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USE OF ETHEPHON AND GIBBERELLIC ACID FOR SYNCHRONIZING FRUIT RIPENING IN HAWAIIAN COFFEE ORCHARDS

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SUMMARY

Poor synchrony of coffee (*Coffea arabica* L.) fruit ripening in Hawaii increases labor costs and reduces returns from mechanical harvesting. Treatments designed to improve the synchrony of ripening and the proportion of ripe fruit in a single-pass commercial harvest were tested in a hand-harvested orchard on Oahu (Waialua Coffee) and a mechanically-harvested orchard on Kauai (Kauai Coffee). Gibberellic acid (GA) and ethephon were applied at different times to stimulate synchronized flower opening and fruit ripening, respectively. Treatments were tested on their own or in combination. Ethephon increased the proportion of ripe fruit in the final harvest by at least 20% in both the hand harvested and mechanically harvested trials. GA had more variable effects that were dependent on the pre-existing synchrony of bud development. Applying GA at flowering and ethephon at ripening was no more effective than applying just ethephon. Neither treatment caused excessive defoliation or a reduction in yield, but in the hand-harvested trial ethephon did cause an increase in the proportion of green beans in the smaller size classes.

INTRODUCTION

An extensive coffee industry is now developing in low elevation, irrigated leeward areas of Hawaii. The aim of the industry is to produce high quality specialty coffees, recognized by the name of the 'estate' on which they are grown. Coffee growing in many subtropical and tropical production areas is characterized by poorly synchronized floral development and a prolonged hand-harvesting period (Crisosto et al. 1992a). Because of the high cost of hand harvesting, most new coffee producers in Hawaii are using mechanical harvesting. Mechanical harvesters have poor selectivity between ripe fruits and both immature and over-ripe fruits that co-exist on the same tree (Norris 1997). The final cupping quality and value of the coffee depends in part on avoiding or separating immature and over-ripe fruits and maximizing the proportion of prime ripe fruits. To optimize mechanical harvesting, cultural practices are required that synchronize fruit development and maximize the proportion of fruits that are ripe when harvested (Crisosto et al. 1992b).

Fruit development in coffee can be synchronized by treatments designed to synchronize flower opening, or fruit ripening, or both. Flower opening in coffee is naturally synchronized by a period of drought followed by irrigation or rainfall (Alvim 1960, Cannell 1985). Coffee flower buds grow for around two months after initiation, then pass into a period of dormancy. Dormancy is broken by a period of water stress, and rainfall or irrigation provides the trigger for renewed growth and flower opening around 10 days after the period of water stress ends (Cannell 1985). Renewed bud growth is accompanied by a rise in the concentrations of gibberellic acid (GA), a natural plant growth regulator (Browning 1975). The utility of controlled drought followed by irrigation for synchronizing fruit development, as practiced in Australia (Drinnan 1997), is limited in Hawaii by unpredictable rainfall and the lack of prolonged dry periods. Application of external GA can stimulate the opening of dormant buds and partially overcome the need for water stress (Schuch et al. 1990, Schuch et al. 1992). Ethylene gas, another plant growth regulator, is involved in the processes of fruit ripening, leaf senescence and leaf drop. Ethephon (2-chloroethyl phosphoric acid), an ethylene-releasing agent, can be applied prior to harvest to enhance fruit ripening and reduce fruit removal force (Crisosto et al. 1992b).

The aim of this study was to determine whether GA and ethephon can be used to synchronize coffee fruit ripening and increase the proportion of prime ripe cherry at the time of a 'single-pass' harvest. Previous studies have tested the effects of both GA and ethephon on vegetative growth, bud initiation, the timing of flowering and fruiting, and the synchrony of fruit ripening (e.g. Schuch et al. 1990, Crisosto et al. 1991b). However, it has not yet been demonstrated whether either substance can be practically used to improve returns of ripe cherry in a commercial orchard in Hawaii. GA can be used to trigger an earlier flowering, but it is not known if this will lead to a useful increase in the synchrony of ripening (Crisosto et al. 1991a). Ethephon can improve the synchrony of ripening, but it can also cause excessive leaf drop. Ethephon may also accelerate the ripening of immature cherry, resulting in an undesirable reduction in cupping quality. With both treatments there is a risk that improved synchrony will lead to overbearing dieback and reduced yield in the following year. Ethephon and GA were therefore tested in commercial orchards on the islands of Oahu and Kauai. On Oahu, treatments were applied in 1997 and 1998 using a knapsack sprayer and the coffee harvested by hand. On Kauai, treatments were applied in 1998 using a tractor-drawn blast sprayer and the coffee harvested mechanically. Here we report the initial results for the effects of treatments on fruit ripening, yield and bean size. A more complete report will be prepared at a later date, along with the results of cupping tests.

MATERIALS AND METHODS

Treatments

Five treatment regimes were tested:

1. Control: Spray with surfactant only.
2. GA 100 ppm when flower buds were at the open white cluster stage (flower buds at this stage are dormant but receptive to GA).
3. GA 100 ppm at the open white cluster stage and again when fruits were at the pinhead stage (GA can promote expansion of developing fruits).
4. GA 100 ppm at the open white cluster stage and ethephon 100 ppm when approximately 20% of the fruits were turning color.
5. Ethephon 100 ppm when approximately 20% of the fruits were turning color.

Trade names for the two compounds were: ProGibb plus 2X® (GA3), Abbott Laboratories, Chicago, IL, and Ethrel® (ethephon), Rhône-Poulenc Ag Co., Research Triangle Park, NC. The registration process for ethephon has begun, but neither compound has yet been registered for commercial use on coffee.

Hand Harvested, Waialua

At Waialua Coffee on Oahu, each treatment was applied to a plot of three 'Guatemalan' ('Typica') plants in a randomized complete block design, with three blocks distributed along a single row of plants (45 plants in total, with untreated trees between plots). Plants were spaced 3 ft apart, drip irrigated, and were 1.5 years old at the time of first treatment. A surfactant (Tween 20, 0.25% by volume) was added and spray applied to runoff over each plant using a knapsack sprayer. In 1997, the GA treatments were applied on February 19 and March 27, the ethephon treatment on September 12, and the harvest was on September 26. To assess the effects of treatments on future harvests, the treatments were repeated in 1998 on the same row (Row 1), and applied for the first time to a new set of plots in a second row (Row 2, 100 yards from Row 1). In 1998, GA was applied on February 2 and April 1, ethephon on September 3, and the harvest was on September 21. Plants were harvested individually, with all fruit removed by hand and taken to the laboratory for determination of the proportions of immature, ripe and over-ripe fruit. Over-ripe fruit were separated by flotation, and immature and ripe fruit were separated by color. A sub-sample of 50 randomly selected ripe fruits was weighed for determination of average fresh mass per cherry.

Machine Harvested, Kauai

At Kauai Coffee on Kauai, treatments were applied in 1998 to row plots of 11 year old 'Yellow Catuai' plants, with 700 to 900 ft of row per plot in a randomized block design with three blocks and a buffer row between plots. Treatment 3 (two GA applications) was omitted from this experiment because it had no effect on fruit ripening in the 1997 hand harvested experiment. Plants were spaced 3 ft apart within the row and 12 ft apart between rows. Spray was applied at a rate of 190 gal/acre using a tractor drawn, 500 gal blast sprayer (Streamliner). Growth regulators were first mixed with a small amount of water, then added with a surfactant (Excel 90, Monterey Chemical Co., Fresno, CA, 0.25% by volume) to the spray tank. GA was applied on February 25, and ethephon on October 26. All rows were harvested on November 11 and 12 using a modified Korvan 9200 berry picker, travelling at 0.5 mph with the shaker speed set at 850 rpm. Samples were collected at frequent intervals from the harvester conveyer, pooled and set aside for later analysis. The harvested fruit from each plot was weighed using a loader equipped with a weigh scale. In the laboratory, a sub-sample of the fruit collected from the harvester conveyer was separated into immature, ripe and over-ripe fruit by color, and each fraction weighed and counted. The size distribution of green beans harvested from Kauai and Waialua in 1998, was assessed by passing a sample of beans through sieves with mesh sizes ranging from 20/6 in to 15/64 in (#20 to #15 screens).

RESULTS

Hand Harvested, Waialua

Ethephon applied two weeks before harvest increased the proportion of ripe fruit in both years (Fig. 1). GA applied to promote synchronized flowering caused an increase in the proportion of ripe fruit in 1997, but had no effect in 1998. Overall synchrony in 1997 was higher, with 54% ripe fruit on untreated plants and an average of 80% ripe fruit on plants that had been treated with GA, ethephon, or both. No over-ripe fruit were observed in 1997. Overall synchrony in 1998 was lower, with an average of 21% ripe fruit on untreated and GA treated plants, and 52% ripe on ethephon treated plants (Fig. 1). Over-ripe fruits (up to 17%) were observed on all but one plant in 1998, and there was no relationship between the proportion of over-ripe fruits and treatment. Low synchrony in 1998 was related to multiple flowering events. In a random sample of four branches per tree, 47% of fertile nodes already had pinhead fruits at the time of application of GA, suggesting an earlier flowering had already occurred. GA application caused flower opening on 50% of the fertile nodes, compared to 12% in untreated plants. A third flowering was observed one month after the first GA treatment.

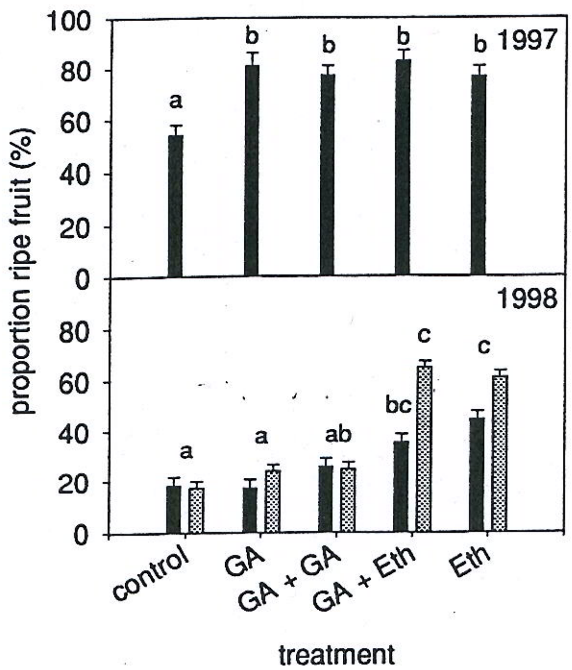

Fig. 1. Effect of GA and ethephon treatments on the proportion of ripe fruit in the hand harvested crop at Waialua in 1997 and 1998. Dark bars are for row 1, first treated in 1997, and grey bars are for row 2, first treated in 1998. Bars with the same letter are not significantly different ($p = 0.05$, Tukey's HSD).

Neither GA nor ethephon had any consistent effect on the total yield of fruit from each tree (Fig. 2). In 1997, the trees were in their first year of fruiting and yields were low. An unusually high yield from trees that received ethephon in 1997 (treatment 5, Fig. 2) is thought to be the result of variation in tree size between treatments, rather than a real treatment effect. In 1998, yields were higher and there was no evidence that treatment of plants in 1997 had caused reduced yields in the same plants in 1998. The average mass of a ripe fruit was unaffected by treatments in 1997 or 1998. In 1997, average mass per fruit was 1.66 ± 0.01 g. In 1998, average mass per fruit was 1.91 ± 0.02 g for row 1, and 2.17 ± 0.03 g for row 2. While there was no detectable effect on average fruit mass, in 1998 ethephon did increase the proportion of green beans in the smallest size class. In row 1 the proportion (by mass) of beans in the < 15/64 in size class (< #15 screen) increased from 5% to 14%, and in row 2 from 1% to 5%. GA had no effect on bean size.

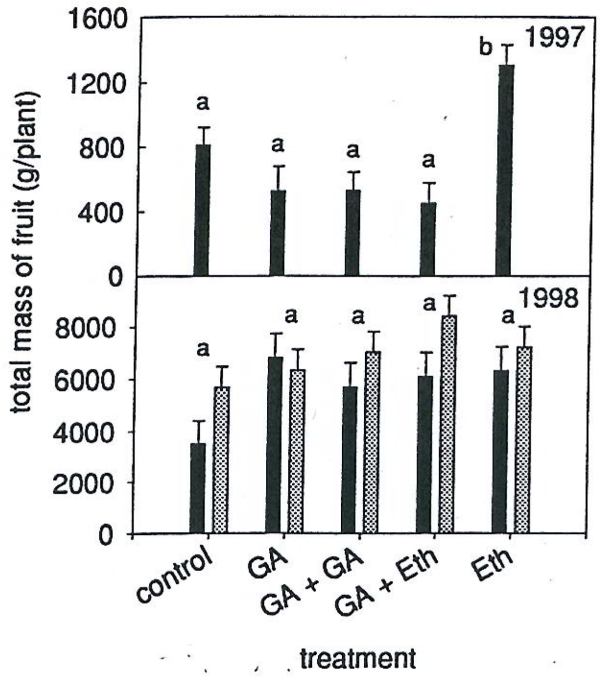

Fig. 2. Effect of GA and ethephon treatments on the total yield of fruit (immature, ripe and over-ripe) harvested by hand at Waialua in 1997 and 1998. For explanation of bars and letters, see Fig. 1.

Machine Harvested, Kauai

GA and ethephon treatment both increased the proportion of ripe fruit in a single pass mechanical harvest (Fig. 3). GA treatment to promote earlier flower opening increased the proportion of ripe fruit from 46% in the untreated rows to 57% in the treated rows. Ethephon had a stronger effect, increasing the proportion of ripe fruit to 69%. Although there was no significant difference between rows that received GA and ethephon and rows that received just Ethephon, the higher proportion of ripe and over-ripe fruits in the rows that received both treatments suggests that GA had advanced the timing of ripening (Fig. 4).

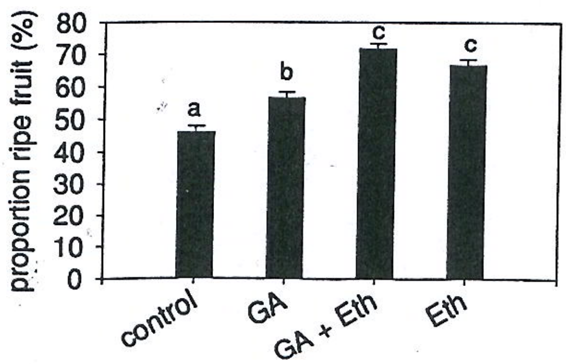

Fig. 3. Effect of GA and ethephon treatments on the proportion of ripe fruit in the mechanically harvested crop on Kauai in 1998. Bars with the same letter are not significantly different (p = 0.05, Tukey's HSD).

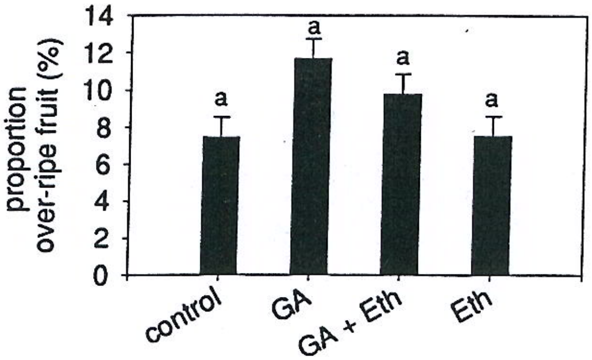

Fig. 4. Effect of GA and ethephon treatments on the proportion of over-ripe fruit in the mechanically harvested crop on Kauai in 1998. Bars with the same letter are not significantly different (p = 0.05, Tukey's HSD).

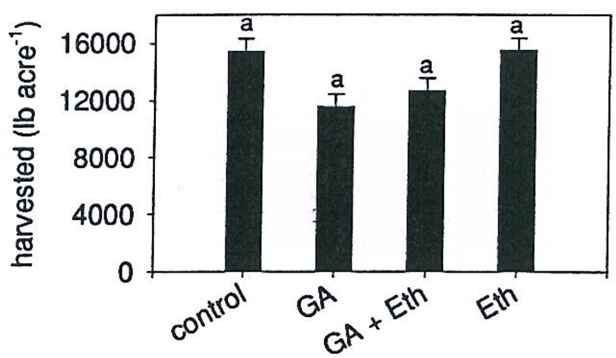

Fig. 5. Effect of GA and ethephon treatments on the total yield of fruit (immature, ripe and over-ripe) harvested mechanically on Kauai in 1998. Bars with the same letter are not significantly different (p = 0.05, Tukey's HSD).

The yield of mechanically harvested fruit was not significantly affected by GA or ethephon treatment, although yields in both GA treatments were lower than the control and ethephon only treatment (Fig. 5). Other results suggest that harvester efficiency was unaffected by the growth regulator treatments, with around 75% of the total crop harvested by the machine, with the remainder falling to the ground or left on the plant (data not shown). Average mass per ripe fruit was 1.68 ± 0.01 g, with no differences between treatments. Neither GA nor ethephon had any significant effect on the size distribution of green beans from the mechanically harvested trial.

DISCUSSION

Ethephon applied at low concentrations at the beginning of the ripening period increased the proportion of ripe fruit in both the hand harvested and mechanically harvested trial. In the hand harvested trial the proportion of ripe fruits was increased from 54% to 80% in the first year and 21% to 52% in the second year. In the mechanically harvested trial the increase was from 46% to 69% ripe fruit. In previous studies, ethephon applied at higher concentrations (200 - 2000 mg L^{-1}) resulted in significant increases in the harvest of ripe fruit, but it also caused unacceptable defoliation and shoot dieback (Crisosto et al. 1991b, Winston et al. 1992). At lower concentrations defoliation is restricted to the bearing nodes (Crisosto et al. 1992b), and in this study there is not yet any indication that repeated application of ethephon at low concentrations in successive years will lead to biennial bearing or a decline in yield or plant health. Ethephon increased the proportion of smaller green beans in the hand harvested trial in 1998, but had no effect on bean size in the mechanically harvested trial. Overall synchrony was poorer in the hand-harvested trial and there was a larger proportion of immature fruits on the trees when ethephon was applied. This suggests that ethephon can cause the ripening of immature cherries if it is applied early when a large proportion of fruits are unripe. Negative effects on bean size may be minimized if it is applied later when more of the crop is near maturity, as was observed in the mechanically harvested trial. Even if some immature cherry are ripened by ethephon, the net effect may still be a useful increase in the yield of mature green bean after immature beans are separated by size.

If the effects of ethephon on bean size can be controlled and cupping quality is unaffected, ethephon should prove useful for improving the efficiency of both hand and mechanical harvesting of coffee in Hawaii (Crisosto et al. 1992b). If hand harvesting is used, ethephon can synchronize and shorten the harvesting period and concentrate labor requirements. If mechanical harvesting is used, ethephon can increase the proportion of ripe fruit recovered from a single aggressive pass (this study), or improve the selectivity of less aggressive multiple passes (Crisosto et al. 1992b). Ethephon is known to reduce the fruit removal force of coffee cherries (Norris 1997), but in this study it had no detectable effect on the efficiency of mechanical harvest (data not shown). The most important effect seemed to be an increase in the total proportion of ripe fruit, rather than an increase in the ease with which ripe fruit could be detached from the plant. If ethephon is registered for use on coffee, application at low concentrations would cost approximately $5 per acre plus the cost of application*. A 20% increase in the harvest of ripe cherry should more than cover the cost of application and increase returns from mechanical harvesting.

GA applied to trigger flowering of dormant flower buds had variable effects on the proportion of ripe fruit in the final harvest. Variation is probably dependant on the number of receptive, dormant buds present at the time of application (Schuch et al. 1990). A good flowering response to GA can be expected when a large proportion of the year's total number of flower buds has reached the dormant stage without being triggered to flower by rainfall. An early synchronized flowering should result in early synchronized ripening. Rows that received GA in the mechanically harvested trial flowered earlier, had more ripe fruits and slightly more over-ripe fruits than the untreated rows at the time of harvest. If the flowering season is repeatedly interrupted by rainfall then a synchronized population of receptive buds cannot develop and GA will be less effective for synchronizing flowering and ripening. This situation occurred in the hand harvested trail during 1998. Drought followed by rainfall had already released the dormancy of some buds, application of GA induced a second flowering, and a third set of buds matured and flowered later in the season. Overall synchrony was therefore unaffected by GA treatment. In the mechanically harvested trial a large population of receptive buds was present and application of GA did advance the time of ripening. GA may still prove useful if it can be used in combination with ethephon to alter the timing of ripening or in combination with drought or irrigation treatments that improve the underlying synchrony of bud development. If GA is registered for use on coffee, application to promote flowering would cost approximately $102 per acre plus the cost of application*.

*Based on: 200 gal/acre spray volume, 0.17 lb/acre active ingredient (GA or ethephon). Ethrel® (4 lb/gal ethephon) $104 per gal. ProGibb plus 2X® (20% w/w GA3) $122 per lb.

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