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

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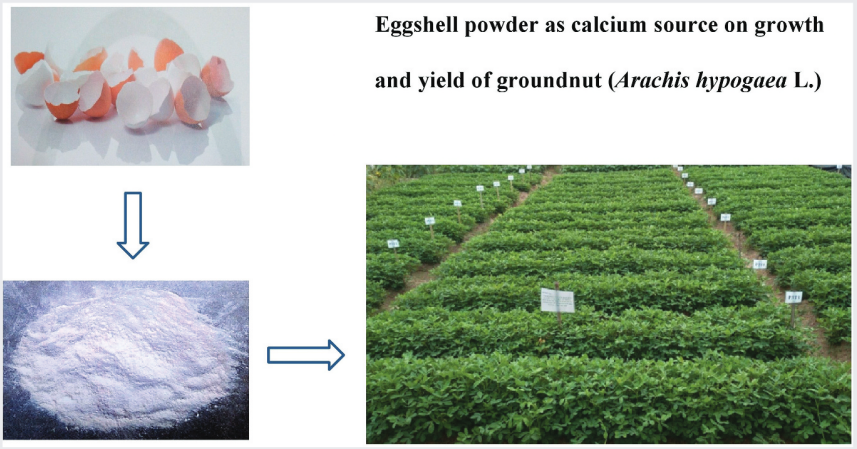
ABSTRACT

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 aimed to investigate 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 result 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

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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 (Gashti 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° 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 x 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_2O_5 (superphosphate 18%), and 60 kg K_2O (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 8603, 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 oven-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 $p \leq 0.05$.

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}	26.5^{bcd}	1.15^{bc}
	A1	28.1^{abc}	27.5^{abc}	26.9^{bc}	1.16^{bc}
	A2	29.4^{a}	29.7^{a}	31.6^{a}	1.36^{a}
	A3	28.6^{ab}	28.7^{ab}	26.3^{bcd}	1.16^{bc}
	A4	27.9^{abc}	27.4^{abc}	25.3^{cde}	1.14^{bc}
T2	A0	25.9^{c}	25.6^{c}	24.5^{de}	1.05^{c}
	A1	26.3^{bc}	25.7^{c}	24.5^{de}	1.10^{bc}
	A2	26.5^{bc}	25.8^{c}	25.2^{cde}	1.13^{bc}
	A3	28.2^{abc}	27.6^{abc}	27.8^{b}	1.20^{b}
	A4	26.5^{bc}	27.4^{c}	24.0^{e}	1.16^{bc}
Source of variation					
Application time (T)		ns	*	*	*
Application 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^{ab}	0.277^{de}
	A1	8.91^{a}	42.7^{a}	258.3^{ab}	0.307^{d}
	A2	9.40^{a}	44.1^{a}	267.5^{a}	0.463^{a}
	A3	9.31^{a}	43.4^{a}	269.2^{a}	0.410^{b}
	A4	8.96^{a}	42.2^{a}	257.3^{ab}	0.367^{c}
T2	A0	8.35^{a}	41.0^{a}	220.8^{d}	0.213 ^{f}
	A1	8.53^{a}	41.2^{a}	222.5 ^{cd}	0.233 ^{f}
	A2	8.65^{a}	41.9^{a}	237.5^{bcd}	0.240^{ef}
	A3	8.83^{a}	43.3^{a}	244.2^{bc}	0.280^{d}
	A4	8.62^{a}	41.7^{a}	242.5^{bcd}	0.210 ^{f}
Source of variation					
Application time (T)		*	**	**	**
Application rate (A)		ns	ns	**	***
TxA		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.

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 parameters, application times had significant effects on all physiological traits. Across application rate, application before sowing had higher values for leaf area, SPAD, nodule number, and nodule weight compared to applying after flowering (Table 4). Whereas across application timing, lime and eggshell powder applications caused variations in nodule number and nodule weight. The interaction between the application time and eggshell powder rates was significant for nodule weight only. Combining the effect of application time and rate, there were no significant differences among treatments for leaf area and SPAD. At each application rate, applications at T1 showed significantly higher values of the nodule number and nodule weight than those at T2. Application of A2 at T1 had the highest nodule weight (0.463 g plant^{-1}) followed by A3 (0.410 g plant^{-1}) at T1.

Effects of eggshell powder application on yield components of groundnut

Similar to growth and physiological measurements, application time 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