Kernel quality can be determined using visual evaluation (shape, size, etc.) and analytical evaluation (moisture content, bulk density, sugar and starch contents) 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).
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 1 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 caliper reading to 0.1 mm. The weight of husked ears was measured using a WPE 2000p balance with an
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 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

<table>
<thead>
<tr>
<th>Particular</th>
<th>1&lt;sup&gt;st&lt;/sup&gt;</th>
<th>2&lt;sup&gt;nd&lt;/sup&gt;</th>
<th>3&lt;sup&gt;rd&lt;/sup&gt;</th>
<th>4&lt;sup&gt;th&lt;/sup&gt;</th>
<th>LSD α = 0.05</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture content (%)</td>
<td>77.41&lt;sup&gt;a&lt;/sup&gt; (0.95)</td>
<td>75.62&lt;sup&gt;bc&lt;/sup&gt; (0.88)</td>
<td>72.31&lt;sup&gt;c&lt;/sup&gt; (1.05)</td>
<td>69.83&lt;sup&gt;d&lt;/sup&gt; (1.09)</td>
<td>2.05</td>
</tr>
<tr>
<td>Yield (t/ha)</td>
<td>18.64&lt;sup&gt;a&lt;/sup&gt; (1.15)</td>
<td>17.98&lt;sup&gt;bc&lt;/sup&gt; (1.21)</td>
<td>16.31&lt;sup&gt;c&lt;/sup&gt; (0.98)</td>
<td>15.88&lt;sup&gt;d&lt;/sup&gt; (1.11)</td>
<td>1.20</td>
</tr>
<tr>
<td>Length (cm)</td>
<td>22.21 (2.09)</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Max. diameter (cm)</td>
<td>4.94 (0.98)</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Number of kernels per row</td>
<td>28.05 (1.57)</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Number of kernel rows</td>
<td>14.72 (1.54)</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Bulk density (kg/m&lt;sup&gt;3&lt;/sup&gt;)</td>
<td>612.21&lt;sup&gt;a&lt;/sup&gt; (9.12)</td>
<td>619.54&lt;sup&gt;bc&lt;/sup&gt; (8.65)</td>
<td>624.36&lt;sup&gt;ab&lt;/sup&gt; (10.21)</td>
<td>634.54&lt;sup&gt;d&lt;/sup&gt; (8.86)</td>
<td>9.36</td>
</tr>
</tbody>
</table>

Numbers in the same line followed by the same letter are not significantly different at P < 0.05.
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/m³ and the bulk density of cut kernels from 585.51 to 609.11 kg/m³ at different harvest dates.

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

<table>
<thead>
<tr>
<th>Particular</th>
<th>1st</th>
<th>2nd</th>
<th>3rd</th>
<th>4th</th>
<th>LSD ( \alpha = 0.05 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compression force</td>
<td>29.48*(1.78)</td>
<td>35.54ab (1.32)</td>
<td>42.71c (1.54)</td>
<td>49.56bc (1.23)</td>
<td>7.11</td>
</tr>
<tr>
<td>Shear force</td>
<td>8.21a (0.28)</td>
<td>10.41ab (0.32)</td>
<td>12.34b (0.41)</td>
<td>15.21bc (0.37)</td>
<td>3.21</td>
</tr>
<tr>
<td>Puncture force</td>
<td>9.11a (0.18)</td>
<td>12.65bc (0.19)</td>
<td>15.28bc (0.17)</td>
<td>17.23bc (0.21)</td>
<td>4.56</td>
</tr>
</tbody>
</table>

Numbers in the same line followed by the same letter are not significantly different at \( P < 0.05 \).
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 (Lv 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

<table>
<thead>
<tr>
<th>Particular</th>
<th>Harvest date</th>
<th>LSD α = 0.05</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1st</td>
<td>2nd</td>
</tr>
<tr>
<td>Total sugars</td>
<td>6.24a (0.24)</td>
<td>5.92ba (0.21)</td>
</tr>
<tr>
<td>Starch</td>
<td>14.49a (0.22)</td>
<td>16.21ba (0.24)</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Particular</th>
<th>Harvest date</th>
<th>LSD α = 0.05</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1&lt;sup&gt;st&lt;/sup&gt;</td>
<td>2&lt;sup&gt;nd&lt;/sup&gt;</td>
</tr>
<tr>
<td>Processing recovery (%)</td>
<td>41.14&lt;sup&gt;a&lt;/sup&gt; (3.48)</td>
<td>43.13&lt;sup&gt;b&lt;/sup&gt; (3.98)</td>
</tr>
<tr>
<td>Corn cut yield (t/ha)</td>
<td>7.67&lt;sup&gt;a&lt;/sup&gt; (0.13)</td>
<td>7.75&lt;sup&gt;bc&lt;/sup&gt; (0.11)</td>
</tr>
<tr>
<td>Bulk density (kg/m&lt;sup&gt;3&lt;/sup&gt;)</td>
<td>585.51&lt;sup&gt;a&lt;/sup&gt; (9.42)</td>
<td>592.31&lt;sup&gt;ab&lt;/sup&gt; (9.12)</td>
</tr>
</tbody>
</table>

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 1<sup>st</sup> and 2<sup>nd</sup> 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 corn cobs 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 content). However, the following harvest date had an advantage in a higher processing recovery and a higher cut corn yield.

References


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**Abstrakt**


Období optimální sklizňové zralosti kukuřice cukrové je velmi krátké a kvalita sklízeného zrna se rychle mění těsně před optimalizem a po něm. Cílem této práce bylo stanovení jakosti zrna kukuřice cukrové na základě některých fyziologických a chemických vlastností jako například tlačového parametru tlakového a penetračního testu objemové hmotnosti, obsahu cukrů a škrobu, tvaru zrn, výnos užití a továrnačích následných termínech sklizně. Vlhkost obsahu cukrů a celková hmotnost klasů se snížila, obsah škrobu a objemová hmotnost zrn se zvýšila, přesně jako také výnos užití a obsah škrobu. První sklizňový termín byl určen při výsledcích snížení vlhkosti, obsahu cukrů a škrobu výrazně a případně také výškou výnosu užití a objemovou hmotností zrn.


Obiodo optimalnog sklizn'ovog razloga kuku'rice cukrov'oe je velmi kratko a kvalita sklizenog zrnama se rychle meni tespno pred optimalizom i po nema. Cilom toto prava bio stanovenje jakosti zrna kuku'rice cukrov'oe na zisk na nektar fizi'ologichih i kemichih vlastnosti kao napriklad tlakovih parametara tlakoveg a penetračnog testa objemovih hmotnosti, obsaha cucur'a i škroba, tvaru zrna i pravo užitka i továrnickih naslednih terminech sklejanja. Vlakost, obsah cucur'ih i celovih hmotnosti klasa se snizila, obsah škroba i objemova hmotnost zrna se zvishila, prav'e tak i výnos využitenih zrn. Prvnji sklizno'vij termin

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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

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