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A Compressed Air Test for Carpel Adhesion in Pickling Cucumbers[1]

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Abstract. **Compressed air was injected into fruit of pickling cucumber (*Cucumis sativus* L.) to simulate the build-up of gas during brining. Four size grades were tested from 4 cultivars over 2 harvests and 2 seasons. Carpel adhesion, as measured by the air pressure required to separate the carpels, was negatively correlated with fruit size. Higher air pressure was required to separate the carpels of cultivars resistant to balloon bloating. The formation of balloon bloaters in cucumbers brined in commercial tanks was correlated with results from the compressed air test of carpel adhesion, especially with fruit 45 to 51 mm in diameter.**

Balloon bloating of pickling cucumbers is a condition in which gas pockets develop between the carpel walls during brining (3). This disorder can result in serious losses since about 50% of the pickling cucumber crop is stored in brine before processing. Carpel separation, fruit firmness, and skin toughness were all closely associated with balloon bloating (11). The separation of carpels was also associated with a delay in processing after harvest (10) and with damage caused by mechanical harvesting and grading (7, 8). Carpel rupture in fruit harvested at processing stage was found to be controlled by 1 gene (2), while in fruit harvested at the mature stage it was found to be controlled by 2 or 3 genes, with a heritability of 39% to 45% (12). Build-up of internal carbon dioxide gas pressure during storage in brine tanks has been suggested as the cause of bloating of pickling cucumbers (5).

Since the 1950s, direct evaluation of brinestock has been used extensively to evaluate lines for bloater resistance (6). Recently, more rapid tests have been developed to evaluate resistance to balloon bloating. Marshall et al. (9) obtained a high correlation with balloon bloating using an Instron Universal Testing Machine to measure the force required to separate the carpels of a 6-mm slice of a grade 3 fruit. Sneed and Bowers (11) obtained high correlations ($r = 0.804$) between balloon bloating and the frequency of carpel separation in green stock.

Purging brine tanks with gas reduced the frequency of bloaters (4). To keep purging costs to a minimum, Fleming (3) recommended that tanks be purged with nitrogen gas only to the critical level of carbon dioxide. That level depended on the cultivar, the tank, the brine temperature, and other factors, but was in the range of 30 to 50% saturation (3). Bloater-resistant cucumber cultivars, therefore, would still be valuable, since they would require less purging of the brine tank.

The objectives of this study were to measure the amount of variation between cultivars and between grades of pickling cucumbers for carpel adhesion and to develop a direct test for carpel adhesion to be used as an index of balloon bloater resistance.

Materials and Methods

Three cultivars were seeded at Clinton, N.C., on May 1, 1980, for the spring crop, and 4 cultivars were seeded on July 28 and August 4 for the summer crop. The monoecious cultivars were planted in the first of 2 plantings for the summer crop in order

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Table 1. Air pressure [psi(KPa)] required to separate the carpels of pickling cucumber fruit, 1980.[z]

Fruit grade[y]	Spring harvest			Summer harvest			
	Addis	Greenpak	Pixie	Addis	Regal	Greenpak	Pixie
1B	30(207)	27(184)	27(187)	29(197)	23(159)	21(144)	18(124)
2B	24(166)	22(153)	19(133)	22(150)	15(107)	14(96)	18(121)
3B	21(146)	15(103)	13(87)	20(134)	16(107)	12(79)	13(92)
4A	15(104)	11(78)	11(76)	17(116)	17(115)	10(72)	13(92)
	LSD[x] 0.05 = 3(19) CV = 19%			LSD[x] 0.05 = 2(16) CV = 22%			

[z]Mean of 10 fruit per grade and 2 harvests per season (5 fruit per grade in first spring harvest).
[y]Hand-graded by diameter, where 1B is 23 to 27 mm, 2B is 32 to 39 mm, 3B is 45 to 51 mm, and 4A is 51 to 57 mm in diameter.
[x]LSD for each season is for comparing any 2 means over both rows and columns.

to have the gynoecious hybrids at the same harvest stage as the monoecious cultivars. 'Pixie', 'Greenpak', and 'Addis' were used in both seasons, and 'Regal', was added in the summer. 'Pixie' and 'Addis' are monoecious, and 'Greenpak' and 'Regal' are gynoecious hybrids. 'Pixie' and 'Greenpak' are susceptible to balloon bloating, and 'Addis' and 'Regal' are resistant (R.L. Lower, Personal communication).

Cucumbers were harvested June 20 and 24 from the spring crop, and September 16 and 23 from the summer crop. After removing off-size and misshapen fruit, the cucumbers were hand-graded into diameter size grades 1 (< 27 mm), 2 (27 to 39 mm), 3 (39 to 51 mm), and 4 (> 51 mm). To further reduce the variability due to diameter, fruit were sorted into the following half-size diameter grades: 1B (23 to 27 mm), 2B (32 to 39 mm), 3B (45 to 51 mm), and 4A (51 to 57 mm). The cucumbers were stored overnight at 11°C and then brought to room temperature before fruit length, diameter, weight, volume, and carpel adhesion were measured.

Carpel adhesion was measured by injecting air into the peduncle end of the fruit through an 18-gauge hypodermic needle. The hypodermic needle had been pushed through a 5-mm-thick by 3-cm-diameter rubber washer which was liberally coated with vacuum grease before each test to prevent air escaping from the fruit. Air pressure was used to clear the hypodermic needle of any obstructions before each test. To prevent the hypodermic needle from being clogged by fruit tissue, a hole was made in the fruit by pushing another 18 gauge needle 35 mm into the fruit through the peduncle scar and gently moving the needle to make a small cavity in the fruit. The valve on the pressure regulator was opened after the hypodermic needle had been inserted into the hole in the peduncle end of the fruit and the washer had been carefully seated. Air pressure was slowly and steadily increased from 0 to 30 psi (0 to 207 KPa) at a rate of around 3 psi (20 KPa)/sec by manually adjusting the control diaphragm on the 2-stage pressure regulator.

Changes in air pressure were recorded on a strip chart recorder as voltage changes from a Setra System Model 205 gas pressure transducer connected to the air line immediately below the hypodermic needle. The pressure at which the carpels separated was determined from the strip chart recording of the pressure curve. The positive slope of the air pressure curve became momentarily negative when the carpels separated. Other inflection points occurred as the result of slight disturbances of the air pressure system. Since the person holding the fruit could detect the point of carpel seapration, he was able to indicate at which inflection point that occurred. Each fruit was immediately cut open after the air pressure test to determine whether the carpels had separated. Where the carpels failed to separate, a value of 30 psi (207 KPa) was assigned since this was the highest pressure detectable by the transducer. The most common reason for carpels failing to separate was rupturing of the fruit.

The experimental design used was a completely random factorial with 2 seasons (spring and summer), 2 harvests, 3 or 4 cultivars ('Addis', 'Greenpak', and 'Pixie' in both seasons, and 'Regal' in the summer), 4 grades (1B, 2B, 3B, and 4A) and 5 or 10 fruit per treatment as the replication effect (all but the first spring harvest had 10 fruit per treatment).

As a measure of commercial performance, cucumbers from the second spring harvest were also brined in unpurged tanks at Mt. Olive Pickle Co., Mt. Olive, N.C. Fruit were harvested June 24, hand-graded into 4 sizes as described above, and evaluated for balloon, lens, and honeycomb bloaters on August 26. A subjective estimate was made of the percent of endocarp and mesocarp tissue in each fruit damaged by each bloater type. The experimental design was a completely random factorial with 3 tanks, 3 cultivars (Addis, Greenpak, and Pixie), 4 grades (1B, 2B, 3B, and 4A) and 10 fruit per treastment as the replication effect.

Correlations were run between the air pressure measurements of carpel adhesion and fruit length, diameter, weight, and bloater damage in commercial tanks.

Results and Discussion

Statistically significant differences in carpel adhesion were measured between both cultivars and size grades of pickling cucumbers using the air pressure test (Table 1). The average air pressure over all grades, harvests, and seasons required to separate the carpels of 'Addis', 'Regal', 'Pixie', and 'Greenpak'

Table 2. Comparison of air pressure test of pickling cucumber fruit with commercial brine test for carpel strength and balloon bloater resistance, 1980.[z]

Fruit grade[y]	Carpel separation pressure [psi(KPa)]			Balloon bloater damage (% of fruit tissue)		
	Addis	Greenpak	Pixie	Addis	Greenpak	Pixie
1B	30(207)	25(172)	26(177)	0	12	9
2B	21(146)	27(187)	22(154)	1	12	8
3B	24(164)	17(118)	14(99)	4	17	23
4A	16(111)	12(83)	11(78)	3	20	41
	LSD[x] 0.05 = 3(19) CV = 19%			LSD[x] 0.05 = 10 CV = 148%		

[z]All data are from the second spring harvest and are presented as the means of 10 fruit per grade.
[y]Hand-graded by diameter, where 1B is 23 to 27 mm, 2B is 32 to 39 mm, 3B is 45 to 51 mm, and 4A is 51 to 57 mm in diameter.
[x]LSD for each variable is for comparing any 2 means over both rows and columns.

Table 3. Bloater damage of pickling cucumber fruit from commercial brine tanks, 1980.

Fruit grade[z]	Bloater damage (% of fruit tissue)								
	Balloon bloater			Lens bloater			Honeycomb bloater		
	Addis	Greenpak	Pixie	Addis	Greenpak	Pixie	Addis	Greenpak	Pixie
1B	0	12	9	1	1	0	0	0	0
2B	1	12	8	0	0	2	1	3	0
3B	4	17	23	3	4	1	11	8	2
4A	3	20	41	4	2	4	22	12	6
LSD[y] 5%		10			3			4	

[z]All data are from the second spring harvest and are presented as the means of 10 fruit per grade.
[y]Hand-graded by diameter, where 1B is 23 to 27 mm, 2B is 32 to 39 mm, 3B is 45 to 51 mm, and 4A is 51 to 57 mm in diameter.
[x]LSD for each bloater type is for comparing any 2 means over both rows and columns.

was 22.1, 17.7, 16.4, and 16.1 psi (152, 122, 113, and 111 KPa), respectively. Regardless of cultivar, carpel separation occurred at progressively lower pressures with increasing fruit size (Table 1). The average pressure required to separate the carpels of grades 1B, 2B, 3B, and 4A was 24.9, 19.2, 15.5, and 13.5 psi (172, 132, 107, and 93 KPa), respectively. Fruit diameter and carpel adhesion measured by air pressure had a highly significant negative correlation ($r = -0.712$ in spring, and $r = -0.448$ in summer). The results with fruit from both the spring and summer seasons were fairly consistent.

Results of the air pressure test agreed with those of a commercial brining test for balloon bloaters in the second spring harvest (Table 2). The correlation ($r = -0.698$) between the air pressure test and balloon bloater damage over all grades was significant. The closest correlation between the tests in commercial tanks and the air pressure test occurred with grade 3B fruit. When only grade 3B fruit were tested, the correlation became highly significant ($r = -0.999$). In contrast, there was no significant correlation between the air pressure test and balloon bloater damage when only grades 1B, 2B, or 4A fruit were tested. There was also no significant correlation between the air pressure test and either lens or honeycomb bloater damage.

Evaluation of bloater resistance by brining in commercial tanks was hampered by the extreme variability of the data. The coefficient of variability was 148% for balloon bloating in commercial tanks (Table 2). Data from the air pressure test was much more consistent, having a coefficient of variability of only 19%.

Although there was a tendency for larger fruit to have a higher degree of lens bloater damage, this bloater type did not occur at a significant level (Table 3). The frequency of damage by honeycomb bloaters increased with fruit size and had a highly significant negative correlation with balloon bloating ($r = -0.176$). Honeycomb bloaters were especially serious in 'Addis'. Therefore, it appears that cucumbers with strong carpels resisted balloon bloating, but succumbed to honeycomb bloating. There was a small but significant correlation between balloon and lens bloating ($r = -0.103$). Others have also observed an inverse correlation between balloon and lens bloating (1). It may be that the formation of one bloater type in a cucumber fruit releases the build-up of internal gas pressure so that other bloater types are less likely to form.

The advantage of the air pressure test of carpel strength over the use of mechanical testers such as the Instron, is that it permits pressure to be applied from the center out. The Instron test of Marshall et al. (9) used force applied along the main axis of the fruit and, therefore, measured tissue firmness in addition to carpel strength.

The equation for calculating Fisher's least significant difference (LSD) can be used to find the number of fruit required for an air pressure test of balloon bloater resistance. The error mean square was about 15 for both the spring and fall seasons, so under those conditions it would be necessary to measure 8, 14, or 30 fruit per line to be able to detect a difference of 4, 3, or 2 psi, respectively. The test could be further improved by using only grade 3 or 3B fruit as described above.

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