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Effects of calcium sources on physiological traits related to pod and seed yield of peanut

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Abstract Gypsum is an important calcium source in peanut production system as calcium is required for pod and seed filling to attain acceptable pod yield. Other sources of calcium may be used as gypsum substitutes in case they are available at low cost or free available. Calcium sources were significantly different for crop growth rate (CGR), pod growth rate (PGR), total dry matter at 65 and 92 DAP, and seed yield at harvest. Crop growth rate during planting to 65 DAP was significantly related to pod yield with R^2=0.56**. Pod growth rates during 65 to 92 DAP and 92 to 125 DAP were significantly related to pod yield with R^2 = 0.35** and 0.54**, and also related to seed yield with R^2 = 0.29* and 0.57**, respectively.

Keywords: Eggshell waste, FGD gypsum, Phosphogypsum, Pod growth rate

Introduction

Peanut (*Arachis hypogeal* L.) is an oil crop in Leguminosae family (Sharma and Bhatnagar-Mathur, 2006). Peanut is an excellent source of cheap protein, edible oil, important minerals and vitamins (Kassa *et al*., 2009; Yadav *et al*., 2015). According to FAO (2017), world production area of peanut was estimated at 26.3 million ha with seed production of 45.5 million tons and productivity of 1,740 kg ha^{-1}.

In Thailand, peanut is important as a cash crop, and it is grown in many cropping systems in three main growing seasons including early rainy season, late rainy season and in the dry season after rice harvest with irrigation. Peanut is also grown on river bank after recession of water level with or without irrigation. Although it is not a staple food, peanut is used as an ingredient in many food recipes and dipping. Peanut is also consumed as a snack in many different forms such as boiled peanut, roasted peanut and creamy-coated peanut.

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Calcium deficiency is an important limiting factor of peanut production and, because of subterranean nature of peanut pods, peanut requires sufficient calcium concentration in soil for pod development (Rajendrudus and Williams, 1987). Cost of calcium application adds up into cost of production and reduces the profit of the farmers. In Thailand, commercial gypsum is a sole form of gypsum available in the market and it cost is also high. However, there are other sources of gypsum that are not used in peanut production and it is available at low cost or freely available. Phosphogypsum, fuel gas desulfurization gypsum (FGD), and eggshell waste might be used as alternate sources of gypsum in peanut production. However, the information on the efficacy of these gypsum sources in peanut production is still lacking. Phosphogypsum is produced from waste of mollusk shell, and FGD is waste from electricity power plant using lignite as a fuel, whereas eggshell waste is freely available from urban restaurants.

To the best of our knowledge so far, few studies on the application of these alternative sources of gypsum in agriculture especially in peanut are available in the literature. Eggshell waste is used as a fertilizer and calcium supplement in nutrition for human, animals, plants, etc. (Faridi and Arabhosseini, 2018). Peanuts may benefit from Ca^{2+} better by using gypsum as the soil application and calcium nitrate as the foliar application to prevent disorders of Ca^{2+} deficiency under sandy soil conditions (Hamza *et al*., 2021). The overall growth and development of potato and pea plants increased, and the average plant heights after 30, 60 and 90 days were greater in the plants treated with eggshell waste (Wasir *et al*., 2018). Application of gypsum as a source of calcium could increase growth and yield of peanut, but application of gypsum plus lime though it increased yield was not economical for small-scale farmers (Sikhakhana, 2016). Growth parameters and chemical composition as well as seed yield of peanut was beneficially increased with increasing rate of applied gypsum sources (Aza and Mahmoud, 2013).

Growth and yield of peanut rely heavily on its ability to take advantage of environmental resources (Bell *et al*., 1991). Plant requires time for growth and partitions growth into economic yield. Growth rate depends on the ability of a crop to capture light and the conversion efficiency of intercepted radiation into biomass (Caliskan *et al*., 2008). The partitioning of photosynthesis to fruits during pod filling stage is the most influential physiological factor in yield determining of peanut. Crop growth rate (CGR) and pod growth rate (PGR) contribute to yield of peanut (Banterng *et al*., 2003). Pod yield also depends on number of mature pods and 100-seed weight, and, thus, yield is the summation of the rate of pod filling for each fruit multiplied by the duration of its filling period. Partitioning, pod filling duration and pod growth rate are the main factors affecting the variation in pod yield of peanut. The highest yield of peanut can be reach by crop breeding and improvement of agronomic practices (Mane *et al*., 2017). Peanut requires balance nutrients to promote healthy plants with sustainable growth, yield, and quality (Magen, 2008). Peanut also requires calcium for pod development and takes up calcium by its root system and developing pods (Hartzog and Adams, 1973). The application of calcium ($CaCO_3$) is important for proper kernel development in peanut. Calcium carbonate can be used as a calcium source, but it is a slow releasing source due to less solubility. Therefore, gypsum ($CaSO_4.2H_2O$) can be used at flowering stage to ensure the adequate availability of fruiting zone to enhance the pod development (Teilep *et al*., 2019). For this reason, calcium is preferred in the form of gypsum, which release nutrients faster than calcium carbonate and without changing soil pH. The reduced cost of by-product gypsum should be an advantage for producers on soils low in calcium (Grichar *et al*., 2002).

However, there are different types of calcium available in the market each of which has different price due to different origin. The objective of this study was to compare the effects of calcium sources on physiological traits to find strategies that will increase peanut yield and reduce production costs.

Materials and methods

Location and experimental design

This experiment was conducted in the farmer's field at Khang Phlu, Non Thai District, Nakhon Ratchasima Province, Thailand (15˚ 139′ N, 101˚ 96′ E). Five treatments consisting of 1) non-gypsum application, 2) gypsum ($CaSO_4.2H_2O$), 3) phosphogypsum, 4) fuel gas desulfurization gypsum (FGD) and 5) eggshell waste were arranged in a randomized complete block design with four replications.

Gypsum was purchased from the local market as it is a sole gypsum form available in the market. Phosphogypsum was prepared from waste of mollusk shell. The amount of 50 kg mollusk shell was loaded onto a mixing mortar followed by 30 kg of SP-24 solution consisting of 24% sulfur and 4% phosphoric acid by mass, and the mollusk shell mixture was stirred gently. Care must be taken during pouring the acid mixture into mollusk shell because it had strong reaction and produced a large amount of gas bubbles. Therefore, stirring of the mixture could reduce gas bubbles. The process took about 10-15 minutes until the reaction was completed, and the mixture was left in the mix tank until it dried in few minutes.

Fuel gas desulfurization gypsum (FGD) was kindly donated from Mae Moh Power Plant in Mae Moh Sub-district, Mae Moh District, Lampang Province, Thailand. FGD is the waste from the power plant using lignite as a fuel. Eggshell waste was collected from the local restaurants. The waste was air-dried and crushed into coarse powder.

Soil preparation, planting and cultural practices

The soil was ploughed twice at different directions, and the soil surface was levelled. The experimental site was further divided into 20 plots or raised beds with a plot size of 3×5 m, leaving the alley of 1 m between each plot for convenience of field management.

Peanut seed of KK 6 was treated with ethephon generator 2-chloroethylphosphonic acid 52% W/V at the rate of 6 ml per 20 l of water to break possible dormancy of the seed. Phthalimide N-(trichloromethylthio) [cyclohex-4-ene-1.2-dicarboximide 50% WP] at the rate of 5 g per kg of seed was applied to the seed to control soil born diseases. Seed was also inoculated with *Rhizobium* spp. before planting to promote biological nitrogen fixation. The seed was planted on each plot at a spacing of 30×30 cm, and each plot accommodated 72 hills. Each hill had 2 or 3 seeds and re-planting was carried out within 7 days after planting. The seedlings were thinned to obtain 1 plant per hill at 14 days after planting.

All gypsum treatments were applied to peanut at 25 days after planting (flowering stage) at the rate of 312.5 kg/ha. Manual weed control was carried out twice at 15 and 20 days after planting. Irrigation was applied by a sprinkler system at two-day intervals.

Data collection and data analysis

Growth stages of the crop (germination, flowering, pod formation) were monitored on a weekly basis and the data were collected for total dry weight, pod yield, seed yield, shelling percentage, filled seed, un-filled seed and 100-seed weight at 65, 92 and 125 days after planting (DAP). Crop growth rate (CGR), pod growth rate (PGR) and partitioning coefficient (PC) were recorded at 3 stages including first planting date to 65 DAP, 65 to 92 DAP and 92 to 125 DAP. Data were subjected to analysis of variance (ANOVA) using MSTATC software of Michigan State University (Bricker, 1989). Duncan's Multiple Range Test (DMRT) was used to compare means. In linear regression analysis, final pod yield and final seed yield were pod against crop growth rate and pod growth rate during different growth stage based on plot data to understand the effects of crop growth rate and pod growth rate on pod yield and seed yield.

Results

Crop growth rate

Crop growth rates (CGR) of peanut ranged between 4.0 and 5.1 g m^{-2} d^{-1} during planting (PT) to 65 DAP, 19.5 and 32.1 g m^{-2} d^{-1} during 65 DAP to 92 DAP, and 3.1 and 9.1 g m^{-2} d^{-1} during 95 to 125 DAP (Table 1). Significant differences ($P < 0.01$) among gypsum treatments were found for crop growth rate evaluated during PT to 65 DAP and 65 DAP to 92 DAP. During PT to 65 DAP, FGD gypsum and eggshell waste had the highest CGR of 5.1 g m^{-2} d^{-1} and 5.1 g m^{-2} d^{-1}, respectively, and they were not significantly different from no-gypsum (control) (4.4 g m^{-2} d^{-1}) and gypsum (4.2 g m^{-2} d^{-1}), whereas phosphogypsum had the lowest CGR (4.0 g m^{-2} d^{-1}).

During 65 to 92 DAP, FGD gypsum had the highest CGR of 32.1 g m^{-2} d^{-1} followed by phosphogypsum (23.1 g m^{-2} d^{-1}) and eggshell waste (23.1 g m^{-2} d^{-1}), respectively, whereas no-gypsum (control) had the lowest CGR (19.5 g m^{-2} d^{-1}), which was not significantly different from gypsum (22.2 g m^{-2} d^{-1}), phosphogypsum (23.1 g m^{-2} d^{-1}) and eggshell waste (23.1 g m^{-2} d^{-1}). During 92 to 125 DAP, all gypsum treatment were similar for CGR. However, it is likely that gypsum had the highest CGR (9.1 g m^{-2} d^{-1}) followed by eggshell waste (8.0 g m^{-2} d^{-1}).

Table 1. Means for crop growth rate (CGR) of KK 6 peanut variety evaluated at 65 days after planting (DAP), 92 DAP and 125 DAP as affected by different sources of gypsum

Treatment	**CGR (g m^{-2} d^{-1})**		
	PT to 65 DAP	65 to 92 DAP	92 to 125 DAP
No-gypsum (Control)	4.4^{ab}	19.5^{b}	7.2
Gypsum	4.2^{ab}	22.2^{b}	9.1
Phosphogypsum	4.0^{b}	23.1^{ab}	5.4
FGD gypsum	5.1^{a}	32.1^{a}	3.1
Eggshell waste	5.1^{a}	23.1^{ab}	8.0
F-test	**	**	ns
(C.V)%	9.3	16.6	57.6

PT = planting, DAP = days after planting

ns = non significant

** = significantly different at $P < 0.01$

Means within the same column followed by the same letter are not significantly different by DMRT

Total dry weight

The ranges of total dry weight among gypsum treatments were between 2.64 and 3.36 t/ha at 65 DAP, 8.13 and 12.00 t/ha at 92 DAP and 10.53 and 13.03 t/ha at 125 DAP (Table 2). Gypsum treatments were significantly different (P < 0.01) for total dry weight at 65 and 92 DAP, but they are not significantly different at 125 DAP. At 65 DAP, eggshell waste and FGD gypsum had the highest total dry weight of 3.36 and 3.32 t/ha, respectively, followed by no-gypsum (2.87 t/ha) and gypsum (2.73 t/ha), respectively, whereas phosphogypsum had the lowest total dry weight (2.64 t/ha).

At 92 DAP, FGD gypsum had the highest total dry weight, which as significantly higher than other treatments. At 125 DAP, FGD gypsum was still the highest treatment for total dry weight although it was not significantly different from other treatments.

Table 2. Means for total dry weight of KK 6 peanut variety evaluated at 65 days after planting (DAP), 92 DAP and 125 DAP as affected by different sources of gypsum

Treatment	Total dry weight (t/ha)		
	65 DAP	92 DAP	125 DAP
No-gypsum (Control)	2.87[ab]	8.13[b]	10.53
Gypsum	2.73[ab]	8.74[b]	11.74
Phosphogypsum	2.64[b]	9.06[b]	10.86
FGD gypsum	3.32[a]	12.00[a]	13.03
Eggshell waste	3.36[a]	9.60[b]	12.24
F-test	**	**	ns
(C.V)%	9.3	10.7	10.5

DAP = days after planting
ns = non significant
** = significantly different at P < 0.01
Means within the same column followed by the same letter are not significantly different by DMRT

Pod growth rate

Pod growth rates (PGR) among gypsum treatments were highest during 65 to 92 DAP (11.2-15.0 g m^{-2} d^{-1}), intermediate during 92 to 125 DAP (8.5-14.0 g m^{-2} d^{-1}) and lowest during PT to 65 DAP (0.13-0.18 g m^{-2} d^{-1}) (Table 3). Gypsum treatments were significantly different (P < 0.01) for PGR during 65 to 92 DAP, but they were not significantly different during PT to 65 DAP and 92 to 125 DAP. During 65 to 92 DAP, FGD gypsum had the highest pod growth rate of 16.5 g m^{-2} d^{-1} followed by eggshell waste (15.0 g m^{-2} d^{-1}). However, eggshell waste was not significantly different from phosphogypsum (13.1 g m^{-2} d^{-1}), gypsum (12.9 g m^{-2} d^{-1}) and no-gypsum (11.2 g m^{-2} d^{-1}).

Table 3. Means for pod growth rate (PGR) of KK 6 peanut variety evaluated 65 days after planting (DAP), 92 DAP and 125 DAP as affected by different sources of gypsum

Treatment	PGR (g m^{-2} d^{-1})		
	PT to 65 DAP	65 to 92 DAP	92 to 125 DAP
No-gypsum (Control)	0.15	11.2[b]	10.7
Gypsum	0.16	12.9[b]	9.8
Phosphogypsum	0.14	13.1[b]	8.5
FGD gypsum	0.13	16.5[a]	10.2
Eggshell waste	0.18	15.0[ab]	14.0
F-test	ns	**	ns
(C.V)%	16.8	8.4	32.9

PT = planting, DAP = days after planting
ns = non significant
** = significantly different at $P < 0.01$
Means within the same column followed by the same letter are not significantly different by DMRT

Pod yield

Pod yield increased with time from 65 to 125 DAP (Table 4). At 65 DAP, pod yields ranged between 0.06 and 0.07 t/ha, and the differences among gypsum treatments were not significant. At 92 DAP, pod yields ranged between 2.25 and 2.85 t/ha, and the differences among gypsum treatments were significant ($P < 0.01$). At 125 DAP, pod yields ranged between 4.04 and 5.52 t/ha, and the differences among gypsum treatments were not significant. At 92 DAP, FGD gypsum had the highest pod yield of 2.85 t/ha, and it was significantly higher than other treatments, which were similar for this trait.

Table 4. Means for pod yield of KK 6 peanut variety evaluated at 65 days after planting (DAP), 92 DAP and 125 DAP as affected by different sources of gypsum

Treatment	Pod yield (t/ha)		
	65 DAP	92 DAP	125 DAP
No-gypsum (Control)	0.06	2.25[b]	4.46
Gypsum	0.07	2.26[b]	4.27
Phosphogypsum	0.06	2.28[b]	4.04
FGD gypsum	0.06	2.85[a]	4.96
Eggshell waste	0.07	2.62[b]	5.52
F-test	ns	**	ns
(C.V)%	17.1	8.2	15.3

DAP = days after planting
ns = non significant
** = significantly different at $P < 0.01$
Means within the same column followed by the same letter are not significantly different by DMRT

Partitioning coefficient

Gypsum treatments were not significantly different for partitioning coefficient (PC) evaluated during PT to 65 DAP, 65 to 92 DAP and 92 to 125 DAP (Table 5). Partitioning coefficients were lowest during PT to 65 DAP (0.02-0.04), intermediate during 65 to 92 DAP (0.34-0.38) and highest during 92 to 125 DAP (0.41-0.54).

Table 5. Means for partitioning coefficients (PC) of KK 6 peanut variety evaluated between planting (PT) to 65 days after planting (DAP), 65 DAP to 92 DAP and 92 DAP to 125 DAP as affected by different sources of gypsum

Treatment	**PC**		
	PT to 65 DAP	65 to 92 DAP	92 to 125 DAP
No-gypsum (Control)	0.03	0.38	0.51
Gypsum	0.04	0.37	0.41
Phosphogypsum	0.04	0.35	0.45
FGD gypsum	0.02	0.34	0.46
Eggshell waste	0.03	0.38	0.54
F-test	ns	ns	ns
(C.V)%	24.8	9.8	11.81

PT = planting, DAP = days after planting
ns = non significant

Yield and yield components of peanut

Gypsum treatments were significantly different ($P < 0.05$) for seed yield and harvest index, but they were not significantly different for filled seeds, unfilled seeds, and 100-seed weight (Table 6). Eggshell waste had highest seed yield of 3.81 t/ha followed by FGD gypsum (3.22 t/ha) and no-gypsum (3.03 t/ha), respectively. Phosphogypsum and gypsum had the lowest seed yields of 2.75 and 2.54 t/ha, respectively.

Gypsum treatments were also significantly different for shelling percentage. The highest shelling percentages were found in no-gypsum control, phosphogypsum, FGD gypsum and eggshell waste, and they were significantly higher than commercial gypsum. Gypsum treatments were similar for filled seed, unfilled seed and 100-seed weight. However, Eggshell waste had the highest percentage of filled seed (94.95%) and the lowest un-filled seed (5.91%) whereas no-gypsum had the highest 100-seed weight 83.1 g.

Table 6. Means for seed yield, shelling percentage, percentage of filled seeds, percentage of un-filled seeds and 100-seed weight of KK 6 peanut variety at harvest as affected by different sources of gypsum

Treatment	Seed yield (t/ha)	Shelling percentage (%)	Filled seed (%)	Un-filled seed (%)	100-seed weight (g)
No-gypsum (Control)	3.03[ab]	67.8[a]	93.32	6.92	83.1
Gypsum	2.54[b]	59.4[b]	88.65	11.11	72.2
Phosphogypsum	2.75[b]	67.7[a]	93.25	6.27	76.3
FGD gypsum	3.22[ab]	64.8[a]	93.40	6.76	67.6
Eggshell waste	3.81[a]	68.8[a]	94.95	5.91	80.9
F-test	*	*	ns	ns	ns
(C.V)%	16.6	5.1	3.6	49.2	18.1

ns = non significant
* = significantly different at $P < 0.05$
Means within the same column followed by the same letter are not significantly different by DMRT

Relationship between crop growth rate and pod yield

Linear relationship between crop growth rate (CGR) and pod yield was positive and significant ($R^2 = 0.56^{**}$) during early reproductive stage (PT to 65 DAP) (Figure 2). The relationship was still positive but it was not significant (R^2 = 0.13) during middle reproductive stage (65 to 92 DAP), whereas the relationship become negative and not significant (R^2 = -0.05) during late reproductive stage (92 to 125 DAP). Growth during early reproductive stage had the highest contribution to pod yield, and growth during middle reproductive stage had low contribution to pod yield, whereas growth during late reproductive stage was somewhat detrimental to pod yield.

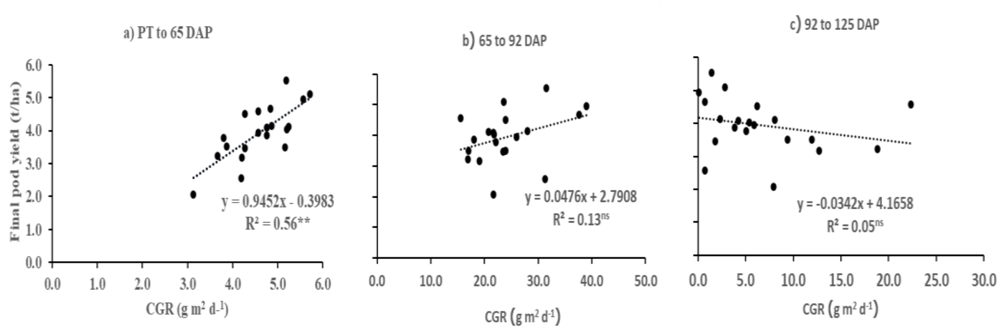

Figure 1. Relationship between CGR and final pod yield at harvest of KK 6 peanut variety at different reproductive stages

Relationship between crop growth rate and seed yield

Linear relationship between crop growth rate (CGR) and seed yield was positive and significant (R^2 = 0.55**) during early reproductive stage (PT to 65 DAP) (Figure 2). During the middle reproductive stage (65 to 92 DAP), the relationship was still positive, but it was not significant (R^2 = 0.11). During the late reproductive phase, however, the relationship was negative although it was not significant (R^2 = -0.06). The results indicated that growth during early reproductive stage was most important for seed yield of peanut.

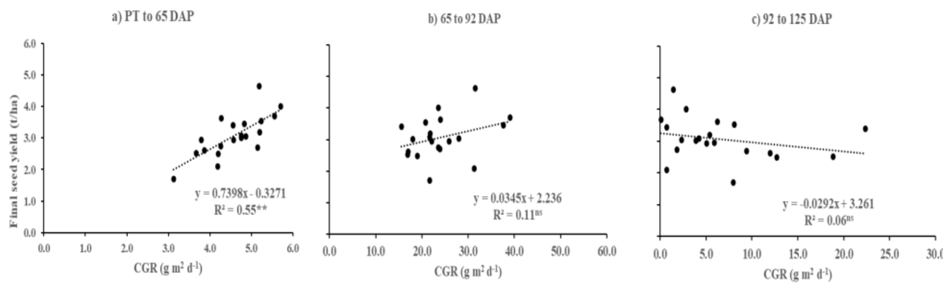

Figure 2. Relationship between CGR and final seed yield at harvest of KK 6 peanut variety at different reproductive stages

Relationship between pod growth rate and pod yield

The relationship between pod growth rate (PGR) and pod yield was not significant at early reproductive stage (PT to 65 DAP) (Figure 3). However, strong and positive relationships were observed during early reproductive stage (65 to 92 DAP) (R^2 = 0.35**) and late reproductive stage (65 to 92 DAP) (R^2 = 0.54**). The results indicated that pod growth rates during middle and late reproductive stages were more important for pod yield than pod growth rate during early reproductive stage.

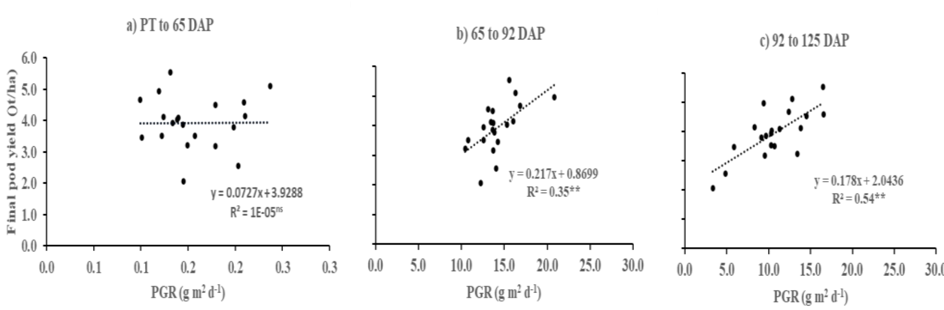

Figure 3. Relationship between PGR and final pod yield at harvest of KK 6 peanut variety at different reproductive stages

Relationship between pod growth rate and seed yield

The relationship between pod growth rate (PGR) and seed yield was similar to that between pod growth rate and pod yield. The relationship was not significant during early reproductive stage (R^2 = 0.00) (Figure 4). However, the relationships were positive and significant during middle reproductive stage (R^2 = *0.29) and more pronounced during late reproductive stage (R^2 = 0.57**). The results indicated that pod growth during middle and late reproductive stages was resulted from seed growth during these reproductive stages.

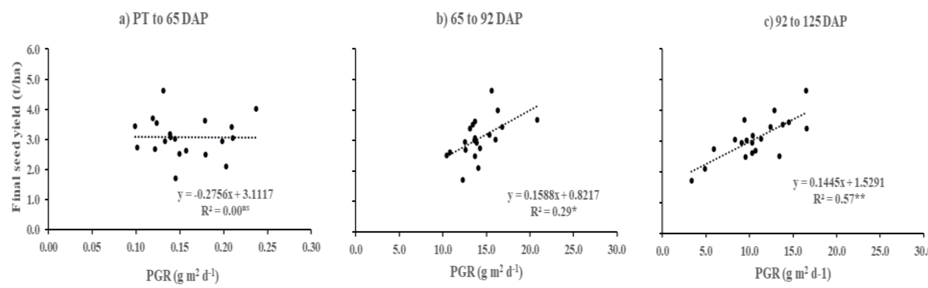

Figure 4. Relationship between PGR and final seed yield at harvest of KK 6 peanut variety at different reproductive stages

Discussion

Growth and yield

This study compared three types of gypsum and no gypsum control to investigate their effects on growth and yield of peanut, and evaluation was carried out at three reproductive stages including early reproductive stage (65 DAP), middle reproductive stage (92 DAP) and at harvest (125 DAP). As commercial gypsum is the main type available in the market and its price is still high, it might be more economical to use other types as substitutes for commercial gypsum. This study did not consider lime as a calcium source for peanut production as it is very costly compared to other sources. Therefore, we were interested in other promising sources including waste from power plant (FGD gypsum), mollusk shell waste and eggshell waste.

FGD gypsum was used as the original form from power plant. Mollusk shell waste was transformed into phosphogypsum before use, and eggshell waste was merely crushed into coarse powder. The authors were interested in their efficacy for peanut production, and, thus, the chemical compositions of these calcium sources were not determined. The differences in the results might be caused by the differences in chemical compositions and the ability of calcium sources to release calcium available for plant. Organic sources of calcium such as fish bone, chicken bone (Phiraphinyo *et al*., 2006) and eggshell waste (Khairnar and Nair, 2019) also provide other nutrients available to plant, while calcium sources from industrial waste might be contaminated with heavy metals (Yadav *et al.*, 2021). Gypsum is an ideal source of calcium for agriculture as it does not change soil pH (Walia and Dick, 2016). The pH range between 6.0 and 7.0 is most favorable for crop growth as most nutrients are available at this range. However, the range for calcium is slightly higher (Gentili *et al*., 2018). Peanut also responds to soil pH and gypsum rate. At a soil pH of 5.2 gypsum did not increase yield, and at a soil pH of 5.6 gypsum did not affect yield when applied at 340 kg/ha; gypsum at 680 kg/ha decreased yield (Jordan and Barnes, 2020).

As no gypsum control was relatively high for most parameters, peanut might have low responses to some treatments. This would be due to high residual calcium in the soil. Exchangeable calcium in this experimental site was 172.13 mg kg^{-1}, which may confound the results. According to Adams *et al*. (1993), peanut did not respond to calcium application at calcium level higher than 125 mg kg^{-1}. Calcium deficiency is rare in nature, but it might be not sufficient in light soils with high sand particles because calcium in this soil type is easily lost through leaching.

However, there were significant differences of the treatments for some parameters. Gypsum treatments were significantly different for crop growth rate during early reproductive stage and middle reproductive stage, and the growth rates were highest during middle reproductive stage. Similar results were also found for total dry weight. For these parameters, FGD gypsum and eggshell waste seemed to be better than gypsum and phosphogypsum, and they were also better than no-gypsum control. Application of gypsum at the rates of 25, 50, 75 and 100% of gypsum requirement increased root weight, shoot weight and nodule number of peanut, and it also increased nitrogen in seed and haulm (Ullah *et al*., 2019). Application of calcium in the form of gypsum at the rate of 90 had the highest pod yield, kernel yield and oil content of peanut, but application of calcium had no significant effect on protein content (Gashti *et al*., 2012). Application of gypsum is known to prevent hollow-heart symptom (unfilled pods) resulted from calcium deficiency in peanut (Yang *et al*., 2020). Direct comparison among different sources of calcium in different studies is difficult. Based on growth parameters, these alternative gypsum sources can be used as commercial gypsum substitutes for peanut production.

For yield related parameters, the treatments were significantly different for pod growth rate and pod yield during middle reproductive stage although partition coefficients were not different for all sampling dates and pod yields at harvest were also not different. The results showed small variations among calcium treatments for these parameters, indicating that other calcium sources such as phosphogypsum, eggshell waste and FGD gypsum can be used as gypsum substitutes in peanut production. In comparison between agricultural gypsum and power plant waste gypsum, no differences in peanut yield, or grade were noted with each gypsum source (Grichar *et al*., 2002). Based on these parameters, eggshell waste and FGD gypsum were most promising for use as commercial gypsum substitutes as they were highest for pod yield at harvest. In previous study, Wallace *et al*. (1993) reported that crop growth rate, pod growth rate and partitioning coefficient were physiological traits related to pod yield of peanut. Therefore, these parameters can be used as criteria for indirect selection for high yielding peanut genotypes (Banterng *et al*., 2003; Jogloy *et al*., 2011).

FGD gypsum and eggshell waste were better than commercial gypsum and phosphogypsum for seed yield, and shelling percentage were rather similar except for low shelling percentage in commercial gypsum, whereas no gypsum control was rather high for both seed yield and shelling percentage. However, gypsum treatments were similar for filled seed, un-filled seed and 100-seed weight. In this study, the authors did not collected data for seed grade, and this parameter may explain the differences in yield among the treatments.

Previous studied indicated that application of calcium sources increased total dry weight and yield of peanut due to reduction in percentage of un-filled seeds (Kamara *et al*., 2011; Arnold *et al*., 2017). This may be because FGD gypsum contains nutrients other than calcium such as sulphur and boron (Warren, 2011). Moreover, calcium also increased the size of the peanut kernels, resulting in an increase in the 100-seed weight (Gashti *et al*., 2012).

Relationships between physiological traits and yield

A better understanding on the relationships between physiological traits and yield might help improve agronomic practices to maximize yield and assist selection of superior genotypes based on physiological traits. Final pod yield and final seed yield were plotted against crop growth rate and pod growth rate during different reproductive stages to understand the effects of crop growth rate and pod growth rate on pod yield and seed yield. According to Gomes and Lopes (2005), pod yield was positively correlated with pod number, pod weight, number of mature kernels, weight of mature kernels, shelling percentage, 100-seed weight, primary and secondary branches per plant, and harvest index. Selection of associated traits and target traits would result in yield improvement.

In this study, the relationship between crop growth rate and final pod yield and the relationship between crop growth rate and final seed yield were in a similar pattern. Strong and positive correlations were found during early reproductive stage. The correlations were weaker during intermediate reproductive stage and slightly negative during late reproductive stage.

According to Phakamas *et al*. (2008), number of pod determined yield differences among peanut lines, and crop growth rates during R6 to R7 were closely correlated with pod yield at harvest. Crop growth rate, pod growth rate, and partition coefficient were the important physiological parameters determining pod yield under drought (Oteng-Frimpong *et al*., 2019). Our results were consistent with those reported in previous studies.

The relationships could be explained in this way. During early reproductive stage, final pod yield depended mostly on vegetative growth that supplied assimilates to developing pods. As KK 6 is a semi-determinate variety, which continues vegetative growth for some extent after flowering, vegetative growth of this peanut variety played the roles of both sink and source. For example, source provided assimilates to pods, while sink competed for assimilates. Therefore, the relationships were weaker during middle growth stage.

The importance of early growth stages on final yield is common in most terminated crop species. As rice varieties differ greatly in times required from sowing to maturity, grain yield of early mature photo-period insensitive varieties depend largely on growth at early growth phase compared to late mature rice varieties (Vergara *et al*., 1966). Peanut requires suitable growing conditions for optimum growth and yield and early planting is necessary for accumulation of growing degree days. However, late mature peanut varieties can prolong their life cycle for some extents, and, therefore, early growth stage is less important in late mature varieties (Canavar and Kaynak, 2010).

Vegetative growth still continued during late growth stage but with slow growth. Pod growth at this stage depended largely on assimilates accumulated in the plant, and vegetative growth seemed to be parasitic as indicated by negative relationship between pod yield and seed yield with crop growth rate at harvest.

Although peanut varieties have different maturity classes and plan types, appropriate planting dates and maturity are important for optimum yield as early developing pods can be rotted and spoiled and late developing pods can be too young to harvest (Ijaz *et al*., 2021). Better sink efficiency and better partitioning of photosynthates to mature pods was also key factors determining pod yield of peanut (Sengupta and Sharma, 1984).

The previous findings were similar to the results in this study. CGR increased between 60 and 80 days after sowing and decreased during maturity (Kathirvelan and Kalaiselvan, 2006; Mane *et al*., 2017). Although the patterns were similar, the exact timings of the reproductive stages might be differences among genotypes, plant types and maturity groups.

Similar to the above relationships but different in timing, the relationship between pod growth rate and final pod yield and the relationship between pod growth rate and final seed yield were in a similar pattern. Pod growth rate was not correlated with final pod yield and final seed yield during early reproductive stage. It had positive and strong correlations during middle reproductive stage, and the relationships were stronger during late reproductive stage.

According to Jogloy *et al*. (2011), correlation coefficients among crop growth rate, pod growth rate and partitioning efficiency were positive and significant. The results in this study supported previous findings. Unfortunately, previous study did not report the correlations at early reproductive phase. The correlations between pod growth rate at early reproductive phase and pod yield would be low because the onset of pod filling was starting at this phase and seed bulking occurred at the latter phases.

The relationships between pod growth rate with final pod yield and final seed yield could be explained by the following way. During early reproductive stage, formation of pods and seeds was starting and pod growth rate at this stage was still very low. Therefore, pod growth rate at this phase did not provide a significant contribution to pod yield and seed yield.

During middle reproductive growth stage, pod growth rate was high, and its relationships with pod yield and seed yield were stronger. This stage was similar to the late stage of reproductive phases in which pod growth rate was also high because rapid seed filling. Therefore, pod growth rates during middle and late reproductive phases had high contribution to pod yield and seed yield.

According to Liew *et al*. (2021), peanut is a determinate crop. The flowering pattern is bell-shaped from 25 days after planting (DAP) until 106 DAP. Therefore, the pods at harvest have different maturity levels. The phenology of peanut and the efficiency to develop flowering into mature pods would determine pod yield at harvest.

Although pod growth rate did not have significant contribution to final pod yield and final seed yield, pod number and seed number at early reproductive phase might contribute to pod yield and seed yield at harvest because they represent sink strength. Previous study reported that number of pods per plant was positively correlated with pod yield (Saleh and Masiron, 1994), and Kotzamanidis *et al*. (2006) suggested that selection based on plants that have shorter pod distance from the main root and larger seed size and also larger 100-pod weight.

To maximize pod yield and seed yield at harvest, crop management should be preformed properly to maintain high crop growth rate especially during early stage of reproductive phases as it provided high contribution to pod yield and seed yield. The crop should not be exposed to any stress during middle and late reproductive phases to maintain high rate of seed filling.

In this study, the authors compared three calcium sources with commercial gypsum available in the market and investigated their effects on growth and yield of peanut. The goal of this study was to find out if these calcium sources can be used in peanut production and to select the most appropriate calcium sources for peanut production in loamy sandy soil in the Northeast, Thailand. Phosphogypsum, FGD gypsum and eggshell waste can be used as commercial gypsum substitutes because they are comparable to commercial gypsum and more economical than commercial gypsum. FGD gypsum and eggshell waste should be the best choices in term of high CGR and PGR.

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References

Adams, J. F., Hartzog, D. L. and Nelson, D. B. (1993). Supplemental calcium application on yield, grade, and seed quality of runner peanut. Agronomy Journal, 85:86-93.

Arnold, J. A., Beasley, J. P., Harris, G. H., Grey, T. L. and Cabrera, M. (2017). Effect of gypsum application rate, soil type, and soil calcium on yield, grade and seed quality of runner type peanut cultivars. Peanut Science, 44:13-18.

Aza, H. and Mahmoud, A. M. (2013). Effect of different sources of calcium, organic and inorganic nitrogen on sandy soil, peanut yield and components. Topclass Journal of Agricultural Research, 1:51-59.

Banterng, P., Patanothai, A., Pannangpetch, K., Jogloy, S. and Hooggenboom, G. (2003). Seasonal variation in the dynamic growth and development traits of peanut lines. The Journal of Agricultural Science, 141:51-62.

Bell, M. J. Harch, G. and Wright, G. C. (1991). Plant population studies on peanut (*Arachis hypogaea* L.) in subtropical Australia. 1. Growth under fully irrigated conditions. Australian Journal of Experimental Agriculture, 31:535-543.

Bricker, A. A. (1989). MSTAT-C User's Guide. Michigan State University, East Lansing, MI.

Caliskan, S., Caliskan, M. E., Erturk, E., Arslan, M. and Arioglu, H. (2008). Growth and development of Virginia type groundnut cultivars under Mediterranean conditions. Acta Agriculturae Scandinavica. Soil and Plant Science, 58:105-113.

Canavar, Ö. and Kaynak, M. A. (2010). Growing degree day and sunshine radiation effects on peanut pod yield and growth. African Journal of Biotechnology, 9:2234-2241.

FAO (2017). FAOSTAT. Retrieved from https://goo.gl/cwxMEM.

Faridi, H. and Arabhosseini, A. (2018). Application of eggshell wastes as valuable and utilizable products: A review. Research in Agricultural Engineering, 64:104-114.

Gashti, A. H., Vishekaei, M. N. S. and Hosseinzadeh, M. H. (2012). Effect of potassium and calcium application on yield, yield components and qualitative characteristics of peanut (*Arachis hypogaea* L.) in Guilan Province, Iran. World Applied Sciences Journal, 16:540-546.

Gentili, R., Ambrosini, R., Montagnani, C., Caronni, S. and Citterio, S. (2018). Effect of soil pH on the growth, reproductive investment and pollen allergenicity of *Ambrosia artemisiifolia* L.. Frontiers in Plant Science, 9:1335. Retrieved from doi: 10.3389/fpls.2018.01335

Gomes, R. L. F. and Lopes, A. C. A. (2005). Correlations and path analysis in peanut. Crop Breeding and Applied Biotechnology, 5:105-112.

Grichar, W. J., Besler, B. A. and Brewer, K. D. (2002). Comparison of agricultural and power plant by-product gypsum for South Texas peanut production. Texas Journal of Agriculture and Natural Resources, 15:44-50.

Hamza, M., Abbas, M., Elrahman, A. A., Helal, M. and Shahba, M. (2021). Conventional versus nano calcium forms on peanut production under sandy soil conditions. Agriculture, 11:767. Retrieved from https:// doi.org/10.3390/agriculture11080767.

Hartzog, D. and Adams, F. (1973). Fertilizer, gypsum, and lime experiments with peanuts in Alabama. Agricultural experiment station / Auburn university.

Ijaz, M, Nawaz, A, Ul-Allah, S, Sher, A, Sattar, A, Sarwar M, Hussain, I., Rehman, A. U., Wahid, M. A., Ansari, M. J. and Hessini, K. (2021). Optimizing sowing date for peanut genotypes in arid and semi-arid subtropical regions. PLoS ONE, 16:e0252393. Retrieved from https://doi.org/10.1371/journal.pone.0252393

Jogloy, C., Jaisil, P., Akkasaeng, C., Kesmala, T. and Jogloy, S. (2011). Heritability and correlation for components of crop partitioning in advanced generations of peanut crosses. Asian Journal of Plant Sciences, 10:60-66.

Jordan D. L. and Barnes, J. S. (2020). Peanut response to interactions of soil pH and gypsum. Archives of Agriculture Research and Technology, 1:1020. Retrieved from https://www.corpuspublishers.com/article-info/peanut-response-to-interactions-of-soil- ph-and-gypsum-153

Kamara, E. G., Olympio, N. S. and Asibuo, J. Y. (2011). Effect of calcium and phosphorus fertilizer on the growth and yield of groundnut (*Arachis hypogea* L.). International Research Journal of Agricultural Science and Soil Science, 1:326-331.

Kassa, M. T., Yeboah, S. O. and Bezabih, M. (2009). Profiling peanut (*Arachis hypogea* L.) accessions and cultivars for oleic acid and yield in Botswana. Euphytica, 16:293-301.

Kathirvelan, P. and Kalaiselvan, P. (2006). Growth characters, physiological parameters, yield attributes and yield as influenced by the confectionery groundnut varieties and plant population. Research Journal of Agriculture and Biological Sciences, 2:287-291.

Khairnar, M. D. and Nair, S. S. (2019). Study on eggshell and fruit peels as a fertilizer. International Conference on Sustainable Development (ICSD 2019), Mumbai, India, pp. 25-27.

Kotzamanidis, S. T., Stavropoulos, N. and Ipsilandis, C. G. (2006). Correlation studies of 21 traits in F2 generation of groundnut (*Arachis hypogaea* L.). Pakistan Journal of Biological Sciences, 9:929-934.

Liew, X. Y. Sinniah, U. R., Yusoff, M. M. and Ugap, A. W. (2021). Flowering pattern and seed development in indeterminate peanut cv. ‘Margenta’ and its influence on seed quality Seed Science and Technology, 49:45-62.

Magen, H. (2008). Balanced crop nutrition: fertilizing for crop and food quality. Turkish Journal of Agriculture and Forestry, 32:183-193.

Mane, V. A., Ladole, M. Y., Shinde, A. A. and Bhuyar, A. R. (2017). Physiological analysis of growth and yield variation in groundnut. Electronic Journal of Plant Breeding, 8:1258-1264.

Oteng-Frimpong, R., Kassim, Y. B., Danful, R., Akromah, R., Wireko-Kena, A. and Forson, S. (2019). Modeling groundnut (*Arachis hypogaea* L.) performance under drought conditions, Journal of Crop Improvement, 33:125-144.

Phakamas, N., Patanothai, A., Jogloy, S., Pannangpetch, K. and Hoogenboom, G. (2008). Physiological determinants for pod yield of peanut lines. Crop Science, 48:2351- 2360.
Phiraphinyo, P., Taepakpurenat, S., Lakkanatinaporn, P., Suntornsuk, W. and Suntornsuk, L. (2006). Physical and chemical properties of fish and chicken bones as calcium source for mineral supplements. Songklanarin Journal of Science and Technology, 28:327-335.
Rajendrudus, G. and Williams, J. H. (1987). Effect of gypsum and drought on pod initiation and crop yield in early maturing groundnut (*Arachis hypogaea*) genotypes. Experimental Agriculture, 23:259-271.
Saleh, G. B. and Masiron, N. A. (1994). Performance and heritability studies on some peanut lines and cultivars. Journal of Islamic Academy of Sciences, 7:39-43.
Sengupta, U. K. and Sharma, A. (1984). Studies on assimilate translocation in relation to yield in groundnut. Indian journal of plant physiology, 27:232-238.
Sharma, K. K. and Bhatnagar-Mathur, P. (2006). Peanut (*Arachis hypogaea* L.). Methods in Molecular Biology, 343:347-58. Retrieved from https://doi: 10.1385/1-59745-130-4:347.
Sikhakhana, G. S. (2016). Evaluation of the effect of calcium source application on groundnut (*Arachis hypogaea* L.) yield and quality in Okhahlamba local municipality, Kwazulu- Natal, South Africa. (Master Thesis). University of South Africa, South Africa.
Teilep, W. M. A. K., El-Saady, A. M., El-Dahshouri, M. F. and Fergany, M. (2019). Influence of foliar spray of different calcium sources on nutritional status, seed yield and quality for some peanut genotypes. Bioscience Research, 16:309-319.
Ullah, M. A., Hyder, S. I. and Ahmed, R. (2019). Effect of gypsum application on groundnut growth and nodules under rain fed condition. International Journal of Research in Agriculture and Forestry, 6:8-13.
Vergara, B. S., Tanaka, A., Lilis, R. and Puranabhavung, S. (1966). Relationship between growth duration and grain yield of rice plants. Soil Science and Plant Nutrition, 12:31-39.
Walia, M. K. and. Dick, W. A (2016). Soil chemistry and nutrient concentrations in perennial ryegrass as influenced by gypsum and carbon amendments. Journal of Soil Science and Plant Nutrition, 16:832-847.
Wallace, D. H., Baudoin, J. P., Beaver, J. S., Coyne, D. P., Halseth, D. E., Masaya, P. N., Munger, H. M., Myers, J. R., Silbernagel, M., Yourstone, K. S. and Zobel, R. W. (1993). Improving efficiency of breeding for higher crop yield. Theoretical and Applied Genetics, 86:27-40.
Warren, A. (2011). Gypsum as an agricultural amendment. Associate Vice President for Agricultural Administration and Director, Ohio State University Extension. 35.
Wasir, A., Gul, Z. and Hussain, M. (2018). Comparative study of various organic fertilizers effect on growth and yield of two economically important crops, potato and pea. Agricultural Sciences, 9:703-717.
Yadav, R., Jat, L. K., Yadav, S. N., Singh, R. P. and Yadav, P. K. (2015). Effect of gypsum on growth and yield of groundnut (*Arachis hypogaea* L.). Environment and Ecology, 33:676-679.
Yadav, V. K., Yadav, K. K., Cabral-Pinto, M. M. S., Choudhary, N., Gnanamoorthy, G., Tirth, V., Prasad, S., Khan, A. H., Islam, S. and Khan, N. A. (2021). The processing of calcium rich agricultural and industrial waste for recovery of calcium carbonate and calcium oxide and their application for environmental cleanup: A review. Applied Science, 11:4212. Retrieved from https://doi.org/10.3390/app11094212
Yang, S., Wang, J., Tang, Z., Guo, Zhang, F., Y., Zhang, J., Meng, J., Zheng, L., Wan, S. and Li, X. (2020). Transcriptome of peanut kernel and shell reveals the mechanism of calcium on peanut pod development. Scientific, 10:15723. Retrieved from https://doi.org/10.1038/s41598-020-72893-9

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