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Determination of pineapple (*Ananas comosus*, MD-2 hybrid cultivar) plant maturity, the efficiency of flowering induction agents and the use of activated carbon

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ABSTRACT

Natural flowering is one of the major agronomic problems in pineapple (*Ananas comosus*) cultivation. It causes heterogeneous flowering and fruit development with multiple harvest passes of the same field as an inevitable consequence. To avoid natural flowering, pineapple plants are induced to synchronize flowering by external ethylene treatments. In this research it is shown that pineapple plants (MD-2 hybrid cultivar) are already sensitive to external ethylene treatments at an early developmental stage, i.e. 3 months after planting, although no natural flowering occurs during this early stage of plant development. These results indicate that young pineapple plants already possess all the necessary factors to induce flowering in response to ethylene treatments. Additionally the efficiencies of flowering induction of different external ethylene treatments, including a novel agent developed at our lab, called 'zeothene', were evaluated. Zeothene (=zeolite containing ethylene gas) and ethylene dissolved in water (both applied in the central cup of the plant) were proved to be very efficient flowering induction agents. The commercial cultivation practice, in which ethylene gas is sprayed with water over whole plants, was found less efficient confirming that central cup applications are more efficient than whole plant spraying. Cup applications allow the active ingredient (ethylene or ethephon) to be taken up immediately by the apical meristem resulting in an efficient flowering induction signal. The addition of activated carbon to enhance the flowering induction treatment was found to be useful only with a very high dose of activated carbon (5%) and a long interaction time (at least 5–30 min) between the activated carbon and the flowering induction solution.

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1. Introduction

Ananas comosus is the most important representative of the Bromeliaceae family and is cultivated worldwide all around the tropical and subtropical regions for local consumption and international export. Pineapple holds the third rank in world tropical fruit production only preceded by banana and citrus (Uriza Avila, 2005). The MD-2 hybrid cultivar, developed by Del Monte Fresh Produce International Inc., has gained market share over the last few years, especially on the international fresh fruit market (Rebolledo-Martínez et al., 2005). This cultivar possesses a high production capacity and good fruit quality characteristics compared with the 'Smooth Cayenne' cultivar (Chan et al., 2003).

A remarkable hallmark of Bromeliaceae species is the possibility to induce flowering by external ethylene treatments. This

feature is exploited worldwide by commercial pineapple growers to synchronize flower and fruit development resulting in a single harvest pass. This synchronization is of crucial importance in pineapple cultivation due to the non-climacteric nature of the fruit. However, natural flowering can occur before a flower induction treatment is applied, resulting in unsynchronized flower and fruit development and necessitating multiple harvest passes of the same field. Natural flowering is one of the long lasting agronomic problems in pineapple cultivation causing considerable losses and a disrupted market supply (Min and Bartholomew, 1996; Wang et al., 2007).

Natural flowering can occur under different environmental conditions, namely low night temperatures (van Overbeek and Cruzado, 1948a; Friend, 1981), short photoperiods (Friend and Lydon, 1979), water deficit (Py et al., 1984), flooding (Py et al., 1984), geotropic stimulation (van Overbeek and Cruzado, 1948b) and mechanical stress, e.g. hitting the stem base (Ruiz, J., personal communication). These inductive conditions trigger ACC synthase gene expression, resulting in increased ACC production and

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consequently augmented ethylene biosynthesis (Botella et al., 2000; Trusov and Botella, 2006). Ethylene is responsible for signaling the switch from vegetative into flowering stage (Burg and Burg, 1966; Min and Bartholomew, 1997). The developmental stage at which the plant is susceptible to natural flowering conditions or external ethylene applications remains to be revealed. Das et al. (1965, cited by Norman, 1982) stated that pineapple plants should have at least 21 leaves before they are susceptible to flowering induction. Py et al. (1984) suggested that plants ('Smooth Cayenne') should weigh at least 1 kg before applying flower induction treatments. However, no representative maturity level has yet been determined so far. The plant maturity level can be defined as the moment on which the plant becomes susceptible to flowering induction signals and switches from juvenile (vegetative development) into mature stage (generative development) (Larcher, 1995).

Environmental conditions promoting natural flowering also increase the plants sensitivity towards external flowering induction applications. Flowering induction can be achieved by a range of commercial induction agents, thoroughly summarized by Bartholomew et al. (2003). The most frequently used chemicals in present pineapple cultivation are ethephon (2-chloroethylphosphonic acid) and ethylene gas.

Ethephon is a pH dependent ethylene-releasing chemical which is stable at low pH (≤ 3) and breaks down under more alkaline conditions ($\text{pH} \geq 5$) to release ethylene gas (Yang, 1969; Dass et al., 1976). The product is sprayed over entire plants by large boom sprayers. Multiple applications may often be necessary to secure a successful flower induction since unfavorable climate conditions such as high temperatures and low relative humidity can cause failure in ethephon uptake (Turnbull et al., 1999).

Ethylene gas is more effective than ethephon to achieve flowering induction but is difficult to apply (Py et al., 1984). Ethylene gas is properly applied with a pressurized sprayer which uses water as carrier for the gas. Ethylene can partially dissolve in the water droplets which will make contact with the plant tissue. The solubility of ethylene gas in water is temperature dependent, i.e. 61.6 g/dm^3 at 30°C , 76.7 g/dm^3 at 20°C and 101.8 g/dm^3 at 10°C (L'Air Liquide, 1976). For this reason late evening or night applications of ethylene gas flower induction treatments are favored. To enhance the efficiency of the flowering induction treatment activated carbon is added to the water because it increases ethylene absorption and consequently total amount of ethylene exposed to the plant. As the activated carbon will slowly release the gas, the exposure time of ethylene gas to the plant is extended (Py et al., 1984; Soler et al., 2006).

In this article we report on a study to unravel the exact MD-2 hybrid pineapple plant maturity level. In addition, the efficiency of five different flower induction agents, including four known and one novel (zeothene), were tested on pineapple plants cultivated on a commercial plantation. Finally the use of activated carbon, to enhance the flower induction reaction, was evaluated.

2. Materials and methods

2.1. Plant material

Field experiments were carried out on a commercial pineapple plantation in Ecuador (2006). The 'San José' plantation is located between the cities Quevedo and Santo Domingo de los Colorados and enjoys a tropical coastal climate. This plantation is a monoculture of the MD-2 hybrid pineapple cultivar, also known as the 'Golden Ripe' or 'Extra Sweet' cultivar (Chan et al., 2003). All plants were treated by standard cultural practices such as irrigation, fertilization and pest-control to obtain optimal plant

growth and maximal fruit production. Planting material was obtained from suckers with an average fresh weight of 450–500 g.

2.2. Determination of pineapple plant maturity

To determine plant maturity level, pineapple plants at different developmental stages were induced to flowering. The flowering induction treatment was applied at 1 MAP (month(s) after planting) up to 8 MAP by means of a new induction agent: zeothene. Zeothenes (also known as 'ethylene pills') are zeolite pearls loaded with pure ethylene gas which is released upon contact with water (Parton, 2001). Each zeothene weighs about 13.5 mg and contains approximately 0.7 mL pure ethylene gas. Three to four zeothene pearls were dropped into the central cup of each plant ($n = 25$) where contact is made with the standing chalice water. Zeothenes have already been found to successfully induce flowering in many ornamental Bromeliaceae species such as *Guzmania*, *Aechmea*, *Billbergia*, *Vriesea* and *Tillandsia* (Parton, 2001; Plevier, 2004). A similar solid flower induction agent (ethylene clathrate) has previously been tested and approved by Soler (1985).

One month after flowering induction, the apical meristem was visually examined by making a longitudinal stem section. The vegetative apical meristem is typically characterized by a flat dome shape, while a generative plant shows vertical elongation of the apical meristem (Kerns et al., 1936; Bartholomew, 1977; Wee and Rao, 1979). Plant characteristics such as plant fresh weight (g), number of leaves, D-leaf (=the biggest leaf of the plant; Krauss, 1948) length (cm), D-leaf fresh weight (g), D-leaf width measured at the base (cm) and D-leaf width measured at the middle, were also recorded 1 month after flowering induction.

2.3. Efficiency of different flowering induction agents

The efficiency of five different flowering induction agents was compared, i.e. zeothene, ethephon, ethylene dissolved in water, ethylene dissolved in water with activated carbon and a commercial ethylene gas field application. Each treatment was applied to 100 plants at the optimal commercial flowering induction moment (8–9 MAP) and was repeated three times. The flowering induction agents were brought into the central cup of the plants, except for the commercial ethylene gas field application which was achieved by spraying the entire plant with a mixture of water and activated carbon (Smurfit-Stone, Calgon Carbon Corporation, Pittsburgh, PA, USA) as carrier for the gas by means of a pressurized sprayer. This is the standard flower induction application of the plantation and consists of 2.272 kg ethylene gas sprayed with a mixture of 7000 L water and 20 kg activated carbon per hectare (Hepton, 2003; Saltarén, L., personal communication).

For practical reasons, a defined amount of zeothenes were used for making the ethylene–water solutions. Three different concentrations were made: $0.389 \text{ g C}_2\text{H}_4/\text{L}$, $0.292 \text{ g C}_2\text{H}_4/\text{L}$ and $0.195 \text{ g C}_2\text{H}_4/\text{L}$ corresponding respectively to 100%, 75% and 50% of the commercial dose described above. Both maximum and minimum concentration of ethylene–water solutions were repeated with addition of 2.86 g/L activated carbon (equal to a commercial dose of 20 kg activated carbon in 7000 L water/ha).

Ethephon (Ethrel, Bayer CropScience, Germany) was provided with a commercial dose of 0.5 kg ethephon (active ingredient) per hectare dissolved in 2000 L water with 5% urea and brought at pH 3 (Bartholomew et al., 2003).

Zeothenes were applied as described under "Determination of pineapple plant maturity". The efficiency of the different flowering induction agents was evaluated by counting the number of plants

Table 1

Percentage of flowering and length of the flowering stem (cm) with s.e., measured for MD-2 hybrid pineapple plants ($n = 25$) evaluated 1 month after applying the flowering induction agent zeothene at different developmental stages (1–8 months after planting). The D-leaf length (cm) and D-leaf fresh weight (g) of MD-2 hybrid pineapple plants ($n = 25$) were also measured at the same time. Statistically differences ($*P < 0.05$) between different groups are indicated by different letters (Duncan's multiple range test).

Treatment moment	% Flowering	Flowering stem length (cm)	D-leaf	
			Length (cm)	Fresh weight (g)
1 MAP	0	–	59.7 ± 6.1 (A)	26.8 ± 5.8 (A)
2 MAP	27	1.07 ± 0.18 (A)	57.0 ± 4.2 (A)	24.6 ± 4.6 (A)
3 MAP	100	3.10 ± 0.95 (B)	58.8 ± 5.1 (A)	24.6 ± 5.0 (A)
4 MAP	100	3.51 ± 0.32 (C)	73.8 ± 6.3 (B)	46.8 ± 8.5 (B)
5 MAP	100	3.53 ± 0.28 (C)	94.0 ± 7.5 (C)	70.4 ± 16.1 (C)
6 MAP	100	3.33 ± 0.17 (BC)	105.2 ± 6.9 (D)	94.2 ± 15.9 (D)
7 MAP	100	3.47 ± 0.21 (C)	111.3 ± 5.7 (E)	113.6 ± 19.2 (E)
8 MAP	100	3.45 ± 0.16 (C)	120.5 ± 7.5 (F)	141.6 ± 17.9 (F)

that were in the same floral developmental stage at exactly 73 DAI (days after induction). This period of time was chosen arbitrary to facilitate counting. Six main floral developmental stages are distinguished: opening of the apical chalice, red bud stage (=inflorescence tip is visible), 1st flower (=lowest petals are visible), 2nd flower (=middle petals are visible), 3rd flower (=upper petals are visible) and wilting stage (=all petals are wilted) (Rohrbach and Taniguchi, 1984; Ruiz, J., personal communication). Flowering induction treatments with high homogeneity have high percentages of plants in the same developmental stage. This will cause synchronized flower and fruit development ultimately resulting in a single harvest pass.

2.4. Influence of activated carbon on ethylene gas absorption

Airtight glass flasks (300 mL; SCOTT) provided with a septum were filled with 100 mL of activated carbon solutions (pro-analyse, Vel NV, Belgium). Three different concentrations were used, i.e. 0.05%, 0.5% and 5%. With an airtight syringe (1 mL, 0.8 mm diameter) approximately 1.25 ppm of ethylene gas was injected into the headspace of the airtight flasks. The flasks were continuously shaken (150 rounds/min) to promote optimal interaction between ethylene and the activated carbon solution. At regular intervals between 30 s and 60 min air samples of 1 mL ($n = 3$) were taken and ethylene content was determined with FID (flame ionization detection) gas chromatography (DI 200, Delsi Instruments, France) (De Greef and De Proft, 1978). The experiment was carried out under standard conditions (1013 hPa and 23 °C).

3. Results

3.1. Determination of pineapple plant maturity

Flowering induction of MD-2 hybrid pineapple plants at different developmental stages revealed the exact maturity level (Table 1). Plants of 3 MAP and older are totally (100%) sensitive to external ethylene treatments resulting in flowering. These observations demonstrate that plants of 3 MAP have already reached maturity. Among plants of 2 MAP only 27% showed characteristics of flower development, while plants of 1 MAP did not show any signs of flowering.

The length of the developed generative stem of plants of 3 MAP and older ranged between 3.10 cm and 3.53 cm (Table 1). This illustrates the independence of plant size at the moment of flowering induction for the outgrowth of the flowering stem, during the first month after induction. The flowering stem of the minority of plants of 2 MAP which showed flowering characteristics was less developed (1.07 ± 0.18 cm), indicating a retarded inflorescence development.

The D-leaf length and the D-leaf fresh weight are suitable parameters that can be linked with plant maturity (Table 1). Nevertheless no significant ($*P < 0.05$) differences were found for plants of 2 MAP and 3 MAP, while plants of 3 MAP and 4 MAP could be distinguished significantly ($*P < 0.05$) concerning these parameters (Table 1). The D-leaf length and fresh weight can therefore be utilized as an efficient on-field parameter to determine the plant maturity. For illustration, Fig. 1 shows the evolution of D-leaf length and D-leaf fresh weight from shoot planting until harvest.

Fig. 1. Box plots showing the evolution of the D-leaf fresh weight (g) and D-leaf length (cm) of MD-2 hybrid pineapple plants from shoot (0 MAP; months after planting) to harvest (12 MAP). The plant maturity level at 3 MAP and the optimal commercial flowering induction moment at 8–9 MAP are indicated.

Table 2

Percentage of MD-2 hybrid pineapple plants (homogeneity percentage, %) in the same flowering stage 73 days after induction for different flowering induction treatments (agent, dose and the potential addition of 2.86 g/L activated carbon). Statistically differences ($*P < 0.05$) between different treatments are indicated by different letters (Duncan's multiple range test). ($n = 100$; repetitions = 3).

Treatment			Homogeneity (%)	Flowering stage
Flower induction agent	Dose (g C ₂ H ₄ /L)	Activated carbon (2.86 g/L)		
Control	–	No	92.3 ± 2.0 (A)	No flowering
Zeothene	–	No	92.7 ± 3.6 (A)	3rd flower
Ethephon	–	No	82.6 ± 3.3 (AB)	2nd flower
Ethylene gas field application	0.389	Yes	78.4 ± 7.1 (B)	3rd flower
Ethylene dissolved in water	0.389	Yes	90.6 ± 4.6 (AB)	3rd flower
	0.389	No	83.0 ± 11.7 (AB)	3rd flower
	0.292	No	89.6 ± 5.2 (AB)	3rd flower
	0.195	Yes	93.2 ± 7.2 (A)	3rd flower
	0.195	No	95.0 ± 7.6 (A)	3rd flower

The maturity border (3 MAP) and the optimal commercial flowering induction moment (8–9 MAP) are indicated. The plant maturity level is situated just before the starting point of increased D-leaf development (length and fresh weight). This moment corresponds with the end of the initial lag-phase and the beginning of the exponential log-phase.

3.2. Efficiency of different flowering induction agents

The varying efficiency of different flowering induction agents that were tested was revealed by the homogeneity percentages which range from 78.4% to 95.0% (Table 2). The control group consisted of 92.3% of plants which did not show flowering and 7.7% of flowering plants as a consequence of natural flowering.

Zeothene and ethylene dissolved in water proved to be excellent flowering induction agents. The homogeneity percentage of zeothene amounts to 92.7% and those for the ethylene–water treatment varied dependent on the used dose. Puzzlingly the lower dose (0.195 g C₂H₄/L, 95.0%) of the ethylene–water solution was more efficient than the higher doses (0.292 g C₂H₄/L and 0.389 g C₂H₄/L, respectively 89.6% and 83.0%). These results might indicate that the optimal concentration for ethylene dissolved in water lies around 0.292 g/L or lower. The addition of activated carbon increased the flower homogeneity percentage for the highest ethylene–water concentration (from 83.0% to 90.6%) while it decreased the homogeneity percentage for the lowest concentration (from 95.0% to 93.2%). However, these changes were not significant different ($*P < 0.05$).

The ethephon treatment caused a low homogeneity percentage of 82.6%. The observed flowering stage for this treatment, at the moment of evaluation, was '2nd flower' instead of '3rd flower' compared with the other treatments. This might indicate retarded inflorescence development.

The commercial field application with ethylene gas showed the lowest homogeneity percentage (78.4%) and was significant different ($*P < 0.05$) from the zeothene treatment and the lowest dose of ethylene dissolved in water. Consequently the commercial field treatment might result in more heterogeneous flowering and fruit development and increasing the need of more harvesting passes.

3.3. Influence of activated carbon on ethylene gas absorption

It is generally accepted that the addition of activated carbon increases the efficiency of flowering induction treatments because it absorbs an extra amount of ethylene gas. However, our field experiments (Table 2) did not provide sufficient evidence that activated carbon always improves flowering induction treatments. For this reason absorption of ethylene gas was evaluated by adding

activated carbon to water and monitoring ethylene content by means of gas chromatography (Fig. 2).

The absorption isotherms showed very high ethylene absorption during the first 5 min for the control treatment and the different activated carbon concentrations (0.05%, 0.5% and 5%). During the first 15 min of exposure, no significant differences ($*P < 0.05$) were found between different treatments. Although after 5 min 58.2% of potential absorption is already reached for the 5% activated carbon solution. From this moment absorption increase is slower reaching 87.7% of potential absorption after 20 min. After 30 min of exposure, an absorption equilibrium is reached. The 5% activated carbon solution showed significant higher ($*P < 0.05$) ethylene absorption (+60%) than pure water (0.033 μ L C₂H₄/100 mL instead of 0.020 μ L C₂H₄/100 mL) starting at 20 min and persisting for at least another 40 min (Fig. 2). On the contrary the activated carbon solutions of 0.5% and 0.05% did not absorb significantly ($*P < 0.05$) more ethylene gas than pure water during the entire exposure period.

4. Discussion

Our results have clearly shown that MD-2 hybrid pineapple plants of 3 MAP and older are 100% sensitive to external ethylene treatments. The plant maturity level is reached considerably earlier than the moment of the commercial flowering induction treatments (8–9 MAP). However, it should be mentioned that all

Fig. 2. Rates of ethylene gas absorption (μ L C₂H₄/100 mL solution) by pure water (■) and water-activated carbon solutions (5% (□), 0.5% (△) and 0.05% (○)) during an exposure period of 60 min ($n = 3$). Statistically differences ($*P < 0.05$) between the 5% solution and the other solutions is indicated by (*) (Duncan's multiple range test).

cultivated plants on the studied plantation originate from vegetative propagation (shoots or suckers) as usual for commercial pineapple plantations. All vegetative propagules first have to outgrow a juvenile stage before they reach maturity. During the first months after planting (lag-phase) the young shoots will mainly invest in root development and rebuilding of damaged tissue. Subsequently (3–4 MAP) the apical meristem starts to develop new leaves. From this moment on the apical meristem is also responsive to external ethylene treatments which can initiate inflorescence development. D-leaf length and fresh weight are reliable parameters representing general pineapple plant growth (Malézieux et al., 2003). Our results have additionally shown that the D-leaf can be used as an efficient on-field characteristic to determine plant maturity and the optimal flowering induction moment.

Natural flowering occurs when plants are exposed to inductive stress conditions. In practice, natural flowering is negligible during the initial growth period (Saltarén, L. and Ruiz, J., personal communication). However, our results showed that young pineapple plants (3 MAP and older) are already sensitive to external applied flowering induction agents (ethephon or ethylene). It is possible that young plants still need to develop a certain sensitiveness towards natural flowering inductive conditions. According to Trewavas (1981, 1991) the sensitivity of an active ingredient and the magnitude of the evoked response is related to the ethylene receptor and signal transduction physiology. It is not clear from our results if the number of ethylene receptors or their affinity, or the signal transduction pathway is the controlling factor in flowering induction. However, pineapple plants of 3 MAP are able to sense external applied ethylene and transfer the signal resulting in flowering but they do not yet respond towards natural flowering conditions. From this developmental moment, it is likely that the ability to synthesize ethylene *de novo* (at the level of the apical meristem) is a primary controlling factor towards responding to natural flowering inductive conditions. If young plants are not yet capable to increase their ethylene production (at the level of the apical meristem) in response to natural flowering inductive conditions, no flowering will occur. It would be of great interest to further investigate flowering sensitivity in relation to plant development and different kinds of external stress conditions such as temperature, irradiation, day length and drought in order to achieve normalized time scales which indicate sensitivity levels for natural flowering induction during pineapple development (Min and Bartholomew, 1993; Bradford and Trewavas, 1994). This information could be of major importance for pineapple growers to take possible measures on the right moment of time to prevent natural flowering, e.g. by adjusting cultural techniques, optimizing planting periods or chemical interventions (e.g. with aviglycine, Kuan et al., 2005; Wang et al., 2007, or 1-MCP, Sisler, 2006).

The efficiency of the flower induction reaction in response to external applied flowering agents is mainly dependent on the type of agent, the mode of application, plant genotype and environmental conditions (e.g. temperature, humidity, wind, rain, etc.) (Bartholomew et al., 2003). Our experiments demonstrated that zeothene is a very efficient flowering induction agent for MD-2 hybrid pineapple plants. We also confirmed that ethylene treatments (zeothene or ethylene dissolved in water) applied into the central cup brings about more homogeneously flowering than the application of ethylene gas to the entire plant.

It is generally accepted that ethylene is a more effective flowering induction agent than ethephon (Py et al., 1984). Nevertheless, application of ethephon into the central cup caused a higher flowering homogeneity percentage than whole plant ethylene gas treatments. These observations indicate the possibility of ethephon as a very effective flowering induction agent if

applied in the right way. The retarded inflorescence development, noticed after ethephon treatments, might rely on delayed stimulation because ethephon first has to break down into ethylene before any physiological action can be exerted. Turnbull et al. (1999) also showed that ethephon was more efficient when applied in the central cup instead of whole plant spraying.

Central cup applications promote immediate contact of the active ingredient (ethylene or ethephon) with the apical meristem favoring rapid uptake of the active ingredient and ultimately resulting in a better signal transfer (Firn, 1986). The active ingredient which is applied into the central cup easily dissolves in the cup water, extending its contact time with the plant apical meristem. Because the cup water is protected from sunshine it has a lower temperature (especially late in the evening) which will increase the solubility of ethylene gas. Precision agricultural techniques with optical plant recognition may facilitate central cup applications increasing the efficiency of ethylene or ethephon treatments.

If ethylene gas is applied by pressurized sprayers, the contact time between the gas and the water droplets is very short, reducing the total amount of ethylene which can dissolve and make contact with the plant. In addition, much ethylene will get lost due to evaporation or by running off the leaves without ever reaching the apical meristem. Moreover, whole plant spraying with ethylene gas can also cause unnecessary senescence effects on the foliage.

These thoughts are supported by Turnbull et al. (1999) as they proved that ethephon uptake by pineapple plants is higher in the basal white leaf tissue (near the apical meristem) than in green leaf tissue. The same conclusion might be drawn for ethylene, although no research has yet been executed to evaluate ethylene absorption in the basal white leaf tissue. However, Min and Bartholomew (1993, 1996) found that the basal white leaf tissue and the stem apex showed a very high ethylene production compared to green leaf tissue which did not produce any ethylene, illustrating the physiological activity of the meristem region.

The use of activated carbon to enhance flowering induction treatments is common practice in commercial pineapple cultivation. However, our experiments did not show any significantly higher homogeneity percentages if a commercial dose of activated carbon (20 kg activated carbon in 7000 L water/ha = 0.286% solution) is added. Low concentrations ($\leq 0.5\%$) of activated carbon did not show an increased absorption of ethylene gas compared to pure water. Only very high concentrations of activated carbon (5%) stimulated ethylene gas absorption. Our results clearly show that addition of the commercial dose of activated carbon (0.286%) will not enhance ethylene absorption and will consequently not stimulate the flowering induction treatment. The water itself, as carrier for the gas, will absorb enough ethylene for successful flower induction treatment. In addition, during present commercial field treatments with ethylene gas, the exposure time between the gas and the water is limited to several seconds. Since a significant amount of time is needed to reach considerable ethylene absorption (5–30 min), the current field practice has to be improved by increasing the contact time between the different components. To date, the practice of adding activated carbon has no influence on the flowering induction treatment.

5. Conclusion

MD-2 hybrid pineapple plants are sensitive to external ethylene treatments at a very early developmental stage (3 months after planting). This developmental stage and the optimal commercial flowering induction moment can be determined conveniently by evaluating the D-leaf length and fresh weight. Natural flowering will only occur much later during plant development. It is not yet

clear if plant sensitivity or ethylene production capacity is the key factor in the ability to respond to natural flowering. This topic requires further investigation.

It is of great importance for pineapple growers to realize that a successful flower induction treatment is highly dependent on the total amount of active ingredient (ethylene or ethephon) that actually reaches the plant apical meristem. Our measurements confirmed the higher flowering induction efficiency of central cup applications compared to whole plant treatments. Precision agriculture techniques may provide an outcome to the realization of these specific treatments in practice. The addition of activated carbon will only enhance the flower induction treatment when added in very high concentration (5%). Low doses of activated carbon, such as those currently used in commercial practice, have no influence on the efficiency of the flower induction treatment at all and hence its use is only a pricy custom.

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