Korean J. Crop Sci. 44(3) : 267~272 (1999)

Sugars, Soluble Solids, and Flavor of Sweet, Super Sweet, and Waxy Corns during Grain Filling

Suk Soon Lee*†, Sang Hee Yun*, and Jae Hyeun Kim*

ABSTRACT

In order to determine the optimum harvest time of vegetable corns, the changes in sugars, soluble solids, and flavor of kernels of sweet (cv. 'Golden Cross Bantam 70'), super sweet (cv. 'Cocktail E-51'), and waxy corns (cv. 'Chalok 2') were observed at different ripening stages. Sucrose was a major sugar in the sweet and super sweet corns and the content increased from 15 to 21 and 27 days after silking (DAS), respectively and then decreased. Glucose and fructose contents of sweet and super sweet corns tended to decrease with kernel maturity. Total sugar content of the sweet corn analyzed by the anthrone method increased rapidly from 15 to 21 DAS, while that of the super sweet and the waxy corns increased slowly up to 24 and 26 DAS, respectively and decreased thereafter. The content of soluble solids in sweet corn was much higher than that of super sweet corn. Starch content of the sweet corn increased slowly from 15 to 33 DAS, while that of the super sweet corn increased a little rapidly from 15 to 21 DAS and then leveled off to 33 DAS. Starch content of the waxy corn increased continuously from 21 to 38 DAS. There was a positive correlation between the sum of individual sugars (sucrose, glucose, and fructose) and soluble solids in both sweet and super sweet corns, while the content of soluble solids was not related to the sum of individual sugars or total sugars. The flavor rate of sweet and super sweet corns maintained high between 21 and 27 DAS and that of waxy corn decreased from 24 to 33 DAS. The optimum harvest time for sweet, super sweet, and waxy corns was thought to be 21 to 24 DAS considering sugar and starch contents, flavor, and marketing.

Keyword : sweet, super sweet, waxy corn, sugar, soluble solids, starch, flavor, harvest time.

In Korea, traditionally waxy and flint corns were harvested at maturity to use as a foodstuff after grinding. Also, some immature fresh corns were harvested between soft and hard dough stages to eat as a snack after boiling, steaming, or toasting. However, in recent years sweet corn (*su*) is popular instead of flint corn. Also, newly introduced super sweet corn (*sh-2*) has a potential to grow in Korea, because it constitutes about 40% of the sweet corn seed market in the United States (Dale et al., 1991). Super sweet corn hybrids are attractive to consumers, since they have more sucrose than sweet corn, extend the time of edible maturity, and better shipping to distant markets (Wilson & Trawatha, 1991).

In sweet and super sweet corns the sugar content is one of the primary appreciations of flavor and quality, while starch content is in waxy corn. Vegetable corns (sweet, super sweet, and waxy corns) go through many physical and chemical changes during silking and harvest, which greatly influences flavor and keeping quality of the kernels (Garwood et al., 1976; Kim et al., 1994; Lee et al., 1987a). In sweet and super sweet corns, the major sugar at harvest time was sucrose, but the highest total sugar content of super sweet corn hybrids was 2-3 times higher than that of sweet corn hybrids (Lee et al., 1987a).

In the United States, sweet corn hybrids are harvested 20 days after silking when sugar content is highest (Kientz et al., 1965; Spalding et al., 1978). As maturation advances, sugar content decreases, starch accumulates, and pericarp thickens. Therefore, the flavor rate of sweet corn decreases with maturity after the sugar content of kernels reached the highest point. However, Koreans who are used to eating waxy and flint corns may like sweet corn, for something to chew, which was harvested later than in the United States and the optimum harvest time of sweet hybrids was recommended as 24 to 26 DAS (Lee et al., 1987a; Jung et al., 1996). In contrast, the optimum harvest time of waxy corn was about 30 DAS considering kernel size, flavor, and stickiness of boiled corn (Kang et al., 1988). However, those who are used to eating soft sweet corn may like soft waxy corn instead of a slightly harder kernel. In other words, the flavor of sweet corn and waxy corn may be changing.

Therefore, in this experiment the optimum harvest time of sweet corn, super sweet corn, and waxy corn was discussed considering the changes in monosaccharides, oligosaccharides, soluble solids, and starch with maturity which are related to flavor.

* School of Biological Resources, Coll. of Natural Resources, Yeungnam Univ., Kyongsan, 712-749, Republic of Korea. *† Corresponding author : (E-mail) sslee@ynucc.yeungnam.ac.kr (Phone)+82-53-810-2914. Received 30 Aug., 1999.

MATERIALS AND METHODS

A sweet corn hybrid, 'Golden Cross Bantam 70 (GCB 70)', a super sweet corn hybrid, 'Cocktail 51', and a waxy corn hybrid, 'Chalok 2', were planted on the Yeungnam University Experimental Farm in Kyongsan, Korea on 5 April 1998. After mulched with transparent polyethylene film, two pre-germinated seeds were planted in a hill at a 25 cm distance in 60 cm rows. At the 3-leaf stage extra plants were thinned out to leave one plant in a hill. The fertilization level of $N-P_2O_5-K_2O$ was 150-120-120 kg/ha and all the fertilizers were applied as basal before the mulching of transparent polyethylene film.

Silking date of plants was marked dayly. The changes in sugars, soluble solids, and starch contents of kernel were observed from 15 to 33 DAS at 3-day intervals for the sweet and super sweet corns and from 20 to 38 DAS for the waxy corn. Flavor test was conducted at 20, 23, 26, and 30 DAS for the sweet and super sweet corns and 24, 27, 30, and 33 DAS for the waxy corn.

For the determination of total sugars and starch, kernels were dried in a 80℃ forced air dryer for 2 days. However, fresh kernels were homogenized immediately after harvest for the analysis of monosaccharides, oligosaccharides, and soluble solids.

Analysis of monosaccharides and oligosaccharides

Five grams of fresh kernels were placed into a 15 ml test tube and 10 ml of 95% ethanol was added. A glass ball was placed on the top of the tube and heated in boiling water for 10 minutes to inactivate enzymes. The samples were made up to 10 ml with 80% ethanol and homogenized for 30 minutes at 5,000 rpm. The samples were centrifuged at 5,000 rpm for 15 minutes and supernatant was decanted into a 50 ml centrifuge tube. These extractions were repeated two more times and then combined all the supernatant. The combined supernatant was evaporated to 5 ml and passed through a column containing polyvinylpolypyrrolidone (PVPP), Amberlite IRA 94, Dowex 50X4-200 at the 0.5 ml/min using a peristaltic pump (EYELA, Japan) to remove phenolic compounds, anions, and cations, respectively (Boersig & Negm, 1985). Then the samples were lyophilized and dissolved with 1 ml purified water and filtered with a membrane filter (pore size 0.45 μm, Whatman, England) and the 20 μl samples were injected into the HPLC (Younglin M930) by using a carbohydrate analysis column (Waters 84038) and a differential refractometer (R401 RI detector, Waters, USA). The mobile phase consisted of 80% acetonitrile and 20% water (v/v) for glucose, fructose, sucrose, and maltose and 70% of acetonitrile for raffinose and stachyose. Flow rate was 1.8 ml/min.

Analysis of total sugars

Dried kernels were ground in a ball mill (Willey Mill, USA) to pass through a 100 mesh screen. Five hundred milligram was placed into a 15 ml centrifuge tube and 10 ml of 80% ethanol was added. Then a glass ball was placed on the top of the tube and kept in a water bath at 80℃ for 30 minutes. It was centrifuged and the decanted supernatant was put into a 50 ml centrifuge tube. These extractions were repeated two more times and all the supernatants were combined. The supernatant was evaporated in a water bath at 80℃ until most of the alcohol was removed and volumed up to 25 ml with distilled water to make a sample solution for total sugar analysis. Then 10 ml of ice cold 0.2% anthrone reagent in 98% sulfuric acid was added to 5 ml of the sample solution, mixed well and immediately heated in boiling water for exactly 7.5 minutes and then cooled in ice water as in the method described by Yoshida et al. (1972). Absorbance of the samples and glucose standards was measured at 630 nm with a spectrophotometer (Uvikon, England).

Analysis of soluble solids

For the determination of soluble solids, 10 g of fresh kernels collected from 5 different ears were ground in a mortar and centrifuged at 3,000 rpm for 10 minutes. A drop of the supernatant was put in a refractometer (Atago NI Refractometer, Japan) and measured soluble solids as Brix %.

Analysis of starch

Two milliliters of distilled water were added to a centrifuge tube containing dried residue which was used for the total sugar analysis. The tubes were heated in boiling water for 15 minutes by stirring occasionally and cooled at room temperature. Then 2 ml of 9.2N $HClO_4$ was added and allowed to react for 15 minutes at room temperature by stirring occasionally. The suspensions were volumed up to about 10 ml with distilled water, centrifuged at 5,000 rpm, and the supernatant was collected in a 50 ml centrifuge tube. Two milliliters of 4.6N $HClO_4$ was added to the residue again and the suspension was stirred for 15 minutes and volumed up to 10 ml with distilled water. It was centrifuged and the two supernatant were combined and volumed up to 50 ml with distilled water to make sample solutions for starch analysis. The next steps were the same as total sugar analysis.

Evaluation of flavor

Hybrids were planted from 5 April to 5 May, 1998 at 5-day intervals to get ears of corns with varying maturity on the same date. Silking date of plants was marked dayly and harvested ears reached 21, 24, 27, and 30 DAS for sweet and super sweet corns and 24, 27, 30, and 33 DAS for waxy corn. A panel of 15 graduate students evaluated the flavor of cooked fresh corn. The corn was scored on a numerical scale of one to five, five being the best flavor and one being the poorest. The term "flavor" is used to denote all factors commonly associated with flavor.

RESULTS AND DISCUSSION

Monosaccharides and oligosaccharides

Changes in monosaccharides and oligosaccharides of sweet and super sweet corns are presented in Fig. 1. The major sugar of both sweet and super sweet corns was sucrose. Glucose and fructose contents were much less than sucrose, while maltose, stachyose, and raffinose were not detected. Sucrose content increased from 15 to 21 DAS in sweet (2.1%) and 27 DAS in super sweet (3.7%) and then decreased. Glucose and fructose contents of sweet corn increased from 15 to 21 DAS and then decreased, but those of super sweet decreased from 15 to 33 DAS continuously. Similar results were also reported by other researchers (Kim et al., 1994; Kientz et al., 1965; Lee at al., 1987a; Toshiaki et al., 1991).

Total sugars

Changes in the total sugars of sweet and super sweet corns and waxy corn are shown in Fig. 2. Fifteen days after silking the total sugar content of sweet corn was 4.5% on the dry weight basis, increased rapidly to 21 DAS (9.5%), then decreased rapidly as maturity advanced. In contrast, the total sugar content of the super sweet corn 15 DAS was much higher than that of sweet (10.3%), increased to 24 DAS, then decreased relatively slowly compared with the sweet corn. The changing patterns of total sugars in sweet and super sweet corns were similar to the sum of sucrose, glucose, and fructose in Fig. 1. Waxy corn contained about 4% total sugars between 21 and 27 DAS, and decreased thereafter. Similar results are also reported by Creech (1965).

Soluble solids

The content of soluble solids in sweet and super sweet corns is presented in Fig. 3. Soluble solids of sweet corn were much higher than those of super sweet. The content of soluble solids in sweet corn increased from 15 to 24 DAS, then leveled off, while that of super sweet increased from 15 to 21 DAS, then leveled off. Similar results are also reported by

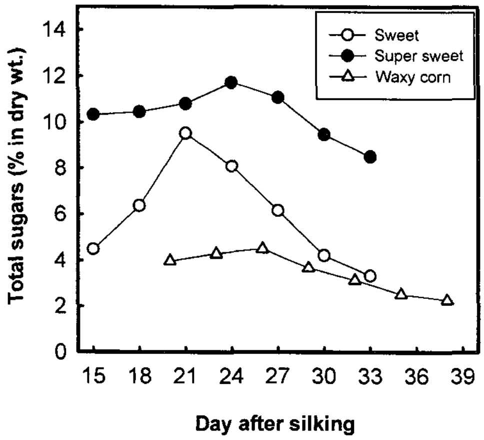

Fig. 2. Changes in total sugar content of sweet, super sweet, and waxy corns.

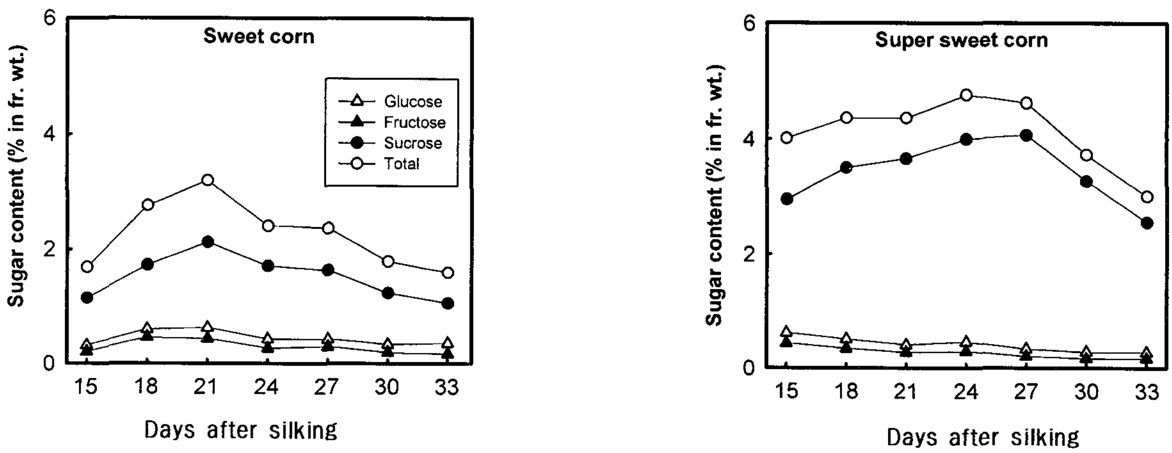

Fig. 1. Changes on glucose, fructose, and sucrose contents of sweet and super sweet corns.

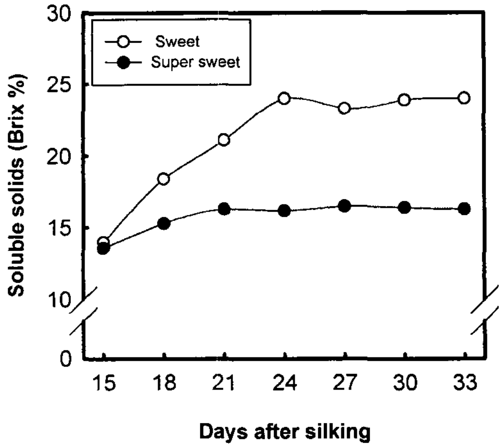

Fig. 3. Changes in soluble of sweet and super sweet corns.

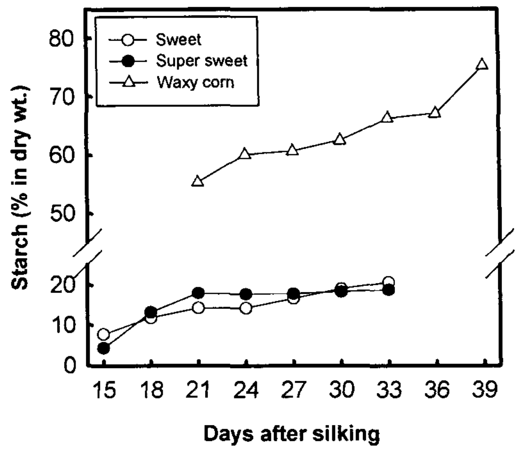

Fig. 4. Changes in starch content of sweet, super sweet, and waxy corns.

Lee et al.(1987a).

Starch content

Changes in the starch content of sweet, super sweet, and waxy corns are presented in Fig. 4. Starch content of sweet corn increased at a similar rate from 15 DAS (7.7%) to 33 DAS (20.6%), while that of super sweet corn increased rapidly from 15 DAS (4.5%) to 21 DAS (17.9%) and then leveled off at 33 DAS (about 20%). In general, starch content of sweet and super sweet corns was similar, while it was much lower than that of waxy corn which increased continuously from 20 DAS (55%) to 38 DAS (80%). Similar starch accumulation patterns of sweet and super sweet corns were also reported by other research workers (Lee at al., 1987a; Toshiaki et al., 1991).

Relationships among total sugars, the sum of individual sugars, and soluble solids

There was a highly significant positive correlation among the sum of individual sugars (sucrose, glucose, and fructose) and total sugars in both sweet and super sweet corn (Fig. 5). However, no correlation was found among the content of soluble solids and the sum of individual sugars or total sugars in both sweet and super sweet corn (Fig. 6).

The content of soluble solids is widely used as an index of sweetness of fruits and sweet corn, because the measurement of soluble solids by a refractometer is much simpler than the various chemical analysis. However, the content of soluble solids does not represent sugar content of sweet and super sweet corn. A similar result was also reported by Lee et al (1987a).

Flavor of cooked fresh corn

Flavor rate of panels for sweet, super sweet, and waxy corns are shown in Fig. 7. The flavor rate of sweet corn maintained high from 21 DAS to 27 DAS,

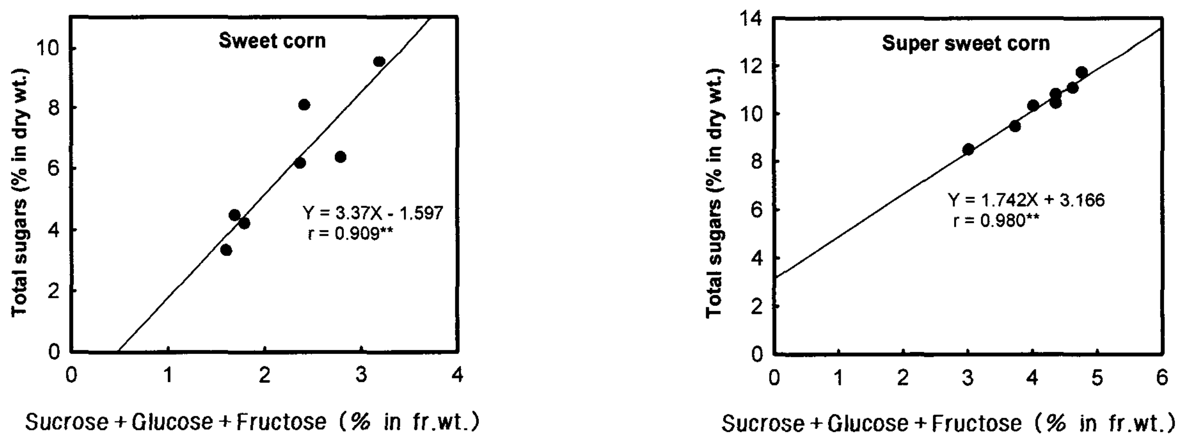

Fig. 5. Relationship between socrose + glucose + frucrose and total sugars of sweet and super sweet corns.

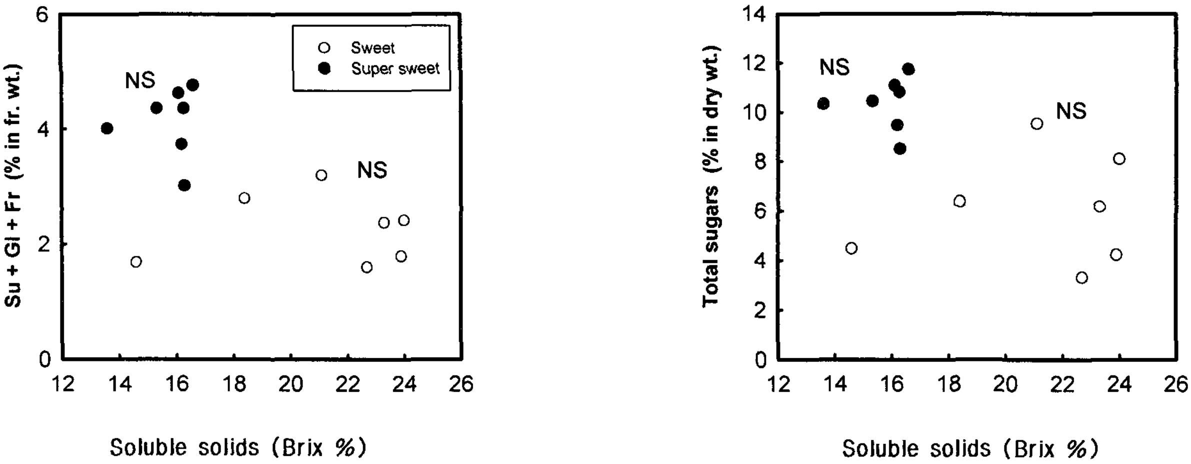

Fig. 6. Relationship between soluble solids and sucrose + glucose + fructose or total sugars of sweet and super sweet corns.

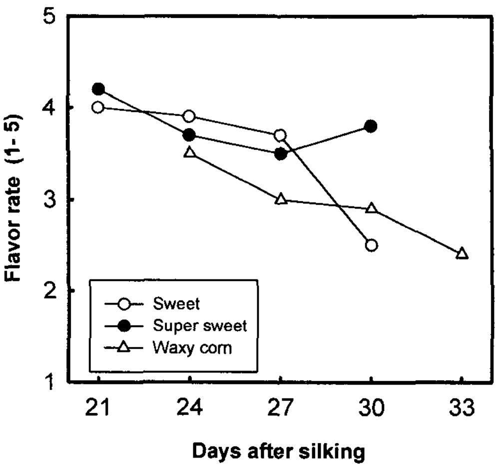

Fig. 7. Changes in the flaver rate of cooked fresh corns.

then decreased rapidly. The low rate of flavor 30 DAS may be related to the low sugar and high starch contents and thick pericarp (Glenn & Brewbaker, 1981; Kang et al., 1988; Wolf et al., 1969). In contrast, the flavor rate of super sweet corn decreased from 21 to 27 DAS, and then increased thereafter. The lower flavor rate between 24 and 27 DAS may be related to the too high sugar content (Winter et al., 1955) as shown in Fig. 2. Super sweet corn did not accumulate starch from 21 to 33 DAS (Fig. 4), so 30 DAS the lowered sugar content at may have increased the flavor rate. In the United States, sweet corn is harvested when sugar content reaches the highest level (Fig. 2), 20 DAS. However, while in this experiment the prolonged harvest time may represent the habits of Koreans who used to eat waxy or flint corn which accumulates more starch than sweet corn.

The flavor rate of waxy corn was lower than that of sweet and super sweet corn and decreased continuously from 24 to 33 DAS. Commonly, waxy corn is recommended to harvest between 28 and 35 DAS (Kang et al., 1988; Kim et al., 1994). However, the later harvest reduces flavor due to hard kernels. At the present time, young people tend to like soft sweet corn and, for this reason, they may like soft waxy corn too. Similar results are reported by other research workers (Kim et al., 1994; Lee et al., 1987a; Park et al., 1992).

In Korea, sweet corn is shipped to market without refrigeration, which takes 2~3 days before cooking. Therefore, most sugars disappeared by changing to starch or consumed by respiration at high temperatures (Lee et al., 1987b). Therefore, it may be necessary to harvest sweet corn when sugar content is highest.

In conclusion, the optimum harvest time of sweet, super sweet, and waxy corns was thought to be between 21 and 24 DAS considering quality and marketing process.

ACKNOWLEDGEMENT

This study was supported by the Korean Ministry of Education through a research fund.

REFERENCES

Boersig, M. R., and F. B. Negm. 1985. Prevention of sucrose inversion during preparation of HPLC sample. HortScience. 20(6): 1054-1056.

Creech, R. G. 1965. Genetic control of carbohydrate synthesis in maize endosperm. Genetics. 52: 1175-1186.

Dale, O., Wilson. Jr., and S. E. Trawatha. 1991. Physiology maturity and vigor in production of 'Florida Staysweet' shurunken-2 sweet corn seed. Crop Sci. 31: 1640-1647.

Garwood, D. L., I. J. Mcardle, S. F. Vanderslice, and J. C. Shanon. 1976. Postharvest carbohydrate transformation and processed quality of high sugar maize genotypes. J. Amer. Soc. Hort. Sci. 101: 400-404.

Glenn, M. I., and J. L. Brewbaker. 1981. Genetic advance through mass selection for tenderness in sweet corn. J. Amer. Soc. Hort. Sci. 106(4): 496-499.

Kang, Y. K., Y. H. Cha, S. D. Kim, and K. Y. Park. 1988. Maturity effects on moisture, total sugar contents and flavor of fresh waxy corn. Korean J. Crop Sci. 33(1): 70-73.

Kientz. J. F., J. K. Greig, and H. L. Mitchell. 1965. Sugar components of sweet corn cultivars as influenced by maturity. Proc. Amer. Soc. Hort. Sci. 87: 313-317.

Kim, S. L., S. U. Park, S. W. Cha, J. H. Seo, and T. W. Jung. 1994. Changes of major quality characters during grain filling in waxy corn and super sweet corn. Korean J. Crop Sci. 39(1): 73-78.

Lee, S. S., T. J. Kim, and J. S. Park. 1987a. Sugars, soluble solids and flavor as influenced by maturity of sweet corn. Korean J. Crop Sci. 32(1): 86-91.

Lee, S. S., S. J. Lee, and D. Y. Kim. 1987b. Quality of sweet corn stored at different temperatures and duration. Korean J. Crop Sci. 32(2): 137-143.

Toshiaki, M., S. Tutimoto, M. Ogura, and T. Iio. 1991. Changes in chemical components in sweet corn(cv. Golden Earlipark) kernels during maturation. Nippon Shokuhin Kogyo Gakkaishi Vol. 38(9): 758-764.

Winter, J. D., R. E. Nylund, and A. F. Legun. 1955. Relation of sugar content to flavor of sweet corn after harvest. Proc. Amer. Soc. Hort. Sci. 65: 393-395.

Yoshida, D. A., Forno, J. H. Cook, and K. A. Gomez. 1972. Laboratory manual for physiological studies of rice (2nd ed). IRRI. Los Banos, Philippines.

Willson, D. O. Jr., and S. E. Trawatha. 1991. Physiological maturity and vigor in production of 'Florida Staysweet' shrunken-2 sweet corn seed. Crop Sci. 31: 1640-1647.

Wolf, M. J., I. M. Cull, J. L. Helm, and M. S. Zuber. 1969. Measuring thickness of excised mature corn pericarp. Agron. J. 61: 777-779.