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Evaluation of Bloater Resistance in Pickling Cucumbers Using a Brine Carbonation Method

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Abstract. **The feasibility of testing the resistance of pickling cucumber (*Cucumis sativus* L.) cultivars to bloater damage was determined using a procedure of artificial carbonation at several concentrations of dissolved CO_2 during brine storage of unfermented cucumbers. The use of grade 3-size fruit carbonated to saturation with CO_2 during brine storage in 18-liter (5-gal) plastic pails appeared to be a simple, rapid (6 days), inexpensive, and reproducible method to test for cultivar differences in susceptibility to bloater damage. The method involves the use of a prescribed brine composition and sequential introduction of N_2 and CO_2 into the brined cucumbers. Thirty-five cucumber lines and cultivars were statistically separable using the method. Based on the data collected, it is recommended that 6 replications of 15 grade 3 fruit per cultivar or line be used, although good data can be obtained with as few as 2 replications of 5 fruit.**

Bloater damage in brined cucumbers can cause serious post-harvest losses to the pickle industry. The problem has been attributed to a building of gas pressure within the brined fruit (10), which results in formation of gas pockets within the flesh noted as balloon, lens, or honeycomb bloating, depending upon the characteristics of tissue disruption (6).

Purging of CO_2 from fermenting cucumber brines will reduce bloater formation (4, 5, 9, 12) and has been a common commercial practice for several years with great economic benefit (8). There is an interest, however, in determining whether bloater-resistant cucumber cultivars can be stored in brines with a higher concentration of CO_2 than normally permitted so that the expense of purging can be minimized. Thus, variations in susceptibility of cucumber cultivars to bloater damage is of continuing interest.

Various efforts have been made to determine the resistance of cultivars to bloater damage. Cucumber breeders typically test cultivars for brining properties by placing 22-kg (1 bushel) lots of green cucumbers into labeled mesh or burlap bags which then are placed in commercial brine tanks as described by Jones et al. (14). Although the test fruit are exposed to the same conditions as the commercial fruit, this procedure has certain disadvantages. Location of the test fruit of each cultivar can have a sizeable effect on bloater susceptibility, which increases the variability of the test. Fleming et al. (11) found that bloater susceptibility was affected by hydrostatic pressure, buoyancy pressure, and CO_2 concentration, all of which vary within the commercial tank. Fermentations in commercial tanks also are subject to vagaries that are common and unpredictable. Furthermore, most commercial tanks are now purged and may not routinely provide a suitable challenge for bloater susceptibility that breeders could rely on to make their selections each year.

Attempts have been made more recently to develop rapid tests to predict fresh cucumbers' resistance to balloon bloating. Such tests have included the measurement of the force required to separate the carpels of cucumber fruit slices as measured by the Instron Universal Testing Machine (17), the measurement of carpel separation and skin toughness in green stock (19), and measurement of the air pressure required to separate carpels in whole fruit (20). While these indirect methods may prove useful as predictors of bloating susceptibility of fresh fruit, a direct method for testing threshhold levels of CO_2 for bloater damage and cultivar influences during brine storage of cucumbers would be valuable. Conditions exist in brining that may influence bloating resistance. For example, it is known that osmotic effects, such as those present during brine storage, influence susceptibility to bloater formation (3).

Although carpel separation may be induced environmentally by delaying the processing of cucumbers after harvest (18), or by damaging the fruit by mechanical harvesting and grading (15, 16), it appears to be controlled genetically. Carpel rupture in fruit harvested at the processing stage was found to be controlled by a single 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% (21).

The purpose of this research was to develop a simple, inexpensive, and reproducible method to test cucumber cultivars for susceptibility to bloater damage during brine storage. Fermentation of the cucumbers was prevented by addition of a preservative, so that response to CO_2 concentration could be determined in the absence of microbial growth. The cucumbers were brined and carbonated by various CO_2/N_2 combinations to obtain the desired dissolved CO_2 concentrations. Thus, the method was designed to provide a test for resistance of brined cucumbers to gas pressure from artificial carbonation of the brine. The test was not designed to evaluate factors other than the physial resistance of cucumbers to bloater formation (such as cucumber-microbial interactions that may be involved in the production of CO_2 in brine tanks).

Materials and Methods

Bloater resistance was evaluated in pickling cucumber lines and cultivars for 2 years (1980, 1981) in commercial tanks and in 18-liter (5-gal) pails. Three cultivars were used in the 1980 experiment and 35 cultivars and lines were tested in 1981.

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Experimental design. Three cultivars ('Addis', 'Greenpak', and 'Pixie') were seeded on raised beds on 1 May at the Horticultural Crops Research Station at Clinton, N.C. Plants were grown using standard horticultural practices. Fruits were harvested on 20 and 24 June and were divided randomly into 3 groups. One group was taken to the Mt. Olive Pickle Co. in Mt. Olive, N.C. for brine storage in unpurged tanks for about 6 months. The 2nd group was taken to Raleigh and placed into 18-liter pails for 5 days. The 3rd groups was checked for defects as greenstock to provide a control for the brined fruit.

The experimental design for the commercial tanks was a factorial in a randomized complete block with 3 cultivars, 4 grade sizes (North Carolina grades 1, 2, 3, and 4 with diameters of < 27, 27–38, 39–50, and > 50 mm, respectively), and 3 tanks (replications) of 10 fruit per treatment. Fruit were hand-harvested, machine-graded, and then hand-sorted to remove culls before placing in tanks.

The experimental design for the 18-liter pails was a factorial in a randomized complete block with 3 cultivars (same as for the commercial tanks), 4 levels of CO_2 (0%, 60%, 80%, and 100%) in N_2 as purge gases, and 4 replications of 10 grade 3 fruit per treatment. Only one grade size was tested in the pails to keep the experiment to a manageable size. Fruits were harvested, graded, and sorted as described for the commercial tanks. Four gas mixtures of N_2 and CO_2 were tested to determine the optimum level of CO_2 to use as purging gas for the 18-liter pails.

Thirty-five lines (breeding lines and cultivars) were tested in 18-liter pails in 1981 with 100% CO_2 as the purging gas to evaluate the method in separating lines for bloater resistance. The experimental design was a randomized complete block with 35 lines, 2 harvests (replications), and 10 grade 3-size fruit per treatment. Cultural practices and harvests were handled as described for the 1980 experiment, except that cucumbers were planted 27 Apr. and harvested 22 and 29 June.

Commercial brining procedure. Twelve to 15 cucumbers of each of the 4 grade sizes of each cultivar were placed into burlap bags. The bags then were placed into unpurged, 1000-bushel (22 MT) commercial brine tanks, one tank for each replication. The bags were arranged across the top of a nearly full tank and tied in place, then covered with 2 m of cucumbers before heading the tank. The cucumbers were removed from the tanks after 6 months of storage and evaluated as described below.

Laboratory brining procedure. Twelve to 15 cucumbers of each cultivar tested were placed in a labeled, plastic mesh bag (formed from 16-inch lay flat, 15/46 yellow rope, Bemis Co. Inc., St. Louis, Mo.). Four bags of cucumbers, each representing separate cultivars, were placed into an 18-liter plastic pail (Fig. 1), resulting in a total of 46.2 kg (21 lb.) of cucumbers for each pail. The bags were positioned such that each bag constituted a vertical quadrant of the pail. Brine of the following composition was poured into the pail of cucumbers to the 18-liter mark: 10.6% NaCl, w/v; 0.32% acetic acid, v/v; 0.2% sodium benzoate, w/v. The cucumber:brine ratio thus approximated 1:1. Only 10 of the fruit from each bag were evaluated for bloaters and defects.

A plastic header was placed on the cucumbers and the pail then was capped. N_2 was introduced through a plastic sparger (Fig. 1) at a continuous rate of 50 ml/min for 2 days. Then a CO_2/N_2 gas mixture was introduced at a continuous rate of 100 ml/min for 4 days. CO_2 concentrations in the brine approached equilibrium values within 24 hrs (Fig. 2). The pails were opened after 4 days and the cucumbers were evaluated. The room temperature was 27° C during the entire period of brine storage.

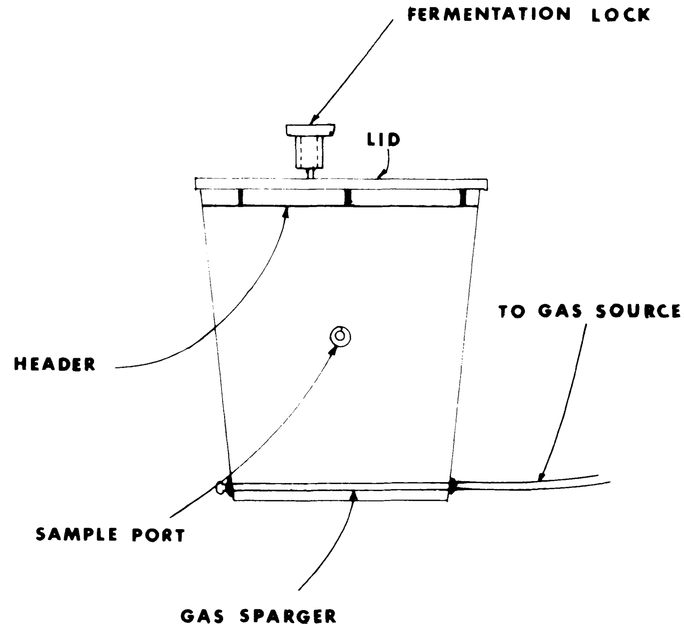

Fig. 1. Carbonation vessel for testing bloater susceptibility of cucumber lines and cultivars to bloater damage.

The general procedure for brining in 18-liter pails was adopted from earlier studies (7, 9) and the rationale for the procedure of introducing N_2 and CO_2 to cause bloater formation was based on the work of Fleming et al. (13).

The pails were adapted for use as carbonation vessels (Fig. 1) as follows: The sprager consisted of polyethylene tubing (4.8 mm i.d.) which was inserted 2 to 5 cm from the bottom of the pail, horizontally, through a rubber serum stopper (Cat. No. 02-225-5, Fisher Scientific Co.) positioned in the sides of the pail. Three uniformly spaced holes then were made in the tubing with a 27-gauge (0.4-mm-diameter) needle. One end of the sparger that protruded through the container was heat-sealed; the other end was connected to a flow meter through which purging gas entered. A rubber serum stopper was placed in the side of the

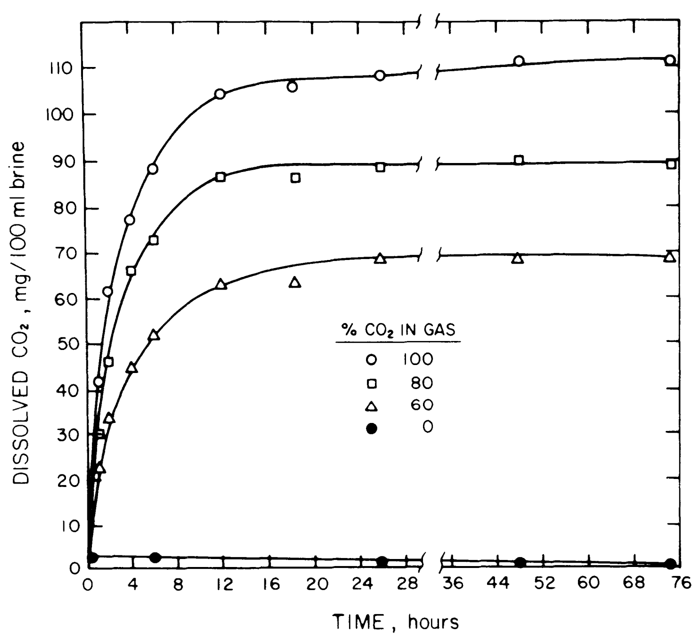

Fig. 2. Rate of dissolution of CO_2 in carbonated, brined cucumbers.

pail at mid-depth for use as a brine sampling port (optional). The plastic header and lid are standard items for the pail and are supplied by the various manufacturers that provide pails to the pickling industry. The pail, lid, and header preferably should be from the same manufacturer to ensure proper matching of these items. A fermentation lock (Presque Isle Wine Cellars, 5422 Glenwood Park Ave., Erie, PA 16509) was mounted in the lid through a rubber serum stopper to allow escape of purging gas. Water was added to the fermentation lock through which purging gas exited.

Evaluation of brined cucumbers. Brined cucumbers were sliced longitudinally and evaluated for the percentage and degree of balloon, lens, and honeycomb bloater damage as illustrated by Etchells et al. (6). Results were expressed as bloater indexes according to Fleming et al. (11). The bloater index approximates the percentage of the cucumber tissue that would be unsuitable for those pickle products that must be free of serious physical defects.

Firmness was reported as the average force readings obtained by punching fruit halves with a USDA fruit pressure tester equipped with an 8-mm-diameter tip. Other defects such as natural carpel separation, placental hollows, blossom-end defects, and soft centers were scored 0 to 9 (0 = no defect, 1–3 = slight, 4–6 = moderate, 7–9 = severe defect). In addition, carpel strength was measured by estimating the force required to separate the carpels of fruit cut in half longitudinally by exerting thumb pressure on the carpels. Carpel strength was scored 1 to 9 with 1 = weak, 5 = average, 9 = strong.

Table 1. Bloater index (mean percentage of each fruit damaged by bloating) for 3 cultivars and 4 grade sizes of pickling cucumbers brined in commercial brine tanks.[z]

Grade sizes	Cultivar		
	Addis	Greenpak	Pixie
	Balloon bloaters		
1	0.2	12.4	8.9
2	1.1	12.4	8.3
3	3.5	17.2	23.3
4	3.3	20.2	40.9
Mean	2.0	15.6	20.4
	LSD (5%) = 9.5	CV (%) = 148	
	Lens bloaters		
1	0.9	0.6	0.0
2	0.0	0.0	1.5
3	3.1	4.1	0.6
4	3.7	2.2	3.9
Mean	1.9	1.7	1.5
	LSD (5%) = 3.4	CV (%) = 395	
	Honeycomb bloating		
1	0.0	0.0	0.0
2	1.1	3.1	0.0
3	11.1	7.6	2.0
4	21.5	11.7	5.9
Mean	8.4	5.6	2.0
	LSD (5%) = 4.3	CV (%) = 157	
	Total bloating		
1	1.1	13.0	8.9
2	2.2	15.6	9.8
3	17.8	28.9	25.9
4	28.5	34.1	50.7
Mean	12.4	22.9	23.8
	LSD (5%) = 10.4	CV (%) = 103	

[z]Data are means over 3 replications of 10 fruit each.

Table 2. Bloater index (mean percentage of each damaged by bloating) for 3 cultivars of pickling cucumbers stored in 18-liter pails purged with CO_2-N_2 gas mixtures.[z]

CO_2 concn[y] (%)	Cultivar		
	Addis	Greenpak	Pixie
	Balloon bloating		
0	0.0	0.8	0.0
60	1.9	8.9	11.6
80	4.7	28.3	12.6
100	5.1	40.6	23.0
Mean	2.9	19.7	11.8
	LSD (5%) = 7.4	CV (%) = 146	
	Lens bloating		
0	0.0	0.0	0.0
60	0.0	0.3	0.0
80	0.3	0.0	0.3
100	0.7	3.2	0.1
Mean	0.3	0.8	0.1
	LSD (5%) = 1.2	CV (%) = 693	
	Honeycomb bloating		
0	0.0	0.0	0.0
60	6.9	7.0	7.4
80	17.2	18.0	17.5
100	29.8	32.4	27.2
Mean	13.5	13.8	12.8
	LSD (5%) = 4.9	CV (%) = 82	
	Total bloating		
0	0.0	0.8	0.0
60	8.8	16.2	19.0
80	22.2	46.3	30.4
100	35.6	72.7	49.1
Mean	16.7	34.0	24.6
	LSD (5%) = 5.4	CV (%) = 60	

[z]Data are means over 4 replications of 10 grade 3-size fruit each.
[y]The difference was made up with nitrogren gas.

Data were subjected to analysis of variance and means compared using Fisher's least significant difference (LSD) where the F tests indicated significant effects (5% level). Correlations were used to test the relationships among firmness, bloater resistance, and the thumb test for carpel strength.

Results and Discussion

Commercial tests. In the commercial tanks, 'Addis' was most resistant to balloon bloating, with 'Pixie' slightly more susceptible than 'Greenpak' (Table 1). Most balloon bloating occurred in grade sizes 3 and 4 with the greatest differences between cultivars occurring in grade 4 fruit. 'Greenpak' and 'Pixie' reversed places in grades 1 and 2, where 'Greenpak' had the most balloon bloating. 'Greenpak' appeared to be more susceptible than 'Pixie' because it had high levels of bloating even in grades 1 and 2.

Lens bloating occurred at a low level in all 3 cultivars, none of which were significantly different from each other. The coefficient of variation (CV) was high for lens bloating, indicating much variability among treatments. Grades 3 and 4 tended to have more lens bloating than grades 1 and 2, but the differences were not always statistically significant.

Honeycomb bloating occurred least in 'Pixie', with 'Addis' having more damage than 'Greenpak'. Honeycomb bloating was worst in grades 3 and 4 with no significant damage in grades 1 and 2. Resistance to honeycomb bloating appeared to be unrelated to either lens or balloon bloating.

Laboratory tests. Balloon bloating increased as the concentration of CO_2 in the purging gas was increased from 0% to 100% (Table 2). No significant bloating occurred when the purging gas was 0% CO_2 (100% N_2), but the results were similar to balloon bloating in commercial tanks when the purging gas was 80% or more CO_2. The greatest differences among cultivars occurred when the purging gas was 100% CO_2. 'Addis' could be brined in tanks with CO_2 levels as high as 80% without significant balloon bloater damage, but the other 2 cultivars would have to be kept in brine with less than 60% CO_2 to prevent damage. Thus, cultivars with balloon bloater resistance may reduce the need for purging of commerical brine tanks. Lens bloating was not important in any cultivar or at any CO_2 level, a result similar to that obtained for commercial tanks.

Honeycomb bloating, like balloon bloating, increased as the CO_2 concentration in the purging gas was increased from 0% to 100%. As in the commercial tanks, 'Pixie' had the lowest level of honeycomb bloater damage, but the difference was signficant only for 100% CO_2 in the purging gas.

The 35 lines tested in 1981 were easily separated statistically for balloon and honeycomb bloater resistance (Table 3). Lens bloating did not occur to a significant degree. The 18-liter pail test appeared to be a reliable method for distinguishing lines for bloater resistance. CV for balloon and honeycomb bloating were 68% and 75%, respectively. Those were fairly low compared with the CV of 100 to 300 normally obtained in commercial tanks, (C.H. Miller and T.C. Wehner, unpublished data).

The equation for calculating the LSD can be used to estimate the number of replications required to obtain a certain level of

Table 3. Bloater index (mean percentage of each fruit damaged by bloating) and firmness of 35 lines tested in 18-liter pails purged with 100% CO_2.[z]

Rank	Cultivar or line	Seed source	Bloater type (% of fruit damaged) Total	Balloon	Lens	Honeycomb	Firmness (pressure test in kg)
1	SC 144	Clemson Univ.	3.3	0.8	0.0	2.5	9.4
2	Sampson	PetoSeed	5.4	2.5	0.0	2.9	9.1
3	Pikmaster	Northrup-King	7.7	4.2	0.4	3.1	8.5
4	Target	PetoSeed	8.1	4.6	0.4	3.1	8.7
5	NCX 5010	Niagara Seed	9.0	5.2	0.0	3.7	8.8
6	Score	Asgro Seed	9.0	2.5	0.0	6.5	8.9
7	4 JC 2	Harris Seed	9.4	6.7	0.0	2.7	8.6
8	79-1197	Musser Seed	10.0	1.7	0.4	7.9	8.8
9	PSR 10780	PetoSeed	11.9	8.3	0.0	3.5	9.8
10	E 0212	Ferry-Morse	12.3	3.3	0.8	8.1	8.5
11	Explorer	PetoSeed	12.7	4.2	0.4	8.1	9.0
12	SC 200	Clemson Univ.	13.3	5.4	0.0	7.9	8.7
13	Carolina	PetoSeed	13.3	6.0	0.4	6.0	9.4
14	Triplemech	PetoSeed	13.3	10.8	0.0	2.5	9.2
15	G 56 D	N.C. State Univ.	13.5	6.8	2.6	4.1	8.6
16	Commander	PetoSeed	13.7	10.0	1.7	2.1	8.5
17	Calico	PetoSeed	14.0	8.8	0.0	5.2	10.1
18	Tempo	Harris Seed	14.2	7.5	0.4	6.3	9.1
19	Multipik	PetoSeed	14.4	7.5	0.4	6.5	9.0
20	E0210	Ferry-Morse	15.8	12.3	0.4	3.0	8.5
21	Regal	Harris Seed	16.2	7.9	1.7	6.7	9.4
22	G 53	N.C. State Univ.	17.1	5.0	0.4	11.7	8.4
23	Salvo	PetoSeed	17.5	10.0	0.0	7.5	9.2
24	4 J 73	Harris Seed	17.7	10.0	0.4	7.3	7.2
25	PSR 1479	PetoSeed	18.5	15.2	0.4	2.9	8.7
26	Tamor	Asgrow Seed	22.5	16.3	1.7	4.6	8.3
27	Calypso	PetoSeed	22.7	13.3	6.7	2.7	8.8
28	Beit Alpha	Dessert Seed	26.7	19.4	2.1	5.2	5.7
29	XPH 1191	Asgrow Seed	27.5	18.8	0.0	8.8	9.3
30	Greenpak	Harris Seed	31.7	24.6	0.0	7.1	6.7
31	G 76	N.C. State Univ.	32.9	25.6	3.1	4.2	7.1
32	Castlehy 2014	Castle Seed	33.7	24.6	1.3	7.8	7.0
33	Lucky Strike	PetoSeed	38.1	32.3	0.4	5.4	9.0
34	XPH 1304	Asgrow Seed	46.5	41.7	1.7	3.1	8.0
35	Castlehy 2012	Castle Seed	58.5	48.7	0.0	9.8	7.1
		LSD (5%)	19.7	17.2	4.0	8.3	0.9
		CV (%)	52	68	245	75	5

[z]Data are means of 2 replications of 15 fruit each.

precision (assuming an error mean square of 95 as was measured in this study). To obtain an LSD of 10% for balloon bloating, 6 or 7 replications of 15 fruit each would have to be measured. That could be achieved by using the fruit from 3 replications in 2 different harvest dates to reduce the time, labor, and number of fruit required to run each test.

Other test factors. Firmness, as indicated by the USDA pressure tester, was negatively correlated (significant at the 5% level) with balloon, lens, honeycomb, and total bloating in the 18-liter pail test in 1981 (−0.55, −0.28, −0.32, and −0.61, respectively). This association also was reported by Bowers and Bowden (1). The correlations probably were too low to be of use in selecting bloater-resistant lines, but they might be used as a guide for initial selections.

Placental hollows, blossom-end defects, soft centers, and carpel separations occurred only at a low rate in the lines tested in this experiment. The fruit that were checked for defects before brining as a control in 1980 had almost no defects. Also, the number of defects did not increase with brining. Thus, it appears that defects can be scored as accurately in greenstock as in brinestock, and that differences in bloating among the cultivars tested did not result from defects in greenstock.

Fruit diameter was measured in 1980 as a covariate to correct for variation in bloater resistance within treatments; however, it appeared not to have much effect within grade sizes. It would be more efficient to classify fruit into the 4 grades by machine, to control variability due to size because of the extra effort involved in measuring fruit diameter by hand.

18-liter pail test. Bloater resistance can be evaluated faster and easier in 18-liter pails than in commercial tanks (6 days instead of 6 months), and there is less environmental variability and greater likelihood of detecting important differences among cultivars. The optimum CO_2 level to use as the purging gas is 100%, since that level produces large differences among cultivars and because it is cheaper to purchase tanks of pure CO_2 than mixtures of CO_2 and N_2.

The best size to use in bloater tests is a large grade 3 (45 to 51 mm diameter), since the greatest differences among lines for bloater resistance occur in that size and because that size is commercially important.

Artificial carbonation of unfermented, brined cucumbers, as described herein, appears to be a simple, rapid, inexpensive, and reproducible method for determining differences among pickling cucumber cultivars for resistance to balloon, lens, and honeycomb bloater formation. We recommend that 6 replications of 15 grade 3-size fruit, carbonated to saturation with CO_2 (100% CO_2 as the purging gas), be used to test the resistance of cultivars to internal gas pressure during brine storage.

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