

Genetic Modifications of Sweet Corn Quality¹

E. V. Wann, G. B. Brown and W. A. Hills²

Agricultural Research Service
U. S. Department of Agriculture
Charleston, South Carolina

Abstract. Carbohydrate analyses were made at harvest and after 7 days of postharvest storage at 65°F on sweet corn hybrid cultivars with endosperm mutant genotypes *ae wx*, *ae du wx*, and *sh₂* and of standard sweet corn (*su₁*). Cultivars with the mutant genotypes contained from 1.5 to 2.0 times as much total sugar at harvest as the standard. They also lost more total sugar during the post-harvest period. Still, the hybrids with *ae du wx* and *sh₂* genotypes contained significantly more sugars than the standard after the 7-day storage treatment. The mutant cultivars were low in water soluble polysaccharides but relatively high in starch. All cultivars had approximately the same amount of total carbohydrate. Moisture loss from the kernels during the storage period was significantly less in the mutant cultivars. Therefore, they maintained their fresh appearance longer, and they were slower than standard sweet corn to show kernel denting. Taste tests indicated a preference for the sweetness of the *ae wx* and *ae du wx* genotypes over the standard cultivars Golden Security and 'Iobelle' (Florida 104), but they were rated below the standards for pericarp toughness. These studies indicated that, with further refinement of certain horticultural and quality characteristics, the *ae wx*, *ae du wx*, and *sh₂* endosperm mutant genotypes have a definite potential for improving the initial quality and the ability for maintaining good quality during normal post-harvest handling of fresh sweet corn.

The quality of fresh sweet corn depends to a large extent on kernel texture and flavor, which are directly related to the sugar and polysaccharide content of the endosperm. Culpepper and Magoon (4) concluded that the nature of polysaccharides present and the total sugar content were preeminently associated with sweet corn quality.

The basic genetic difference between standard sweet corn cultivars and starchy corn is the presence of the recessive allele at the *sugary-1* locus on chromosome 4 in sweet corn. This recessive gene conditions an eight to ten-fold increase in the water soluble polysaccharides (WSP) and a 2-fold increase in sugars over the normal genotype. At optimum edible maturity high quality sweet corn contains 70 to 75 percent moisture and about 20 percent of the dry matter as sugar. Doty et al. (5), and Showalter et al. (10) gave evidence that these attributes of quality deteriorate rapidly once the corn is harvested unless special precautions, such as precooling and refrigeration, are used to preserve the quality. Some such deterioration was inevitable, however, with the best post-harvest storage and handling practices. Showalter (8) reported that Florida grown sweet corn, marketed in the northeastern U. S. A. through normal channels, averaged 7 days from harvest until it was finally retailed. During this period it had lost 40-60 percent of the initial sugars.

Much has been done in recent years to improve the consumer quality of fresh sweet corn through improved marketing practices. Plant breeders have improved some of the quality characteristics of sweet corn cultivars through selective breeding within the *su₁/su₁* genotype. However, the genetic limitations of this genotype preclude further substantial increase in the total sugar content.

Laughnan (7) reported that the *shrunk-2* (*sh₂*) gene on chromosome 3 imposed a genetic block in the conversion of sucrose to WSP, resulting in the accumulation of sugar. The cultivar Illinichief Super Sweet (later renamed 'Illini Extra-Sweet') released in 1961 had the *sh₂* allele and contained more than twice the sugar content of standard sweet corn. Studies by Showalter and Miller (9) showed that consumer reaction to this high-sugar cultivar indicated a strong preference for sweeter corn. However, there was some indication that the optimum

sugar level was exceeded by the high-sugar cultivar, as 19 percent of questioned consumers stated that it was too sweet. They also reported that a significant feature of the high-sugar corn was its maintenance of sweetness under adverse handling practices. Unfortunately, 'Illinichief Super Sweet' has not been readily accepted for large scale production by the commercial seed industry or by sweet corn producers because of some undesirable seed characteristics.

There are several other gene mutations in maize which have been shown to alter carbohydrate type and quantity during kernel development. The effects of specific gene mutations and many of the double and triple mutant combinations have been studied and reviewed extensively by Creech and McArdle (2) and Creech (3). They suggested that certain combinations of the endosperm mutant genes might have practical application for improving the quality of sweet corn. Specifically, the mutants *ae* (*amylose extender* on chromosome 5) *du* (*dull* on chromosome 10) and *wx* (*waxy* on chromosome 9) appeared to produce the desired effect for quality improvement either with or without the *su₁* gene.

To investigate the genetic potential of the endosperm mutant genes for improving sweet corn quality we developed inbred lines and F₁ hybrids of the most promising genotypes and determined some of their quality characteristics at harvest and after a period of post-harvest storage. Studies were made, specifically, of the quality factors related to the amount of sugar, water soluble polysaccharides (WSP) and starch in the kernels, and of the inherent ability of the corn to maintain freshness and good quality during post-harvest handling.

Materials and Methods

The endosperm mutant genes *ae*, *du* and *wx* were introduced from a genetic stock obtained from H. H. Kramer, Purdue University. This stock was crossed with several of our standard sweet corn inbreds beginning in 1962 followed by one and in some lines two backcrosses to the inbred lines. Inbred lines with all possible combinations of the mutant genes *ae*, *du*, *wx* and *su₁* were synthesized at the beginning for preliminary observations. From these observations we eliminated all genetic combinations except *ae wx* and *ae du wx* on the basis of either poor taste or excessive amounts of shrinkage of the dry kernels. Included in the final evaluation, the data from which are reported herein, were mutant hybrids M6212A *ae wx* and

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²Research Geneticist, Chemist and Horticulturist, respectively, Crops Research Division.

M6210B *ae du wx*, 'Illinichief Super Sweet' *sh₂* and two standard sweet corn cultivars, Golden Security and Iobelle (Florida 104). In a separate experiment to investigate the relative rates of moisture loss during post-harvest storage by the various genotypes, we substituted 'Truckers Favorite', a starchy roasting-ear type, for 'Golden Security' and M6209A *ae wx* for M6212A *ae wx*. The corn was grown on the U. S. Vegetable Breeding Laboratory farm at Charleston, South Carolina, during the 1970 spring season with harvest in mid-June. The entries were arranged in a randomized complete block design with four replications. All ears were hand-pollinated to insure genetic purity and maximum uniformity of maturity. The ears were harvested 15 days after pollination.

In preliminary tests made in 1968 and 1969, we took duplicate 6-ear samples from each plot. One sample was analyzed for moisture and carbohydrate contents at the time of harvest and the other was placed in a controlled temperature room at 65°F ± 2° for 5 days, then subjected to similar analyses. Hereinafter we shall refer to the 2 treatments as "before" and "after." Some variation was evident between the duplicate samples. Therefore, for the final evaluation we used the same ear-sample for both the "before" and "after" post-harvest storage determinations. We found this to be a more satisfactory method of sampling and it yielded much more uniform data than duplicate samples. Also, the storage period was lengthened to 7 days.

Immediately after harvest the shank portion of each ear was trimmed so that they had approximately the same husk covering. Kernel samples were collected by making a slit along one side of the ear and removing 2 kernel rows with a sharp knife. The husks were put back in place, secured with a rubber band and placed on an open tray in the storage room. After 7 days in storage the husks were removed and two kernel rows taken from the opposite side of the ear.

In the experiment on rates of moisture loss we took a 24-ear sample from each cultivar and divided it into 4 subsamples. Moisture determinations were made immediately on one set of subsamples and the other 3 were placed in the controlled temperature room at 65°F. Determinations were made on these at 3-day intervals. The moisture content of the kernel samples was determined by weighing 10 grams of cut corn into an aluminum drying cup and placing it in a drying oven at 90°C until a constant weight was attained.

For carbohydrate analysis, a 10-gram sample of kernels was accurately weighed and placed in a small bottle with 100 ml of boiling 80 percent ethanol. The samples were stored from 30 to 60 days at room temperature until the analysis could be made. Quantitative determinations were made for total sugars, water soluble polysaccharides (WSP), starch, and total carbohydrates according to the following procedures: The preserved samples were macerated in a laboratory blender and the sugars extracted with alcohol in a Soxhlet apparatus. The alcohol was evaporated off and total sugars measured by the Lane-Eynon method as modified by Hildreth and Brown (6). WSP was extracted from the residue by shaking for 60 minutes in cold water, hydrolyzed with HCl (Sp. Gr. 1.1029) and the resultant sugar determined as above. Starch was determined by the same method as WSP, by using the residue from the WSP extraction (sugar × 0.9 = WSP or starch). Total carbohydrate is the sum of the sugar, WSP, and starch fractions. Statistical procedures were applied to these data as applicable in order to determine significant differences.

Results and Discussion

Most sweet corn cultivars reach optimum edible maturity in the Southeastern United States during midsummer at 15 to 17 days after pollination, at which time the moisture content of the kernels is between 75 and 80 percent. Slight variations in kernel moisture content at harvest occurred between the

cultivars in this study, even though they were harvested the same number of days after pollination. To compensate for these variations, the actual moisture content was determined (Table 1) and the carbohydrate determinations expressed as the percent of dry weight. Figure 1 shows the various carbohydrate fractions and the total carbohydrate for each variety at the time of harvest and after 7 days of post-harvest storage at 65°F.

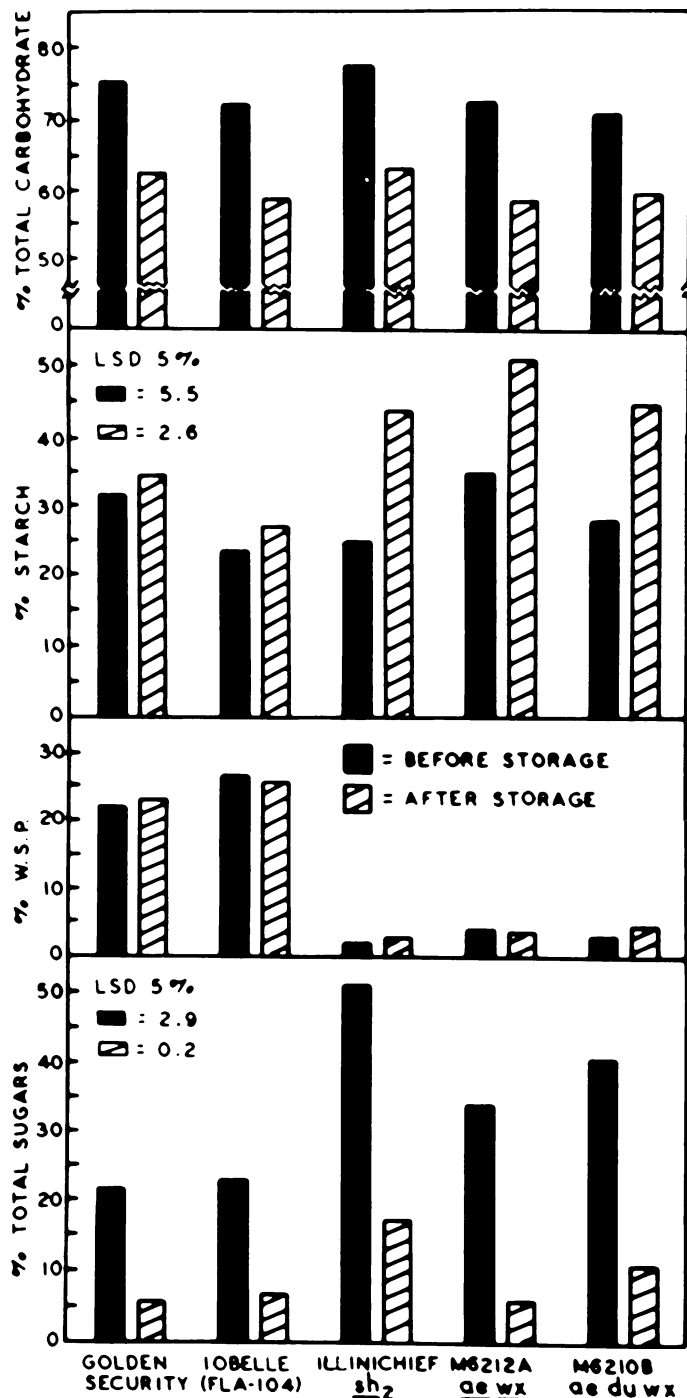


Fig. 1. The quantities of carbohydrates, expressed as percent of dry weight, in sweet corn kernels of various genotypes at the time of harvest and after 7 days postharvest storage at 65°F ± 2°.

The determinations for total sugars included all reducing sugars and sucrose extracted in the alcohol soluble fraction. The total sugar contents are shown in the bottom graph of Fig. 1. The sugar contents of the endosperm mutants were significantly higher than either of the two standard cultivars before storage. 'Illinichief' and M6210B were still significantly higher than the

Table 1. Moisture content of kernels of sweet corn cultivars at the time of harvest and after a post-harvest storage period of 7 days at 65°F ± 2°.

Cultivars	Percent moisture	
	Before storage	After storage
Golden Security	75.9	70.0
Iobelle (Fla. 104)	79.8	74.9
Illinichief (<i>sh</i> ₂)	79.0	77.3
M6212A <i>ae wx</i>	76.4	71.3
M6210B <i>ae du wx</i>	76.6	75.4
LSD 5%	1.1	2.0

standards after the 7-day storage period. The two standards were not significantly different from each other for sugar content, either before or after storage, but they both lost approximately two-thirds of their total sugars during storage. The amount of sugar lost by the high-sugar lines was greater than in the standards, but because they had larger amounts of sugar to begin with, M6212A was still about equal to 'Illinichief' and M6210B greater than, the standard cultivars after storage. These data indicate that 'Illinichief', M6212A and M6210B may be expected to have sweeter corn than standard cultivars up to 7 days after harvest with minimum refrigeration. Appleman and Arthur (1) reported that the rate of sugar loss from green sweet corn during post-harvest storage was approximately doubled for each 10° rise in temperature between 0° and 30°C. Therefore, if temperatures below 65°F were maintained during postharvest handling, as is generally the case in commercial practice, the sugar content no doubt could be kept at a higher level and for a longer period of time than we did in this test.

The differences in sugar content between 'Illinichief' and M6212A or M6210B were highly significant, but in view of Showalter and Miller's (9) findings that 19 percent of a consumer survey indicated that 'Illinichief' was too sweet, we believe M6212A and M6210B have close to the optimum level of sugar for maximum consumer acceptance.

The effect of WSP on sweet corn quality is not clearly understood. It is a non-sweet polysaccharide that probably has some effect on the kernel texture. The high-sugar cultivars are exceptionally low in this fraction (Fig. 1), yet they have very fine flavor and texture. Although not statistically significant in this test, the hybrid M6210B generally contained slightly more of the WSP fraction than 'Illinichief' or M6212A *ae wx*.

The starch fraction (Fig. 1) made up the balance of the total carbohydrate content after sugars and WSP were removed. Generally the cultivars that were low in WSP had a high starch content. We found a significant difference in the starch content before and after the storage period.

Total carbohydrate (Fig. 1) differed very little among the cultivars tested. There was a significant loss of total carbohydrates in all entries during storage which was expected due to normal respiration processes. This loss too could probably have been reduced if the storage temperature had been lower than 65°F.

Tenderness and succulence of the kernels are important factors that must also be considered in measuring sweet corn quality. Moisture content at harvest and moisture loss during post-harvest handling have a decided influence on the ultimate quality of the corn. In earlier studies, we noted that rapid moisture loss seemed to be related to the early appearance of denting of the kernels. We noticed also that lines with high sugar and low WSP appeared to be slower to show denting than the standard cultivars. That this relationship existed is indicated by the differences in moisture loss shown in Table 1. 'Illinichief' and M6210B lost 1.7 and 1.2 percent, respectively, while the standard cultivars lost 5.9 and 4.9 percent. M6212A however, lost 5.1 percent and showed kernel denting comparable to the standard cultivars.

Fig. 2 shows the relative rates of moisture loss in 5 cultivars of different genotypes over a 6-day post-harvest period. The *ae wx* hybrid (M6209A) showed a moisture loss very close to that of the *ae du wx* hybrid (M6210B). We are unable to explain the apparent difference between the two *ae wx* hybrids, M6209A and M6212A, for moisture loss during storage. They had only one parent in common, therefore the difference could be caused by a genetic difference in the other parents. Significant, however, is the fact that 'Illinichief', M6209A *ae wx* and

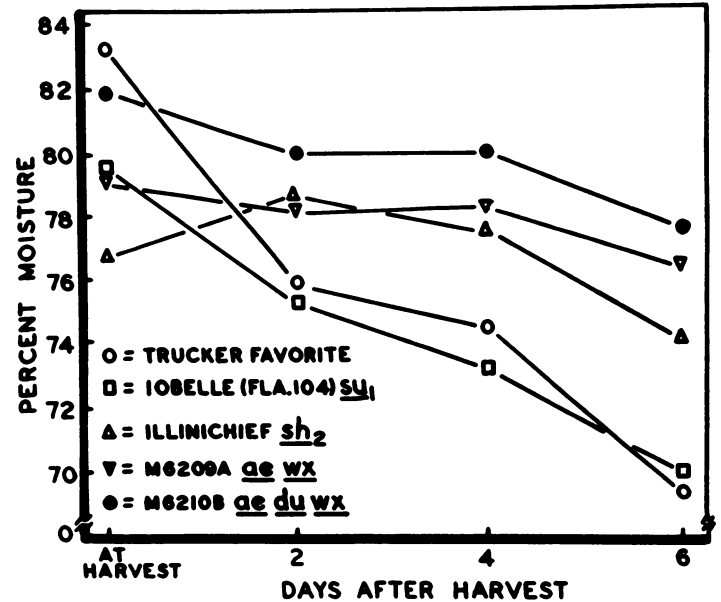


Fig. 2. Moisture loss from sweet corn kernels of various genotypes during postharvest storage at 65°F ± 2°.

M6210B *ae du wx* had completely different moisture curves from either 'Truckers Favorite' or 'Iobelle'. The endosperm mutant hybrids dropped 2 to 4 percent in moisture content while 'Truckers Favorite' and 'Iobelle' dropped 14 and 8 percent respectively. A slight increase in the percent moisture was shown by 'Illinichief' during the first 2 days of storage, and by M6209A and M6210B during the second 2-day interval. 'Iobelle' and 'Truckers Favorite' showed no such increase.

We can only speculate as to the reason for the differences in moisture loss between the high-sugar and standard sweet corn cultivars. Doty et al. (5) reported a small moisture gain by sweet corn immediately after harvest, and suggested that it was due to water being set free by condensation of sugars to polysaccharides and to water formed by respiration. This appears to be the case in our experiments, since a larger amount of sugars were being condensed to WSP and starch in the high-sugar corn, and over a longer period of time, than for other types. This would explain both the slight moisture gain and the maintenance of a higher percent moisture throughout the storage period by the high-sugar corn. As a result of the low moisture loss, the high-sugar corn maintained a fresh appearance and was slower to show denting of the kernels than either 'Iobelle' or 'Truckers Favorite'.

Taste tests of fresh corn indicated that the *ae wx* and *ae du wx* hybrids had a sweeter taste than standard sweet corn both before and after the post-harvest storage period. Also, they were described as having a "More natural corn flavor" than 'Illinichief'. Taste comparisons of randomized samples of canned whole-kernel corn were made by 10 staff members of the Vegetable Breeding Laboratory. The *ae wx* and *ae du wx* hybrids were rated superior to a popular brand of fancy whole kernel corn obtained from a local supermarket for color and sweetness, but below the commercial pack for overall preference. We wish to point out, however, that this may not be

a valid comparison, since the samples were not processed under identical conditions. In all our taste tests the mutant hybrids were rated as slightly tough. At this stage of development it appears that the *ae wx* and *ae du wx* genotypes would be better suited for fresh market production than for processing. Some refinement will be required before any of our mutant hybrids can be recommended for commercial production. However, based on these carbohydrate analyses, moisture relationships, and taste tests, we believe that the *ae wx* and *ae du wx* genotypes have a definite potential for improving the quality of fresh sweet corn.

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