Influence of sweet corn harvest date on kernels quality

M. Szymanek

Department of Agricultural Machines Sciences, University of Life Science in Lublin, Lublin, Poland

Abstract: Sweet corn has a very short period of optimum harvest maturity, and its quality changes rapidly close to and following the peak. The aim of this study was to determine the sweet corn quality on the ground of some physicochemical properties of intact kernels (moisture content, compression, shear and puncture force, bulk density, sugar and starch contents) and cut kernels (processing recovery, cut corn yield) at four subsequent harvest dates. The moisture content, sugars level, and ear yield decreased. The starch level, bulk density (intact and cut kernels), compression force, shear force and puncture force, processing recovery and cut corn yield increased. The first harvest date showed a greater advantage in the higher sweet corn quality for processing than the following harvest date. The moisture decreased from 77.41% to 69.83% with delayed harvest date. A decline was observed of sweet corn quality (increase of force in compression, shear and puncture tests, raise in the starch level). However, the following harvest date had an advantage in a higher processing recovery and cut corn yield.

Keywords: sweet corn; kernels; quality; physicochemical properties; recovery

Kernel quality can be determined using visual evaluation (shape, size, etc.) and analytical evaluation (moisture content, bulk density, etc.) as well as physical and mechanical properties estimation (Boumans 1985; Korunic *et al.* 1996). The product quality is a major issue in the sweet corn production. High quality sweet corn must be superior in both physical condition and cosmetic appearance. The quality of the raw product predetermines the type of product that will be produced: fancy whole ear pack, fancy freezer, whole kernel, or cream style (Smith 1955). Quality can be defined in many ways. For processing, the primary standard is moisture percentage in the kernels (cut corn). Tenderness and sweetness are the key sensory attributes that determine the overall acceptability of fresh and processed sweet corn (Azanza *et al.* 1994). However, pericarp percentage (thoughness of kernels) and flavour (measured subjectively) are also major quality constituents (Azanza *et al.* 1996). One of the goals of sweet corn producers is to produce sweet corn with a high sugar concentration in the endosperm. In sweet corn, sweetness is the major component of flavour and is affected by the amounts of sugar and starch in the endosperm. Other characteristics of high quality sweet corn are creamy texture and a low starch content (Dickert & Tracy 2001). Sweetness is determined not only by genetics, but also by the way the respective varieties are managed and harvested. Based on the nature of kernel sweetness, sweet corns can also be classified into four basic groups: standard, super sweet, sugary enhanced, and synergistic. Sweet corn for processing is harvested at a relatively immature stage as compared to field corn. Processing of corn is used to increase its shelf life but as a consequence, a significant loss of nutrients may occur via heat degradation or leaching (Scott & Eldridge 2005). Sweet corn for processing is picked at different stages of maturity depending on the way it is to be processed. The corn for freezing is harvested at about the same stage as that for fresh market, while the corn for whole kernel pack and cream-style is harvested at a slightly later stage of maturity (Kadam & Shinde 1998). For whole kernel canning and freezing, optimum kernel moisture ranges from 70% to 76%. For cream-style canning corn, optimum kernel moisture is about 66%.

Experience showed that it correlated very closely with the moisture percentage and with postharvest grade evaluation Olson (2000). There are many reasons why crops should be harvested at optimal maturity for their specific end uses. An accurate determination of the sweet corn maturity for harvest can ensure the best possible crop yield and quality (Ruan *et al.* 1999).

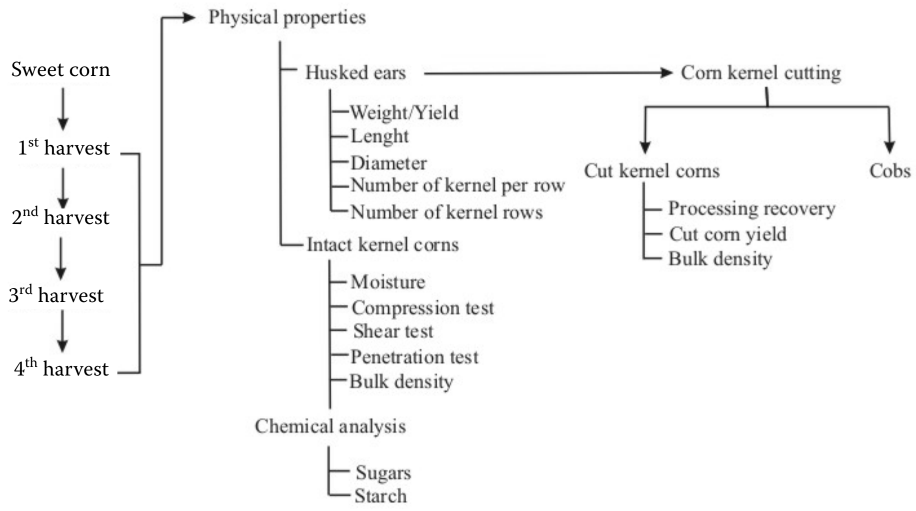

Figure 1. The chart of experimental design

The optimum moisture for harvesting shrunken sweet corn for freezing and canning is no less than 76% and no more than 79%. This compares to the range for standard sweet corn of 70%–72%. Because the shrunken sweet corn loses only about Ľ percent of moisture per 24-hr period at the 76% level as compared to 1% per 24-hr period for standard sweet corn, the harvest window for shrunken corn harvest for a processing line and results in fewer bypassed fields due to planting, mistiming, or weather delay (Olsen *et al.* 1990; Marshall & Tracy 2003). However, according to Warzecha (2003), it is easier to mechanise the harvest of standard sweet corn than that of shrunken sweet corn. The standard sweet corn compares to shrunken varieties mature to longer (Warzecha 2003). Sweet corn has a very short period of optimum harvest maturity, and its quality changes rapidly close to and following the peak. Ears harvested immature will have a small diameter, a poor cob fill, and kernels that are watery and lack sweetness. At optimum harvest maturity, the kernels are plump, sweet, milky, tender, and nearly of maximum sizes. After optimum harvest maturity has been reached, the eating quality of sweet corn begins to decrease rapidly, while the husk appearance changes very little. Overmature corn is rather starchy than sweet, tough, and the kernels are often dented (Motes *et. al.* 2007). However, according to Kumari *et al.* (2007), the unfavourable correlation coefficients between the sugar content and grain weight suggested that it is difficult to obtain high-yielding sweet corn hybrids of good quality.

The objective of this research was to determine the effect of sweet corn harvest date on kernels quality. The quality of sweet corn was determined on the basis of some physical and chemical properties of intact kernels (moisture content, compression, shear and puncture force, bulk density, sugars and starch contents) and cut kernels (processing recovery, cut corn yield, bulk density). Additional objectives were to determine the ear yield, length, ear diameter, number of kernels per a row, and number of kernel rows.

MATERIALS AND METHODS

The Boston variety of sweet corn used in the present study was obtained from the crop grown, as a representative of commercial processing, during 2007 in the zone of Warsaw, Poland. When the corn attained optimal maturity for processing (monitored by the moisture content and juice consistency of kernels), harvesting began. Sweet corn harvesting was continued 4 times every 2 days. At the harvest, the ears were randomly manually picked, husked, sorted, inspected, and evaluated for the weight, length, maximum diameter, and kernels number. Then the ear was taken to the processing lab and evaluated for the moisture, sugars and starch contents, strength tests (compression, shear, and puncture), bulk density (intact kernel corns and cut kernel corns), and processing recovery. The corn ear selected for the study was healthy, of a straight shape and a high degree of kernel filling. The chart of the experimental design is presented in Figure 1.

To determine the average size of the sweet corn, a sample of 100 ears was randomly selected. The length and ear diameter were measured using a calliper reading to 0.1 mm. The weight of husked ears was measured using a WPE 2000p balance with an

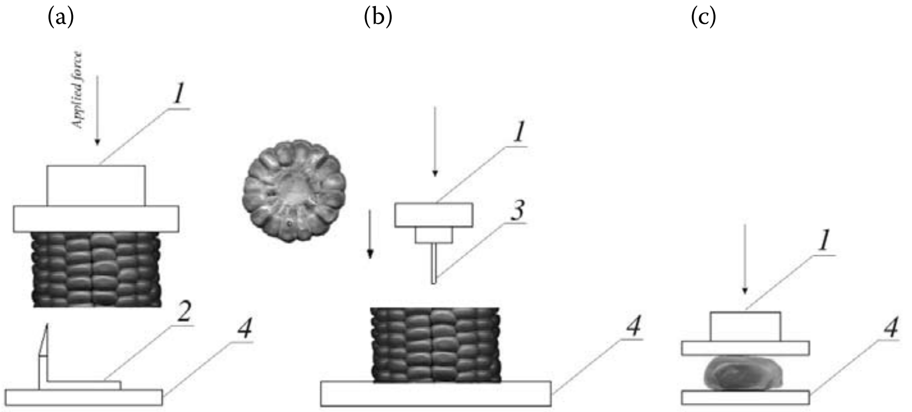

Figure 2. Instron testing machine: (a) shear test, (b) puncture test, (c) compression test: 1 – crosshead, 2 – knife, 3 – plunger, 4 – plate

accuracy of 0.1g. The yield of husked ears was determined according to Wong *et al.* (1994).

The moisture content was determined according to standard methods (ASAE Standards 1996).

The average bulk density of the intact and cut kernels corns was determined using the standard test weight procedure AOAC method (AOAC 1980). This involved the filling of a 500 ml cylinder with kernels from a height of 15 cm at a constant rate and then weighing the content.

A universal testing machine INSTRON 6022 equipped with a 200 N load cell at a crosshead speed of 50 mm/min was used for the compression, shear and puncture tests of the intact corn kernel. The shearing and puncture tests (Figure 2a, b) were made on the kernels on the cob (around 6 cm long pieces of the central cob part). The knife of corn cutting machine SC-120 FMC FoodTech was used in the shearing test. In the puncture test a 2 mm diameter steel plunger was used. The single kernels, which were removed by hand, were compressed between two flat parallel plates (Figure 2c).

The measurements were carried out on a sample of 30 kernels in each test. The typical force-deformation curves were recorded with an analog recorder and stored for further processing using a high-speed data acquisition system. The measurement accuracy was ± 0.01 N in force and 0.001 mm in deformation.

Sugars (total sugars) and starch were extracted in the laboratory and were determined using HPLC.

To determine sugars and starch contents, representative kernels were taken from 30 ears, with 10 kernels randomly selected from each. Three experiments were conducted and the mean values obtained are presented.

The processing recovery was calculated as the percentage of the weight of the husked ears recovered as cut corn. Kernels were detached from the sweet corncob in the cutting machine SC-120 FMC FoodTech. The measurements were taken at the rotational speed of the cutter head of 167.5 rad/s and the linear speed of the cob feeder 0.31 m/s.

The data were analysed by analysis of variance. The means separation was determined by the pro-

Table 1. The mean values of kernels moisture content, ear yield, ear length, ear diameter, number of kernels per row, number of kernel rows, and bulk density with standard deviations in parentheses

Particular	Harvest date				LSD α = 0.05
	1st	2nd	3rd	4th	
Moisture content (%)	77.41^{a} (0.95)	75.62^{ba} (0.88)	72.31^{c} (1.05)	69.83^{d} (1.09)	2.05
Yield (t/ha)	18.64^{a} (1.15)	17.98^{ba} (1.21)	16.31^{c} (0.98)	15.88^{dc} (1.11)	1.20
Length (cm)	22.21 (2.09)	–	–	–	–
Max. diameter (cm)	4.94 (0.98)	–	–	–	–
Number of kernels per row	28.05 (1.57)	–	–	–	–
Number of kernel rows	14.72 (1.54)	–	–	–	–
Bulk density (kg/m^3)	612.21^{a} (9.12)	619.54^{ba} (8.65)	624.36^{cb} (10.21)	634.54^{d} (8.86)	9.36

Numbers in the same line followed by the same letter are not significantly different at $P < 0.05$.

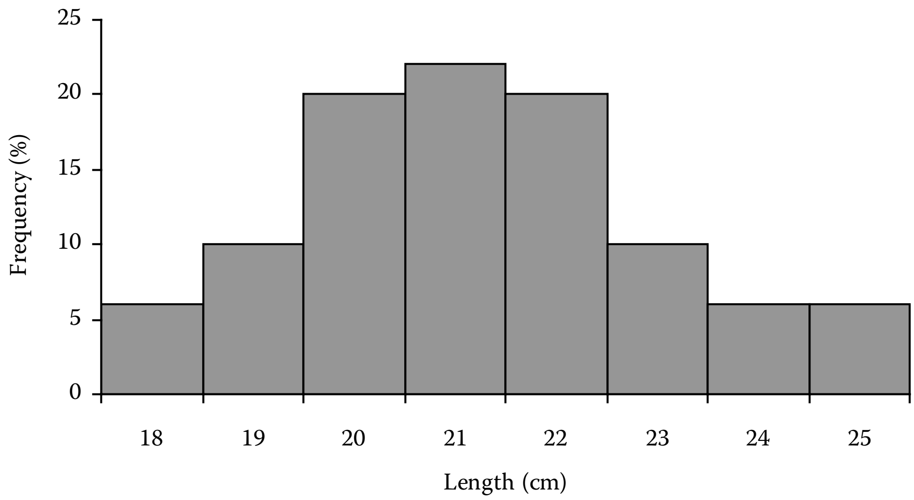

Figure 3. Frequency distribution curves of husked corns length at 1st date of harvest

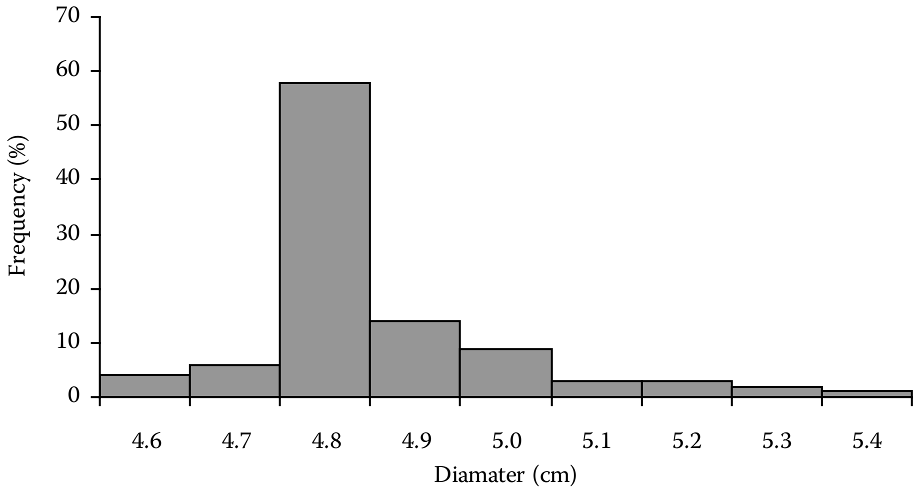

Figure 4. Frequency distribution curves of husked corns max. diameter at 1st date of harvest

tected least significant difference test. The data were subjected to analysis of variance (ANOVA). The comparison of means was conducted with the Tukey's least significant difference (LSD) test, at a significance level $P = 0.05$. The results are expressed as the mean standard deviations.

RESULTS AND DISCUSSION

The results of sweet corn ear size measurements at different harvest dates are presented in Table 1. The mean size of 100 husked ears measured at the first harvest date was: length 22.21 ± 2.09 cm and max. diameter 4.94 ± 0.98 cm. The yield decreased from 18.64 to 15.88 t/ha, while the moisture content of kernels decreased from 77.41% to 69.83%. A similar decrease of the moisture content with increasing harvest maturity was reported by Kulvadee and Chowladda (1997), and Wong *et al.* (1994).

The bulk density of intact kernels varied from 612.21 to 635.54 kg/m^3 and the bulk density of cut kernels from 585.51 to 609.11 kg/m^3 at different

Table 2. The means values of compression, shear and puncture force (in N) with standard deviation in parentheses

Particular	Harvest date				LSD α = 0.05
	1st	2nd	3rd	4th	
Compression force	29.48^{a} (1.78)	35.54^{ba} (1.32)	42.71^{c} (1.54)	49.56^{dc} (1.23)	7.11
Shear force	8.21^{a} (0.28)	10.41^{ab} (0.32)	12.34^{cb} (0.41)	15.21^{dc} (0.37)	3.21
Puncture force	9.11^{a} (0.18)	12.65^{ba} (0.19)	15.28^{cb} (0.17)	17.23^{dc} (0.21)	4.56

Numbers in the same line followed by the same letter are not significantly different at $P < 0.05$.

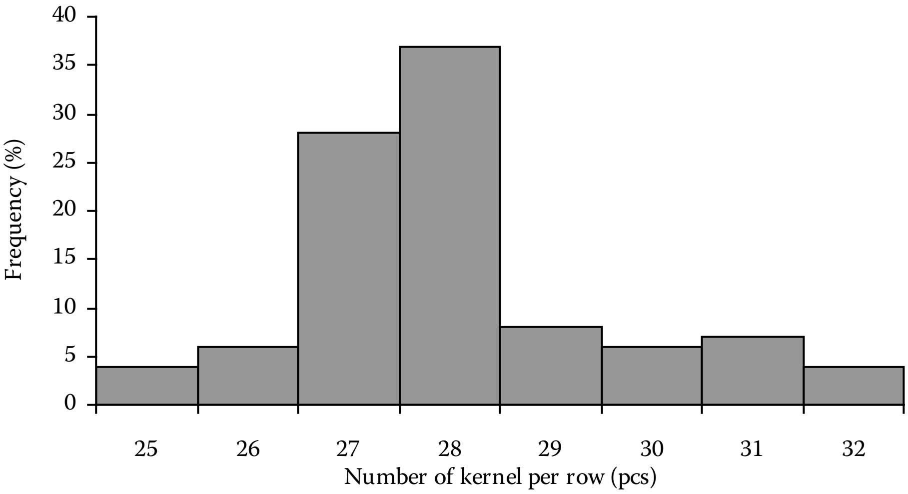

Figure 5. Frequency distribution curves of number of kernels per row at 1st harvest date

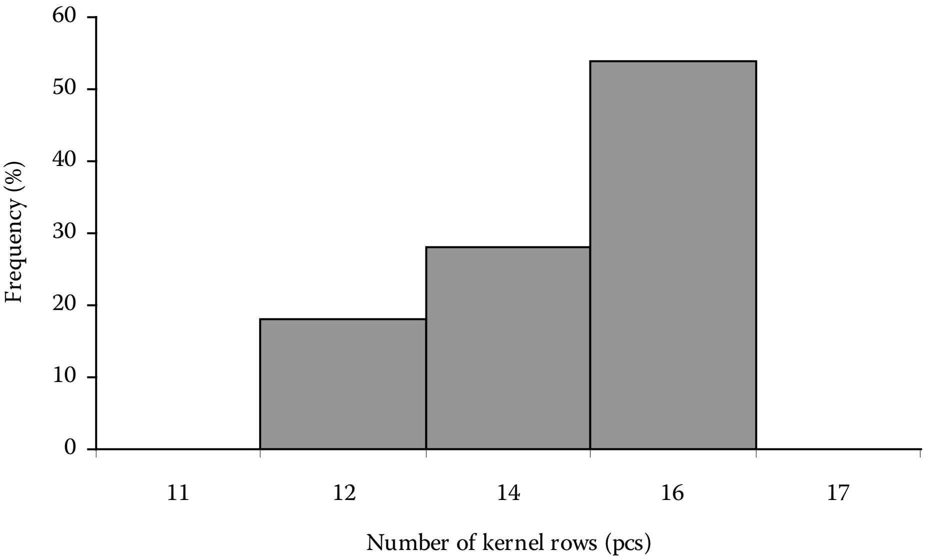

Figure 6. Frequency distribution curves of number of kernel rows at 1st harvest date

dates of harvest (Table 1). A similar trend in bulk density was reported by Coskun *et al.* (2006).

Figures 3–6 show the frequency distribution curves for the means values of the length, diameter, number of kernels per row, and rows. The frequency distribution curves show a trend towards a normal distribution. About 62% of the husked corns had a length ranging from 20 to 23 cm; about 58%, had maximum diameter ranging from 4.8 to 4.9 cm, about 65%, had the number of kernels per row ranging from 27 to 28 pcs, and about 54% had about 16 kernel rows.

At all harvest dates (moisture contents), increased deformation was observed with an increase in the applied forces (Table 2). The hull rupture is marked by an audible "click", and a sudden decrease of the force occurs. The point marked by the abrupt force decrease is often called the bio-yield point (Lu *et al.* 2005), and the loading is stopped once this point has been reached. The measured parameters were

Table 3. The means values of total sugars and starch levels (in %) with standard deviations in parentheses

Particular	Harvest date				LSD α = 0.05
	1st	2nd	3rd	4th	
Total sugars	6.24^{a} (0.24)	5.92^{ba} (0.21)	5.54^{c} (0.19)	5.11^{d} (0.18)	0.41
Starch	14.49^{a} (0.22)	16.21^{ba} (0.24)	18.70^{c} (0.21)	22.19^{d} (0.23)	2.24

Numbers in the same line followed by the same letter are not significantly different at $P < 0.05$.

Table 4. The means values of processing recovery, cut corn yield, and bulk density with standard deviations in parentheses

Particular	Harvest date				LSD α = 0.05
	1st	2nd	3rd	4th	
Processing recovery (%)	41.14[a] (3.48)	43.13[ba] (3.98)	48.25[cb] (4.11)	50.02[dc] (4.02)	6.86
Corn cut yield (t/ha)	7.67[a] (0.13)	7.75[ba] (0.11)	7.86[cb] (0.10)	7.94[dc] (0.12)	0.13
Bulk density (kg/m^3)	585.51[a] (9.42)	592.31[ba] (9.12)	601.74[cb] (9.06)	609.11[dc] (9.21)	12.36

Numbers in the same line followed by the same letter are not significantly different at $P < 0.05$.

the rupture force, when the kernel hull undergoes failure during compression, shear and puncture, deformation up to the rupture point.

The force required for the hull rupture increased as the moisture content decreased. At the moisture content ranging from 77.41% to 69.83%, the compression force increased from 29.48 to 49.56 N, the shear force increased from 8.21 to 15.21 N, and the penetration force increased from 9.11 to 17.23 N. Burton (1982) reported that the average puncture tensile strength forces increased with a later harvest date.

During the period when sweet corn ears were suitable for harvesting and the kernel moisture was decreasing, total sugars content decreased from 6.24% to 5.11% and the starch content increased from 14.49% to 22.19% (Table 3).

It was observed that the harvest date affects total sugars and starch levels. The mean values of total sugars and starch were not significantly different only between 1st and 2nd harvest dates (Table 3). A similar trend was reported by Simonne *et al.* (1999), Suk and Sang (1999), Waligóra (2002), and Liu-Peng *et al.* (2003).

The processing recovery and cut corn yield increased (from 41.14% to 50.02%, and 7.67 to 7.94 t/ha, respectively) with different harvest dates (Table 4).

The explanation for this increase in recovery could be found in the decrease of themoisture level and increase of the starch content. Michalsky (1986) found that a lower average moisture content and a higher starch level make easy the mechanical cutting the kernel off the cob and reduce the losses of the kernel flesh. This is why the sweet corn intended for the whole kernel canning is harvested at a lower moisture content than that destined for frozen – style corn. Although the cut corn yield was the highest at the lowest moisture content (69.83%), it was observed that some single kernels began to wrinkle. A similar result was reported by Olson (2000), who found that that the highest quality cut corn from most of the standard sweet corn hybrids would be obtained at the kernel moisture level of 72% to 73%. At 74% to 75% moisture content, the flavour and taste were good but the kernel size and uniformity, colour, and cut-corn yield of the standard sweet hybrids might be below par. At 70% to 71%, the critical dividing point, the yield was higher but the cut corn would appear to be older (large; darker yellow kernels) and might be tougher.

CONCLUSION

The delay of the corncobs harvest date affected the sweet corn quality. The moisture content, sugars level and ear weight decreased. The bulk density (intact and cut kernels), compression, shear and puncture force, starch content, processing recovery, and cut corn yield increased. The first harvest date proved to be more advantageous due to a higher sweet corn quality for processing than the following harvest date. It was observed that the analysed key attributes of the sweet corn quality for processing, that is moisture and sugars contents had the highest values at this time. When the moisture content decreased from 77.41% to 69.83% with delayed harvest date, a decline was observed in the sweet corn quality (increase of force in compression, shear and puncture tests, rise of the starch level). However, the following harvest date had an advantage in a higher processing recovery and a higher cut corn yield.

References

AOAC (1980): Official Methods of Analysis. 13th Ed. Association of Official Analytical Chemists, Washington, DC.

ASAE Standards (1996): S352.2. Moisture Measurement – Unground Grain and Seeds. 4rd Ed. ASAE , St. Joseph.

Azanza F., Juvik J.A., Klein B.P. (1994): Relationships between sensory quality attributes and kernel chemical composition of fresh-frozen sweet corn. Journal of Food Quality, **17**: 150–172.

Azanza F., Klein B.P., Juvik J.A. (1996): Sensory characterization of sweet corn lines differing in physical and chemical composition. Journal of Food Science, **61**: 253–257.

Boumans G. (1985): Grains, oilseeds, derivatives and substitutes. In: Grain Handling and Storage. Elsevier Science Publishers, Amsterdam, 7–23.

Burton L.V. (1982): The measurement of maturity of country gentlemen corn. Canner, **54**: 27–29.

Coşkun M.B, Yalç Ý., Őzarslan C. (2006): Physical properties of sweet corn seed. Journal of Food Engineering, **74**: 523–528.

Dickert T.E., Tracy W.F. (2001): Irrigation and sugar in sweet corn. In: Wisconsin Fertilizer, Aglime, and Pest Management Conf. Proc. Available at http://www.soils.wisc.edu/extension/FAPM/2001.php.

Kadam S.S., Shinde K.G. (1998): Other crucifers. In: Salunkhe D.K., Kadam S.S. (eds): Handbook of Vegetable Science and Technology: Production, Composition, Storage, and Processing. Marcel Dekker, Inc., New York, 359–371.

Korunic Z., Fields P.G., Kovacs M.I, Noll J.S., Lukow O.M., Demianyk C.J., Shibley K.J. (1996): The effect of diatomaceous earth on grain quality. Postharvest Biology and Technology, **9**: 373–387.

Kulvadee T., Chowladda T. (1997): Effect of harvesting period on field and quality of Cannes whole kernel sweet corn. Food, **27**: 248–254.

Kumari J., Gadag R.N., Jha G.K. (2007): Genetic analysis and correlation in sweet corn (*Zea mays*) for quality traits, field emergence and grain yield. Indian Journal of Agricultural Sciences, **77**: 613–615.

Liu-Peng, Hu-Chang Hao, Dong-Shu Ting, Wang-Kong Jun (2003): The comparison of sugar components in the developing grains of sweet corn and normal corn. Agricultural Science in China, **2**: 258–264.

Lu R., Srivastava A., Beaudry R. (2005): A new bioyield tester for measuring apple fruit firmness. American Society of Agricultural and Biological Engineers, **21**: 893–900.

Marshall S.W., Tracy W.F. (2003): Sweet corn. In: Ramstad P.E., White P. (eds): Corn Chemistry and Technology. American Association of Cereal Chemists, Minneapolis, 537–569.

Michalsky F. (1986): Zuckermais – ein Gemüse mit Zukunft? Mais, **2**: 40–43.

Motes J.E., Roberts W., Cartwright B. (2007): HLA-6021-Sweet corn production. Available at http://osufacts.okstate.edu.

Olsen J.K., Giles J.E., Jordan R.A. (1990): Post-harvest carbohydrate changes and sensory quality of three sweet corn cultivars. Scienta Horticulturae, **44**: 179–189.

Olson K. (2000): Northland foods: planning the end. International Food and Agribusiness Management Review, **3**: 423–432.

Ruan R.R, Chen P.L., Almaer S. (1999): Nondestructive analysis of sweet corn maturity using NMR, HortScience, **34**: 319–321.

Scott C.E., Eldridge A.L. (2005): Comparison of carotenoid content in fresh, frozen and canned corn. Journal of Food Composition and Analysis, **18**: 551–559.

Simonne E., Simonne A., Boozer R. (1999): Yield, ear characteristics, and consumer acceptance of selected white sweet corn varieties in the southeastern United States. Hort Technology, **1**: 289–293.

Smith G.M. (1955): Sweet corn. In: Sprague G.F. (ed.): Corn and Corn Improvement. Academic Press, New York, 441–463.

Suk S.L., Sang H.Y. (1999): Sugars, soluble solids and flavor of sweet, super sweet and waxy corns during grain filling. Korean Journal of Crop Science, **44**: 267–272.

Waligóra H. (2002): Kukurydza cukrowa i możliwości jej uprawy w Polsce. Wieś Jutra, **47**: 20–23.

Warzecha R. (2003): Słodki smak kukurydzy. Owoce Warzywa Kwiaty, **6**: 20–21.

Wong A.D., Juvik J.A., Breeden D.C., Swiader J.M. (1994): Shrunken sweet corn yield and the chemical components of quality. Journal of the American Society for Horticultural Science, **119**: 747–755.

Received for publication April 3, 2008
Accepted after corrections June 30, 2008

Abstrakt

Szymanek M. (2009): **Vliv termínu sklizně kukuřice cukrové na jakost zrna.** Res. Agr. Eng., **55**: 10–17.

Období optimální sklizňové zralosti kukuřice cukrové je velmi krátké a kvalita sklizeného zrna se rychle mění těsně před optimem a po něm. Cílem této práce bylo stanovení jakosti zrna kukuřice cukrové na základě některých fyzikálně-chemických vlastností jak nepoškozených ručně oddělených zrn (vlhkosti, parametrů tlakového, smykového a penetračního testu objemové hmotnosti, obsahu cukrů a škrobu) tak i zrn vyluštěných (zpracovatelská výtěžnost, výnos luštění) a to ve čtyřech následných termínech sklizně. Vlhkost, obsah cukrů a celková hmotnost klasů se snižovaly, obsah škrobu, objemová hmotnost (jak ručně oddělených tak vyluštěných zrn), a „tvrdost" z mechanických testů se zvyšovaly, právě tak i zpracovatelská výtěžnost a výnos vyluštěných zrn. První sklizňový termín byl výhodnější než následné termíny z hlediska vyšší zpracovatelské jakosti kukuřice. Pozdější termín sklizně vedl k poklesu obsahu vlhkosti ze 77,41 % na 69,83 % a došlo ke zhoršení jakosti zrna (zvýšení "tvrdosti" v mechanických testech a zvýšení obsahu škrobu). Výhodou pozdějšího termínu sklizně byl však vyšší zpracovatelský výnos a výtěžek vyluštěných zrn.

Klíčová slova: kukuřice cukrová; zrna; jakost; fyzikálně-chemické vlastnosti; výtěžek

Corresponding author:

Mariusz Szymanek, Ph.D., University of Life Sciences in Lublin, Department of Agricultural Machines Science, Gleboka 28, 20-612 Lublin, Poland
tel.: +081 445 61 34, fax: +081 532 94 63, e-mail: mariusz.szymanek@up.lublin.pl