and Development Centre, Vietnam Field Crop Research Institute was used in this study. This is a high yield and high oil content cultivar which is recommended for most groundnut growing regions in Vietnam. The eggshell powder was provided by Green Techno 21 Company of Japan with diverse nutrient components (Table 1).

**Experimental design**

The experiment was conducted in the open field at Vietnam National University of Agriculture during the spring seasons in 2019. The experimental soil is the alluvial which is the typical soil for growing groundnut in Vietnam. Before plowing, soil samples were collected to analyze initial physical and chemical properties, as shown in Table 2.

The experimental design was a split-plot in a randomized complete block design with three replications. The main-plot factor included two application times, T1 (application was 5-days before sowing) and T2 (application was 5-days after flowering, about 38 days after sowing). The sub-plot factor included five treatments which were A0 (lime at 500 kg ha\(^{-1}\), equivalent to 200 kg Ca ha\(^{-1}\)) and four rates of eggshell powder

| Table 1. Ingredients in eggshell powder*.
|-----------------|-----------------|---------------|
| **Main Properties** | **Value** | **Main Properties** | **Value** |
| Humidity | 1.57% | Mn-citrate | 0.01% |
| N | 0.74% | B-citrate | > 0.002% |
| P | 0.26% | Fe | 0.017% |
| K | 0.08% | Cu | 0.0002% |
| CaCO\(_3\) | 88.08% | Zn | 0.0001% |
| Mg-citrate | 0.57% | Mo | 0.0001% |
| Alkalinity | 50.18% | pH | 10.1 |

*The data were supported by Green Techno 21 Company of Japan
Table 2. The initial physical and chemical properties of the experimental soil.

| Parameters         | Values |
|--------------------|--------|
| pH                 | 6.51   |
| Organic matter (%) | 1.67   |
| Total N (%)        | 0.09   |
| Total P (%)        | 0.18   |
| Total K (%)        | 1.34   |
| Total Ca (%)       | 0.07   |
| Exchangeable N (mg/100 g) | 4.27 |
| Exchangeable P (mg/100 g) | 50.02 |
| Exchangeable K (mg/100 g) | 11.80 |

application, including A1 (200 kg ha\(^{-1}\)), A2 (300 kg ha\(^{-1}\)), A3 (400 kg ha\(^{-1}\)), and A4 (500 kg ha\(^{-1}\)) and corresponding to 70, 106, 141 and 176 kg Ca ha\(^{-1}\), respectively. The sub-plot size was 7.5 m\(^2\) (5 m × 1.5 m) with a 10 × 30 cm of hill spacing (one plant per hill).

Mineral fertilizers with amounts of 30 kg N (urea 46%), 90 kg P\(_2\)O\(_5\) (Superphosphate 18%), and 60 kg K\(_2\)O (potassium chloride 56%) per hectare were supplied before planting. The eggshell powder was fertilized at the same time with the application of mineral fertilizer (T1 treatment) and 5 days after flowering (T2 treatment) and covered well with soil. Weeds were controlled by manual weeding. Pesticides were not applied because of no evidence of pests or diseases during the experimental period. Other cultivation practices were carried out following recommendations for a groundnut crop in the Vietnam National Technical Regulation on Testing for Value of Cultivation and Use of Groundnut Varieties (Ministry of Agricultural and Rural Development, 2011).

Data collection

Growth parameters

At full flowering stages (58 days after sowing), three plants per sub-plot were selected randomly to measure the SPAD value, the leaf area, the number of nodules, and the nodule fresh weight. The second fully expanded leaf from the top of the main stem of the sample plant was used for SPAD measurement by a chlorophyll meter (SPAD-502 Plus, Konica, Minolta Sensing Inc., Osaka, Japan). After that, all leaves of the sample plant were collected to measure the leaf area by a leaf area meter (Li-3100C Area Meter, LI-COR, Lincoln, Nebraska, USA). Root samples were cleaned with tap water. The nodules were separated from the root to count, then weight to measure nodule fresh weight.

In each subplot, five plants at harvest were collected for measurement of plant height and primary branch length. The root was separated and cleaned with tap water. Pods were separated from each sample plant to determine yield components. After that, the whole plant sample parts were oven-dried at 80°C for 48 hours to determine the shoot (including pods and stover) dry weight and root dry weight.

Yield components

Pods separated from the sample plant were counted to determine the number of filled pods, then air-dried to approximately 8% moisture content to measure the weight of 100 pods, and the weight of 100 seeds was also recorded. The shelling percentage was calculated by the ratio of total seed weight of 100 pods and weight of 100 pods. Pods of remaining plants in each sub-plot were harvested and air-dried to determine the total plot yield.

Soil calcium content and pH

At harvest, the soil sample was taken from a depth of 0–20 cm to determine calcium (Ca) content and pH. After air-drying, a part of the soil sample was suspended in distilled water (1:5, v/v), and measured for pH by a pH-EC meter (Ag 8003, SevenEasy, Mettler Toledo, Switzerland). The rest of the soil sample was digested with a nitric, sulphuric, and perchloric acid mixture. Then Ca content of the soil was determined by the Atomic Absorption Spectrometry method using a spectrophotometer (Atomic Absorption Spectro-Photometer, ANA-182).

Calcium content in plant

At harvest, whole parts of the sample plant after over-drying (stem, leaves, pods, and root) were ground by a grinder (RT-N04, Rong Tsong, Taiwan). The Ca content in the plant was determined by the Atomic Absorption Spectrometry method using a spectrophotometer (Atomic Absorption Spectro-Photometer, ANA-182).

Data analysis

Data were subjected to analyses of variance (ANOVA) according to a split-plot design using Statistix 10 package. Data of sub-plot factor (lime and eggshell powder application rates) within application time (main-plot factor) for investigated traits were analyzed according to a randomized complete block design. Means were compared by Tukey multiple comparisons test at p ≤ 0.05.

Result

Effects of eggshell powder application on growth characteristics of groundnut

Analysis of variance showed that application timing had significant effects on branch length, shoot and root weight, but not on plant height with higher means at
Table 3. Effects of application times and rates of eggshell powder on plant height (PH), branch length (BL), shoot weight (SW), and root weight (RW) of L27 groundnut cultivar.

| Time | Rate | PH (cm) | BL (cm) | SW (g plant$^{-1}$) | RW (g plant$^{-1}$) |
|------|------|---------|---------|----------------------|--------------------|
| T1   | A0   | 27.8$^{abc}$ | 27.2$^{bc}$ | 26.3$^{bcd}$ | 1.15$^{bc}$ |
|      | A1   | 28.1$^{abc}$ | 27.5$^{bc}$ | 26.9$^{bc}$ | 1.16$^{bc}$ |
|      | A2   | 29.4$^{a}$   | 29.7$^{a}$   | 31.6$^{a}$   | 1.36$^{a}$   |
|      | A3   | 28.6$^{b}$   | 28.7$^{b}$   | 26.3$^{bc}$ | 1.16$^{bc}$ |
|      | A4   | 27.9$^{bc}$  | 27.4$^{bc}$  | 25.3$^{cde}$ | 1.14$^{bc}$ |
| T2   | A0   | 25.9$^{c}$   | 26.2$^{b}$   | 24.9$^{de}$  | 1.05$^{c}$   |
|      | A1   | 26.3$^{bc}$  | 25.7$^{b}$   | 24.5$^{de}$  | 1.10$^{bc}$  |
|      | A2   | 26.5$^{bc}$  | 25.8$^{b}$   | 25.2$^{de}$  | 1.13$^{bc}$  |
|      | A3   | 28.2$^{bc}$  | 27.6$^{bc}$  | 27.8$^{b}$   | 1.20$^{b}$   |
|      | A4   | 26.5$^{bc}$  | 27.4$^{b}$   | 24.0$^{c}$   | 1.16$^{bc}$  |

Source of variation
App. time (T) ns * * * ***
App. rate (A) * * * ***
T x A ns ns *** ***

Note: T1 = Application before sowing; T2 = Application after flowering; A0 = application of lime at rate of 500 kg ha$^{-1}$, A1, A2, A3 and A4 = application rates of 200, 300, 400 and 500 kg ha$^{-1}$ of eggshell powder, respectively. Different alphabet letters show significance among treatments at p < 0.05 by the Tukey test. ns, *; ** *** means non-significant, significant at p < 0.05, 0.01 and 0.001, respectively.

Table 4. Effects of application times and rates of eggshell powder on leaf area, SPAD, nodule number (No.N), and nodule dry weight (NW) of L27 groundnut cultivar.

| Time | Rate | Leaf Area (dm$^{2}$) | SPAD | No.N (Nodule) | NW (g plant$^{-1}$) |
|------|------|----------------------|------|--------------|--------------------|
| T1   | A0   | 8.66$^{a}$          | 42.4$^{a}$ | 251.7$^{bc}$ | 0.27$^{bc}$         |
|      | A1   | 8.91$^{a}$          | 42.7$^{a}$ | 258.3$^{bc}$ | 0.30$^{bc}$         |
|      | A2   | 9.40$^{b}$          | 44.1$^{b}$ | 267.5$^{b}$ | 0.46$^{b}$         |
|      | A3   | 9.31$^{b}$          | 43.4$^{b}$ | 269.2$^{b}$ | 0.41$^{b}$         |
|      | A4   | 8.96$^{a}$          | 42.2$^{a}$ | 257.3$^{bc}$ | 0.36$^{bc}$         |
| T2   | A0   | 8.35$^{a}$          | 41.0$^{a}$ | 220.8$^{d}$ | 0.24$^{d}$         |
|      | A1   | 8.35$^{a}$          | 41.2$^{a}$ | 222.5$^{d}$ | 0.23$^{d}$         |
|      | A2   | 8.65$^{b}$          | 41.9$^{b}$ | 237.5$^{d}$ | 0.24$^{d}$         |
|      | A3   | 8.83$^{a}$          | 43.3$^{a}$ | 244.2$^{d}$ | 0.28$^{d}$         |
|      | A4   | 8.62$^{a}$          | 41.7$^{a}$ | 242.5$^{d}$ | 0.21$^{d}$         |

Note: T1 = Application before sowing; T2 = Application after flowering; A0 = application of lime at rate of 500 kg ha$^{-1}$, A1, A2, A3 and A4 = application rates of 200, 300, 400 and 500 kg ha$^{-1}$ of eggshell powder, respectively. Different alphabet letters show significance among treatments at p < 0.05 by the Tukey test. ns, *; ** *** means non-significant, significant at p < 0.05, 0.01 and 0.001, respectively.

T1 (earlier application before sowing) compared to the application at T2 (after flowering). Differences in lime and rates of eggshell powder applications also caused variations in plant height, branch length, the number of leaves, shoot weight, and root weight. The interaction between application time and eggshell powder treatment was only significant for shoot and root weight (Table 3). Application at the rate of A2 at T1 showed significantly better plant height and branch length than those of all treatments of application rate at T2 (except for A3). Shoot and root dry weight were highest by application rate of A2 at T1. The application rate of A3 at T2 had also high values for shoot and root dry weight. However, a significantly higher was found in shoot dry weight when compared to other application rates at T2 and A4 at T1, meanwhile, root dry weight was higher than that of A0 at T2 only.

Effects of eggshell powder application on the physiological performance of groundnut

Similar to growth and physiological parameters, application times had significant effects on 100-seed weight, 100-pod weight, and pod yield. Early application before sowing (T1) resulted in significantly higher these parameters than the application after flowering (T2), except for the number of filled pods and shelling percentage (Table 5). L27 obtained an average of 143.8 g for 100-pods weight, 57.1 g for 100-seeds weight, and 10.3 pods for the number of filled pods at T1 and while those at T2 were an average of 135.0 g for 100-pods weight, 50.9 g for 100-seeds weight, and 10.0 pods for the number of filled pods. Pod yield was also higher at T1 (3.24 t ha$^{-1}$) than at T2 (2.81 t ha$^{-1}$).

Lime and eggshell powder applications caused variations in the number of filled pods, 100-seeds weight, shelling percentage, and pod yield. The interactions between application time and eggshell powder treatment were significantly different in pod yield only (Table 5). The application rates of A2 and A3 at T1 showed better values for the number of filled pods with 11.0 and 10.9 pod plant, respectively. However, those were significantly higher than by applying at the rate of A1 at T1 and at rates of A0 and A1 at T2 only. At
Table 5. Effects of application times and rates of eggshell powder on number of filled pods (No.P), 100-pods weight (100P-W), 100-seeds weight (100S-W), shelling percentage (%), and pod yield of L27 groundnut cultivar.

| Time | Rate | No.P (Pod Plant\(^{-1}\)) | 100-PW (g) | 100-SW (g) | Shelling % (%) | Pod Yield (Tones ha\(^{-1}\)) |
|------|------|---------------------------|------------|------------|----------------|---------------------------|
| T1   | A0   | 9.7\(^{bc}\)              | 141.2\(^{abcd}\) | 54.9\(^{abc}\) | 70.4*          | 2.76\(^{cd}\)          |
|      | A1   | 9.3\(^{bc}\)              | 142.6\(^{abc}\) | 57.2\(^{ab}\)  | 66.3*          | 2.83\(^{cd}\)          |
|      | A2   | 11.0*                     | 146.1*      | 58.7*       | 73.5*          | 3.60*                  |
|      | A3   | 10.9*                     | 143.9\(^{gh}\) | 56.3\(^{ab}\) | 73.8*          | 3.30\(^{ab}\)         |
|      | A4   | 10.0\(^{bc}\)             | 142.2\(^{abc}\) | 56.2\(^{ab}\) | 72.0*          | 3.25\(^{ab}\)         |
| T2   | A0   | 9.1*                      | 133.2\(^{cd}\) | 47.4*       | 72.7*          | 2.69\(^{d}\)          |
|      | A1   | 9.1*                      | 134.2\(^{ed}\) | 48.8*       | 68.3*          | 2.68\(^{d}\)          |
|      | A2   | 10.2\(^{bc}\)             | 135.1\(^{cd}\) | 50.6\(^{cd}\) | 71.1*          | 2.79\(^{cd}\)         |
|      | A3   | 10.7\(^{ab}\)             | 136.1\(^{bcd}\) | 51.9\(^{bcd}\) | 72.3*          | 3.11\(^{bc}\)         |
|      | A4   | 9.9\(^{bc}\)              | 134.4\(^{cd}\) | 52.1\(^{bcd}\) | 68.2*          | 2.65\(^{d}\)          |

Source of variation

| T   | ns   | ns   | ns   | ns   | ns   |
|-----|------|------|------|------|------|
| A   | ***  | ns   | *    | *    | ***  |
| T x A | ns  | ns   | ns   | ns   | ***  |

Note: T1 = Application before sowing; T2 = Application after flowering; A0 = application of lime at rate of 500 kg ha\(^{-1}\); A1, A2, A3 and A4 = application rates of 200, 300, 400 and 500 kg ha\(^{-1}\) of eggshell powder, respectively. Different alphabet letters show significance among treatments at p < 0.05 by the Tukey test. ns, *,**,*** means non-significant, significant at p < 0.05, 0.01 and 0.001, respectively.

Each application rate, applications early at T1 showed significantly higher 100-pod weight and 100-seed weight than that at T2 (except for A3). The shelling percentage was not significant difference among combined timing and rate treatments. A better pod yield was gained by applying eggshell powder at the rate of A2 at T1 (3.60 t ha\(^{-1}\)) which was significantly higher than other treatments (except for A3 and A4 at T1). There was no difference in the yield of A0 and A1 at T1 compared to other treatments at T2. Application at the rate of A3 achieved a better yield (3.11 t ha\(^{-1}\)) than other rates at T2 (except for A2).

Investigating the relationship of pod yield with the amount of Ca application, the polynomial correlations are presented in Figure 1. The highest pod yield was obtained at the rate of 106 kg Ca ha\(^{-1}\) corresponding to applying 300 kg eggshell powder ha\(^{-1}\) (A2) when applying before sowing and at the rate of 141 kg Ca ha\(^{-1}\) corresponding to applying 400 kg of eggshell powder ha\(^{-1}\) (A3) when applying after flowering.

![Figure 1](image-url)
**Effects of eggshell powder application on soil pH, soil and plant calcium status**

Application time significantly affected pH, Ca content of the soil, and total Ca uptake in the plant (Figure 2). Application at T2 caused higher soil pH and soil Ca, but lower Ca uptake than those at T1.

There were upward trends in changes in soil pH and soil Ca by applying lime and increasing eggshell powder rates (Figure 2a, b). Application of eggshell powder at A4 (500 kg ha$^{-1}$) showed the highest soil pH, while the lowest pH was found at lime application treatment at both application times (T1 and T2). Higher soil Ca was also observed in higher eggshell powder rates (A2 to A4 compared to A1 and lime treatment).

Application of lime and eggshell led to variation in total Ca uptake in groundnut plants. Among treatments, the plant Ca uptakes were significantly higher at A2 and A3 rates, viz. 0.71 g plant$^{-1}$ and 0.64 g plant$^{-1}$ when applying eggshell before sowing at the rate of 300 kg ha$^{-1}$ (A2) and after flowering at the rate of 400 kg ha$^{-1}$ (A3) respectively (Figure 2c).

**Discussion**

In this study, we analyzed the effects of application time and eggshell powder rates on growth responses and yield of the L27 groundnut cultivar. Eggshell powder applied before sowing generally resulted in better growth characteristics such as branch length, shoot weight, root weight (Table 3), nodule number, nodule weight (Table 4), 100-pod weight, 100 seed weight, and pod yield (Table 5). Interaction of application timing and rate was presented in shoot dry weight and root dry weight, nodule weight, and pod yield. Better pod yield was achieved by combining the application of eggshell at the rate of 300–500 kg ha$^{-1}$ before sowing. Moreover, increasing the application rate of eggshell powder up to 300 kg ha$^{-1}$ if applied before sowing or 400 kg ha$^{-1}$ if applied after flowering resulted in the highest pod yield (Figure 1) and Ca uptake of plants (Figure 2c). In addition, soil pH and soil Ca increased as eggshell powder rates increased, and were higher when applied after flowering (Figure 2a, b).

Previous studies also reported that applying Ca source in the forms of lime or gypsum brings advantages in growth, yield, and seed quality of groundnut, especially on acidic soil (Gashti et al., 2012). For example, Ca application significantly decreased the number of empty pods and increased shoot length and root lengths, dry mass (Kamara, 2010), shelling percentage, 100-seeds weight, and yield (Wiatrak et al., 2006; Gashti et al., 2012; Ullah et al., 2019). However, additional Ca

![Figure 2](image-url)
application did not increase groundnut growth and yield when the soil already had adequate Ca levels or was Ca-rich (Hartzog & Adams, 1973; Walker & Keisling, 1978). Kamara et al. (Kamara, 2010) and Ullah et al. (2019) also agree with our findings that the growth and yield of groundnut increase but cease when applying gypsum or lime up to the optimum doses. The polynomial correlation between pod yield and Ca application level (Figure 1) revealed that the growth and yield of groundnut are diminished by exceeding the application of Ca. This might due to the competition of Ca and other mineral elements such as K or Mg. Alva et al. (1989) explained that in groundnut production when the ratio of Ca and K in soil was less than 3:1, the absorbance of Ca was limited because of the adversary to K during the diffusion process into the hull. High concentrations of K limited Ca diffusion. Conversely, over-application of Ca may limit general K uptake by the plant and subsequently reduce yields. Moreover, Singh and Vidya Chaudhari (2007) also reported that increasing Ca levels decreased K and Mg concentrations in the groundnut plant tissues. This agrees with the previous study by Hartzog and Adams (1973) who recommended that Ca fertilization should be based on the knowledge of soil Ca level before planting to determine if Ca applications would be effective.

In this study, the application of eggshell powder showed better growth and agronomic traits compared to lime application. This result is in line with previous results of Holmes et al. (2011) who reported that corn yield was higher with eggshell application than with lime application. Eggshells contain nearly equal Ca content and more macro and micro-nutrients than lime. Therefore, in most cases, more adequate nutrients from eggshells might help plants perform better growth. However, in groundnut roots, Ca moves upward via the xylem, but a non-significant amount of Ca moves back from the leaves down to the developing reproductive organs (Bledsoe et al., 1949; Mizuno, 1959; Wiersum, 1951). Once the groundnut peg has penetrated the soil, root-absorbed Ca is no longer translocated to the developing pod. Then, the groundnut pod must directly absorb Ca from the soil (Skelton & Shear, 1971). Eggshell is an organic Ca source; groundnut peg and pod might take more time to absorb Ca. Thus, the late application (after flowering) and lower Ca amount, might cause the deficiency of Ca compared to lime application. Our study’s result showed significantly lower values for growth, physiological, and yield parameters in later application treatments (after flowering) than earlier treatments (before planting) for both lime and eggshell applications. The results suggested that Ca application, especially from organic sources should be applied before sowing to provide more benefits for groundnut growth and yield performance.

As a Ca source, eggshell powder enriches the pH and Ca content of the soil. Therefore, in this study, the soil pH and Ca contents in the soil and plants increased with increasing the rates of eggshell powder application. Similarly, Holmes et al. (2011) showed that soil pH was increased to a higher level with increasing duration after eggshell powder application. Kirthisinghe et al. (2014) showed raising in soil pH when increasing gypsum application. However, the ideal range of soil pH for groundnut is 5.5 (slightly acidic) to 7.0 (neutral). If the soil is more alkaline, deficiencies in Zn, and possibly Fe can occur (GRDC, 2017). Therefore, applying eggshell powder over the optimum rates could lead to a decrease in the growth and yield parameters of groundnut. In addition, application of both lime and eggshell powder after flowering seemed to increase soil pH and Ca content in the soil than application before sowing. Later application of these Ca sources could be the reason for higher Ca residue in the soil. It is in agreement with Gascho et al. (1993) that Ca fertilization often applied at first bloom increased soil Ca content. In normal, higher Ca application resulted in higher pH and Ca content in the soil. However, in our experiment, soil pH and soil Ca were lower in lime than those in eggshell powder application. It is presumably because of the presence of readily soluble Ca from lime in the root zone. Ca from lime is a relatively soluble material subject to leaching by rainfall and irrigation (Daughtry & Cox, 1974); hence, the lowest values of the soil pH and Ca content were observed in the lime treatment. On the other hand, higher Ca application also resulted in higher Ca uptake in the plant, as observed in lime (500 kg ha⁻¹) and eggshell powder application of 300 and 400 kg ha⁻¹. However, higher yields were recorded for eggshell powder use, implicating its effectiveness in groundnut production.

In conclusion, the eggshell powder can be an alternative to supplying Ca to groundnut. However, early application of eggshell powder before sowing resulted in better growth and yield performance in groundnut. Increasing the rates of eggshell powder increased the soil pH and Ca content in the soil and the groundnut plant. Among four application rates of eggshell powder, the application of 300 kg ha⁻¹ before sowing brought the most benefit for groundnut production.

Disclosure statement

No potential conflict of interest was reported by the author(s).
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Abbreviation

Ca, Calcium.

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