and yield might have been correlated with nutrient uptake characteristics of the rootstocks.

The similarity of nutrient levels of 'Bartlett' scions grafted directly on quince rootstock and those with an Old Home interstem is interesting. 'Bartlett' grafted directly on quince is not as compatible as is 'Bartlett'/Old Home/quince. The data of Tables 3 and 4 indicate that nutrient uptake and passage through the union is unrelated to the degree of graft compatibility. Also the use of different interstocks with *P. calleryana* and Bartlett seedling roots (Table 1) appear to have little influence on nutrient levels of the leaves. Thus the genotype of the root itself appears to be the important determinant of nutrient uptake, rather than the interstock.

Literature Cited

1. Cameron, H. R., M. N. Westwood, and P. B. Lombard. 1969. Resistance of *Pyrus* species and cultivars to *Erwinia amylovora*. *Phytopathology* 59:1813-1815.
2. Chaplin, M. H. and A. R. Dixon. 1974. A method for analysis of plant tissue by direct reading spark emission spectrocopy. *Applied Spectroscopy* 28:5-8.
3. Lombard, P. B. and M. N. Westwood. 1976. Performance of six pear cultivars on clonal Old Home, double rooted, and seedling rootstocks. *J. Amer. Soc. Hort. Sci.* 101:214-216.
4. Schuman, G. E., A. M. Stanley, and D. Knudsen. 1973. Automated total nitrogen analysis of soil and plant samples. *Soil Sci. Soc. Amer. Proc.* 37:480-481.
5. Terblanche, J. H., W. J. Pienoar, and P. E. le R. Van Niekerk. 1970. The effect of various rootstocks on the concentrations of nutrient elements in pear leaves. *Decid. Fruit Gr.* 20:14-16.
6. Westwood, M. N., P. B. Lombard, and H. O. Bjornstad. 1976. Performance of 'Bartlett' pear on Standard and Old Home x Farmingdale clonal rootstocks. *J. Amer. Soc. Hort. Sci.* 101:161-164.
7. _____ and _____. 1966. Pear rootstocks. *Proc. Ore. Hort. Soc.* 58:61-68.
8. Woodbridge, C. G. 1973. Effect of rootstocks and interstocks on nutrient levels in 'Bartlett' pears leaves, on tree growth and fruit. *J. Amer. Soc. Hort. Sci.* 98:200-202.

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Effect of Simulated Frost Injury on Fruit Development in Three Pear Cultivars[1]

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Abstract. **Simulated frost injury to ovaries at intervals after full bloom significantly increased fruit malformation, reduced fruit weight, and increased fruit drop in 'Bartlett', 'Bosc', and 'Comice' pear (*Pyrus communis* L.). Time of injury did not affect fruit weight and malformation in most cases, but did significantly affect fruit drop. Significant positive correlations were found between fruit weight and seed content, while negative correlations were found between fruit malformation and seed content for all cultivars.**

Spring frosts commonly occur in Oregon during the period of early fruit development. Survival of a flower or fruit following a frost depends upon the amount of damage to the vital tissues and the capacity of the remaining intact cells to continue growth and development (9). If the placenta is killed, ovules cease development and abscission usually occurs (2, 6, 7, 8, 11, 16); however, if only a portion of the placenta and ovules are killed the fruit may survive (3). On the other hand, some pear fruit develop to maturity even when the ovules have been completely destroyed (7). 'Bartlett' and 'Bosc' pear cultivars have a greater tendency to retain ovary injured fruit to harvest than 'Anjou', 'Comice', and 'Winter Nelis' (15).

Fruit malformation results from injury to the fruit cortex (10, 11). Frost injury usually causes a flattening of the fruit calyx in apple (12), but may cause neck thickening or fruit elongation in pear (6). Distorted fruit growth, cracking, and cork formation are the result of cortical injury and restricted meristematic activity (9, 10).

This investigation was undertaken to study the effect of the timing of simulated fruit frost injury on fruit drop, size, and malformation in order to determine if a period exists during early fruit growth in which fruit development is less affected by frost injury.

Materials and Methods

Paired limb units were selected on the south sides of five 9-year-old 'Bartlett', 'Bosc', and 'Comice' hedgerow trees on *P. communis* (OPR-1) rootstocks in 1976. Ten clusters on 1 limb were thinned to the largest fruit in every cluster to promote maximum fruit set (14). Each fruit was injured by rotating a needle inserted through the calyx which usually destroyed the placenta and ovules and has been used to simulate frost injury (J. Huet personal communication). Ten clusters on the other limb were similarly thinned but not injured and fruit were tagged. Treatments were repeated on 5 different trees of each cultivar at about 10-day intervals after full bloom. The ovules were destroyed in 'Bartlett' fruit at 9, 20, 24, 30, and 35 days after full bloom and 'Bosc' fruit at 10, 18, 21, 33 and 40 days after full bloom, while 'Comice' fruit were injured at 21, 31 and 40 days after full bloom in 1976. An additional study was conducted with the 'Comice' cultivar in 1977 in which fruit were injured at 10, 20, 30, 40 and 50 days after full bloom.

Data were collected on fruit weight, seed number, % drop, and malformation on each limb unit during the usual harvest period for each cultivar.

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Results and Discussion

Statistical analysis of fruit weight data showed simulated frost injured fruit of 'Bartlett', 'Bosc', and 'Comice' to be significantly smaller than uninjured fruit (Table 1). Injured fruit averaged 22, 12, 13, and 46% smaller by weight than uninjured fruit of 'Bartlett', 'Bosc', and 'Comice' (1976), and 'Comice' (1977) respectively. Time of injury did not significantly affect fruit weight in 'Bartlett', 'Bosc', and 'Comice' (1977), however, 'Comice' (1976) fruit injured at 21 days after full bloom were significantly larger than those injured at 40 days after full bloom (Table 2). The larger size of 'Comice' fruit injured earlier in the season may have resulted from a lack of competition since few fruit remained on the branches after injury (4). No significant condition × time of injury interactions were found in fruit weight analyses.

A significant positive correlation was found between seed content and fruit weight for all cultivars, although correlation coefficients were low (Table 3). These results agree with correlations found between seed content and fruit diameter by Lombard et al. (5).

Fruit malformation was significantly ($F < 1\%$) greater in injured than uninjured fruit (Table 1, Fig. 1). Fruit malformation was not significantly affected by time of injury in 'Bartlett',

Table 1. Effect of simulated frost injury to the ovary at various periods after full bloom on fruit weight, fruit malformation, and percent drop of 3 pear cultivars.

Factor	Cultivar	Year	Mean at all injury periods[z]	
			Injured	Not injured
Fruit weight (g)	Bartlett	1976	93.7	119.8**[y]
	Bosc	1976	141.3	160.0**
	Comice	1976	131.6	151.7*
	Comice	1977	101.9	187.7**
Fruit malformation[x]	Bartlett	1976	3.3	1.2**
	Bosc	1976	2.6	1.3**
	Comice	1976	2.9	1.3**
	Comice	1977	3.6	1.1**
Fruit drop (%)[w]	Bartlett	1976	54.2	16.6**
	Bosc	1976	39.8	16.4**
	Comice	1976	36.8	37.3
	Comice	1977	96.8	49.9**

[z]Mean of 5 observations from 5 branches at all injury periods.

[y]Means within rows significantly different at the 5% (*) and 1% (**) level.

[x]Index scale: 1 = normal shaped, 2 = slight calyx flattening, 3 = slight calyx flattening and malformation (Federal Standards would cull fruit indexed 3 to 5), 4 = moderate malformation, 5 = very malformed and contorted.

[w]Statistical tests were conducted on arcsin $\sqrt{\%\ \text{drop}}$ data and back transformed to percent drop for table values.

Table 2. Effect of simulated frost injury to the ovary at various intervals on 'Comice' fruit weight 1976.

Days after full bloom	Mean[z] fruit weight over condition
21	159.0 a
31	136.7 ab
40	129.3 b

[z]Mean of 5 injured and 5 uninjured branches of fruit.

[y]Mean separation by LSD 5% level.

Table 3. Coefficient (r) and linear regression equations for correlation between fruit weight (g) and seed number for 3 pear cultivars.

Cultivar	Year	n	r	SE[z]	Linear regression equation[y]
Bartlett[x]	1976	260	0.35	.53	Fruit wt = 99.64 + 3.22 X (seed no.)
Bosc	1976	341	0.18	.69	Fruit wt = 146.72 + 2.25 X (seed no.)
Comice	1976	178	0.35	.93	Fruit wt = 119.53 + 4.61 X (seed no.)
Comice	1977	149	0.59	.91	Fruit wt = 124.38 + 7.99 X (seed no.)

[z]Standard error of the estimate.

[y]The model for the regression equations in which the independent variable correlates linearly with the dependent variable takes the form: $Y = \alpha + b X$ where Y is the estimated fruit weight, α is the Y intercept, b is the regression coefficient or slope, and X is the independent variable, seed number.

[x]Significant (1% level) regression relationship for all cultivars and years.

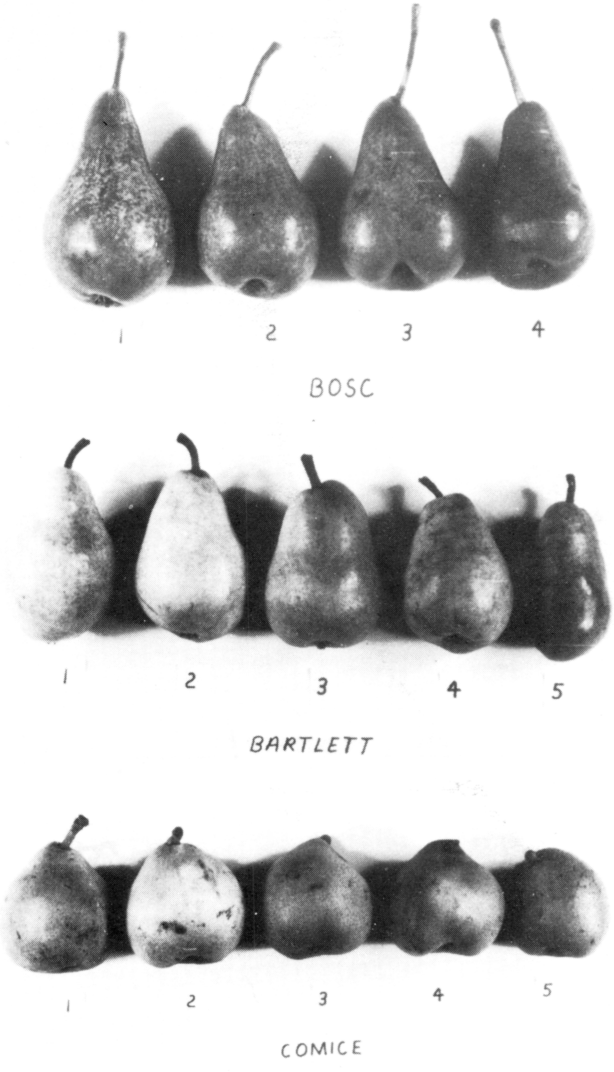

Fig. 1. 'Bosc', 'Bartlett', and 'Comice' malformation scale: 1 = normal shaped, 2 = slight calyx flattening, 3 = slight calyx flattening and malformation, 4 = moderate malformation, 5 = very malformed and contorted. (Federal standards would cull fruit indexed 3 to 5).

Table 4. Coefficient (r) for correlation between fruit malformation[z] and seed number for 3 pear cultivars.

Cultivar	Year	n	r	SE[y]
Bartlett[x]	1976	260	−.68	.02
Bosc	1976	341	−.46	.02
Comice	1976	178	−.65	.02
Comice	1977	149	−.59	.02

[z]Index scale: 1 = normal shaped, 2 = slight calyx flattening, 3 = slight calyx flattening and malformation, 4 = moderate malformation, 5 = very malformed and contorted. (Federal standards cull fruit indexed 3 to 5).

[y]Standard error of the estimate.

[x]Significant (0.1% level) regression relationship for all cultivars and years.

Table 5. Effect of interval of simulated frost injury on percent fruit drop for 3 pear cultivars.

Cultivar	Year	Days after full bloom	Mean % fruit drop[z]	
			Injured	Not injured
Bartlett	1976	9	90 ± 17[y]	34 ± 13
		20	66 ± 23	28 ± 31
		24	64 ± 29	28 ± 13
		30	34 ± 21	6 ± 6
		35	14 ± 21	10 ± 12
Bosc	1976	10	56 ± 32	6 ± 6
		18	62 ± 39	36 ± 43
		21	28 ± 22	14 ± 15
		33	40 ± 16	48 ± 15
		40	16 ± 16	10 ± 12
Comice	1976	21	84 ± 15	84 ± 15
		31	34 ± 24	10 ± 7
		40	8 ± 13	22 ± 16
Comice	1977	10	100 ± 0	58 ± 19
		20	100 ± 0	58 ± 27
		30	100 ± 0	60 ± 32
		40	88 ± 16	54 ± 13
		50	16 ± 31	20 ± 14

[z]Mean % fruit drop from 5 branches.

[y]SD.

'Bosc', and 'Comice' (1976). However, 'Comice' fruit in 1977 showed a significant ($F < 5\%$) effect of time of injury and a significant ($F < 5\%$) condition × time of injury interaction. Thus, malformation was greater in fruits injured at 40 days after full bloom than those injured at 50 days after full bloom. The differences between the 1976 and 1977 'Comice' results are hard to explain and warrant further study. Correlations between seed number and fruit malformation were significant for all cultivars (Table 4). The correlation coefficients for 'Bosc' tended to be lower than those for other cultivars (Tables 3 and 4), suggesting that fruit weight and malformation were less affected by seed number.

Fruit drop was significantly ($F < 1\%$) greater following ovary injury for 'Bartlett', 'Bosc', and 'Comice' 1977, but no significant increases in fruit drop was found for 'Comice' in 1976 (Table 1).

Time of simulated frost injury significantly ($F < 5\%$) affected fruit drop in all cultivars. Since, fruit drop was not uniform for all periods of injury, due to the natural occurrence of fruit drop in waves, further analysis was not carried out. No significant condition × time of injury interactions were found.

Simulated frost injury of the fruit exerted an influence on 'Bosc' fruit drop at 10 and 18 days after full bloom, while the injury effect on 'Bartlett' fruit drop extended up to 30 days after full bloom (Table 5). This may reflect the greater tendency for 'Bosc' to set seedless fruit (5). Percentage fruit drop for injured 'Comice' was higher at 10 and 20 days after full bloom than that found for 'Bartlett' and 'Bosc'. This study substantiates the results of others (5, 13), in which under natural field conditions seedless 'Comice' fruit set is lower than that of 'Bartlett' and 'Bosc'.

Injury to 'Comice' in 1977 reduced fruit weight and increased fruit drop more than in 1976 (Table 1). This emphasizes the variability in cropping found with young 'Comice' trees on *P. communis* rootstocks by Lombard (unpublished).

In general, the increased set of injured fruit with increasing time after full bloom agrees with results of Modlibowska (7) and Abbott (1) on pears and apples respectively.

Simulated frost injury has been observed by the authors to cause a reduction in fruit size and both an increase in fruit malformation and drop similar to that caused by frost injury in the field found by others (6, 10, 11, 12).

These studies emphasize cultivar differences in response to the interval of frost injury to young fruit as related to the reduction in fruit size, increase in fruit malformation and degree of fruit drop.

Literature Cited

1. Abbott, D. L. 1959. The effects of seed removal on the growth of apple fruitlets. Annu. Rpt. Long Ashton Res. Sta. for 1958. p. 52-56.
2. Dorsey, M. J. 1918. Russet ring on the apple. *Minn. Hort.* 46:415-416.
3. _____. 1940. The low temperature hazard to set of fruit in the apple. *Univ. Ill. Agr. Expt. Sta. Bul.* 473.
4. Lombard, P. B. 1967. Bartlett pear thinning. *Proc. Wash. State Hort. Soc.* 63:169-170.
5. _____, M. N. Westwood, and M. M. Thompson. 1971. Effective pollination the facts of life behind uniform pear cropping. *Proc. Ore. Hort. Soc.* 62:31-36.
6. Modlibowska, I. 1961. Stimulation of fruit development in frost damaged pears. Rpt. East Malling Res. Sta. for 1960. pp 46-48.
7. _____. 1962. Frost damage and recovery in plant tissues. 16th Intern. Hort. Congr. p 180-183.
8. _____. 1962. Some factors affecting supercooling of fruit blossoms. *J. Hort. Sci.* 37:249-261.
9. _____. 1968. Effects of some growth regulators on frost damage. *Cryobiology.* 5:175-187.
10. Simons, R. K. 1969. Tissue response of young developing apple fruits to freeze injury. *J. Amer. Soc. Hort. Sci.* 94:376-382.
11. _____ and C. C. Doll. 1976. Morphological and anatomical response of apples to a late spring frost in relation to stage of fruit development. *J. Amer. Soc. Hort. Sci.* 101:315-320.
12. _____ and R. V. Lott. 1963. The morphological and anatomical development of apple injured by late spring frost. *Proc. Amer. Soc. Hort. Sci.* 83:88-100.
13. Stephen, W. P. 1958. Pear pollination studies in Oregon. *Ore. State College Agr. Expt. Sta. Tech. Bul.* 43.
14. Westwood, M. N. and H. O. Bjornstad. 1974. Fruit set as related to girdling early cluster thinning and pruning of 'Anjou' and 'Comice' pear. *HortScience* 9:342-344.
15. Young, F. D. 1929. Frost and the prevention of frost damage. *U.S. Dept. Agr. Farmer's Bul.* 1588.
16. _____ and C. C. Cate. 1923. Damaging temperatures and orchard heating in the Rogue River Valley, Oregon. *Monthly Weather Rev.* 51:617-639.