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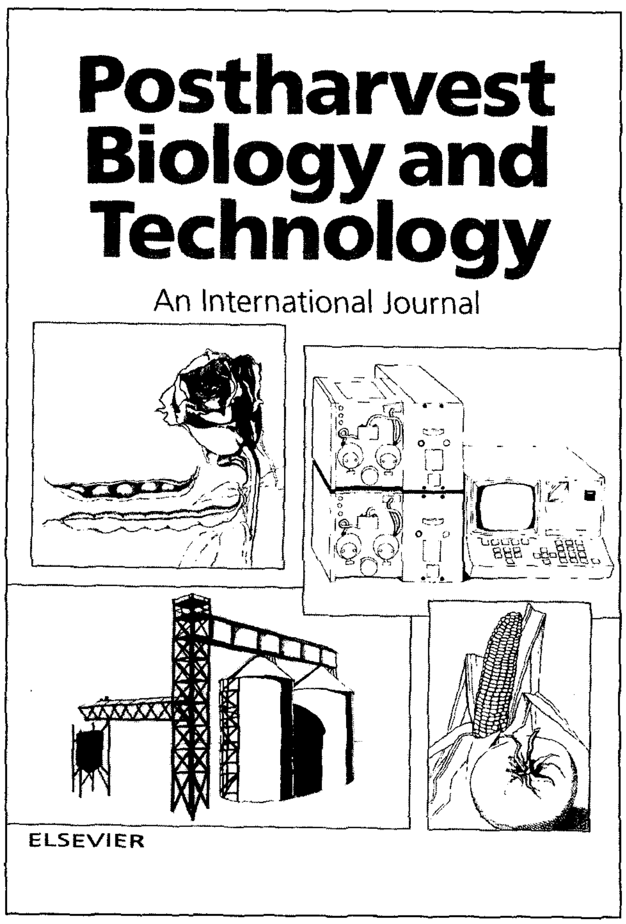

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Synchronization of fruit ripening in coffee with low concentrations of ethephon

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ABSTRACT

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Ethephon [2-(chloroethyl) phosphoric acid] was applied to 2-year-old coffee (*Coffea arabica* L. cv. Guatemalan) plants when the first mature fruits on the bearing branches were turning red. Applications of 100 and 200 mg liter^{-1} significantly accelerated ripening. At 15 days post-application, ethephon treatment increased the harvest from 15% of the yearly total harvest to 33%. Fruit removal force (FRF) was reduced by 30–50% and the ratio between red versus green fruits mechanically harvested was improved by 15% on the ethephon treatments. Beyond 15 days post-application there were no residual effects of ethephon on fruit ripening and FRF. Ethephon at all concentrations accelerated leaf abscission, but only from the fruit-bearing branches. These effects on leaf abscission persisted longer than 15 days after application. Quality of the processed coffee, as assessed by a taste panel, was not affected by ethephon treatment although the percentage of beans in the largest size category was reduced. Under Hawaiian conditions, application of 100 mg liter^{-1} of ethephon at the onset of the fruit ripening period has considerable potential for shortening the harvest period and improving the selectivity for mechanical harvest, without inducing detrimental leaf abscission.

INTRODUCTION

Coffee is grown commercially under full sun in the Kona District of Hawaii (Big Island) and is currently under evaluation for large-scale mechanized production in low elevation, leeward areas (Oahu, Maui and Kauai). In Kona, coffee beans are

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hand-harvested when fully ripe (bright red color). As a result of continuously inductive short-day conditions and repeated flushes of flowering (Cannell, 1985), the harvest period extends over a period of 4 to 6 months (Goto and Fukunaga, 1956). Within a single node, fruit ripening over a period of several weeks has been observed (Browning and Cannell, 1970; Gopal, 1976). As a result, harvesting costs in Hawaii may exceed one-half of the value of the harvested crop (P. Tausend, personal communication). Extensive coffee cultivation in Hawaii will require development of practices or cultivars with adequately synchronized fruit ripening to allow economical mechanical harvesting.

Several management practices with potential to improve floral synchronization are under investigation, including controlled irrigation regimes (Crisosto and Grantz, 1990) and application of gibberellins (Schuch et al., 1989). Color development and abscission of fruits and leaves are mediated in part by ethylene (Abeles, 1987; Burg and Burg, 1965), suggesting a potential management strategy.

Ethephon, an ethylene-releasing agent, enhances fruit ripening and reduces fruit removal force (FRF) in many crops (Lipe and Morgan, 1972; Abeles, 1973, 1987; Martin et al., 1981; Wood, 1989). Enhancing of red color formation of fruit has been reported in coffee grown under shade conditions in India (Gopal, 1976), Puerto Rico (Rodriguez and Molero, 1970) and Kenya (Browning and Cannell, 1970).

In Hawaii, under full sun conditions (Crisosto et al, 1991), ethephon at 250–1000 mg liter^{-1} applied when the first mature fruits were turning red (onset of fruit ripening) significantly reduced the harvest period, increased the yield of the first harvest, and reduced FRF of 'Guatemalan' coffee trees. However, in all cases these beneficial effects were offset by excessive leaf abscission, shoot dieback, and occasional plant death.

Thus, our purpose was to investigate if lower concentrations of ethephon, applied at the onset of the fruit ripening period, would reduce the harvesting period and increase adaptation to mechanical harvesting (ratio of ripe to unripe (green) mechanically harvested fruits), without having significant adverse effects on leaf abscission and crop quality.

MATERIALS AND METHODS

Two experiments were performed in established coffee orchards in Hawaii. The first experiment was carried out on 2-year-old 'Guatemalan' coffee trees growing in a Kunia silty clay with full water replacement of evapotranspiration (Class A pan) by drip irrigation near Waipahu (elevation 100 m), island of Oahu, Hawaii. The second experiment was performed to evaluate adaptability of ethephon treated coffee trees for mechanical harvest near Eleele (elevation 60 m), island of Kauai, Hawaii.

Ethephon at 0, 50, 100, and 200 mg liter^{-1} was foliarly applied to runoff early in the morning on three trees in each plot. Treatments were applied when the first mature fruits on bearing branches began turning red (15 August 1989). Yield and maturity parameters were evaluated on thirteen random branches, three from the vegetative zone (upper part of the tree canopy), five from the bearing zone (basal portion of the branches located in the lower and midlevel tree canopy), and five from the floral differentiation zone (apical part of the branches located in the bearing and basal part of the branches in the upper part of the tree canopy).

Coffee trees were harvested and maturity parameters and yield evaluated 15, 30, 60, and 120 days following ethephon applications. On each harvest date, measurements of number of leaves per node, number of new vegetative nodes and fruit maturity were determined on labeled branches and whole trees. Fruit maturity was evaluated as the percent of red color (ripe) fruits based on the final number of harvested ripe fruits on the labeled branches and the whole tree.

Fruit removal force (FRF) was measured on 50 pinkish red to red fruits from each of the experimental trees (total of 300 fruits per treatment) by grasping a single fruit in a collar attached to a pull scale, pulling the fruit parallel to the pedicel, and recording the force required to detach the fruit. Mechanical harvesting and FRF measurements were done early in the morning (7–9 a.m.) to assure the maximum differences in FRF between green and ripe fruits as described by Crisosto and Nagao (1991).

Fruit size was determined as the average fruit weight per green coffee bean. Bean size distribution at 10–12% moisture (w/w) was evaluated by passing green coffee beans (unroasted but separated from the pulp) through slotted sieves with apertures of 0.72 cm, 0.70 cm, 0.69 cm and 0.61 cm.

Experiment 2 involved application of ethephon at 100 and 150 mg liter^{-1} to coffee trees growing commercially (cvs. Guatemalan and Yellow Catuai) on the island of Kauai just prior to the final commercial harvest (12 December 1989). Because experiment 1 and our previous work (Crisosto et al., 1991) showed leaf phytotoxicity on coffee trees above 200 mg liter^{-1}, applications of only 100 and of 150 mg liter^{-1} were used in experiment 2. Adaptability to mechanical harvesting was evaluated by using a modified, over-the-row harvester (Littau), which dislodged fruits with flailing rods on both sides of the row. The numbers of ripe and green harvested fruits were counted and the subsequent proportion that were dislodged determined for each treatment. FRF determinations were done as described previously on a total of 150 fruits per treatment.

In both experiments, coffee quality was assessed by the Hawaii Division of Marketing and Consumer Services, Kona, Hawaii. The percentage of defective beans and bean size distribution were assessed and a taste or cupping test was performed on roasted, brewed coffee.

Statistical analysis

Experiment 1 was arranged in a randomized block design using 11 rows (6 + 5 guards), each row having 42 trees (counting guard trees on the ends of the rows). Every row represented a separate block with alternate rows (3.0 m row spacing) providing a guard between blocks. Within each block, the four experimental treatments were assigned at random to three-tree plots and separated by six untreated trees as guards. Data were obtained from the center tree of each plot (six trees per treatment).

In this experiment, a preliminary analysis of the data indicated no significant differences among the blocks. Therefore, to evaluate the interaction between ethephon concentration and time, data was analyzed using a completely randomized design with factorial experiments considering blocks as replications of the experiment. Regression models considering both ethephon concentration and time as dependent variables were used separately, a log transformation was used when considered to be relevant. Slope comparisons were done by using a *F* test according to Neter et al. (1983).

Experiment 2 was established as a completely randomized design with three replications. A row of 35 trees was assigned to each treatment for both cultivars growing in adjacent fields. Each treated row was separated by two untreated guard rows and replicated three times.

The SAS program (SAS Institute Inc. SAS/STAT User's Guide, Release 6.03 Edition, SAS, 1988) was used for the analysis of variance and regression analysis. Mean comparisons were performed using the Ryan–Einot–Gabriel–Welch (REGWF) *T* test (Ramsey, 1978).

RESULTS AND DISCUSSION

Experiment 1. Ethephon at all concentrations increased the yield of ripe fruits at the first harvest on 'Guatemalan' pre-labeled branches (data not shown) and whole trees (Fig. 1). The 100 and 200 mg liter^{-1} concentrations were more effective than the 50 mg liter^{-1}. There was no difference in vegetative growth and final yield on labeled branches and whole trees among treatments. The acceleration of ripening (color development) did not persist beyond 15 days after ethephon application on whole trees (Fig. 1). There was a compensatory decline in harvestable yield for the

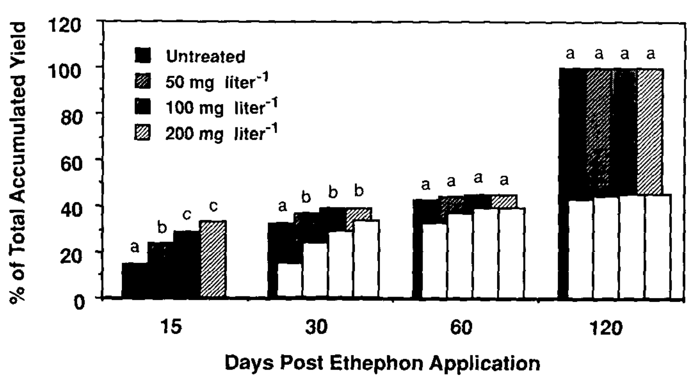

Fig. 1. Effect of ethephon concentrations applied at the onset of fruit ripening on the percent of the final accumulated harvest at: (A) 15, (B) 30, (C) 60, and (D) 120 days after application (Experiment 1). Mean separation by LSD test; same letter within each harvest date indicates no significant differences ($P = 0.05$). Average of six trees per treatment. Bold line represents total yield on that harvest date.

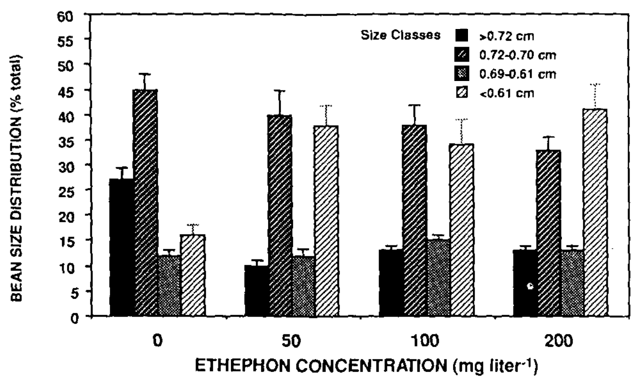

Fig. 2. Effect of ethephon concentrations applied at the onset of fruit ripening on bean size distribution (% of total) measured 15 days after application (Experiment 1). Bars indicate standard deviations. Each ethephon concentration is represented by six observations.

ethephon treatments by 30 days post-application, indicating a significant effect of ethephon on enhancing ripening just after 15 days post-application.

There were no quality differences between beans from ethephon-treated trees and those from untreated trees. Ethephon treatment did not affect the number of defective beans or the taste of the product as determined by a taste panel during a formal 'cupping test' (data not shown). Similar results have been reported for *Coffea arabica* in Kenya (Browning and Cannell, 1970) and for *Coffea robusta* in India (Gopal, 1976) after ethephon sprays.

At 15 days post-application (Fig. 2) ethephon reduced the percentage of beans in the largest size category (>0.72 cm), and increased the percentage in the smallest category (<0.61 cm). Average bean weight at 15 days was significantly reduced by 3% and 6% by the 100 and 200 mg liter^{-1} ethephon treatments, respectively. Ethephon treatments had no persistent effect on bean size or weight at later harvest dates.

Fruit removal force (FRF) decreased with increasing ethephon concentration at 15 days post-application. Ethephon at 50, 100 and 200 mg liter^{-1} reduced the FRF by about 14%, 27% and 55%, respectively, in 'Guatemalan' fruits. Ethephon treatments did not affect FRF measured 30 days after application.

All ethephon treatments accelerated leaf abscission only on bearing branches (Table 1). The 200 mg liter^{-1} treatment caused complete leaf abscission and terminal necrosis of about 15% of the bearing branches by 120 days post-application. In our research, leaf abscission was not observed on either the vegetative or flower differentiation zones, in contrast to an earlier report (Crisosto et al., 1991; Rodriguez and Molero, 1970; Gopal, 1976; Browning and Cannell, 1970), in which concentrations higher than 250 mg liter^{-1} were used. This selective defoliation observed in our trial did not limit vegetative growth and potential yield of future crops, in contrast with pecan trees, for example, in which yield decreased in the years following application of ethephon at rates of 500 mg liter^{-1} or higher (Wood, 1989). This decrease in yield in pecan was associated with leaf area reduction and

TABLE 1

Effect of ethephon concentrations applied at the onset of fruit ripening on number of persisting and green leaves per node measured at various times after application

Ethephon concentration	Mean number of persisting and green leaves			
	0	50	100	200
Days post application				
0	2.00 a	2.00 a	2.00 a	2.00 a
15	1.97 a	1.76 b	1.48 b	1.04 b
30	1.38 b	1.36 b	1.02 c	0.44 c
60	1.24 b	1.36 b	0.64 d	0.05 d
120	0.50 c	0.49 c	0.40 d	0.03 d
Significance of linear regression				
R^2	0.89	0.87	0.76	0.73
P-value	0.0001	0.0001	0.0001	0.0001

Mean separation after ANOVA by the REGWF Test ($P = 0.05$), same letter indicates no significant differences within a column. Due to the significant interaction between the two factors analyzed by the ANOVA, each value represents an average within each concentration at each time of measurement (Experiment 2).

suppression of photosynthetic carbon assimilation. In our study, only senescent or shaded leaves with low photosynthetic capacity abscised (Crisosto et al., 1990). The following year, the total number of fruits per tree counted one month before the first harvest (4 August 1990) revealed no detrimental effect of the ethephon treatments on fruit productivity. Therefore, application of ethephon at rates lower than 200 mg liter^{-1} to accelerate ripening in the current year should not adversely affect yields in subsequent years.

The analysis of variance showed a significant interaction ($P = 0.002$) between concentration and time for the number of leaves per node that persisted. For this reason, application of the REGW *F*-test to the data in Table 1 indicated which differences in leaf persistence within each concentration of ethephon were significant (at $P = 0.05$). A regression analysis using time as a predictor of the number of persistent leaves showed that the slope for the ethephon concentration of 200 mg liter^{-1} was significantly ($P = 0.001$) different from those of the other three concentrations, which is indicative of a real effect on leaf drop rate. However, although ethephon at 200 mg liter^{-1} was more effective than 100 mg liter^{-1} in reducing FRF and enhancing fruit ripening (data not shown), it caused more leaf abscission (Table 1) and a reduction in bean size (see Fig. 2 for 15 day post-treatment data). For these reasons, concentrations above 150 mg liter^{-1} were not used in the second experiment.

Experiment 2. Even though ethephon at 100 mg liter^{-1} reduced the FRF on 'Yellow Catuai' and 'Guatemalan' by only 26%, the machine harvester picked mostly red fruits on treated versus untreated trees. In both varieties 'Guatemalan' and 'Yellow Catuai', about 15% more ripe fruit were mechanically harvested from the ethephon treated trees than from the untreated trees (Table 2). There was no

TABLE 2

Effect of ethephon on the adaptability to mechanical harvesting of 'Guatemalan' and 'Yellow Catuai' coffee fruit at 20 days following the application of ethephon

Ethephon ($mg\ l^{-1}$)	Total fruit harvested (%)		Fruit removal force (FRF) (N)	
	Guatemalan	Y. Catuai	Guatemalan	Y. Catuai
0	79 a[z]	57 a	8.1 a	8.6 a
100	94 b	74 b	5.9 b	6.4 b
150	94 b	76 b	4.8 b	5.2 b

Mean comparisons were performed by a REGWF Test at 5% significance level. Means with the same letter are not significantly different. Each FRF value represents an average of 50 fruits per each of the three replications (150 fruits) taken between 7 and 9 am. (Experiment 2).

additional benefit in fruit adaptation for mechanical harvesting by increasing the concentration of ethephon from 100 to 150 mg liter^{-1}. In Puerto Rico, Silva et al. (1968) reported that the proportion of ripe to green fruits typically decreases as the harvest season progress. During the early and mid-season, there is a high ratio between green and red fruits, thus, if ethephon were applied during the early harvest it would likely result in a larger proportion of ripe fruits mechanically harvested than just the 15% observed with the late application used in our trial.

It is concluded that ethephon at 100 mg liter^{-1} accelerates ripening and decreases FRF by 15 days post-application without adversely affecting yields. Because of the lack of ethephon effect beyond 15 days post-application, it is suggested that multiple applications during coffee harvest (every 15–30 days) may be necessary to enhance coffee fruit ripening, reduce FRF and hence increase adaptability for mechanical harvesting.

A combination of ethephon treatment as described here, with controlled water deficit treatments as described previously (Crisosto and Grantz, 1990) could form a basic management protocol which should be studied further to be used commercially for the extensive cultivation of coffee in Hawaii.

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