Effects of 2-Chloroethane Phosphonic Acid and Its Interaction with Gibberellic Acid on Quality of 'Early Italian' Prunes[1]

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Abstract. The growth regulator, 2-chloroethane phosphonic acid (Ethrel) advanced color and soluble solids development by about 2 weeks, softening by 1 week when applied at 80 ppm 3½ weeks before commercial maturity of untreated fruit. Lesser effects of a similar nature were produced by rates down to 10 ppm on the same date. Gibberellic acid (GA) delayed softening by 1 week, color and soluble solids development by 1 or 2 days when applied at 50 ppm 3½ weeks before commercial maturity of untreated fruit. Internal browning was reduced. Ethrel combined with GA to produce better colored fruit with higher soluble solids and less internal browning than untreated checks.

Introduction

'Italian' and 'Early Italian' prunes, *Prunus domestica,* L., are shipped from Washington, Oregon and Idaho as fresh plums. In some years internal browning, a physiological disorder of the fleshy pericarp, is a serious problem (9, 13). It has been shown that gibberellic acid (GA) will reduce the incidence of internal browning, sometimes at the cost of a delay in development of skin color and soluble solids (10).

A chemical that produces ethylene-like responses (14) was identified as 2-chloroethane phosphonic acid (4) and subsequently designated "Ethrel" (1). Preliminary experiments in 1967 showed that Ethrel would substantially advance color and soluble solids development in 'Early Italian' prunes without increasing internal browning.

The experiments reported here were designed to define the amount of response obtainable from Ethrel and to determine whether the beneficial effects of GA and Ethrel could be combined to produce earlier coloring prunes with a lower incidence of internal browning.

Procedure

In 1967 a screening trial compared Ethrel, in an alcohol base formulation designated as 66–329,[2] at 100 ppm, with GA[3] at 50 ppm and an untreated check. Both sprays were applied 5 weeks before harvest to ½ tree plots with 6 replications. For timing purposes "harvest" refers to the date of commercial harvest of untreated fruit.

In 1968 Ethrel (Amchem glycol base formulation 68–

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[2]Provided by Amchem Products, Inc., Ambler, Pa.

[3]Provided by Amdal Company, N. Chicago, Ill.

lengths (12 and 16 hr) and 2 temperatures (70° day–60°F night and 80° day–70° night). All plants bloomed by January 1968, from previously initiated flowers. After this date only plants under short daylength continued to flower while plants under long days formed runners. The number of stems originating from the crown in each inflorescence was counted along with the total number of flowers. An inflorescence borne on a single peduncle would have a high flower to stem ratio based on the total flowers produced, inflorescences with basal branching (branching at the base of the crown) would have a lower ratio, and inflorescences with branching confined to the crown (unbranched inflorescences) would have one flower per stem for a ratio of 1.0.

For the short daylength treatment the number of fruits per stem originating from the base of the inflorescence is plotted against time in Fig. 3. When flowers were initiated under short day-length the amount of basal branching increased in 'Surecrop' and the "unbranched" phenotype of 'La. 9-1158' was produced. There were no consistent differences attributable to temperature.

Relation of fruit size and basal branching. It was of interest to know if the "unbranched" habit of 'La. 9-1158' was correlated with a change in the typical pattern of fruit size decline similar to varieties with branched inflorescences. Flowers of 'La. 9-1158' initiated during the winter in the greenhouse were hand pollinated to insure a satisfactory seed set and the unbranched inflorescences classified as to blossom position based on morphology and ripening sequence. Fruit weight and achene number (for both developed and undeveloped achenes) were determined in a technique previously described (4).

The results shown in Fig. 4 indicate a decline in fruit size and achene number with fruit position similar to that previously reported for other cultivars such as 'Surecrop'. Thus basal branching in 'La. 9-1158' is not associated with a changed pattern of fruit size within the strawberry inflorescence in the greenhouse.

The branching pattern of the inflorescence in 'La. 9-1158' depends on the amount of elongation of the peduncle as shown by the GA experiment. Elongation of the peduncle in strawberry is influenced by photoperiod. Thus, under 12 hr photoperiod in environmental control chambers, 'La. 9-1158' produced extreme basal branching with most flower stems arising from the base of the inflorescence, as has been observed under field conditions at Baton Rouge, Louisiana, while 'Surecrop' produced some branching at the base of the inflorescence. Under normal field conditions at Lafayette, 'La. 9-1158' and 'Surecrop' produced normally branched inflorescences. There was no association between basal branching of 'La. 9-1158' and uniform fruit size within the inflorescence under greenhouse conditions at Lafayette.

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Table 1. Comparison of maturity and quality of Ethrel-treated Early Italian prunes with check and GA-treated prunes harvested a week later (1967).

	Ethrel	Check	GA
Rate	100 ppm		50 ppm
Date harvested	8/15	8/22	8/22
Soluble solids (%)	16.0	16.3	15.6
Color (rating)	2.6	2.6	2.2
Firmness (lb.)	7.5	6.9	10.3
Size (lb./100 prunes)	7.0	7.4	7.7
% Ripe, 3–4 days at 70°F	48	30	41
Browning Index (%) 7 days at 70°	46	78	28

62)[2] was applied at 10, 20, 40, 80 and 160 ppm 3½ weeks before harvest. Sprays of 40 ppm Ethrel were applied 7 weeks and 1½ weeks before harvest. GA at 50 ppm and Ethrel at 40 ppm were applied 3½ weeks before harvest to ½ tree plots in a 2^2 factorial experiment with 16 replications. Whole trees were used for checks to avoid contamination. Two check plots per replication were used to assure a more reliable base level for treatment comparisons.

Six to 8 lb. samples of prunes were harvested from all plots on August 5 and 6, at commercial maturity, July 29 and 30, a week earlier, and August 12 and 13, a week later than normal harvest. Additional samples from Ethrel 80 ppm, GA 50 ppm, and the check plots were harvested July 25, August 19 and August 26.

Subsamples of the fruit were graded for color, soluble solids, firmness, size and flesh condition. The main samples were treated with Captan at 1½ lb./100 gal then stored at 35°F for 2 weeks. Ripening was at 70°. This combination of storage and ripening temperatures has consistently developed substantial internal browning. Quality evaluations were made after 4 and 7 days.

Skin color was determined by the method of Ingalsbe, et al. (7) on 20 ⅜″ discs of epidermis removed from the cheeks of 10 prunes, extracted in 100 ml 95% ethanol with 1% HCl, diluted 1:10, and optical density (OD) measured with an Evelyn colorimeter. In 1967 the color was graded and rated on a color scale from 0 (no purple) to 4 (100% purple) as described earlier (10). Soluble solids were measured with a hand refractometer on a composite juice sample from the apical end of 10 prunes. Firmness was measured with a Magness-Taylor pressure tester using a 5/16″ plunger on fruit with the skin intact. Ripeness was rated as the number of fruit whose flesh became juicy, amber, and non-astringent. Internal Browning Index (13) is a rating that approximates the per cent of pit cavity area affected.

Results

Preliminary trial—1967. Ethrel-treated prunes reached acceptable color and soluble solids about a week earlier than did the check fruit (Table 1). The Browning Index was lower than that of check fruit of comparable maturity but was higher than GA-treated fruit. In a year when ripening did not proceed normally, the Ethrel-treated fruit ripened more fully than did check fruit.

Table 3. Effect of GA at 50 ppm and Ethrel at 40 ppm, alone and combined, both applied 3½ weeks pre-harvest, on maturity and quality components of Early Italian prunes harvested at the time of commercial maturity of untreated fruit (August 5–6).

Harvest date	Check	GA	Ethrel	GA + Ethrel
Soluble solids (%)	16.0a[x]	16.4a	17.6b	18.1b
Skin color (OD)	1.0a	1.0a	1.8b	2.0b
Firmness (lb.)	10.9b	13.0c	9.4a	10.7b
Size (lb./100 prunes)	7.7a	7.9a	7.6a	8.0a
Browning Index (%) 7 days at 70°F	16.8b	9.2a	16.5b	9.0a

[x]Means followed by the same letter do not differ significantly at the 5% level.

Ethrel concentration and timing—1968. Ethrel advanced soluble solids development (Table 2). Application 3½ weeks pre-harvest was more effective than 7 weeks or 1½ weeks. High rates were more effective than low rates.

All rates of Ethrel applied 3½ weeks before harvest significantly increased skin color with higher concentrations having more effect than lower concentrations. Early or late applications did not significantly increase color. All Ethrel-treated fruit harvested a week after commercial harvest maturity had significantly more color than the check.

Chlorophyll degradation, as indicated by proportion of fruit with yellow flesh at harvest, was advanced by Ethrel applied 3½ weeks pre-harvest, not when applied 7 weeks or 1½ weeks before harvest.

All Ethrel-treated fruit was softer than fruit from check trees.

Application of Ethrel 7 weeks pre-harvest produced a significant number of gum pockets in the fruit.

Internal browning differences were not significant at the time of commercial harvest of untreated fruit. Interestingly, a week after normal harvest the 2 lowest rates of Ethrel produced fruit with significantly less browning than the check.

There was no significant effect of Ethrel on fruit size or ripeness on August 5 so these data were not included in Table 2.

Ethrel, GA factorial—1968. GA had no significant effect on color or soluble solids (Table 3). It increased firmness. It reduced browning significantly. Size was not increased significantly at commercial harvest. A week later GA-treated fruit was significantly larger. Ripening was not delayed significantly.

Ethrel increased color and soluble solids significantly. Ethrel-treated fruit was softer and riper than check fruit. It had no effect on size or internal browning.

Combining GA with Ethrel combined the desirable features of both chemicals. Fruit was as well colored and as high in soluble solids as Ethrel-treated fruit and as low in browning and as large as GA-treated fruit.

Ripening curve—Ethrel and GA. From samples collected before and after the 3 main harvests a ripening curve was constructed to compare Ethrel and GA with the

Table 2. Effect of Ethrel applied (1968) at different dates and rates on maturity and quality components of Early Italian prunes harvested at the time of commercial maturity of untreated fruit (August 5–6).

Conc. Ethrel (ppm)	0	10	20	40	80	160	40	40
Applied (weeks before harvest)		3½	3½	3½	3½	3½	7	1½
Soluble solids (%)	15.8a[x]	17.6bc	18.2bcd	17.7bc	19.4d	18.9cd	17.3abc	16.6ab
Color (OD)	1.0a	2.1c	2.2c	2.0cd	2.9d	3.0d	1.5ab	1.4ab
% Yellow flesh at harvest	6a	24bc	30c	29c	55d	55d	14ab	12ab
Firmness (lb.)	10.9e	9.1c	8.3b	9.1c	8.0b	7.0a	10.1d	10.0d
% with gum pockets	1a	1a	2a	1a	0a	1a	26b	4a
Browning Index (%) (7 days at 70°F)	19.8a	17.4a	19.6a	15.8a	16.2a	20.2a	21.5a	14.0a

[x]Means followed by same letter do not differ at the 5% level of significance.

Table 4. Changes in quality characteristics of Early Italian prunes treated with GA (50 ppm 3½ weeks pre-harvest) and Ethrel (80 ppm, 3½ weeks pre-harvest) compared with untreated check over 32-day period.

	Skin color (OD)			Firmness (lb.)			Soluble solids (%)		
	Ck	GA	Eth	Ck	GA	Eth	Ck	GA	Eth
7/25	.5	–	1.3	18.6	–	14.5	13.9	–	16.2
7/29	.6	.6	2.3	14.4	15.1	11.0	15.3	14.8	18.0
8/5	.9	.8	2.9	11.0	13.3	8.0	15.8	15.6	19.4
8/12	1.8	1.5	3.3	8.2	11.0	6.3	17.0	17.4	20.7
8/19	2.8	2.7	4.2	5.5	7.0	5.1	19.9	21.0	23.6
8/26	3.1	3.5	4.7	4.5	6.9	4.1	20.9	22.6	25.2
Normal values at harvest	(.5 to .9)			(10.0 to 15.0)			(14.0 to 17.0)		
	Size (lb./100 prunes)			% Ripe, 4 days at 70°			Browning Index, 7 days at 70°		
7/25	6.8	–	6.4	16	–	25	1.6	–	6.0
7/29	7.4	7.2	7.8	34	21	85	16.6	3.6	25.8
8/5	7.7	7.5	8.2	100	100	100	15.6	8.0	16.2
8/12	8.0	8.4	8.3	100	100	100	38.8	14.8	36.4
8/19	8.3	9.0	8.7	100	100	100	76.0	42.0	68.0
8/26	8.4	9.3	8.7	100	100	100	63.7	48.3	56.4

check and each other in terms of days advancement or delay (Table 4). Normal values, derived from 60 samples of commercially harvested fruit, are included as reference points.

Ethrel advanced coloring by as much as 17 days in the mid-maturity range, soluble solids by about 16 days. In both characteristics Ethrel-treated fruit continued to increase for at least 3 weeks after the normal harvest date. Softening was advanced by about a week. The margin was quite constant through the normal ripening period.

GA delayed coloring by no more than 2 days, 1 day at normal harvest. Soluble solids of GA-treated fruit were 2 to 3 days behind the check at normal harvest, then developed to higher values than the check 2 and 3 weeks after normal fresh fruit harvest. GA retarded softening by 7 days in mid-season but only 1 to 2 days early in the period of normal firmness. GA-treated fruit continued growth longer than did Ethrel-treated or check fruit.

Ethrel advanced apparent ripening by 3 or 4 days; GA delayed it by 1 or 2 days. Ethrel had no effect on browning index on any given date. GA delayed development of browning by about a week.

Discussion

The objective of this work is to produce a well-colored prune with adequate soluble solids while it is still firm. In addition we want to produce fruit that will ripen properly and that will develop less internal browning at a given firmness.

It has been well established that firm prunes are less likely to develop internal browning than soft prunes (13). GA retards softening and reduces internal browning (10). Also, it usually retards color and soluble solids development but to a lesser degree.

When related to firmness rather than time, Ethrel and GA both resulted in higher color and soluble solids (Fig. 1). The Ethrel and GA effects were nearly additive so that fruit from the combined treatment had much higher color and soluble solids at a given firmness, and softened at a rate very similar to the untreated check.

Extrapolating the GA curve in Fig. 1 to the 10 lb. firmness line we find color of about 1.75 O.D., the same as Ethrel, compared with about 1.3 for the check and 2.25 for GA and Ethrel combined. In years of poor color development fruit may become too soft before developing adequate color. This situation, which sometimes contributes to the internal browning problem, can apparently be corrected with GA and Ethrel.

Browning increased as the fruit softened (Fig. 1), especially after the fruit became softer than 10 lb. All 3 treatments produced less browning in fruit of equal firmness. Ethrel plus GA softened at about the same rate as the check but developed only about half as much browning.

In commercial application we can anticipate that use of Ethrel will eliminate any further concern over color or soluble solids failing to reach satisfactory levels. Because of this we expect to be able to apply GA a little earlier and be assured of maximum effectiveness without worrying about excessive adverse effects on color and soluble solids development. A possibility not yet explored is the post-harvest application of Ethrel to accomplish much the same objectives cited above.

Response of 'Early Italian' prunes to ethylene was generally consistent with what one might extrapolate from post-harvest observations on closely related fruit (5, 12).

Ripening was accelerated. However, all ripening processes apparently were not accelerated equally. Anthocyanin development, chlorophyll degradation, and soluble solids development appeared to be most affected. Softening, implying pectic changes and cell volume increases, was affected to a lesser degree. Fruit size, also

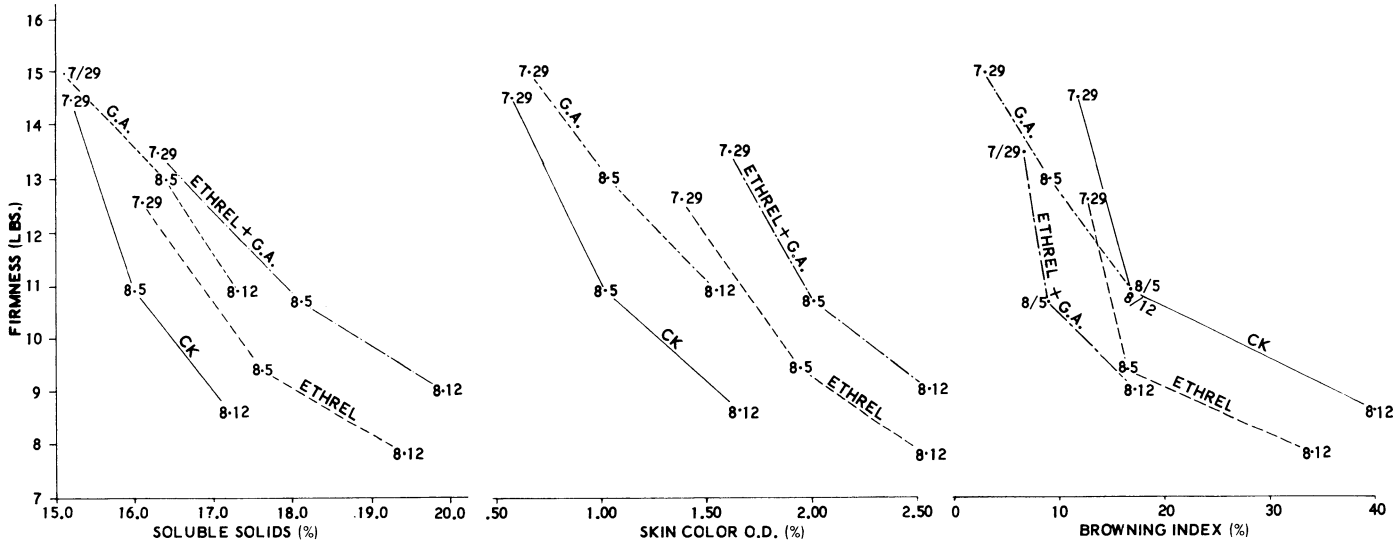

Fig. 1. Relation of firmness to soluble solids, skin color and browning index of Early Italian prunes as affected by GA and Ethrel.

reflecting cell volume increases, was increased very little, if at all. Textural changes are deeply involved in 'Early Italian' prune quality problems, especially in differences between years. Ethrel may provide new insight into the nature of this behavior.

It has been stated as a maxim that a fruit must have achieved a certain minimum state of maturity (or development) before it can be affected by ethylene (3). Our data suggest that ethylene, applied as a spray of Ethrel, is effective on 'Early Italian' prunes over a long period of time. The minimum maturity is either an extremely immature state or the Ethrel effect persists until the fruit has developed sufficiently. Since the characteristic response to applied ethylene is stimulation of ethylene formation (3), early applications of Ethrel might induce a low level of ethylene production that would be self-sustaining until the minimum maturity is reached.

An application of Ethrel as early as 9 weeks before harvest also advanced color and soluble solids development. In this case 80% of the fruit showed gum pockets compared with 26% when applied 7 weeks and 1% when applied 4 weeks before harvest (Table 2). Gumming was quite apparent on the green fruit shortly after application of the spray.

The gumming reaction suggests that a number of responses in 'Early Italian' prunes may be related through ethylene production:

1) Gum production is a characteristic response to injury in *Prunus* (6).

2) Ethylene production is stimulated by wounding (3).

3) Ethrel produces gumming from uninjured trunks and branches of other stone fruit species (2).

4) Prunes whose stems have been removed (producing a wound) ripen better and have less internal browning than prunes with stems attached (9).

5) Gum spot is a common disorder of 'Early Italian' prune fruits (8).

6) Ethrel induces gumming in prune fruits.

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