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Full Length Article

Potential of Gypsum Application One Month before Artificial Flower Induction to Improve the Quality of Pineapple Fruit in Ultisol Soil in Humid Tropical Climate

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Abstract

Most of the post-harvest losses in pineapple fruit are associated with low calcium (Ca) in the fruit. In this study, the impact of gypsum application on the fruit quality, crown, longest leaf with a leaf angle of 45° from the soil surface (D-Leaf), stem, and root of 'MD-2' pineapple was examined. A randomized complete block design with three replications was used to conduct the experiment. The treatments included (i) untreated (G0), (ii) gypsum: 0.5 Mg ha^{-1}; Ca: 116 kg ha^{-1} (G1), (iii) gypsum: 1.0 Mg ha^{-1}; Ca: 233 kg ha^{-1} (G2), (iv) gypsum: 1.5 Mg ha^{-1}; Ca: 349 kg ha^{-1} (G3), and (v) gypsum: 2.0 Mg ha^{-1}; Ca: 465 kg ha^{-1} (G4) were applied by spreading it in between pineapple rows one month before the artificial floral induction. In general, G2 treatment gave higher Ca in the leaf, adequate Ca in soil, increased the stem weight, D-Leaf width and length, increased the crown size (weight and length), and improved the fruit texture, but not the fruit soluble solids or the fruit weight. There was no difference in root density, fresh and dry root weight in all treatments. The results showed that during a time of high Ca demand at flowering and fruit structure construction, gypsum fertilizer with the proper amount one month prior to artificial floral induction satisfied the plant's need for Ca. Gypsum might be useful to reduce fruit loss due to lack of quality. Further work is needed to determine the effect of gypsum timing application to the pineapple fruit. © 2022 Friends Science Publishers

Keywords: Artificial floral induction; Fruit texture; Calcium; D-Leaf; Gypsum; Pineapple

Introduction

Pineapple (*Ananas comosus* L. Merr) is the most economically significant crop in tropical and subtropical climates, which is traded second most widely in the world after bananas. It is grown on more than 2.1 million acres in over 82 countries, contributing to over 20% of the world production of tropical fruits (Medina and Garcia 2005; Ndungu 2014). The main exporting countries of canned pineapple and pineapple juice are Indonesia, the Philippines and Thailand, while those of fresh pineapple are Costa Rica, the Philippines and Panama (Hossain 2016; UNCTAD 2016). When pineapple is grown for fresh fruit rather than canned pineapple, the fruit quality, including both the inside and exterior physical appearance, is particularly important. The primary sources of postharvest losses include mechanical injury, translucency, chilling injury, and postharvest diseases (Paull and Chen 2020). An essential nutrient for plants, calcium (Ca) is involved in a number of physiological processes that affect the composition of cell walls and membranes (White and Broadley 2003; Thor 2019).

The Ca assimilation in the cell wall and the temperature of the flesh were considered as variables influencing translucency (Cano-Reinoso *et al.* 2021). To reduce the incidence of translucency, high Ca and silicon ion assimilation (Ca: 22.60 and Si: 3.29 weight %, respectively) was required (Cano-Reinoso *et al.* 2022). Ca (in $CaCl_2$) spray at 75 Kg ha^{-1} increased turgor and rigidity in the pineapple cell wall, according to scanning electron microscopy analysis (Loekito *et al.* 2022). Ca is also necessary for the regular functioning of plant membranes, the synthesis of new cell walls, particularly the middle lamellae that divide cells into new cells, and the production of new cell walls (Taiz *et al.* 2018). Ca is related to a variety of physiological issues in fruits and vegetables (Olle and Bender 2009). Ca increased fruit firmness, lowering incidence of cork spot and brown core, and reducing ethylene production and respiration which improved apple fruit quality and extended shelf life (Conway *et al.* 2002). The decrease in firmness was delayed by Ca in tomato (Cheour and Souiden 2015), and high level of Ca was also associated with a reduction in the incidence of pineapple disorders (bruising) during handling, transportation, and shipping (Selvarajah *et al.* 1998). Low Ca causes fruit deformities and poor quality by causing cell membrane integrity to deteriorate and produce leaking and translucency (Silva *et al.* 2006; Khalaj *et al.* 2016; Souri and Hatamian 2019). In pineapple, Ca application may reduce the intensity of translucency (Paull and Chen 2015; Dayondon and Valleser 2018).

The balance of nutrients in soil and plant life is significantly influenced by Ca (Tailep *et al.* 2019). Basically, pineapple has a very low requirement for Ca (Vásquez-Jiménez and Bartholomew 2018). In highly weathered soils under a humid tropical climate, deficiency can occur due to low soil pH caused by the long-term use of acidifying fertilizers. Dolomite lime is frequently used to give Ca and magnesium (Mg) to soil and to change the pH of the soil. However, liming acid soils for pineapple should keep the pH not more than pH 5.5 to reduce the incidence of heart and root rots disease caused by fungus Phytophthora sp (Silva *et al.* 2006; Mite *et al.* 2010; Loekito *et al.* 2022). Gypsum could be used when it is desirable to supply Ca, but not change the soil pH (Vásquez-Jiménez *et al.* 2018), and not affect the root health (Silva *et al.* 2006). It is not enough to simply add more Ca to the soil to treat pineapple fruit disorders in the affected tissues brought on by a lack of Ca. Following absorption, Ca moves with transpirational water in the xylem, and very little Ca translocation in the phloem occurs resulting in poor Ca supply to roots and storage organs (Havlin *et al.* 2017).

Generally, gypsum is applied during soil tillage, nevertheless in these experiments, gypsum was applied to the soil one month before artificial flower induction. Ca is important after induction of artificial flowering due to the fact that it is a time of accelerated cell growth and division, which may enhance cell structure and lessen fruit translucence (Vásquez-Jiménez and Bartholomew 2018). In bell pepper (*Capsicum annuum* L.), (Mayorga-Gomez *et al.* 2020) revealed that fruit Application of Ca during bloom and the early stages of fruit development may prevent or reduce Ca deficiency disorders in bell peppers because Ca uptake persists throughout fruit development. The concentration of Ca in apple fruit reaches its peak immediately after flowering and then drops quickly as the fruit develops rapidly (Jones *et al.* 1983; Saure 2005). The cell wall composition of apricot fruit largely determines its texture, and treatment with 1% Ca followed by cold storage at 5°C can preserve a firmer texture and slow down cell wall polysaccharide degradation (Liu *et al.* 2017). The hypothesis of this experiment is that the application of gypsum as a soluble source of Ca nutrition one month before artificial flower induction can improve overall plant growth, yield, and fruit texture (firmness) of pineapple.

The objectives of this study were (1) to determine the effects of various amounts of gypsum as a source of Ca applied at a month before artificial flower induction on the plant (stem weight, D-Leaf length and D-Leaf width) and roots (weight and density), and (2) to determine the effects of gypsum on the fruit weight, crown size, and fruit quality. The D-Leaf, which has a leaf angle of 45 degrees from the soil surface, is the longest leaf of any plant. D-Leaf length is prevalent to be used to estimate the pineapple plant weight in the pineapple industry.

Materials and Methods

Description of site location and experimental design

The experiment was carried out at the Great Giant Pineapple Company (GGP) plantation's research station located in Lampung, Indonesia, with the following geographic coordinate: latitude 04º49'13'' South and longitude 105º13'13'' East, with an average altitude of around 46 m. The soil samples were taken three times in 0–20 cm depth, before plowing (4 months before planting), before planting, and two months after gypsum treatment. The initial soil pH is acidic (pH 4.5), has a sandy clay loam soil texture similar to that of a Red Yellow Podzolic soil or Ultisol, and low organic carbon content (Table 1). Two Mg ha^{-1} of dolomite lime was applied as a plantation practice standard to all blocks before plowing during soil tillage (4 months before planting), and the soil test result before and after dolomite application (Table 1). The pH increased slightly, as well other nutrients, except phosphor (P).

The soil was applied with basal fertilizer with the rate of 200 kg KCl, 200 kg DAP, 300 kg Kieserit, and 10 kg $CuSO_4$ before planting. The cow dung compost was administered at a rate of 4 Mg ha^{-1}. The climate is typical humid tropical, with annual rainfall of approximately 2.500 mm, temperature between 21–33°C, relative humidity around 83%, duration of effective sunshine 4.6 h per day, and standard evaporation rate (ETo) 3.6 mm per day.

Treatments G0 (untreated), G1 (0.5 and 116), G2 (1.0 and 233), G3 (1.5 and 349), and G4 (2.0 and 465) of gypsum amendments in Mg ha^{-1} and Ca in kg ha^{-1} were used in the experiment. The experiment was set up with three replications in a randomized complete block design. Gypsum was spread on the soil between the plant rows a month before induction of artificial flowering.

This experiment used single row planting system (non-raised bed) with planting distance 27 cm × 55 cm, so in 1 ha consisting of 67,340 plants ha^{-1}. Each plot in this experiment comprised at least 200 plants in ten single row beds, and there was a border of four rows between the plots to prevent plot edge effects. The seed was from suckers of 'MD-2' (about 35 cm in length). Spraying 3 kg ha^{-1} of ethylene, 25 kg ha^{-1} of kaolin, and 50 kg ha^{-1} of urea diluted in 4000 L ha^{-1} of water was used to induce artificial flowering 12 months after planting.

Data and analysis of soils, pineapple plant, roots and fruit quality

The following soil qualities were investigated using the methods listed below. (a) pH with pH Meter; (b) organic carbon (C) with Walkley and Black method in FeSO4 0.5 N; (c) nitrogen (N) with Kjeldahl method; (d) phosphorus (P) with P Bray 1 method; (e) kalium (K), Ca, and Mg were analyzed using acetic acid pH 7 extraction and reading with Atomic Absorption Spectrophotometer (AAS); (f) Micronutrient (Fe, Zn, Cu) analysis was performed using DTPA extraction and AAS reading; (g) Soil fraction (texture) analysis was performed using the hydrometer method.

Leaves nutrient analysis were done one month after artificial floral induction. The D-leaf was sampled, cut into pieces, and dried in a 70°C oven for 24 h. The dry leaves sample was ground and sieved with a 0.5 mm sieve. HNO_3 and H_2O_2 were used for extraction, while 175°C was used for destruction. The ASS was used to read macro and micronutrients, with the exception of P, which was read using a spectrometer.

Data of crop performance were collected from treatment plots 135–140 days after artificial flowering induction when the fruits were at the 25% mature stage. Pineapple eating quality is said to be the best at shell color number 3 (Table 2), if the fruit is harvested when about 20–35% of its shell color has already changed to yellow. This classification is based on GGP experience in long year cultivation of pineapple. At harvest, stem weight was measured after the leaves and roots had been removed and cleaned off the stem.

From each treatment plot, the longest leaf with a leaf angle of 45º from the soil surface (D-Leaf) was collected. A ruler was used to measure the length of the D-Leaf from bottom to top, while D-Leaf width was measured at the widest point with a ruler. The D-Leaf fresh weight also was measured with a digital scale. Root samples were collected by around a plant with a steel ring (54.5 cm in diameter and 25 cm in height), then watering the soil carefully such that the water reached the roots. To achieve the fresh weight, the roots were removed from the basal stem and dried at room temperature. They were then oven dried for 8 h at 105ºC to acquire the dry weight. The fruit weight, crown weight and length of fifteen fruits were measured in each treatment when 25% of the shell color had already changed to yellow (135–140 days after artificial flower induction).

Only the fruits with a maximum diameter range of 11.0–14.5 cm were taken to observe the fruit texture (firmness). Fifteen fruit samples were sliced horizontally at the biggest diameter for each treatment. Fruit firmness was assessed using a Brookfield Ametex CT3 Texture Analyzer, a compression and tension testing equipment for rapid quality control analyses, at three places on triangular portions of fruit slices selected from the central area (Fig. 1). There were four texture parameters observed, e.g., the deformation at the peak, work, peak load and final load.

To determine sweetness, fruit soluble solids content was measured. The juice was extracted from the fruit flesh, which did not include the fruit skin, core, or the top and bottom 3 cm of the fruit and was cut into small pieces. The juice was homogenized, and the temperature was checked. Then juice correction factor (cf) was determined at 20ºC. The filtrate was tested using a hand refractometer to determine the total soluble solids (TSS). The refractometer prism was cleaned with tissue paper dampened with distillated water. As the refractometer is temperature-sensitive, each sample was allowed time to reach room temperature.

Statistical analysis

The pineapple quality data were evaluated using an analysis of variance (ANOVA) in Minitab 16, and the means were compared with the Tukey Test with a 95 percent difference ($p<0.05$). The soil and leave nutrients were analyzed by comparing with the nutrient adequacy of pineapple 'MD-2' cultivar.

Results

Effects of gypsum application on soil and leaf chemical characteristics

As shown in Table 1, the soil pH was 4.39 at planting time, two months after gypsum application (around 13 months after plating), the soil pH was 4.27 at G0 (no gypsum application) and 4.47–4.54 in gypsum treatment. The P content tended to increase with gypsum application compared to G0 (14.65 mg kg^{-1}), while G3 dan G4 were 23.2 and 21.03 mg kg^{-1}, and G2 slightly increase (16.27 mg kg^{-1}) (Table 3). All treatments showed that Ca were more than 100 mg kg^{-1}. Mg levels were also higher than 50 mg kg^{-1}, with the maximum level recorded in G0 (0 kg gypsum) at 83.43 mg kg^{-1}.

The macronutrient (N, P, K, Ca, Mg) and micronutrient (Fe, Zn) content of pineapple leaves two months after gypsum application were almost the same in all gypsum application, except G3 treatment (1.5 Mg ha^{-1} gypsum) which gave higher value for all nutrient except Cu (Table 4). Without gypsum application, the content of Ca in the leave was 3.4 g kg^{-1} almost the same with G1 (0.5 Mg ha^{-1} gypsum), while G2, G3, G4 gave 4.2, 4.8 and 4.3 g kg^{-1} Ca respectively. Micronutrient, Zinc (Zn), was highest in G3 (1.5 Mg ha^{-1} gypsum) which content 51.39 mg kg^{-1} compared to G0 with only 37.61 mg kg^{-1} which was almost the same with G1, G2 and G4.

Table 1: Initial soil parameters and before planting after dolomite application

Soil parameter	Unit	Initial	After applied dolomite
pH		4.15	4.39
C	%	1.20	1.28
N	mg kg^{-1}	Not analyzed	13.50
P	mg kg^{-1}	12.03	8.62
K	me $100g^{-1}$	0.12	0.23
Ca	me $100g^{-1}$	0.42	0.63
Mg	me $100g^{-1}$	0.44	0.57
Cu	mg kg^{-1}	0.50	0.75
Exchangeable Al	me $100g^{-1}$	1.57	Not analyzed
Soil Fraction			
Clay	%	30.27	
Sand	%	59.11	
Silt	%	10.62	

Table 2: Shell color numbers according to pineapple fruit ripeness standards*

Shell Color	Description
SC0	Fruit is totally green. No traces of yellow color.
SC1	Majority of the eyes have green color with yellow color in 10% of their area.
SC2	Majority of the eyes have yellow color in>10–20% of their area.
SC3	Majority of the eyes have yellow color in>20–35% of their area.
SC4	Majority of the eyes have yellow color in>35–50% of their area.
SC5	All the eyes have yellow color in>50–75% of their area.
SC6	All the eyes have yellow color in>75–100% of their area with some green color to totally yellow.

*) Source: Great Giant Pineapple Company

Table 3: Soil chemical properties two months after gypsum application

Treatment (Mg ha^{-1})	pH	P (mg kg^{-1})	K (mg kg^{-1})	Ca (mg kg^{-1})	Mg (mg kg^{-1})
0 (G0)	4.27	14.65	38.54	121.21	83.43
0.5 (G1)	4.47	14.63	54.30	102.11	58.35
1.0 (G2)	4.49	16.27	42.21	236.95	70.83
1.5 (G3)	4.54	23.20	41.88	264.03	63.68
2.0 (G4)	4.47	21.03	42.47	243.97	75.06

Table 4: Leave nutrients content at two months after gypsum application

Treatment	N	P	K	Ca	Mg	Fe	Zn	Cu
(Mg ha^{-1})	(g kg^{-1})	(g kg^{-1})	(g kg^{-1})	(g kg^{-1})	(g kg^{-1})	(g kg^{-1})	(g kg^{-1})	(g kg^{-1})
0 (G0)	15.9	2.8	38.2	3.4	4.5	179.83	37.61	6.92
0.5 (G1)	16.6	2.7	40.5	3.6	4.3	165.77	33.11	9.11
1.0 (G2)	15.8	2.8	39.3	4.2	4.2	204.27	37.67	7.43
1.5 (G3)	16.2	4.0	51.0	4.8	5.6	229.10	51.39	9.80
2.0 (G4)	16.1	2.7	42.0	4.3	4.1	202.84	38.27	7.06

Effect of gypsum on the pineapple plant and roots

The effects of gypsum level on the pineapple plant and roots growth were small (Table 5, 6). There were only small but significant differences between G0 and the other treatments in all components measured (Table 5). Any of the root parameters had no significant effects. (Table 6). There was no significant difference in the fresh root weight, the dry root weight or the root density between the plants treated by 0.5–2.0 Mg ha^{-1} of gypsum (G1, G2, G3, and G4) and the untreated plant (G0) in this experiment (Table 6).

Effect of gypsum on the fruit quality and crown of the pineapple

The effect of soil applied gypsum on fruit weight was not significantly different between gypsum-treated plants and untreated plants in this experiment (Table 7). However, the Tukey test revealed that the fruit texture, crown weight, and crown length were significantly different at $p<0.05$.

The unit of CT3 Texture Analyzer, fixture TA5, was used to measure the metrics observed as indications of fruit texture, such as peak load, deformation at the peak (Def peak), work, and final load. The energy required to deform the structure of the pineapple fruit flesh was only 10.2 mJ if the soil was not treated with gypsum G0 (untreated). Otherwise, if the soil was treated with gypsum, especially 0.5 Mg ha^{-1} (G1) or 1 Mg ha^{-1}(G2), it needed more energy (13.5 mJ and 14.0 mJ, respectively) and was significantly different from G0.

Deformation is the process of the pineapple fruit changing in shape or anthesis, especially through the

Table 5: Effect of soil applied gypsum on pineapple plant

Treatment (Mg ha^{-1})	Stem weight (g)	D-Leaf length (cm)	D-Leaf width (cm)
0 (G0)	476±30 a	88.3±5.2 a	5.3±0.4 a
0.5 (G1)	581±141 ab	94.5±7.0 a	5.4±0.3 ab
1.0 (G2)	635±123 b	97.4±5.1 b	5.7±0.2 b
1.5 (G3)	616±120 b	97.8±6.2 b	5.5±0.3 ab
2.0 (G4)	635±108 b	97.4±6.6 b	5.5±0.2 ab
P-value	0.00	0.00	0.02

*The mean in the same column followed by the same letter signifies that they are not significantly different at P<0.05 by the Tukey test

Table 6: Effect of soil applied gypsum on pineapple roots

Treatment (Mg ha^{-1})	Fresh root weight (g)	Dry root weight (g)	Root density g (cm^3)$^{-1}$
0 (G0)	63.3±2.3 a	22.3±1.3 a	1.1±0.1 a
0.5 G1)	43.0±3.4 a	18.9±0.7 a	0.7±0.1 a
1.0 (G2)	48.0±4.7 a	19.1±1.1 a	0.8±0.1 a
1.5 (G3)	52.0±3.3 a	23.4±1.4 a	0.9±0.0 a
2.0 (G4)	70.8±3.4 a	25.2±2.2 a	1.2±0.1 a
P-value	0.69	0.88	0.69

*The mean in the same column followed by the same letter signifies that they are not significantly different at P<0.05 by the Tukey test

Table 7: Effect of soil applied gypsum one month before harvest on pineapple fruit quality and crown

Treatment	Fruit texture				Fruit SS	Fruit weight	Crown weight	Crown Length
(Mg ha^{-1})	Peak load (g)	Def peak (mm)	Work (mJ)	Final load (g)	(°Brix)	(g)	(g)	(cm)
0 (G0)	353±28 a	4.6±0.4 a	10.2±0.6 a	339±26 a	14.5±0.3 a	1,132±240 a	156±24 a	13.1±2.4 a
0.5 (G1)	445±11 b	4.6±0.2 ab	13.5±0.6 b	439±41 b	14.2±0.3 a	1,100±218 a	215±79 ab	18.6±4.1 b
1.0 (G2)	443±7 b	4.9±0.2 b	14.0±1.1 b	448±38 b	15.4±0.5 a	1,230±305 a	232±50 b	18.5±4.4 b
1.5 (G3)	418±29 ab	4.6±0.1 ab	13.4±0.9 ab	389±23 ab	15.2±0.4 a	1,264±315 a	185±71 ab	16.3±3.4 b
2.0 (G4)	406±11 ab	4.3±0.2 ab	13.1±1.0 ab	381±21 ab	14.6±0.5 a	1,346±319 a	224±76 b	18.0±3.0 b
P-value	0.08	0.32	0.01	0.06	0.14	0.13	0.01	0.00

*The mean in the same column followed by the same letter signifies that they are not significantly different at P<0.05 by the Tukey test

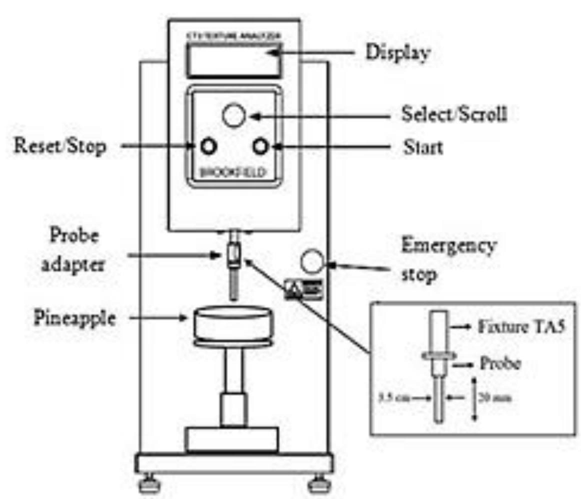

Fig. 1: Scheme of CT3 Texture analyzer

application of pressure. Def peak is the distance to which the fruit sample was compressed when the peak load occurred. The other parameters were the final load and the peak load; the final load usually occurs at the target deformation. The peak load is the highest load during the test. The gypsum treatments of G2 showed the highest value of deformation, work, and final load, which differed considerably from the control (G0).

Discussion

The soil pH used in this experiment was still below 5.5 (Table 1, 3) and suitable for pineapple grow. The ideal pH range for pineapple is from 4.5 to 5.5 (Maia *et al.* 2020). The level of soil nutrient after 2 months of gypsum application was adequate for pineapple requirement, except for P which was very low. P is not one of the most readily absorbed macronutrients by pineapple and is typically absorbed in the following order: K > N > Ca > Mg > S > P. (Maia *et al.* 2020). The soil requirement for Ca was 100–150 mg kg^{-1}, and Mg was 50–100 mg kg^{-1} (Vásquez-Jiménez and Bartholomew 2018). Treatment G2–G4 (1–2 Mg ha^{-1} gypsum) gave the highest value of Ca (>300 mg kg^{-1}) which almost 3 times compare to G0 (121 mg kg^{-1}), although the level of Ca in G0 (untreated) was adequate (>100 mg kg^{-1}).

Based on the adequacy of pineapple ‘MD-2’ nutrient in the leaves (Vásquez-Jiménez and Bartholomew 2018), the level of leave nutrient in all treatment were categorized adequate for pineapple, except for Cu in all treatment and Ca for G0 and G1 treatment (Table 4). The nutritional leaf adequacy (g kg^{-1}) for pineapple 'MD-2' should be 15–18 for N, 2.0 for P, 27–30 for K, 2.5–3.0 for Ca and Mg, and 10–15 mg kg^{-1} for Cu (Vásquez-Jiménez and Bartholomew 2018). Micronutrient concentration in the leaves positively correlated with Ca content but did not affect macronutrients. Mg concentration was reduced with increasing Ca supply when young orange was grown in pots (Eticha *et al.* 2017).

The results revealed that applying 1.0 Mg ha^{-1} of gypsum had a significantly greater impact on the D-Leaf index (width × length) and the stem weight compared to the untreated sample (Table 5). D-Leaf index are significantly affected by gypsum treatment, with G2 treatment having a higher index than that of G1, G3, G4, and control untreated (G0). However, G2 treatment has the same stem weight of the G4 treatment (635 g) with half dose needed only. Ca is an immobile element in phloem when it is absorbed by the roots and reaches the leaves or fruit through a complicated process. The D-Leaf possessed asucculent-brittle' leaf base, which is often used to assess plant nutritional status as an indicator of growth (Souza and Reinhardt 2007).

Ca is required for the synthesis of new cell walls, notably the synthesis of the middle lamella that separates newly divided cells (Taiz *et al.* 2018). Actually, the plant's stem weight gradually increases after planting, with no noticeable morphological changes until the reproductive growth phase begins (Malezieux *et al.* 2003). The Ca from the application of 1.0 to 2.0 Mg ha^{-1} of gypsum (G2, G3 and G4) affected the stem weight, which was significantly different from the untreated plant. In this case, the plants may have accumulated a starch reserve in the stem during the fast-generative growth stage, especially when the night temperatures were cooler from July to August during this experiment. Starch yield of the pineapple plant is decreasing after flowering and fruiting. It was also reported from India that the starch yield at 9-month growth stage (before flowering) was 16.03 ± 0.84%, then decreased to 11.58 ± 0.44% at 15 months (after flowering), and down then to 11.08 ± 0.77 at 18 months (after fruiting) (Rinju and Harikumaran 2019).

In this experiment, it was shown that there was no statistically significant difference in fresh root weight, the dry root weight or the root density between the plants treated by 0.5–2.0 Mg ha^{-1} of gypsum (G1, G2, G3, and G4) and the untreated plant (G0) (Table 6). This may be due to the fact that the application of Ca at one month before artificial flower induction was performed too late to improve the growth of the roots. There is evidence that root growth slows after floral induction and that peak root mass occurs at anthesis (Malezieux and Bartholomew 2003). The roots of the pineapple plant can develop constantly all year. Proliferation, however, is dependent on the availability of water and minerals in the rhizosphere. Root growth is slowed when the rhizosphere is excessively dry or deficient in nutrients. When the rhizosphere's condition improves, root development increases (Taiz *et al.* 2018). Actually, the availability of Ca in the rhizosphere promotes root cell elongation (De Freitas and Mitcham 2012).

From the results, it can be said that adding 1 Mg ha^{-1} of gypsum to the soil one month before induction of artificial flowering significantly increased the pineapple fruit flesh texture (Table 7) and potentially eliminated the occurrence of the translucency problem in the pineapple fruit. Gypsum ($CaSO_4.2H_2O$) is known as a moderately soluble source of the Ca nutrient, and the solubility is approximately 200 times greater than lime ($CaCO_3$). Thus, it is the reason why Ca gypsum is more mobile and more easily absorbed by the roots of the pineapple plant in the soil treated with gypsum in all treatments (G1, G2, G3 and G4). When more soluble Ca is accessible in the soil, pineapple fruit Ca uptake and flesh firmness will rise. Previous research found that a high Ca level could prevent cell wall pectate deterioration and that it was critical to maintain cell membrane integrity and cell wall stabilization (Hawkesford *et al.* 2012). High Ca leaves also reported indicates higher cell wall material content and higher leaf firmness of the orange plant (Eticha *et al.* 2017).

Sugar content determines fruit quality in most fruits (Villanueva *et al.* 2004). An increase in the sugar concentration in the flesh tissue apoplast of the pineapple fruit would favor the occurrence of translucency (Chen and Paull 2001). The total soluble solids (TSS) values of fruit treated with gypsum, namely, G1, G2, G3 and G4 were not significantly different from the TSS value of G0. It can be said, therefore, that the application of 0.5 to 2.0 Mg ha^{-1} of gypsum, equal to 116 to 465 kg ha^{-1} of Ca, did not increase the TSS value significantly. TSS of translucent fruit was not found to be significantly different from that of normal fruit (Soler 1993). However, all the pineapple harvested with all the treatments met the desired criteria for the fresh fruit market. A minimum of 12–13 °Brix (TSS 12–13%) content in the fruit is required for the pineapple fresh fruit market in Hawaii and Australia (Anonymous 2006; Lobo and Yahia 2017), while TSS levels for all treatments ranged from 14.2–15.4 °Brix.

No significant difference was seen among treatments G0, G1, G2, G3 and G4 in terms of the fruit weight. The average fruit weight with gypsum treatments G1, G2, G3 and G4 was larger compared to G0, but not significantly different from G0. Furthermore, Table 7 demonstrated that there was a significant difference in the weights of the crown harvested from the plants with gypsum treatments especially G2 and G4 compared to G0 (untreated plant). The application of treatment G2 brought about more crown weight, by 76 g, than the untreated plant (G0). In addition, the results showed that gypsum could also generate a significant increase in the crown length of up to 5.4 cm. Overall, gypsum was able to increase the size of the crown, especially when 1.0 Mg ha^{-1} of it was applied to the soil. Ca promotes the absorption of certain nutrients such as NH_4, K and P, stimulates photosynthesis, and increases the size of the sellable plant (Taiz *et al.* 2018).

Gypsum applications increased significantly crown weight and length as shown in Table 7. Thus, it is indicated that the Ca in gypsum plays a role in crown size. Fruit with larger crowns had less of translucency (Paull and Reyes 1996; Murai *et al.* 2021). In Hawaii, the occurrence of fruit translucency was low during the August to November when the fruit has the largest crowns (Paull and Chen 2015).

Conclusion

Application of 1.0 Mg ha^{-1} of gypsum one month before artificial flower induction caused different responses to the stem weight, the longest leaf at each plant with D-leaf length and width, the fruit texture and the crown size (weight and length) compared to control (untreated plant), but no significant difference in the fruit weight, fruit total soluble solids (TSS), fresh root weight, dry root weight or root density. The application of gypsum of 1.0 Mg ha^{-1}, also gave the highest Ca in leaf, and adequate Ca in soil. Further research should be focused in order to gain a better understanding of the best timing for applying gypsum (2–3 months before artificial floral induction), in relation to having a better effect on the fruit, and in order to consider an easier method for implementing the procedure on the broad scale since most of the pineapple leaf canopy has already closed a month before artificial flower induction.

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Author Contributions

Loekito S: preparing the experiment, conducting the analysis and writing the manuscript. Afandi and Afandi A.: Help prepare experiments and conduct analysis. Koyama H. and Senge M.: Assist the process of making and improvising the manuscript.

Conflicts of Interest

The author declares no conflicts of interest.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Ethics Approval

Not applicable in this paper

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