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Advancement of Nectarine Fruit Ripening with Daminozide and Fenoprop[1]

Ruth Ben-Arie and Sylvia Guelfat-Reich
The Agricultural Research Organization, The Volcani Center, P.O.B. 6, Bet Dagan, Israel

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Abstract. **Spraying trees of nectarine (*Prunus persica* (L.) Batsch) with succinic acid-2,2-dimethylhydrazide (daminozide) or 2-(2,4,5-trichlorophenoxy) propionic acid (fenoprop; 2,4,5-TP) at initiation of pit hardening induced earlier fruit ripening by enhancing the rates of growth and color development. The climacteric peak occurred earlier in fruit from either treatment than in the controls. Whereas fenoprop enhanced CO_2 evolution more than daminozide, daminozide stimulated postharvest ethylene production more than fenoprop. Treatment with both regulators did not have an additive effect in advancing the harvest date, in spite of a significant increase in color development and a somewhat increased rate of fruit softening. There was, however, an additive effect in stimulation of ethylene evolution.**

Daminozide, which was originally reported to be a growth retardant (3) and to delay maturation of some fruits (11), accelerates ripening of stone fruits (1, 2, 12, 17). These two opposing effects are reminiscent of the contradictory reports on the effect of auxins on fruit maturation. Though today it is generally accepted that auxin inhibits fruit ripening (8, 16, 18), earlier work in both the field and laboratory showed that auxins can accelerate ripening of other fruits (5, 6, 7, 11, 14). The most obvious difference between the effects of the 2 types of growth regulator is that, whereas daminozide either represses or stimulates ethylene evolution in different species, depending on whether it is retarding or accelerating maturation, auxins stimulate ethylene production in all cases, even when ripening is retarded. This might indicate that each regulator is acting on a different phase, level or pathway of fruit maturation. If this is so, then it should be feasible to induce even earlier ripening of nectarine fruits by combining the 2 growth regulators (9).

This report deals with the influence of daminozide and fenoprop singly or in combination on the maturation and ripening of "Sunred" nectarine.

Materials and Methods

'Sunred' nectarine trees, in full bearing age, were sprayed during stage II of the signoid growth cycle (determined by examining the hardening of the stone), about 45-50 days after full bloom. This has been shown to be the most effective time for daminozide application to peaches (13) and for fenoprop application to apricots (5). Spraying was done at dusk, when the relative humidity was above 70%. Using a motorized knapsack sprayer, about 6 liters per tree was applied to run-off. The experiments were planned in randomized blocks of single-tree replicates, as described in Table 1.

At each harvest the fruit from each tree was weighed, packed in nest-packs, and samples were taken for assessment of ripening parameters and for examination during storage at 20° or at 0°C, followed by shelf life at 20°.

Ripening parameters. Fruit was graded according to red coloration from 1 = less than 20% red color, to 5 = 100% red color. Fruit firmness was determined with a Hunter penetrometer (11.1 mm tip) after it had been examined for tangible softening; total soluble solids (TSS) with a hand refractometer; and acidity by titration of extractable juice with 0.1 N NaOH to pH 8.2. For measurement of CO_2 and C_2H_4 evolution, 4 fruits (200-250 g) per replicate were enclosed in jars (from each tree-replicate separately) through which a CO_2-free humidified air stream was passed at a constant rate of about 100 ml/min. Samples from the effluent stream were taken daily and injected into Packard gas chromatographs equipped with a thermal conductivity detector for CO_2 or a flame ionization detector for C_2H_4. As there was some variance between the replicates in the day on which the climacteric peak was attained, the average day for peak respiration or ethylene evolution was calculated, and the peak data for all replicates were averaged for that day. Averages of the pre- and post-climacteric data for all replicates were calculated accordingly.

Results

Acceleration of nectarine ripening was obtained by daminozide and by fenoprop orchard sprays, applied 50 days after full bloom, i.e., at pit-hardening, in proportion to spray concn, except for the lowest concentrations for each compound, which were almost ineffective (Fig. 1). The criteria used for harvest were similar to those used for commercial purposes, i.e., initiation of fruit color and size (not less than 5 cm in diameter). The increased amount of fruit harvested at the beginning of the season indicated that each compound had enhanced color development and accelerated the growth rate of the fruit (Fig.

Table 1. Description of experiments conducted to induce early ripening of 'Sunred' nectarines.

Experiment and year	Spray material	concn (M)	No. of replicates
A. 1972, 1973*	Daminozide	0	3
		6.25×10^{-3}	
		12.5×10^{-3}	
		18.75×10^{-3}	
B. 1974, 1976**	Fenoprop	0	
		3.75×10^{-5}	6
		7.5×10^{-5}	
		11.25×10^{-5}	
C. 1975**	None		8
	Daminozide	12.75×10^{-3}	
	Fenoprop	7.5×10^{-5}	
	Daminozide + fenoprop	12.75×10^{-3} + 7.5×10^{-5}	

*Two different orchards.
**The same orchard.

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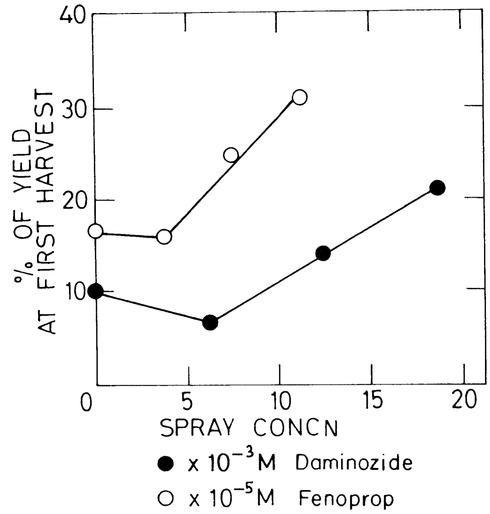

Fig. 1. The effect of increasing concentrations of daminozide and fenoprop at pit-hardening on the percentage of fruit harvested at the first harvest.

1). Other parameters of ripening, such as fruit firmness, TSS, and acidity were less markedly affected (Table 2).

Both regulators enhanced respiration and caused an earlier CO_2 climacteric peak. Daminozide accelerated the ethylene rise and caused an earlier and higher peak. The effect of fenoprop on ethylene evolution was very small (Fig. 2).

When both fenoprop and daminozide were sprayed at their intermediate concentration on the same trees at initiation of pit-hardening, the time of harvest was not advanced in comparison with fenoprop alone which, in this experiment, was more effective than daminozide at the beginning of the season

Table 2. The effect of increasing concentration of daminozide and fenoprop sprays at pit-hardening on the firmness, TSS content, and acidity of nectarines at harvest. (Data are averages of the first 2 harvests from a representative experiment for each compound, 3 replicates per harvest).

Spray material	concn (M)	Firmness (kg)	TSS (%)	Titratable acidity (% as malic acid)
Daminozide	0	13.1 a[z]	12.9 a	1.62 a
	6.25×10^{-3}	12.9 a	13.7 b	1.56 b
	12.5×10^{-3}	12.8 a	13.0 ab	1.50 b
	18.75×10^{-3}	10.1 b	12.3 a	1.51 b
Fenoprop	0	14.0 a	12.5 a	1.50 a
	3.75×10^{-5}	13.7 ab	12.3 ab	1.51 a
	7.5×10^{-5}	13.0 b	11.8 b	1.40 b
	11.25×10^{-5}	13.6 ab	12.0 ab	1.52 a

[z]Mean separation in columns for each compound by Duncan multiple range test, 5% level.

(Table 3). In spite of this, 2 of the parameters measured at harvest – fruit color and firmness – showed that ripening had been accelerated by a combination of the 2 compounds (Table 3). Firmness after storage was similarly affected. The significant loss in acidity caused by the fenoprop spray in this experiment was no further increased by additional treatment with daminozide, which also had no effect of its own on this parameter. The TSS content of the fruit was not affected by any of the treatments.

An additive effect of the combined treatment was observed in the respiratory behavior and ethylene evolution of the fruit at 20°C immediately following harvest and especially after 2 weeks' storage at 0° (Fig. 3). Each compound induced an increased respiration rate immediately after harvest. In this instance the effect of daminozide was more pronounced than

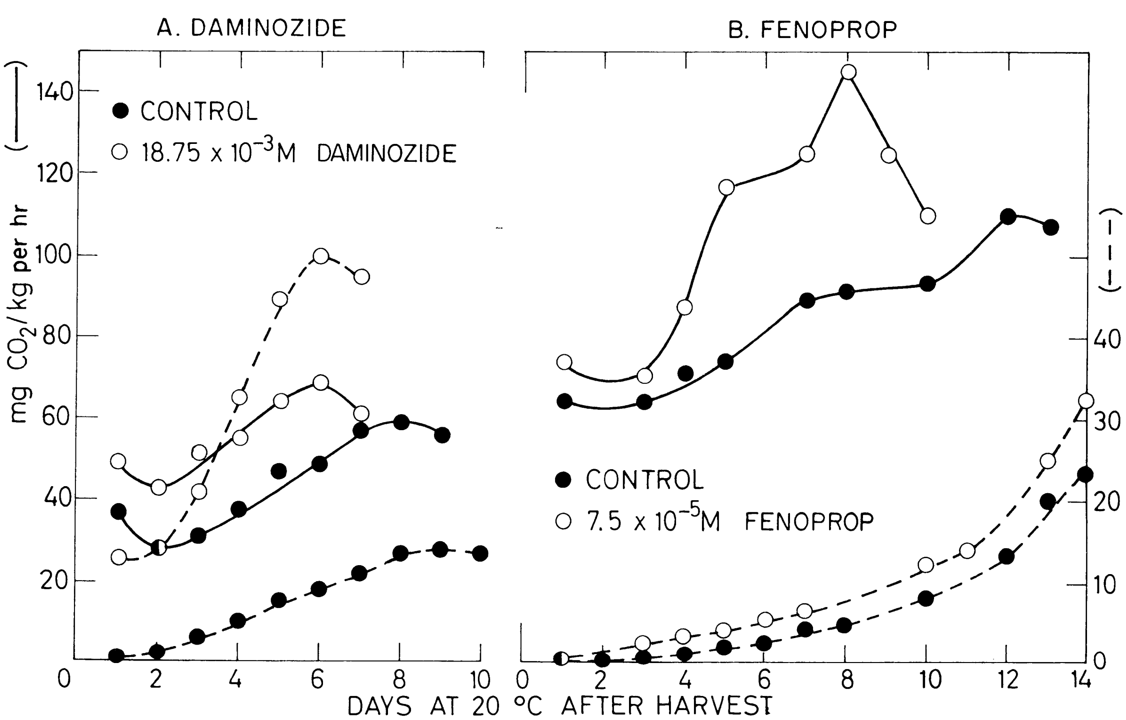

Fig. 2. The effect of orchard sprays with daminozide and fenoprop on postharvest respiration and ethylene evolution by nectarine fruits at 20°C. (Data from 1st harvest.)

Table 3. The effect of combined daminozide and fenoprop orchard sprays on advancement of harvest, color, firmness and acidity of 'Sunred' nectarines on 2 dates at the beginning of the harvest season.

Treatment	Cumulative % of yield[y]	Color[z]	Firmness (g)	Acidity (% as malic acid)
		1st Harvest May 13		
Control	8.2 a[x]	2.9 a	15.2 a	1.46 ab
Daminozide, 12.5 x 10^{-3}M	14.4 a	3.5 b	15.0 ab	1.53 a
Fenoprop, 7.5 x 10^{-5}M	26.5 b	3.6 b	14.8 b	1.30 c
Daminozide, 12.5 x 10^{-3}M + Fenoprop, 7.5 x 10^{-5}M	28.1 b	4.1 c	13.8 c	1.41 cb
		2nd Harvest May 18		
Control	39.5 a	3.3 a	13.8 a	1.15 a
Daminozide, 12.5 x 10^{-3}M	56.5 b	3.9 b	12.7 ab	1.12 a
Fenoprop, 7.5 x 10^{-5}M	62.7 b	3.8 b	12.3 bc	1.05 b
Daminozide, 12.5 x 10^{-3}M + Fenoprop, 7.5 x 10^{-5}M	63.6 b	4.3 c	11.1 c	1.00 b

[z]Color graded from 1 (less than 25% red color), to 5 (100% red color).

[y]Avg yield about 65 kg/tree.

[x]Mean separation in columns by Duncan's multiple range test, 5% level.

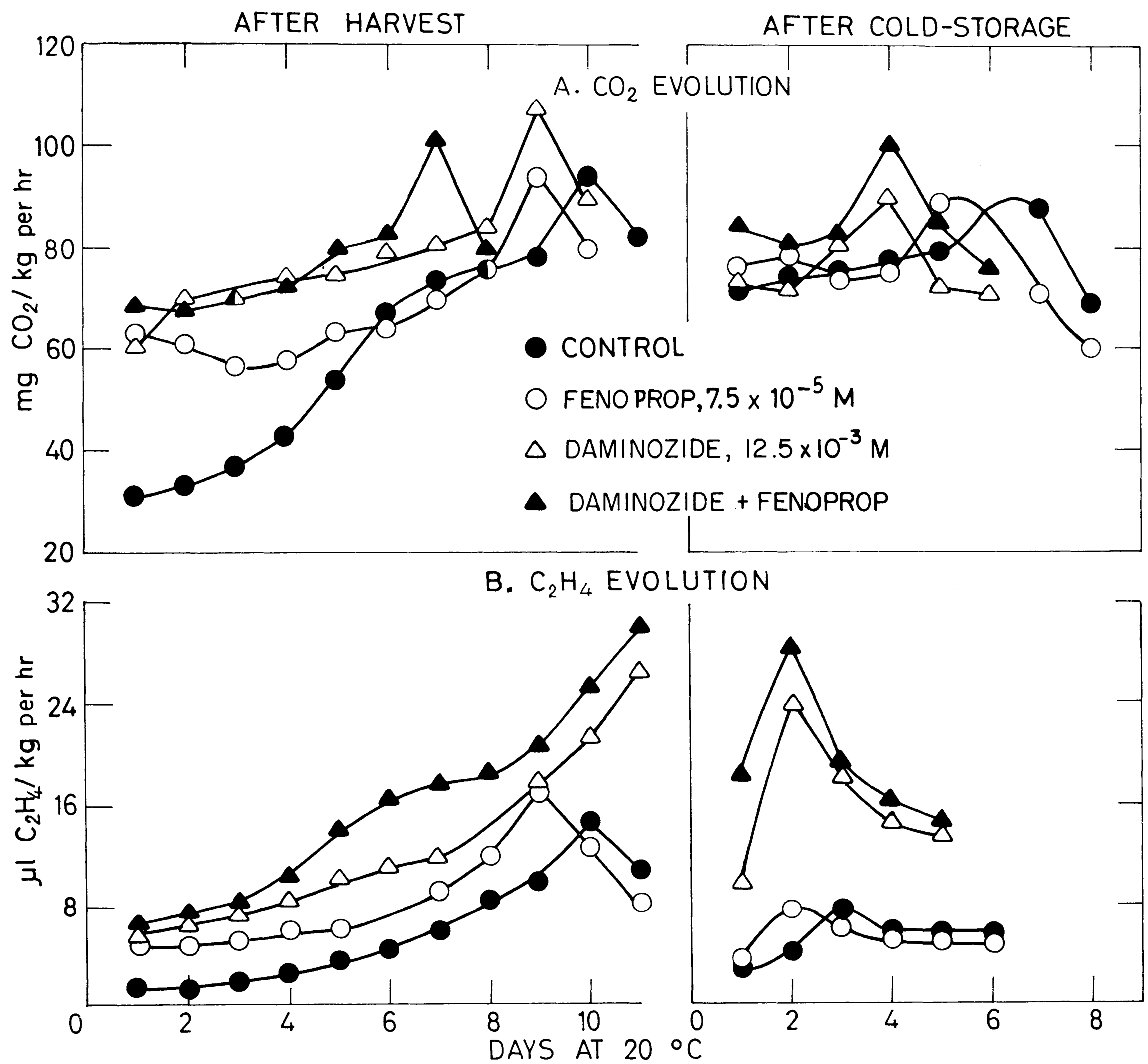

Fig. 3. The effect of separate and combined orchard sprays of daminozide and fenoprop on postharvest and poststorage respiration and ethylene evolution of nectarine fruits. (Data from 2nd harvest.)

that of fenoprop (Fig. 3A). The combined treatment raised the respiration rate only slightly but induced the peak in respiration to occur 2 days earlier. A similar respiratory response was observed after cold storage. The effect on ethylene evolution was different for each compound. Whereas fenoprop induced but a slight increase in ethylene evolution, daminozide doubled the ethylene output after harvest and trebled it after storage (Fig. 3B). The effect of the combined treatment on ethylene production was almost additive. The peak after storage occurred for all 3 treatments at the same time. There was no peak in ethylene evolution in daminozide-treated fruit following harvest in spite of the peaks in respiration. This was probably due to fruit cracking which began to occur in some of the fruits which became very soft in the respiration jars of these treatments.

Discussion

The acceleration of 'Sunred' nectarine ripening obtained by an orchard spray of fenoprop at the initiation of pit-hardening, was as effective as, if not more so, than that of daminozide, applied at the same time and at a molar concentration about 2 orders of magnitude greater. Each regulator enhanced fruit coloration and increased growth rate, with some effect on the rates of softening and loss in acidity. Although hastening of peach ripening by orchard sprays of daminozide has been widely reported (2, 12, 17), the application of auxins to peaches has not been studied extensively (12, 14, 19).

The induced ripening of stone fruits by auxin contradicts the prevalent opinion that auxin inhibits ripening (4, 16). It is possible that auxin has diverse effects on different fruit species. However, if we wish to consider that the mechanism which controls fruit ripening is fundamentally common to higher plants, the discrepancy might arise from opposite auxin effects at changing endogenous concentrations, such as the well-known growth response curve of Avena coleoptiles to increasing auxin concentrations.

Although both of the regulators enhanced the ripening rate of nectarine fruit, a marked difference in the quality of their effects was observed in the postharvest rates of respiration and ethylene evolution. As previously reported (1, 12), daminozide increased the respiration rate and caused an earlier climacteric peak, probably as a result of the marked stimulation of ethylene evolution. Fenoprop caused a similar and sometimes greater rise in the respiration rate, but the simultaneous increase in ethylene evolution was only slight. These findings can be interpreted in at least 2 ways. One possibility is that both of these regulators induce earlier fruit ripening by similarly affecting a control mechanism other than ethylene evolution. McMurchie et al. (15) have postulated a 2-stage system of ethylene biogenesis in which stage 1 is initiated and controlled by another factor. Such a factor could be, for example, the increase in abscissic acid, which was found to occur just before and during stage III of the sigmoidal growth curve of peaches (13), which just follows the time of application of both of the regulators.

However, if these regulators act on this stage of fruit ripening, the combined treatment (at their intermediate concentrations) would be expected to cause an additive acceleration of ripening such as can be obtained by increasing the concentration of either of the regulators and this was generally not the case (Fig. 1). The main additive effect was on ethylene evolution and the possibility has to be considered that each compound affects a different phase or pathway involved in fruit ripening. The different effects on the respiratory climacteric and ethylene evolution lend support to this supposition. In such a case the effect of the combined treatment could be synergistic, additive or similar to whichever of the compounds has the more dominant effect. The last possibility appeared to be the situation with regard to the most obvious parameters of fruit ripening, in spite of the additive effect on ethylene evolution.

It is of interest that, whereas daminozide greatly increased autocatalytic ethylene production in comparison with fenoprop, the latter compound had a generally more dominant effect on fruit ripening. It appears that, although autocatalytic ethylene production accompanied nectarine ripening, its rate was not controlled by the rate or amount of ethylene released. The modes of action of these regulators will no doubt be better understood, when the changes in different hormone levels within the fruit, immediately following their application and up till the time of harvest are examined.

From the commercial point of view, fenoprop seems to be the more advantageous in advancing ripening of nectarines than the combination of daminozide and fenoprop because of its more moderate effect on the rate of fruit softening.

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