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Relationship of Harvest Date, Storage Conditions, and Fruit Characteristics to Bruise Susceptibility of Apple

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Abstract. **Susceptibility of apples (*Malus domestica* Borkh. 'Gala' and 'Granny Smith') to impact damage increased from early to late harvest time and decreased during storage at 1°C. Impact damage was quantified as bruise depth, diameter, volume, or weight. Bruise weight calculated as a percentage of fruit weight was the least variable measurement of bruising that was also proportional to height to impact of the fruit. Although a range of 22 New Zealand-grown apple cultivars differed in susceptibility to bruising, the variation was not correlated with fruit density, fruit firmness, or polyphenol content and polyphenoloxidase (PPO) activity in epidermal and cortical fruit tissues.**

Mechanization of apple harvesting, sorting, and packing has led to increased concern over impact damage to fruit. In addition to bruising that occurs prior to shipping, members of the apple industry are particularly concerned about fruit damage during subsequent handling and transport. A reduction in damage can be achieved only if the factors governing susceptibility of fruit to bruising are well-understood. Such an understanding is also important for researchers trying to develop indirect methods of bruise assessment such as optical reflectance (3), CO_2 production from injured tissue (11), or using artificial fruit with internal accelerometers (15). These indirect measurements are useful only if they correlate closely with actual fruit damage.

The purpose of this research was to examine methods of bruise measurement and the effects of harvest date and length of storage time on bruise susceptibility of 'Gala' and 'Granny Smith' apples, two of New Zealand's major export cultivars. A range of apple cultivars was also examined in an attempt to correlate differences in bruise susceptibility with differences in fruit density, flesh firmness, or polyphenoloxidase (PPO) activity and polyphenol concentration in epidermis and cortex, since PPO is the major enzyme involved in browning of apple tissues (28).

Materials and Methods

'Gala' and 'Granny Smith' apples harvested from DSIR research orchards before, during, and after the commercial harvest period for export were used to determine the effect of harvest date and length of storage time on bruising. 'Gala' fruit firmness at harvest ranged from 81.7 to 72.7 N over three harvests in 1983 and from 76.4 to 66.6 N over four harvests in 1985. Fruit firmness at harvest for 'Granny Smith' ranged from 80.5 to 76.4 in 1984 and from 81.7 to 69.7 N in 1985, over four harvests in each season. Two apple size classes, 88 and 125 fruit/carton (average 227 and 160 g/fruit respectively), were harvested in 1984; in 1985 only fruit in the 125–138 fruit/carton size (144–160 g/fruit) were picked. In 1984, four fruit of each size were picked at each harvest for each storage period; in 1985, 20 fruit were picked at each harvest for each storage period. Some fruit were tested for bruise susceptibility within 48 hr after each harvest, while the rest were held at 1°C in air and were removed from storage for bruising trials 3, 6, and 12 weeks postharvest.

Apples were bruised once by dropping them on their cheek 10 or 40 cm to a wooden table surface and catching them on the first bounce. The table top was covered with chalk dust to identify the location of the bruise on the fruit. Fruit were usually dropped immediately after removal from storage and bruises were allowed to develop for 12 to 24 hr at 18°C. There was no change in observable bruised tissue in apples held longer than 12 hr (data not shown). In some experiments, fruit held at 1° or 18° for 12–18 hr prior to impact were divided into two groups and returned to 1° or 18° while bruises developed, to determine the effect of initial fruit temperature and subsequent holding temperature on bruise severity. The apples were weighed, and two firmness measurements were taken from opposite peeled unbruised areas of the fruit using an Effegi penetrometer with an 11-mm tip. The fruit then were cut through the bruise along the stem–calyx axis. The radius of the apple and the diameter and depth of the browned area of the bruise were measured on the cut surface to calculate bruise and fruit volume (20), after which the browned tissue was excised with a scalpel and weighed.

Twenty-two apple cultivars were sampled over the 1984 and 1985 seasons to correlate physical or physiological parameters with relative susceptibility to bruising. Fruit were held at 1°C for up to 3 weeks before being bruised as previously described. Density was determined by a water displacement method (2). At least 20 fruit of each variety were sampled.

Eight apple varieties covering the range of bruise susceptibility were analyzed further for total polyphenol content and PPO activity of epidermal and cortical tissue after 5 months of storage at 1°C. Total polyphenols were measured by a modification of the method of Smit et al. (21). After removing about 5 g of skin with a fruit peeler, about 15 g of flesh was excised to a depth of 1 cm from around the fruit. Tissues were homogenized for 1 min in an ultrasonic homogenizer at high speed in 4 times their weight of acetone. The resulting slurry was vacuum-filtered through Whatman No. 1 paper and the residue washed with 2 volumes of petroleum ether (b.p. 38°–60°). The

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acetone-insoluble residue was air-dried at 40° and stored in airtight plastic bags at −5° for later PPO analysis.

The acetone–ether extract was taken to dryness under vacuum at 40°C. The resulting reddish (epidermal) or greenish-grey (cortical) residue was dissolved in distilled water, filtered through Whatman No. 1 paper, and made up to 25 ml. One milliliter of sample was mixed with 5 ml of 10× diluted Folin-Ciocalteu phenol reagent (Merck) and 4 ml of 7.5% Na_2CO_3, let stand for 3 min, mixed well, and left at room temperature for 1 hr. The absorbance of the resulting bluish-green solution was read at 765 nm. Duplicate samples were run for each of four to five replicate apples, and the entire extraction procedure was repeated at least twice. Gallic acid was used to construct a standard curve.

Polyphenoloxidase activity was measured using a method modified from that of Ryugo and co-workers (16, 28). Two hundred milligrams of acetone-insoluble residue were extracted with 10 ml of 0.1 M phosphate buffer at pH 6.2 in an ultrasonic homogenizer. Enzyme activity was determined by mixing 2 ml of filtered extract rapidly with 0.1 ml of 0.1 M catechol and measuring the change in optical density (ΔOD) at 420 nm after 1 and 2 min. Protein content of the 0.5-ml extract was determined using the method of Bradford (4).

Results

Of the bruise parameters measured, only bruise weight and volume were related proportionately to drop height of the fruit (Table 1), with similar results for both cultivars in 1984 and 1985. Other parameters, such as bruise area, diameter, or depth, increased less than 4-fold as drop height increased from 10 to 40 cm. The CV of bruise weight and volume were high, however, at 24.6 and 32.1, respectively. Expressing bruise weight and volume as a percentage of fruit weight and volume reduced the CV only for weight.

Bruise susceptibility increased with lateness of harvest and decreased over storage time (Table 2). Storage period appeared to be more significant than harvest date in governing susceptibility to damage. The greatest decrease in bruise susceptibility occurred during the initial storage period. Since results were similar in both seasons for both 'Gala' and 'Granny Smith', the means of the main effects and the interaction of harvest date and length of storage time on bruise weight (as a percentage of fruit weight) are presented over both seasons and cultivars. Averages of results from the two drop heights (10 and 40 cm) are shown, since the amount of damage measured was proportional to drop height. Correlations between bruise susceptibility and maturity indices such as internal ethylene concentration, starch content, and ground color were not significant (data not shown).

Absolute bruise volume and weight were greater in both large-sized 'Gala' and 'Granny Smith' (Table 3) than in smaller fruit, which was not unexpected. When bruising was expressed as a percentage of fruit volume or weight, however, there was no difference attributable to fruit size, except for 'Granny Smith' on a weight percentage basis. Curiously, in this instance, small fruit seemed to have a greater percentage of damaged tissue than large fruit. Because results from 1984 indicated that size was not of great importance in predisposing fruit to bruising when measured as percentage by weight, only one size of fruit was used in 1985.

Fruit temperature at impact or during subsequent bruise development had no effect on bruise susceptibility of 'Granny Smith' (Table 4) or 'Gala' apples (data not shown).

The apple cultivars surveyed (Table 5) could be placed into groups on the basis of bruise susceptibility. Of the major export cultivars tested, the least bruise-prone on the basis of bruise weight percentage (BWP) was 'Dougherty', followed by 'Golden Delicious' and 'Sturmer Pippin'. 'Granny Smith' and 'Braeburn' comprised the next most bruise-susceptible group, with 'Delicious', 'Gala', and 'Cox's Orange Pippin' being the most susceptible to bruising of the export cultivars surveyed. Of the other 14 (mostly domestic-market) cultivars, 'Kempton' was the least bruise-prone, while 'Giant Geniton' was the most susceptible to bruising, as determined by BWP.

Although correlations presented in Table 6 are statistically significant, the highest correlation between a fruit characteristic and any of the measured bruise parameters (i.e., fruit weight and bruise diameter) ($r = 0.28$, $P = 0.1\%$), only indicated that 8% of the variation in bruise diameter was attributable to variation in fruit weight. Therefore, statistically significant correlations did not necessarily indicate meaningful relationships between fruit and bruise measurements. In addition, bruising was not related to length of time from anthesis to harvest. Early maturing cultivars, such as 'Cox's Orange Pippin' and 'Lord Nelson' (1.49 and 1.18 BWP, respectively) and late cultivars, such as 'Dougherty' and 'Granny Smith' (0.83 and 1.33 BWP, respectively) spanned the range of bruise susceptibility.

Peel tissue was higher in acetone-insoluble residue and total polyphenols and lower in protein content and PPO activity than cortical tissue in all cultivars sampled (Table 7). Highly red-colored apples, such as 'Dougherty', 'Richared Delicious', and 'Splendour', were relatively higher in total polyphenols in the peel than other cultivars surveyed, probably because of the greater amount of anthocyanins present. 'Golden Delicious' and 'Granny Smith' cortical tissues were relatively lower in polyphenols and PPO activity than 'Richared Delicious', 'Sturmer Pippin', and 'Dougherty', as other researchers have noted (14, 27). While

Table 1. Bruise measurements of 'Gala' and 'Granny Smith' apples dropped from 10 or 40 cm. Data combined for both cultivars and seasons over all harvests and storage times.

Drop height (cm)	Bruise measurement						
	Area[z] (mm^2)	Weight		Volume		Diam (mm)	Depth (mm)
		(g)	(%)[y]	(ml)	(%)[y]		
10	78.1	1.0	0.63	0.95	0.54	17.8	6.0
40	199.3	3.8	2.4	4.3	2.4	27.8	10.4
Ratio (40 cm/10 cm)	2.7	3.8	3.8	4.5	4.4	1.6	1.7
CV	18.1%	24.6%	17.5%	32.1%	27.7%	10.6%	10.9%

[z]Area of cut bruise face, calculated as segment of a circle.
[y]Percentage of total individual fruit weight or volume.

Table 2. Effects of harvest date and storage period on bruise weight (percentage) of 'Gala' and 'Granny Smith' apples. Data averaged over 10- and 40-cm drop heights in 1984 and 1985.

Harvest[z]	Storage period (weeks at 1°C)				
	0	3	6	12	$\bar{x}$
1	1.58[y]	1.44	1.44	1.35	1.45
2	1.67	1.56	1.52	1.40	1.54
3	1.66	1.53	1.46	1.35	1.51
4	1.76	1.61	1.51	1.50	1.59
$\bar{x}$	1.66	1.55	1.48	1.40	---

[z]Harvest dates: 'Gala' 7 Feb., 21 Feb., and 29 Feb. 1984; 15 Feb., 22 Feb., 6 Mar., and 14 Mar. 1985. 'Granny Smith' 28 Mar., 9 Apr., 19 Apr., and 1 May 1984; 3 Apr., 11 Apr., 23 Apr., and 7 May 1985.

[y]$LSD_{0.05}$ = main effects 0.04; interaction 0.07.

Table 3. Effect of fruit size on bruising of 'Gala' and 'Granny Smith' apples in the 1984 season, averaged over 10- and 40-cm drop heights.

Size[z]	Bruise measurement			
	Weight (g)	Volume (ml)	Weight (%)[y]	Volume (%)[y]
		Gala		
88	2.81	3.06	1.50	1.44
125	2.45	2.62	1.55	1.48
$LSD_{0.05}$	0.12	0.19	NS	NS
		Granny Smith		
88	3.03	3.20	1.53	1.43
125	2.31	2.18	1.67	1.40
$LSD_{0.05}$	0.06	0.06	0.05	NS

[z]No. fruit/20-kg carton.

[y]Bruise weight or volume as a percentage of total individual fruit weight or volume.

Table 4. Effect of fruit temperature at bruising and subsequent holding temperature on bruise development in 'Granny Smith' apples dropped from 40 cm.

Fruit temp (°C)	Holding temp (°C)	Bruise wt (%)	Bruise vol (%)
1	1	2.37[z]	1.67
	18	2.31	1.82
18	1	2.15	1.61
	18	2.22	1.58

[z]Differences not significant, $LSD_{0.05}$.

PPO activity and polyphenol content may vary during storage (9, 25), there was no evident correlation between these parameters and bruise susceptibility. In fact, 'Dougherty' and 'Kempton', the cultivars least susceptible to bruising, were, respectively, at the high and low ends of the range of polyphenol content and PPO activity for both peel and flesh.

Discussion

Harvest date (a relative indicator of fruit ripeness) and length of time in storage significantly affected susceptibility of apples to impact damage. Increased bruising with later harvests and a decrease in damage with longer storage times have been noted by other investigators as well (8, 24). Schoorl and Holt (19), on the other hand, found increased bruise susceptibility with increasing storage time. Fruit absorbed 1.25 J under their experimental conditions, whereas under conditions reported here and elsewhere (8, 24), fruit absorbed 0.2 to 0.7 J. Perhaps there is an energy absorption threshold above which susceptibility to bruising increases with storage time.

As more attention is paid to modeling fruit damage associated with new developments in mechanical harvesting (10), automatic sorting (15), and packaging and transport (7), it becomes important to have an accurate basis for assessing damage. Previous researchers have calculated volume (18, 20), depth and diameter (5, 8), or crossectional area (24) of the bruise to quantify impact damage. Many workers conducting damage experiments stress ensuring that fruit are uniform in size and weight. Sample uniformity is certainly desirable, but, as shown in Table 3, expressing damage as a percentage of fruit weight or volume appeared to nullify absolute differences in those parameters while maintaining treatment differences.

Bruise weight (as a percentage of fruit weight) was the most accurate determination of damage, since it quantified all the browned tissue while excluding undamaged tissue. Unfortunately, it was a time-consuming parameter to measure, as well as destructive to the sample. Although bruise volume (as a percentage of fruit volume) correlated fairly well with BWP and was easier to measure, it tended to have a high CV, presumably because apple volume was calculated indirectly from radius measurements by idealizing the fruit as a sphere (20), and many apples did not approach sphericity. Apple weight, on the other hand, was measured directly. Bruise diameter correlated well with BWP (Table 6) and was the easiest parameter to measure, but was not linearly related to drop height (Table 1). It is thus useful as a cut-off indicator for commercial acceptance or rejection of fruit damage, but not as a sole basis for quantifying the degree of damage. Ideally, a nondestructive technique, such as the measurement of CO_2 production by damaged tissue (11), might be developed to the point where CO_2 samples from the atmosphere surrounding an enclosed bruised fruit will correlate well with the amount of damage sustained.

Apple temperature at impact or during subsequent bruise development had no effect on bruise susceptibility (Table 4), which some researchers have also noted (19). Other results indicate that bruise susceptibility increases (18) or decreases (26) with increasing fruit temperature. Bruise damage to fruit dropped at temperatures >25°C is less than that of fruit dropped at temperatures between 0° and 20° (12, 19, 23, 26). An exception is the report of Saltveit (18), who found increased bruise damage at 30°, compared to that sustained at lower temperatures. His use of apples that had been stored for 6 mo prior to testing, however, may mean that his results are not comparable to those of other researchers who used fruit that either were freshly harvested or stored for only a few weeks. Despite their overall conclusions to the contrary, data presented by both Saltveit (18) and van Lancker (26) indicate that at 20° or lower, there is no significant effect of temperature on the susceptibility of apples to bruising, consistent with the results presented in Table 4.

The interaction of harvest time and length of storage on fruit susceptibility to bruising may be explained by relative turgidity of the cortical cells subjacent to the epidermis. Pitt and coworkers (13, 17) have shown that vegetative tissues are more prone to failure as cell turgidity increases. The increase in cell sugar content that occurs as apples ripen might promote increased cell turgidity as the harvest season progresses. This increase in cell turgidity in turn would lead to a trend towards increased bruise susceptibility with later harvests, such as is shown in Table 2.

Table 5. Harvest time, fruit density, and bruise measurements of selected apple cultivars averaged over 10- and 40-cm drop heights.

Cultivar	Harvest time[y]	Density ($g \cdot cm^{-3}$)	Bruise measurement: Weight (g)	Weight (%)[z]	Volume (ml)	Volume (%)[z]	Diam (mm)	Depth (mm)
Dougherty	L	0.79	1.16	0.83	1.50	0.82	19.8	6.3
Kempton	L	0.83	1.59	0.94	1.35	0.63	19.4	6.3
Kidd's Orange Red	E	0.84	1.59	1.10	1.45	0.80	18.2	7.3
Ballarat	M	0.82	2.37	1.13	2.46	0.92	22.7	7.9
Democrat	L	0.82	2.21	1.13	2.58	0.94	22.4	8.9
Lord Nelson	E	0.83	2.23	1.18	2.33	0.84	22.2	7.9
Golden Delicious	M	0.78	1.72	1.20	2.35	1.37	22.3	7.9
Splendour	M–L	0.79	2.33	1.23	2.86	1.14	24.6	7.6
Sturmer Pippin	M–L	0.80	2.02	1.29	2.29	1.12	22.5	8.1
Yates	L	0.82	1.38	1.33	1.38	0.98	18.7	6.9
Spartan	E	0.79	2.27	1.31	2.44	1.04	22.8	8.2
Jonathan	E	0.75	2.40	1.32	3.02	1.18	24.0	8.7
Granny Smith	L	0.83	1.87	1.33	2.35	1.49	21.8	8.3
Braeburn	M–L	0.87	2.48	1.37	2.38	1.15	21.5	8.7
Frimley Beauty	L	0.82	2.11	1.38	1.97	0.97	20.0	8.2
Stayman's Winesap	M	0.86	2.35	1.41	2.50	1.22	22.5	8.5
Delicious	M	---	2.47	1.44	2.79	1.39	23.3	8.6
Gala	E	0.82	2.16	1.45	2.82	1.63	22.9	8.3
Rome Beauty	L	0.81	2.28	1.46	2.66	1.27	22.7	9.0
Cox's Orange Pippin	E	0.77	1.94	1.49	1.85	1.15	19.8	8.3
Richard Delicious	M	0.83	2.81	1.49	3.17	1.46	24.0	9.0
Giant Geniton	M–L	0.85	2.01	1.68	1.81	1.20	19.8	8.2
$LSD_{0.05}$		0.01	0.38	0.13	0.47	0.20	1.5	0.6

[z]Percent of total individual fruit weight or volume.
[y]E = early; M = middle; L = late.

Table 6. Correlations among fruit characteristics and bruise measurements of selected apple cultivars, averaged over 10- and 40-cm drop heights.

		A	B	C	D	E	F	G	H	I
Fruit firmness	(A)									
Fruit density	(B)	0.46[z]								
Fruit weight	(C)	NS	0.26							
Fruit volume	(D)	NS	0.36	0.83						
Bruise weight	(E)	NS	NS	0.25	0.20					
Bruise volume	(F)	NS	0.11	0.25	0.21	0.92				
Bruise depth	(G)	NS	NS	0.16	0.13	0.92	0.88			
Bruise diameter	(H)	NS	0.16	0.28	0.23	0.89	0.96	0.84		
Bruise weight (%)[y]	(I)	NS	0.12	NS	NS	0.94	0.86	0.90	0.84	
Bruise volume (%)[y]	(J)	NS	NS	NS	−0.16	0.82	0.89	0.84	0.86	0.90

[z]Degrees of freedom = 350.
[y]Percentage of total individual fruit weight or volume.
[NS]Nonsignificant or significant at the 5% ($r = 0.09$), 1% ($r = 0.13$), or 0.1% ($r = 0.18$) levels.

The vapor pressure gradient between the atmosphere of the cool room and that of the interstitial air spaces in the fruit cortex leads to moisture loss from fruit in storage (22). Moisture loss is likely to occur primarily from cortical cells just under the epidermis. As turgidity of these outer cortical cells decreases over storage time, their susceptibility to bruising would also decrease, perhaps explaining the decrease in bruise susceptibility over storage time noted in Table 2. A vapor deficit promoted by a period of high temperature would also lead to decreased cell turgor in the outer cortex, explaining many growers' claims that "wilting" apples in the sun for several hours between harvest and storage will reduce fruit bruising during handling. Holding apples at 38°C for 4 days immediately prior to storage at 1° led to decreased bruise susceptibility in fruit stored for 4 months (J.D. Klein, unpublished results).

Neither fruit density nor time of harvest appeared to affect bruise susceptibility (Table 5). Fruit densities reported in Table 5 agree closely with those determined by Aeppli (1), who used a more complex experimental technique. The exception is 'Cox's Orange Pippin', with a density found by Aeppli to be 0.85 $g \cdot cm^{-3}$ and reported here to be 0.77 $g \cdot cm^{-3}$. This finding supports the suggestion that early ripening cultivars (such as 'Cox' under New Zealand conditions) tend to be less dense than late-ripening cultivars (such as 'Cox' under Northern Hemisphere conditions) (1, 6).

None of the fruit parameters measured correlated well with

Table 7. Percentage of acetone-insoluble residue, polyphenol and protein concentration, and polyphenoloxidase (PPO) activity in epidermis and cortex of selected apple cultivars. Means ± SE of two experiments, four to five replicates each.

Cultivar	Tissue	Insoluble residue (%)	Total polyphenols (mg/g fresh wt)	Protein (mg/g fresh wt)	PPO activity $\times 10^{-3}$ ($\Delta OD \cdot min^{-1} \cdot mg^{-1}$ protein)
Braeburn	Epidermis	14.8 ± 0.8	2.1 ± 0.13	4.5 ± 0.4	6.7 ± 0.8
	Cortex	7.2 ± 0.6	0.6 ± 0.03	17.0 ± 1.9	10.7 ± 0.6
Dougherty	Epidermis	22.2 ± 0.6	2.9 ± 0.17	1.4 ± 0.2	4.9 ± 0.5
	Cortex	10.2 ± 0.6	1.1 ± 0.18	3.5 ± 0.5	40.6 ± 3.0
Golden Delicious	Epidermis	13.8 ± 0.9	1.5 ± 0.09	4.2 ± 0.5	3.0 ± 0.2
	Cortex	5.3 ± 0.3	0.7 ± 0.03	33.4 ± 2.2	4.1 ± 0.3
Granny Smith	Epidermis	16.3 ± 0.4	2.4 ± 0.19	8.2 ± 0.7	3.9 ± 0.2
	Cortex	8.0 ± 0.6	0.9 ± 0.05	13.0 ± 1.2	3.5 ± 0.4
Kempton	Epidermis	14.9 ± 0.6	2.0 ± 0.15	2.4 ± 0.3	6.9 ± 0.7
	Cortex	8.7 ± 0.3	0.8 ± 0.04	4.9 ± 0.7	8.9 ± 2.1
Richared Delicious	Epidermis	15.5 ± 1.0	3.8 ± 0.36	4.2 ± 0.5	11.7 ± 1.0
	Cortex	4.2 ± 0.6	1.1 ± 0.04	32.9 ± 4.1	14.6 ± 0.4
Splendour	Epidermis	13.4 ± 0.5	2.8 ± 0.15	5.2 ± 0.7	6.7 ± 0.7
	Cortex	8.2 ± 0.5	1.2 ± 0.08	6.9 ± 1.7	21.0 ± 1.4
Sturmer Pippin	Epidermis	18.6 ± 0.8	2.7 ± 0.17	2.1 ± 0.2	11.0 ± 0.8
	Cortex	8.7 ± 0.4	1.0 ± 0.06	9.4 ± 0.8	16.1 ± 1.4

susceptibility of the fruit to bruising. The common notion that heavy, firm fruit are most prone to bruising was not supported (Table 6). Although bruise weight and volume were proportional to apple weight and volume, on a relative basis large and small fruit were equally susceptible to impact damage (Table 3). Cultivars such as 'Splendour' and 'Sturmer Pippin' are considered by industry to be more easily damaged than Dougherty' or 'Golden Delicious'. This perception is evidently not based on cultivar differences in relative browning capacities (due to PPO activity or substrate polyphenol concentration) of either epidermal or subjacent cortical tissues. A study using electron microscopy may help determine whether cultivar differences in bruise susceptibility are due to differences in cell wall thickness or cell packing arrangement, especially in the hypodermal and immediately subjacent cortical layers.

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Promotion of Floral Longevity by the Ovary in Carnation Flowers

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Abstract. **Cut carnation (*Dianthus caryophyllus* L.) flowers held in sucrose have a substantially longer vase life than flowers held in water. Excision of the gynoecium does not affect the longevity of flowers in water; however, gynoecia excision did reduce flower longevity when stems were supplied sucrose. Maintenance of cut flower life by the gynoecium was apparently due to the presence of the ovary and not the styles. Excision of gynoecia from buds of intact carnation flowers left to age on the plant also reduced longevity. Gynoecium removal did not result in a significant reduction of total sucrose or glucose in petal content of flowers held in a sucrose solution for 5 days, but absence of the gynoecium did result in a slightly but significantly lower fructose content in petals. It is suggested that the reduction in longevity resulting from gynoecium excision is not due to the failure of petals to take up sugars.**

During the onset of senescence, carnation flowers produce a burst of ethylene, followed by rapid incurling and wilting of the petals (6, 7). Whether petal senescence occurs independently, or is influenced by other organs is the subject of some controversy. The gynoecium, for example, might stimulate petal senescence, since the ethylene produced by the gynoecium on a per unit weight basis is relatively great (9). An increase in ACC level in extrapetal portions of the flower appears to precede that which occurs in the petals, and it has therefore been suggested that ACC migrates to the petals from the gynoecium inducing senescence (1). Supporting this contention is the finding that the carnation ovary begins to increase in size preceding any visible signs of petal senescence (5, 7). However, since removal of the gynoecium does not result in an increase in petal longevity, Mor et al. (5) concluded that petal senescence is not directly influenced by the gynoecium. Nevertheless, isolated petals taken from physiologically young flowers last significantly longer than intact petals of the same physiological age (4, 11), indicating that some extrapetal factor probably induces petal senescence. The present work was undertaken to help clarify the role of the gynoecium in petal senescence.

Materials and Methods

Standard carnations ('White Sim') were all harvested at the open stage, when outer petals were perpendicular to the stem axis. Gynoecia were either excised from mature flowers at harvest or from intact flower buds at the stage when petals were extended about 5 mm above the calyx. Flowers treated in the bud stage were allowed to remain intact on the plant, where they underwent normal development, opening to the open stage in about 10 days. In some experiments, gynoecia of flower buds were excised, and flowers were allowed to develop and to senesce on the plants. To remove the gynoecium, the calyx of each flower was slit to its base and the petals opened carefully to expose the gynoecium. Gynoecia were then excised from treated flowers using a forceps. All control flowers were treated in a similar manner by slitting the calyx and opening the petals, except that the gynoecium was left intact. In some experiments, only the styles were excised. The petals then were placed carefully in their original positions, and the calyx was closed and held in place with a narrow band of tape. Ten flowers were used for each treatment.

After harvest, stems were recut to a convenient length and leaves below the surface of the holding solution were removed. The holding solutions consisted of 150 ppm 8-hydroxyquinoline citrate and 40 ppm commercial bleach (containing 5.25% sodium hypochlorite) with or without the addition of 2% sucrose. Flowers in these solutions were then held at 20.5°C under continuous cool-white fluorescent light, at a level of 90 $\mu mol \cdot s^{-1} \cdot m^{-2}$.

Fresh weights and ethylene evolution were measured daily. For ethylene determinations, flowers were placed in 990-ml glass jars fitted with a serum stopper. Ethylene was allowed to accumulate for 1 hr, and 1-ml gas samples were withdrawn using a syringe. Samples were analyzed by gas chromatography, using

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