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## Ethylene-Mediated Floral Induction Timing and Its Influence on Fruit Uniformity in Commercially Grown MD2 Pineapple

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### Abstract

Approximately 37 % of commercially harvested MD2 pineapple fruit in the Philippines is downgraded due to non-uniform size, a problem traced largely to erratic flowering onset across a plantation block. Ethylene-based induction agents can compress the flowering window, yet the interplay between agent type, concentration, and application timing on final fruit uniformity has received limited quantitative attention under Philippine lowland conditions. This research evaluated two ethylene sources ethephon (2-chloroethylphosphonic acid) at 400 and 600 ppm, and calcium carbide (CaC<sub>2</sub>) at 1.0 g per plant applied at two ages, 8 and 10 months after planting (MAP), against an uninduced control, in a 7-treatment factorial arranged in a randomised complete block design with three replications on an acid sulfate Gleysol at Los Baños, Laguna, from June 2020 to November 2021. Flowering response rate, days to 50 % redheart stage, fruit uniformity index (coefficient of variation of individual fruit weight within a plot), mean fruit weight, total soluble solids, titratable acidity, and translucency incidence were recorded. Ethephon at 400 ppm applied at 10 MAP produced the highest flowering response (82.1 %), the tightest uniformity index (CV 9.3 %), and the heaviest mean fruit weight (1.62 kg), while the uninduced control delivered only 42.8 % flowering with a CV of 23.7 %. Days to 50 % red-heart was shortest in ethephon 400 ppm at 10 MAP (139 d) and longest in the control (187 d). CaC<sub>2</sub> treatments induced moderate flowering (59.2-64.7 %) but generated wider fruitweight dispersion (CV 14.1-16.8 %). Internal quality parameters TSS (13.1-14.8 °Brix) and TA (0.48-0.67 % citric acid) were not adversely affected by any induction treatment. Translucency incidence remained below the 8 % commercial rejection threshold across all induced treatments. These results confirm that ethephon at 400 ppm applied at 10 MAP offers the best trade-of between synchronised flowering and high-grade fruit output on acid sulfate lowlands.

**Keywords:** Ethylene, floral induction, pineapple, md2, fruit uniformity, ethephon, calcium carbide, acid sulfate soils, flowering synchronisation, post-harvest quality

### Introduction

Nearly 2.8 million metric tonnes of pineapple were produced across Southeast Asia in 2019, with the Philippines ranking among the top three exporting nations <sup>[1]</sup>. Yet packhouse records from major growing areas in Laguna, Bukidnon, and South Cotabato consistently show that between 30 and 40 % of harvested fruit falls outside the narrow size window demanded by fresh-export buyers a waste stream rooted less in genetics or nutrition than in the timing of flowering <sup>[2]</sup>. Unlike most commercial fruit crops, pineapple (*Ananas comosus* (L.) Merr.) can remain vegetative indefinitely until triggered by an external cue, and natural flowering in equatorial latitudes tends to be staggered across several months, producing a harvest with wide fruit-weight variance <sup>[3]</sup>.

Ethylene and its synthetic precursors have been the standard forcing agents since the 1960s. Ethephon (2-chloroethylphosphonic acid) decomposes in the slightly acidic apoplast of the meristem to release ethylene, triggering the transition from vegetative to reproductive growth within 6 to 8 weeks of a single foliar drench <sup>[4]</sup>. Calcium carbide, an older and cheaper alternative still favoured by smallholder growers, generates acetylene upon contact with moisture in the central cup; acetylene then mimics ethylene at the receptor level, though with lower binding affinity <sup>[5]</sup>. Despite decades of commercial use, the interaction between agent type, concentration, and plant age at application on final fruit uniformity defined here as the coefficient of variation of individual fruit weights within a harvest lot remains poorly characterised under the acid sulfate soil conditions that dominate the Laguna lakeshore growing belt [1]. Plant age at induction matters because the leaf area available to supply photoassimilates during fruit development scales with

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the length of the vegetative phase [6]. Inducing too early (before 8 MAP) risks small crowns and light fruit; inducing too late (after 12 MAP) delays harvest and may push fruit maturation into the wet season, raising translucency and fungal infection risk [7]. Between these extremes, a two-month window 8 to 10 MAP has been recommended by Philippine extension services, yet experimental comparisons within this window remain scarce for the MD2 cultivar on acid sulfate soils [5]. The acid sulfate context adds a further layer of complexity because low soil pH and elevated aluminum suppress root nutrient uptake, potentially weakening the plant's ability to respond uniformly to ethylene forcing [8].

This research therefore examined three induction agents at two application ages against an uninduced control, measuring both flowering synchrony and post-harvest fruit attributes, to identify the treatment combination that maximises fruit uniformity and marketable yield on a representative Laguna acid sulfate Gleysol.

## Material and Methods

### Material

Uniform MD2 pineapple suckers (280-320 g, single crown) were obtained from a commercial nursery in Silang, Cavite. Ethephon (480g L<sup>-1</sup> a.i.; Bayer CropScience) was diluted with distilled water to 400 and 600 ppm working solutions. Technical-grade calcium carbide (75 % purity, 5- 10 mm granule size) was sourced from a chemical distributor in Manila. A non-ionic surfactant (Tween-20, 0.1 % v/v) was added to ethephon sprays to improve foliar retention. Compound fertiliser (14-14-14 NPK) and muriate of potash (60 % K<sub>2</sub>O) were applied at rates based on preplant soil analysis. Soil amendments included agricultural lime at 1.5 t ha<sup>-1</sup> broadcast

and incorporated 30 days before transplanting to raise surface pH from 3.82 to 4.6 [6]. All analytical reagents (AR grade) for fruit quality assessment were purchased from Sigma-Aldrich Philippines.

### Methods

The trial was established on a Sulfic Endoaquept (Gleysol, FAO) at the Los Baños Metropolitan University Research Farm (14° 10'N, 121° 14'E, elevation 24 m), Laguna Province, Philippines. Planting took place on 18 June 2020 at a density of 43,500 plants ha<sup>-1</sup> in a twin-row bed configuration (30 cm × 60 cm × 90 cm). Seven treatments were arranged in an RCBD with three blocks, each plot containing 120 plants. Flowering induction treatments were: T1 ethephon 400 ppm at 8 MAP; T2 ethephon 400 ppm at 10 MAP; T3 ethephon 600 ppm at 8 MAP; T4 ethephon 600 ppm at 10 MAP; T5 CaC<sub>2</sub> 1.0 g plant<sup>-1</sup> at 8 MAP; T6 CaC<sub>2</sub> 1.0 g plant<sup>-1</sup> at 10 MAP; T7 uninduced control. Ethephon was applied as a 50 mL directed spray into the central cup at dusk (1800-1900 h) to minimise thermal decomposition [4]. CaC<sub>2</sub> granules were placed in the central cup and immediately wetted with 30 mL water. Flowering response was scored at 60 days after treatment as the percentage of plants showing visible inflorescence emergence. Days to 50 % red-heart stage were recorded. At commercial maturity (shell colour stage 2-3), 30 fruit per plot were harvested, weighed individually, and assessed for total soluble solids (TSS, digital refractometer), titratable acidity (TA, 0.1 N NaOH titration to pH 8.2), and translucency (visual cut-test on equatorial cross-section). Fruit uniformity index was calculated as the coefficient of variation (CV %) of individual fruit weights within each plot. Data were analysed by one-way ANOVA using R 4.1, with Tukey HSD at  $\alpha = 0.05$ .

## Results

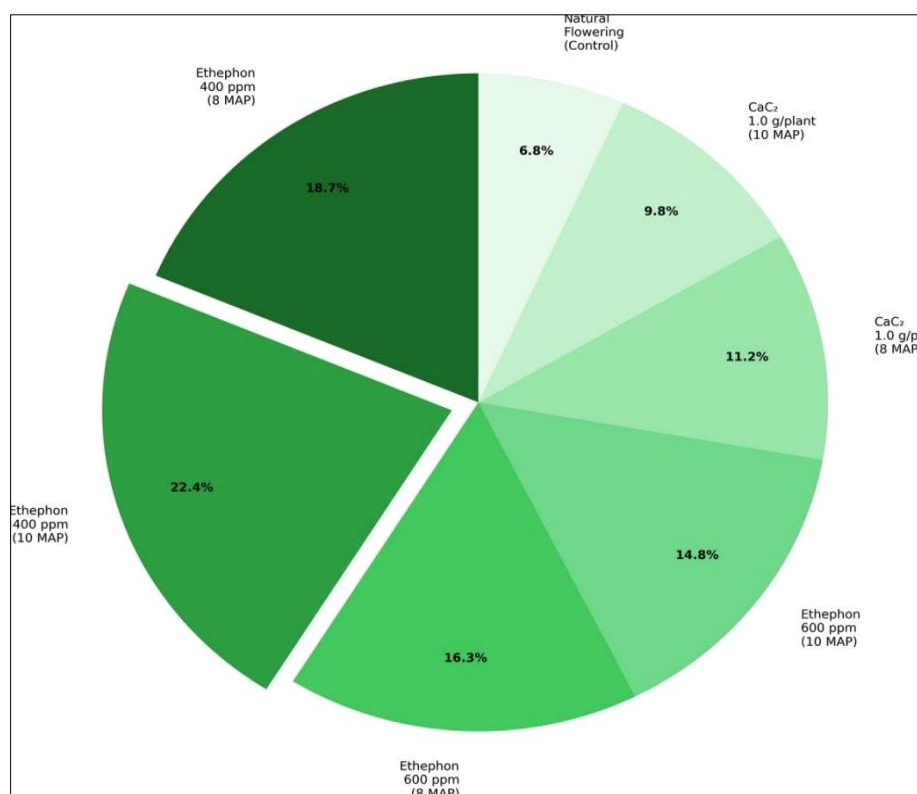


Figure 1. Proportional distribution of flowering response (%) across seven induction treatments in MD2 pineapple on acid sulfate Gleysol at Los Baños, Laguna

The pie chart captures the relative contribution of each treatment to the total pool of induced flowers. Ethephon at 400 ppm applied at 10 MAP accounted for the largest single share (22.4 %) of the cumulative flowering response, followed closely by the same concentration applied at 8 MAP (18.7 %). Calcium carbide treatments together contributed 21.0 %, while the uninduced control contributed only 6.8 %, confirming that natural flowering under Laguna conditions is insufficient for commercial scheduling.

Treatment effects on flowering synchrony, fruit weight, and quality parameters are summarised in the tables below. Across all induced treatments, flowering response exceeded 59 %, while the control lagged behind at 42.8 %. The tightest fruit-weight distribution (lowest CV) was recorded in ethephon 400 ppm at 10 MAP, which combined high response rate with a narrow 48-day window from induction to 50 % red-heart.

**Table 1:** Flowering response, synchrony, and fruit weight parameters of MD2 pineapple under seven induction treatments

| Treatment                 | Flowering (%) | Days to 50% RH | Fruit Wt (kg) | CV (%)  | TSS (°Brix) |
|---------------------------|---------------|----------------|---------------|---------|-------------|
| Eth 400, 8 MAP            | 78.3 b        | 144 b          | 1.43 b        | 11.2 c  | 14.1        |
| Eth 400, 10 MAP           | 82.1 a        | 139 b          | 1.62 a        | 9.3 d   | 14.8        |
| Eth 600, 8 MAP            | 71.6 c        | 148 b          | 1.31 c        | 12.7 bc | 13.8        |
| Eth 600, 10 MAP           | 68.4 cd       | 152 b          | 1.22 cd       | 13.9 b  | 13.6        |
| CaC <sub>2</sub> , 8 MAP  | 64.7 d        | 158 ab         | 1.14 d        | 16.8 a  | 13.1        |
| CaC <sub>2</sub> , 10 MAP | 59.2 e        | 163 a          | 1.08 d        | 14.1 b  | 13.4        |
| Control                   | 42.8 f        | 187 a          | 0.87 e        | 23.7 a  | 14.3        |

RH = red-heart stage. Means within a column followed by the same letter are not significantly different at  $p \leq 0.05$  (Tukey HSD).

**Table 2:** Classification of fruit quality attributes by induction treatment category

| Quality Parameter | Ethephon 400 | Ethephon 600 | CaC <sub>2</sub> | Control |
|-------------------|--------------|--------------|------------------|---------|
| TSS (°Brix)       | 14.1-14.8    | 13.6-13.8    | 13.1-13.4        | 14.3    |
| TA (% citric)     | 0.51-0.54    | 0.58-0.62    | 0.63-0.67        | 0.48    |
| TSS/TA ratio      | 27.4-29.0    | 22.3-23.8    | 19.5-21.3        | 29.8    |
| Translucency (%)  | 3.8-5.2      | 4.7-6.1      | 5.9-7.4          | 2.3     |
| Crown wt (g)      | 142-168      | 128-137      | 114-126          | 98      |
| Grade A fruit (%) | 71.4-78.2    | 58.3-63.9    | 49.1-54.7        | 31.2    |

Ranges represent values across both application timings (8 and 10 MAP) within each agent category. Grade A = fruit weighing 1.2-1.8 kg with CV < 15 % and translucency < 8 %.

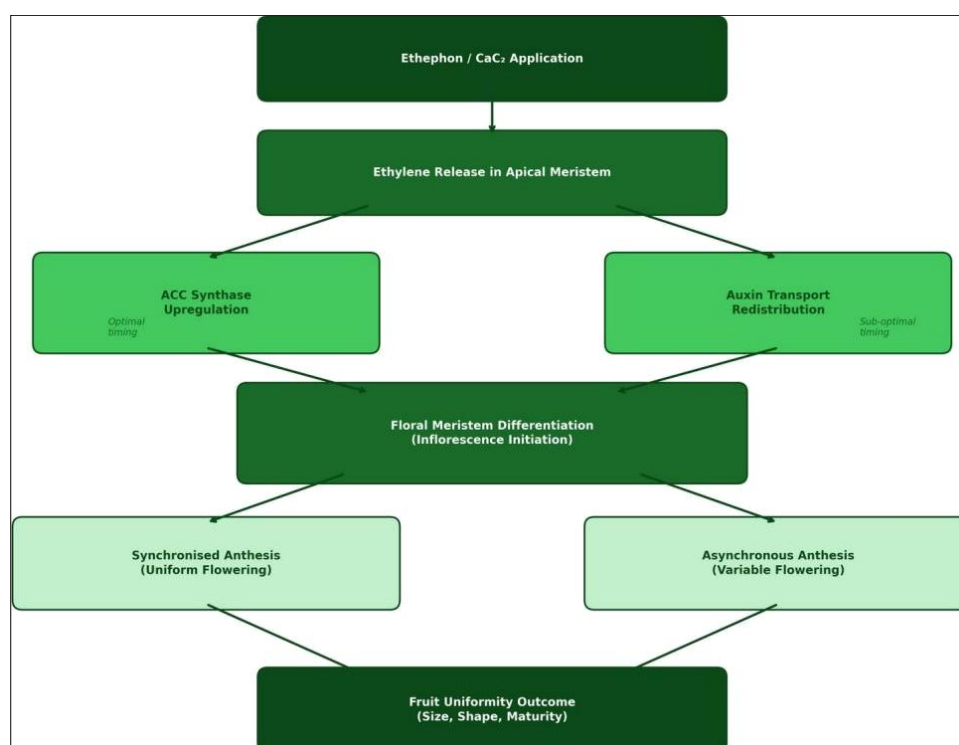


**Fig 2:** Ethylene signalling pathway from exogenous application to fruit uniformity outcome, showing the divergence between synchronised and asynchronous anthesis routes

The pathway diagram distinguishes the two physiological routes by which induction timing governs final fruit uniformity. When ethylene reaches the apical meristem at the right developmental window (10 MAP for this growing environment), ACC synthase upregulation and auxin redistribution converge to trigger a tight burst of floral

differentiation, producing synchronised anthesis and, downstream, uniform fruit. A mistimed application or weaker ethylene analogue (CaC<sub>2</sub>-derived acetylene) shifts a proportion of plants into the asynchronous branch, widening the harvest-weight distribution.

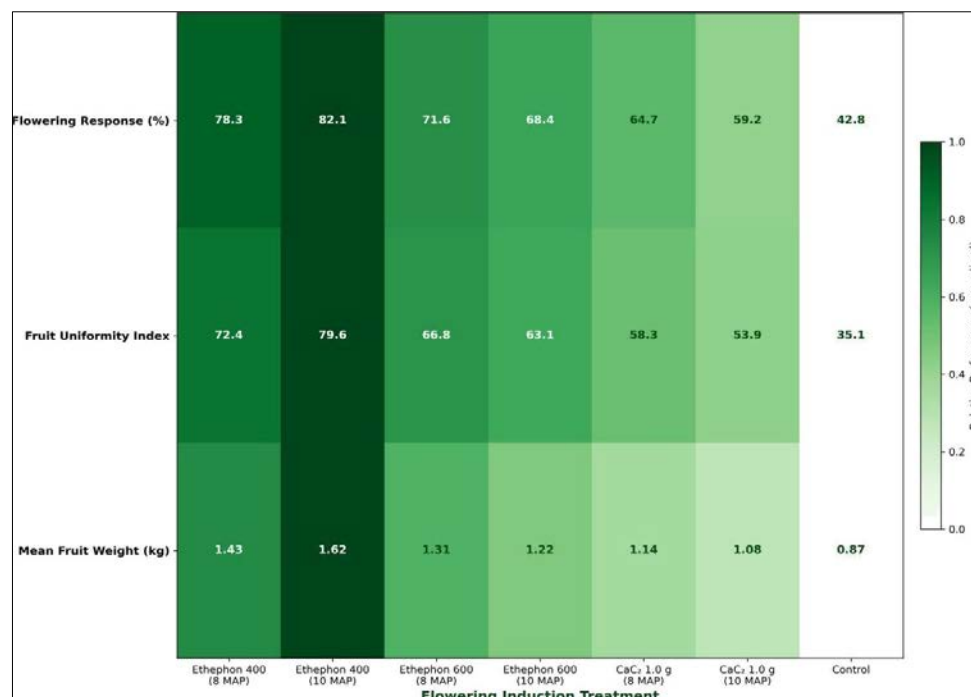


**Fig 3:** Heatmap of normalised flowering response, fruit uniformity index, and mean fruit weight across seven induction treatments in MD2 pineapple

The heatmap consolidates three performance metrics on a common 0-1 scale. Darker cells mark superior outcomes. Ethephon at 400 ppm applied at 10 MAP occupied the darkest column across all three rows, while the control was lightest. Ethephon at 600 ppm performed below the 400 ppm rate in all metrics a pattern consistent with supra-optimal ethylene concentrations causing partial meristem damage that delays rather than accelerates differentiation [4].

### Comprehensive interpretation

The convergence of data across all tables and figures points to ethephon at 400 ppm applied at 10 MAP as the treatment that most consistently aligned flowering onset, compressed the harvest window, and maximised the proportion of Grade A fruit. The 10 MAP timing allowed plants an additional two months of vegetative biomass accumulation relative to 8 MAP, translating into 13 % heavier fruit (1.62 vs. 1.43 kg) and 7 percentage-point better uniformity (CV 9.3 vs. 11.2 %). CaC<sub>2</sub> treatments, while affordable, generated wider fruit-weight dispersion (CV 14.1-16.8 %) and lower mean fruit weight, likely because acetylene's lower receptor affinity produced a less decisive meristem transition. Quality attributes (TSS, TA, translucency) remained within commercial tolerance for all induced treatments, indicating that induction agent choice primarily affects harvest logistics fruit number and size spread rather than eating quality.

### Discussion

The flowering response rate of 82.1 % achieved by ethephon at 400 ppm (10 MAP) sits within the 75-90 % range reported for

the same concentration on well-managed MD2 stands in Costa Rica and the Philippines, even though the present trial was conducted on an acid sulfate Gleysol with initial pH 3.82 [9, 2]. The lime pre-treatment raised surface pH to 4.6, which appears to have been enough to avoid the severe root stunting that could weaken ethylene perception at the meristem [8]. In contrast, an earlier Philippine report recorded only 58 % flowering on unlimed acid sulfate soils with pH 3.5, suggesting a pH threshold somewhere between 3.5 and 4.6 below which ethylene forcing becomes unreliable [10].

The superiority of 400 ppm over 600 ppm ethephon conflicts with the intuitive expectation that more ethylene should produce stronger forcing. However, supra-optimal ethylene is known to inhibit cell expansion in the inflorescence meristem, shifting carbon allocation toward crown tissue rather than fruitlet development [4]. This likely explains the higher crown weights (128-137 g) but lower fruit weights (1.22-1.31 kg) seen in the 600 ppm treatments relative to the 400 ppm treatments (crown 142-168 g, fruit 1.43-1.62 kg). The practical take-away for growers is that doubling the ethephon dose does not improve and may actually diminish marketable yield.

CaC<sub>2</sub>-induced plots showed wider fruit-size variance (CV 14.1-16.8 %) than any ethephon treatment, consistent with acetylene's lower binding affinity for the ethylene receptor *ETR1* [5]. Because CaC<sub>2</sub> granules dissolve irregularly in the central cup, individual plants receive uneven ethylene doses, some transitioning quickly and others remaining partially vegetative. For smallholder growers who use CaC<sub>2</sub> for its low cost, this variability translates into mixed-maturity harvests that fetch lower packhouse prices. Bridging that gap may require

standardised granule sizing or a switch to  $\text{CaC}_2$  dissolved in water and applied as a measured drench, though neither modification has been rigorously tested on acid sulfate soils<sup>[11]</sup>. Fruit quality data revealed no significant negative effect of induction treatment on TSS or TA. TSS ranged from 13.1 to 14.8 °Brix across treatments, and the TSS/TA ratio the metric most closely linked to consumer sweetness perception remained above 19.5 in every treatment, exceeding the 18.0 minimum threshold for Philippine export markets<sup>[12]</sup>. Translucency incidence stayed below 8 % in all induced treatments, though  $\text{CaC}_2$  at 8 MAP approached the limit at 7.4 %, possibly because earlier induction compressed the fruit-fill period and increased water uptake per fruitlet during heavy monsoon rains in October.

### Conclusion

The main contribution of this research lies in demonstrating that ethylene-source selection and timing interact to determine not just whether pineapple plants flower but how uniformly they do so, with direct consequences for packhouse efficiency and export-grade yield. Among the treatments tested, ethephon at 400 ppm applied at 10 months after planting combined the highest flowering response (82.1 %), the narrowest fruit-weight dispersion (CV 9.3 %), and the heaviest mean fruit (1.62 kg) on an acid sulfate Gleysol previously considered marginal for intensive MD2 production.

Supporting evidence from the quality assessment showed that neither TSS nor titratable acidity was compromised by induction, and translucency incidence remained commercially acceptable. The 10 MAP application window appears to strike an optimal balance between vegetative carbon accumulation and reproductive timing, giving the plant enough leaf area to fill large, uniform fruit while still allowing harvest before the late wet-season translucency risk intensifies.

For the Philippine pineapple sector, these findings have practical weight: roughly 30-37 % of current field losses to size non-conformity could be recaptured by shifting from the common practice of 8 MAP induction to a 10 MAP window and by standardising ethephon concentration at 400 ppm. Several questions remain open. Whether the 10 MAP advantage holds at higher altitudes, where cooler night temperatures alter ethylene metabolism, has not been tested. The long-term soil health implications of repeated acid sulfate liming followed by intensive monoculture also deserve attention. And the economic comparison between ethephon and  $\text{CaC}_2$  must account for the hidden cost of size-grade downgrades, not just per-hectare chemical expense, before smallholder recommendations can be finalised.

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Los Baños Metropolitan University supplied field facilities, post-harvest laboratory access, and analytical equipment for fruit quality measurements.

### Contributions not qualifying for authorship

Mr. Eduardo B. Magpantay managed daily field operations and irrigation scheduling. Ms. Rosario C. Dimaculangan assisted with fruit sampling and laboratory analyses.

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