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Quality of Sweet Corn Stored in Controlled Atmospheres or under Low Pressure[1]

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Abstract. **'Iobelle' sweet corn (*Zea mays* var. *saccharata* (Sturtev.) Bailey) stored for 3 weeks at 1.7°C and 98-100% relative humidity in controlled atmospheres (2 or 21% O_2 with 0, 15, or 25% CO_2) or at low atmospheric pressure (50 mm Hg) did not differ significantly in appearance or flavor. Sucrose content of stored corn remained higher in 2% O_2 at normal or low atmospheric pressure (76 mm Hg) than in other atmospheres. Ethanol content increased during storage, except in 21% O_2 without added CO_2, and was highest in corn stored in atmospheres containing 25% CO_2. The high sucrose content of 'Florida Sweet' even after 3-weeks-storage suggests that for maintenance of high market quality, breeding cultivars that retain quality in combination with prompt precooling offers more chance of success than modified atmospheres.**

Sweet corn tastes best when picked in the milk stage and cooked and eaten immediately. Delay in cooking results in loss of flavor. Flavor of sweet corn is closely related to sugar content and losses of flavor and sugar can be retarded by precooling (11). Early workers (1) showed that 50% of the total sugars is lost within 25 hr after harvest in sweet corn held at 25°C, whereas only 10% is lost when held at 10°C. Recommendations to retard loss of quality are to pre-cool promptly, top-ice, and hold sweet corn as close to 0°C as possible (5).

Corn, as it usually arrives on the market, should not be expected to retain acceptable quality in cold storage for more than 4 to 8 days (5). Thus, new methods are needed to maintain the quality of sweet corn during long-distance shipment and marketing lasting 2-3 weeks. We initiated the present study to evaluate the use of a controlled atmosphere (CA) or low pressure (LP) system as a supplement to refrigeration that might extend the marketing life of corn.

Materials and Methods

'Iobelle' and 'Florida Sweet' sweet corn in the milk stage was picked from fields in Dade County, Florida and returned immediately to the laboratory where the silks and shank were cut-off close to the ear. Trimming reduces weight for economical shipping, removing the silks eliminates decay-prone tissue, and cutting the shank off close to the base of the ear retards denting of kernels (8). The ears were then hydrocooled to a cob temp of 1.7°C in ice water containing 100 ppm sodium hypochlorite through which air was bubbled.

Sweet corn was stored for 3 weeks at 1.7°C and 98-100% relative humidity (RH) in CA's of 2 or 21% O_2 with 0, 15, or 25% CO_2 or in LP's of 50 or 76 mm Hg. This was the lowest temp that the chamber at Miami could reliably maintain and approximately that used in shipping corn. The design and operation of the CA and LP chambers are described elsewhere (9, 10). Air exchange in the LP chamber was set at 1 exchange per hr. Twelve ears of corn were used for each treatment in a given test. The CA and LP tests shown in Table 2 represent 4 replicates run consecutively during the 1975-76 winter vegetable season in Dade County. The sweet corn season extends from Dec. to April with planting schedules adjusted to provide a continuous harvest.

The following evaluations of appearance, flavor, and chemistry were made before and after storage. The appearance of the husks and the cut end of the shank, whether fresh-appearing, discolored, or decayed, were rated separately as 1=poor, 3=fair, 5=good, and 7=excellent. Corn rated excellent should have a fresh appearance without visible defects. Kernels were examined, but not rated, for denting, discoloration, and decay.

Sugars. Composite kernel samples were prepared for sugar analyses in accordance with a sampling method supplied by Leonard L. Morris of the Dept. of Vegetable Crops, Univ. of California, Davis. Six ears of corn, selected at random from each treatment, were husked and 6 rows of kernels were removed from each ear. Kernels were undercut carefully with a scalpel, so that none of the cob was included. The kernels were mixed thoroughly and used as a source of composited kernels in various tests. For sugar analyses, two 50-g samples were placed in beakers containing 100 ml of boiling 95% ethyl alcohol and boiled for 5 min. The samples were then blended in a high-speed blender with sufficient 80% ethanol to make a slurry. The samples were decanted and washed with 80% ethanol onto filter paper in a glass funnel. The slurry was then washed with successive small volumes of 80% ethanol to a final volume of

Table 1. Sugar content of 'Iobelle' sweet corn stored at 1.7°C and 98-100% relative humidity in air or a controlled atmosphere (CA) at normal atmospheric pressure (NP) or in air at low atmospheric pressure (LP).[z]

Storage atmosphere[y]	Storage time (weeks)	Fructose (%)	Glucose (%)	Sucrose (%)
Fresh corn	0	0.8	0.9	2.7
Air	1	0.5	0.6	1.3
	2	0.5	0.5	1.0
	3	0.4	0.5	0.9
CA	1	0.7	0.8	2.2
	2	0.7	0.8	1.9
	3	0.6	0.7	1.6
LP	1	0.7	0.8	2.2
	2	0.7	0.7	1.6
	3	0.6	0.6	1.5

[z]Each figure is the mean of 2 samples.
[y]Air at NP (760 mm Hg) with pO_2 = 21%; CA at NP with pO_2 = 2%; and LP (76 mm Hg) with pO_2 = 2%.

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Table 2. Quality of 'Iobelle' sweet corn stored at 1.7°C and 98-100% relative humidity for 3 weeks in various controlled atmospheres at normal (NP) or low atmospheric pressure (LP).[z]

Storage atmosphere O_2 (%)	CO_2 (%)	External appearance rating[y]	Total soluble solids[x] (%)	Fructose (%)	Glucose (%)	Sucrose (%)	Ethanol (mg/100g)	Flavor rating[y]
Fresh corn		6.7a	20.4a	0.37a	0.53bcd	2.34a	25d	--
NP (760 mm Hg)								
21	0	3.6c	18.7b	0.29b	0.44d	1.05c	151cd	3.4ab
21	15	5.0b	19.0b	0.33ab	0.57bc	1.12c	304bc	3.0bc
21	25	4.6bc	18.9b	0.34ab	0.71a	1.04c	508ab	2.2c
2	0	4.3bc	19.4b	0.29b	0.46d	1.59b	364bc	2.7bc
2	15	5.2b	19.2b	0.30b	0.48cd	1.15c	498ab	3.6ab
2	25	4.7b	18.5b	0.31ab	0.60b	1.19c	651a	4.2a
LP (50 mm Hg)								
1	0	3.8c	19.0b	0.27b	0.38d	1.00c	293bc	3.3ab

[z]Each figure is the mean for 4 separate tests. Mean separation in columns by Duncan's multiple range test, 5% level.
[y]In the rating systems, 1=poor, 3=fair, 5=good, and 7=excellent. Corn tasted after cooking 5 minutes in boiling water.
[x]Expressed as sucrose.

500 ml. The samples were then sealed tightly in glass containers and stored at 1.7°C until analyzed by a modification of a method suggested by Waters Associates, Inc. (E. Conrad, personal communication). Glucose, fructose, and sucrose were determined on 10 ml aliquots of the alcoholic extract which were concentrated to 1 ml and filtered through a millipore filter of 0.8 μm pore size to exclude bacteria. A 10 μl sample of the concentrated extract was injected into a liquid chromatograph (Waters Associates model 202/401)[4] with a micro Bondapak/carbohydrate column (4 mm × 30 cm) and a differential refractometer detector. A 15 water: 35 isopropanol: 50 ethyl acetate solvent system and a flow rate of 3 ml/min were used.

Ethanol. Composited kernels (100g) were sealed in aluminum foil and frozen until analyzed for ethanol. Thawed kernels (25g) were homogenized for 1 min in 25 ml of distilled water and the homogenate was filtered through cheesecloth. Ten ml of the filtrate was diluted with 10 ml of 0.05 M hydroxylamine hydrochloride. Two 10-ml aliquots were placed in 60-ml bottles fitted with rubber septums. After 1 hr at 36°C, 2 ml of headspace air were removed with a syringe and analyzed by gas chromatography (4). The instrument used was a Microtek GS-2000R with a flame ionization detector, a carbowax 20-M column (6 mm × 23 cm) at 105°C, and N_2 carrier at 100 ml/min.

Moisture. A 50-g sample of composted kernels was blended and a small portion of the blended kernels was placed in each of 3 preweighed aluminum weighing dishes. The dishes were reweighed and then placed in an oven at 80°C for 48 hr, removed and reweighed. Percent moisture content of the kernels was then calculated on the basis of the difference in fresh and dry weight.

Soluble solids. A portion of the blended kernels used to determine moisture content was centrifuged and a small volume of the clear supernatant fluid placed in a refractometer for determination of soluble solids.

Flavor. A panel of 5-7 untrained tasters evaluated flavor. Six ears of sweet corn from each treatment were cut in half and cooked on-the-cob for 5 min in boiling water. Each treatment was coded and 2 half ears were evaluated by each taster. Panelists tasted all corn in one session; corn from each treatment was cooked and evaluated in succession. In this way as many as 6 treatments plus a fresh sweet corn sample (later planting of same cultivar) were evaluated within 1.5 hr. Panelists were allowed to salt, but not to butter the corn. Corn was first rated as acceptable or not acceptable (poor). If acceptable, the corn was then rated as fair, good, or excellent. Flavor ratings were later converted to numerical values as follows: poor=1, fair=3, good=5, and excellent=7. A rating of 3 was considered minimum acceptability.

Results

CA and LP storage. Fructose, glucose, and sucrose concns of sweet corn were higher after 3-week-storage in CA or LP than after only 1-week-storage in air (Table 1). Sugar concn of corn stored in CA or LP were similar.

During storage the external appearance rating of sweet corn husks decreased from excellent to a level of fair to good (Table 2). The husk ratings were significantly higher for corn stored in atmospheres containing 15% CO_2 than for 21% O_2 without added CO_2 or for corn stored at 50 mm Hg. For the following general observations, data are not shown. Traces of browning occurred on the cut ends of the shanks in corn from 2 or 21% O_2 and slight browning in corn from 50 mm Hg, but not from atmospheres containing added CO_2. Some kernels were white (bleached) in corn from 2% O_2 with 25% CO_2 and from 21% O_2 with 15 or 25% CO_2. No denting of kernels or off-odors developed during storage, regardless of atmosphere. Moisture content of kernels was similar (79.1 ± 1.0%) for stored and fresh corn.

The total soluble solids of sweet corn decreased only about 1% during storage (Table 2), regardless of atmosphere. The fructose content of corn stored in 21% O_2 with 15 or 25% CO_2 or 2% O_2 with 25% CO_2 did not differ significantly from fresh corn. The glucose content of stored corn did not differ significantly from freshly harvested corn, except for a significant increase in corn stored in 21% O_2 with 25% CO_2. The glucose concn of corn was also significantly higher from 21% O_2 with 25% CO_2 than from 2% O_2 with 25% CO_2. Generally, the higher the CO_2 concn of the storage atmosphere, the higher the glucose and fructose content of the stored corn. The sucrose content of stored corn decreased significantly in all atmospheres, but decreased significantly less in 2% O_2 without added CO_2 than in other atmospheres.

The ethanol content of sweet corn increased significantly in all atmospheres except 21% O_2 without added CO_2 (Table 2). Corn contained more ethanol in 2 or 21% O_2 with CO_2 than in 2% O_2 without added CO_2. Ethanol content of corn in LP was similar to that in 2% O_2 without added CO_2 or 21% O_2 with 15% CO_2. Corn stored in 2% O_2 with 25% CO_2 contained 26 times as much ethanol as fresh corn. In general, the higher

Table 3. Percentage of tasters detecting off-flavors in 'Iobelle' sweet corn stored in various atmospheres at normal (NP) or low atmospheric pressure (LP).

Storage atmosphere		Tasters detecting off-flavors[z]				
O_2 (%)	CO_2 (%)	Test I Feb. 3, 1976 (%)	Test II Feb. 4, 1976 (%)	Test III March 30, 1976 (%)	Test IV April 27, 1976 (%)	Mean[y]
NP (760 mm Hg)						
21	0	0	33	29	0	16b
21	15	20	67	43	80	52a
21	25	80	67	43	60	62a
2	0	60	50	57	20	47ab
2	15	40	17	57	0	28ab
2	25	40	67	29	0	34ab
LP (50 mm Hg)						
1	0	40	17	57	40	38ab
Mean		45a	45a	40a	28a	

[z]Corn tasted after cooking 5 min in boiling water. The number of tasters in Tests I, II, III, and IV was 5, 6, 7 and 5, respectively.

[y]Mean separation by Duncan's multiple range test, 5% level.

Table 4. Changes in sugar concentrations in 'Iobelle' and 'Florida Sweet' sweet corn during storage at 1.7°C and 98-100% relative humidity for 3 weeks.[z]

Cultivar	Storage time (weeks)	External appearance rating[y]	Moisture (%)	Total soluble solids[x] (%)	Fructose (%)	Glucose (%)	Sucrose (%)	Ethanol (mg/100g)
Iobelle	0	6.5	76.8	20.9	0.33	0.53	2.37	46
	1	6.1	76.9	20.5	0.25	0.40	1.57	18
	2	3.5	76.9	21.0	0.23	0.38	1.07	22
	3	2.7	77.6	20.1	0.23	0.41	0.92	26
Florida Sweet	0	6.5	77.7	16.0	0.30	0.50	7.53	60
	1	4.3	79.2	14.6	0.24	0.40	7.13	32
	2	2.9	80.4	13.7	0.22	0.37	6.42	22
	3	2.3	80.1	14.0	0.23	0.34	6.06	33

[z]Data based on 1 dozen ears per treatment.

[y]In the rating system, 1=poor, 3=fair, 5=good, and 7=excellent.

[x]Expressed as sucrose.

the CO_2 concn, the higher the ethanol concn.

Sweet corn flavor deteriorated during storage, regardless of atmosphere (Table 2). Flavor of cooked corn was either unacceptable (less than fair) or barely acceptable, depending upon the storage atmosphere. Corn stored in 21% O_2 without added CO_2 (common air storage) did not differ significantly in cooked flavor from corn stored in other atmospheres, except 21% O_2 with 25% CO_2 from which corn flavor was poorest. Tasters varied widely in rating of stored corn, but consistently rated fresh corn (same cultivar as stored, but a later planting) good to excellent (data not shown). Added CO_2 seemed to improve the flavor of corn in 2% O_2, but not in 21% O_2. Tasters reported significantly more off-flavors in corn stored in 21% O_2 with 15 or 25% CO_2 than in 21% O_2 without added CO_2 (Table 3). Added CO_2 tended to decrease the off-flavor of corn in 2% O_2.

Common storage of different cultivars. In external appearance of husks, 'Iobelle' was rated better than 'Florida Sweet' during each week of storage, but husks of both cultivars were poor to fair after 2-3 weeks (Table 4). Moisture content of kernels of 'Florida Sweet' and 'Iobelle' generally remained constant during storage. 'Florida Sweet' kernels had a slightly higher moisture content than 'Iobelle'. Soluble solids content was about 5-6% less in 'Florida Sweet' than in 'Iobelle'. Fructose and glucose contents were similar in kernels of both cultivars, and both sugars decreased during storage. Sucrose content of fresh 'Florida Sweet' was 3 times that of fresh 'Iobelle'. However, sucrose concn decreased at a similar rate in both cultivars during storage. The change in sucrose concn in both cultivars after 3-weeks-storage was almost the same (1.45–1.47%). Ethanol content was similar in both cultivars and did not increase during storage. Informal taste tests showed a consistent preference for 'Florida Sweet' which after 3 weeks still tasted slightly sweet, whereas 'Iobelle' had a flat taste. After 3 weeks, however, none of the stored corn was as tasty and firm as fresh corn.

Discussion

The finding that loss of sucrose in corn during storage was less in 2% O_2 than the other atmospheres tested is similar to that shown for 'Golden Cross' sweet corn stored in 1% O_2 (7). The retardation of sucrose loss was also noted in corn stored at 76 mm Hg (pO_2 = 2%), but not at 50 mm Hg (pO_2 = 1%). The reason for the failure to retard sucrose loss by storage under LP at 1% O_2 is not known, but may be related to differences in metabolism of corn during CA and LP storage. The effect of 2% O_2 on sucrose loss is also nullified by the presence of CO_2 in the atmosphere, possibly due in part to more ethanol production from sucrose in 2% O_2 with 15 or 25% CO_2. The effect on sucrose should be studied in detail, since the retardation of loss appears to be easily nullified.

Total soluble solids content did not change appreciably during storage and gave no indication of sugar content or flavor. Fresh 'Florida Sweet' corn actually had a lower total soluble solids content than fresh 'Iobelle' corn, but had 3 times as much sucrose.

Ethanol content increased with a high CO_2 concn (25%) in the storage atmosphere. Similar results were reported for citrus fruits stored in CA (3) and Chace et al. (2) suggested that off-flavors in citrus might be related to ethanol production. The present tests showed a coefficient of correlation of –0.44 between cooked flavor of 'Iobelle' sweet corn and ethanol production in the atmospheres tested. Tasters noted significantly more off-flavor and analyses showed more ethanol in 'Iobelle' corn stored in 21% O_2 with 15 or 25% CO_2 than in 21% O_2 without added CO_2. However, tasters preferred corn stored in 2% O_2 with 25% CO_2 that had the highest ethanol content of corn from all atmospheres tested. Somehow off-flavors are altered or masked in corn stored in 2% O_2 with 25% CO_2 so that tasters not only do not notice an off-flavor, but preferred the taste. Nevertheless, corn stored for 3 weeks loses most of its appealing fresh flavor. Much additional work is needed to identify all components associated with flavor. 'Florida Sweet' has more sucrose after 3 weeks than 'Iobelle' corn had when fresh, but has still lost much of its fresh flavor.

Very high concn of CO_2 were reported (6) to retard loss of sugars in corn. The CO_2 concn used in the present tests failed, with the exception of glucose in corn stored in 2 or 21% O_2 with 25% CO_2, to retard the loss of sugars during storage. Sucrose correlated more with the flavor of cooked corn than glucose or fructose. The coefficient of correlation for cooked flavor was 0.50 for fructose, –0.20 for glucose, and 0.76 for sucrose. The comparison between 'Iobelle' and 'Florida Sweet' also emphasized the importance of sucrose to the quality and taste of sweet corn. Fresh 'Florida Sweet' tasted much sweeter than fresh 'Iobelle' corn and contained 3 times as much sucrose as 'Iobelle', whereas the fructose and glucose contents of both cultivars were similar.

The data reported here offer little promise that a modified atmosphere will be found that will maintain the fresh flavor of sweet corn for a transit and marketing period of 3 weeks. The sweetness of 'Florida Sweet' has wide consumer appeal in Florida (12) and in present tests was still slightly sweet (though much less tasty than fresh corn) even after 3 weeks. The results with 'Florida Sweet' suggest that breeding, together with prompt cooling, could help solve the problem of maintaining the quality of corn during local and overseas marketing.

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