**Potential Of Gypsum Application To Improve The Fruit Quality Of Pineapple In Ultisol Soil Under Humid Tropical Climate**

**Supriyono Loekito1\*, Afandi2, Auliana Afandi3, Hiroyuki Koyama4 and Masateru Senge5**

1Research and Development, PT Great Giant Pineapple,Jl. Raya Terbanggi Km 77,Central Lampung, Lampung Indonesia, 34163

2Department of Soil Science, Faculty of Agriculture, Lampung University, J. Sumantri Brojonegoro 1, Bandar Lampung, Lampung, Indonesia 35145

3Department of Plant Protection, Faculty of Agriculture, Lampung University, J. Sumantri Brojonegoro 1, Bandar Lampung, Lampung, Indonesia 35145

4Faculty of Applied Biological Science, Gifu University, 1-1 Yanagido, Gifu, Japan

5Gifu University Laboratory, Ltd. Union, 1-1 Yanagido, Gifu, Japan

\*For correspondence: Supriyono.Loekito@ggpc.co.id

*Received \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_; Accepted \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_; Published \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_*

**Novelty statement**

Application of gypsum as a soluble source of calcium nutrition a month before artificial flower induction could be employed as an alternative to improve overall plant growth, yield, and fruit firmness in pineapple, especially in ultisol soil under humid tropical climate, where calcium in soil tends to be low. Besides, based on this research outcome, with the implementation of the most optimal treatments, the fruit damage during post harvest and shipment could be mitigated.

**Abstract**

Most of the post-harvest losses in pineapple fruit are associated with low calcium (Ca) in the fruit. The effect of gypsum application on ‘MD-2’ pineapple to the fruit quality, crown and the longest leaf with a leaf angle of 45° from the soil surface (D-Leaf), stem, and root were investigated in this study. The experiment was conducted in a randomized complete block design with three replications. 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 a month before the artificial floral induction. In general, G2 treatment gave the 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. Result showed that gypsum fertilization with the correct amount one month before artificial floral induction met the plant Ca requirement during a period of high Ca demand at flowering and fruit structure building. 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.

**Keywords**: *Artificial floral induction, Fruit texture, Calcium, D-Leaf, Gypsum*

**Introduction**

Pineapple (*Ananas comosus* L. Merr) is the second most traded product in the global market after bananas and the most economically important crop in tropical and subtropical regions. 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). The fruit quality, in terms of both inside and outside physical appearance, is very important, especially when pineapple is cultivated for the fresh fruit business, rather than canned pineapple. Mechanical injury, translucency, chilling injury, and postharvest disease are the main causes of postharvest losses (Paull and Chen 2020). Calcium (Ca) is an essential plant nutrient involved in several physiological processes related to the structure of cell wall and membrane (Thor 2019; White and Broadley 2003). Ca also is required for the synthesis of new cell walls, especially the middle lamellae that separate the new cells during cell division, and for the normal function of the plant membranes (Taiz et al. 2015). Many physiological disorders of fruits and vegetables are related to Ca (Olle and Bender 2009). Ca improved apple fruit quality and enhanced shelf life by increasing fruit firmness, lowering incidence of cork spot and brown core, and reducing ethylene production and respiration (Conway et al. 2002). The decrease in firmness was delayed by calcium in tomato (Cheour and Souiden 2015), and high level of calcium was also associated with a reduction in the incidence of pineapple disorders (bruising) during handling, transportation, and shipping (Selvarajah et al. 1998), while low calcium would make cell membranes lose integrity and lead to leakage and translucency (Silva et al. 2006), causes fruit defects and low quality (Khalaj et al. 2016; Souri and Hatamian 2019). Application of calcium could reduce translucency severity in pineapple (Paull and Chen 2015; Dayondon and Valleser 2018).

Calcium plays an important role in nutrient balances in plant and soil (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 commonly applied to amend the soil pH as well as to supply Ca and magnesium (Mg). 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* (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). Pineapple fruit disorders in the affected tissues caused by an inadequate Ca content cannot be corrected simply by supplying additional Ca to the soil. 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 a month before artificial flower induction. Ca is important after induction of artificial flowering because it also is a period of rapid cell division and growth, and may improve cell structure and reduce fruit translucence (Vásquez-Jiménez and Bartholomew 2018). In bell pepper (*Capsicum annuum* L.), (Mayorga-Gomez et al. 2020) showed that fruit Ca uptake continues throughout fruit development, therefore Ca application during bloom and early fruit development may prevent or minimize Ca deficiency disorders in bell pepper. The maximum concentration of Ca in apple fruit is usually reached shortly after flowering, then it drop rapidly, beginning at the initial stage of rapid fruit growth (Jones et al. 1983; Saure 2005). Apricot fruit texture largely depends on cell wall composition, and treatment with 1% Ca followed by cold storage at 5oC can maintain a firmer texture and reduce cell wall polysaccharide degradation (Liu et al. 2017). The hypothesis of this experiment is that the application of gypsum as a soluble source of calcium nutrition a 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 different amounts 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. D-Leaf is the longest leaf of any plant with leaf angle of 45o from the soil surface. D-Leaf length is prevalent to be used to estimate the pineapple plant weight in the pineapple industry.

**Material and methods**

1. *Description of site location and experimental design*

The experiment was conducted at the research station in a pineapple field of the Great Giant Pineapple Company (GGP) plantation located in Lampung, Indonesia. 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), with sandy clay loam soil texture of a Red Yellow Podzolic soil or Ultisol, with low organic carbon (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 was showed in Table 1. The pH increased slightly, as well other nutrients, except P.

The soil were applied with basal fertilizer with the rate of 200 kg KCl, 200 kg DAP, 300 kg Kieserit, and 10 kg CuSO4 before planting. The compost from cow dung was applied at the rate of 4 Mg ha-1. The climate is a typical humid tropical climate with high rainfall of about 2.500 mm per year, temperature between 21-33°C, relative humidity around 83%, duration of effective sunshine 4.6 hours per day, and standard evaporation rate (ETo) 3.6 mm per day.

The experiment consisted of gypsum amendments in Mg ha-1 and Ca in kg ha-1, namely, G0 (untreated), G1 (0.5 and 116), G2 (1.0 and 233), G3 (1.5 and 349) and G4 (2.0 and 465). The experiment was arranged in a randomized complete block design with three replications. 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 x 55 cm, so in 1 ha consisting of 67,340 plants per ha. In this experiment, each plot contained 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). The artificial flower induction was performed 12 months after planting by spraying 3 kg ha-1 of ethylene, 25 kg ha-1 of kaolin and 50 kg ha-1 of urea dissolved in 4000 liters ha-1 of water.

1. *Data and analysis of soils, pineapple plant, roots and fruit quality*

The following soil properties were analyzed using the following methods (a) pH with pH Meter; (b) Carbon (C) organic with Walkley and Black method in FeSO4 0.5 N; (c) Nitrogen (N) with Kjeldahl method; (d) Phosphor (P) with P Bray 1 method; (e) Kalium (K), Ca and Mg were analyzed using extraction by acetic acid pH 7 and reading with Atomic Absorption Spectrophotometer (AAS); (f) micronutrient (Fe, Zn, Cu) was analyzed using extraction by DTPA and reading with AAS; (g) Soil fraction (texture) was analyzed using hydrometer method.

Leaves nutrient analysis were done one month after artificial floral induction. The D-leaf were sampled, cut into pieces and dried in oven with temperature 70oC for 24 hours. The dry leaves sample was grinded and sieve with 0.5 mm. Extraction was done using HNO3 and H2O2, and destruction was done in temperature 175oC. The ASS was used for reading macro and micronutrient, except P using 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.

The longest leaf with a leaf angle of 45o from soil surface (D-Leaf) was collected from each treatment plot. The D-Leaf length was measured from the bottom to the top using a ruler, 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 taken by circling a steel ring (54.5 cm in diameter and 25 cm in height) around a plant; then the soil was watered carefully so that the water would reach the roots. The roots were cut from the basal stem and dried at room temperature to obtain the fresh weight. Then, they were oven dried at 105oC for 8 hours to obtain 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 per treatment were sliced horizontally at the largest diameter. Fruit firmness was measured at three points on triangular regions of the fruit slices taken from the middle section using a Brookfield Ametex CT3 Texture Analyser, a compression and tension testing tool for rapid quality control analyses (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 fruit flesh, not including the fruit skin, fruit core or the top and bottom 3 cm of the fruit, and was cut into small pieces juice was extracted with a small juice extractor. The juice was homogenized, and the temperature was checked. Then juice correction factor (cf) was determined at 20oC. To determine the total soluble solids (TSS), the filtrate was measured with a hand refractometer. 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.

1. *Statistical analysis*

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

**Results**

1. *Effects of gypsum application on soil and leave chemical properties*

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 compare 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. Magnesium (Mg) was also above 50 mg kg-1, with the highest value found in G0 (0 kg gypsum) 83.43 mg kg-1.

The content of macro nutrients (N, P, K, Ca, Mg) and micronutrient (Fe, Zn) in 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. Micro nutrient, Zink (Zn), was highest in G3 (1.5 Mg ha-1 gypsum) which content 51.39 mg kg-1 compare to G0 with only 37.61 mg kg-1 which was almost the same with G1, G2 and G4.

1. *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 and Table 6). There were only small but significant differences between G0 and the other treatments in all components measured (Table 5). There were no significant effects on any of the root parameters (Table 6).

In this experiment, it was shown that 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) (Table 6).

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

The effect of soil applied gypsum on the pineapple fruit quality and the crown is shown in Table 7. In this experiment, it was shown that the effect of soil applied gypsum on the fruit weight was not significantly different between the gypsum-treated plants and the untreated plants. But the fruit texture, crown weight and crown length were significantly different at p<0.05 by the Tukey test.

The parameters observed as indicators of the fruit texture, e.g., peak load, the deformation at the peak (Def peak), work and final load were measured by a CT3 Texture Analyzer, fixture TA5. 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 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 was significantly different from the control (G0).

**Discussion**

The soil pH used in this experiment was still below 5.5 (Table 1 and Table 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 among the most absorbed macronutrients by pineapple, and usually follows this absorption 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 in Table 4 were categorized adequate for pineapple, except for Cu in all treatment and Ca for G0 and G1 treatment. For pineapple ‘MD-2’, the level of nutrient leave adequacy (g kg-1) should be 15-18 for N, 2.0 for P, 27-30 for K, 2.5-3.0 for Ca and Mg, and for Cu should be 10-15 mg kg-1 (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 showed that application of 1.0 Mg ha-1 of gypsum generated a really higher 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). While, 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 had ‘succulent-brittle’ leaf base that are commonly used to evaluate the plant nutrient status as an index of growth (Souza and Reinhardt 2007).

Ca is used in the synthesis of new cell walls, particularly the synthesis of the middle lamella to separate the newly divided cells (Taiz et al. 2015). Actually, the stem weight increases progressively after planting, with no unique morphological changes in the plant until the reproductive development 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 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) (Table 6). This may be due to the fact that the application of Ca at a month before artificial flower induction was performed too late to improve the growth of the roots. There is evidence that the root growth decreases after the flower induction and that the maximum root mass is reached at anthesis (Malezieux and Bartholomew 2003). The roots of the pineapple plant may grow continuously throughout the year. However, the proliferation depends on the availability of water and minerals in the rhizosphere. If the rhizosphere is too dry or poor in nutrients, the root growth is slow. The root growth increases when the condition of the rhizosphere improves (Taiz et al. 2015). Actually, the availability of Ca in the rhizosphere supports the elongation of the root cells (De Freitas and Mitcham 2012).

From the results, it can be said that adding 1 Mg ha-1 of gypsum to the soil a 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 (CaSO4 2H2O) is known as a moderately soluble source of the Ca nutrient, and the solubility is approximately 200 times greater than lime (CaCO3) (Liming and Warren 2011). 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 available in the soil, the Ca uptake into the pineapple fruit and the firmness of the flesh will increase. Previous research reported that a high level of Ca could prevent the deterioration of the cell wall pectate and that it was important to maintain the integrity of the cell membrane and the 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).

The fruit quality in the most fruit is determined by sugar content (Villanueva et al. 2004). An increase in the sugar concentration in the pineapple fruit flesh tissue apoplast 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. It was reported that TSS of translucent fruit was not 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. The requirement for the pineapple fresh fruit market in Hawaii and Australia is a minimum of 12o-13o Brix (TSS 12%-13%) content in the fruit (Anonymous 2006; Lobo and Yahia 2017), while the TSS level of all treatments were in range of 14.2-15.4 o 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, it was shown in Table 7 that there was a significant difference between 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. Over all, gypsum was able to increase the size of the crown, especially when the soil was treated with 1.0 Mg ha-1 of it. Ca increases the absorption of some nutrients, such as ammonium, potassium and phosphorus, stimulates photosynthesis, and increases the size of the sellable plant parts (Taiz et al. 2015).

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 (Murai et al. 2021; Paull and Reyes 1996). In Hawaii, the occurrence of fruit translucency is low during the August to November when the fruit has the largest crowns (Paull and Chen 2015).

**Conclusions**

This study showed that the application of 1.0 Mg ha-1 of gypsum a month before artificial flower induction caused significantly different responses to the stem weight, the longest leaf at each plant with a leaf angle of 45ofrom the soil surface (D-Leaf) length, the D-Leaf 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 calcium (Ca) in leaf, and adequate Ca in soil. Moreover, advanced research should be done 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.

**Data Availability**

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

**Conflicts of Interest**

The author declares no conflicts of interest.

**Funding Statement**

This research was funded by PT.Great Giant Pineapple (GGP) Lampung, Indonesia and a part of the research was supported by RONPAKU-Program of UGSAS-Gifu University, Japan.

**Acknowledgments**

The authors would like to express their gratitude to the United Graduate School of Agricultural Science (UGSAS), Gifu University, Japan for the support for this research through the Ronpaku Program. Sincere thanks are also extended to the Management of Great Giant Pineapple Company, for permitting and supporting this study.

**References**

Anonymous (2006). Fresh fruit varieties. *In: Pineapple best practice manual*, pp:1-10. Queensland

Department of Agriculture and Fisheries, Australia. <https://www.daf.qld.au/_data/assets/pdf_file/0005/51449/CH-7-Fresh-Fruit-Varieties.pdf>

Chen and RE Paull (2001). Fruit temperature and crown removal on the occurrence of pineapple fruit translucency. *Sci Hortic* 88:85-95.

Cheour and Y Souiden (2015). Calcium delays the postharvest ripening and related membrane-lipid changes of tomato. *J Nutr Food Sci* 5:1-5.

Conway WS, CE Sams, KD Hickey (2002). Pre-and postharvest calcium treatment of apple fruit and its effect on quality. *Acta Hort* 594:413-419

Dayondon and VC Valleser (2018). Effects of urea and calcium-boron applied at flower-bud stage on ‘MD-2’ pineapple fruit. *Int J of Sci and Res Pub* 8:322-328.

De Freitas and EJ Mitcham (2012). Factor involved in fruit calcium deficiency disorders. *Hortic Rev* 40:107-146.

Eticha D, A Kwast, TR De Souza Chiachia, Horowitz, H Stützel (2017). Calcium nutrition of orange and its impact on growth, nutrient uptake and leaf cell wall. *Citrus R&T* 38:62-70.

Havlin JL, S Tisdale, L Nelson, JD Beaton (2017). Soil fertility and fertilizers: an introduction to nutrient management, 8 edn. Pearson, India

Hawkesford M, W Horst, T Kichey, H Lambers, J Schjoerring, Moller, P White (2012). Functions of macronutrients. *In: Marschner P (ed) Marschner’s mineral nutrition of higher plants, 3 edn*, pp:135-189, Elsevier, Amsterdam.

Hossain MF (2016). World pineapple production: An overview. Afr *J of Food, Agric, Nutr and Dev* 16:11443-11456.

Jones HG, Higgs, TJ Samuelson (1983). Calcium uptake by developing apple fruits I Seasonal changes in calcium content of fruits. *J Hort Sci* 58:173-182

Khalaj K, Ahmadi, MK Souri (2016). Improvement of postharvest quality of Asian pear fruits by foliar application of boron and calcium. *Hortic* 3:1-15

Liming and AD Warren (2011). Gypsum as an agricultureal amendment, general uses guidelines.

Bulletin 945, pp:1-36, The Ohio State University. <http://fabe.osu.edu/sites/fabe/files/Soybean/Gypsum%20Bulletin.pdf>

Liu H, Chen, F Lai, S Tao, J Yang, Z Jiao (2017). Effect of calcium treatment and low temperature storage on cell wall polysaccharide nanostructures and quality of postharvest apricot (*Prunus armeniaca*). *Food Chem* 225:87-97

Lobo and E Yahia (2017). Biology and postharvest physiology of pineapple. *In: Handbook of pineapple technology: Production, postharvest science, processing and nutrition,* pp:39-61. Lobo and RE Paul (Eds). Wiley, London

Loekito, S., Afandi, A. Afandi, N. Nishimura, H. Koyama, and M. Senge (2022). Study on soil properties and species conformity of *Phytophthora* species in pineapple field. *Intl J Agric Biol* 27:361-370

Maia VM, RF Pegoraro, I Aspiazu, Oliveira, DAC Nobre (2020). Diagnosis and management of nutrient constraints in pineapple. *In: Fruit crops: Diagnosis and management of nutrient Constraints*, pp:739-760. Srivastava and C Hu (Eds). Elsevier, Amsterdam

Mayorga-Gomez A, SU Nambeesan, Coolong, J Diaz-Perez (2020). Temporal relationship between calcium and fruit growth and development in bell pepper (*Capsicum annuum L.). Hort Science* 55:906-913.

Malezieux E and DP Bartholomew (2003). Plant Nutrition. *In: The Pineapple: Botany, production and uses*, pp:143-166. Bartholomew DP, RE Paull, KG Rohrbach, (Eds). CABI Publishing, London

Malezieux E, Cote, DP Bartholomew (2003). Crop environment, plant growth and physiology. *In: The pineapple: Botany, production and use*s, pp:69-108. Bartholomew DP, RE Paull and KG Rohrbach (Eds). CABI Publishing, London

Medina and HS Garcia (2005). Pineapple: Post-harvest operations. *In: Agricultural and food engineering technologies service*, pp:1-38. Mejia D (Ed). FAO of the UN

[www.fao.orgt/publications/card/en/c/cd17633e-2f36-4631-9836-5bf8130d7d.71](http://www.fao.orgt/publications/card/en/c/cd17633e-2f36-4631-9836-5bf8130d7d.71)

Mite F, Espinosa, L Medina (2010). Liming effect on pineapple yield and soil properties in volcanic soils. *BetterCrop. Plant Food* 94:7-9.

Murai K, Chen, RE Paull (2021). Pineapple crown and slip removal on fruit quality and translucency. *Sci Hortic* 283.

Ndungu S (2014). A report on conventional pineapple production in Kenya. Swedish Society for Nature Conservation. <https://old.naturskyddsforeningen.se/sites/default/files/conventional_pineaple_production_kenya.pdf>

Olle and I Bender (2009). Causes and control of calcium deficiency disorders in vegetables: a review. *J Hortic Sci and Biotechnol* 84:577-584

Paull and MEQ Reyes (1996). Preharvest weather conditions and pineapple fruit translucency. *Sci Hortic* 66:59-67.

Paull and NJ Chen (2015). Pineapple translucency and chilling injury in new low-acid hybrids. *Acta Hortic* 1088:61-66.

Paull and Chen, N. J. (2020). Tropical fruits: Pineapples. *In: Controlled and modified atmospheres for fresh and fresh-cut produce*, pp:381-388. Gil and R Beaudry (Eds). Academic Press, Cambridge

Rinju and TBS Harikumaran (2019). Characterization studies on starch extracted from the stem of pineapple plant (*Ananas comosus*) at different growth stages. *Biosci Biotech Res Comm* 12:623-630

Saure MC (2005). Calcium translocation to fleshy fruit: its mechanism and endogenous control. *J Hort Sci* 105:65-89

Selvarajah S, HMW Herath, Bandara, DMGA Banda (1998). Effect of pre-harvest calcium treatment on post-harvest quality of pineapple. *Trop Agri Res* 10:214-224

Silva JA, R Hamasaki, R Paull, R Ogoshi, DP Bartholomew, S Fukuda, NV Hue, Uehara, GY Tsuji (2006). Lime, gypsum, and basaltic dust effects on the calcium nutrition and fruit quality of pineapple. *Acta Hortic* 702:123–131

Soler A (1993). Enzymatic characterization of stress-induced translucence of pineapple flesh on the Ivory Coast. *Acta Hort* 334:295-304.

Souri and M Hatamian (2019). Aminochelates in plant nutrition; a review. *J of Plant Nutrition* 42:67-78

Souza and DH Reinhardt (2007). Pineapple. *In: Fertilizing for high yield and quality tropical fruits of Brazil*, pp:179-201. Johnson AE (Ed). International Potash Intitute, Horgen

Tailep WMAK, AM El-Saadani, F El-Dahshouri, Mohamed (2019). Influence of foliar spray of different calcium sources on nutritional status, seed yield and quality for some peanut genotypes. *Biosci Res* 16:309-319

Taiz L, Zeiger, IM Moller (2015). Plant physiology and development, 6 edn. Oxford University Press, New York

Thor K (2019). Calcium-nutrient and massager. *Front Plant Sci* 10:440. https://doi.org/10.3389/fpls.2019.00440

United Nations Conference on Trade and Development (UNCTAD) (2016). Pineapple, an infocom commodity profile.

https://unctad.org/system/files/official-document/INFOCOMM\_cp09\_Pineapple\_en.pdf

Vásquez-Jiménez J and DP Bartholomew (2018). Plant nutrition. In: The pineapple: Botany, production and uses, 2 edn, pp:175-202. Sanewski GM, DP Bartholomew, RE Paull (Eds). CABI Publishing, London

Vásquez-Jiménezz J, GM Sanewski, GM Reinhardt, DP Bartholomew (2018). Cultural system. *In: The pineapple: Botany, production and uses, 2 edn*, pp:143-174. Sanewski GM, DP Bartholomew , RE Paull (Eds). CABI Publishing, London

Villanueva MJ, MD Tenorio, Esteban, Mendosa. (2004). Compositional changes during ripening of two cultivars of mask melon fruits. *Food Chem* 87:179-183

White and MR Broadley (2003). Calcium in plants. *Annal of botany* 92:487-511.

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

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

|  |  |
| --- | --- |
| **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** | **pH** | **P** | **K** | **Ca** | **Mg** |
| **Mg ha-1** | **mg kg-1** | **mg kg-1** | **mg kg-1** | **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** | | **mg kg-1** | **mg kg-1** | **mg 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 |

**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 a | 88.3 a | 5.3 a |
| 0.5 (G1) | 581 ab | 94.5 a | 5.4 ab |
| 1.0 (G2) | 635 b | 97.4 b | 5.7 b |
| 1.5 (G3) | 616 b | 97.8 b | 5.5 ab |
| 2.0 (G4) | 635 b | 97.4 b | 5.5 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

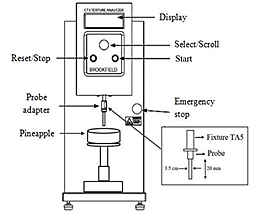
|  |  |  |  |
| --- | --- | --- | --- |
| **Treatment**  **Mg ha-1** | **Fresh root weight**  **(g)** | **Dry Root weight**  **(g)** | **Root density**  **g (cm3)-1** |
| 0 (G0) | 63.3 a | 22.3 a | 1.1 a |
| 0.5 G1) | 43.0 a | 18.9 a | 0.7 a |
| 1.0 (G2) | 48.0 a | 19.1 a | 0.8 a |
| 1.5 (G3) | 52.0 a | 23.4 a | 0.9 a |
| 2.0 (G4) | 70.8 a | 25.2 a | 1.2 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**  **Mg ha-1** | **Fruit texture** | | | | **Fruit**  **SS** | **Fruit Weight** | **Crown weight** | **Crown Length** |
| **Peak load (g)** | **Def peak (mm)** | **Work (mJ)** | **Final load (g)** | **(°Brix)** | **(g)** | **(g)** | **(cm)** |
| 0 (G0) | 353 a | 4.6 a | 10.2 a | 339 a | 14.5 a | 1.132 a | 156 a | 13.1 a |
| 0.5 (G1) | 445 b | 4.6 ab | 13.5 b | 439 b | 14.2 a | 1.100 a | 215 ab | 18.6 b |
| 1.0 (G2) | 443 b | 4.9 b | 14.0 b | 448 b | 15.4 a | 1.230 a | 232 b | 18.5 b |
| 1.5 (G3) | 418 ab | 4.6 ab | 13.4 ab | 389 ab | 15.2 a | 1.264 a | 185 ab | 16.3 b |
| 2.0 (G4) | 406 ab | 4.3 ab | 13.1 ab | 381 ab | 14.6 a | 1.346 a | 224 b | 18.0 b |
| P-value | 0.08 | 0.32 | 0.01 | 0.06 | 0.14 | 0.13 | 0.01 | 0 |

\*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