Glutathione as an indicator of SO_2-induced stress in soybean. Environ. Expt. Bot. 26:147–152.

Davis, T.D., G.L. Steffens, and N. Sankhla. 1988. Triazole plant growth regulators, p. 63–105. In: J. Janick (ed.). Horticultural reviews. vol. 10. Timber Press, Portland, Ore.

DeKok, L.J., P.J.L. deKan, O.G. Tanczos, and P.J.C. Kuiper. 1981. Sulphate induced accumulation of glutathione and frost-tolerance of spinach leaf tissue. Physiol. Plant. 53:435–438.

Dhindsa, R.S., P. Plumb-Dhindsa, and T.A. Thorpe. 1981. Leaf senescence: Correlated with increased levels of membrane permeability and lipid peroxidation, and decreased levels of superoxide dismutase and catalase. J. Expt. Bot. 126:93–101.

Duncan, D.R. and J.M. Widholm. 1987. Proline accumulation and its implication in cold tolerance of regenerable maize callus. Plant Physiol. 83:703–708.

Fletcher, R.A. and G. Hofstra. 1988. Triazoles as potential plant protectants, p. 321–331. In: D. Berg and M. Plempel (eds.). Sterol biosynthesis inhibitors: Pharmaceutical and agrochemical aspects. Ellis Harwood, Cambridge, U.K.

Frankel, E.N. and W.E. Neff. 1983. Formation of malonaldehyde from lipid oxidation products. Biochim. Biophys. Acta 754:264–270.

Frogatt, P.J., W.D. Thomas, and J. Batsch. 1982. The value of lodging control in winter wheat as exemplified by the growth regulator PP 333, p. 71–87. In: A.F. Hawkins and B. Jeffcoat (eds.). Opportunities for manipulating cereal productivity. British Plant Growth Regulat. Working Group Monogr. 7. Long Ashton, U.K.

Hanson, A.D., C.E. Nelson, and E.H. Everson. 1977. Evaluation of free proline accumulation as an index of drought resistance using two contrasting barley cultivars. Crop Sci. 17:720–726.

Koike, S. and B.D. Patterson. 1988. Diurnal variation of glutathione levels in tomato seedlings. HortScience 23:713–714.

Kushad, M.M. and G. Yelenosky. 1987. Evaluation of polyamine and proline levels during low temperature acclimation of citrus. Plant Physiol. 84:692–695.

Larson, R.A. 1988. The antioxidants of higher plants. Phytochemistry 27:969–978.

Proebsting, E.L. and H.H. Mills. 1985. Cold resistance in peach, apricot, and cherry as influenced by soil-applied paclobutrazol. HortScience 20:88–90.

Rabinowitch, M.D. and D. Sklan. 1980. Superoxide dismutase: A possible protective agent against sunscald in tomatoes (*Lycopersicon esculentum* Mill.) Planta 148:162–167.

Senaratna, T., C.E. Mackay, B.D. McKersie, and R.A. Fletcher. 1988. Uniconazole-induced chilling tolerance in tomato and its relationship to antioxidant content. J. Plant Physiol. 133:56–61.

Silim, S.N., P.D. Hebblethwaite, and M.C. Heath. 1985. Comparison of the effects of autumn and spring sowing date on growth and yield of combining peas (*Pisum sativum* L.). J. Agr. Sci. 104:35–46.

Upadhyaya, A., D. Sankhla, T.D. Davis, N. Sankhla, and B.N. Smith. 1985. Effect of paclobutrazol on the activities of some enzymes of activated oxygen metabolism and lipid peroxidation in senescing soybean leaves. J. Plant Physiol. 121:453–461.

Walser, R.H. and T.D. Davis. 1989. Growth, reproductive development, and dormancy characteristics of paclobutrazol-treated tart cherry trees. J. Hort. Sci. 64:435–441.

Wang, C.Y. 1985. Modification of chilling susceptibility in seedlings of cucumber and zucchini squash by the bioregulator paclobutrazol (PP 333). Scientia Hort. 26:293–298.

Webster, A.D., J.D. Quinlan, and P.J. Richardson. 1986. The influence of paclobutrazol on the growth and cropping of sweet cherry cultivars. I. The effect of annual soil treatments on the growth and cropping of cv. Early Rivers. J. Hort. Sci. 61:471–478.

Whitaker, B.D. and C.Y. Wang. 1987. Effect of paclobutrazol and chilling on leaf membrane lipids in cucumber seedlings. Physiol. Plant. 70:404–411.

Wingate, V.P.M., M.A. Lawton, and C.J. Lamb. 1988. Glutathione causes a massive and selective induction of plant defense genes. Plant Physiol. 87:206–210.

HORTSCIENCE 24(6):957–959. 1989.

Growth Regulators and Herbicides for Delaying Apple Fruit Abscission

Richard P. Marini[1], Ross E. Byers[2], and Donald L. Sowers[3]
Department of Horticulture, Virginia Polytechnic Institute and State University, Blacksburg, VA 24061

Additional index words. *Malus domestica*, stop-drop chemicals

Abstract. **Various chemicals were applied to whole-tree, quarter-tree, or single-limb units to determine their efficacy for delaying apple (*Malus domestica* Borkh.) fruit abscission. NAA and the herbicides fenoprop, dicamba, triclopyr, lontrel, fluroxypyr, and chloroxuron delayed fruit abscission. Benzoic acid, calcium acetate; the growth regulators lactidichlor ethyl, mefluidide, BA, GA_{4+7}, and chlormequat; and the herbicides pronamide, pendimethalin, chloramben, and DCPA did not delay fruit abscission. Chemical names used: benzoic acid,3,6-dichloro-2-methoxy,2-ethoxy, 1-methyl,2-oxoethylester (lactidichlor ethyl); 1-naphthaleneacetic acid (NAA); *N*-(phenylmethyl)-1*H*-purin-6-amine (BA); gibberellin (GA_{4+7}); *N*-[2,4-dimethyl-5-[[(trifluoromethyl)sulfonyl]amino] phenyl]acetamide (mefluidide); 3,5-dichloro(*N*-1,1-dimethyl-2-propynyl)benzamide (pronamide); *N*-(1-ethylpropyl)-3,4-dimethyl-2,6-dinitrobenzenamine (pendimethalin); 3,6-dichloropicolinic acid (lontrel); 3-amino-2,5-dichlorobenzoic acid (chloramben); 2-chloro-*N,N,N*-trimethylethanaminium chloride (chlormequat); 4-amino-3,5-dichloro-6-fluoro-2-pyridinyl oxyacetic acid (fluroxypyr); butanedioic acid mono 2,2-dimethylhydrazide)4-chlorophenyl)methyl]-(1,1-dimethylethyl)-1-*H*-1,2,4,triazol-1-ethanol (paclobutrazol); *N'*-[4-(4-chlorophenoxy)phenyl]-*N,N*-dimethylurea (chloroxuron); dimethyl tetrachloroterephthalate (DCPA); 3,6-dichloro-2-methoxybenzoic acid (dicamba); 2-(2,4,5-trichlorophenoxy) propanoic acid (fenoprop).**

Commercial fruit producers have used NAA, fenoprop, and daminozide to delay apple fruit abscission until fruit develop an adequately red skin and desirable maturity for harvest. Fenoprop was the most effective material (Southwick et al., 1953; Mattus et al., 1956), but is no longer available. Daminozide effectively delayed fruit drop, enhanced redness, and increased flesh firmness (Batjer and Williams, 1966), but it is no longer available. NAA is the only stop-drop material currently available for apples. NAA often does not adequately delay abscission, particularly when labor is in short supply and especially for late-season cultivars. New chemicals are needed to reduce preharvest apple fruit drop; the purpose of this study was to evaluate chemicals for their effectiveness. Chemicals selected for screening belong to classes that have exhibited auxin-like activity, delayed leaf or fruit abscission, or delayed plant senescence.

Seven experiments were performed over 3 years. Specific information about each experiment, including cultivars, treatments, and application dates, are presented in Table 1. All treatments in Expts. 1 and 2 were applied with a handgun to runoff at a rate of 4040 liters·ha^{-1} and a pressure of 4.14 MPa. Mature trees growing in Blacksburg, Va. were visually divided into quarters and two treatments plus a control were applied to quarter-tree units of each tree. The dropped fruit under each tree quarter were counted and removed periodically until all fruit were harvested, ≈40 days after treatment (DAT). The cumulative percent of fruit originally on a tree quarter, and the portion that dropped by each date before harvest, was calculated. There were six replicates per treatment in a randomized complete block design (RCBD).

In Expt. 3, whole 6-year-old trees were sprayed with a handgun to runoff at the rate of 1200 liters·ha^{-1}. The dropped fruit under each tree were counted and removed periodically, and percent cumulative fruit drop was calculated for each date before harvest. There were six single-tree replicates in a completely randomized design.

In Expt. 4, mature trees growing at Winchester, Va. were sprayed with an airblast

Received for publication 13 Jan. 1989. The cost of publishing this paper was defrayed in part by the payment of page charges. Under postal regulations, this paper therefore must be hereby marked *advertisement* solely to indicate this fact.
[1]Associate Professor.
[2]Professor.
[3]Research Technician.

Table 1. Description of treatments and response of apple cultivars to sprays of various chemicals for delaying fruit abscission.

Expt.	Year	Cultivar	Treatment	Chemical	Application date	Days after full bloom	Concn (mg a.i./liter)	Response relative to control
1	1986	Waynespur Delicious	1,2	LE	26 Aug.	128	0,100	None
			3,4	LE	8 Sept.	141	0,100	Hastened drop
			5	NAA	8 Sept.	141	10	Delayed drop
2	1986	Vance Delicious	1	BA	10 Sept.	139	100	None
			2	GA_{4+7}	10 Sept.	139	100	None
			3	BA + GA_{4+7}	10 Sept.	139	100,100	None
			4	NAA	10 Sept.	139	10	Delayed drop
			5	BA + NAA	10 Sept.	139	100,10	Same as NAA
			6	BA + GA_{4+7} + NAA	10 Sept.	139	100,100,10	Same as NAA
3	1987	Imperial Delicious	1,2	LE	4 Sept.	133	100,200	None
			3	BA	15 July	84	12.5	None
			4	GA_{4+7}	15 July	84	12.5	None
			5	BA + GA_{4+7}	15 July	84	12.5,12.5	None
			6	BA + GA_{4+7} + LE	15 July	84	12.5,12.5	
					4 Sept.	133	100,200	None
4	1986	Fullred Delicious	1,2	Mefluidide	9 Sept.	140	0,100	None
5	1988	Vance Delicious	1,2,3,4	Pronamide	8 July	73	0–1000	None
			5,6,7,8	Pendimethalin	8 July	73	0–1000	None
			9,10,11,12	Lontrel	8 July	73	0–1000	Delayed drop
			13,14,15,16	Fluroxypyr	8 July	73	0–1000	Delayed drop
								Phytotoxicity at 100 mg
6	1988	Redchief Delicious	1,2,3,4	Calcium acetate (Ca)	14 July	79	0–130	None
			5,6,7,8	Ca + oil	14 July	79	0–130, 5 $ml\cdot liter^{-1}$	None
			9,10,11,12	Benzoic acid (BA)	14 July	79	0–100,000	None
			13,14,15,16	BA + oil	14 July	79	0–100,000,	None,
							5 $ml\cdot liter^{-1}$	Phytotoxic at 100,000 mg
			17	NAA	14 July	79	10	Delayed drop
			18,19,20	Chloramben	14 July	79	0–500	None
7	1988	Winesap	1,2,3,4	Lontrel	25 July	90	0–1000	Delayed drop
			5,6,7,8	Fluroxypyr	25 July	90	0–20	Delayed drop
			9,10,11,12	CCC	25 July	90	0–1000	None
			13	Daminozide	25 July	90	2000	None
			14	Paclobutrazol	25 July	90	2000	Delayed drop
			15	Chloroxuron	25 July	90	1000	Delayed drop
			16	DCPA	25 July	90	1000	None
			17	NAA	25 July	90	10	Delayed drop
			18	Dicamba	25 July	90	10	Delayed drop
			19	Fenoprop	25 July	90	10	Delayed drop
			20	Triclopyr	25 July	90	20	Delayed drop

Table 2. Percent cumulative drip of 'Winesap' half-fruit as influenced by several chemicals.

Chemical	Concn ($mg\cdot liter^{-1}$)	Cumulative abscission (%)[z] Days after treatment 8	10	15
		Experiment 7a		
Control	---	47 a	87 a	93 a
NAA	10	13 b	34 b	59 b
Fenoprop	10	7 b	7 c	21 c
Dicamba	10	4 b	9 c	39 bc
		Experiment 7b		
Control	---	62 a[z]	82 a	100 a
Daminozide	2000	68 a	68 ab	89 a
Paclobutrazol	2000	30 b	49 b	88 a
Chloroxuron	1000	30 b	63 ab	93 a
DCPA	1000	63 a	67 ab	90 a

[z]Mean separation within columns by Tukey's HSD, $P = 0.05$.

sprayer at a rate of 2805 $liters\cdot ha^{-1}$. There were six single-tree replicates in a RCBD. Untreated buffer trees were left between treated trees within the row and between treated rows. Three limbs per tree, with 10 to 20 fruit per limb, were marked and fruit were counted before treatment and periodically thereafter for 4 weeks. On each date, data were expressed as the cumulative percent of the fruit that abscised from each limb.

The half-fruit method (Marini and Byers, 1988) was used to test the efficacy of various treatments in Expts. 5–7. Limbs with eight to 12 fruit were used as experimental units and solutions were sprayed with a hand sprayer to runoff. There were three replicates, or one limb per treatment on each of three trees; trees served as blocks in a RCBD. The day before treatment, the calyx half of each fruit was removed and the number of fruit remaining on the limbs was recorded periodically for 2 to 3 weeks. The cumulative percent of fruit that dropped was calculated for each date.

Since the distribution of percent data in most experiments appeared skewed, percent data were transformed to the square root of the arcsin of the proportion and were analyzed by analysis of variance or regression.

Results of our preliminary experiments with a variety of chemicals over 3 years are summarized in Table 1. The growth regulators CCC, BA, and GA_{4+7} did not delay fruit drop. Lactidichlor ethyl (LE) alone, or combined with BA and GA_{4+7}, also did not delay fruit drop; neither did mefluidide, pronamide, pendimethalin, benzoic acid, daminozide, DCPA, or calcium acetate. Calcium has delayed abscission of bean petioles (Poovaiah and Rasmussen, 1973) and pecan leaves following ethephon treatment (Martin et al., 1980), but Ca had no effect on apple abscission in this study. Some benzoic acids have auxin-like activity (Leopold, 1964, p. 83). Of the benzoic acids tested in this study (LE, chloramben, benzoic acid, and dicamba), only dicamba delayed apple drop. Daminozide, when applied 50 days before

Table 3. Effect of fluroxypyr on abscission of 'Winesap' half-fruit.

Concn (mg·liter^{-1})	Cumulative abscission (%)^z Days after treatment 8	13	20
0	34	79	88
5	47	88	96
10	33	52	73
20	15	54	54
Linear	NS	NS	NS
Quadratic	*	*	*

^{NS,*}Nonsignificant or significant at $P = 0.05$, respectively.

Table 4. Effect of lontrel on abscission of 'Winesap' half-fruit.

Concn (mg·liter^{-1})	Cumulative abscission (%)^z Days after treatment 8	13	20
0	19	56	76
250	61	75	96
500	32	66	76
1000	0	8	12
Linear^z	NS	NS	NS
Quadratic	*	**	*

^{NS,*,**}Nonsignificant or significant at $P = 0.05$ or 0.01, respectively.

harvest, delayed apple fruit drop (Pollard, 1974), but our data indicate that treatment closer to harvest is ineffective. Results from these preliminary experiments indicate that three different classes of herbicides, each known to have auxin-like activity, are capable of delaying apple fruit abscission. The three types of herbicides include: 1) phenoxys (fenoprop and chloroxuron), 2) benzoic acids (dicamba), and 3) pyridines (triclopyr, lontrel, and fluroxypyr).

Dicamba had been identified as a drop inhibitor with the half-fruit technique (Marini and Byers, 1988). Dicamba was as effective as fenoprop and more effective than NAA on 'Winesap' at the same concentration (Table 2, Expt. 7a). Paclobutrazol (PZ) and chloroxuron delayed fruit drop for ≈10 days (Table 2, Expt. 7b), which would be too short-lived for commercial use. PZ is usually applied during the first 10 weeks after bloom to suppress shoot extension (Greene, 1986), but we are not aware of reports on delayed fruit drop with PZ. PZ may have stop-drop activity when applied within 2 weeks of harvest, but further work is needed to verify these preliminary results and to determine possible residual effects the year following treatment. Although chloroxuron delayed drop, other phenoxys such as fenoprop and dichlorprop (Marini et al., 1988) have delayed fruit abscission for >15 days after treatment.

Apple abscission was reduced nonlinearly with increasing concentrations of fluroxypyr and lontrel (Tables 3 and 4). Fluroxypyr appears effective at 20 mg·liter^{-1} and lontrel seems most effective at 1000 mg·liter^{-1}. More work is needed with both of these pyridine-type herbicides to identify the most-effective concentrations and application dates on whole trees and with different cultivars.

Literature Cited

Batjer, L.P. and M.W. Williams. 1966. Effects of N-dimethyl amino succinamic acid (Alar) on watercore and harvest drop of apples. Proc. Amer. Soc. Hort. Sci. 88:76–79.

Greene, D.W. 1986. Effect of paclobutrazol and analogs on growth, yield, fruit quality, and storage potential of 'Delicious' apples. J. Amer. Soc. Hort. Sci. 111:328–332.

Leopold, C.A. 1964. Plant growth and development. McGraw-Hill, New York.

Marini, R. and R. Byers. 1988. Methods for evaluating chemical inhibitors of apple abscission. HortScience 23:849–851.

Marini, R.P., R.E. Byers, D. Sowers, M.E. Marini, and R.W. Young. 1988. Fruit abscission, fruit quality, and residue levels of dichlorprop used to control preharvest drop of apple. HortScience 23:717–719.

Martin, G.C., R.C. Campbell, and R.M. Carlson. 1980. Effect of calcium in offsetting defoliation induced by ethephon in pecan. J. Amer. Soc. Hort. Sci. 105:34–37.

Mattus, G.E., R.C. Moore, and H.A. Rollins, Jr. 1956. Preharvest growth regulator sprays on apple: II. Drop and maturity for 1954 and 1955. Proc. Amer. Soc. Hort. Sci. 67:63–67.

Pollard, J.E. 1974. Effects of SADH, ethephon and 2,4,5-T on color and storage quality of 'McIntosh' apples. J. Amer. Soc. Hort. Sci. 99:341–343.

Poovaiah, B.W. and A.C. Leopold. 1973. Inhibition of abscission by calcium. Plant Physiol. 51:848–851.

Southwick, F.W., I.D. Demoranville, and J.F. Anderson. 1953. The influence of some growth regulating substances on preharvest drop, color, and maturity of apples. Proc. Amer. Soc. Hort. Sci. 61:155–162.