Centre of Excellence AGROPHYSICS
for Applied Physics in Sustainable Agriculture

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Harvest and Technology
Physical Properties and Quality

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PREFACE

The monograph was prepared in the frame of activity of the Centre of Excellence for Applied Physics in Sustainable Agriculture with the acronym Agrophysics. The authors are grateful to the 5th EU Framework for Research, Technological Development and Demonstration Activities, which founded the Centre of Excellence and to dr. eng. Andrzej Stępniewski – coordinator of CE, who prepared this project and is a person responsible for contact with Commission of EU. We also owe thanks and appreciation to General Supervisor of the Centre - prof. dr. Ryszard T. Walczak, a member of Polish Academy of Sciences for the opportunity of editing, presented herein work. The monograph is in the area of interest of Work Package 9 - Physical Methods of Evaluation of Fruit and Vegetable Quality, leaded by prof. dr. eng. Bohdan Dobrzański, Jr., who is also co-author of this work.

This is a book about sweet corn. Sweet corn belongs to the species as a most remarkable cereal grain, *Zea mays* L., or maize, or as it is better known in North America, corn. Corn is one of the major cereal crops in the world and its grain is used in the production of cornflakes and other breakfast cereals, popcorn, and – in the form of corn flour - for bread baking, but sweet corn is grown and sold as a vegetable. Sweet corn cobs, cylindrical in shape, have lengths of 20 to 25 cm. Beneath the cob husks there are parallel rows of yellow-gold kernels, with delicate threads running along the kernel rows towards the tip of the cob. The kernels, with sweet and milky meat, have a delicate skin. The harvest of sweet corn cobs begins when the kernels attain moisture content of 70-75 %. For processing purposes, corn kernels are acquired in the process of their cutting off corn cobs. Sweet corn is a highly valuable plant with almost universal application in human nutrition. An important feature of sweet corn is its lack of gluten, which – with the increasing number of food allergies – may have a significant effect on its growing consumption. Increased demand may, in turn, result in an increase in the area of corn sowing. The climate and soil conditions on most of the territory of Poland are favourable for corn growing, and therefore sweet corn production can be successfully conducted all over the country.

At present the production of sweet corn fully satisfies the market demand which is low due to a lack of consumer habits. The scope of sweet corn growing in Poland is not determined by economic reasons or by the production capacity of farms. The level of production is determined primarily by the demand and by the possibility of utilization of the crops obtained. Barriers limiting corn production include also a lack of well organized national market for sweet corn as a raw material and an insufficient level of development of the processing and cold storage industries.

In chapter 1, the authors describes origin of sweet corn and its economic significance, beginnings of sweet corn cultivation and the World's leading producers and exporters of fresh and processed sweet corn. Raw material overview covers market trends and development, the market in majors producers as France, Thailand and Hungary. Production, supply and demand consumption and trade, as well as, directions of use and nutritional value of sweet corn kernels are also presented. Agricultural requirements for sweet corn cultivation, climatic and soil requirements, tillage and fertilization, sowing and plant care fulfil chapter 2. In chapter 3, readers can find characterization of sweet corn varieties including: sweet (sugary) varieties, varieties with increased (enhanced) content of sugars, super sweet varieties. As an example is shown Syngenta list of varieties such as: sweet corn varieties, yellow, white and bicolor sweet corn hybrids and supersweets hybrids, as well as, TripleSweet with comparison to others varieties and explanation what is a TripleSweet.

Sweet corn kernel structure, chemical composition, and sensory qualities are submitted in chapter 4. In chapter 5 are printed standards and definitions, test procedures, estimation of physical and chemical properties of sweet corn. Mechanical properties of sweet corn kernels, the methods of study under quasi-static conditions at shearing, penetration and compression test, as well as study at dynamic conditions are presented in chapter 6. Energy consumptions, measurement of kernel cut-off process efficiency and method for the measurement of the degree of corn kernel mass detachment are indicated as useful for the measurement of the share of kernel fractions and kernel quality at cut-off process.

Methods of sweet corn cob harvest and sweet corn cob processing technology, corncob husking equipment, cutters and equipment for cut-off the sweet corn kernel are presented in chapters 7 and 8. The effect of harvest time on quality, physical properties and detachment process of sweet corn kernels its quality and sugar content, the effect of storage and blanching conditions on the mechanical properties and on the cutting process of sweet corn kernels, as well as, cutting efficiency and kernel quality, effect of cob blanching on the energy consumption and efficiency of the cutting process are described in chapter 9. Postharvest cooling freezing and handling of sweet corn are separated in subchapter 9.3. Labour, costs and effects in sweet corn production are included in Chapter 10. In Chapter 11 are submitted some utilization ways (Baking, Boiling, Grilling, Microwave) of sweet corn in human nutrition and tips for preparation of dishes with sweet corn kernel as a major ingredient. Summary and conclusions – chapter 12. The monograph is decorated and equipped with colour photo appendix (chapter 13), presenting sweet corn on the field, and at harvest and processing.

This monograph presents some methodological aspects of the process of sweet corn kernel cutting off cobs, and studies focused on the physical properties of corn kernels that are important from the viewpoint of kernel cutting, as well as studies concerned with settings of the working parameters of cutters and their effect on the efficiency of the kernel cutting process. The monograph discusses also the requirements of sweet corn in terms of tillage, and a characterization of sweet corn cultivars available on the Polish market. Also discussed are the methods of corn cob harvesting and the techniques of cob processing, and an analysis is made of the mechanical process of kernel separation from cob cores, as well as an evaluation of the effectiveness of the production of the crop in Poland. Experimental studies presented herein covered the determination of selected physical properties of sweet corn cobs, and especially of the mechanical properties of kernels of cultivars included in the studies, the effect of cutter parameters on the quality of the kernel cutting, estimation of the suitability of particular cultivars and assessment of losses in the process of kernel cutting, as well as the technical and technological aspects of corn growing under the conditions of Polish agriculture, and the methods applied for sweet corn cob harvest and processing, both with relation to corn for direct consumption and for the processing industry. Also presented is an estimation and analysis of the effectiveness of sweet corn production as determined by process characteristics and by changes in the mechanical properties of kernels and cobs of sweet corn in the process of kernel cutting.

The study of the mechanical properties of corn kernels was performed under quasi-static and dynamic conditions. Tests of kernel cutting, penetration and compression were made with the help of an Instron strength tester, recording such parameters as force, energy, modulus of elasticity, and relative strain. Shearing force and energy required to cut kernels off cobs was recorded up to the moment of reaching the maximum values of force. Kernel cutting off cobs under dynamic conditions was effected on a test stand equipped with a kernel cutter. Studies on the effect of the cutting rate, the cob feeder speed and the head rotary speed on corn kernels acquisition efficiency were conducted in the process of kernel cutting off cobs. The determinations included the energy consumption, degree of seed cutting, share of kernels of various sizes, and quality of kernels obtained in the process of cutting. The mechanical properties of corn kernels determined in selected tests proved the strong effect of limit values of the parameters as well as of kernel orientation on the process of cutting. The results showed that the speed of the cutter head had a significant effect on the values of force and energy, and on the efficiency of sweet corn kernel cutting. Increase in the cutter head and feeder speeds resulted in a drop in the unit process energy by an average of 76% (within the range from 92 to 40%), and in the share of kernels of poorer quality by about 70% (from 81 to 66%). On the other hand, increase in the values of the working parameters of the cutter caused an increase in the mass of kernels acquired by about 40% (from 23 to 58%). A positive effect of the depth of cutting was observed (toward the cob axis), which caused an increase in the cutting energy required. Kernel cutting as close to the cob core as possible results not only in an increase in the kernel mass obtained, but also in an increase in the sugar content in the kernel mass shorn due to the fact that in this case the cutting involves also kernel parts with a high sugar content. Results obtained in the course of the experiments showed that the efficiency of the kernel cutting process may be increased also through alteration of the cutter parameters, and the results can be implemented in practice. Mathematical models permit the explanation of the effect of factors studied in the process of corn kernel cutting off cobs and may provide a basis for optimisation of the process, with energy consumption and raw material quality remaining as the primary criteria.

The level and quality of the crop yield are determined by the choice of cultivars suitable for given site conditions, by optimum time of sowing, rational mineral fertilization, and comprehensive protection of the plantation against weeds, diseases and pests. Machines used in the cultivation, sowing and care of sweet corn are commonly available and generally used for the cultivation of fodder corn and cereals. As to harvesting, corn cobs can be collected by hand or mechanically, with the help of trailer-type or self-propelled combines. The process of kernel separation from cob cores requires the application of cutters. Hence the process of kernel cutting is significantly dependent on the mechanical properties of both the kernels and the cobs of sweet corn. The technological value of the kernels obtained depends, in turn, on harvest techniques and technology and on cob processing.

The production of sweet corn can be relatively profitable, provided the cobs produced can be readily sold. High commercial risk is involved especially in the production of sweet corn for direct consumption. In production for industrial purposes, the success of the plantation is determined by such factors as its location within a reasonable distance from the processing plant and favourable contractual terms and conditions. At the present level of profitability, increase in the production of sweet corn, and therefore increase in the profitability of farms, is possible if there is a growth in domestic demand and in access to new markets.

Although other books on the harvest and technology of sweet corn have been published, none is recent. Much new knowledge is contained in this book. Anyone interested in any aspect of sweet corn research and development, marketing, utilization, etc., should find this monograph useful. The editors, as representatives of the Centre of Excellence, are grateful to each of the authors and reviewer. We also wish to thank the Institute of Agrophysics staff - in person of prof. dr. Ryszard T. Walczak, member of Polish Academy of Sciences – director of the Institute and deputy director for scientific affair - prof. Józef Horabik, for their advice, help, and technical editing.

INTRODUCTION

Corn as a plant is characterized by an abundance of forms with highly differentiated features, both botanical and of utility character. Among the numerous corn subspecies grown, sweet corn (*Zea mays ssp. saccharata*) has become more and more important. Its taste and nutritional value has made it a valued crop in all countries, and the scope of cron production is constantly increasing. Sweet corn has been known since the 18th century. It is a corn subspecies that is mostly used for consumption and is classified among vegetable plants. As a vegetable, it arrives at the fresh produce market for direct consumption, to the fruit and vegetable processing industry for frozen and caned foods, and for industrial processing. It is a crop plant and it is totally domesticized, with no wild growing varieties to be found anywhere. It is protected from self-seeding by the strong attachment of kernels on the cob core and by the fact that the cob is enclosed in several layers of cover leaves, rendering kernel shedding impossible [20,60,76,140,155].

Sweet corn requires the application of suitable breeding and cultivation measures. It cannot develop without human intervention. The soil and climate requirements of sweet corn are similar to those of fodder corn. In Poland it can be grown over the whole territory of the country, with the exception of the north-eastern regions. It is the most popular in the south and east of the country. The area of corn growing increases systematically, and at present amounts to about 3500 hectares. However, sweet corn consumption in Poland is still low, not exceeding 1 kg per person. A lack of tradition in sweet corn cultivation and consumption and problems related with selling the produce constitute a barrier to a broad expansion of the valuable crop plant in this country [34,67,127,151].

Sweet corn is a preishable product that has to be delivered onto the market in the form of fresh cobs, or to processing plants in the form of corn kernels for canned or frozen foods, as soon after the harvest as possible. In this country sweet corn ripens in August and September. To extend the supply season for cobs for direct consumption various measures are applied, including varied times of sowing, choice of cultivars with different times of ripening, or soil covering with foil [7,39,73].

The climatic and soil conditions in Poland are favourable for sweet corn production. The fact that sweet corn provides valuable, tasty and healthy food for people and fodder for farm animals makes the crop highly prospective for cultivation. It can be consumed throughout the year and used in the preparation of a variety of dishes, thus improving the diversity of our diet. In this situation, the possibility of extensive utilization of sweet corn as a vegetable indicates the advisability of expanding its production in Poland. It is also a known fact that it is a vegetable rich in proteins, vitamins, moicroelements and sugars and therefore deserves greater popularity [34,73,143,148,152,153].

In receent years there has been an increase in the number of Polish farms interested in sweet corn as a crop. This is related to the appearance on the market of new hybrids that provide good crop yields under our climate and soil conditions. Average yield of cobs with cover leaves are on the level from 12 to 18 $t \cdot ha^{-1}$, with kernel water content of 72–76%, while the yield of cobs may attain the level of 40–60 thousand $cobs \cdot ha^{-1}$. Current market availability includes over 40 hybrid cultivars of sweet corn that can be successfully grown in this country [1, 57, 68, 86, 145, 150].

In the technologies of sweet corn production used so far, in most cases cobs were collected by hand. Only in recent years there appeared in Poland high efficiency combines for the harvest of corn cobs. Also the fruit-and-vegetable plants involved in processing sweet corn seed use better and better technological lines for corn cob processing. Therefore, the continuing increase in production causes the search for new and more efficient methods for sweet corn production, harvest and processing [14,91,92,95,96,129,147].

Sweet corn is the latest bred variety of the species [135]. It has recessive genes that delay the process of transformation of sugars into starch [67]. At present it occupies a small percentage of cultivated land in this country (about 3000 ha) [153]. That is the reason why it is often referred to as a vegetable, even though it belongs to the family of cereal plants [151]. The plant, however, becomes increasingly popular due to the sensory and nutritional values of its kernels [115,151].

In this country corn is not yet a plant with any greater economic importance, but the situation is changing systematically [1]. The popularity of the plant among consumers increases, and the level of consumption is now at the level of 0.5 kg per person. For comparison, in the United States and in Western Europe the level of annual consumptios is in the range of 10–15 kg per person [99]. The highest economic importance of sweet corn is observed in the United States, France and Italy, and in Japan, Australia and Hungary. The production in the United States and Canada covers about 75% of the world requirements of the processing industry.

Increasing popularity of sweet corn in Poland causes a situation where less and less corn seed is imported from abroad, and more and more Polish processing plants are involved in corn kernel separation from the cob cores. There is also a systematic increase in the area of corn cultivation. In spite of the increasing trends, the popularity of sweet corn cultivation and consumption in Poland is still insufficient. One of the reasons for that is the seasonal character of the plant. The period of the plant availability as a vegetable is short and usually does not exceed three weeks [140]. Sweet corn is a relatively new plant in Poland, and increase in its consumption depends not only on psychological aspects, but also on the knowledge of the principles of its cultivation and utilization [152]. In Europe the area of sweet corn cultivation has increased notably over the last 10 years. Its cultivation inder the European climatic conditions is characterized by lower yields, higher variability of cob shapes, and varied times of ripening [24].

For human consumption, sweet corn kernels are acquired when not yet fully ripe [84]. In contrast to the physiological ripeness, such kernels are characterized by a high water content (above 70%) and have no defined so-called „natural limit of separation". The soft kernels adhere to one another very closely, as they do to the cob core. Dynamic chemical and physical transformation taking place in the kernels affect both the quality of the raw material and the process of their sheraing off the cobs. The result of all this is the fact that the classical methods used for corn threshing in the phase of full ripeness are not applicable for direct separation of sweet corn kernels [56].

Sweet corn seed acquisition for processing purposes through shearing involves high quantitative (related to seed mass acquired) and qualitative (related to the content of nutrients) losses. The requirements relating to the quality of corn seed shron include, among other things, smooth shearing surface, even length of kernels shorn, lack of mechanical damage to the kernels, low reductions in seed mass and nutrient content (especially sugars), and lack of core fragments in the mass of kernels shorn.

Depending on the cultivar, the efficiency of seed shearing off cobs is only 35-55% [38]. The reasons for this result both from the morphological and physical properties of the plant/cob itself, amd form the design and operation parameters of the shearing machines.

Knowledge of the mechanical properties of sweet corn kernels can be valuable for corn breeders and producers, and for design engineers and processing plants alike. It is all the more important since new foreign hybrid cultivars are continually introduced onto Polish plantations [153]. The mechanical properties of corn kernels reflect not only the technological value of the kernels, but also their resistance to the action of machines. Variability of the properties depends on a number of factors that not always can be expressed in terms of absolute values.

Increasing interest in the raw material on the part of breeders, producers, consumers, and processing plants makes the plant a wirthy object of further studies. Assessment of the effect of the fundamental mechanical properties of corn cobs and kernels on the parameters of the process of mechanical shearing of kernels off cob cores may provide significant cues for the optimization of the process, the primary criteria of such optimisation being raw material quality and energy requirements of the process of kernel shearing. For these reasons a study was undertaken on the relationships mentioned above and on their effect on the quality of the raw material [94].

CHAPTER 1

ORIGIN OF SWEET CORN AND ITS ECONOMIC SIGNIFICANCE

1.1. BEGINNINGS OF SWEET CORN CULTIVATION

The origin of corn and the beginnings of its cultivation are not known with any degree of accuracy. The oldest findings and data on domesticated corn come from excavations in Mexican caves. They indicate Central America, and specifically Mexico, as the homeland of the plant. From Mexico it spread onto South America (Chile, Peru, Bolivia) and then North America (USA and Canada).

Corn played an important role in the development of Mexican culture. It was an object of beliefs and of a religious cult. Most of the religious ceremonies had the objective of increasing the yields of the highly valued plant. In the civilisations of the Mayas, of the Aztecs in Yucatan and Mexico, and of the Incas in South America, it was one of the most favoured foods [81,85,155,164].

Domesticated by Indians, corn went through a continuous process of evolution. Crossbreeding of a variety of varietys let to the formation of corn types that were similar to varietys grown at present times. It was the Peruvian Indians who were the first breeders of sweet corn. From among several corn subspecies, sweet corn is the one that is used as a vegetable plant [54,83,115].

The earliest references to sweet corn come from the year 1779. The subspecies, named *Zea mays ssp. saccharata,* was isolated in 1820. The first breeder and producer of seeds of hybrid varietys was Noyes Darling from New Haven, Connecticut. But it was not until the beginning of the 20th century that sweet corn production began on a larger scale. Although the plant had been known in Europe earlier, but achieved a greater economic significance only after World War II. Also in Poland sweet corn got to be grown on larger areas towards the end of the 20th century [76,118,133,135].

In Poland, every year for over 10 years, the area of sweet corn cultivation has been constantly increasing (Fig. 2). At present, the area of sweet corn cultivation is estimated at over 3 thousand hectares. In Europe the main countries producing sweet corn are Hungary (39 000 ha) and France (26 000 ha). Significant levels of production of the crop are observed also in Italy (3 800 ha), Spain (3 000 ha) and in

Fig. 1. The major regions of sweet corn cultivation (source: Waligóra H., 2004. Kukurydza jadalna-znaczenie gospodarcze i rola w żywieniu człowieka. Forum Producentów Roślin Zbożowych, Kukurydzy i Rzepaku, 12-17.)

Fig. 2. Area of sweet corn cultivation in Poland

(source: Waligóra H., 2004. Kukurydza jadalna-znaczenie gospodarcze i rola w żywieniu człowieka. Forum Producentów Roślin Zbożowych, Kukurydzy i Rzepaku, 12-17.)

Israel (3 500 ha). The world record in this respect belongs to the USA (300 000 ha), where sweet corn is a “national” vegetable [154]. USA is the greatest producer and exporter of sweet corn (Fig.1). Dynamic development of breeding and production caused that it has become a very important crop and is now a „national vegetable”. Its annual consumption in the USA exceeds 10 kg per capita. For many years now sweet corn has enjoyed high popularity also in Europe. The fashion for healthy food caused that the attractiveness of the plant has been systematically growing also in Poland.

Table 1. The area of sweet corn cultivation in selected countries [147]

Country	Area of cultivation, (ha)
World	**500000**
USA	300000
Australia	40000
Canada	15
Brazil	15
Europe	**100000**
France	25000
Hungary	24000
Germany	7000
Israel	4400
Italy	3800
Poland	3500
Spain	3000
Finland	2000

The areas of sweet corn cultivation in selected countries are presented in Table 1.

1.2. THE WORLD'S LEADING PRODUCERS AND EXPORTERS OF FRESH AND PROCESSED SWEET CORN

The world's leading producers and exporters of fresh and processed sweet corn include the United States, Hungary, and Thailand. However, the U.S. share of world processed sweet corn exports by quantity has been shrinking over the last decade, dropping from 70 percent in 1998, to 33 percent in 2003. Over the same period, the U.S. share of world frozen sweet corn exports slipped from 50 percent to 30 percent. In contrast, Hungary and Thailand's shares of canned and frozen sweet corn grew rapidly over this period. Furthermore, Hungary just surpassed the United States to become the largest exporter of processed sweet corn.

France is the third largest sweet corn producer in the world. Canned sweet corn accounts for the majority of production of France's processed sweet corn. Severe heat, drought, and corn ear worm hurt the 2003 French sweet corn crop. As a result, 2003 French sweet corn production is estimated down 20 percent. The EU-15 was the fifth largest canned sweet corn exporter in 2003, accounting for only about 5 percent of the world's exports. Hungary's new membership into the EU-25 will greatly augment the EU rank as a processed sweet corn exporter since Hungary is presently the world's largest exporter of canned and frozen sweet corn.

1.2.1. HUNGARY

Over the last several years, Hungary has grown from an insignificant exporter to the world's largest exporter of processed sweet corn by quantity. By 2003, Hungary acquired a 34-percent share of world canned sweet corn exports and a 31-percent share of world frozen sweet corn the expense of the U.S. share. In 2003, Hungary exported about 148,000 tons of sweet corn and close to 50,000 tons of frozen sweet corn.

1.2.2. THAILAND

Thailand's production and exports of processed sweet corn have grown steadily over the last several years. In 2003, Thailand ranked as the world's eighth largest sweet corn producer and the third largest exporter of canned sweet corn. In this same year, Thailand acquired a 20-percent share (76,118 tons) of the world canned sweet corn exports at the expense of the U.S. share.

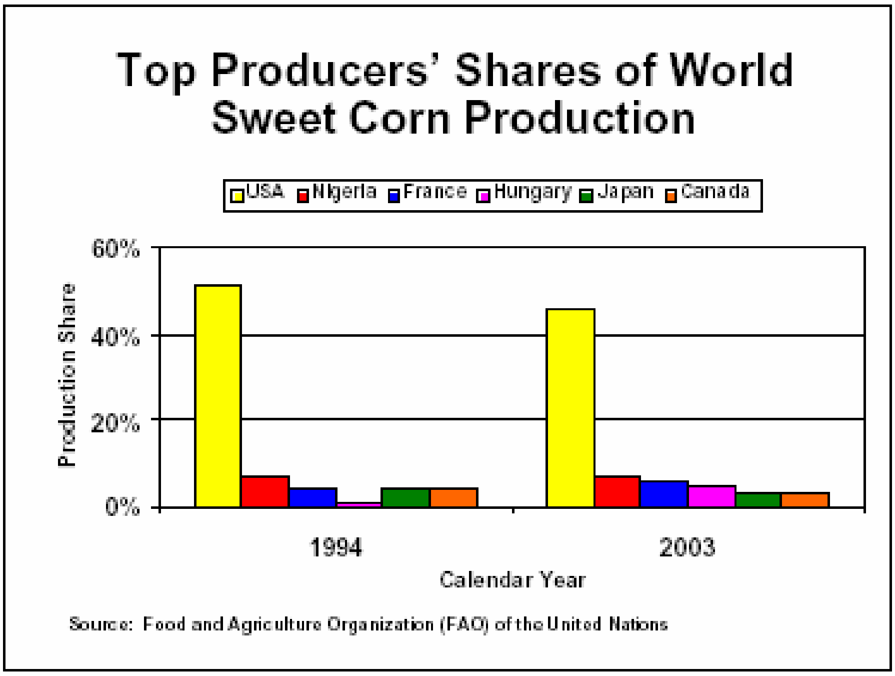

Fig. 3. World sweet corn production [174]
(source: *http://www.fas.usda.gov/scriptsw/attacherep/default.asp*.)

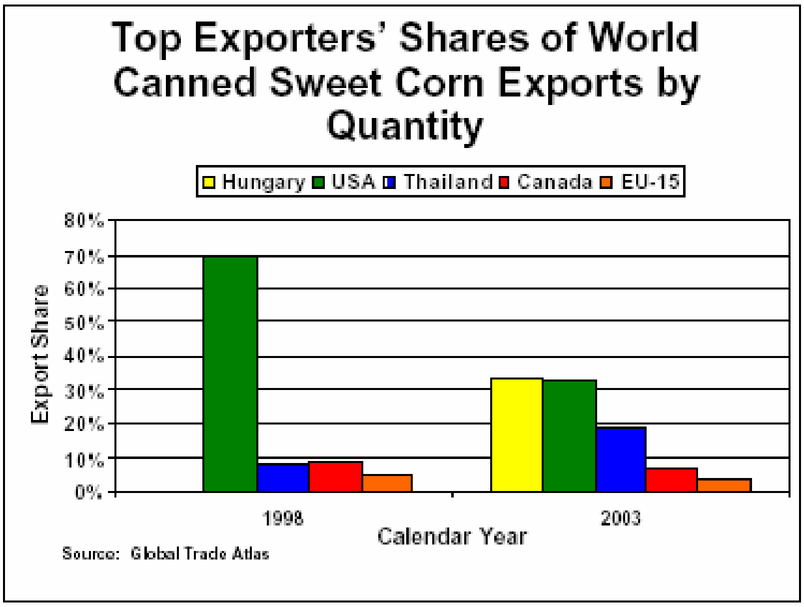

Fig. 4. World canned sweet corn exports [174]
(source: *http://www.fas.usda.gov/scriptsw/attacherep/default.asp.*)

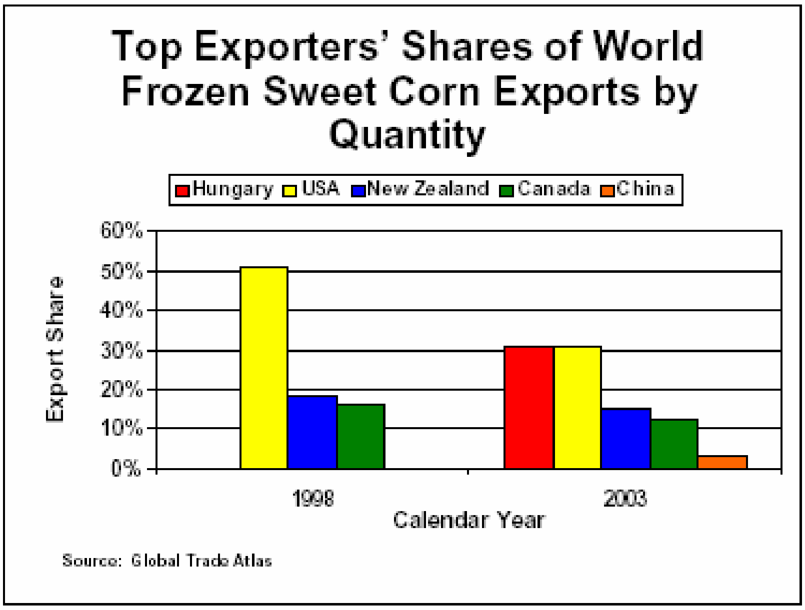

Fig. 5. World canned frozen sweet corn exports [174]
(source: *http://www.fas.usda.gov/scriptsw/attacherep/default.asp.*)

1.2.2.1. Raw Material Overview

Supplies of sweet corn in Thailand increased each year between 1999 and 2001. Attractive prices in 2000 caused sweet corn growers to expand their cultivating areas and other vegetable planters to switch to sweet corn. It also increased the number of factories making sweet corn products.

However, in 2002, the situation became much gloomier. There were limited supplies all year because of a shortage of ATS2 seed at the beginning of the year. Levels of fresh supplies available in the market were very low, increasing slightly in March and April, which is considered a shorter period than usual. The shortage directly affected canned sweet corn factories, some of which had to halt production for a while. There were also some reports that sweet corn planters switched to cultivate other crops that gained a better price.

There was interesting news of the discovery of a new variety of sweet corn seed - ATS3 - at the beginning of the year. ATS3 was developed by breeding Thai and US sweet corn. It is sweeter and larger and improves yields for farmers. It is estimated that fresh sweet corn production would reach only 180,000 tons (whole cob weight) in 2002, despite a continued expansion in planted area in major cultivating regions in response to the relatively more attractive return from corn contract farming as compared to sugar cane, the alternative crop, according to the report from USDA. The price of fresh sweet corn in 2002 was approximately 3-4 baht per kilogram, compared with 3 baht per kilogram in 2001.

Thailand has about 400,000 rai of sweet corn cultivating areas (1 rai = 2.5 acres), and output is about 6,000 tons per year valued at 800 million baht. Accounting for 4 percent of global production, Thailand is now the fourth biggest sweet corn producer in the world after the US, France and Hungary, which account for 37, 17 and 14 percent of global production volume, respectively.

1.2.2.2. Weather Woes

Unfavorable weather and Downy mildew disease continued to be dominant problems for Thai sweet corn cultivation in 2002, directly affecting the volume and quality of supplies.

In March and April, there were some reports that high temperatures and drought damaged a lot of sweet corn supplies in main producing areas, resulting in small vegetables with missing kernels. Weights were also low, with 4-5 ears of sweet corn needed for 1 kilogram, whereas in the past only 3-4 ears were needed. Sweet corn plants need a lot of water to grow.

From May to August, Downy Mildew disease (Peronosclerospora Sorghi) spread across the major growing areas in the Central Plain, which account for over half of total production. The disease is a major threat to sweet corn and occurs every rainy and cool season as a result of humidity. The disease was discovered in August and many supplies were damaged.

Farmers had to stop cultivation in that area for a while to ease the disease. At the end of the year, heavy rain and flash floods hit the main cultivating areas in the north, including Chiang Mai, Chiang Rai, Nan and Lumpoon, which cover about 30 percent of total production. Worms also spread in some areas. A large amount of raw material was damaged. Sweet corn farmers could not grow their new crop for a while because the land remained soggy.

1.2.2.3. MARKET TRENDS AND DEVELOPMENT

Thai canned sweet corn exports are expected to be positive for the next 3-4 years, as US supplies appear to be poor quality and there continue to be concerns over GM products from the US, the world's largest supplier of canned sweet corn. As a result, non-GM canned sweet corn from Thailand is becoming more attractive due to the relatively cheaper export price.

There is another concern over US sweet corn. After the September 11 terrorist attacks, fears of anthrax have dented consumer confidence in American supplies.

The Philippines and Indonesia are also competitors for, but these countries are of less concern as Thai sweet corn is considered better quality. The Thai Ministry of Commerce has warned Thai canned sweet corn exporters to declare production certificates if they are shipping goods to South Korea. Otherwise, their products could be charged a tariff rate of 50 percent, which is currently applied to processed vegetables (Code No. 2008.99.9000). In fact, the appropriate tariff rate for sweet corn (Code No. 2005.8.0000) is only 20 percent. The reason for the warning may be traced back to a case in 1992 when shipments of Thai canned sweet corn destined for South Korea were detained on claims that Thailand had no sweet corn cultivation. Therefore, Thai sweet corn was put into the processed food category, which was subject to a higher tariff rate. In order to resolve this problem, the Thai Ministry of Commerce and the Ministry of Agriculture and Agricultural Cooperatives have since cooperated to issue sweet corn production certificates to exporters as proof of eligibility for the lower import tariff.

Table. 2. Exports of Thai canned sweet corn, 2000-2002 [174] (Source: *FoodMarketExchange.com*)

Year	Export	
	Volume (tons)	Value (million baht)
2000	25,868	625.85
2001	35,816	978.75
2002	57,442	1,581.82

The Thai Customs Department reported that the total export volume of canned sweet corn in 2000 was 25,868 tons. This increased to 35,816 tons in 2001 as a result of increasing demand from foreign buyers. In 2002, Thailand exported

57,442 tons of canned sweet corn, an increase of 38 percent from 2001. The main destinations for Thai canned sweet corn were the Republic of Korea, Germany, Argentina, Japan, China and the UK. In both 2000 and 2001, the main destination was the Republic of Korea, accounting for 4,774 tons and 7,044 tons, respectively. However, in 2002 the main destination was the UK, which imported 10,559 tons of Thai canned sweet corn, up 58 percent from 4,451 tons in 2001. It is expected that canned sweet corn exports will increase further as a result of increasing demand.

1.2.2.4. The Market in 2003

The outlook for Thai sweet corn in 2003 continues to be positive, due to strong demand from both domestic and foreign markets. However, limited fresh supplies in the market as a result of unfavorable weather will continue to be an obstacle.

Source: FoodMarketExchange.com

1.2.3. France*

1.2.3.1. Executive Summary

France is the largest producer of sweet corn in Europe, with 85 percent of the canned sweet corn production and 70 percent of the frozen sweet corn production in 2002. However, in 2003, EU and French sweet corn production was severely damaged by drought and abnormally high temperatures. These climatic conditions favored the development and infestation of the corn ear worm throughout the French sweet corn production area [176]. Production is expected to shrink 20 percent from 2002 levels. French sweet corn competes with U.S., Thai and Hungarian products in the EU and Russia. The favorable exchange rate of the U.S. dollar favored U.S. exports to Europe in MY 2002/03 and the decline in the 2003 European harvest may be a new marketing opportunity for U.S. products.

1.2.3.2. Production, Supply and Demand

France is by far the largest producer of sweet corn in the European Union. In 2002, French production accounted for 85 percent of EU canned sweet corn production, and 70 percent of EU frozen sweet corn production. Most of the French production is canned, to meet domestic consumption and export demand, while the frozen market is limited. Fresh sweet corn production is marginal, as consumption is almost non-existent in France. The area planted to sweet corn was 29,780 ha in 2002, of which only 2,000 ha were for fresh sweet corn production.

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* Sweet Corn Annual 2003, USDA Foreign Agricultural Service GAIN Report No. FR3054, Approved by: K. Seifarth U.S. Embassy, prepared by: M.C. Hénard [176]

Table 3. Export for selected countries of France canned sweet corn [MT] (Source: Eurostat)

Country	2001	Country	2002
U.S.	0	U.S.	0
Germany	27432	UK	25873
UK	22773	Germany	22653
Spain	21288	Spain	20156
Italy	12481	Italy	13363
Belgium	6336	Belgium	5195
Russia	4939	Sweden	3871
Sweden	4331	Denmark	2670
Switzerland	3417	Switzerland	2215
Denmark	2632	Russia	1746
Israel	1487	Austria	1200
Total for Others	107116		98942
Others not Listed	9562		9456
Grand Total	116678		108398

Table 4. France import of canned sweet corn from selected countries [MT] (Source: Eurostat)

Country	2001	Country	2002
U.S.	183	U.S.	148
Others		Others	
Germany	2367	Germany	2379
Thailand	1846	Thailand	2115
Netherlands	1119	Netherlands	1606
Italy	746	Spain	916
Spain	531	Italy	532
Canada	278	Canada	266
Total for Others	6887		7814
Others not Listed	392		232
Grand Total	7462		8194

Table 5. French frozen sweet corn export trade matrix for selected countries [MT] (Source: Eurostat)

Country	2001/02	Country	2002/03
U.S.	0	U.S.	0
Others		Others	
Belgium	5318	Belgium	5074
UK	5161	Germany	928
Germany	1258	Netherlands	766
		UK	754
Total for Others	11737		7522
Others not Listed	1526		889
Grand Total	13263		8411

Table 6. France import of frozen sweet corn from selected countries [MT] (Source: Eurostat)

Country	2001/02	Country	2002/03
U.S.	71	U.S.	0
Others		Others	
Spain	1042	Germany	1610
Belgium	1620	Spain	1433
Netherlands	488	Belgium	1407
Total for Others	3150		4450
Others not Listed	1001		952
Grand Total	4222		5402

The 2003 French sweet corn crop was severely affected by drought and by a new pest (Heliolithis hermigera, or corn ear worm), which infested 10 percent of the plantings. This pest is usually found in African countries. The pest favors extreme heat. The abnormal heat and drought of the summer 2003 favored its development in France. As a result, French sweet corn production is estimated to shrink 20 percent in 2003.

The graphs below indicate that France has had a leading position in the sweet corn market for a number of years:

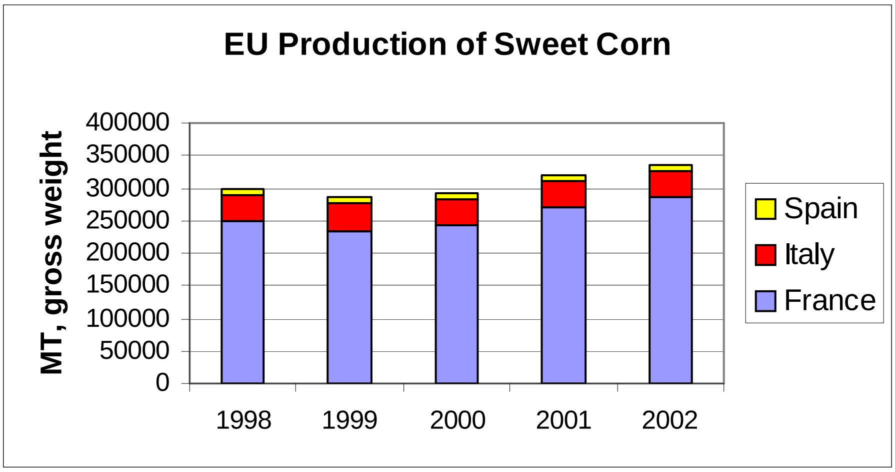


Fig. 6. EU Production of sweet corn (source: Sweet Corn Annual 2003)

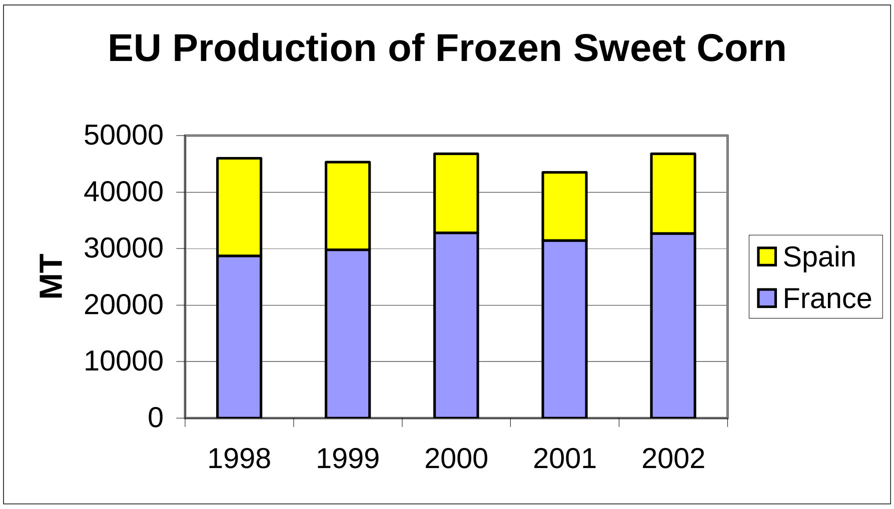


Fig. 7. EU Production of frozen sweet corn (source: Sweet Corn Annual 2003)

In France, there are 14 factories canning sweet corn that belong to the companies Bonduelle, Conserves France, D'Aucy, and Green Giant (Géant Vert). There are 7 plants freezing sweet corn: Aquitaine Surgelés, Bonduelle, D'Aucy, and LLS.

1.2.3.3. Consumption

In 2002, 68 percent of French households purchased canned sweet corn. The number of buyers of canned sweet corn increased slightly (0.3%) from 2001 to 2002.

The EU per capita consumption of sweet corn (1.5 kg per year) remains significantly lower than the U.S. per capita consumption of sweet corn (2.5 kg per year). However, French per capita consumption is one of the highest in Europe.

1.2.3.4. Trade

France is a net exporter of sweet corn, and exports half of its production, mainly to Germany, the United Kingdom and Spain. In France and Europe, French sweet corn competes with U.S., Thai, and Hungarian products.

In MY 2002/03, French exports of canned sweet corn to Germany, Spain and Russia declined to the benefit of U.S. and Hungarian exports, due to the increasingly favorable exchange rate of the U.S. dollar (see report FR3026, 6/25/03). Similarly, French exports of frozen sweet corn to Germany declined significantly.

1.3. Directions of Use and Nutritional Value of Sweet Corn Kernels

Sweet corn kernels can be consumed both as fresh produce and in processed forms. In practice, most frequently three basic directions of their utilization are distinguished [148, 149]:

– direct consumption - cobs harvested at milk ripeness of seed, for so-called fresh-produce market (approx. 20%);
– fruit-and-vegetable processing industry - cobs harvested at late-milt ripens of seed, for pickles (approx. 70%) and frozen foods (approx. 10%);
– industrial processing - cobs harvested at full ripeness of seed, for flour, meal, etc. (approx. 1%).

Sweet corn usually sets and forms from 1 to 2-3 cobs. Their length varies from 10 to 20 cm. The cobs are enclosed in several layers of closely fitting membranous cover leaves. The edible part of the cobs is the kernels, located on cob cores in over a dozen regular rows. The kernels contain amylodextrins which constitute reserve substance for the parenchyma and provide them with sweet taste. The kernels of particular varietys differ in shape, colour, size, nutrient content, and consistency [71, 104].

Corn kernels have a high nutritional value. They contain large amounts of proteins, and most vitamins and microelements. They are also rich in sugars. Sweet corn, used as a vegetable, is suitable for direct consumption as its kernels, at milk ripeness, are soft and contain 74–76% of water. Moreover, kernels of very sweet varieties contain many sugars easily soluble in water (6–12%). High dietary and energy value of the kernels (Table 7) causes that adults and children alike readily consume them.

Table 7. Chemical composition and energetic value of sweet corn in 100 g of fresh kernels [72]

Macroelements, (mg)					β-ka-roten, (μg)	Vitamins, (mg)				
K	P	Mg	Na	Ca		C	E	B_1	B_2	PP
283	102	37	7	6	56	12,0	0,52	0,143	0,080	1,70

Energetic value		Protein	Fat	Carbohy-drates	Cellulose	Energy with:		
						Protein	Fat	Carbohydrates
(kJ)	(kcal)	(g)	(g)	(g)	(g)	%	%	%
460	111	3,7	1,5	23,4	3,3	14	12	74

Valuable components of sweet corn kernels include also such microelements as selenium, chromium, zinc, copper, nickel and iron. Special attention should be turned to selenium which, together with vitamin E and β-carotene reduces the metabolic activation of cancer genes and facilitates the detoxification of substances harmful for our organism. A significant role is also played by cellulose which accelerates the peristalsis of the intestines, facilitating the passage of food consumed through the digestive system and lowering the absorption of cholesterol and glucose concentration in blood, thus displaying antiatherogenic activity [72, 117,126].

Sweet corn, due to its nutritional and sensory values, constitutes an important component of human diet all over the world. It is highly popular among the vegetarians. Sweet corn kernels do not contain gluten, which means that they occupy a significant position in gluten-free diet. The fundamental component of gluten-free bakery products and nutritive preparations for children with celiac disease is flour from sweet corn kernels. It is a valuable raw material for the production of health food. At present, menus include various groups of dishes with a content of sweet corn. The most popular are salads with pickled sweet corn kernels. In turn, sweet corn seed of poorer quality is used for fodder for domestic animals. It is a source of highly energetic fodder for farm animals, and especially for poultry and for pigs [16,70,82,87,135].

The highest sensory value is that of kernels collected at the early phase of milk ripeness. Then the kernels are very sweet, tender and succulent. The highest content of sugars is found in kernels in fresh cobs and in cobs not yet fully grown. With delayed harvest, the value of kernels notably deteriorates. They become hard and mealy, and their content of saccharose – which gives them their sweet taste - decreases, while their content of starch grows. This makes less suited for direct consumption. For cooking purposes, in turn, the best are cobs in their full or final phase of milk ripeness. For the purpose of extending the period of sweet corn suitability for direct consumption, freezing of whole cobs or of kernels is employed. Cobs boiled-off and then frozen can be stored for several months. This procedure is aimed at stopping the activity of enzymes that cause the conversion of monosaccharides into starch and a change in the kernels colouring [9,27,97,134,165].

The primary direction of sweet corn utilization is using it as raw material for the processing industry (Fig. 8). In this case, at the time of harvest sweet corn should be in the phase of late-milk ripeness. Shiny yellow or white kernels that have the highest content of nutrients and a dry mass content on the level of 24–28% then characterize it. In the course of industrial processing, preserved, canned and frozen foods are obtained. Corn products most popular on the Polish market include sweet corn kernels in sugar syrup, frozen mixes with other vegetables, and meat and vegetable canned foods in which one the components is sweet corn [31,127,140].

Like under home conditions, industrial freezing of sweet corn kernels is preceded with the process of scalding. The freezing takes place at the temperature of –40°C, and frozen corn is stored at the temperature of about –20°C. Sweet corn is frozen by numerous plants in Poland, among others by the Przedsiębiorstwo Przemysłu Chłodniczego in Poznań, ZPOW Hortex in Środa Wielkopolska, Cold Storage Plants in Toruń, Koszalin, Dębica and Włocławek. Canned foods and preserves of sweet corn are made, among others, by ZPOW Rajdimpex, Pudliszki S.A., ZPOW Kwidzyń, Dawtona Leszno, and by ZPOW Ziębice [57,146].

The least popular way of sweet corn utilization in Poland is the industrial processing of ripe kernels into meal or flour. This is related to the lack of hybrids ensuring the obtaining of suitably low kernel moisture under field conditions and at full ripeness, necessary for obtaining products of high quality.

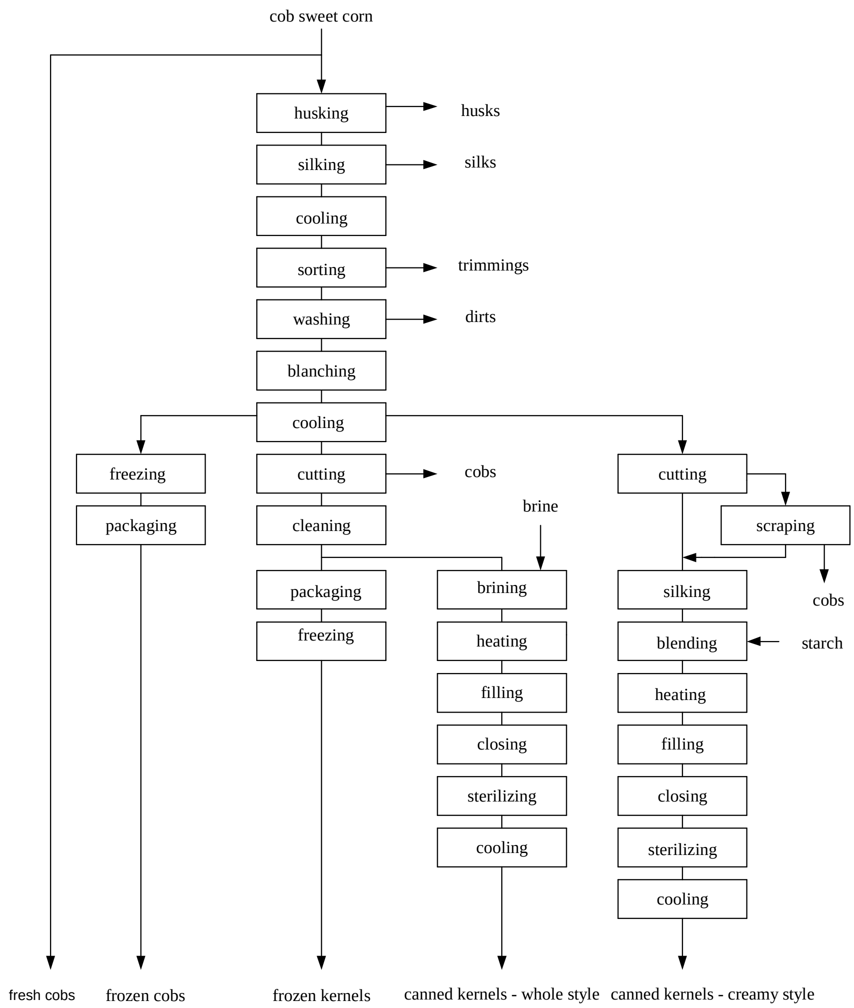


Fig. 8. Ways of utilization of cobs and kernels of sweet corn [59]

Kernel moisture during harvest at the phase of technological ripeness should be from 30 to 40%. Therefore, in Poland sweet corn production for kernels is mostly destined for direct consumption and for the fruit and vegetable processing industry [34,128,145,152].

CHAPTER 2

AGRICULTURAL REQUIREMENTS FOR SWEET CORN CULTIVATION

2.1. CLIMATIC AND SOIL REQUIREMENTS

Sweet corn is a stenothermal plant that requires high isolation and appropriate levels of moisture. Though a short-day plant, it displays photoperiodic response lower than other subspecies. Temperature and precipitations are factors that determine correct growth development and yielding of corn. Rapid and even emergence of the plant requires temperatures above 10°C. Lower temperatures and high moisture cause a delay in emergence and a drop in the emergence rate. Also, high soil moisture causes the decay of germinating seeds both at low and at high temperatures. Optimum temperature from emergence till blooming is 21–27°C. In the course of blooming, temperatures over 30°C, especially when combined with low humidity, are harmful for the plants. Such conditions cause a lowering of pollen vitality, which leads to a situation where not all the flowers in a cob are pollinated and then the cob is not completely filled with kernels [99,141,149].

Corn reacts to spring and autumn frosts. Ground frost, frequent in Poland in the period of emergence, retards the growth of young plants but does not cause their wilting. More harmful are early autumn frosts that can cause leaf wilting and even kernel cracking. Once they happen, the plants should be harvested immediately. The best temperature for harvesting sweet corn is 10–16°C. Then the monosaccharides in the kernels transform into starch very slowly. The duration of the vegetation period of the plants depends primarily on air temperature, insolation, amount of precipitation, time of sowing, and on soil fertility. In cool, cloudy and dry years it can be extended by several to about a dozen days in comparison to years with warm, sunny and wet weather. Sweet corn grows best under conditions of good insolation, and therefore requires appropriate plant spacing per unit of area of cultivation [74,76,138].

Water requirements of corn are high over the whole period of vegetation and amount to about 400 mm. Its well-developed bundle root system, reaching deep into the soil profile, makes corn more tolerant of temporary shortages of water than other plants. The level of water requirement depends on the development phase of corn. It is the lowest in the initial period of vegetation (approx. 100 mm), and the maximum coincides with the phase of blooming and cob setting (150–200 mm). During cob ripening, in turn, the demand for water decreases and amounts to from 50 to 100 mm. The yielding of sweet corn is negatively affected by strong winds and hail, especially if they occur in the phase of blooming. The climatic conditions of Poland are suitable for sweet corn cultivation. The most favourable conditions in this respect are to be found in the west and south of the country, i.e. in regions where fodder corn is grown for kernels.

Sweet corn is not a plant with excessively high requirements with respect to soil. It can be grown on most soil types occurring in Poland. Exceptions are waterlogged soils, cold, very heavy, clay, dry sandy, and piedmont and mountain soils. Most suitable are fertile soils, rich in humus, with high water capacity, warm, and containing available nutrients. These are chernozems, black earths, and loess soils. The obtaining of high and good quality crop yields depends also o the exposition of the soil. Most favourable is south exposition, providing good soil warming in spring. Sweet corn is characterized by high degree of tolerance to soil reaction. The highest yields are obtained on soils with reaction close to neutral (pH 6.0–6.5).

2.2. TILLAGE AND FERTILIZATION

In crop rotation, sweet corn requires to be grown exclusively in the main crop. The possibility of its cultivation is not restricted by the forecrop, the only limitation being that it permits prewinter ploughing to be made on time, it being the primary tillage for the vegetable. The best forecrops for sweet corn are root crops over manure, small-seed papilionaceous plants, and mixes of papilionaceous plants with grasses, industrial plants, mixes of cereals and leguminous plants, and cereals. Sweet corn does not like to be grown in monoculture. For phytosanitary reasons, it cannot be grown on the same field with time intervals shorter than 4–5 years [76,140]. Multiyear cultivation would result in depletion of microelements from the soil and in intensification of weed and diseases, which would have a significant deteriorating effect on the quality of the raw material.

The fundamental condition for obtaining high and good quality crop yields is careful and deep tillage. It should ensure proper loosening of the soil, favourable air-water relations, and favourable thermal conditions. For this reason, all tillage measures, both autumn and spring, should be performed with special care. Preparation of the field for sweet corn culture should be begun already in the preceding year, directly after the harvest of the forecrop [143].

The autumn tillage measures include:

– skimming applied after the harvest of cereals;
– prewinter ploughing to the depth of 25 to 30 cm (this depends on the soil depth). In the case of shallow arable horizon, the ploughing should be made with a subsoiler. Application of manure also requires that it is ploughed over in autumn.

The spring tillage, in turn, should include:

– early dragging or harrowing of the soil, which has to be repeated if the soil is weedy or crusty;
– presowing cultivator tillage to the depth of 8 to 10 cm, with a string roller.

For soil preparation for sowing, it is advisable to use a tillage array composed of a narrow-tine cultivator and two string rollers, one in front and one after of the cultivator. Spring ploughing, on the other hand, is not recommended tillage operation in sweet corn cultivation, as it leads to excessive drying of the soil. In spring the soil should prepared so that corn seeds are placed at uniform depth in loosened and warm soil layer, with easy availability of water and nutrients.

The nutrient requirements of sweet corn are similar to those of fodder corn, and the plant makes good use of components available in organic and mineral fertilizers. Fertilization is one of the factors that determine the level of sweet corn crop yields and the quality of the crop. This in turn has a decisive effect on the level of selling price that can be obtained for the product and directly affects the profitability of sweet corn plantation.

In the cultivation of sweet corn it is recommended to apply manure, ploughed over in autumn. That organic fertilizer provides the soil with the basic nutrients and microelements. Manure dosage of 30 $t\cdot ha^{-1}$ supplies the soil with about 120 kg N, 90 kg P_2O_5, 180 kg K_2O and 50 kg MgO, out of which approximately. 30% of nitrogen and phosphorus and 80% of potassium are used in the first year. Hence, manure fertilization at lower doses and of poorer soils requires supplementary mineral fertilization. In most cases the dosage of mineral fertilization is related to the soil and site conditions in crop rotation. Proper mineral fertilization for sweet corn depends on the soil fertility and should fall within the dosage ranges shown below [69,76,88,140]:

– 100-150 kg $N\cdot ha^{-1}$,
– 70-90 kg $P_2O_5\cdot ha^{-1}$,
– 150-200 kg $K_2O\cdot ha^{-1}$,
– 30-40 kg $MgO\cdot ha^{-1}$.

Thanks to its effectiveness, the combination of surface fertilization with starter fertilization is becoming increasingly popular. By definition, the technology of starter fertilization is used as complementary to the presowing fertilization. However, new forms of elements in modern fertilizers permit the application of a higher proportion (or sometimes even the full dose) of the fertilizer together with seed sowing, without risk of causing damage to the emerging plants. When determining the dosage, it should be kept in mind that the effectiveness of starter fertilization is 25 % greater with relation to surface fertilization. The condition for the application of starter fertilization is having a special combination drill that will ensure that the fertilizer is placed correctly – minimum 5 cm beneath the seed and to the side from the corn seeds. Care of proper soil reaction and regular analyses of nutrient reserves in the soil permit the application of precision „crop-oriented" fertilization, avoiding unnecessary traffic and the risk of deterioration in the yield and quality of the crop.

Correct fertilization causes good enrooting of corn plants and their proper development. It also improves their resistance to diseases and has a significant effect on the yield and quality of the crop. Sweet corn uptakes potassium and nitrogen most intensively, while its requirements for phosphorus, calcium and magnesium are notably lower. Potassium, exceptionally large amounts of which are accumulated by sweet corn in its stems, is untaken most intensively from the phase of 5–6 leaves and in the phase of blooming. Then the rate of the uptake slows down but the uptake continues up to the end of vegetation. Potassium deficiency results in retardation of the growth of corn plants, poor kernel filling, reduction in the resistance of the plants to diseases and to difficult environmental conditions, increasing their susceptibility to lodging. Characteristic symptoms of potassium deficit include the appearance of spots on leaf edges and dark green colouring of leaves. For best effects, potassium fertilizers should be applied during the prewinter ploughing [34, 152].

Nitrogen uptake by corn is the most intensive in the phase of blooming, and somewhat slower throughout the remaining phases of its vegetation. Nitrogen uptake by corn plants is related to the weather. At temperatures below 5°C it is very slow, attaining the highest rates at temperatures of 20–25°C. Limited uptake of nitrogen in early spring causes retardation of growth and yellowing of leaves of sweet corn, and in later period affects the shape of the leaves. They become narrow, pale green, and tend to wilt early. The result is low yield and poor quality of the crop. Sweet corn requirement for nitrogen continues until the end of vegetation. Therefore, nitrogen fertilizers used in sweet corn cultivation should be characterized by slow and long action, like urea (carbamide) and ammonium sulphate used for alkaline soil fertilization. The full dose of such fertilizers is applied before sowing, e.g. under the cultivator, which ensures good mixing with the soil, or – in the case of lighter soils – the dosage can be divided. From 30 to 50% of the urea or ammonium nitrate dose is applied before the sowing, and the remaining part as top dressing in the phase of 5–6 leaves [69, 88, 140, 162]. That application should be made with the help of a drill hoe with controlled-dosage applicator that ensures fertilizer application close to the rows of plants, or by broadcasting over the whole soil surface area. The division of the full dose ensures also favourable yield-enhancement effects, mostly due to reduced losses of nitrogen through its leaching from the soil.

Nutrient requirements of corn with relation to phosphorus are considerably lower than those for nitrogen and potassium. Phosphorus uptake is sweet corn is the most intensive at high temperatures. Lower temperatures (<12°C) occurring during plant emergence and initial development cause a limitation of phosphorus uptake. This in turn results in retarded growth of the plants. Deficit of phosphorus is evidenced as red discolouration along leaf edges. Phosphorus fertilization on the required levels significantly affects the ripening of the plants, the development of their root systems, and the degree of kernel formation. Dosage of phosphorus and potassium fertilizers should take into account the nutrient requirements of the plants and the so-called balance differences resulting from the fertility of the soil. The fertilizers should be applied once, in autumn with the prewinter ploughing, in recommended doses. If manure fertilization is used, the doses of the fertilizers should be reduced by 30–40% [76, 152].

Calcium and magnesium are also important nutrients for sweet corn. Calcium deficit disturbs hydrocarbon transformations in corn plants, which is manifested in the form of leaf sticking. Calcium fertilizers must be applied in early spring or in autumn, when soil pH is under 5.5. Average doses of calcium are at the level of 1–2 $t \cdot ha^{-1}$ CaO and should be supplemented with magnesium lime. Magnesium deficit, in turn, causes disturbance during the period of blooming and pollination. Its shortage is observable in the form of bright discolorations along leaf veins. Indicative dosage of magnesium on soils with average levels of fertility is 30–40 $MgO \cdot ha^{-1}$ [76].

The chemical fertilizer market offers also a broad spectrum of multi-component fertilizers that permit the application of suitable fertilization in the cultivation of sweet corn. The plant is particularly sensitive to the deficit of iron, zinc, copper, molybdenum, and boron in the soil. Therefore, the application of multi-component fertilizers that, apart from the macroelements, also contain the necessary microelements is highly advantageous. They also enhance correct growth and development of plants, their resistance to diseases, and the yield and quality of the crop. Microelement deficits that may occur can be rectified through plant spraying with appropriate foliar fertilizers. Dosage examples of selected Polish-made multiple fertilizers are presented in Table 8.

Table 8. Recommended doses of some multiple fertilizers for sweet corn [140]

The kind of fertilizer	Dose, ($kg \cdot ha^{-1}$)
Azofoska	250–500
Fruktus 1	400–600
Fruktus 2	250–500
Plon	800–1000
Mikro	800–1000

Application of the fertilizers presented above results in good enrooting of the plants and their correct development from the moment of emergence. It also has a beneficial effect on the yield and the biological value of the crop, and on the sensory values and shapeliness of the cobs. Foliar fertilization of plants, in turn, as opposed to fertilization with solid fertilizer forms, provides sweet corn with smaller doses of nutrients. The leaves, thus reducing the degree of contamination of the natural environment, immediately absorb these. In foliar fertilization it is important to observe the recommendations provided in the instructions for a given fertilizer of preparation.

2.3. Sowing and Plant Care

Under the climatic conditions of Poland, sweet corn sowing time depends to a considerable extent on soil temperature. Seed sowing should be begun when soil temperature at the depth of 10 cm reaches the level of 10°C. Uniform germination of sweet corn seeds takes place at similar soil temperature conditions. The time of sowing varies depending on the region of the country. In southwest regions it can begin as early as 25th-30th April, while in southeast from 30th April till 5th May and in the remaining regions it begins from 10th May [142].

Earlier or delayed sowing times are also possible. Sweet corn seeds sown at an earlier time and into cold soil germinate more slowly, are more susceptible to pests and fungal diseases, and the emerging plants often die off as a result of ground frost occurring at the time. With delayed sowing one should expect a drop in the yield and the quality of the crop. To improve the thermal conditions during seed germination and the initial phase of plant growth we can employ plantation covering with light polypropylene unwoven cloth, polyethylene foil, or with bedding or mulch that decomposes under the effect of sunlight or microbial activity. This results in soil temperature increase by 2–6°C as compared to non-covered soil, thanks to which the time of corncob harvest may be accelerated by 7–10 days [2, 101].

When purchasing and sowing corn seed as sowing material, attention should paid to variety's purity, high germination force and energy, and the quality of the seed. In the cultivation of sweet corn the crop yield is largely determined by the quality of the sowing material and by the varieties selected. When choosing the variety to be sown, the duration of its vegetation period and the crop yield potential should be taken into consideration. The choice of a variety with a shorter vegetation period reduces the risk involved in cob ripening and permits the obtaining of cobs of higher quality. Also early cob harvest time gives the possibility of taking advantage of better weather conditions and of getting a better price for the produce. At present, advantageous effects are achieved in the case of cultivation of new generation varieties that are more resistant to spring chills and do not respond so strongly to weather changes [7,39,76].

Sweet corn is an anemophilous plant and requires spatial isolation from corn grown for fodder. A safe distance between plantations is assumed to be 500 m, with 300 m being the absolute minimum. Cross pollination of sweet corn plants with pollen of fodder corn causes a decrease in the content of sugars in the kernels of the former. Also, very sweet varieties need to be isolated from normally sweet ones. In this case the safe distance should be at least 300 m, as such cross pollination leads to deterioration in the value of cobs [76,140,152].

Primary objective of sweet corn cultivation is to obtain 1 or 2 simultaneously ripening and shapely cobs per plant. Therefore, plant spacing cannot be too dense or overly sparse. Excessive plant density causes incomplete filling of cob tip section with kernels, which results in a deterioration of quality of cobs for direct consumption. Lower plant density causes that frequently plants produce non-fully developed, poorly kernel filled and later ripening second cobs. Optimum plant density for most sweet corn hybrids is 5–7 plants per square meter. For early varieties a higher plant density is applied, and a sparser density for later varieties. Plant density is also related to the soil-climate conditions. Under favourable conditions a higher density is recommended, i.e. 7 plants/m^2, and under less favourable conditions – 5 plants/m^2 [141,150].

In the case of sweet corn cultivated for „mini" cobs, so-called *„baby corn"*, two systems of their production can be employed. The first consists in applying the normal plant density of about 54 thousand/ha. The upper cobs are kept on the stems until the required phase of ripeness is achieved, and the remaining ones are collected as „mini" cobs. In the second, a higher plant density is applied, on the level of 84–109 thousand/ha, and then all the cobs on the stems are collected as *„baby corn"*. In this variant the yield of cobs without the cover leaves can be on the level of from 900 to 1100 kg from 1 hectare [76,70].

The quality of sowing material, the optimum time of sowing and the placement of seeds at the required depth in the soil all determine the subsequent crop yield.

The depth of sowing depends on the type of soil and on the time of sowing. On heavier and colder soils, and with earlier sowing times, seeds are sown at the depth of 3–4 cm, while later sowing and on lighter soils is made at the depth of 5–6 cm. Before the sowing is actually performed, one should remember about sweet corn seed dressing. Plants grown from dressed seed develop stronger root systems, grow faster and are more resistant to fungal diseases. Seed grassing should be performed immediately before the sowing, using pesticides against diseases, insects and birds.

Under the conditions of field cultivation, seeds are sown by means of mechanical or pneumatic drills for single-seed sowing. Seed spacing in a row should be 20–30 cm, with row spacing of 65–75 cm. Drills available on the market and suitable for sweet corn sowing include the following: Aeromat 2 (8-row), Aeromat 3 (6-row), SPC 6 M, Pneumasem DKV 6, Puma and Monosem. They all ensure the required sowing density with uniform seed and row spacing. There are also sowing drills that, in a single passage, sow corn seeds, starter fertilizers or herbicides, and can cover the rows with biodegradable foil. This type of sowing technique permits earlier sowing, improves the rate of emergence and ensures more effective action of chemicals thanks to accelerated warming of the soil.

In the case of sweet corn cultivation for direct consumption an important factor is the obtaining of possibly early crop of cobs, which usually guarantees a higher selling price. This can be achieved through corn planting from seedlings with the help of disc or carousel planters. This method permits cob harvest acceleration by 1–3 weeks. However, when making the decision to cultivate sweet corn from seedlings one should keep in mind that corn is not one of those plant species that easily regenerate damaged root systems. Therefore, the seedlings should be grown in pots with soil mixture with peat, and planted with sufficient care. This method of cultivation – due to the high costs involved – is recommended for small plantations and in years with cold and delayed spring [75,76].

To achieve continuity of corncob harvest both for direct supply to the market and for the processing industry it is possible to apply successive sowing of seed batches. Under the climatic conditions of Poland it is practicable to sow sweet corn at weekly intervals from 20th April until 20th May. Further extension of the sowing period may lead to a considerable reduction in the level of yield achievable. In the USA, on the other hand, corn producers proceed with the next sowing the moment when plants from the preceding batch grow three leaves. That method ensures 10–14 day intervals between harvests of cobs from fields sown in succession [53, 76,118].

Young seedlings of sweet corn grow very slowly and, due to the low competitive capacity of the plants in the initial stage of vegetation, the plantation may be prone to weediness. Plant care has to be exercised by applying measures aimed at destroying the weeds and ensuring air access to the root systems of the plants. In fields sown with sweet corn weeds can be destroyed using both mechanical and chemical methods. Plantation weediness can be largely reduced through destroying the fore crop weeds, early prewinter ploughing, and timely performance of presowing and post-sowing tillage [144].

In the case of large plantations, mechanical crop cultivation consists in harrowing the sown field with a light harrow and can be applied within the period from emergence to the phase of 2-3 leaves. During later phases of vegetation, mechanical methods of weed control may prove hazardous and not very effective. This kind of weed control is most frequently effected using tools for inter-row cultivation and it ensures the destruction of not more than approximately 50% of the weeds. It also causes soil loosening, which has a positive effect on the development of plants, as corn plants are sensitive to soil crusting. The intertillage is performed shallow, maintaining a distance of 10 cm from the plants to avoid damaging their root systems. Soil loosening and weeding can be applied and repeated until the plants cover the interrows.

A more effective method of weed control is the application of herbicides. Up till now in Poland no specific recommendations have been formulated for the application of herbicides in sweet corn growing. The producers, on their own risk and responsibility, frequently use herbicides normally applied in growing fodder corn. This is a highly hazardous approach; as such preparations may have a negative effect on the content of nutrients in sweet corn kernels. Triazine herbicides, containing atrazine and simazine as active agents, reduce the content of monosaccharides and starch, and increase the content of nitrogen and proteins in cobs [76]. In sweet corn growing, care is recommended in the application of herbicides, and the instructions and recommendations of the Institute of Plant Protection and of the manufacturers of the preparations must be observed.

Sweet corn gets attacked by a relatively low number of infectious diseases and pests. The most common diseases include mosaic and plant dwarfism, leaf sheath spotting, seedling gangrene, corn blight, corn head nodosity, and fusarian diseases of cobs, stems and roots. Corn pests, on the other hand, include millet pyralidid, cereal frit fly, aphises, wireworms, grubsnoctuid moths, and birds.

Leaf sheath spotting is one of the most common corn diseases. Its symptoms are small watery spots on the inner side of leaf sheaths. During prolonged rainy periods viscous bacterial mucus appears within the spots, and there occurs rapid decomposition of affected plant tissues and their decay. Fungi remaining in the soil on residue of affected plants cause seedling gangrene. It appears at the moment of seed germination during cool and wet weather and delayed plant growth.

Corn head nodosity is also a fungal disease which intensifies during dry and warm summer. The disease causes the appearance of nodal warts on seedlings, panicles or cobs, resulting in their decay or disqualifying cobs as material for consumption or for processing. Introducing into cultivation corn varieties resistant to fungal diseases can restrict spreading of the disease. Prevention of infectious diseases is limited to sowing material dressing. For sweet corn protection against diseases a variety of seed dressing preparations can be used, with the following dosage per 100 kg of seed [76]:

– Maxim XL 035 FS – 100 ml/700-1100 ml of water,
– Sarox T 500 FS – 375 ml/750 ml of water,
– Vitavax 200 FS – 250-300 ml/250-300 ml of water,
– Suspension dressing Zaprawa T – 250 g/750 ml of water,
– Oxafun T 75 dressing: dry application – 200 g, or wet application – 250 g/1000 ml of water.

Millet pyralidid is a dangerous pest for sweet corn kernels. The effects of damage inflicted by the pest are considerably more serious here than in the case of fodder corn. Larvae of the pest feed on the cobs, gnawing into cob and stem tips. The damage thus inflicted disqualifies the material from processing and from direct consumption as fresh produce. The pest spreads during warm summer periods. Protective measures consist in deep ploughing which makes it difficult for the larvae to last through the winter. In June the chrysalides transform into butterflies and live till the end of July. After 48 hours from hatching, they lay their eggs by night on the underside of leaves. Larvae hatch within 3–7 days, and feed in leaf sheaths and in cover leaves of blooming corncobs. After the second moult they bite into the stem, panicle or cob. Pest control in this case consists in the application of granulated pesticides, e.g. Basudin 10 GR or Diazinon 10 GR in doses of 15 $kg \cdot ha^{-1}$, or in spraying with the Karate ZEON 050 CS preparation in doses of 0.2 $1 \cdot ha^{-1}$ during the paniculation of sweet corn and after the appearance of the pest. The spraying acts on all the development stages of the insects – eggs, larvae, and adult forms.

Chemical control of millet pyralidid is justified economically when 15% of plants in a plantation are affected. The percentage of plants affected from the moment of paniculation can be determined by taking minimum 5 samples of 20 plants each from various points in the plantation. The sampling should be repeated. Sweet corn can be harvested after three weeks from the application of spraying. The most suitable for millet pyralidid control on sweet corn plantations are biological preparations, e.g. Bactospeine WP 16000, Dipel 3,2 WP, Thuridan and Thuridan cream [57].

Cereal frit fly causes retardation of growth and decay of seedlings. Larvae feeding inside the stems inflict the damage. The pest population grows the best during cool spring and may cause crop yield losses of over 12%. The application of the modern preparation Karate ZEON 050 CS is recommended. It is an insect and spinning mite extermination agent in the form of suspension of capsules in a liquid, for dilution with water. The preparation has content and gastric action and exterminates biting and sucking pests. It is characterized by surface action when applied on plants. Plant spraying with the preparation is performed when the third leaf forms on corn plants, and the recommended dosage is 0.1 l/ha [76].

Wireworms are larvae of elaterids destroying sweet corn crops. They appear on fields where sweet corn is too frequent an element of crop rotation. Their population can be reduced through the application of deep ploughing, soil liming, and seed dressing prior to sowing. Seed dressing against the frit fly and wireworms can be made using the following preparations, in doses per 100 kg of seed:

– Gaucho 600 FS – 500-600 ml,

– Mesurol 500 FS – 1000 ml,

– Marshal 250 DS. dressing – 300-500 g.

In areas with abundance of wireworms, also preparations applied to the soil should be used, in the course of seed sowing or after the emergence of plants:

– Diafuran 5 GR – 15 $kg \cdot ha^{-1}$,

– Furadan 5 GR – 15 $kg \cdot ha^{-1}$.

Birds, and especially crows, jackdaws, rook and pigeons can also cause considerable losses in sweet corn cultivation. Feeding on fields, they eat up germinating seeds and damage emerging plants. In this situation, in regions of high hazard and extensive damage to sweet corn plantations, it is recommended to apply seed dressing with repellents, e.g. the Mesurol 500 FS preparation in doses of 10 $ml \cdot kg^{-1}$ of seed. Such repellents are non-toxic or low-toxicity substances with repelling action against birds and game.

CHAPTER 3

CHARACTERIZATION OF SWEET CORN VARIETIES

The choice of variety is one of the more important factors the determine whether sweet corn production is a success. Population (fixed) varieties have been largely replaced in cultivation by hybrid (heterotic) varieties, created by man in the first half of the 20th century as new forms of the crop plant. Hybrid varieties spread less, produce bigger and evenly ripening cobs, and are higher yielding compared to the population varieties. They are characterized by high sensory qualities and are suitable for direct consumption and for the processing industry alike. They meet the requirements of the fruit and vegetable processing industry in terms of having very delicate kernel skin and kernels easy to separate from the cobs in whose mass the kernels constitute 30–40%. Primary differences among the hybrid varieties include the duration of their vegetation period, content of sugars, and suitability for various uses. Sweet corn varieties grown in Poland are mainly foreign varieties, with a few locally bred. The COBORU (center of research on crop plant varieties) list of vegetable plants, compiled in 2003, includes 26 sweet corn varieties, out of which 3 are French, 7 American, 10 Dutch, and 6 are Polish. The productive value of the varieties is determined primarily by their yield capacity and the earliness of their ripening.

Producers involved in sweet corn growing for direct consumption are interested in obtaining a large number of well kernelled cobs. Those producing sweet corn for industrial processing expect a high yield of material suitable for processing. In terms of the length of the vegetation period the following groups of corn varieties are distinguished:

– early varieties (70–80 days),
– medium early varieties (85–90 days),
– late varieties (95–110 days).

Also important is the division of varieties with respect to the content of sugars in kernels at the phase of harvest ripeness. With reference to their genetic features, they are classified as:

– normally sweet, with the gene *„su-1” (sugary)*,
– with increased content of sugars, with the gene *„se”* or *„se+” (sugary enhancement)*,
– very sweet, with the gene *„sh-2”(shrunken 2)*.

Variety selection is an important consideration in sweet corn production and includes factors such as sweetness, days to maturity, seed color, size, yield potential, and tolerance to pests. The Cooperative Extension Service can provide a list of varieties recommended for each region.

Table 9: Sweet Corn Genotypes [177]

Genotype	Sweetness	Conversion of sugars to starch	Isolate from	Comments
Normal sugary (su)	Moderately sweet	Rapid	(sh2) varieties	Early; germinates in cold soil
Sugary enhanced (se), (se+)	Sweeter than (su), less sweet than (sh2)	Not as rapid as (su)	(sh2) varieties	(se+) is sweeter than (se)
Super sweet or shrunken (sh2)	Very sweet	Very slow	(su), (se) & (se+) varieties	Longest shelf-life; germinates poorly in cold soils

(source: ATTRA - National Sustainable Agriculture Information Service http://attra.ncat.org/attra-pub/PDF/sweetcorn.pdf

Modern sweet corn varieties are classified as: "normal sugary" (su); "sugary enhanced" (se) and (se+); and "shrunken" (sh2), also called "super sweet." These differ in flavor and tenderness, and in the rate at which starches are converted to sugar. In general, (se) lines yield the best, followed by (sh2), and finally (su).

Cross-pollination of sweet corn with other kinds of corn or with some other sweet corn genotypes can result in starchy-tasting kernels. Generally, a minimal isolation distance of 250 feet between those varieties or types is recommended; 700 feet, however, is preferred for more complete isolation. Table 9 summarizes the general characteristics of sweet corn genotypes, including isolation requirements.

The normally sweet varieties contain 4–6% of sugars in fresh kernel mass, those with higher sugar content from 6 to 8%, and the very sweet varieties, sometimes also called super sweet or extra sweet, from 8 to 12%. Another criterion of division or classification of cucltivars is the colour of their kernels which can be yellow (the largest group of varieties), white, yellow-white *(bicolor)* and red [17, 109,161].

3.1. SWEET (SUGARY) VARIETIES

BONUS – a late hybrid variety, with a vegetation period of 110 days. Cobs with a length of approximately 20 cm and an average weight of 210 g (without cover leaves), are set on the stems at the height of 60 cm. Highly suitable for freezing.

BOSTON – late hybrid variety (vegetation period of 100–105 days). Characterized by strongly growing stems, resistant to mechanical damage and reaching heights of about 200 cm. Cobs with a length of about 20 cm, set at the height of 65 cm. Thanks to uniform cob size and their high kernel yield it is excellent produce for both the fresh market and for processing. Both of these varieties have been bred by the Dutch company Syngenta Seeds [76].

GAMA – Polish-bred medium early hybrid variety. Vegetation period of 85–90 days. It forms shrubby plants with 1 or 2 high-set cobs of fusiform or slightly tapering shape with kernels located regularly in 14–18 rows. Kernels with good taste qualities, suitable for direct consumption. Variety bred by Horticulture Plant Breeding Station in Krzeszowice [76].

JUBILEE – late hybrid variety with a vegetation period of 105–110 days that for years has been considered model variety for the processing industry. Plants reach the height of up to 220 cm, with cobs set at 70–80 cm. Average length of cobs is 21 cm and their diameter is about 4.5 cm. Recommended for direct consumption. Variety bred by the Dutch breeding firm Syngenta Seeds.

SMOLICKA – medium early population variety bred in Poland, characterized by a strong tendency of branching. Plants reach heights of about 150 cm. Cobs with the length of about 19 cm are set at the height of 40–50 cm. Especially recommended for direct consumption [140].

SPIRIT – medium early hybrid variety with a vegetation period of 90–95 days and low sensitivity to spring cold. Plants reach the height of 170 cm and form uniform cobs with a length of about 20 cm set at the height of 40–50 cm. Cobs with large and very tasty kernels, suitable for direct consumption as well as for processing. Variety bred by the Dutch firm Syngenta Seeds.

WAZA – late hybrid variety with a vegetation period of 110 days. Mean weight of cob without cover leaves is 290 g, and its length – about 20 cm. Cobs set on stems at the height of about 65 cm. Suitable for direct consumption and for processing. Polish variety bred by Plant Breeding in Smolice [76].

ZŁOTA KARŁOWA – early population variety with a vegetation period of 90 days. Strongly branching plants with heights of 80–100 cm, forming from 3 to 5 low-set cobs. Cobs are small and slightly tapering, with almost totally kernel-filled tips. Variety suitable for direct consumption and for multiple harvest of cobs, Polish-bred by Plant Breeding in Snowidza.

3.2. VARIETIES WITH INCREASED (ENHANCED) CONTENT OF SUGARS

ANAWA – medium early hybrid variety with a vegetation period of 90–95 days. Plants reach the height of about 200 cm. Cobs with a weight of 210 g after removal of cover leaves, with a length of 18–20 cm and a diameter of 5 cm. Very high-yielding variety, resistant to diseases. Provides good raw material for processing and good produce for the fresh market. Polish-bred by Horticulture Plant Breeding in Krzeszowice [76].

CHAMP – early and very high-yielding hybrid variety. Plants with a height of about 190 cm produce cylindrical cobs of a length of 19 cm, set at the height of 40–50 cm. Yellow kernels in 16 straight rows. Cob tips are kernel-filled and covered with leaves. Suitable primarily for canning and for kernel freezing. Variety bred by the Dutch firm Asgrow [140].

DALLAS – medium early hybrid variety. Tall plants of about 220 cm, producing cobs of a length of about 18.5 cm set at the height of 60 cm. Due to strong tendency of branching, recommended mainly for growing in vegetable gardens. Kernels of good taste qualities, suitable for direct consumption. Bred by the American breeding firm Novartis [140].

EARLIBELLE-LEGENDE – very early variety with a vegetation period of 70–78 days. Weakly branching plants with average height of 160 cm. Kernels of very good quality in 14–16 rows on cobs of 19–20 cm in length. Cobs well filled with kernels are slow to overripe and set at the height of about 55 cm. Recommended for direct consumption and for processing. Bred by the French breeding firm Clause Semences [76].

ROYALITY – medium early hybrid variety. Plants reaching the height of about 200 cm, with cobs set at the height of 70 cm, with tendency to branching and considerable resistance to lodging. Kernels of very good quality on cobs with a length of about 19 cm. Recommended mainly for direct consumption. Variety bred by the Dutch breeding firm Pop Vriend Seeds [140].

SWEET LINCOLN – late hybrid variety with a vegetation period of 105–110 days. Plants reach the height of about 220 cm and produce large cobs of a length of about 22 cm and a diameter of 5 cm. Very high-yielding variety with strong resistance to diseases. Provides good raw material for processing and good produce for the fresh market. Bred by the Dutch breeding firm Syngenta Seeds [76].

3.3. SUPER SWEET VARIETIES

CABARET – medium late variety with two-colour yellow and white kernels. Plants reach the height of 190–200 cm and produce cobs at the height of 70 cm. Cobs are 21 cm long and have slender kernels in 16–20 rows. Suitable for direct consumption as well as for frozen and canned products. Variety bred by the Dutch breeding firm Seminis Vegetable Seeds [170].

CANDLE – very early variety with a vegetation period of 70–73 days. Very high-yielding, also in cooler summers. Plants of average height (150–160 cm), weakly branching, produce cobs of a length of 19–20 cm. Yellow kernels in 14–16 rows, with cob tips well filled with kernels. Grown for the processing industry and for the fresh produce market. Bred by the Dutch breeding firm Seminis Vegetable Seeds [170].

CHALLENGER – early variety with a vegetation period of 70–78 days. Strongly resistant to lodging, which facilitates cob harvest. Plants reach heights of up to 220 cm and produce at least 2 cobs per plant, set on the stems at the height of about 60 cm. Cobs are 21 cm long and well filled with slender yellow kernels in 16–18 rows. Suitable for freezing and canning of kernels and whole cobs. Variety bred by the breeding firm Seminis Vegetable Seeds.

COMANCHE – early variety with a vegetation period of about 80 days. Very high-yielding, also in cooler summers. Relatively short plants (about 150–160 cm) and weakly branching, produce cobs of a length of 19–20 cm. Yellow kernels in 14–16 rows, cob tips well filled with kernels. Grown for the processing industry and for the fresh produce market. Variety bred by the American breeding firm Hortag Seed Company [76].

DICKSON – late variety with a vegetation period of 100–105 days. Plants produce cobs of a length of about 21 cm set at a height of 70 cm. Yellow kernels in 16 rows, cob tips well filled with kernels. Suitable for direct consumption. Variety bred by the Dutch breeding firm Syngenta Seeds.

ENDEAVOR – early variety with a vegetation period of 75–80 days, with very good taste qualities. Plants reach heights of over 200 cm and produce straight cobs of a length of 20–21cm, set at a height of about 70 cm. Yellow kernels in 16–18 straight rows. Cob tips, well filled with kernels, are tightly enclosed with cover leaves. Cobs can be left on the plants for a little longer, as sugars in the kernels transform into starch very slowly. Suitable for direct consumption of fresh cobs, for canning of kernels, and for freezing cobs. Variety bred by the breeding firm Seminis Vegetable Seeds [170].

EVEN SWEETER – variety with white kernels of very high content of sugars, delicate skin, and „crunchy” consistency. Plants are very tall (about 215 cm) and produce cobs at the height of 75–80 cm. Cobs, 19–20 cm long, are made up of very tasty, narrow and slender kernels in 18 rows. Perfect raw material for the processing industry [170].

FRYGA – medium late variety with a vegetation period of 102 days. One of the tall varieties whose plants reach heights of more than 225 cm. On the stems, cobs with an average weight of 260 g, with a length of over 20 cm and average diameter of 5 cm. Highly popular both in the fresh produce market and with the processing industry. Polish variety bred by Plant Breeding in Smolice [76].

GOLDA – late variety with a vegetation period of 108–110 days. Long and large cobs are set at the height of 70 cm on the stems. Weight of cobs without cover leaves is 250–280 g, and their length exceeds 20 cm. Suitable both for fresh produce market and for processing industry. Variety bred by the Dutch breeding firm Pop Vriend Seeds [76].

INDIRA – medium late variety with a vegetation period of 98–100 days. Plants reach the height of about 225 cm and produce cobs 19-20 cm long and about 4.6 cm in diameter, set at the height of about 70 cm. Resistant to lodging and diseases but has a certain tendency to branching, therefore recommended for direct consumption. Variety bred by the Dutch breeding firm Pop Vriend Seeds.

LANDMARK – early variety with a vegetation period of 75–85 days. Germinates well in cool soil and is fairly tolerant of cold spells during vegetation. Plants reach heights from 180 to 200 cm. Cobs with a length of 19–21 cm are set evenly at the height of 55 cm and are well suited for mechanical harvest. Good raw material for the processing industry as well as for direct consumption [76, 140].

MADONNA – medium early variety with a vegetation period of 80–85 days. Plants reach a height of over 200 cm. Cobs with average length of 20 cm are set at the height of 75 cm and are well suited for mechanical harvest. Bicolor kernels (yellow and white) are evenly arranged in 16–20 rows. Suitable both for direct consumption and for the processing industry. Variety bred by the breeding firm Seminis Vegetable Seeds.

NAVAHO – medium early variety with a vegetation period of about 95 days. Plants about 200 cm tall produce long cobs of over 20 cm in length, at a height of about 70 cm. Kernels are very tasty and characterized by very slow conversion of monosaccharides into starch. This permits extension of the harvest time and allows cobs to be stored for several days without any notable deterioration in technological or sensory quality. Recommended both for the processing industry and for direct consumption. Variety bred by the American breeding firm Hortag Seed Company [76].

PINACLE – medium late variety with a vegetation period of 95–104 days. Plant height is about 200 cm and cob setting height is about 65 cm. Cobs with average weight of about 400 g have length of 21–24 cm and diameters of up to 5 cm. Due to its delicate seed cover and sweet taste it is recommended for the fresh produce market as well as for the processing industry. Variety bred by the French breeding firm Clause Semences.

POKUSA – late variety with a vegetation period of about 106 days. Cob setting height is about 60 cm. Average cob weight is up to 300 g and cob length up to 22 cm. Yellow kernels are arranged in 16 rows. Recommended for the fresh produce market and for the processing industry. Polish-bred by ZPHU Konsmet L.I. [76].

PRIMETIME – late variety with a vegetation period of 100–105 days. Cobs with a length of about 22 cm, set on stems at the height of about 75 cm. Yellow kernels, due to their delicate fruit cover and sweet taste, recommended primarily for the fresh produce market. Variety bred by the Dutch breeding firm Syngenta Seeds.

PUNCHLINE – medium early, very high-yielding variety, well tolerant of the hardships of transport. Tall plants of about 200 cm. Cobs set at the height of 40–45 cm have lengths of 17–19 cm. Pale yellow kernels are arranged in 16–18 rows. Recommended primarily for consumption, as well as for canning and cob freezing [170].

SHAKER – very high-yielding early variety with a vegetation period of 80–85 days. Tall plants (about 210 cm) producing cobs 22 cm long, set at the height of about 75 cm. Gold-yellow kernels in 14–18 rows and well filling the tips of the cobs. Cobs angled away from the stems which greatly facilitates harvest, both mechanical and by hand. Suitable for direct consumption, as well as for cob and kernel freezing and for canned products. Classified among the tasty varieties. Bred by the Dutch breeding firm Seminis Vegetable Seeds [76].

SHEBA – early variety with a vegetation period of 70–73 days and plant height of about 180 cm. Cobs with a length of 21–22 cm, well covered with cover leaves, are set at the height of about 50 cm. Shapely gold-tinted kernels arranged in 14–16 regular rows. Highly suitable for the fresh produce market and for processing. Bred by the Dutch breeding firm Seminis Vegetable Seeds.

SHIMMER – very early high-yielding variety with a vegetation period of 78–80 days. Plants reach average height of 200 cm and usually produce single cobs high-set on the stems (about 75 cm). This makes the variety suitable for mechanical harvest. Cobs are long (about 20 cm) and cylindrical in shape. Popular in cultivation both for processing purposes and for direct consumption. Variety bred by the breeding firm Seminis Vegetable Seeds.

SWEET EAR – medium late high-yielding variety with a vegetation period of 90–100 days. Average plant height of 215 cm. Cobs 20–22 cm long and 400 g in weight (without cover leaves), set on the stems at a height of about 65 cm. Recommended for the processing industry and for direct consumption. Variety of the French breeding firm Clause Semences.

SWEET NUGGET – very early and high-yielding variety with a vegetation period of 70–83 days. Plants reach average height of 200 cm and usually produce single cobs set on the stems at the height of 60 cm which makes them suitable for mechanical harvest. The cobs are about 380 g in weight and very long (21–23 cm), cylindrical in shape. Popular among growers, both for processing and for direct consumption. Variety of the breeding firm Agri-Saaten [76].

SWEET TROPHY – very early variety, resistant to lodging, with a very short vegetation period (75–78 days). Strong plants produce large and well filled cobs of a length of about 20–22 cm. Dark-yellow kernels set in 14–16 straight rows. Very good material for frozen and canned products, as well as for direct consumption.

Yields reliably also under less favourable growing conditions. Variety of the Dutch breeding firm Seminis Vegetable Seeds.

TROPHY – medium early high-yielding variety with a vegetation period of from 75 to 100 days. Plants reach average heights of about 200 cm and usually produce single cobs high-set on the stems, which makes them suitable for mechanized harvest. Very long, cylindrical cobs. Popular among growers, both for processing and for direct consumption. Variety of the breeding firm Royal Sluis [140].

YUMA – medium early high-yielding variety with a vegetation period of about 95 days. Yellow-white kernels set in 12 rows on cob cores. Cobs with average weight of 270 g and length of 20–22 cm. Plants reach average height of 200 cm and usually produce single cobs set at the height of 65 cm. Suitable for mechanical harvest and popular among growers both for processing and for direct consumption. Variety of the American breeding firm Hortag Seed Company [76].

Sweet corn varieties can have kernel coulouring of yellow, white, and bicolor (yellow and white kernels). The Polish market is dominated by varieties with yellow-coloured kernels. Almost all the varieties are hybrids (F1), with the exception of a few population varieties like e.g. Złota Karłowa or Smolicka. None of the varieties sold and grown in Poland are genetically modified (GMO).

According to Warzecha (154), the main distributors of sweet corn seed in the Polish market are the following companies: Syngenta Seeds Sp. z o. o. in Piaseczno n/Warsaw, Seminis Vegetable Seeds Polska in Warsaw, Floraland in Legionowo, Plant Breeding „Selecta" in Poznań. Varieties bred in Poland originate from the firms of Plant Breeding Smolice Sp. z o.o., and Horticulture Plant Breeding in Krzeszowice Sp. z o.o.

- Seminis offers in its latest catalogue 7 varieties of very sweet corn (*sh2*) and one sweet variety (*su*), bred by the Dutch breeding firms Royal Sluis and Asgrow. The very sweet varieties are Candle and Sheba – early, with a vegetation period of 75-80 days, Sweet Trophy (+5 days), Challenger (+7 days), Basin (+7 days), Shaker (+8 days), Shimmer (+10 days), and a sweet variety Powerhouse (+10 days). The numbers in brackets indicate ripening time with relation to the Candle variety. The most popular among corn producers are the varieties: Candle, Sweet Trophy, Challenger – all three suitable both for processing and for the fresh produce market, and Sheba – for the fresh produce market. The remaining varieties, relatively newer in our market - Basin and Shimmer – are suitable for the fresh produce market and for processing, and Shaker – for the fresh produce market. Powerhause (*su*) is a variety recommended for processing – for kernel canning and whole cob freezing.
- Floralnd is a distributor of sweet and very sweet corn varieties of the Dutch breeding firm Pop Vriend Seeds. The best known in the Polish market are medium late varieties of *sh2* type, Golda and Helena, with vegetation periods of about 100 and 110 days. Both varieties are suitable both for the fresh produce market and for processing. The varieties combine high yield, excellent quality, great taste, and resistance to diseases.

- Plant Breeding Selecta offers sweet corn varieties of the American breeding firm Hortag Seed Co. The best known in the Polish market are two varieties from Hortag – the early variety Comanche (sowing to harvest period of about 80 days) and the medium early variety Navaho. Both varieties are of the very sweet type and suitable both for the fresh produce market and for processing. They are characterized by slow transformation of sugars into starch, thanks to which harvest can be extended in time (even up to 3 weeks, especially in the case of Navaho) without loss of technological and sensory qualities. Variety Navaho has exceptional taste qualities thanks to the high content and suitable composition of sugars and to the delicate skin.
- Plant Breeding Smolice offers the very sweet variety Fryga and the sweet variety Waza. Both varieties represent high taste and technological qualities. Variety Anawa, bred by PHRO Krzeszowice, has a vegetation period of 86-95 days, is characterized by increased content of sugars (9-10%) and slower transformation of sugars into starch.
- Syngenta currently has the largest share in the market for seed of sweet corn type „su", used for freezing whole cobs and for canned corn kernels. The firm currently offers the very early variety Spirit, with a vegetation period of 90-95 days, Boston (100-105 days), and Jubilee (105-110 days), as well as Sweet Lincoln with increased sugar content (*se*) - 105-110 days. The Jubilee and Boston varieties are acknowledged European standards in canned corn processing. New offers of Syngenta include the varieties GH 2041, Nemphis, and Bold. All three of them represent the „*su*" type. Also available from Sygenta are some very sweet varieties (*sh2*): Primetime (100-105 days) – for processing industry and for the fresh produce market, Dickson (105 days) – for fresh produce market, and GSS 9377 (110 days) – also for the fresh produce market – a very sweet variety with strong flavour. New offer of Syngenta in the group of very sweet varieties (*sh2*) includes GSS 5022 and GSS 3486 varieties – both of them relatively early.

3.4. SYNGENTA* SWEET CORN VARIETIES

In its present form, Syngenta is a young company. But it stems from an industrial tradition going back almost 250 years. Syngenta has a broad offer in vegetables including tomatoes, lettuce, melons, watermelons, cucumbers, cabbage, sweet corn, hot and sweet peppers, beans and oriental radishes. Syngenta has also developed a variety of seeds, young plants and cuttings in a wide range of flower species have been developed for commercial growers. S&G® is a leading brand for vegetables in Europe, Africa and Asia and is further known throughout the world for its high quality flower seeds and young plants. ROGERS® is the brand name for vegetables throughout the Americas [178].

* Rogers/Syngenta Seeds, Inc. (Source: http://www.rogersadvantage.com/products/corn.asp)

3.4.1. Yellow Sweet Corn Hybrids

Table. 10. Syngenta yellow sweet corn hybrids (Source: rogersadvantage.com)

	**Jubilee** *su* - Superb eating quality, high yields and worldwide consumer acceptance have made Jubilee the gold standard for excellence.
	Approx. Days to Maturity: 81
	Average Ear Length x Diameter (in.): 8.5 x 1.8
	Row Count: 16-20
	Husk Appearance: Medium green.
Early Sunglow *su*	Produces long ears early in the season helping you be the first to market with quality, locally grown sweet corn.
Approx. Days to Maturity:	70
Average Ear Length x Diameter (in.):	7.5 x 1.7
Row Count:	12-14
Husk Appearance:	Medium dark green.
Kandy King EH Homozygous *se*	A mid-early variety renowned for its outstanding eating quality. Demonstrated cool-soil emergence gives KK its early advantage.
Approx. Days to Maturity:	73
Average Ear Length x Diameter (in.):	8.5 x 1.8
Row Count:	16-18
Husk Appearance:	Dark green. Good flags.
Kandy Korn EH Heterozygous *se*	Devoted followers easily recognize this variety's unique burgundy husks.
Approx. Days to Maturity:	81
Average Ear Length x Diameter (in.):	9 x 1.85
Row Count:	16
Husk Appearance:	Burgundy coloring.
Tendertreat EH Heterozygous *se*	Tendertreat's vigorous plants support their king-sized ears, so your customers can get more for their money.
Approx. Days to Maturity:	87
Average Ear Length x Diameter (in.):	9 x 1.85
Row Count:	14-18
Husk Appearance:	Medium green.
Golden Queen *su*	A widely adapted variety for home gardeners and roadside stand growers with eating quality reminiscent of Silver Queen.
Approx. Days to Maturity:	88
Average Ear Length x Diameter (in.):	8.5 x 1.8
Row Count:	12-16
Husk Appearance:	Outstanding package.

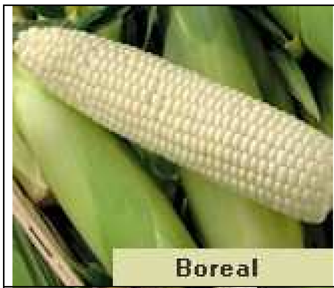
3.4.2. WHITE SWEET CORN HYBRIDS

Table. 11. Syngenta white sweet corn hybrids (Source: rogersadvantage.com)

<table>
<tr><td rowspan="5">
</td><td>Silver Princess Homozygous se - Grow Silver Princess and enjoy the advantages of marketing ears with great eating quality, early in the season.</td></tr>
<tr><td>Approx. Days to Maturity: 74</td></tr>
<tr><td>Average Ear Length x Diameter (in.): 7.5 x 2</td></tr>
<tr><td>Row Count: 14-16</td></tr>
<tr><td>Husk Appearance: Very good cover.</td></tr>
<tr><td rowspan="5">
</td><td>Silver King Homozygous se - In home garden and local market plantings, Silver King has been repeatedly noted for its superb eating quality in a product consumers will go out of their way for.</td></tr>
<tr><td>Approx. Days to Maturity: 82</td></tr>
<tr><td>Average Ear Length x Diameter (in.): 8 x 1.9</td></tr>
<tr><td>Row Count: 16</td></tr>
<tr><td>Husk Appearance: Medium green. Good cover.</td></tr>
<tr><td rowspan="5">
</td><td>Silver Queen su - The most popular white sweet corn in America because of its superb eating quality and wide range of adaptation. One of the few varieties consumers ask for by name.</td></tr>
<tr><td>Approx. Days to Maturity: 88</td></tr>
<tr><td>Average Ear Length x Diameter (in.): 8 x 1.8</td></tr>
<tr><td>Row Count: 14-16</td></tr>
<tr><td>Husk Appearance: Outstanding package.</td></tr>
<tr><td colspan="2">Silver Knight Heterozygous se - A very early season variety with good ear length, tip fill and husk cover for this class.</td></tr>
<tr><td>Approx. Days to Maturity:</td><td>67</td></tr>
<tr><td>Average Ear Length x Diameter (in.):</td><td>9 x 1.87.5 x 1.8</td></tr>
<tr><td>Row Count:</td><td>14-16</td></tr>
<tr><td>Husk Appearance:</td><td>Very good cover.</td></tr>
</table>

3.4.3. White Supersweets Hybrids

Table. 12. Syngenta white supersweet corn hybrids (Source: rogersadvantage.com)

<table>
<tr><td rowspan="5">
</td><td>Boreal - Impressive Disease Package and Excellent Tip Fill. A mid-season fresh market variety suitable for shipping</td></tr>
<tr><td>Approx. Days to Maturity: 78</td></tr>
<tr><td>Average Ear Length x Diameter (in.): 8 x 1.8</td></tr>
<tr><td>Row Count: 14-16</td></tr>
<tr><td>Husk Appearance: Dark green. Good flags. Adequate cover.</td></tr>
<tr><td rowspan="5">
</td><td>Tahoe - Cylindrical Ears with Good Tip Fill Suited for commercial shipping. Tahoe has attractive ears that are relatively cylindrical with good tip fill.</td></tr>
<tr><td>Approx. Days to Maturity: 81</td></tr>
<tr><td>Average Ear Length x Diameter (in.): 7.7 x 1.85</td></tr>
<tr><td>Row Count: 14-18</td></tr>
<tr><td>Husk Appearance: Dark green. Medium flags.</td></tr>
<tr><td rowspan="5">
</td><td>Whistler - High Quality Ears and Maize Dwarf Mosaic Virus Tolerance. A main season fresh market variety designed for commercial shipping.</td></tr>
<tr><td>Approx. Days to Maturity: 78</td></tr>
<tr><td>Average Ear Length x Diameter (in.): 7.25 x 1.8</td></tr>
<tr><td>Row Count: 16-18</td></tr>
<tr><td>Husk Appearance: Medium green. Good flags.</td></tr>
<tr><td colspan="2">Brighton - This hybrid retains the supersweet shelf life and sweetness, but has far superior emergence even in cool soil conditions.Targeted for the Desert Southwest where ear length and protection from sunburn is needed.</td></tr>
<tr><td>Approx. Days to Maturity:</td><td>80</td></tr>
<tr><td>Average Ear Length x Diameter (in.):</td><td>9 x 1.8</td></tr>
<tr><td>Row Count:</td><td>14-16</td></tr>
<tr><td>Husk Appearance:</td><td>Medium green. Good flags.</td></tr>
<tr><td colspan="2">Aspen - The only supersweet variety proven to deliver the ear length that the Southern California market requires.</td></tr>
<tr><td>Approx. Days to Maturity:</td><td>82</td></tr>
<tr><td>Average Ear Length x Diameter (in.):</td><td>9 x 1.8</td></tr>
<tr><td>Row Count:</td><td>14-16</td></tr>
<tr><td>Husk Appearance:</td><td>Medium green. Long flags</td></tr>
</table>

3.4.4. YELLOW SUPERSWEET HYBRIDS

Table. 13. Syngenta yellow supersweet corn hybrids (Source: rogersadvantage.com)

	In commercial plantings, **Primetime** has consistently delivered reliable seed quality and uniform, vigorous stands, for a better percentage of marketable ears.
	Approx. Days to Maturity: 79
	Average Ear Length x Diameter (in.): 8 x 1.75
	Row Count: 14-16
	Husk Appearance: Dark green. Good flags.
	**Prime Plus** - A rust resistant variety delivering high quality ears with excellent tip fill. Ideal for tray packs or crates.
	Approx. Days to Maturity: 78
	Average Ear Length x Diameter (in.): 8 x 1.8
	Row Count: 14-16
	Husk Appearance: Dark green. Good flags.
	**Winstar** is a full-season shipper with an exceptionally clean plant.
	Approx. Days to Maturity: 82
	Average Ear Length x Diameter (in.): 8 x 1.95
	Row Count: 16-20
	Husk Appearance: Dark green. Average flags.
Krispy King - Extra-deep, sweet kernels typically fill each Krispy King ear to the tip, adding to this variety's appeal.	
Approx. Days to Maturity:	78
Average Ear Length x Diameter (in.):	8 x 1.9
Row Count:	18-20
Husk Appearance:	Nice package.
Supersweet Jubilee - A hybrid with exceptional qualities. Refined sweet flavor, smooth texture, and tender pericarp make this a prized variety among consumers.	
Approx. Days to Maturity:	83
Average Ear Length x Diameter (in.):	8.5 x 1.8
Row Count:	16-20
Husk Appearance:	Medium green.

3.4.5. Bicolor Supersweets Hybrids

Table. 14. Syngenta Bicolor supersweet corn hybrids (Source: rogersadvantage.com)

	**Big Time** Superior Bicolor with Savory White and Yellow Kernels. A mid-season shipper that has produced refined, cylindrical ears. Excellent seed quality. Common rust resistant.
	Approx. Days to Maturity: 78
	Average Ear Length x Diameter (in.): 8 x 1.8
	Row Count: 14-16
	Husk Appearance: Dark green. Medium flags.
	**Camas** Exceptionally Sturdy Plant, Excellent Husk, & Short Shank. A full-season shipper with an exceptional sturdy plant and excellent husk cover.
	Approx. Days to Maturity: 84
	Average Ear Length x Diameter (in.): 8 x 1.95
	Row Count: 16-20
	Husk Appearance: Dark green. Average flags.
	**Double Up** Early Bicolor with Good Tip Fill and Larger Ear Size. Early shipper with consistent performance, good tip fill, and larger ear size than comparative varieties. Recommended for growing conditions in Midwest and Northeast.
	Approx. Days to Maturity: 73
	Average Ear Length x Diameter (in.): 8 x 1.8
	Row Count: 14-16
	Husk Appearance: Medium green.

3.4.6. TripleSweet® Varieties

3.4.6.1. What is a TripleSweet®?

TripleSweet is a class of sweet corn that has 75% sugary enhanced (se) kernels and 25% supersweet kernels. TripleSweet varieties combine the exceptional tenderness and sweet corn flavor of se types with extra sweetness, extended shelf life and field holding ability. TripleSweet varieties deliver more consistent, longer lasting sweetness, even under drought stress, making them ideal for roadside markets and local shipping. TripleSweet is a registered trademark of a Syngenta Group Company.

3.4.6.2. TRIPLESWEET® VARIETIES

Table. 15. Syngenta triplesweet corn hybrids (Source: rogersadvantage.com)

	This variety provides strong built-in protection against damage by European corn borers, as well as being a significant IPM tool for the control of corn earworms and fall army worms. Typical of the TripleSweet varieties, the eating quality is outstanding with tender, sweet kernels.
	Approx. Days to Maturity: 82
	Average Ear Length x Diameter (in.): 8 x 1.75
	Row Count: 14-18
	Husk Appearance: Medium green.
	Truly Superior Suited for local and roadside markets in the Midwest and East, Avalon delivers a high quality ear in about 82 days. Consumers of white sweet corn are sure to find Avalon's eating quality truly superior to all other white se types.
	Approx. Days to Maturity: 82
	Average Ear Length x Diameter (in.): 8.2 x 1.75
	Row Count: 16
	Husk Appearance: Medium green with limited flags
	As an 82-day, main season variety, features long, well-filled slightly tapered ears and medium-green husk. Suited for roadside and local markets as well as home gardens and noted for its superb eating quality.
	Approx. Days to Maturity: 82
	Average Ear Length x Diameter (in.): 8 x 1.75
	Row Count: 14-18
	Husk Appearance: Medium green.
Serendipity: TripleSweet Bicolor The variety that launched the TripleSweet family. A bicolor with the superb eating characteristics for the local market.	
Approx. Days to Maturity:	82
Average Ear Length x Diameter (in.):	8 x 1.85
Row Count:	16-18
Husk Appearance:	Medium green.
Honey Select: TripleSweet Yellow The first yellow with the TripleSweet quality. Outstanding flavor for local markets demanding yellow hybrids.	
Approx. Days to Maturity:	79
Average Ear Length x Diameter (in.):	9 x 1.88.5 x 2
Row Count:	18-20
Husk Appearance:	Medium green. Good flags.

3.4.6.3. COMPARE TRIPLESWEETS

Table. 16. Comparison of various characteristics of sweet corn hybrids

Characteristics	TripleSweet®	Synergistic	Sugary Enhanced	Sugary	Supersweet (sh2)
Tender	**		**		
Creamy	**	*	**	*	
Expect Repeat Sales	***				
Sweet but Not too Sweet	*	*			
Consistent High Quality	**				
Good Emergence	*	*	*	*	
Great Corn Taste	**	*	**	*	
Elevated Sugar Content	*	*			***

(Source: http://www.rogersadvantage.com/products/corn.asp)

SWEET CORN KERNEL STRUCTURE, CHEMICAL COMPOSITION, AND SENSORY QUALITIES

Sweet corn cobs constituting raw material for processing must be characterized by the highest quality of kernels [60]. Kernel quality is defined not just by the chemical and sensory properties, but also by the mechanical parameters of kernels. This appears to fully justify joint consideration of all those properties. Sweet corn is probably a mutant of fodder corn [99]. Significant differences between the two are related more to the genetics than to the structure of the kernels [155]. As emphasized by Salunkhe and Kadam [118], the structure of the kernels is strongly related to the genetic modification and to ripeness.

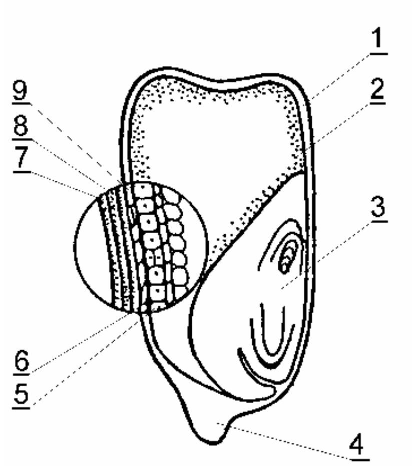


Fig. 9. Schematic of longitudinal cross section of a sweet corn kernel: 1 – pericarp, 2 – endosperm, 3 – germ, 4 – pedicel, 5 – aleurone layer, 6 – tube cells, 7 – epicarp, 8 – mesocarp, 9 – cross cells [118]

Sweet corn kernel is built of the pedicel, the pericarp, the germ, and the parenchyma (Fig. 9). The pedicel is a hard and fibrous remnant of the tissue that joins the kernel to the cob core [128]. During kernel shearing, a part of the pedicel remains on the kernel, which has a negative effect on its nutritional value [118]. Kernel shape is described as flattened and wedge-like, with the tip much broader than the base end by which the kernel is attached to the cob core.

The kernel is deep set on an abbreviated shoot (rachis) forming the cob, and is covered with a thin pericarp [99,134]. The pericarp is a component of the seed coat tissue and forms the outer layer of the kernel. The thickness of the layer determines the kernel skin level of tenderness. This feature is important in the estimation of kernel quality for processing. As compared to other varieties, sweet corn is characterized by lower thickness of the epicarp, on average 25-30 μm [55]. The epicarp is composed of a single layer of pericarp, in the cavities of which single cells of the mesocarp are located. It also includes one or two layers of cross-cells and one or more tube cells adherent to the pericarp. The germ, located obliquely at the base of the kernel, is large and constitutes about 15% of the volume or 11.5-14% of the weight of the kernel [25]. Germ size, however, is cultivar-related and may constitute 5% of the mass of the whole kernel [106]. In turn, the parenchyma is the largest element of the kernel. It is in the parenchyma that the sugars, starch, and water-soluble polysaccharides are accumulated in. In the phase of consumption ripeness, the consistency of kernels is soft, delicate, creamy, and the taste is sweet and fragrant [99,119].

The kernel seed coat has colours from pale yellow to orange, often also with a violet tint and shiny. In the genotype of sweet corn, apart from the genotype of sweet corn, except gene *su* (sugary) gene determining the sweet taste and tenderness of the kernel, also other genes have been discovered, responsible for enhancing the sweetness and the taste and utility qualities – the gene *se* (sugary enhancement) and the gene *sh2* (shrunken 2) [17]. Genetic combinations of the genotypes *su* and *sh2* helped in the creation of very sweet cultivars [120]. In the phase of full ripeness, sweet corn has wrinkled kernels, almost completely filled with vitreous parenchyma, mostly white or yellow in colour. The reserve substance of the parenchyma is composed of amylodexstrins which are responsible for the sweet taste. The kernel has a bulbous shape, oval, wedge-shaped or angular, a smooth or wrinkled surface, and white, yellow, read or brownish colouring. It is enclosed in a cover formed from fused pericarp and seed coat, beneath which there is a layer of aleurone cells, the parenchyma, and the germ [25]. From the moment of pollination till harvest the cob of sweet corn undergoes numerous physical and chemical transformations which largely affect the taste and the quality of kernels [70]. The taste is especially strongly affected by the transformations of sugars [133,160].

With respect to the content of sugars, three types of sweet corn cultivars are distinguished: normally sweet cultivars, type *su* (sugary), with sugar content of 4-6%, cultivars with increased sugar content, type *se* (sugary enhancement) – 6-8%, and very sweet cultivars, type *sh2* (shrunken 2) – 8-12% [153]. Apart from the content of sugars, fresh mass of sweet corn kernels contains 2.1-4.5% of proteins, 3-20% of starch, 1.1-

2.7% of fats, 0.9–1.9% of cellulose, 9–12 mg of vitamin C, small amounts of vitamins A, B_1, B_2, PP, and mineral components such as: sodium, potassium, magnesium, calcium, phosphorus, iron, selenium, copper, nickel and chromium [39,79,127]. The chemical composition of the kernels is related to the weather conditions, ripeness, and method of storage [118]. According to data from the USDA [52], the nutritional value of sweet corn kernels is related to the content of water (72.7%) and to the total content of solid parts (27.3%). Solid parts include hydrocarbons (81%), proteins (13%), lipids (3.5%), and others (2.5%). Starch is the dominant hydrocarbon component.

Sweet corn has the highest nutritional value in the phase of milk ripeness. With progressing phase of ripeness, in the transition to the phase of wax ripeness the content of sugars decreases, accompanied by an increase in the content of starch [85,125,158]. In 100 g of kernels there is about 3.03 g of saccharine, 0.34 g of glucose and 0.31 g of fructose. The content of saccharine increases, and that of reducing sugars decreases as the kernels reach the optimum ripeness [80]. The content of proteins in the kernels decreases from the surface towards the centre of the kernel [131]. The content of proteins, free aminoacids, water-soluble and insoluble hydrocarbons, increases up to the phase of wax ripeness, and then gradually decreases [11]. The amounts of the particular components in various cultivars and in various phases of ripeness variable. In comparison to other cereals, sweet corn is relatively rich in oil. Approximately 90% of the oil is accumulated in the germ [82].

Sweet corn is more tasty than other corn species, thanks to its high content of water-soluble polysaccharides. That component imparts to the kernels their tender and creamy character. The most important parameters that affect the sensory quality of the kernels include sweetness, texture, and taste [162]. Sweetness depends on the content of sugars, while texture depends on a number of factors, such as tenderness of the seed coat, moisture, content of water-soluble polysaccharides. Taste, in turn, is frequently associated with the content of DMS (dimethyl sulphide) [109,158,161].

Decrease in kernel quality related to loss of taste and aroma after the harvest is a problem for the processing industry. The loss of taste in fresh or frozen state of the kernels is caused by enzyme activity [27,136]. Fresh kernels are characterized by faint aroma or its total absence. Wade [139] states that cut kernels have three characteristic types of aroma. Two of these are similar to the aroma of fresh green vegetables, and the third is described by that author as a methol-type aroma. With progressing ripeness of sweet corn, the level of DMS in the kernels decreases [9], which is a serious problem for the processing industry due to the related considerable loss of taste of processed sweet corn products [158,162].

The consumption quality of fresh sweet corn largely depends on the content of sugars and water-soluble hydrocarbons in the kernels [37]. The quality of sweet corn kernels can be determined in many ways. The basic discriminant of kernels for the processing industry is kernel hardness and taste [96]. One of the most important factors determining the quality of kernels for processing is the use of cultivars characterized by uniform ripening. The choice of cultivar affects not only the yield of kernels cut off cobs, but also the taste quality of the kernels. Other quality factors include the colour, sweetness, and tenderness of the kernel cover [97]. With ripening, the cover becomes harder and harder [21]. The quality of sweet corn is correlated to the content of sugars [85]. The transformation of sugars into starch is also related to decreasing moisture content of the kernels [32].

CHAPTER 5

STANDARDS AND DEFINITIONS, TEST PROCEDURES, ESTIMATION OF PHYSICAL AND CHEMICAL PROPERTIES OF SWEET CORN

The initial material for the study was made up by sweet corn cobs of one sugary cultivar (Jubilee) and two very sweet cultivars (Helena, Candle). Sweet corn cobs of cultivars Jubilee and Helena originated from the plantation of the Institute of Plant Breeding and Acclimatization (IHAR) in Radzikowo near Warsaw, and those of cultivar Candle from a private farm in Zajezierze n/Dęblin. The sweet corn plantations were maintained in accordance with the rules of correct corn growing techniques. The selection of the particular cultivars was based on their considerable share in the structure of corn production for the processing industry, on the high technological value of the cultivars, and on their presence on the register of new plant varieties and cultivars. The selection of cultivars for the study was also consulted with the IHAR. Large, uniform, cylindrical cobs and even rows of kernels characterized the cultivars, apart from their relatively high technological value.

Cobs for the tests were acquired through harvesting by hand in the phase of processing ripeness (late milk ripeness). At that phase of ripeness the kernels contain the largest amounts of nutrients, are shiny and easy to separate from the cob cores [16, 104, 140]. Due to the considerable distance between the plantations and the location of the study, cobs collected for tests were stored, in cover leaves and bagged, in a cold storage room with constant temperature and relative humidity. After cover leaves removal, healthy cobs with dimensions and shapes characteristic for a given cultivar were selected for the tests. Attention was also paid to the cob surfaces being free from damage by pests and diseases, and for the cobs to be characterized by a high degree of kernel filling and good linearity. The shape of cobs and quality of kernels of sweet corn may have a significant effect on the results of the tests, so the cobs selected had to be of a size close to that characteristic for the cultivars studied.

Due to the fact that the study was conducted on a variety of test stands and equipment, preparation of cob samples was adapted to the requirements of the particular tests. The required number of measurements N was determined on the basis of the number of preliminary measurements n, according to the relation given by Telejka [132]:

$$N \geq \frac{t_{n,\alpha}^2 \cdot S_x^2}{\delta^2} \quad (no.) \tag{1}$$

where:

$t_{n,\alpha}$ – critical value of Student distribution t, read for n measurements and significance level of α = 0,05,

S_x – standard deviation,

δ – required level of accuracy.

For each of the cultivars the determinations included:

– physical properties, i.e. relative moisture, length and weight of cob without leaves, cob diameter, number of kernels rows and on kernels in a row, biological efficiency, weight of 1000 kernels, mean length of kernel in cob and bulk density in repose, at similar level of kernel moisture of about 72%,
– chemical properties, i.e. the total content of sugars, content of saccharose, content of reducing sugars and of starch.

The biological efficiency was determined according to the formula:

$$W_b = \frac{m_k - m_r}{m_k} \cdot 100 \quad (\%) \tag{2}$$

where:

m_k – weight of cob without cover leaves (g),

m_r – weight of cob core (g).

The weight of the cob and the kernels separated by hand from the cob core were determined by means of a balance type WPE 2000p. The biological efficiency was determined in a manner similar to that applied to the determination of the share of kernels in the cob weight. The only difference was that here the hard fibrous pedicel was cut off from the kernels. Due to the low nutrient value of the pedicels, their weight should not be taken into account in the determination of weight losses of kernels. The share of kernels in the weight of cob of a given cultivar was determined on the basis of a mean value obtained from measurement of 30 cobs.

The relative moisture of kernels was determined according to the balance-drier method as per the Standard No. PN-ISO 6540 [103]. Samples of moist kernels (100 g) were weighed on an analytical balance type WPE 2000p, and then dried in a drier type K, at 130°C, until constant mass was obtained. Moisture measurements were made in 3 replications.

Kernel moisture was determined according to the following formula:

$$W = \frac{m_o - m_1}{m_o} \cdot 100 \quad (\%) \tag{3}$$

where:

m_o – weight of kernels prior to drying (g),
m_1 – weight of kernels after drying (g).

Bulk density of kernels was determined in accordance with the Standard No. PN-73/R-74007 through pouring kernels freely through a filler funnel, from the height of 100 mm, to a test vessel of 0.5 dm^3 in volume. After filling the vessel with kernels and sweeping off excess kernels, the vessel with kernels was weights using balance type WPE 2000p. The measurement was made in 3 replications.

Bulk density of kernels was calculated from the formula:

$$\rho = \frac{m_z - m_n}{V_n} \quad (kg \cdot m^{-3}) \tag{4}$$

where:

m_z – weight of the test vessel with kernels (kg),
m_n – weight of the test vessel (kg),
V_n – volume of the test vessel (m^3).

The determination of the weight of 1000 kernels was made in accordance with the Standard No. PN-68/R-74017. Random selected 1000 kernels were weighed using a balance type WPE 2000p. Measurement of the weight of 1000 kernels was made in 3 replications. The dimensional parameters, i.e. the length and diameter of cobs, were determined using a ruler gauge and a slide calliper. Cob diameter was measured in the middle of the cob length. Cob weight was determined using balance type WPE 2000p. Cob weight values for a given cultivar were determined on the basis of mean value from measurements of 30 cobs. Measurement of the total content of sugars was made in accordance to the DNS method, following the performance of acid hydrolysis according to the Standard No. PN-EN ISO 10520:2002. Reducing sugars were determined prior to the hydrolysis, with the help of the DNS method. Starch content was determined through the difference between the total content of sugars and the content of sugars soluble in ethyl alcohol (40% vol/vol) in accordance with the Standard No. PN-EN ISO 10520:2002. The content of saccharose was determined thought the difference between the content of sugars soluble in ethyl alcohol and the content of reducing sugars.

In the course of reducing sugars content determination with the DNS method, 0.5 cm^3 of the tested solution and 1.5 cm^3 of 3-5-dinitrosalicylic acid (DNS) were added to a test tube, and then boiled for 5 minutes in a bath of boiling water. After cooling down, 6 cm^3 of distilled water was added to a total volume of 8 cm^3 and the extinction of the sample was read against a reagent assay at a wavelength of λ = 550 nm. The results of the extinction measurement were referenced to the model curve. Determination of the content of sugars and starch was made with reference to the dry mass of kernels. To determine the distribution of the content of sugars in the kernel, the kernel was divided into three sections: 1 – lower, 2 – central, 3 – upper. The measurements were made in three replications on 100-gram samples.

Analysis of variance showed that both the physical properties (Tab. 17) and the chemical properties (Tab. 18) were significantly differentiated. The relatively high biological efficiency of the cultivars studied is a parietal feature of sweet corn grown for the processing industry.

Table 17. Physical properties of cob and kernel of sweet corn

Physical properties	Variety					
	Jubilee		Candle		Helena	
	2002	2003	2002	2003	2002	2003
Cob mass, (g)	321,5	320,5	326,2	332,1	347,3	363,6
Cob length, (cm)	19,5	21,4	21,3	19,8	22,5	21,7
Cob diameter, (cm)	4,7	5,4	4,7	4,9	4,8	4,7
Biological Yield, (%)	70,1	70,5	69,8	71,0	67,4	69,8
Bulk dens. ($kg \cdot m^{-3}$)	648,7	617,2	657,4	612,2	601,2	575,5
Moisture, (%)	73,5	72,4	73,5	76,4	74,8	76,7
Approx. number of kernel in row	29,6	28,4	38,4	36,4	39,5	36,2
Number of row	15,2	15,3	12,6	14,2	16,8	14,5

Table 18. Chemical properties of kernel ($g \cdot 100$ g $d.m^{-1}$)

Chemical properties	Variety		
	Jubilee	Candle	Helena
Sugar contents	10,7	13,6	9,4
Saccharose	15,6	3,8	8,0
Starch	6,9	10,3	14,6

The lower sections of kernels (Fig. 10) that in the course of processing are usually not cut off from cob cores are characterized by relatively the highest content of sugars.

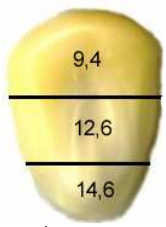


Fig. 10. Sugary content in kernel ($g \cdot 100$ g $d.m^{-1}$)

5.1. UNITED STATES STANDARDS FOR GRADES OF SWEET CORN FOR PROCESSING

Agricultural Marketing Service Fruit and Vegetable Division Fresh Products Branch of United States Department of Agriculture prepared in May 15, 1962 *(Reprinted - January 1997)* Standards 51.3365 U.S. No. 1. and 51.3366 U.S. No. 2. for Grades of Sweet Corn for Processing*[179]. Compliance with the provisions of these standards shall not excuse failure to comply with the provisions of the 1 Federal Food, Drug and Cosmetic Act, or with applicable State laws and regulations.

CULLS

51.3367 Culls.

MATURITY CLASSIFICATIONS

51.3368 Maturity classifications.

DEFINITIONS

51.3369 Similar color characteristics.
51.3370 Fresh.
51.3371 Damage.
51.3372 Blister stage.
51.3373 Milk stage.
51.3374 Cream stage.
51.3375 Dough stage.
51.3376 Hard stage.
51.3377 Serious damage.

APPLICATION OF STANDARDS

51.3378 Purpose of standards.

GRADES OF STANDARDS

51.3379 Grade and maturity determination.

GRADES

§51.3365 U.S. No. 1.

(a) "U.S. No. 1" consists of ears of sweet corn of similar color characteristics which are fresh and free from damage by freezing, cross pollination, denting, worms, birds, fermentation, smut or other disease or other means. Kernels on each ear shall be developed beyond the "blister stage", but shall not have reached the "hard stage" of maturity. (See §51.3379.)

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* United States Standards for Grades of Sweet Corn for Processing 1Grades (51.3365 U.S. No. 1. and 51.3366 U.S. No. 2., 1962 (Reprinted by United States Department of Agriculture - January 1997)

(b) Unless otherwise specified, each ear shall have not less than an average of 4 inches of the cob covered with undamaged kernels, in addition to any good kernels which would necessarily be lost in the usual method of trimming to remove damaged kernels.

§51.3366 U.S. No. 2.

(a) "U.S. No. 2" consists of ears of sweet corn of similar color characteristics which are fresh, free from damage by freezing, fermentation, smut or other disease, and free from serious damage by cross pollination, denting, worms, birds or other means. Kernels on each ear shall be developed beyond the "blister stage", but shall not have reached the "hard stage" of maturity. (See 2 §51.3379.)

(b) Unless otherwise specified, each ear shall have not less than an average of 3 inches of the cob covered with kernels which meet the requirements of U.S. No. 2 grade, in addition to any good kernels which would necessarily be lost in the usual method of trimming to remove damaged kernels.

§51.3367 Culls.

"Culls" consists of ears of sweet corn which fail to meet the requirements of U.S. No. 2 grade.

§51.3368 Maturity classifications.

In addition to the grade classification, a lot of sweet corn may be classified for general overall maturity in terms of one of the following maturity classifications:

(a) A-1: Includes ears in the "milk stage" or younger, more than half of which are in the very tender early "milk stage," and none of the remainder of which are bordering on the "cream stage."

(b) A-2: Includes ears in the "milk stage" or younger with not more than 5 percent bordering on the "cream stage."

(c) A-3: Includes ears in the "milk stage" with more than 5 percent bordering on the "cream stage."

(d) A-B: Includes ears generally in the "milk stage" with 1 to 10 percent in the "cream stage."

(e) B: Includes ears mostly in the "milk stage" with more than 10 percent in the "cream stage."

(f) B-C: Includes ears generally in either the "milk" or the "cream stage" with 1 to 10 percent in the "dough stage."

(g) C: Includes ears more than 10 percent of which are in the "dough stage."

DEFINITIONS

§51.3369 Similar color characteristics.

"Similar color characteristics" means that the kernels on the ears of corn in any lot are of the same general color.

§51.3370 Fresh.

"Fresh" means that the ear does not show evidence of dryness from excessive elapsed time after picking or from other causes.

§51.3371 Damage.

"Damage" means any specific defect described in this section; or an equally objectionable variation of any one of these defects, any other defect, or any combination of defects, which materially lowers the processing quality of the ear. The following specific defects shall be considered as damage:

(a) Freezing when color, texture or flavor of the kernels has been materially affected;

(b) Denting when 5 percent or more of the kernels on the ear show conspicuous depressions in the exposed surfaces;

(c) Cross pollination when 3 percent or more of the kernels on the ear are of a color or maturity which contrasts distinctly with most of the kernels on the ear;

(d) Worms when a corn borer has tunneled into the cob; or when badly discolored remnants of worm-eaten kernels are located among the undamaged kernels more than one inch from the ends of the rows of usable kernels;

(e) Birds when badly discolored or dried remnants of bird-pecked kernels are located among the undamaged kernels more than one inch from the ends of the rows of usable kernels;

(f) Fermentation when any portion of the husked ear has a distinctly sour odor; and,

(g) Smut when any kernel on the ear is more than slightly swollen due to smut infection.

§51.3372 Blister stage.

"Blister stage" means the stage of development in which the kernels are not sufficiently mature for processing. They are small, underdeveloped, have very tender pericarps and contain watery or cloudy liquid which runs freely when released.

§51.3373 Milk stage.

"Milk stage" means the stage of development in which the kernels are moderately to well filled out, have tender pericarps which break with light pressure from the thumb nail, and contain a milky or thin creamy liquid which spreads or runs moderately when released.

§51.3374 Cream stage.

"Cream stage" means the stage in which the kernels have attained full size, have fairly tender pericarps which break with moderate pressure from the thumb nail, and contain a thick creamy substance which spreads or runs very little when released.

§51.3375 Dough stage.

"Dough stage" means the stage in which the kernels have attained full size, have tough pericarps which require heavy pressure from the thumb nail to break, and contain a soft doughy substance which does not spread or run when released.

§51.3376 Hard stage.

"Hard stage" means the stage in which the kernels have very tough pericarps, and contain a heavy, sticky, doughy substance. Ears in this stage are overmature for any processing purpose.

§51.3377 Serious damage.

"Serious damage" means any specific defect described in this section; or an equally objectionable variation of any one of these defects, any other defect, or any combination of defects, which seriously lowers the processing quality of the ear. The following specific defects shall be considered as serious damage:

(a) Cross pollination when 5 percent or more of the kernels on the ear are of a color or maturity which contrasts distinctly with most of the kernels on the ear;

(b) Denting when 10 percent or more of the kernels on the ear show conspicuous depressions in the exposed surfaces;

(c) Worms when a corn borer has tunneled into the cob; or when trimming of the ear by the usual method to remove badly discolored remnants of worm-eaten kernels leaves less than the required area of the ear covered with kernels which meet the requirements of U.S. No. 2 grade; and,

(d) Birds when trimming of the ear by the usual method to remove badly discolored or dried remnants of bird-pecked kernels leaves less than the required area of the ear covered with kernels which meet the requirements of U.S. No. 2 grade.

APPLICATION OF STANDARDS

§51.3378 Purpose of standards.

These standards are intended for use in describing the quality and maturity of loads of sweet corn being delivered by growers to processors. The grade and maturity classification of a load is useful in two ways. First, it provides an equitable basis for pricing the load in relation to its quality.

Second, it enables the processor to use the corn more advantageously.

§51.3379 Grade and maturity determination.

(a) A representative sample from the load shall be used for grade and maturity determination. An exactly weighed quantity from this sample shall be used for analysis. All ears in the analysis sample shall be completely husked. A husked ear is one which has all of the husks removed, the shank or stem trimmed to one inch or less in length, and the cob trimmed, if necessary, so that the portion remaining without usable kernels is not more than one-fourth the length of the trimmed ear.

(b) The husked ears shall be sorted into groups of U.S. No. 1 grade, U.S. No. 2 grade and Culls. The percentage of each group shall be calculated on the basis of weight. Percentages may be determined either on the basis of the total weight of ears in the husk or on the basis of the total weight of husked ears in the sample, depending upon the wording of the contract between grower and processor.

(c) The maturity of the individual ears shall be determined during the process of grading, and a maturity classification assigned to the load on the basis of the percentages of ears in the various stages of maturity.

CHAPTER 6

MECHANICAL PROPERTIES OF SWEET CORN KERNELS

6.1. A REVIEW OF THE RESEARCH ON THE MECHANICAL PROPERTIES OF SWEET CORN KERNELS

Modern technologies of sweet corn harvest and kernel separation from cob cores require knowledge on the mechanical properties of cobs and kernels that affect the optimisation of the processes and limitation of qualitative and quantitative losses occurring in the course of those processes [64]. Sweet corn kernels constitute a material of visco-elastic properties whose strength is determined primarily by the effect of time, moisture, and anatomical structure of the kernels [98]. Determination of standard mechanical properties is a complex and difficult task as it requires that uniform test conditions must be maintained during the measurement of the mechanical properties [43]. Studies of mechanical properties are usually made with the use of strength testers that permit the application of various strain programs. Most frequently the results of the tests are obtained in the form of stress-strain relations [63].

An important factor necessary in the design of machines and equipment used in the agricultural product and food processing industry in the knowledge of relations describing the behaviour of a body subjected to processing to a variety of external effects differencing in form and intensity. In numerous machines used in the food processing industry the fundamental function of working elements is based on mechanical action. Hence the high importance of knowledge of the properties of material (raw material, semi-finished product) which determine the choice of the character and intensity of such action (mechanical properties) [108].

The great variety of biological materials, their variability, anisotropy, metamorphism, and sometimes heterogeneous structure are the source of failure of many research methods, apparatus, and also theoretical concepts that are acknowledged and tested under other conditions and in other applications [48]. The set of mechanical properties is not ordered and, according to various authors, may comprise from several to over two hundred features. In 1975, the British Standard Committee published the standard No. BS 5168 which includes over 250 entries (Dictionary of rheological terms), nearly a half of which are defined and measurable indexes. The American Society of Studies and Materials published a set of 187 terms related to the study of mechanical properties [30].

Physical properties, and especially mechanical properties of biological materials produced by agriculture, have long been the object of interest of science. The growing level of mechanization of work in agriculture and in food processing required that type of knowledge, necessary for the design engineers creating machines and equipment that are more and more aggressive in their operation and cause losses resulting from mechanical damage, sometimes at the level of several dozen percent of the crop or of the material entering the production process [50].

Knowledge of all the mechanical properties of biological materials is necessary fore the design of technological processes. The variety of the mechanical properties studied is assigned to the various types of plant materials and to the large number of purposes for which the results obtained are to be used. Certain properties and methods of their study are of interest to design engineers working on the design of threshing assemblies, and other properties and methods will be of importance for material drying industry or for food processing industry [23].

Similar relations can be observed in studies on the mechanical properties of sweet corn kernels that are determined to meet the requirements of the design of machines and equipment for use in agriculture and in processing. For example, in the processes of shearing a biological object is divided under the effect of shearing stress caused by a tool. In the operation of agricultural machinery, the mechanical properties of plant materials are of high significance. The mechanical properties define the behaviour of the material under the effect of the action of forces, such as compression, tension, and impact. Other properties, such as mass, volume, texture, are important for descriptive characterization of a given product [167]. Mechanical properties such as compressive or shearing strength and resistance to impact are important and frequently required in studies on cereal grain losses [65], or on resistance to cracking in the course of harvest or other operations [5]. Shearing resistance and cohesive strength are important mechanical parameters in the determination of the nature of shearing processes and energy requirements [6, 88].

Strength properties that describe the behaviour of biological materials subjected to mechanical loads depend primarily on grain size and shape and its internal structure, and on the effect of external factors such as moisture and temperature [43]. An especially important factor that determines the mechanical properties of seeds and kernels is their moisture content [41,45]. Moisture is a fundamental factor affecting changes in the mechanical strength of the involucres [28]. Moreover, moisture is the basic factor determining the character of deformation that seeds undergo when subjected to loads [29]. In numerous studies, mechanical properties are determined by means of compression tests under quasi-static conditions. In such tests the speed of the loading element usually does not exceed the value of 0.005 m·s-1. In practice, however, in many cases we have to deal with dynamic loads and high deformation rates [12,13]. Young modulus (modulus of elasticity) is one of the fundamental mechanical properties of grain. It expresses the relation between stress and strain of a body subjected to loading. Its value depends on the chemical composition and on the mechanical structure of the grain and on the rate of deformation and value of the load applied [78].

An important quality feature of sweet corn kernels is the tenderness (softness) related to the thickness of the seed coat, to the phase of ripeness, and to the genotype [36]. The thickness of the seed coat decreases with ripening, but this change is accompanied by an increase in hardness [117]. In studies by Ito and Brewbaker [55] the thickness of the seed coat varied, depending on the cultivar, from 36 to 124 μm. Very sweet cultivars have thinner seed coat than normally sugary cultivars [54].

In his studies, Burton [22] used penetration tests for the determination of the hardness of the seed coat at various stages of ripeness of sweet corn kernels. As the loading element he used a cylindrical glass penetrometer with a diameter of 0.5 mm. He made the hardness measurements on percarp removed from the kernels and stretched on a glass tube. He found that the force of penetration increased with increasing ripeness of the kernels, which was related to increasing hardness of the seed coat. That author states also that there is a distinct differentiation of the seed coat hardness of kernels from different parts of the cob. Kernels from the tip and the base parts of the cob are softer than those from the middle or central part. This is most likely due to variation in ripening. Differentiation of results was observed also on the length of the kernels, which was related to faster decrease in moisture content in the upper part of the kernel than in its base section.

The object of studies by Zoerb [167] was an individual kernel of fodder corn, whole and sheared. The kernels were subjected to compression tests at various levels of moisture content (15.4-23%) and at different orientations (flat and on the side), and at different compression rates (0.0018-0.018 $mm \cdot min^{-1}$). The tests were made with the help of a special apparatus that included, among other things, and force converter and an oscilloscope which was used to record the force values. In the course of the tests also the strain energy and the modulus of elasticity were determined for a variety of conditions. It was found that the strongest effect on the change of mechanical properties was that of the moisture content. All the strength properties decreased in value with increasing moisture. Higher values of the energy of compression were observed at higher moisture content, irrespective of whether the tests were made under static or dynamic conditions. At high kernel moisture content low elasticity of the kernels was observed. The force necessary to deform the kernel to the limit of plasticity decreased with increasing moisture. Apart from the moisture content, the force was also significantly related to kernel orientation [166].

In their studies, Robertson and Lazar [110] determined the bond force of sweet corn kernels with cob core. For the tests they used cobs of sweet corn of five cultivars - Golden Happiness, Golden Jubilee, Stylepak, Vanguard and Ilini Extras Sweet. The moisture content of the kernels tested varied from 70.7 to 72,3%. Figure 11 presents the method of kernels separation from the cobs. To facilitate kernel separation for the tests, the cobs cut in half along the long axis. Such cob halves were pressed by hand against a flat plate of 12x30 mm coupled with a force transducer. To prevent puncture of cracking of kernels the plate was covered with polyurethane foam, and its sharp edges were rounded off. To ensure relatively stable friction coefficient, the plate was dried after every test. The pressure was applied at the angle of 45° until the moment of kernel detachment from the core. The width of the plate permitted the detachment of three kernels. The tests showed that the rachis that constitutes the physiological connection between the kernel and the cob core is the main source of resistance. The force of breaking kernels off the core varied; depending on the cultivar and on the moisture, from 2.6 do 3 N.

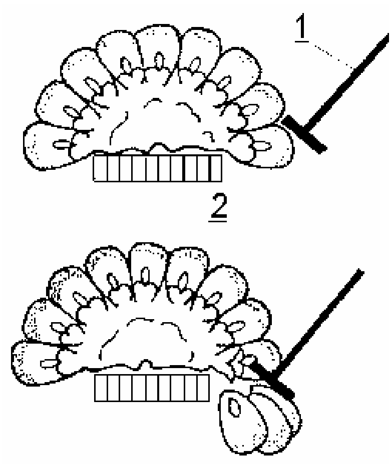

Fig. 11. Schematic of sweet corn kernel detach method: 1 – support plate of force transducer, 2 – base [110]

Similar tests were also made for cobs subjected to 5-minute blanching in water steam of 100°C. They showed a decrease in the breakage force by an average of 20% in comparison to the former studies. Moreover, the authors found that blanching caused a change in the consistency of the kernel parenchyma, which in later stages of kernel processing (especially washing) results in a reduction of juice seepage.

Another test included in the study was concerned with a single row of kernels left on the longitudinally halved cob, fixed in a holder. Force was applied to an individual kernel, at the angle of 90° to the axis, at the rate of 250 $mm \cdot min^{-1}$, at the height of 2/3 from the kernel base (Fig. 12).

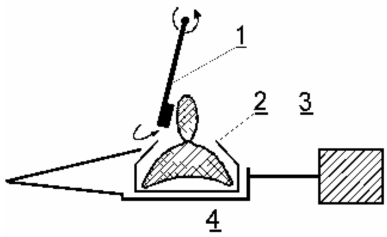

Fig. 12. Sweet corn kernel detach: 1– impact body, 2 – holder, 3 – force sensor, 4 – arm of sensor [113]

A transducer measured the force of breaking a kernel from the core, which varies from 1.3 to 5 N, and the force of friction between neighboring kernels, that was from 2.3 to 4 N. The tests were the referenced to kernels subjected to blanching. As in the previous tests, the values of force were notably reduced with increasing time of blanching. In the case of 1 minute of blanching the decrease was by 6%, and at 5 minutes by as much as 22%. The author did not find any significant effect of moisture on the values of the kernel break off force. He did observe, however, that the value of the force was cultivars related, and especially that it was dependent on the thickness of the pericrp swelling in its bottom part. For cultivars for which high values of the force were recorded, the swelling was 0.032 mm, while for other cultivars, with lower force values; the thickness of the swelling was 0.024 mm.

A separate study was concerned with determination of the degree of kernels detachment on a laboratory apparatus made up of a belt conveyor 15 cm wide, against which a team of people placed halved cobs. The conveyor was constantly dried to maintain a constant value of its friction coefficient. Kernel detachment was continued until obtaining 6-10 kg of kernels. The mass obtained was referenced to the total weight of kernels that comprised the kernels detached and the weight of kernels remaining on the cobs, measured after scraping the kernels off from the cobs. The degree of kernels detachment for the three cultivars under study varied from 89.8 to 92.3%. It was observed that the differences resulted not only from cultivars differences but were also related to the phase of ripeness, i.e. to decreasing moisture. Lower kernel moisture facilitated the detachment of kernels from the cob core and caused an increase in the weight of the kernel mass detached. Within the kernel moisture range studied (from 70.2 to 73.2%) the increase observed was about 30%. However, the authors concluded that the fact could rather be attributed to increased hardness of the seed coat rather than to the ripeness of the kernels [49].

The object of another study sweet corn cobs of two cultivars - W6786 su1 and IL731 su1 with moisture content of 77.9 and 76.3%, was the comparison of the sensory qualities (aroma, taste, texture) that determine the nutritional value of the kernels. Immediately after harvest, the hardness of the seed coat and the firmness of the kernel parenchyma were tested with the help of a cylindrical penetrometer of 2.38 mm in diameter. The tests were made using an Instron strength tester at loading head speeds of 5 and 50 $cm \cdot min^{-1}$ and loads of 20 N. After the tests, the cobs were subjected to blanching. Kernels detached from the cobs (30 g) were subjected to a compression test at the compression rate of 20 $cm \cdot min^{-1}$ and load of 200 N. It was found that the hardness of the seed coat and the firmness of the parenchyma of fresh kernels were weakly correlated with the sensory features of cooked kernels. The firmness of cooked kernels was not correlated with the hardness of the seed coat and the firmness of the parenchyma of fresh kernels. The authors suggest that the textural features (crispiness, tenderness, succulence) should not be assessed on fresh but rather on blanched material [10].

Another study was concerned with determination of kernel quality of fourteen cultivars at two ripeness phases. The first tests were made on the 18th and the second on the 22nd day after blooming. Kernel quality was estimated on the basis of penetrometric tests comprising measurement of kernel hardness (penetration of seed coat) and parenchyma firmness (penetration into the kernels). The tests were made using an Instron strength tester, at loading head speeds of 50 $cm \cdot min^{-1}$, using a steel penetrometer with a diameter of 2 mm. The strength of the seed coat varied from 63 to 110 $g \cdot mm^{-2}$ after 18 days and from 77 to 138 $g \cdot mm^{-2}$ after 22 days. The firmness of the parenchyma was from 39 to 59 $g \cdot mm^{-2}$ after 18 days, and from 40 to 78 $g \cdot mm^{-2}$ after 22 days. Kernel moisture of the cultivars studied on the 18th day was from 73.4 to 77.6 %, and after 22 days from 67.1 to 74.4 %. It was observed also that the mass of kernels on the 18th day was from 42 to 49 g, and after 22 days - from 83 to 172 g. Increase in kernel hardness and firmness was accompanied, however, by a decrease in the content of sugars - from 379 to 151 $mg \cdot g^{-1}$ after 18days, and from 348 to 110 $mg \cdot g^{-1}$ after 22 days, and by an increase in dry mass content - from 17 $mg \cdot g^{-1}$ to 193 $mg \cdot g^{-1}$ after 18 days and from 163 $mg \cdot g^{-1}$ to 476 $mg \cdot g^{-1}$ after 22 days [8].

Penetrometric tests were also used for the determination of kernel firmness by Sprague and Dudley [123]. They found that the value characterizing kernel firmness is largely dependent on the type of equipment and method used in the study. They conducted their studies in two ways. The first consisted in kernel penetration by means of a device made up of a metal tube with a piston with penetration pin, and a manometer. The force required to penetrate the kernel seed coat was determined by means of pressure measurement. The device permits the determination of kernel succulence on cobs in the field. The second method used involved the application of a tender meter (a different version of the device described above) for kernel firmness measurement. In that method, kernels were placed on a special perforated plate, and the force of penetration was also determined with the help of a manometer. On the basis of the tests they determined the kernel hardness degrees with relation to relative deformation. For percarp relative deformation above 7% they adopted the category very hard, from 6 to 7% – hard, from 5 to 6% – medium tender, and from 4 to 5% – tender. Adopting those criteria, the authors found that most kernels harvested for the processing industry at kernel moisture levels of 70-72% were hard, which is not highly desirable [83].

Jindal et al. [58] studied the strength of fodder corn using a penetrometer with a diameter of 6.3 mm, moving at a speed of 0.5 cm·min^{-1}. The values of Young modulus for kernel moisture range from 8.3 to 20,25% were from 82.7 to 554.7 MPa. Burton [22], reports that the main discriminant in the assessment of corn kernels quality is ripeness which determines the ratio of kernel hardness to its succulence. Also, on the basis of test of corn fibers, he formulated the opinion that specific gravity is closely related to the differentiation between "old" and "young" kernels, and between hard and succulent kernels.

Also Mosz and Frontczak [89] studied the strength of fodder corn kernels seed coat. They subjected individual kernels, with a moisture of about 10%, to a penetrometric test. The range of load values was from 69.8 to 124.4 N. Frontczak [44] determined in his study the strength of fodder corn kernel seed coat, parenchyma, and germ, by means of the maximum values of modulus of longitudinal elasticity. The values varied with increasing kernel moisture. Hanzelik [51], in turn, determined the mechanical properties of fodder corn kernels of different sizes and moisture through compression between tow plates. The compressive strength of the kernels decreased with decreasing moisture and size of kernels.

Kramer et al. [66] were also interested in determination of corn kernel quality on the basis of strength tests. In his study he used 5 sweet corn cultivars at three harvest times. The tests were made on fresh kernels and on kernels stored for a certain time in frozen state. The force necessary to penetrate the kernel seed coat with a penetrometer was determined for kernels taken from the middle part of the cob. The penetration tests performed at penetrometer speed of 0.15 cm·s^{-1} and diameter of 1.6 mm yielded force values, for fresh kernels from the first harvest, from 220 to 332 N, and from 242 to 358 N for kernels from the second and from 275 to 353 N from the third harvest time. For thawed out kernels, the respective values were from 193 to 336 N for the first, from 189 to 329 N for the second, and from 224 to 352 N for the third harvest time. The study showed that the seed coat is the only structure of corn kernel, which determines its hardness, and the value of force necessary for penetration with a penetrometer. The authors suggest that this finding may be useful for objective assessment whether a given batch of kernels is fresh or has been frozen. Kernels from the first harvest time were characterized by thinner seed coat and were softer than kernels from later harvest times. The fact of kernel ripening being accompanied by an increase in seed coat hardness results from polymerization of carbohydrates, which entails considerable loss in water content and seed coat shrinking.

The tender meter was used to study the hardness of sweet corn kernels cut off by means of a mechanical cutter. The study was realized on 6 sweet corn cultivars at 5 ripeness stages. It was observed that with increasing kernel ripeness the hardness of the kernels increased. However, the degree of hardness at particular phases of ripeness was different with different cultivars. It was also observed that kernel hardness was also affected by weather conditions [71]. One of the methods of kernel comminution is shearing. The degree of comminution depends on the speed of the working elements, differentiation of kernel sizes, and speed of feeding the material [121]. In their study, Figiel and Frontczak [42] determined the effect of kernel moisture and cutter knife geometry on the resistance and work of cutting corn kernels with a moisture content of 14-30%. They used an Instron 5566 strength tester, with knife of a thickness of 1.75 mm and varied geometry, i.e., with cutting edge incision angles of 0–45° and blade angles of 10–90° (Fig. 13). The speed of the knife movement was 1.2 mm·min^{-1}.

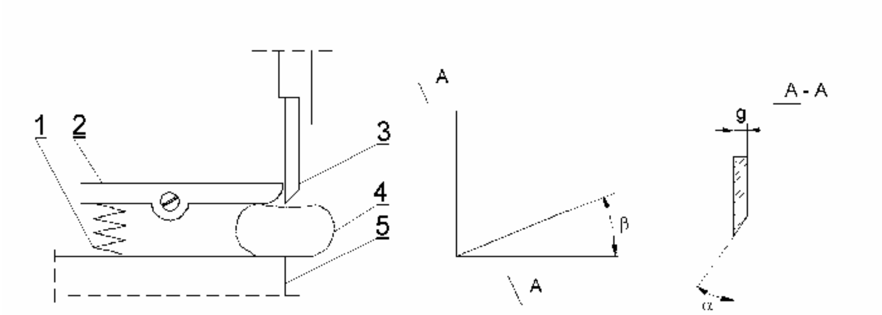

Fig. 13. Schematic of kernel cutting: 1 – spring, 2 – clamp plate, 3 knife, 4 – kernel, 5 – base [42]

They found that changes in both kernel moisture and cutting knife geometry had a significant effect on the kernel cutting process. Kernel moisture increase from 10 to 30% caused a reduction in the cutting force from 50 to 10 N. The lowest resistance to cutting was obtained at cutting edge incision angle of 30°, and the lowest value of work at incision angle of 40° [42].

Energy requirements and resistance occurring in corn kernel cutting depend not only on the speed of the cutting element, but also on the kernel orientation relative to the cutting plane [3]. It is known that unit resistance to cutting is also affected by the thickness of the cutting blade [168]. With increasing blade thickness the unit cutting resistance increases and the blade gets blunted quickly. In the process of cutting stem plants, it is frequent practice to use knives toothed blades that increase cutting resistance and do not require frequent sharpening [100].

In numerous cutting processes, reduction of cutting resistance is realized by increasing, up to a certain limit, the speed of knife penetration into the biological material. This is attributed to that fact that in plant mass, which is an elasto-pastic body, the speed of stress transmission into the depth of the layer is low, and when the knife strikes at a high speed the stress in the material concentrates close to the knife-edge. As a result the thickness of the mass pressed by the blade decreases, and then cutting resistance decreases as well [105]. Knife speed also has a significant effect on cutting energy and unit resistance [169]. Unit energy of cutting is lower at the speed of knife penetration into the plant of about 2.65 m·s^{-1}. Also the maximum and mean stress in cutting are lower at knife speeds of 2.5-3 m·s^{-1}.

6.2. METHODS OF STUDY OF SWEET CORN KERNEL MECHANICAL PROPERTIES UNDER QUASI-STATIC CONDITIONS

Figure 14 presents a laboratory set equipped with an Instron 6022 strength-testing machine as well as control panel and equipment for registration of characteritics.

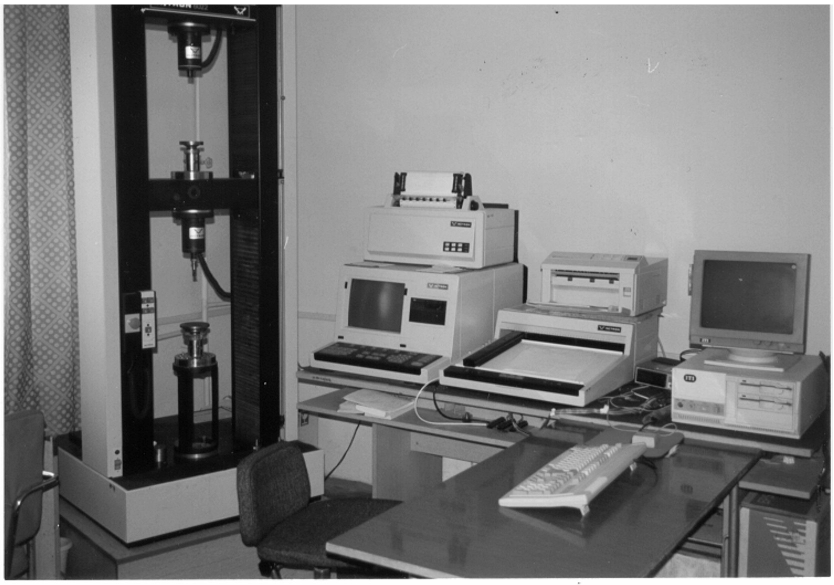

Fig. 14. Laboratory stand equipped with universal testing machine Instron 6022, computer, plotter and printer

Table 19 presents the basic parameters and work conditions of the Instron machine, the type of loading element used, and the measurement range.

Table 19. The parameters of universal testing machine

Test type	Load capacity, (N)	loading tool	Velocity rate of head, (mm·min^{-1})	displacement range (mm)
Shearing	200	Knife	50	20
Penetration	100	Plunger	50	10
Compression	100	Plate	50	3

To determine the variability of distribution of the studied mechanical properties in the kernels of sweet corn, the study was conducted for four measurement positions on the cob length (Fig. 15) and for three levels of depth of kernel cutting (Fig. 16). The division of the experimental material into three measurement positions resulted from the adopted method of research. The determination of standard mechanical properties of materials with methods used in the mechanics of construction materials requires the assurance of uniform experimental material and accurate determination of sample dimensions.

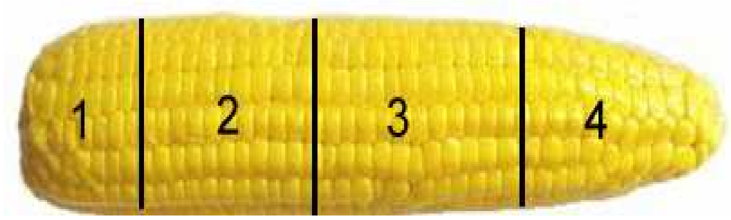

Fig. 15. Cob partition on measuring position

Significant differentiation of the compressive strength of kernels of the studied cultivars was shows by recording the force values from the moment of damage to the seed coat. Due to the morphological structure of the cobs and kernels, it was decided to divide the cobs and kernels into measurement positions. With such a division, the cob and kernel sections different in shape and in their internal structure. This permitted the determination (within the whole cob and kernel lengths) of the distribution of variability of the values studied. In the process of mechanized detachment of kernels from cobs, the mechanical properties determine the quality of the kernels cut and the levels of energy expenditure required.

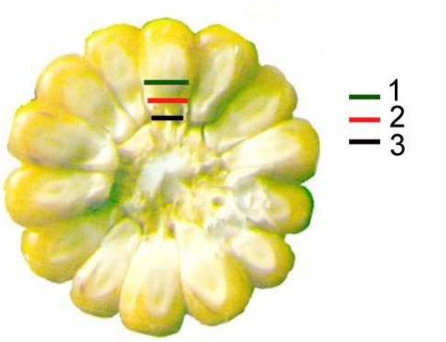

Fig. 16. Kernel partition on the measuring positions

Evaluation of sweet corn kernels as well as the determination of their mechanical properties was performed with the help of strength testing on an Instron 6022 strength-testing machine. This ensured high measurement accuracy and definition of the stress-strain characteristics.

The tests were used to determine values related to the following:

– force corresponding to the limit of mechanical strength of the tissue,
– displacement (deformation) corresponding to that force,
– modulus of elasticity determined within the range of elastic strain from the stress-strain curve below the limit of proportionality (biological flow ability),
– energy of deformation.

Depending on the test performed, suitable loading elements were employed (knife, penetrometer, discs), together with the required special accessory equipment. Since the method of sample gripping and orientation had a strong effect on the results obtained, care was taken to ensure that both the direction of the loading element motion and the point of its contact with the samples tested were always the same for all the samples tested. Also, in measurements of mechanical properties standard procedures developed by the manufacturer of the Instron strength-testing machine were used as well. All the measurements were made in 30 replications.

Results of statistical analysis for kernel shearing, penetration and compression under quasi-static conditions are presented for the Helena cultivar, tested in 2002 at measuring head motion speed of 50 mm·min^{-1} and head load of 200 N in the case of the shear test and of 100 N in the penetration and compression tests. Kernel shearing and penetration on its length and kernel compression tests were performed for kernels taken from the central part of the cob (measurement position 2). To determine the significance of differences between mean values of the measurements and the measurement position, single-element analysis of variance was made, as well as Tukey's test for α = 0,05. The degree of correlation between the variables, in turn, was determined by means of regression analysis.

6.2.1. Kernel Cut-off – Shearing Test

For cutting the kernels, a knife was used that came from a kernel cut-off machine. Figure 17 presents the method of kernel fixing and cut-off. Cob sections were fixed to the moving loading head is such a way that in the course of kernel cutting the knife was positioned parallel to the cob core axis. Measurements were conducted until the moment when the loading head moved by a preset distance, which corresponded to 2-3 kernels being cut off. The force and strain values were recorded and saved in compute5r memory.

Tests of multiple comparisons with Tukey's method showed that the mean values of the shearing force were significantly differentiated on the kernel length, and varied with respect to the measurement positions as follows: position 1-12.36 N, position 2 – 42.84 N, and position 3 – 92.47 N (Fig.18). The effect of the point of shearing (measurement position) on the shearing force is described by a strongly positive exponential relation.

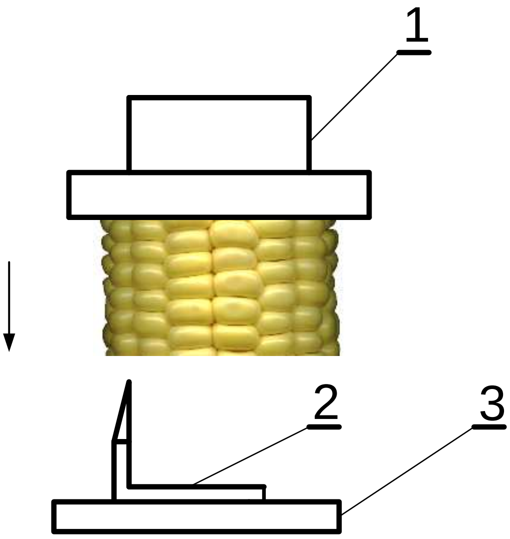

Fig. 17. The kernel cut-off method of the sweet corn: 1 – head measuring, 2 – knife, 3 – base

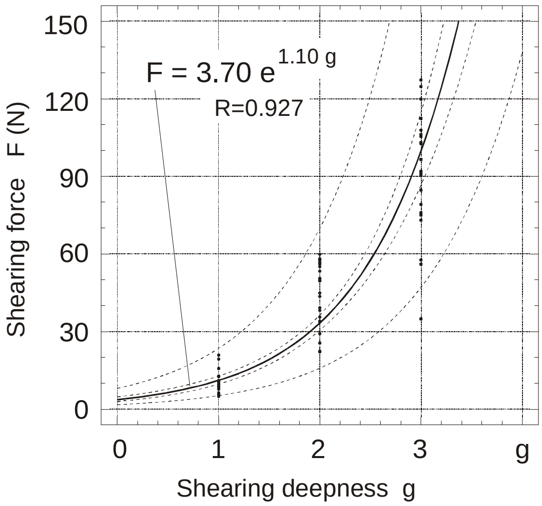

Fig. 18. The shearing force for different deepness of cutting tool (according to fig. 16)

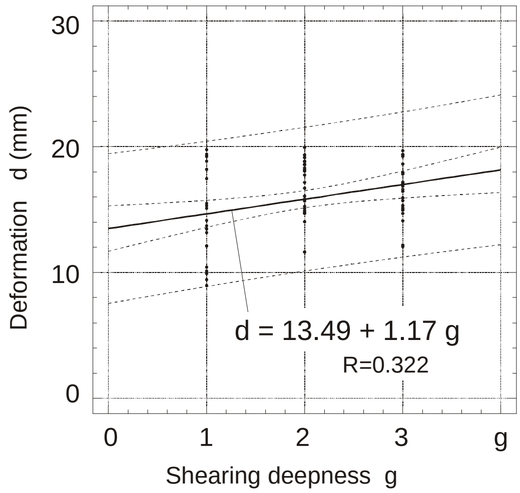

Fig. 19. Deformation for different deepness of cutting tool (according to fig. 16)

The mean values of relative deformation (Fig.19) formed the range from 13.23 to 19.31 mm. Tukey's test showed notable variation between those mean values. Changes of the values of deformation in the function of the measurement position are expressed by a linear function. The modulus of elasticity, in turn, is described by an exponential function. Mean values of the modulus of elasticity varied within the range from 4.45 to 19.62 MPa (Fig. 20).

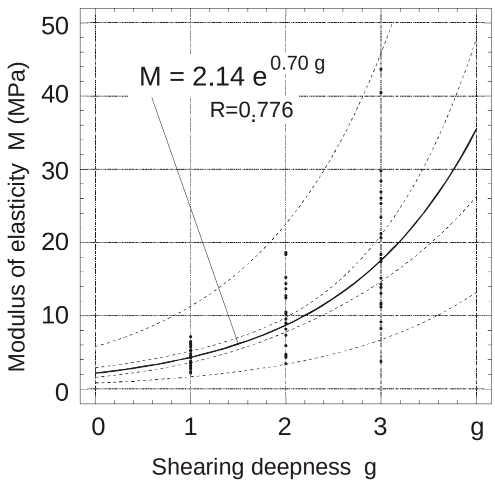

Fig. 20. Modulus of elasticity for different deepness of cutting tool (according to fig. 16)

Analysis of variance and Tukey's tests performed for the shear energy showed that, like in the case of force, deformation and modulus of elasticity, its values were significantly differentiated for the particular measurement positions. The mean values of shear energy fell within the range from 0.17 J in the top section of the kernel (measurement position 2) to 0.91 J in the base section of the kernel (measurement position 1) (Fig. 21).

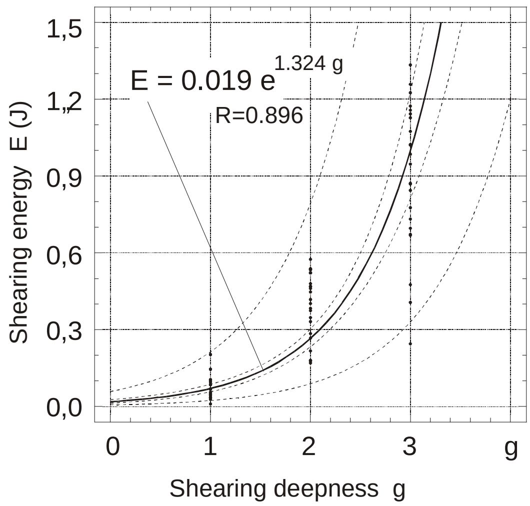

Fig. 21. Cut energy for different deepness of cutting tool (according to fig. 16)

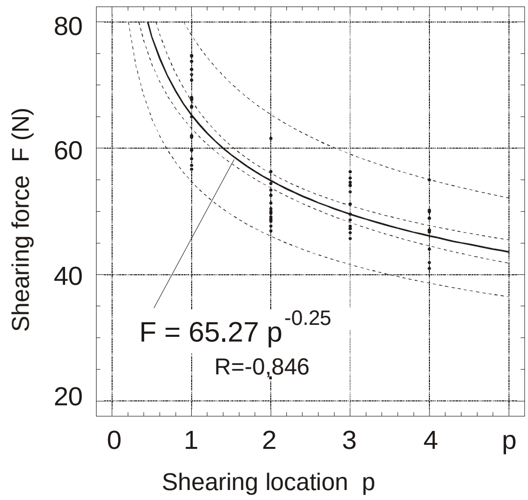

Fig. 22. Shearing force of kernels in different place of cob (according to fig. 17)

The results of analysis of variance, as well as of Tukey's test for the mean values of force, relative deformation, modulus of elasticity, and shear energy of kernels cut off at the different places (measurement positions) on the length of the cob showed that the values of force and energy in the central part of the cob, designated as measurement positions 2 and 3, are not statistically varied. Significant differences can be observed between the extreme parts of the cob. Particularly high values are characteristic of kernels from the lower section of the cob (measurement position 1).

The mean values of the parameters studied varied from 46.82 N (measurement position 4) to 74,31 N (measurement position 1) for the shear force (Fig. 22), from 13.23 to 19.31 mm for relative deformation (Fig. 23), from 4.25 to 6.04 MPa for modulus of elasticity (Fig. 24), and from 0.44 to 0.60 J for the shearing energy (Fig. 25).

High correlation coefficients for the values under consideration indicate the existence of strong relations between the analyzed variables. Analysis of variance showed that the cultivars studied are significantly differentiated with respect to the mean values of the kernel shearing force. Mean values of the shearing force recorded in the shear tests for the particular cultivars were as follows: Helena – 42.84 N, Candle – 38.72 N, and Jubilee – 31.21 N.

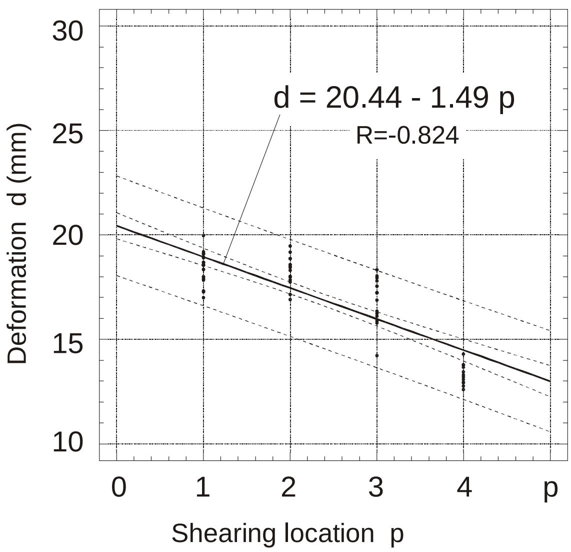

Fig. 23. Deformation of kernel at cutting in different place of cob (according to fig. 15)

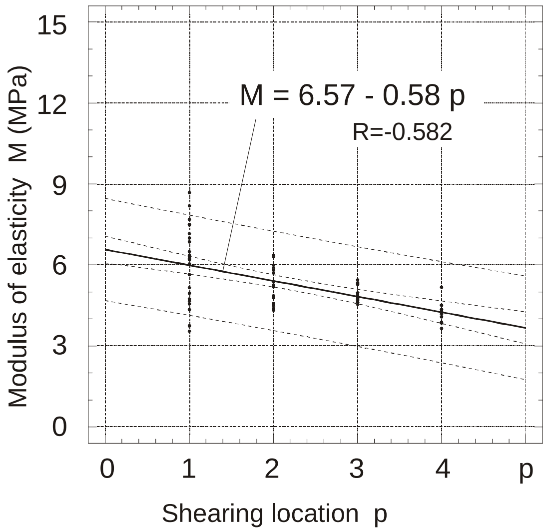

Fig. 24. Modulus of elasticity of kernel in different place of cob (according to fig. 15)

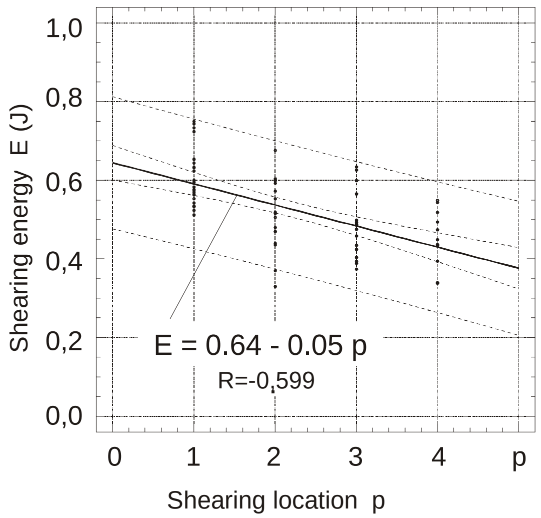

Fig. 25. The energy of kernels shearing in different place of cob (according to fig. 15)

6.2.2. Kernel Penetration – Penetrometric Test

The penetrometric test was performed for kernels on cobs, using a cylindrical steel penetrometr with a diameter of 2 mm.

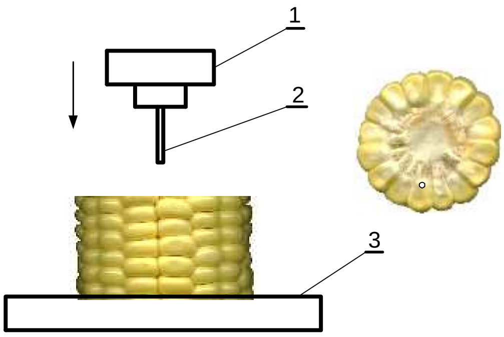

Fig. 26. The measuring set for the study of the seed coat strength: 1–measuring head, 2 –penetrometer, 3 – base plate

In this part of the study kernel penetration tests were made for four measurement positions on the cob length and one measurement position on the kernel length, designated as position number 2 (at the base of the kernel). Analysis of variance of results obtained in tests of seed coat penetration showed significant differentiation between the mean values of force, relative deformation, modulus of elasticity and penetration energy at the particular measurement positions on the kernel length.

Mean values for the particular cutting depths varied within the range from 7.21 (depth 1) to 54.87 N (depth 2) for the penetration force (Fig. 27), from 5.1 to 7.6 mm for deformation (Fig. 28), from 4.6 to 23.4 MPa for modulus of elasticity (Fig. 29), and from 0.021 to 0,066 J for penetration energy (Fig. 30).

In turn, the mean values obtained in kernel penetration tests at measurement positions on the cob length varied from 28.61 N (measurement position 4) to 62.62 N (measurement position 1) for the shearing force and from 0.036 to 0,061 J for the penetration energy. Mean values of the seed cover penetration force recorded in the penetration tests showed significant differences between the cultivars studied, as follows: Helena – 42.84 N, Jubilee – 32.21 N, and Candle – 38.72 N. The comparison was made for kernel penetration at measurement position 2 (at the cob base) and measurement position 2 (in the middle of the cob).

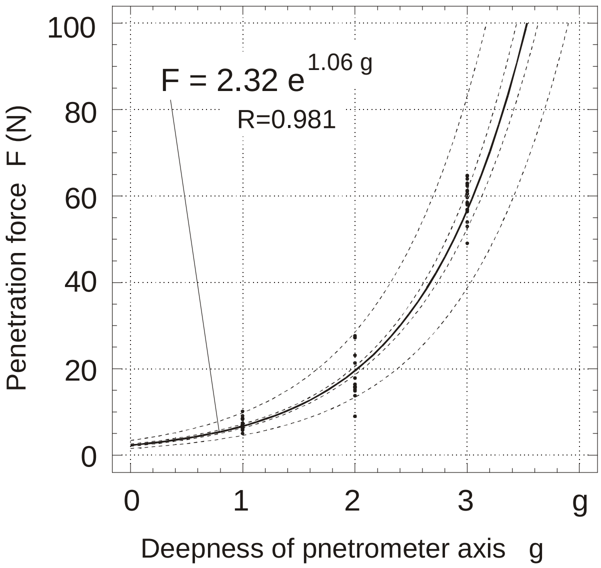

Fig. 27. Penetration force at different deepness of plunger axis (according to fig. 16)

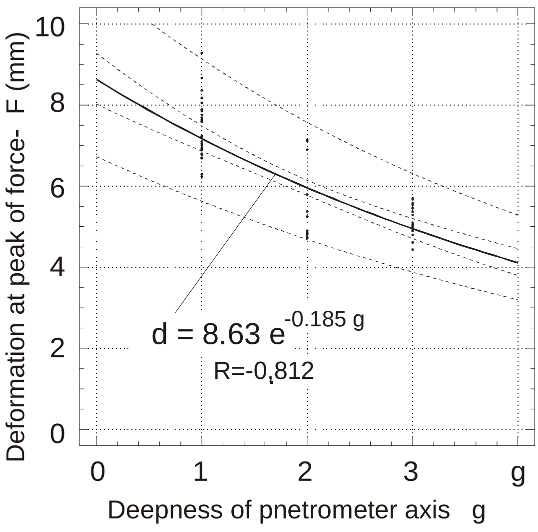

Fig. 28. Deformation at different deepness of plunger axis (according to fig. 16)

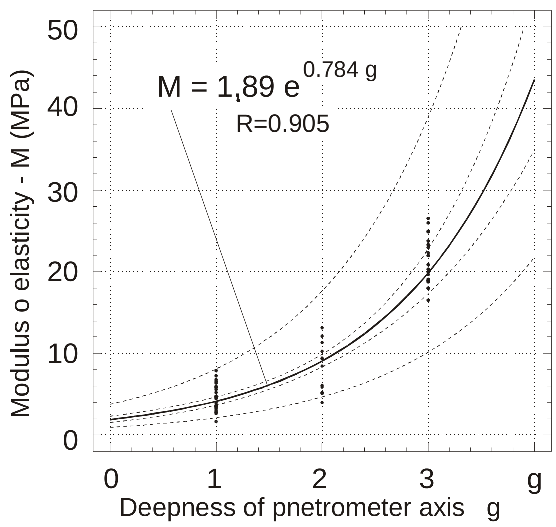

Fig. 29. Modulus of elasticity at different deepness of plunger axis (according to fig. 16)

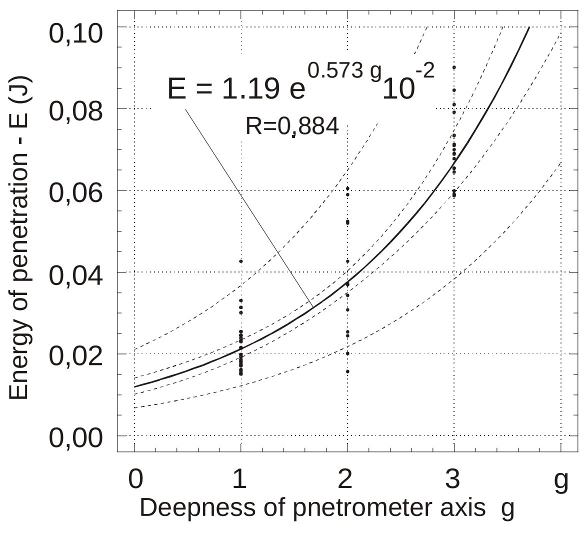

Fig. 30. Penetration energy at different deepness of plunger axis (according to fig. 16)

6.2.3. Kernel Compression – Compression Test

Kernel compression was performed between two circular steel plates, of which the upper one was moving. Individual kernels were placed on the lower (fixed) plate, and then compressed by means of the upper plate (Fig. 31). Measurement was continued until kernel destruction (cracking).

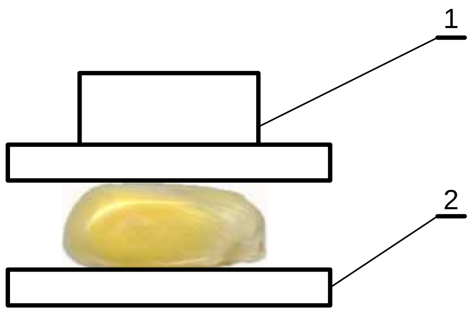

Fig. 31. Compression of the kernel between parallel plates : 1 – measuring head, 2 – base plate

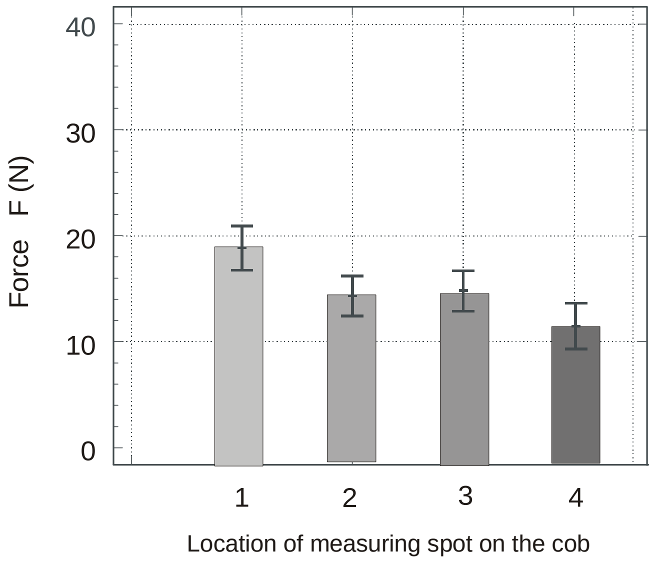

Fig. 32. Force at compression of kernels in different measuring positions (according to fig. 16)

Analysis of variance of measurement results obtained in the compression tests showed that, like in the shearing and penetration tests, kernels from the middle section of the cob (measurement positions 2 and 3) are not statistically differentiated. Mean values of compressive force varied within the range from 12.72 N (measurement position 4) to 18.56 N (measurement position 1) (Fig. 32), and those of compression energy from 0.0082 to 0.0181 J (Fig. 33).

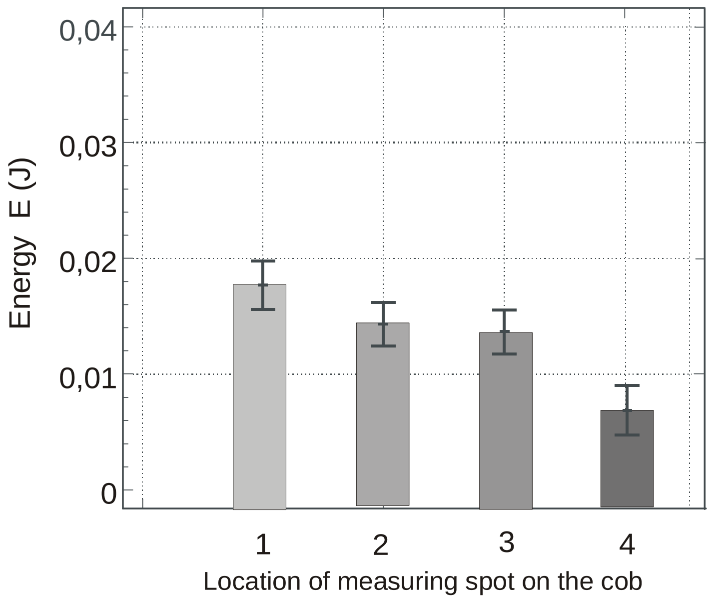

Fig. 33. Press energy in different measuring positions (according to fig. 16)

Significant differentiation was observed in the compressive force when comparing the cultivars studied. Mean values of force required for the kernel seed coat to crack in the compression tests for the particular cultivars were as follows: Helena – 15.92 N, Jubilee – 18.62 N, and Candle – 14.12 N (Fig.34).

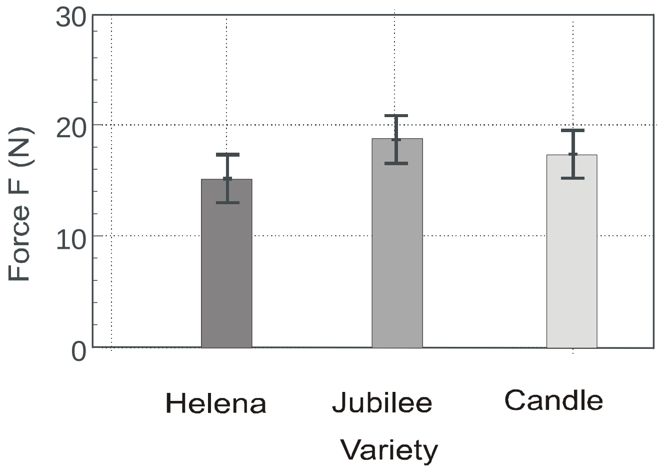

Fig. 34. Force at compression for studied varieties of sweet corn

6.3. MECHANICAL PROPERTIES OF SWEET CORN KERNEL AND CUTT-OFF PROCESS AT DYNAMIC CONDITIONS

The measurement stand for testing kernel cut-off force under dynamic conditions is presented in Fig. 35. Kernel cut-off from the cobs was effected through cob rotation and axial motion of the knife. The cutting force exerted by the knife was transmitted onto a sensor and recorded by the measurement head. Table 20 presents a general characterization of the technical specification and operation conditions of the measurement stand.

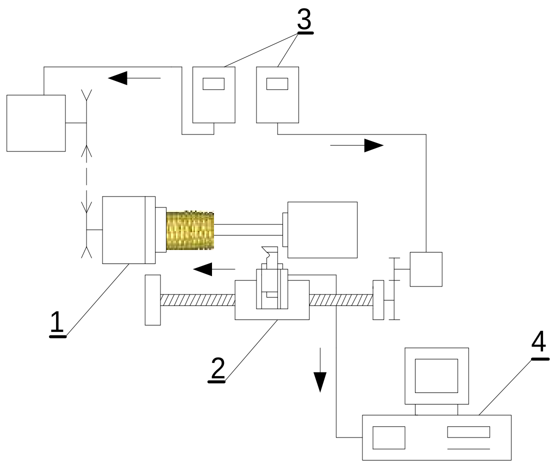

Fig. 35. Schematic of the measurement stand: 1 – clamping head, 2 – knife with force sensor, 3 – frequency transducers, 4 – computer

Table 20. Settings of measurement stand at low angular rates

Working parameters	Value
The shape of cutting tool:	
Tool wedge angle (1°),	8
Nose angle (1°)	15
Angular rate (rad·s^{-1})	130,9; 161,3; 194,7; 226,1
Velocity of cutting tool (m·s^{-1})	0,005; 0,010; 0,015
Cutting position (no)	Przy podstawie – At the base (2)
Cob part (no)	Część środkowa – Middle Part (2)

To obtain uniform samples for the tests, only sections from the central part of the cobs were taken. Cob samples with a length of 10 cm were clamped in the measurement stand and set in rotary motion. Once stable operation conditions were reached, the knife motion was switched on. The cutting force transmitted from the knife to the force sensor was recorded by the measuring head and saved in a computer program. The measurement ended and the recording was stopped when the knife traveled the whole length of the cob sample. Measurements were made in 3 replications.

To determine the statistical significance of the effect of independent variables, i.e. the rotary speed of the head ω_g, linear velocity of the knife v_n, and of the conversion to the dependent variable (shearing force F), three-element analysis of variance was performed. The results of the analysis showed that all the independent variables and their interactions had a significant effect on the value of the shearing force. The strongest effect, however, was that of the rotary speed of the head (approximately 50% of the overall variability of the shearing force).

The relation between the shearing force F and the analyzed factors: rotary speed of head ω_g and linear velocity of knife v_n, was described with the equation:

$$F = b_1\,\omega_g + b_2\,v_n + a \quad \text{(N)} \tag{5}$$

where:

b_1,b_2 – regression coefficients,
a – free argument.

Table 31 presents the regression equations for the change in the shearing force F as a function of the angular velocity of the head ω_g at constant linear velocity of the knife v_n. Figure 36 illustrates the resulting regression curves. The relations are presented on the example of the Helena variety tested in 2003.

Table 21. Regression equations for change of $F = f(\omega_g)$, v_n = const

v_n(m·s^{-1})	Equation	R^2	level (p)
0,005	$F = -48 \cdot 10^{-4}\,\omega_g + 2{,}74$	0,93	0,00001
0,010	$F = -76 \cdot 10^{-4}\,\omega_g + 3{,}12$	0,97	0,00001
0,015	$F = -38 \cdot 10^{-4}\,\omega_g + 2{,}73$	0,91	0,00001

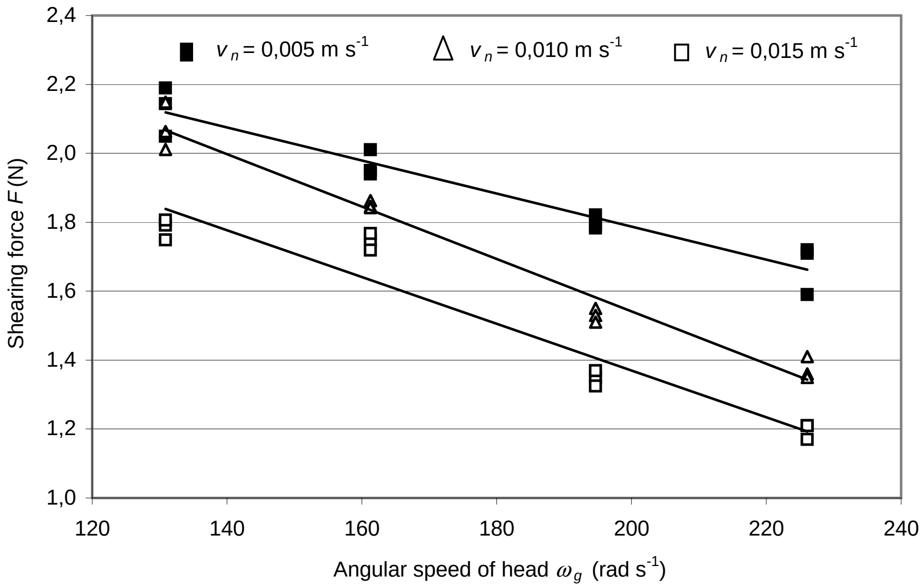

Fig. 36. Dependence of the shearing force F on rotary speed ω_g and linear speed of knife v_n

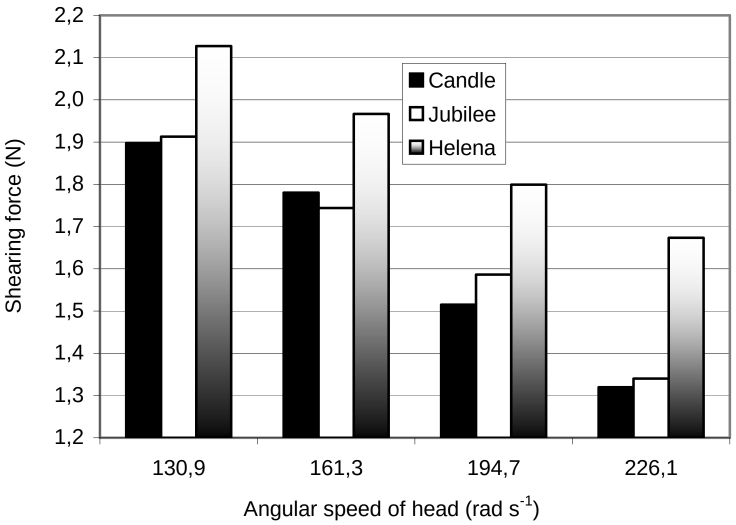

Fig. 37. Changes of the shearing force for different sweet corn varieties

Change in the rotary speed of the head from 130.9 to 226.1 rad·s^{-1} causes a reduction in the shearing force by about 22% at v_n = 0.005 m·s^{-1}, by about 34% at v_n = 0.010 m·s^{-1} and by about 33% at v_n = 0.015 m·s^{-1}. The highest value of the force (2.19 N) was recorded at ω_g = 130.9 rad·s^{-1} and v_n = 0.005 m·s^{-1}, and the lowest (1.17 N) at ω_g = 226.1 rad·s^{-1} and v_n = 0.015 m·s^{-1}. This corresponded to a reduction in the shearing force by about 46%.

Change in the rotary speed of the head ω_g within the range from 130.9 to 226.1 rad·s^{-1} (v_n = 0,005 m·s^{-1}) caused a reduction in the shearing force by from about 22% (Helena) to about 31% (Candle), (Fig. 37). In turn, over the whole range of cob feeder speeds from 0.005 to 0.015 m·s^{-1} the reduction obtained was from 49 (Jubilee) to 42% (Helena).

6.3.1. Energy Consumptions Measurement of Kernel Cut-Off Process

Due to the necessity of accurate positioning of knives and maintaining correct geometry of the blades, which has a significant effect on both the quantity and the quality of kernels cut off, new knives were used for the study and care was taken to ensure their proper alignment. The stand for the tests on the process of kernel detachment from cob cores is presented in Figure 38.

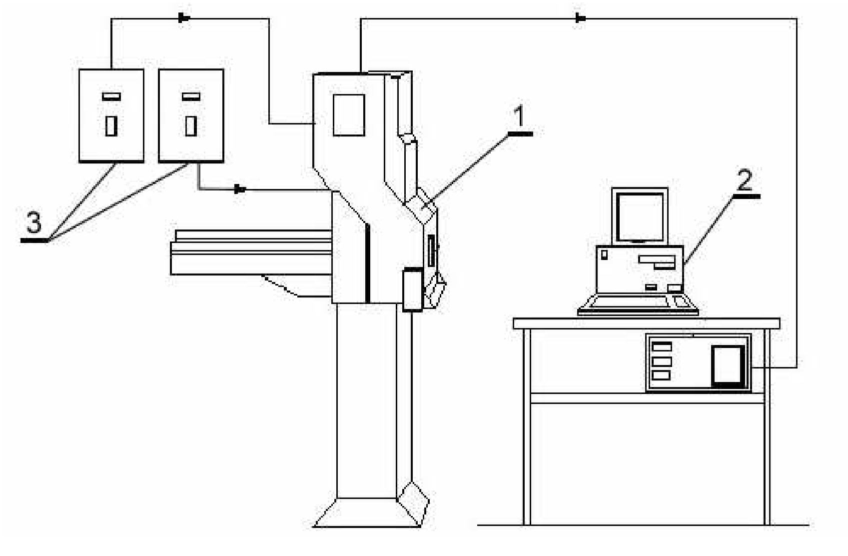

Fig. 38. Measurement stand for cutting of corn kernels: 1 – corn cutter, 2 – system of power and electric energy measurement, 3 – frequency transducers

Sweet corn cobs were transported by means of the cob feeder to the cutting head. Inside the head casing two sets of rollers were installed, feeding cobs to the cutter knives. After kernel cutting, the cob core was ejected outside the head casing by means of a pair of ejection rollers. The kernels cut off from the cob core dropped down out of the head casing. The spacing of the transport rollers adjusted automatically to the cob diameter. The rollers controlled the working gap between the cutter knives.

Control of the rotary speed of the knife head and of the cob feeder was effected by means of two electric motors controlled by frequency transducers. Power end energy consumption of the kernel cutter was recorded in computer memory. Table 22 presents the settings of operating parameters of the cutter used in the tests. Measurements were in three replications, on a sample made up of 5 cobs.

Table 22. Settings of corn cutter at different cob feeder speeds

Working parameters	Value
The shape of cutting tool:	
Tool wedge angle (1°),	8
Nose angle (1°)	15
Setting range of cutting tool (mm)	20-60
Angular rate (rad·s^{-1})	167,5; 201,0; 234,6; 268,1;301,2
Velocity of feeder rate (m·s^{-1})	0,31; 0,51; 0,71; 0,92

The stand was used to determine the quality and energy consumption of the process of kernel cutting, characterized by the following qualitative and quantitative indexes:
– unit power consumption (kW/cob),
– unit energy consumption (kJ/cob),
– cutting efficiency (cobs/min),
– weight percentage of kernels cut off (%),
– fraction percentage of kernels cut off (%),
– percentage of kernels of inferior quality (%).

The significance of the effect of the independent variables on the dependent variable in this fragment of the study was determined with a four-element analysis of variance.

The energy requirement of the process of kernel cutting was measured by connecting the cutter to the measurement system presented in Figure 38. The system utilizes a power, time and energy transducer type Lumel PP83, feeding data to the computer. Power consumption measurements were realized once the

machine reached stabilized speed. The transducer converted and processed measurement data that included:
– total power of the cutting process, N_c (kW),
– idle speed power, N_j (kW),
– cutting process power, N_o (kW),
– total energy of the cutting process, E_c (kWh),
– idle speed energy, E_j (Kw.),
– cutting process energy, E_o (kWh),
– cutting process time (duration), t (s).

Figure 39 presents, on the example of the Helena variety tested in 2002, the changes in power consumption by the cutter during:
– idle run, N_j,
– cutting process, N_o, and
– the total power consumption, N_c.

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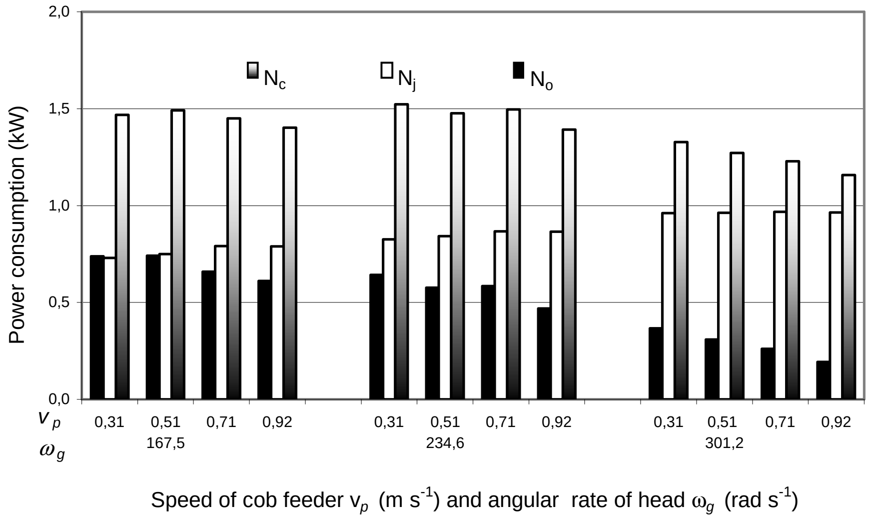

Fig. 39. Changes of power consumption by the corn cutter at idle and under load

Change in the rotary speed of the knife head within the range from 167.5 to 301.2 rad·s^{-1} and in the cob feeder speed from 0.31 to 0.92 m·s^{-1} caused an increase in power consumption at idle run of the cutter by about 33%. The lowest power consumption was observed at ω_g = 167.5 rad·s^{-1} and v_p = 0.31 m·s^{-1} (0.73 kW), and the highest at ω_g = 301.2 rad·s^{-1} and v_p = 0.71 m·s^{-1} (0.97 kW). With cutter under load (during cutting process) a reverse effect was observed – change in the head speed resulted in a decrease in the total power consumption (by about 18%). The changees varied within the range from 1.23 kW (ω_g = 301.2 rad·s^{-1} and v_p = 0.71 m·s^{-1}) to 1.49 kW (ω_g = 234.6 rad·s^{-1} and v_p = 0.71 m·s^{-1}).

The decrease in N_c with increasing working speeds was related to the drop of N_o by about 74%. The highest value (0.74 kW/cob) was recorded at ω_g = 167.5 rad·s^{-1} and v_p = 0.31 m·s^{-1}, and the lowest (0.19 kW/cob) at ω_g = 301.2 rad·s^{-1} and v_p = 0.92 m·s^{-1}. This was caused by the shorter duration of the cutting process on one hand (higher speed of cob feeding), and by lower cutting resistance (higher speed of knife head0 on the other.

In the statistical analysis of results concerning the power consumption, the parameter considered was N_o (kW/cob). Analysis of variance showed that all the independent variables analyzed (rotary speed of the knife head, linear speed of the cob feeder, as well as the variety tested and the year of the tests) had a statistically significant effect (at significance level $\alpha = 0.05$) on the dependent variable (unit power consumption of cutting). The analysis also showed that in every year of the tests the variety tested had a significant effect on unit cutting power.

The relation between N_o and the analyzed parameters: ω_g and v_p was described by means of the equation:

$$N_o = b_1\,\omega_g^{\,2} + b_2\,v_p^{\,2} + a \quad \text{(kW/kolbę)} \tag{6}$$

where:

b_1,b_2 – regression coefficients,

a – free argument.

Table 23 presents regression equations for changes of N_o as a function of ω_g at constant v_p. Figure 40 illustrates the corresponding regression curves.

Table 23. Regression equations for change of $N_o = f(\omega_g)$, $v_p = const$

v_p (m·s^{-1})	Equation	R^2	p
0,31	$N_o = -2\cdot10^{-5}\omega_g^2 + 5{,}4\cdot10^{-3}\omega_g + 0{,}51$	0,93	0,00001
0,51	$N_o = -\,10^{-5}\omega_g^2 + 3{,}2\cdot10^{-3}\omega_g + 0{,}67$	0,96	0,00001
0,71	$N_o = -\,10^{-5}\omega_g^2 + 3{,}9\cdot10^{-3}\omega_g + 0{,}64$	0,92	0,00001
0,92	$N_o = -\,10^{-5}\omega_g^2 + 3{,}8\cdot10^{-3}\omega_g + 0{,}56$	0,95	0,00001

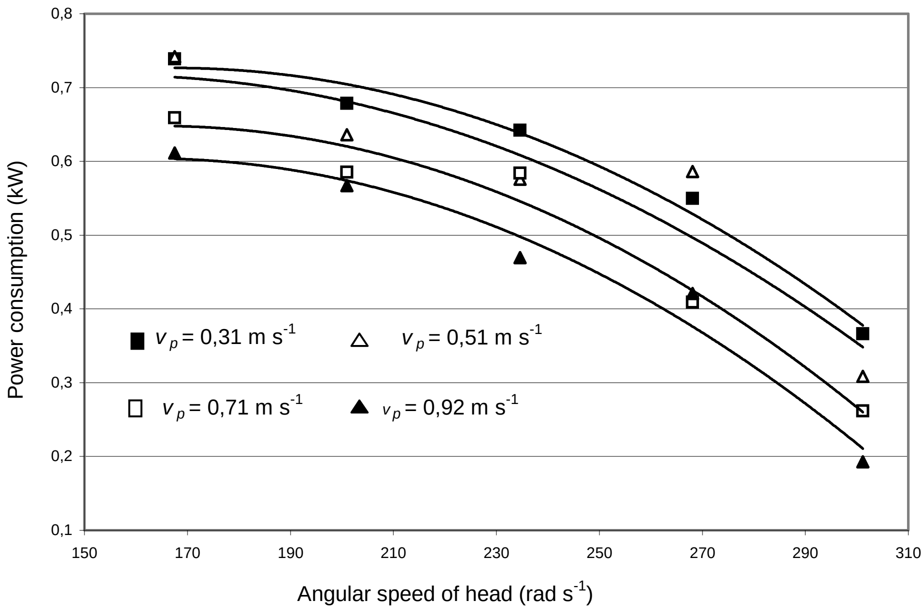

Fig. 40. Dependence of power N_o on head speed ω_g and feeder speed v_p

Analyses of regression and of variance showed that all the parameters of the model were significant at the level of $\alpha = 0.05$. High values of the coefficient of determination (from 0.92 to 0.96) indicate good model fitting. The relation between N_o and ω_g was described by means of square functions. A change in the knife head speed in the range from 167.5 to 301.2 rad·s^{-1} caused a decrease in unit power consumption by about 55% at v_p = 0.31 m·s^{-1}, by about 58% at v_p = 0.51 m·s^{-1}, by about 62% at v_p = 0.71 m·s^{-1}, and by about 68% at v_p = 0.71 m·s^{-1}. The highest value (0.74 kW/cob) was recorded for ω_g = 167.5 rad·s^{-1} and v_p = 0.31 m·s^{-1}, and the lowest (0.19 kW/ cob) for ω_g = 301.2 rad·s^{-1} and v_p = 0.92 m·s^{-1}. This corresponded to a decrease in the unit cutting power by about 74%.

Figures 41 and 42 illustrate changes in the unit power consumption as a function of rotary speed of the knife head for the sweet corn varieties studied. The changes are presented for a constant linear speed of the cob feeder v_p = 0.31 m·s^{-1}. One can state, on the basis of the diagrams, that there is a considerable differentiation in the value of $N_{o,}$ both between the varieties and within a given variety. Change in ω_g in the range from 167.5 to 301.2 rad·s^{-1} (v_p = 0.31 m·s^{-1}) caused a drop in N_o , for the year 2002, from about 50% (Jubilee) to about 34% (Helena), and for the year 2003 – from about 51% (Helena) to about 40% (Jubilee). In turn, over the whole range of cob feeder speeds, from 0.31 to 0.92 m·s^{-1}, the corresponding decrease observed in 2002 was from about 74% (Helena) to about 50% (Candle), and in 2003 – from about 74% (Jubilee) to about 55% (Candle).

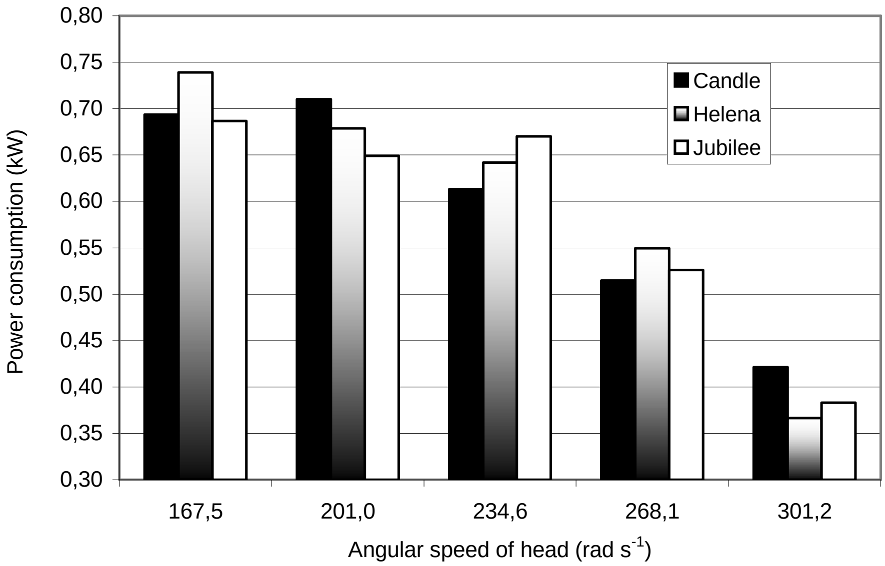

Fig. 41. Changes of power N_o for the studied varieties in the year 2002

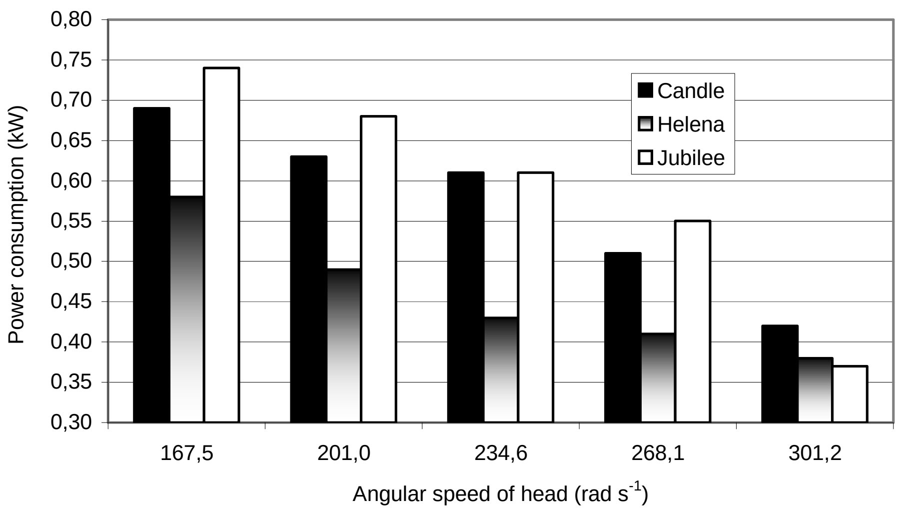

Fig. 42. Changes of power N_o for the studied varieties in the year 2003

Figure 43 presents the changes in electric energy consumption by the corn cutter during:
– idle run, E_j,
– cutting process, E_o,
– and in the total electric energy consumption, E_c.

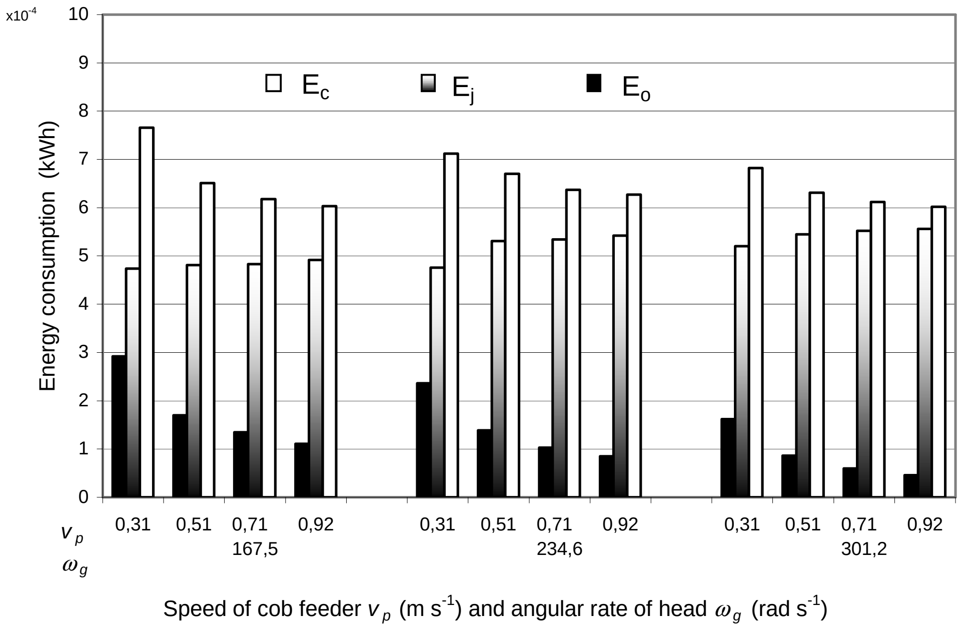

Fig. 43. Distribution of energy consumption by corn cutter

A change in the knife head speed ω_g in the range from 167.5 to 301,2 rad·s^{-1} and in the cob feeder speed v_p from 0.31 to 0.92 m·s^{-1} caused an increase in energy consumption at idle run of the cutter E_j in the range from 4.74 to 5,56·10^{-4} kWh, i.e. by about 17%. The lowest energy consumption was recorded at ω_g = 167.5 rad·s^{-1} and v_p = 0.31 m·s^{-1}, and the highest at ω_g = 301.2 rad·s^{-1} and v_p = 0.92 m·s^{-1}. When the cutter was under load (during the cutting process), it was observed that with changing working speed of the cutter the value of E_c decreased by about 21%. The changes varied within the range from 7.66·10^{-4} kWh (ω_g = 167.5 rad·s^{-1} and v_p = 0.31 m·s^{-1}) to 6.02 10^{-4} kWh (ω_g = 301.2 rad·s^{-1} and v_p = 0.92 m·s^{-1}).

The decrease in the total energy consumption E_c with increasing working speeds resulted from the decrease in the unit energy consumption in the cutting process E_o (by about 84%). The highest value (2.92·10^{-4} kWh/cob) was recorded at ω_g = 167.5 rad·s^{-1} and v_p = 0.31 m·s^{-1}, and the lowest (0.46·10^{-4} kWh/cob) at

ω_g = 301.2 rad·s^{-1} and v_p = 0.92 m·s^{-1}. This was caused by the shorter duration of the cutting process (higher speed of cob feeding) on the one hand, and by the lower resistance to cutting (high speed of the knife head) on the other.

The results of analysis of variance for the dependent variable $E_{o,}$ indicated significance of the independent variables (ω_g, v_p, variety, and year) as well as of their interactions. The strongest effect was that of the variety-year interaction (approx. 35% of the total variability of unit energy consumption). The relation between E_o and the analyzed parameters: ω_g and v_p was described with the equation:

$$E_o = b_1\ \omega_g + b_2\ v_p + a \quad \text{(kWh/kolbę)} \tag{7}$$

where:

b_1,b_2 – regression coefficients,

a – free argument.

A change in the knife head speed in the range from 167.5 to 301.2 rad·s^{-1} (Fig. 44) caused a decrease in the unit energy E_o by about 44% at v_p = 0.31 m·s^{-1}, by about 50% at v_p = 0.51 m·s^{-1}, by about 56% at v_p = 0.71 m·s^{-1} and by about 60% at v_p = 0.92 m·s^{-1}. The highest value (2.92·10^{-4} kWh/cob) was recorded at ω_g = 167.5 rad·s^{-1} and v_p = 0.31 m·s^{-1}, and the lowest (0.46·10^{-4} kWh/cob) at ω_g = 301.2 rad·s^{-1} and v_p = 0.92 m·s^{-1}, which corresponded to a decrease in the unit cutting energy by about 84%.

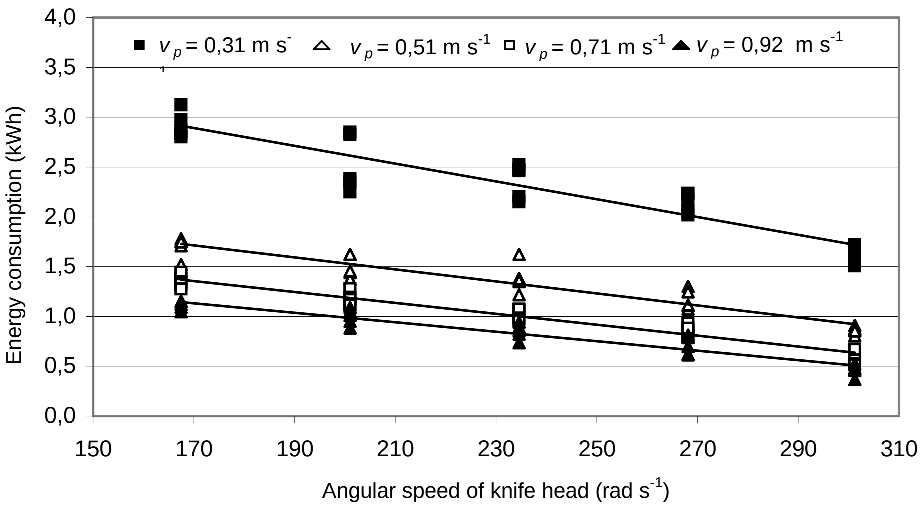

Fig. 44. Dependence of energy E_o on head speed ω_g and feeder speed v_p

Table 24 presents the regression equations for the unit cutting energy E_o as a function of the knife head speed ω_g for a constant linear speed of the cob feeder v_p. Depending on the variety and the year of testing, changes in the value of ω_g in the range from 167.5 to 301.2 rad·s^{-1} for constant v_p (0.31 m·s^{-1}) caused a decrease in E_o by from about 58% (Jubilee) to about 44% (Helena) in the year 2002 (Fig. 45), and from about 56% (Helena) to about 47% (Candle) in 2003 (Fig. 46). In turn, over the whole range of cob feeder speeds, from 0.31 to 0.92 m·s^{-1}, the decrease varied from the level of about 81% (Candle) to about 93% (Jubilee) in the year 2002, and from about 60% (Candle) to approximately 92% (Helena) in 2003.

Table 24. Regression equations for the change of $E_o = f(\omega_g)$, $v_p = const$

v_p (m·s^{-1})	Equation	R^2	p
0,31	$E_o = -0{,}009\omega_g + 4{,}41$	0,85	0,00001
0,51	$E_o = -0{,}006\omega_g + 2{,}72$	0,87	0,00001
0,71	$E_o = -0{,}005\omega_g + 2{,}28$	0,94	0,00001
0,92	$E_o = -0{,}0048\omega_g + 1{,}94$	0,90	0,00001

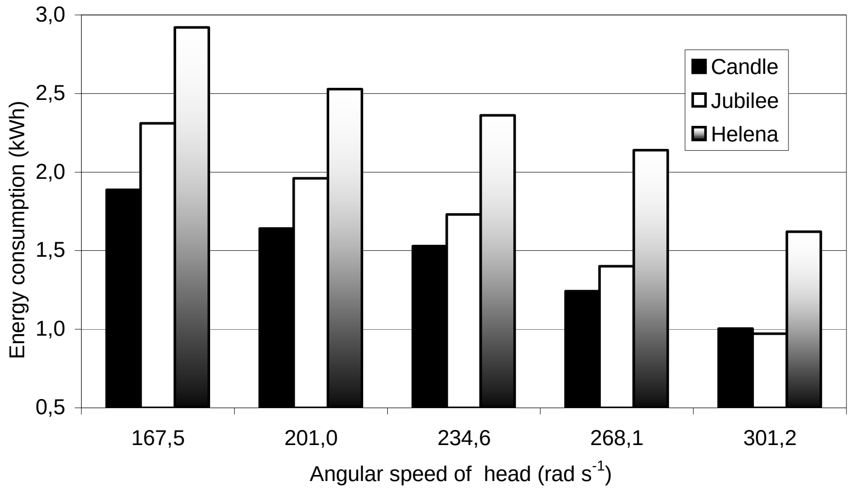

Fig. 45. Changes of energy E_o for the tested varieties in the year 2002

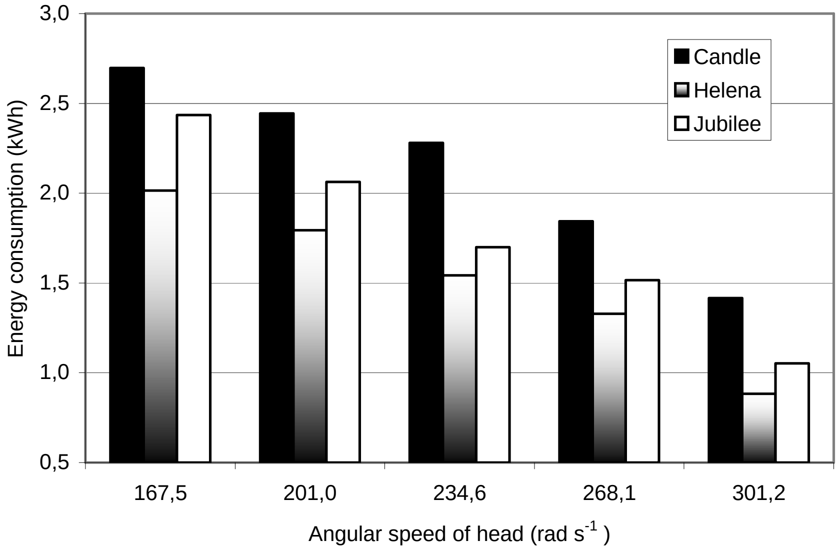

Fig. 46. Changes of energy E_o for the tested varieties in the year 2003

6.3.2. KERNEL CUT-OFF PROCESS EFFICIENCY

The results of analysis of variance showed that all the independent variables analyzed: knife head speed ω_g (rad·s^{-1}), linear speed of the cob feeder v_p (m·s^{-1}), variety, and year of testing, had a significant effect on the independent variable – unit process efficiency Q (cobs/min). To estimate the quantitative effect of the rotary speed of the knife head and of the linear cob feeder speed on unit efficiency of the process of corn cutting, a regression analysis was performed. The changes in the values of Q in relation to ω_g and v_p were described with the equation:

$$Q = b_1\omega_g + b_2 v_p + a \quad \text{(kolb/min)} \tag{8}$$

gdzie:

b_1,b_2 – współczynniki regresji,

a – wyraz wolny.

Figure 47 illustrates the corresponding regression curves. The relation between Q and ω_g was described with linear functions. Change in the knife head speed in the range from 167.5 to 301.2 rad·s^{-1} caused an increase in Q by about 44% at v_p = 0.31 m·s^{-1}, and by about 11% at v_p = 0.51 m·s^{-1}, by about 22% at v_p = 0.71 m·s^{-1} and by about 88% at v_p = 0.71 m·s^{-1}. The highest value (164.21 cobs/min) was recorded at ω_g = 301.2 rad·s^{-1} and v_p = 0.92 m·s^{-1}, and the lowest (53.73 cobs/min) for ω_g = 167,5 rad·s^{-1} and

$v_p = 0.31$ m·s^{-1}. This corresponded to increase in unit efficiency of the cutting process by about 67%. Table 25 presents the regression equations of that relation.

Table 25. Regression equations for change of $Q = f(\omega_g)$, $v_p = const$

v_p (m·s^{-1})	Równanie - Equation	R^2	p
0,31	$Q = 0{,}17\omega_g + 90{,}1$	0,48	0,00001
0,51	$Q = 0{,}16\omega_g + 77{,}9$	0,60	0,00001
0,71	$Q = 0{,}07\omega_g + 76{,}1$	0,41	0,00001
0,92	$Q = 0{,}02\omega_g + 52{,}1$	0,28	0,00001

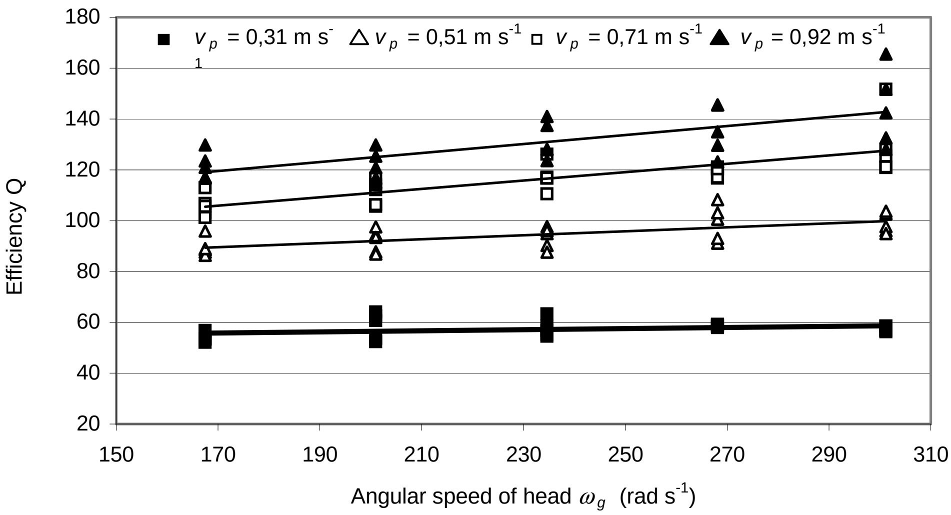

Fig. 47. Dependence of the efficiency Q (cob/min) on head speed ω_g

Figures 48 and 49 present the changes in unit efficiency of the cutting process as a function of rotary speed of the knife head for the sweet corn varieties studied, at constant $v_p = 0.31$ m·s^{-1}. On the basis of the graphs we can observe that there was a considerable differentiation in the values of Q, both between the particular varieties studied and within a given variety. Change of ω_g in the range from 167.5 to 301.2 rad·s^{-1} ($v_p = 0.31$ m·s^{-1}) caused an increase in the value of Q for the year 2002 by from about 15% (Candle) to about 32% (Jubilee), and for the year 2003 – from about13% (Candle) to about 34% (Jubilee). In turn, over the whole range of cob feeder speeds (0.31–0.92 m·s^{-1}) the increase recorded in the year 2002 varied from about 166% (Helena) to about 298% (Candle), and in 2003 – from about 250% (Helena) to about 312% (Jubilee).

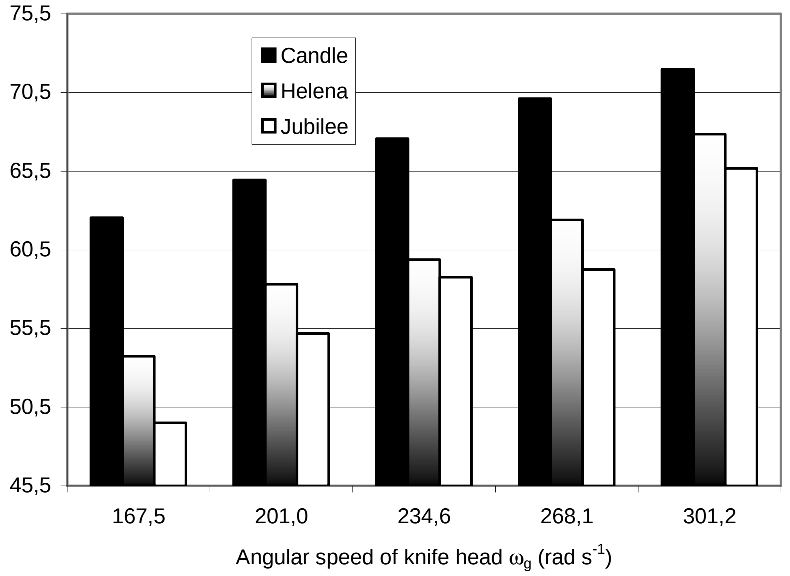

Fig. 48. Changes of efficiency *Q* for the studied varieties in the year 2002

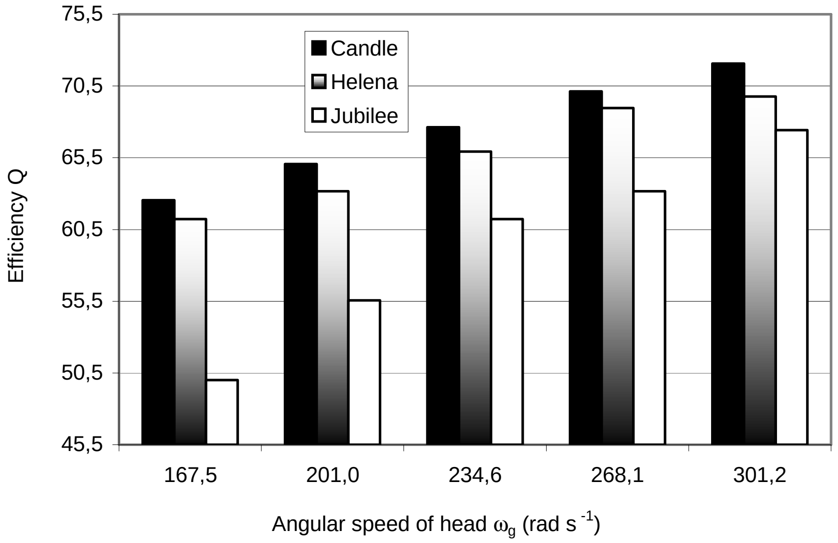

Fig. 49. Changes of efficiency *Q* for the studied varieties in the year 2003

6.3.3. METHOD FOR MEASUREMENT OF THE DEGREE OF CORN KERNELMASS DETACHMENT

The degree of kernel mass detachment S_o was determined in two stages. Stage one consisted in the calculation of the share of kernel mass detached form cob core M_{od} according to the formula:

$$M_{od} = \frac{m_1 - m_2}{m_1} \cdot 100 \quad (\%) \tag{9}$$

where:

m_1 – cob mass prior to the process of kernel cutting (g),
m_2 – cob mass after kernel detachment (g),

and in stage two the value from equation (9) was referenced to the biological yield of the kernels:

$$S_{od} = \frac{M_{od}}{W_b} \cdot 100 \quad (\%) \tag{10}$$

Such a procedure for the calculations resulted from problems with collecting all the kernels cut off (some of which were scattered over the elements of the cutter) and from loss of juice and solid fractions, as well as from difficulties involved in the determination what part of the kernels remained on the cob cores. The weight of the material studied was determined using scales type WPE 2000p.

Analysis of variance showed that the knife head speed ωg was the primary parameter affecting the degree of kernel mass detachment So (approx. 65% of the total variability). Changes in the S_o in relation to ωg and v_p were described by means of the equation:

$$S_o = b_1 \omega_g + b_2 v_p + a \quad (\%) \tag{11}$$

where:

b_1, b_2 – regression coefficients,
a – free argument.

Change in ω_g in the range from 167.5 to 301.2 rad·s^{-1} caused an increase in the value of S_o by about 45% (Fig. 50). The highest value (68.38%) was recorded at ω_g = 301.2 rad·s^{-1} and v_p = 0.31 m·s^{-1}, and the lowest (47.16%) at ω_g = 167.5 rad·s^{-1} and v_p = 0.92 m·s^{-1}.

All values of coefficient of determination (from 0.73 to 0.90) indicate good fitting of the model (Tab. 26).

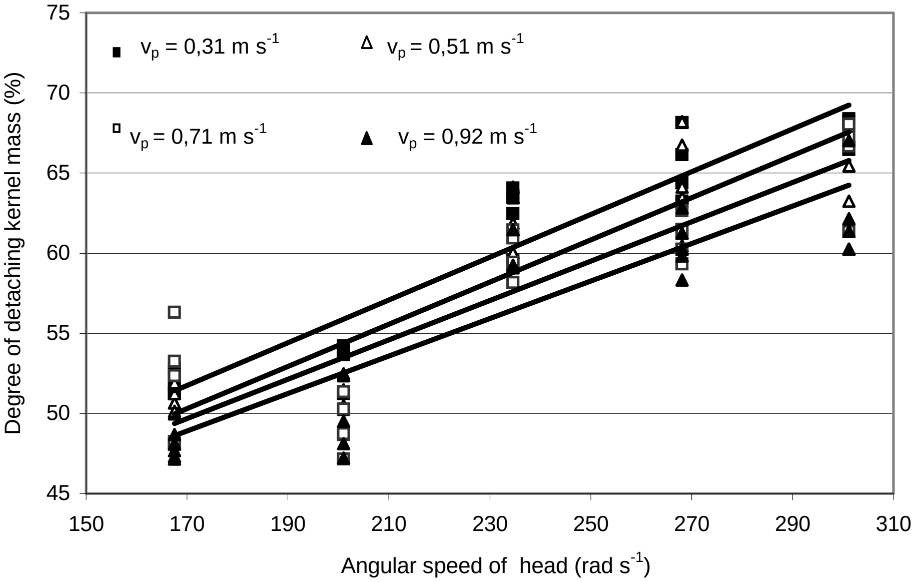

Fig. 50. Changes of the degree of kernel mass detachment S_o as a function of head speed ω_g

Table 26. Regression equations for change of $S_o = f(\omega_g)$, $v_p = const$

v_p (m·s^{-1})	Equation	R^2	*p*
0,31	$S_o = 0{,}14\omega_g + 28{,}46$	0,90	0,00001
0,51	$S_o = 0{,}14\omega_g + 26{,}62$	0,82	0,00001
0,71	$S_o = 0{,}13\omega_g + 27{,}43$	0,76	0,00001
0,92	$S_o = 0{,}12\omega_g + 30{,}11$	0,73	0,00001

Change in the knife head speed ω_g in the range from 167.5 to 301,2 rad·s^{-1} and at constant cob feeder speed v_p (0.31 m·s^{-1}), depending on the variety and the year of study, caused an increase in the degree of kernel mass detachment S_o from about 30% (Jubilee) to about 45% (Helena) in the year 2002 (Fig. 51), and from about 23% (Jubilee) to about 58% (Candle) in 2003 (Fig. 52). Increase of the cob feeder speed above 0.31 m·s^{-1} did not cause any further increase in the value of S_o.

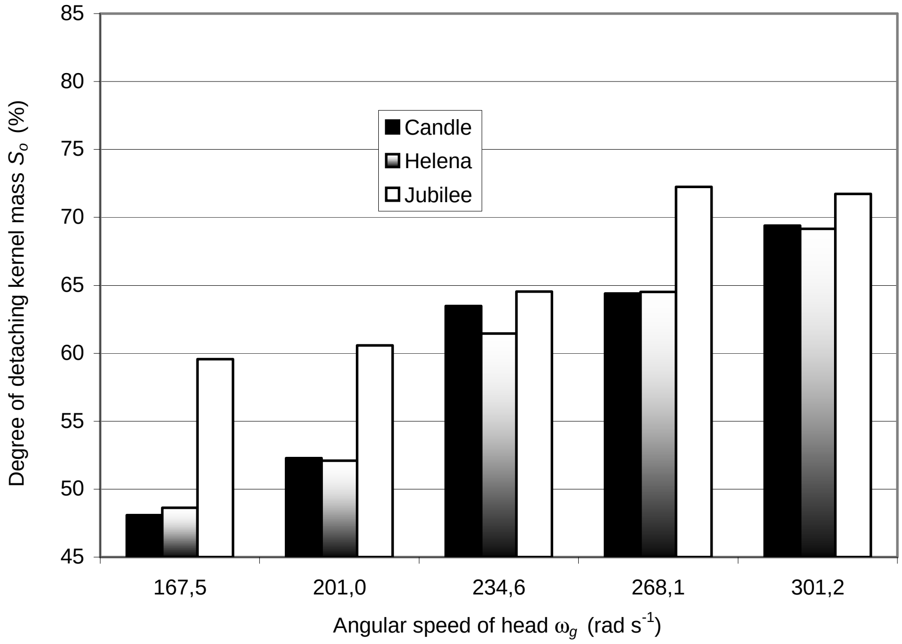

Fig. 51. Changes of degree of kernel mass detachment S_o for the studied varieties in the year 2002

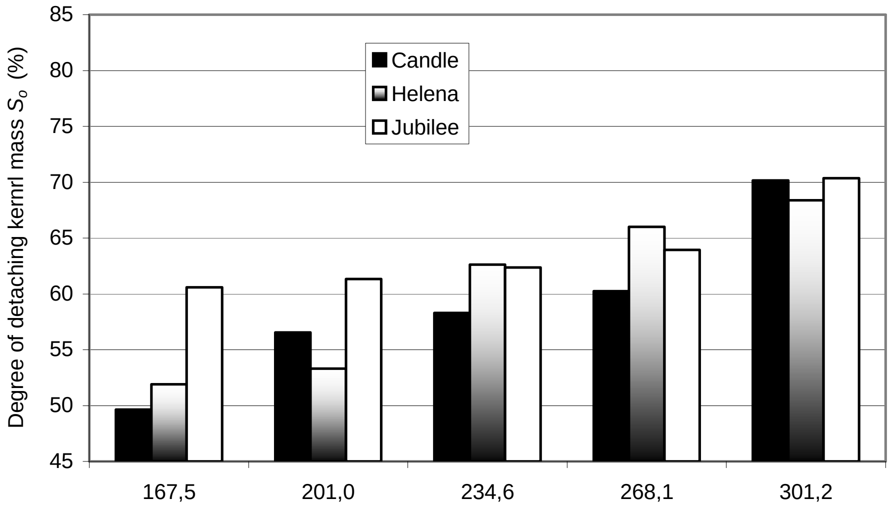

Fig. 52. Changes of degree of kernel mass detachment S_o for the studied varieties in the year 2003

6.3.4. METHOD FOR MEASUREMENT OF THE SHARE OF KERNEL FRACTIONS

Kernel classification into fractions was performed after the measurement of the length of kernels. The measurements were made with the help of a slide caliper on a sample made up of 500 kernels. The final result was a mean value from 3 replications. Due to the lack of literature data and industry standards concerning the classification of detached kernels into size classes, the following classification was adopted:
– class I – kernels with length above 8 mm,
– class II – kernels with length from 4 to 8 mm,
– class III – kernels with length below 4 mm.

The quantitative shares of the particular fractions or classes were determined according to the formula:

$$f_i = \frac{n_i}{\sum_{i=1}^{3} n_i} \cdot 100 \quad (\%) \tag{12}$$

where:

n_i – number of kernels in i–th fraction.

Change of the knife head speed in the range from 167.5 to 301,2 rad·s^{-1} and in cob feeder speed from 0.31 to 0.92 m·s^{-1} caused changes in the share of kernel fractions in the classes (Fig. 53). In class I an increase was observed by about 347%, and in class III – a decrease by about 65%.

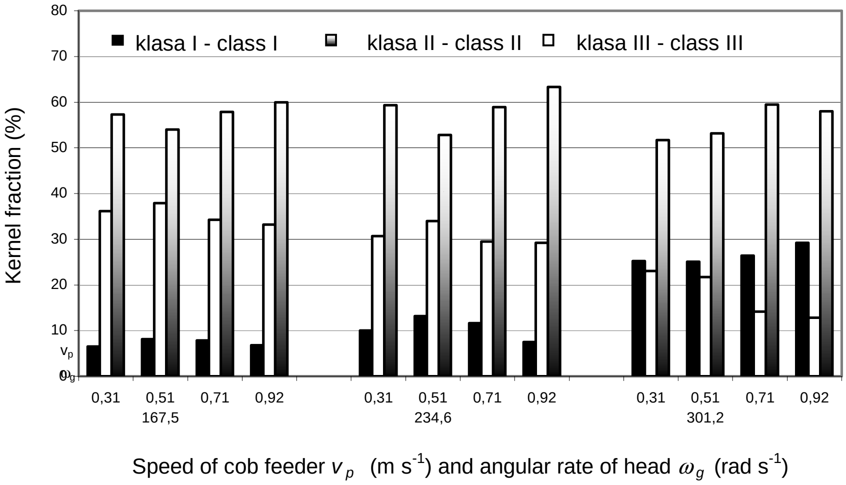

Fig. 53. Share of kernel fractions in classes

Depending on the variety and the year of study, the share of kernel fraction increased from about 14% (Jubilee, 2002) to about 56% (Candle, 2002) in class I and decreased in the range from about 65% (Helena, 2002) to about 34% (Candle, 2002) in class III. In class II, whose share fell within the range from about 40% (Candle, 2003, ω_g = 234.6 rad·s^{-1} and v_p = 0.71 m·s^{-1}) to about 71% (Candle, 2002, ω_g = 234.6 rad·s^{-1} and v_p = 0. 92 m·s^{-1}), no clear increasing or decreasing trends were observed.

The results of analysis of variance for the dependent variable (share of kernel fraction in class I, f_I,) showed that the strongest effect on the value of the variable was that of the knife head speed ω_g (approx. 50% of the total variability of the share of kernels in class I, f_I) and of the year of tests (approx. 34%). In turn, for the dependent variable - share of kernels in class II f_{II}, – the year (approx. 71%), and for the dependent variable – share of kernels in class III f_{III}, – knife head speed (approx. 58%) were the primary parameters that affected the values of the dependent variable. Summing up, we can state that, on the basis of the analyses of variance performed, the knife head speed had the strongest effect on the share of kernels in classes I and III.

6.3.5. KERNRL QUALITY AT CUT-OFF PROCESS

On the basis of kernel sections, the kernel section surface area was analyzed, paying attention to the section smoothness and kernel mass loss. The condition of the section of kernels detached was adopted as the index of the cutting process quality (Fig. 54). Cutting process quality was accepted as good if the kernel section was smooth and without loss to the kernel mass. Every other section qualified the kernel as inferior quality. The share of such kernels was calculated according to the formula:

$$U_{zg} = \frac{n_{zg} - n_{zd}}{n_{zg}} \cdot 100 \quad (\%) \tag{13}$$

where:

n_{zd} – number of kernels of good quality [pcs.],
n_{zg} – number of kernels of inferior quality [pcs.].

Change in the knife head speed in the range from 167.5 to 301.2 rad·s^{-1} and of the cob feeder in the range from 0.31 to 0.92 m·s^{-1} caused a decrease in the share of kernels of inferior quality U_{zg} in the classes (Fig. 55). In class I the decrease was by about 82%, in class II by about 86% and in class III by about 71%. With respect to the variety studied and to the year of study, the values of U_{zg} decreased in the range from about 81% (Helena, 2003) to about 71% (Candle, 2003) in class I, from about 88% (Helena, 2003) to about 69% (Candle, 2003) in class II, and from about 71% (Helena, 2002) to approximately 38% (Jubilee, 2003) in class III.

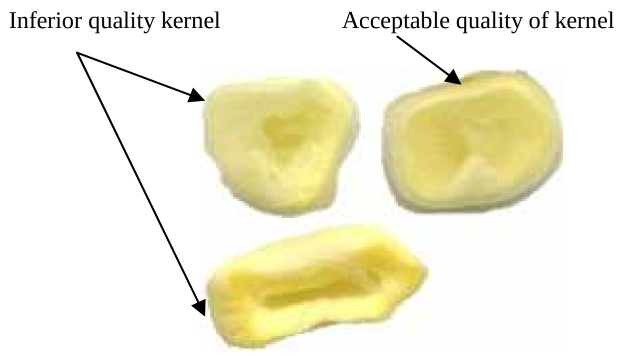

Fig. 54. Surface of detached kernel

The results of analysis of variance showed that the variety had a fundamental effect on the value of U_{zg} in class III (approx. 70% of the total variability of U_{zg}). Both the effect of the knife head speed and that of the cob feeder turned out to be insignificant. In classes I and II, in turn, the main parameter that caused a decrease in the share of kernels of inferior quality was the knife head speed (approx. 66% and 68% of the total variability of U_{zg}).

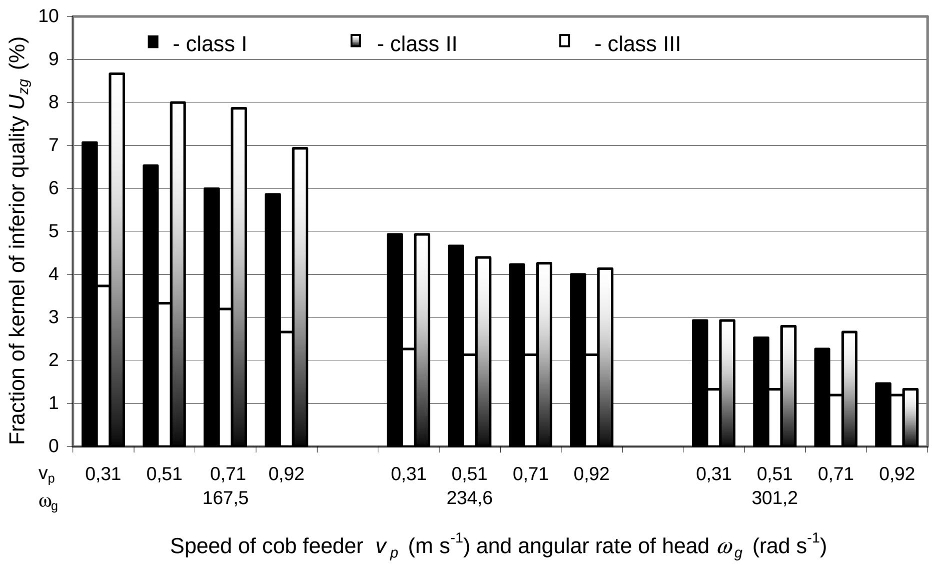

Fig. 55. Fraction of inferior quality kernel U_{zg} in classes

CHAPTER 7

METHODS OF SWEET CORN COB HARVEST

Correct ripening of sweet corn cobs depends on specific selection of varieties, size of cultivation area, observance of the optimum time of harvesting, and good harvest organization. Corncobs can be harvested by hand, in two or three stages depending on their ripening. In the first stage of harvest about 65% of the crop is collected, in the second – 23%, and in the third – 12% [84,110,133,156].

Sweet corn cob of the right ripeness is characterized by having light brown, but not wilted, stigmatism at the cob tip. The upper cover leaves are pale green in colour, frequently with yellow or whitish tint. In some places, brown decayed tissue can be observed at the ends of the leaves. Moreover, the cover leaves are tightly wrapped around the cobs. The kernels are full and shiny, and when crushed there is a characteristic cracking sound and a liquid (not too thick) milky juice with sweet taste seeps out. At the time the seed cover loses its chlorophyll and assumes a colouring that is characteristic for a given variety.

Sweet corn kernels that have not yet reached ripeness give thin juice of a grayish coulour and insipid taste, that rapidly darkens when exposed to air. In turn, kernels of over-ripe sweet corn are matt, with no juice seepage when crushed, with the consistency of soft cottage cheese, and with low content of sugars. Kernels from cobs that are unripe or over-ripe cannot be used for canned foods. Sweet corn producers can recognize when the corn has reached the correct degree of ripeness. When in doubt, one can spread the cover leaves at the top part of the cob and estimate the degree of ripeness visually or on the basis of the kernel texture. Only in really doubtful cases all the cover leaves can be removed from the cob.

In the case of one-stage harvest, it is recommended to sow such varieties that are characterized by uniform ripening of cobs, which permits obtaining of possibly large amounts of homogeneous material of good quality. The highest quality and the best taste are characteristic of freshly picked cobs. When stored at high temperatures, sweet corn cobs rapidly lose their quality (Fig. 56). This fact necessitates harvesting cobs directly prior to selling, possibly the day before. Sweet corn harvest time is from July to September, i.e. in the summer period that is characterized by frequent occurrence of high temperatures. In this situation it is best to harvest corncobs in the morning or evening hours, when cobs have a relatively low temperature and will keep fresh for a longer time [73,92]. In the case when cobs are harvested at high temperature, or when their delivery might be delayed by several days, they should be cooled down as soon after the harvest as possible. The simplest and most frequently used method of corncob cooling is splashing them with cold water (so-called *hydro cooling*). Next, the cobs are placed in refrigerators where, at temperature of 0°C and at relative air humidity of about 95%, they can be stored for several days without any notable deterioration of their quality [20,97,159].

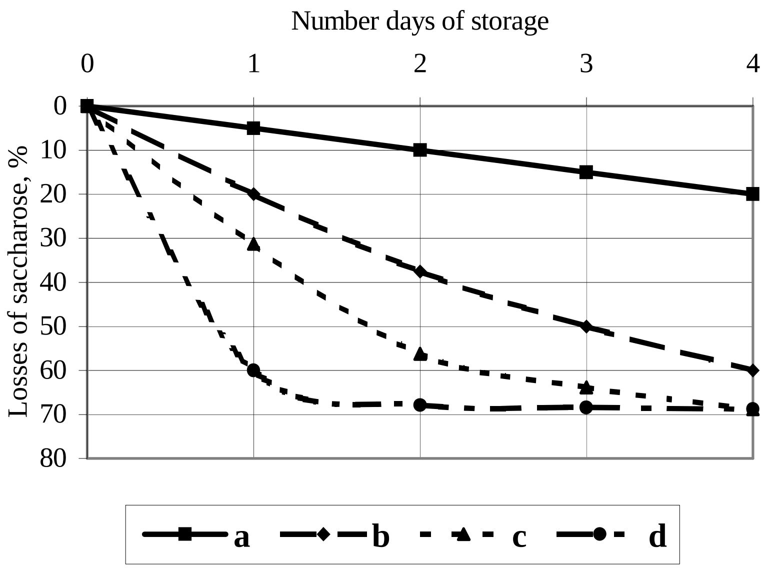

Fig. 56. Drop of the content of saccharose in sweet corn kernels at different temperatures of storage: a) 0°C, b) 10 °C, c) 20 °C, d) 30 °C

7.1. SWEET CORN COB HARVEST BY HAND

Until recently, harvesting sweet corn cobs by hand was the only harvest method used in sweet corn plantations all over the world. Only recently there appeared modern harvesting machines that can replace human labor with the quality of cobs harvested being similar to those collected by hand. However, on smaller plantations collecting sweet corn cobs by hand still remains the only harvest method in use.

Manual picking of cobs is most often used in farms supplying them for direct consumption, i.e. to the so-called fresh produce market. It permits directly for preliminary selection of cobs and picking only those that are in the correct stage of ripeness. This is highly important, as not all cobs ripen at the same time, and making several passes over the plantation and selecting those cobs that are in the required stage of ripeness guarantees obtaining the maximum yield of crop of the highest quality. In the cultivation of branching varieties, harvest by hand is the only form of cob harvesting possible, as the plants form several cobs that ripen at different times.

The whole process of cob harvest by hand consists in cutting the cob off, removing the cover leaves from the cobs collected, and their preliminary sorting. It is a very tedious and labour-consuming process. Fast and efficient picking of cobs from the stems requires several operations to be made by the person harvesting sweet corn cobs. With harvesting cobs by hand from larger plantations, to make the labour of the pickers more efficient special sets of machines are employed, so-called *mule-trains*. Such a mule-train is made up of a truck or tractor combined with a flat-bed trailer and side „wings" on each side, covering a specific number of corn plant rows. A team of 28 people, 16 of whom pick cobs off the stems, works such a set, 11 sort the cobs picked and pack them into special containers, while one person is the driver. Each container takes 48 ripe corncobs, and - when filled – is placed on the trailer moving along with the whole set. An efficient team can pick and pack about 9 thousand containers with corn cobs [172].

Very often such mule-trains are used in two-stage harvest of sweet corn cobs. In the first stage, usually about 50-65% of cobs are picked by hand, choosing those in the optimum phase of ripeness and the most shapely. After several days, the remaining cobs are harvested by means of tractor-towed harvesting machines or highly efficient self-propelled combines.

7.2. CORNCOB HARVEST WITH TRACTOR-TOWED HARVESTERS

Modern machines for corncob harvesting can be tractor-towed or self-propelled. Towed machines are usually single- or two-row harvesters that have found the most extensive application on farms with medium-sized corn cultivation areas varying from several to under twenty hectares [95]. They take the driving power from the towing agricultural tractors. Frequently part of their weight is supported by the tractors, as usually they have only one axle. The productivity of such harvesters depends primarily on the number of rows they are designed to harvest in a single pass, and varies within the range of 0.2 – 0.6 $ha \cdot h^{-1}$, while their power requirement is usually on the level of about 45 kW. From among the whole family of tractor-towed corncob harvesters a few deserve special attention. Figure 57 presents the FMC Single-Row harvester for the harvest of fresh corncobs, that provides high quality and productivity of work.

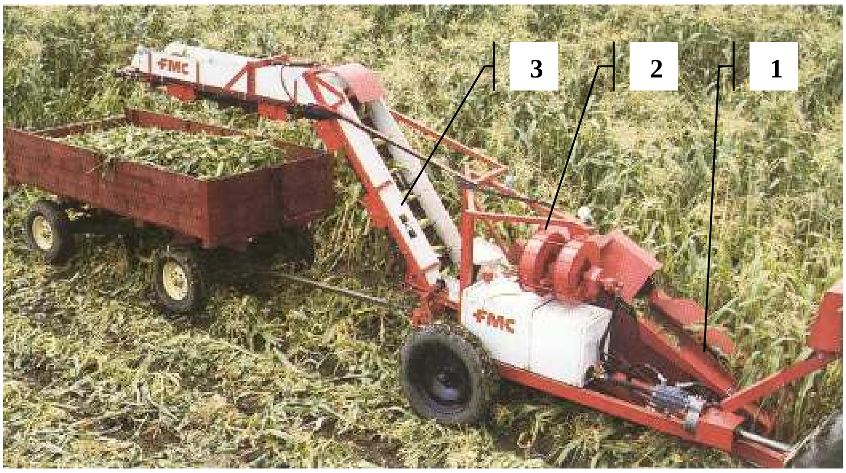

Fig. 57. Tractor-towed FMC Single-Row cob picker during work: 1– single-row cob harvesting unit, 2 – cleaning unit, 3 – belt-slat conveyor [171]

The single-row tractor-towed FMC cob picker is made up of the cob harvesting unit, cleaning unit, and belt-slat conveyor installed in the rear part of the harvester, that delivers the cobs picked onto a trailer attached at the end of the machine team. Working assemblies of the harvester are powered by means of a hydraulic pump driven by the power pick-up of the tractor. During harvester work, they are controlled by the tractor driver via a control panel located on the front of the harvester. The harvester is also equipped with a system of automatic alignment of the cob-harvesting unit with the row of corn plants, which facilitates the work.

Powered chain-and-paddle conveyors on both sides of the plant row feed the plant stems to the cutting rollers. Rotary knives pull the stems down into the harvesting unit until two moving holder belts set at an angle grip a cob. These hold the cob while it is being cut off from the stem by the knife rollers. Such an arrangement permits limitation of damage to kernels to a minimum. Depending on cob size, the spacing of the holder belts is set so that cobs cannot drop out. Also the spacing of the knife rollers with relation to the lower edges of the holder belts is adjustable. This ensures short and accurate cutting of the cob stem, which prevents excessive and unnecessary loss of water and sugars from the cobs and improves the quality of the material harvested.

Corncobs cut from plant stems are transported to the cleaning unit which incorporates an exhauster fan. The fan generates a strong airflow that sucks in leaves and residue of broken stem fragments from among the cobs, and then ejects the collected debris outside. Corncobs cleaned in this manner are moved with the belt-slat conveyor to a trailer or other means of transport. The single-row FMC cob picker has a working speed of 5.6 $km \cdot h^{-1}$, minimum turn radius of 6 m (for a set including the tractor), and has adjustable wheel track (75–100 cm). The basic technical specification of the cob picker is given in Table 27.

Table 27. Technical data of FMC Single-Row cob picker [171]

Contents	Units	Technical data
Height of combine	m	2,32
Length of combine	m	7,8
Track of combine wheels	m	1,94–2,28
Mass of combine	kg	2177
Power consumption	kW	45
Working speed	$km \cdot h^{-1}$	to 8
Height of discharge	m	2,32
Speed of PTO	$rev \cdot min^{-1}$	540 or 1000
Efficiency of combine	$ha \cdot h^{-1}$	0,2–0,4
Tearing off cobs' set	-	rolls-knife
Number of harvested rows	pcs	1
Place of cobs feeding	-	trailer

The machine is characterized by high maneuverability, simplicity and safety of operation, and low operational costs. Its effective productivity is 0.5 $ha \cdot h^{-1}$, at working speed of the tractor of 5 $km \cdot h^{-1}$. Power requirements of the whole set is kW. Technical data of the cob picker described is given in Table 28.

Table 28. Technical data of FMC - model 20 cob picker [171]

Contents	Units of measure	Technical data
Number of harvested rows	pcs	
Track of rows	m	0,9–1,0
Number of cutting head	pcs	2
Number of knives on head	pcs	2
Width of knife	mm	95
Length of knife	mm	550
Own mass	kg	2000
Total length of set	m	9,22
Width of set	m	2,54
Height of discharge	m	4,07

Somewhat different design features and operating principle are characteristic of the cob picker type Pixall One-Row Pull-Pix. It is a single-row machine designed primarily for harvesting corncobs in the milk ripeness phase (Fig. 58).

Fig. 58. Pixall One-Row Pull Pix cob picker during work [171]

Tractors with minimum power of 30 kW can drive the combine. Its productivity, depending on the working conditions, varies from 0.4 to 0,6 $ha \cdot h^{-1}$. Cobs, together with the cover leaves, are cut off from the stems in a special knife roller assembly. The cutting assembly is made up of two counter-rotating knife rollers, with ten knives each (Fig. 59).

Fig. 59. Set of knifes rollers for corncobs cutting [95]

The cutting assembly is controlled hydraulically from the tractor platform, which permits steeples control of working height within the range from 8.5 to 56 cm. Moreover, the harvester has a two-stage cleaning system, made up of a fan, with a diameter of 69 cm, generating airflow that evacuates the light fraction of contaminants, and two vertical cob ejectors that separate the heavier fraction. The conveyor transporting cobs to a container is made of rubber elements, which effectively protects the cobs from mechanical damage. The harvester is adapted to work in a variety of field conditions, in early morning hours and at night, irrespective of the moisture of the cobs harvested. As the elements that get in direct contact with the cobs are made of rubber or else are rubber-coated, and the efficient cleaning system removes all debris and contaminants, the material harvested is characterized by very high quality. The basic technical data of the machine described above are given in Table 29.

Table. 29. Technical data of Pixall One-Row cobs' picker [171]

Contents	Units	Technical data
Number of harvested rows	pcs	1
Power consumption	kW	30
Working speed	$km^{.}h^{-1}$	to 5
Efficiency of combine	$ha^{.}h^{-1}$	0,2–0,4
Cutting off cobs' set	-	rolls-knives
Place of cobs feeding	-	reservoir
Mass of combine	kg	1600

7.3. COMBINE HARVESTING OF SWEET CORN COBS

The short period of sweet corn cob harvest, as well as the fact that the cobs should be harvested fast and under optimum weather conditions (low temperature, no precipitation, etc.) cause that on larger area plantations tractor-towed harvesters or cob more productive multi-row self-propelled combine harvesters replace pickers.

Among lower-productivity combines for sweet corn cob harvesting we should mention the FMC–model 7. It is a self-propelled combine designed for mechanized harvest of corncobs from two plant rows with row spacing from 75 to 100 cm. Optimum working speed of the combine is 5–6 $km^{.}h^{-1}$. Its advantage is the possibility of working in various field conditions, as it has front wheel drive and independent-operation brakes that ensure high maneuverability in difficult terrain conditions. It is also equipped with a self-dumping cob tank with a capacity of 2.5 ton, which eliminates the need for using an additional tractor with trailer for teamwork with the combine (tab. 30).

Table 30. Technical data of FMC - model 7 combine [33]

Contents	Units of measure	Technical data
Height of combine	m	3,7
Width of combine	m	3,05
Track of rows	m	0,75–1,0
Working speed	$km \cdot h^{-1}$	5–6
Mass (with load)	t	6,2 (8,7)
Power consumption	kW	75

The main working elements of the combine are the header unit separators, cob cutting heads, cleaning fan, belt-slat conveyor, and cob tank with dumping conveyor switched on for cobs discharge. Hydraulic motors power all the combine subassemblies, and the whole combine (including the main drive system) is powered by a 75 kW diesel engine. The cutter heads have special hydraulic protection against damage in case of cobs jamming or a stone getting into the system.

Plants growing in rows are directed by the separator chains to the knife rollers, where cobs are cut off from the lower parts of the stems. Adjustable knife length permits accurate cutting of the cob base stems. The remaining parts of the stems together with the cobs are fed to special paddle drums where the cobs get separated from the upper stems. Then the cobs are directed onto a transport conveyor onto which an air stream, generated by a fan, blows to remove debris and contaminants from the cobs. The combine ensures minimum of mechanical damage to the material harvested. It is also equipped with modern and powerful headlights that ensure high comfort of nighttime work. One-lever controlled hydrostatic gearbox permits quick change of driving speed and direction.

Figure 60 presents a schematic of a self-propelled combine for sweet corn cob harvest. The basic working assemblies of the combine include a row header in which cobs are separated from corn stems, a cleaning assembly made up of three exhauster fans, a system of feeders and conveyors for staged transport of the cobs harvested onto transport means, and a drive system providing power to all the subassemblies. The design of the header permits cob harvesting with plant row spacing from 75 to 100 cm.

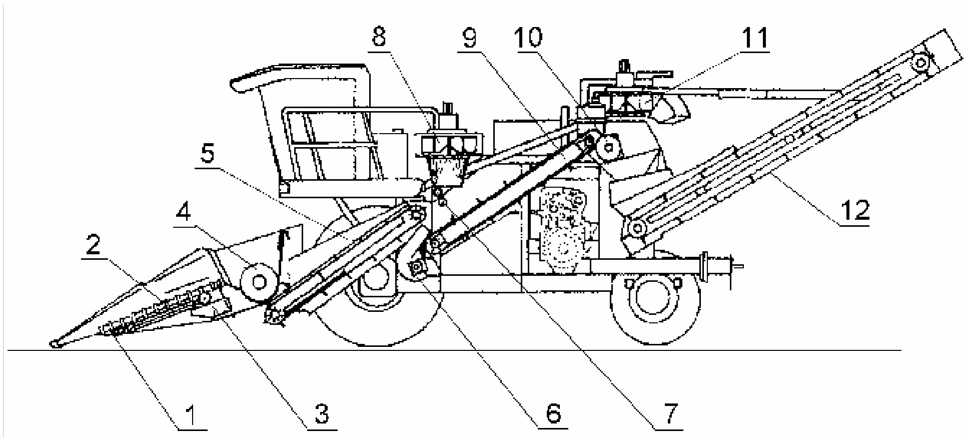

Fig. 60. Schematic of corn cob harvesting combine: 1 – knife rollers, 2 – belt-paddle feeders, 3 – toothed gears, 4 – auger feeder, 5 – belt-slat conveyor, 6 – transverse exhauster, 7 – toothed rollers, 8 – central exhauster fan, 9 – central conveyor, 10 – server cylinder, 11– final exhauster, 12 – unloading conveyor of cobs [40]

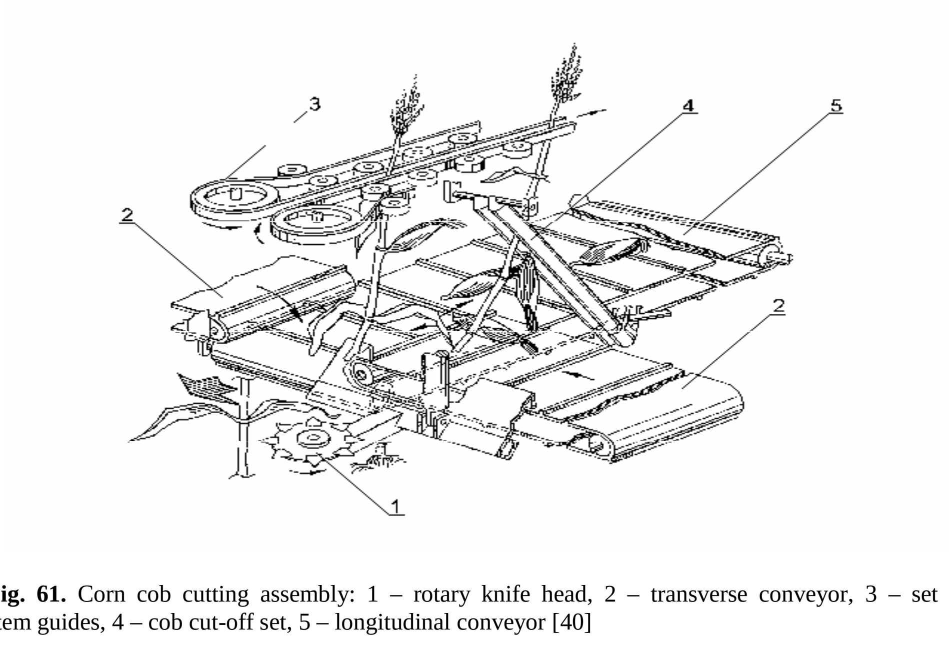

Fig. 61. Corn cob cutting assembly: 1 – rotary knife head, 2 – transverse conveyor, 3 – set of stem guides, 4 – cob cut-off set, 5 – longitudinal conveyor [40]

During the combine operation, the header separators embrace a row of plants and then the belt-paddle feeders direct corn stems between two fixed guide rails. Figure 61 presents a schematic of operation of the header assembly for cob cutting from stems. In a combine equipped with this type of cob cutting assembly, the first step of the process is directing plant stems between the belts of the guide assembly, and the second – stem cutting. Stem tops with cobs are then transported to the rear section of the header. On the way, cobs encounter resistance from the vertical rollers of the cutter assembly. As a result, cobs are broken off the stems and drop onto a transverse conveyor, which takes them to a longitudinal conveyor that directs them to the combine cob tank, or to a trailer moving alongside the combine. Stems after cob separation exit the assembly and, depending on what they are meant for, fall to the ground (usually after prior shredding) or are used as fodder.

In other designs of corn cob combine headers, rotating knife rollers pull corn stems upwards into the bottom part of the header. When corncobs arrive at edges at the bottom of the guide runners, they are cut off from the stems by the knife rollers (Fig. 62). A transverse screw feeder which passes them on to an oblique belt-slat conveyor picks up cut-off cobs. Stems pushed under the header remind on the field. Cobs ejected from the oblique conveyor pass through a strong airflow generated by a fan whose function is to separate light debris and contaminants from the transported cobs. Upper parts of stems remaining with the cobs are separated from them by paddle drums and then sucked out, together with other debris, by an exhauster fan and directed outside the combine. Corncobs cleaned in this manner are transported on to a feeder cylinder and then on by a belt-slat conveyor to the discharge conveyor that sends them out onto a trailer. Above the feeder cylinder there is an additional fan whose function is to separate all remaining contaminants from the cobs. All the elements of the combine that come into direct contact with the harvested cobs are rubber coated or made of rubber to reduce the risk of mechanical damage to the cobs.

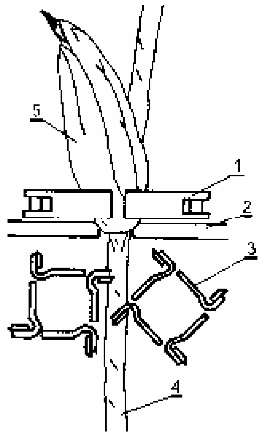

Fig. 62. Schematic of the operation of cob cutting assembly: 1 – belt-slat feeders, 2 – fixed guide runner edges, 3 – knife rollers, 4 – corn stem, 5 – corn cob

More and more frequently, modern headers are equipped with oblique belt conveyors with vertical axes of rotation which protect corn kernels from damage during cob cutting off. During combine operation (Fig. 63), rotating chain-paddle rakes direct corn stems to belt conveyors provided with special edges at the lower part. Next, rollers pull a corn plant beneath the header until the moment when the cob stops on the edges. At that moment the cob is cut off from the stem, and the oblique feeders enclose the cob, protecting it from mechanical damage. The application of belt conveyors in headers greatly improved the quality of the material harvested, not only through a reduction in the level of mechanical damage, but also through more accurate cutting off of the cob base stems, thus helping in the reduction of water and sugars losses [62,84].

Fig. 63. View of combine FMC Corn Comander during harvesting of sweet corn cobs [171]

The American company Pixall also offers multi-row self-propelled corn harvesters. The corn combine EL 30 HARVESTER presented in Fig. 64 is a modern and highly efficient machine for harvesting corncobs from larger areas. It is capable of an effective productivity of about 1.2 $ha \cdot h^{-1}$, at the recommended working speed of 4.5–6.5 $km \cdot h^{-1}$.

Depending on the type of header used, corn can be harvested from 4 or 6 rows at the same time. In the combine modern materials have been used for manufacturing elements involved in cob cutting and transport, which greatly reduced the level of damage to the material harvested. Typically, the combine works in team with a towed trailer type Byron 3000 of 12 t load capacity, ensuring long time of operation between cob unloading operations [62,172].

Fig. 64. View of self-propelled combine EL 30 HARVESTER during work [171]

Under favorable harvest conditions, cobs can be loaded directly onto transport means. The cob cleaning system of the combine is made up of two fans, with diameters of 76 cm and 64 cm, respectively, which efficiently remove all the debris and conmainants that happen to be among the harvested cobs. Thanks to independent drive system to each wheel and hydraulic control of the drive system, header, and cob transport conveyors, work with the combine is not a heavy load on the operator under a variety of conditions, and the productivity of the combine is greatly enhanced (Tab. 31).

Table 31. Technical data of Pixall EL 30 HARVESTER [62]

Contents	Units	Technical data
Height of combine	m	3,8
Lenght (with trailer)	m	7,1 (9,5)
Widht of combine	m	3,4
Mass of combine	t	12
Power of consumption	kW	180

The application of modern technologies for corn production permits corn to be harvested at planned times, even under less favorable conditions, such as harvesting at night, over soft fields, or at increased moisture content of the material harvested. Additionally, they have no negative effect on the quality of harvested cobs.

CHAPTER 8

SWEET CORN COB PROCESSING TECHNOLOGY

8.1. CORNCOB HUSKING EQUIPMENT

Once corncobs are harvested, they are cleaned of the cover leaves and stigmates. As a rule, the process takes place on special cob huskers. An assembly for the removal of cover leaves from sweet corncobs (Fig. 65) is made up of a set of longitudinal shafts or rollers, on the circumference of which there are axial and radial grooves which divide the shaft into cylindrical segments. The shafts can be circular or elliptical in section. The shafts operate in pairs and rotate in opposing directions and are set at close distance from each other. The grooves can be parallel to the shaft axis or follow a helical line. Separation of cover leaves from the cob takes place through mutually counter rotating movement of both cobs and shafts, and cobs pulling in by the longitudinal edges on the shafts. The process is more effective when the base part of the cob is cut off before. Moreover, to reduce the resistance resulting from shaft friction against the cover leaves and to enhance the effectiveness of leaf separation from cobs, cobs are wetted with water for the process of cover leaf removal. The shaft assembly is powered by an electric motor and is usually set at a suitable angle, doubling in function as feeder for cobs to be husked.

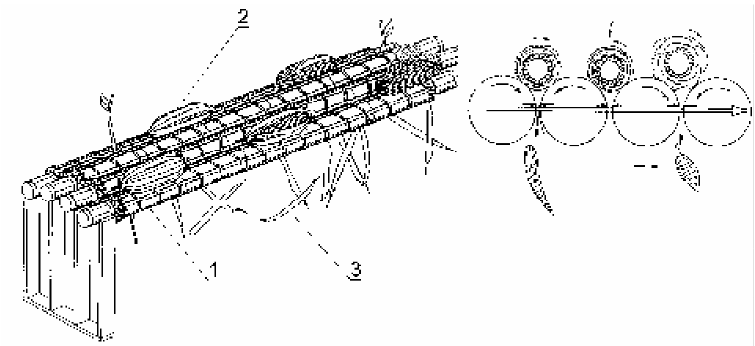

Fig. 65. Corncob cover leaf removing assembly: 1– husking rollers, 2 – corncobs, 3 – cover leaves [113]

Most corn cutters used in the processing industry require that the cobs husked should enter the husking assembly with their narrow end forward. Figure 66 presents a schematic diagram of a device that performs that function. A belt conveyor transports corncobs to rotary disc (table) that works in conjunction with two rotating brushes. The function of the brushes is to pass the cobs on (one by one) to another conveyor that directs the cobs to a cob sorting and aligning device.

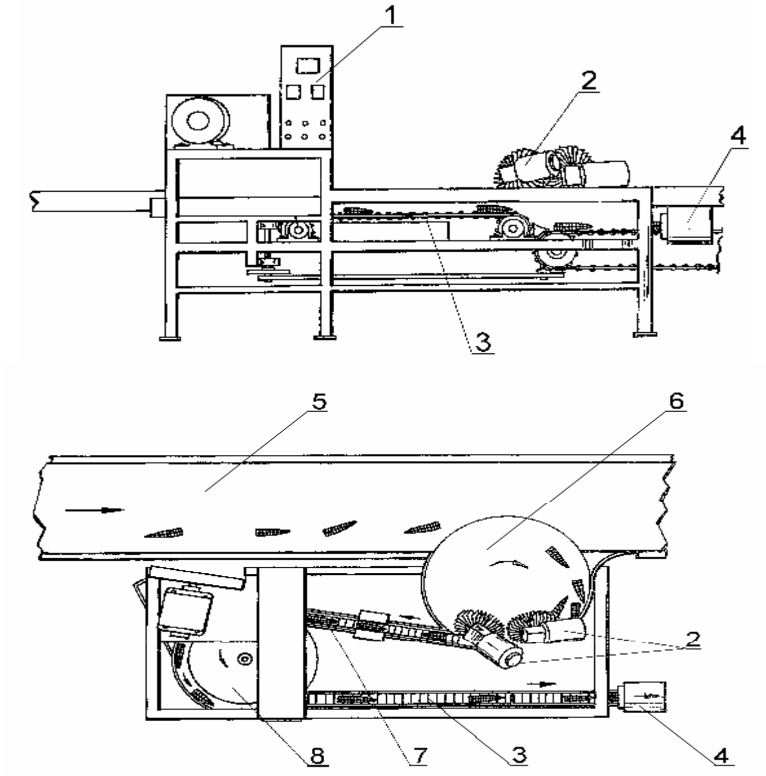

Fig. 66. Device for corn cobs sorting and aligning: 1 – control system, 2 – rotary brushes, 3, 5, 7 – conveyors of cobs, 4 – cutter, 6 – rotary disc of the assembly, 8 – rotary disc for cobs alignment [113]

Cob sorting consists in the use of an optical sensor which, depending on the criterion value (cob thickness or length) controls the opening and closing a horizontal shutter. Opening of the shutter causes that a cob gets carried off to a container. This happens with cobs that do not meet the parameters set. Shutter closing, in turn, causes cobs to change their direction of movement. They get onto a rotating disc that is also an element of the cob alignment system. If a cob on the conveyor is oriented with its narrow end forward, the force sensor will deflect by such a value that the cob slides over the inner circumference of the disc. Such a cob is directed to the kernel cutter without any resistance. If in turn the cob on the conveyor is oriented in the opposite direction, the optical sensor opens the shutter in such a way that the cob moves on the outer part (perimeter) of the disc. At a certain point of the perimeter there is a cam that the cob, moving with the disc, will come upon and that will cause is automatic turn over.

Another device, presented in Figure 67, is the Polish-made corncob husker, type OLK-8. It is a highly efficient piece of equipment used for the separation of cover leaves and stigmates from corncobs. The basic working elements of the machine are counter rotating husking rollers. Corncobs are directed, by means of a belt-slat conveyor, to a cutting assembly in which cob base stems are cut off and cover leaves are torn open. Depending on the number of husking sections used, the productivity of the machine varies from 4 to 20 $t \cdot h^{-1}$. Husking efficiency is over 90%, irrespective of the condition of the cover leaves and the cobs. The machine is frequently set up in a production process line, and cleaned cobs move on in the process while the husked cover leaves are removed outside. This ensures rapid and smooth flow of cobs and removal of waste, as well as effective and efficient operation of the whole processing line.

Fig. 67. The OLK-8 husker for corncob cover leaves removal [171]

Corncobs husked of their cover leaves by means of huskers are frequently subjected to additional washing in order to remove possible contamination or remnants of the stigmates. This facilitates subsequent sorting of the cobs. In the course of the process particular attention is paid to areas of damage to the cobs, resulting from the process of harvesting and processing, or caused by pests. Cob washing is usually performed in the course of transport from the husker. On the cob transport conveyor special rollers are installed that cause the cobs to turn over. Above the rollers spraying nozzles are installed, supplying water under pressure, and the rolling cobs are washed. Frequently, however, special cob washing machines are used instead.

In practice, also combines for simultaneous harvest and processing of sweet corn cobs are used (Fig. 68). Such combines have a set of mechanisms that are responsible for the acquisition of kernels (Fig. 69). Cobs severed but the cutter assembly is directed onto a conveyor that sends them to the husker assembly. Cover leaves and stigmates separated from the cobs are transported by a conveyor outside of the combine – to the ground, to a container, or onto a trailer. Husked cobs are fed to an assembly that orients them the narrow end toward the cutter knife heads. Next the cobs are directed to the kernel cutters were corn kernels are detached from the cob cores. Detached kernels are moved to the main tank of the combine, in which they transported from the field to their destination. Kernels in the intermediate tanks and in the main tank are subjected to the action of a cooling agent, generated by a condenser. Cob cores are ejected, whole or after shredding, onto the field. The operation of such a combine requires a crew of at least 3 persons.

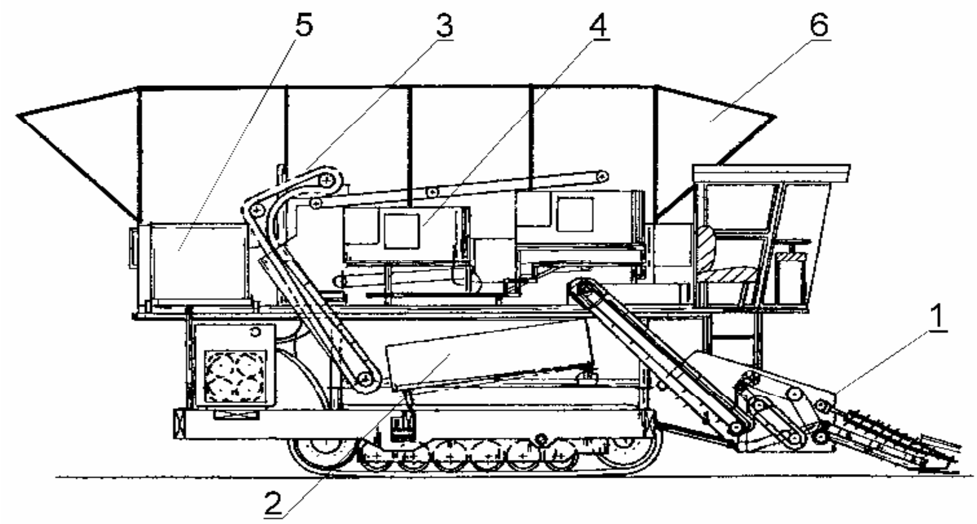

Fig. 68. The scheme of combine to cobs harvesting and kernels' cutting off from their cores: 1 – set of tearing off cobs, 2 – set of tearing off cover leaves, 3 – conveyor of cobs, 4 – set of cutting off kernels, 5 – reservoir of kernels, 6 – the sun-shield [53]

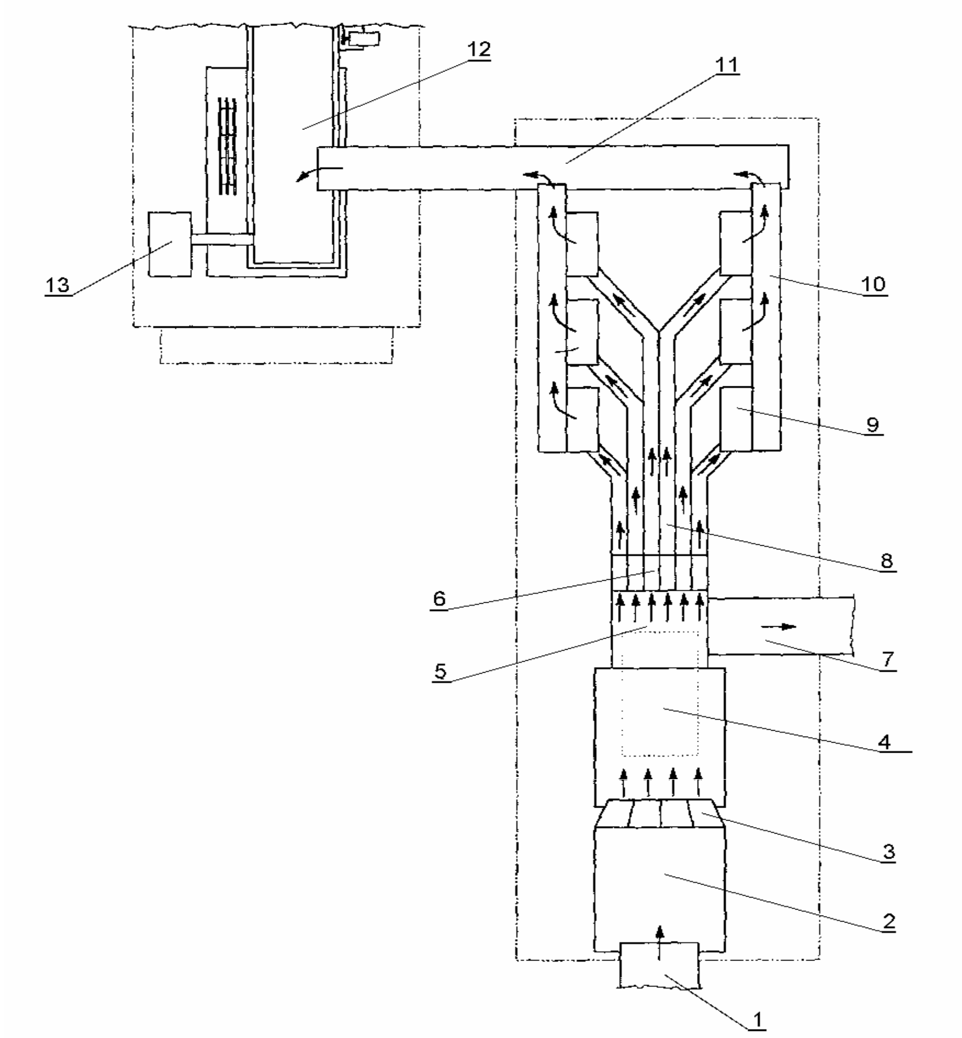

Fig. 69. The scheme of self-propelled set to logging process of kernels: 1 – feeder of cobs, 2 – vibratory table, 3 – shoots channel, 4 – husker rolls, 5 – selective table, 6 – arrangement of steering cobs, 7 – conveyor of wastes, 8 – feeder of cobs, 9 – cutter of kernels, 10 – indirect reservoir of kernels, 11 – feeder of kernels, 12 – reservoir of kernels, 13 – the condenser [53]

8.2. Cutters and Equipment for Cut-off the Sweet Corn Kernel

Detachment of kernels from corncob cores is effected on special machines known as kernel cutters. To obtain kernels of high quality, the working elements of such machines should be carefully adjusted so that all the kernels are cut off as close to the cob core as possible, but without cutting off the cob husks whose presence among the kernels acquired worsens the quality of the product. Until recently it was recommended that kernels should be cut off at 2/3 of their length with the kernel germs remaining on the cob core, as predominant in corn production were varieties with long cob husks. New hybrid varieties of corn are free of that defect, and to increase the amount of material acquired cutter knifes are set to the maximum length of kernels detached. Care must be taken that the cut through the kernel be smooth, without tearing the seed cover, and set so that no thick cob husks are among the kernels detached. This requires frequent sharpening of the cutter knives.

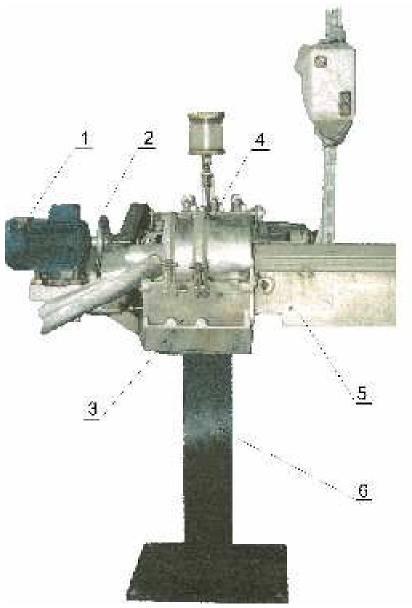

Fig. 70. The cutter of sweet corn's kernels of STELMACH: 1– electric motor, 2 – hyphen, 3 – casing, 4 – knife head, 5 – chain feeder, 6 – basis [171]

Adjustment of the working elements of the kernel cutter should be made suitably to changes in the dimensions and properties of the material processed. Corn cobs should oriented with their narrower end towards the cutter head, as in that position the cutter knives adapt better to correct detachment of kernels. During kernel cutter operation, it is necessary to systematically check all the moving elements of the machine, and to clean and lubricate as required. This has an immense effect on the quality of kernels detached, as with the cutter head dirty the positions of cutter knives take longer to adjust to the changing cob diameter, and them may result in increased amount of incorrectly cut off kernels [35,112,114,116]. An overall view and a description of the structure of a Stelmach kernel cutter can be found in Figure 70.

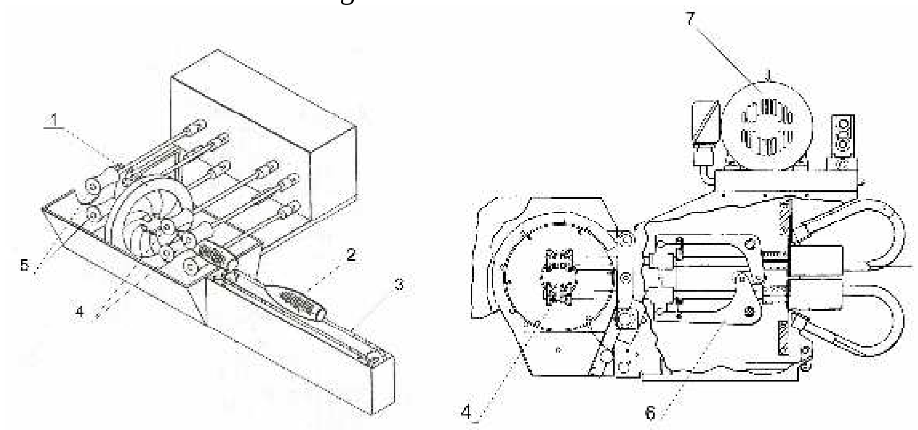

Fig. 71. Schematic of sweet corn kernel cutter: 1 – knife head, 2 – cob, 3 – feeder of cobs, 4 – rollers of copying system, 5 – removing rollers of cob cores, 6 – levers of copying system, 7 – electric motor [115]

The kernel cutter is made up of an electric motor, coupling, casing, knife head, chain feeder, main casing, and base. The main casing consists of the gear casing and a lever for engaging the copying rollers. Inside the gear casing there is a worm which, by means of worm racks, drives six cob transport rollers and the cob feeder. All the worm racks are installed on shafts by means of spring pins. On the worm a pulley is mounted, which – by means of a belt transmission – drives the copying assembly of the cutter head. The electric motor is coupled to the worm transmission by means of an elastic coupling. Additionally, the system is provided with a hand-drive wheel.

Inside the corn kernel cutter casing (fig. 71) the cutter head is installed, as well as three pairs of cob transport rollers, with special spikes for cob transport within the cutter head. Two pairs of rollers are installed in front of the cutter head, and one behind. Moreover, in the casing there are three pivoting screens with a chute, preventing corn kernels from dripping out of the kernel cutter. The chain feeder is bolted onto the head casing. It is made up of the feeder housing, in which a cogwheel is mounted on a drive shaft, and a tensioning wheel on en excentric shaft. Between the wheels two roller chains are stretched, used for corncob transport. The excentric shaft provides correct tensioning of the chains, and the screens running along the chains prevent corncobs from falling out. Between the coupler and the head casing there is the head drive and control assembly. It is made up of a coupling sleeve on which a pulley is mounted, receiving drive from the electric motor. The sleeve is also coupled to the cogwheel which provides direct drive to the cutter head. The whole sleeve assembly is mounted on a shaft between the coupler and the head casing. On the same shaft another cog-wheel is installed, that controls the spacing on the cutting head knives, and a special driving dog causing the shaft to rotate at the same speed as the pulley that provides drive to the whole system. Moreover, on the shaft there is also an additional control disc, coupled to the pulley and to the driving dog. The disc is coupled, via a system of pull rods, with two control turn knobs.

The electric motor, with the bolted coupler, knife head and cob feeder, is mounted on the main casing which is installed on the base. The chain feeder into the casing in which the cutter head is installed feeds corncobs. Inside the casing, in front of the head there are two pairs of transport rollers which take cobs off the feeder and pass them on to the cutter head. After kernel cutting off, cob cores are ejected by a set of two rollers installed behind the head. Kernel detached from the cores fall out of the bottom of the head casing. The spacing of the transport rollers is automatically adjusted to cob diameters, which permits automatic adjustment of the spacing of knives in the cutter head.

Table 32. Technical data of STELMACH corn kernel cutter [171]

Contents	Units of measure	Technical data
Total length with feeder	mm	1680
Width of cutter	mm	768
Total height	mm	1461
Height of feeder from floor	mm	1048
Power consumption	kW	1,5
Efficiency of cutter	$cobs \cdot min^{-1}$	80
Total mass	kg	315

The operating principle of the mechanism is as follows. The spreading of the cob transport rollers, via a system of levers and pull rods, is transmitted onto the shaft of the cutter heed control mechanism, and then, through the bearing housing, onto the drive system disc. Linear motion of the disc protrusions located between the driving dog and the pulley blocks causes angular movement of the control cogwheel relative to the drive cogwheel of the cutter head. This causes an increase in the space between the cutter knives in the head. Thanks to its modern design, the cutter is highly efficient and at the same time easy to operate and to maintain. The basic technical specification of the corn kernel cutter is given in Table 32.

The head is the fundamental working element of cutters for the detachment of kernels from corncob cores. It has six special knives, axially installed, and a mechanism for their automatic positioning with relation to the cob diameters. It is made of corrosion resistant materials and its design permits rapid replacement of knives when they need sharpening. A schematic of the structure of the STELMACH kernel cutter head is presented in Figure 72.

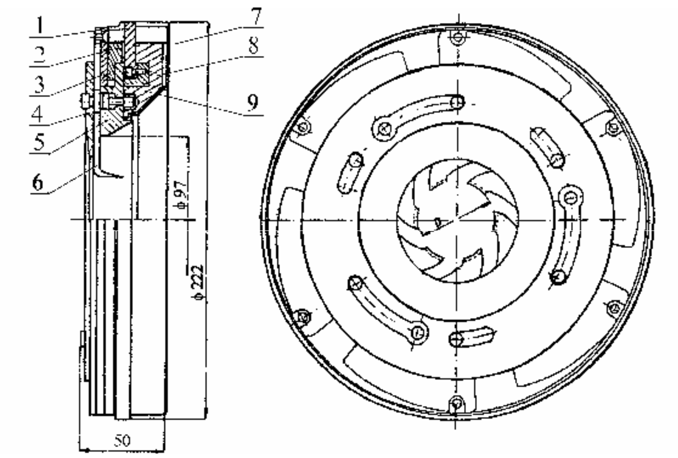

Fig. 72. Cutting head: 1 – trunk, 2 – regulating cog-wheel, 3 – collar, 4–cover, 5–dial, 6 – knife, 7 – shield, 8 – driving cog-wheel, 9 – establishing ring, D – the range of automatic control of knives (20–60 mm)

The sharpening the knives from the cutter head is performed on special sharpeners that ensure correct incision angles of the knife cutting edges and their correct sharpness directly before their installation in the cutter head. The shape and geometry of a knife for corn kernel cutting is presented in Figure 73.

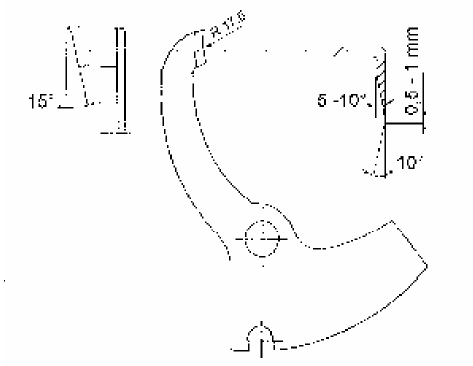

Fig. 73. The shape and geometry of knife’s cutting off

Very similar to the STELMACH corn kernel cutter in terms of structure and operating principle is the FMC S.C.-120 kernel cutter. Its basic technical data are given in table 33, and a general view of the kernel cutter is presented in Figure 74. The machine is made up a chassis, casing, built-in electric motor, cutter head, and chain cob feeder that feed corncobs to the knife head.

Table 33. Technical data of kernels cutter of FMC S.C. – 120 [171]

Contents	Units	Technical data
Lenght	mm	1372
Width	mm	832
Height	mm	572
Power consumption	kW	2,25
Efficiency	$cobs \cdot min^{-1}$	60–90
Mass	kg	225

Fig. 74. The cutter of corn kernels of FMC S.C. – 120 [171]

8.3. SWEET CORN CUTTING AND KERNEL REMOVING FROM THE COB CORES

Two methods are used for sweet corn kernels detachment from cob cores - one consisting in kernel cutting off, and the other in breaking kernels off cob cores. The kernel cutting process, realized by means of conventional machines, is described in numerous publications [62,77,116]. In the first method, kernel detachment is effected by cutting kernels off above the cob core surface by means of knives moving along a rotating cob [35]. As a result, a part of the kernel germ and a section of the kernel are left on the cob core. The rotary speed of the cob and the linear motion of the knives are powered by an electric motor. The shortcoming of the method is the lack of possibility of obtaining high rates of productivity. Every cob has to be carefully fixed in the grip and accurately positioned with relation to the knife assembly. Therefore, kernel cutters operating in this manner have not found a broader application on the industrial scale.

Another design of kernel cutter ensured an improvement in kernel cutting process productivity. In that machine a set of knife heads was employed, as well as copying (repeater) system, permitting better adaptation to cob diameter and ensuring deeper and more efficient cutting off the corn kernels. In that method the cob moves longitudinally in front of a rotating knife head. As a result of the knife head rotation at 1200 r.p.m., the knives, set in their sockets with a certain freedom of movement, are subject to the effect of centrifugal force that causes them to swing out and adapt to the cob diameter. The value of the knife swing is restricted by the copying system, made up of two rollers linked - by means of levers – with the knife head. Increase in cob diameter is accompanied by a change in the relative position of the rollers and a corresponding change in the position of the knives relative to the cob. The machine makes use of a dual set of knife heads. The first head performs kernel cutting off from cob cores, and the second scrapes off the parts of kernels that remained on the cob cores [82].

In Felstehausen's design [40] a different method of cob introduction into the cutting assembly was employed, and the cutting assembly itself is also of a different structure. As opposed to the designs described above, this machine does not require that cobs should be aligned with their tips toward the cutting assembly, but can face the knives with any end. Moreover, the design of the machine employs a different setup of knives and a different copying system, thanks to which the process is much more efficient and productive.

Numerous machines have been designed for detaching unripe kernels from corncob cores. Some of those machines have been subsequently improved for application in industry, for which the kernels were acquired for consumption purposes, or in agriculture, where such kernels were used for seed or fodder. However, many of those machines were characterized by low efficiency or high level of damage to kernels. Moreover, the machines were not flexible enough to be used for cobs of varying shapes and were not very efficient in detaching all the kernels from cob cores. Knives used in the machines could not adapt well enough to the shapes of the cobs. This caused a situation where some kernels were cut off too high, with considerable parts of the kernels remaining on the cores, while other kernels were not cut off at all. Application of knives with curved blades and spring-loaded for better contact with the cobs did not provide a satisfactory solution to the problem. Also, the process of kernel cutting was layout consuming and frequently far from safe for the operators [35]. These shortcomings enforced the necessity of searching for other solutions that would increase the efficiency of kernel detachment and reduce the quantitative losses of kernels [62,84].

In practice, the process of kernel detachment from cob cores takes place through kernel cutting off; therefore this analysis is concerned primarily with the cutting process. Methods permitting kernel detachment without cutting permit limitation of losses on the one hand, and improvement of productivity on the other [157]. Among the methods consisting in kernel breaking off from cob cores, we can distinguish corn kernel detachment by means of conventional equipment used for corn threshing for seed, and by means of special equipment. In the first case, kernels are subjected to fast surface freezing by means of a refrigeration agent [26]. Such an operation ensures increased and uniform hardness of kernels, and increased spacing between kernels in the cob, which permits the kernels to be detached from cob cores in the traditional way [156]. In the other case, the special equipment permits kernels detachment from cob cores by means of a series of bands moving alternately [114]. Prior to such a process of kernel detachment from cob cores, the cobs are longitudinally cut in halves.

The method consisting in the detachment of frozen kernels in conventional threshing machines involved high expenditure of energy and is very costly [27]. Energy is used for the process of freezing, refreezing, and washing. Increased energy requirements result also from heat exchange with the cobs [102]. Financial costs, in turn, are related to the freezing process itself, to the consumption of considerable quantities of the freezing agent and of water necessary for kernel washing. Moreover, there is the risk of contaminating the kernels with the refrigeration agent [165]. Kernel detachment with the method described by Robertson and Farkas [114] is characterized by high-energy consumption, related mainly with cob halving. This shortcoming causes that the method does not find a broader application in practice, even though it provides kernel losses limitation to a minimum. In the methods kernels are detached whole. There are no cut surfaces, so there is no juice seepage. Absence of losses to germs, parenchyma and juice of corn kernel results in improvement of its nutritional value. In the method, compared to the method of kernel detachment through cutting, there is a reduction of liquid components by about 80% and an increase in the kernel mass efficiency by 20%. According to Robertson and Farkas [114], the method can be successfully used for the detachment of kernels with different levels of ripeness, force of kernel to core bond, and kernel length and width values. Thanks to this, kernels can be detached from cob cores under field conditions.

Sweet corn is a material characterized by a high content of parts that are not subject to processing [81]. Such parts, including cover leaves, cob cores and base stems, constitute 50–60% of the mass of cob [15,163]. Kernels, constituting about 70% of the husked cob, are detached only in 60-70 %. The part of kernels that remind on the cob cores is usually never utilized [18,20,114].

The rate of kernels recovery in industry usually does not exceed 40 %. Losses occur not only in the course of kernel cutting off, but also as a result of subsequent processing of kernels (washing, blanching), during their contact with water [113]. This fact partially results from the deficiency of the working elements of machines, but also from the very nature of kernel attachment on cob cores. As can be seen in Figure 75, the lower part of the kernel is set in the cob core below the limit of maximum depth of cutter knife operation.

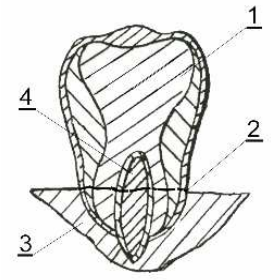

Fig. 75. Schematic of kernel location in the cob core: 1 – endosperm, 2 – location of kernel cutting plane, 3 – cob core, 4 – germ [156]

This causes that there is no possibility of cutting off the part of kernel that is set in the cob core without the knives penetrating the hard core itself [110]. Kernel cutting together with parts of the core leads to accelerated wears of the knives on the one hand, and to unnecessary cutting of lignified core fractions on the other. These fractions, sometimes adhering very strongly to the kernels, are hard to remove [40,84,118]. Therefore, as a rule only the upper parts of the kernels are cut off (about 20-30%). The remaining parts of the kernels, together with a part of the valuable germ, remain on the cob cores. This causes a reduction both in the amount of kernels cut off, and in the nutritional value and taste quality of the kernels. Moreover, according to Dougherty [31], kernels cut off at cob core surface usually have uncovered parenchyma that is susceptible to washing out in the course of the processes of blanching and rinsing, while kernels cut off below cob core surface contain the undesirable lignified kernel rachises. Such kernels cannot be stored in fresh condition. The period of storage life is also limited by high content of oil, mainly in the germs of kernels. This can be the reason for the occurrence of rancid kernels during extended periods to their processing, althout it is kernels on cobs that are especially susceptible to that phenomenon [52]. Undoubtedly, direct action of cutting knives on corn kernels may raise reservations from the sanitary point of view [157]. In spite of the numerous deficiencies of the method compared to other methods, it is characterized by relatively low energy requirements and ensures high process efficiency, achieving average levels of up to 160 cobs per minute, which is a significant advantage on the industrial scale [110].

Attempts are also made at the application of other methods that would cause the detachment of complete kernels and thus limit the losses, although complete kernels, with the hard rachis, require additional operations to remove the rachis. To improve the kernel cut-off process efficiency, various measures are tested that concern both modifications to the cutters, and improvement of the morphological features of cobs and have working conditions. Such measures include

1. Combination of kernel cutting off with the scraping of cob core. Such a solution is used in machines designed by Kerr [61] and Ralph [107], and by Kessler and Harry [62]. The machines are equipped with two knife heads. One cuts off the kernels, and the other – with different knives – scrapes the remaining parts of kernels off the cores. Such form of kernels is used for so-called *style cream.*

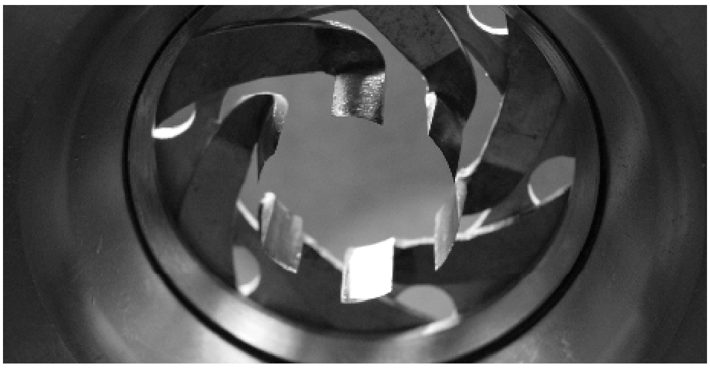

Fig. 76. The cutting head equipped with six knifes

2. Application of various geometry of knives and copying systems, ensuring better adaptation to cob shape. Ralph [107] reports that the efficiency of the kernel cutting process largely depends on the sensitivity of the copying system and the knife positioning mechanism. Maruska [84], on the other hand, emphasizes the fact that knife setting uniformity as well as blade geometry has a significant effect on the quantity and quality of kernels cut off. Variability of cob shapes and knife contact with hard cores accelerate knife blunting, which deteriorates the process of kernel cutting. Sharpening causes a reduction of the active length of knife blades, but also prevents the maintenance of the original

geometry of the cutting edge, so important for the process of kernel cutting off. In his proposed solution, the knife blades are replaceable and have less complex geometry, as well as thinner and more flexible (Fig. 76). This facilitates the replacement of knives and maintenance of the original cutting edge geometry, a change of which would have a significant effect on the process of kernel cutting.

Felstehausen [40] is of the opinion that the above modification of cutter knives does not provide a solution to the problem, as they get blunted fast in any case, and additionally are prone to frequent blade chipping or cracking. The consequence is both damage to the cobs and accelerated blunting of knives. The author adds also that the type of knife used has a fundamental effect both on the quality of cutting and on the resultant cutting resistance. This fact results primarily from the irregularity of cob shape. The tapering shape of corncobs causes that the knives cut off not just the kernels, but also fragments of the harder core. All of this results in accelerated blunting of knives and deterioration of kernel cutting quality.

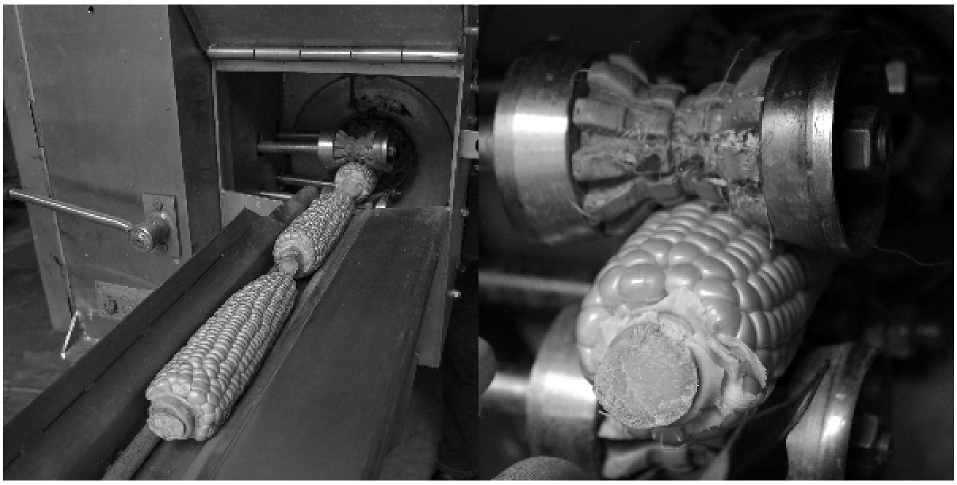

Fig. 77. The kernel cutter of sweet corn

Kessler and Harry [62] point out the fact that the precision of kernel cutting off and the level of kernel losses are affected to a significant degree also by the systems of rollers transporting cobs to the cutter head, and of the copying rollers responsible for correct positioning of knives in the cutter head. The effect of centrifugal force on the knives during the rotation of the cutter had changes the desired setting of the knives, with resulting shallowing of the depth of kernel cutting. In the modification presented by the author, a hydraulic motor controls the systems of cob transport rollers and copying rollers. This ensured very accurate reproduction of the cob surface by the copying rollers, and thus also better knife fitting to the kernel-cutting surface. The final effect was improved efficiency of the kernel cutting process.

In the solution presented by Ross [116] (Fig. 77), the movement of cobs towards the knife head is controlled by a force sensor, which permits stopping the cob movement in a situation when the preceding cob in still in the cutter head. Such a solution protects the system from cob jamming in the cutter head and ensures more efficient kernel cutting off.

3. Blanching of cobs before the cutting and rinsing. This operation reduces the losses by 50%. It also causes increased firmness of kernels, and therefore better kernel cutting off from cob cores [124]. Blanching, through so-called precipitation of starch, reduces liquid losses of kernels through washing out [122]. The level of liquid losses is also affected by the sequence of application of the rinsing and blanching operations in corn kernel processing [31]. The application of blanching before cutting and rinsing, as opposed to blanching after cutting and rinsing, reduces the losses by 10-21% [18].
4. Choice of suitable corn varieties, characterized by cylindrical cobs and uniform kernels [153] and introduction of varieties genetically modified [119,164]. Such varieties include husk-less varieties that allow for easier and deeper cutting off of kernels [46].
5. Delayed time of corn harvest. This is related to a drop in kernel moisture and is conducive to easier kernel cutting off and to a reduction of loss of internal parts of kernels [87].
6. Use of water in the3 process of kernel cutting off. The action of a stream of water on the knife head reduces work resistance for the knives themselves as well as for the whole cutting process, resulting from fragments of kernels penetrating between the moving working elements of the cutter [137].

Mechanical detachment of kernels from cob cores through the process of cutting results in the appearance of quantitative losses and a deterioration of the nutritional quality of the kernels, both in the course of the cutting process and during subsequent operations of rinsing and sorting. In their study, Robertson and Lazar [111] used various combinations of kernel detachment and processing. They proposed the following variants of studies:

1. kernel cutting off:
   a) conventional method (cutting, rinsing, blanching),
   b) modified conventional method (blanching, cutting, rinsing),
2. detachment of complete kernels (breaking off):
   a) cob drilling, longitudinal cob halving, abrasive surface effect, rinsing, blanching,
   b) modified method A (drilling, blanching, halving, detachment, rinsing),
   c) modified method B (blanching, drilling, halving, detachment, rinsing).

The modified methods were characterized by lower losses of liquid seepage by 81–84% in the course of rinsing with relation to the conventional methods. Also in the process of blanching the level of losses was lower by 48-75%. The kernel mass efficiency for the particular sequences of kernel processing was 20-30% higher in the case of the methods of complete kernel detachment (2a, 2b, 2c). The efficiency of the modified conventional method 1b was 4% lower than that of the conventional method 1a. The authors suggest that this could have been caused by the reduced speed of cutting, resulting from increased hardness of kernels subjected to blanching. For the particular sequences of operations, the weight of 100 kernels was as follows: 1a - 8,8 g, 1b - 7,4 g, 2a - 10,4 g, 2b - 9,5 g and 2c - 9,5 g.

Classification of kernels was made with respect to their cutting: a) cutting above the germ, b) cutting across the germ, and to their breaking off: c) complete kernels without rachis, d) complete kernels with pedicels, and e) complete kernels with rachis and pedicels. The moisture of the kernels was, respectively: 66.0; 68.3; 70.4; 71.0 and 71.6%. Adopting kernels e) as 100%, the following mass values were obtained: a) 33%, b) 66%, c) 97%, d) 98%. The content of fiber was: a) 0.58%, b) 0.66%, c) 0.76%, d) 0.78%, e) 1.1% and the content of nitrogen: a) 0.64%, b) 0.64%, c) 0.62%, d) 0.56%, e) 0.52%. The more biological material is bound with the kernels, the higher its mass and the greater their content of fiber. Higher fiber content in kernels may indicate their better health properties [82].

Kernels with moisture content of 69.7%, cut off in the conventional manner, constituted 67% of mass, and on the cobs there remained 33% of kernel mass with moisture content of 79.7%. On the basis of comparative studies [113], it was observed that detachment of complete kernels, as opposed to kernel cutting off, results in a reduction in kernel losses by 80% with rinsing and by 50% with blanching. Also notable is the increase in the mass efficiency of kernels – by 20%.

The process of kernels detachment is also significantly affected by the hardness of the seed cover which tends to increase with kernel ripening. Increased seed cover hardness requires greater force to detach kernels from cob cores. The efficiency of kernel detachment is also related to the structure of kernel to cob core bond. The structure is different in different corn varieties [66]. In his studies, Galinat [47] observed that blanching of halved corncobs affected the level of force necessary for detachment of kernels (with moisture of 74-76%) from cob cores. The force value depended on the time of cob blanching and decreased by 24% at blanching duration of 30 s, by 33.2% at 60 s, by 49.1% at 120 s and by 50,2% at blanching lasting for 180 s.

Factors that reduce the kernel to cob core bond force result from physicochemical changes causing hardening of the seed cover, change in the consistency of the parenchyma to more jelly-like starch, and weakening of enzyme activity [19]. Dougherty [31] studied corn cobs commonly used in processing industry and, experimentally, cobs of husk-less varieties, with kernel moisture content of 70-74%. In his studies he employed the following methods of kernel detachment:

a) cutting off by means of FMC-model 1T 152 cutter - normal cutting close to the cob core,
b) deep cutting off,
c) kernel detachment through the application of cob core drilling,
d) kernel detachment from longitudinally halved cobs through friction.

Kernels detached were subjected to rinsing, blanching, and freezing. The results of the study are presented in Table 34.

Table 34. Losses of kernel (%), [31]

Treatment	Regular cutting	Deeper cutting	Cob hollowing	Kernel friction
Preliminary	38	46	46	41
Washing	36	47	50	43
Blanching	35	44	47	43
Freezing	32	40	43	39

Table 35 presents the percentages of kernels cut-off, complete kernels and cob fragments in kernel mass detached with the methods specified above. The depth of kernel cutting must be precisely determined, which is not possible in practice. If the cutting depth is too shallow, a large amount of kernels remain on the cob cores, and in subsequent operation, especially those of rinsing and cleaning, a lot of starch is lost, as well as of the kernel germs. If the cutting is too deep, together with undesirable fragments of cob cores complete kernels are also included in the kernel mass detached.

Table 35. Participation of corn kernel for different cut-off method (%), [31]

Kernel cutting method	Kernel				Parts of cob
	Dent	Whole	With seat	Damaged	
Regular cutting	80	12	0	3	6
Deeper cutting	41	37	13	4	4
Cob hollowing	22	59	23	1	2
Kernel friction	0	95	3	1	1

Felczyński et al. [39] point out that the content of sugars in kernels from the lower half of the cob is higher than in those from the upper part. They also observed higher sugar content in kernels cut deep from the cob core or plucked out as a whole than in kernels detached from the cob core by shallow cutting. Therefore, their recommendation for the technological process is to cut off the kernels as deep as possible. The corn kernel detachment device presented below (Fig. 78) was used for study on the effect of speed on the quality of kernels detached.

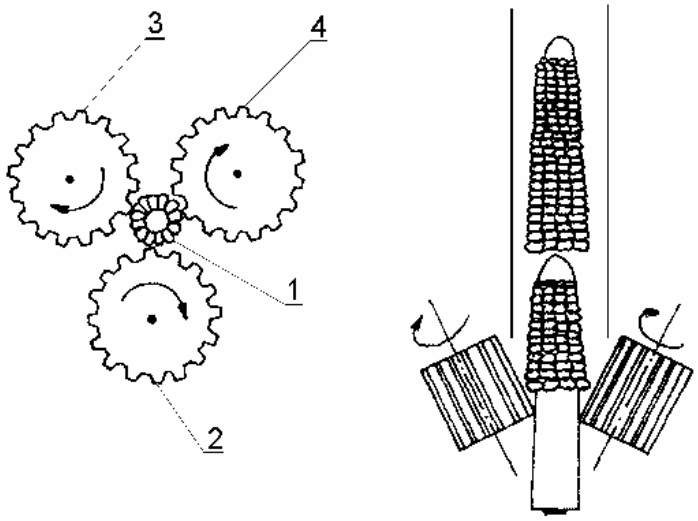

Fig. 78. Schematic of stand for rotational detaching corn from the cob: 1– cob, 2 – medium speed rollers, 3 – high speed rollers, 4 – low speed rollers [4]

The force that causes kernel detachment acts in a static manner, and the process of detachment began at one end of the cob and progressed to the other cob end along a spiral line. The device is mad up of three rollers, with the same direction of rotation but different speeds, with diameters of 9 cm and length of 10 cm, set at an angle of 0.35 rad. The surface of the rollers was coated with crimped rubber, the crimps being 1 cm in pitch and 0.5 cm in height. Four levels of roller speed were applied - 900, 1000, 1100 and 1200 r.p.m. The corncobs used for the tests had moisture content levels of 16, 18, 20, 22 and 24%. The authors found that an increase in roller speed caused an increase in kernel detachment efficiency, a reduction in energy consumption, and an increase in process productivity. Kernels with moisture content above 20% were harder to detach, especially at low roller speeds (below 700 r.p.m.). At higher kernel moisture content levels (above 20%) the process of kernel detachment was much slower than in the case of dry corn.

Detachment of kernels from cob cores requires the application of a certain force whose level depends on the method of detachment and must be selected so as to cause the least damage to the kernels possible. The value of the force is much lower when the direction of its application to the kernel is tangential rather than radial. Detachment force of lower value causes less damage to the kernels detached [6]. In a later study [112], 44 sweet corn cobs were divided into two groups - A and B. The mean diameter of the cobs was 4.41 cm. Cobs included in group A, whose weight was 4.17 kg, were subjected to longitudinal drilling, the hole diameter being 4.75 mm. Their mass decreased to 4.15 kg. The remaining 22 cobs were split in half by means of a wedge. Their mass was 4.08 kg. A force with a value of 2.45-4.90 N was applied by hand to each kernel individually, beginning with kernels located on the extremes, which were detached whole. The weight of 100 kernels was 40.4 g. Group B, with a mass of 4.18 kg, was the control sample. Kernels from those cobs were cut off by means of a corn kernel cutter. Only the upper parts of the kernels were detached from the cob cores. The weight of 100 kernels was 32.6 g. Next, a sample of kernels (2.6 kg) from group A was subjected to rinsing in 25 l of cold water, and then to blanching in the same quantity of water. The authors found that in the water after the rinsing and blanching of cut kernels, with respect to kernels detached whole, there was 70% more of valuable nutritional components.

Kernel losses occurring in the course of kernel cut-off process, as well as the considerable share of unusable parts of the cobs (cover leaves, cores, rachis) cause that in courtiers with large areas of sweet corn cultivation (USA, France) the processes of cob harvesting and kernel cutting off are combined [33]. Cut kernels constitute approximately 25-30% of the mass of the whole cob, while the core and the cover leaves about 70%. Therefore, in order to avoid transporting the unnecessary mass of corn cobs (70-75%) from the field to sometimes-distant processing plants, combines are employed for simultaneous cob harvest and kernel detachment [53,159].

CHAPTER 9

ANALYSIS OF THE PROCESS OF MECHANICAL DETACHMENT OF SWEET CORN KERNELS

The mechanical properties of sweet corn kernels are the decisive factor affecting the process of corn kernels cutting off from the cob cores [129], therefore the study of the process of mechanical detachment of kernels from cob cores was preceded with the determination of the values of selected mechanical properties of kernels.

Assessment of the results obtained was made on the basis of the method of single-element analysis of variance. In the case of finding significant differences between objects on the basis of the test of significance F, quantitative analysis was made on the basis Tukey's intervals of credibility for the level of significance α = 0.05. The accuracy of the results of particular measurements was additionally qualified by giving the values of standard deviation for the arithmetic mean and the lowest and highest values of a given set of values.

9.1. EFFECT OF HARVEST TIME ON QUALITY, PHYSICAL PROPERTIES AND DETACHMENT PROCESS OF SWEET CORN KERNELS

To determine the effect of harvest time on the values of forces of sweet corn kernel cutting, penetration and compression, mechanical tests were performed on a measurement stand composed of an Instron 6022 strength tester and a set of control and recording apparatus. The strength tester permits the performance of tests on corn kernels, but the tests included in this study required that the tensometric head and the permanent elements of the machine be additionally equipped with suitable fixtures for the samples tested and suitable accessory equipment for the interpretation of the results obtained [92]. The main body of the tests was conducted at linear speed of the strength tester head of 50 $mm \cdot min^{-1}$ and at a load level of 100 N. The result of the measurements was the determination, in particular tests, of such mechanical properties of corn kernels as the force, energy, modulus of elasticity, and deformation. The results of the tests for the force and energy are presented in a graphic form, and those for the modulus of elasticity and deformation – in the form of tables [93,129].

9.1.1. Kernel Quality and Content of Sugars

In agricultural practice several methods are used to extend the period of sweet corn cobs supply [154]. Under the conditions of Poland, they usually permit for fresh sweet corn cobs supply to be available from mid July to the end of September, and if cold storage methods are employed, even to the end of October. Warzecha [154] recommends the following methods: sweet corn cultivation from seedlings, earlier sowing of seeds of early corn varieties under foil or unwoven fabric covering, sowing of varieties with different length of the vegetation period, delayed sowing – but not more than till the end of May or the first days of June.

Sweet corn attains its consumption and processing ripeness within 24 to 28 days from blooming that is from the appearance of stigmates and the browning of the stigmates manifests ripeness. In the phase of late milk ripeness, kernels assume yellow-gold colouring. The time of harvest not only determines the physical properties of sweet corn cobs and kernels, but also generally affects the mechanical strength of the kernels. Although the time of harvest mainly affects the mechanical properties of kernels, one should also expect chemical changes related to the ripeness stage, and for this reason the content of carbohydrates in the kernels was also determined (Tab. 36), as were the physical features describing the morphological characteristics of cobs (Tab. 37), i.e. the length, diameter and mass of corn cobs, number of kernel rows and number of kernels in a row, as well as the percentage share of kernels in the mass of cobs. The tests were performed on sweet corn cobs of the Candle variety. Corncobs were harvested at three harvest times (terms) during 2 weeks. The harvest was begun when the kernels reached optimum technological ripeness, and was continued at one-week intervals. In the 3rd harvest time, approximately 8% of sweet corn cobs were characterized by concave kernel surface. During the harvest, the average kernel moisture was 76.7% for harvest time I, 72.3% for harvest time II, and 69.2% for harvest time III.

Table 36. Content of carbohydrates for different harvest terms

Term of harvest	Content of reducing sugars, (g/100g s.m.*)	Content of saccharose, (g/100g s.m.)	Content of starch, (g/100g s.m.)	Content of all sugars (g/100g s.m.)
I	9,2	12,3	13,6	35,1
II	7,6	8,4	16,4	32,4
III	6,7	6,9	24,7	35,3

*s.m. – dry matter

Table 37. Characteristics of physical properties of cobs and kernels of sweet corn

Contents	Results		
	From	To	Mean
Cob mass with leaves, (g)	278,1	436,2	352,2
Cob mass without leaves, (g)	301,1	399,2	332,1
Mass of 1000 kernels, (g)	445,2	454,2	448,7
Part of kernels in cob, (%)	68,3	73,4	72,6
Moisture of kernel, (%)	68,2	78,7	73,5
Cob lenght, (cm)	18,4	24,6	19,8
Cob diameter, (mm)	46,8	52,3	49,8
Mean lenght of kernel, (mm)	4,8	11,6	9,2
Number of kernels for row, (pcs)	34,5	44,1	36,4
Number of kernel rows, (pcs)	12,2	16,6	14,2

9.1.2. Mechanical Properties of Kernels

The measurement values obtained in the particular tests showed a relatively high scatter, which is indicated by the standard deviation as well as the range of variation. The relatively low speed used in the tests permitted precise maintenance of the assumed measurement conditions. Hence the reasons for the considerable scatter of results should be attributed to the variability of the material itself. To illustrate the differences between the values determined for cobs from the different harvest times, mean values were used.

The differences between the mean values of the cutting force were statistically significant and varied within the range from 34.2 for harvest term I to 10.3 N for term III (Fig. 78). The mean values of cutting energy varied correspondingly within the range from 0.054 to 0,016 J (Fig. 79). The difference between the mean values of cutting energy for harvest terms II and III was statistically insignificant. A lack of significance of the difference between the men values for those harvest terms was observed also for the modulus of elasticity. The mean values of the modulus of elasticity were from 5.94 (term I) to 3.85 MPa (term III). The differences between the mean values of deformation, that formed a range from 15.22 (term II) to 12.13 mm (term III), were not significant for the harvest terms I and II, and for terms II and III (Tab. 38).

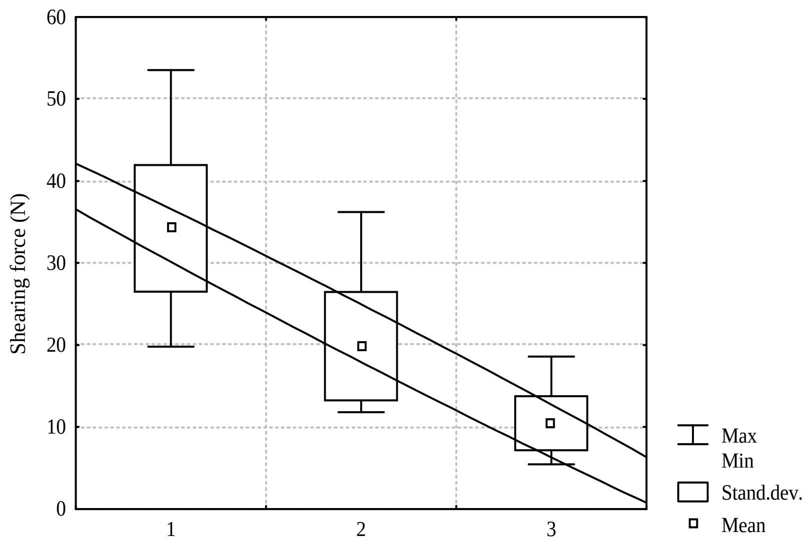

Fig. 78. Cutting force for different harvest terms: 1 – term I, 2 – term II, 3 – term III

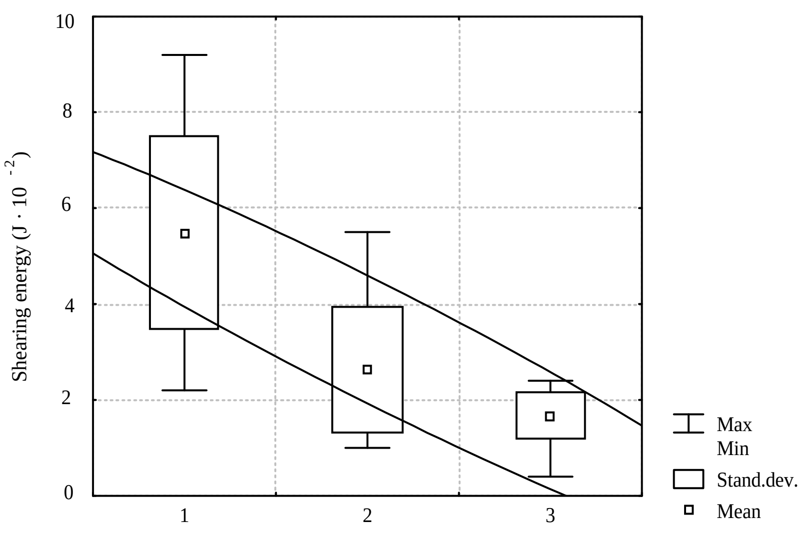

Fig. 79. Cutting energy for different harvest terms: 1 – term I, 2 – term II, 3 – term III

The mean values of force recorded in the tests of seed cover penetration formed a range from 19.75 (term I) to 12.05 N (term III) (Fig. 80). No statistically significant differences were noted between the values of the penetration force for harvest terms II and III. In turn, for the mean values of the penetration energy presented in Figure 81, statistical non-significance occurred for the harvest terms II and I. The mean values of penetration energy fell within the range from 0.064 (term I) to 0.041 J (term III). The mean values of the modulus of elasticity varied from 8.14 (term I) to 3.40 MPa (term III), and the while the mean values of deformation formed the range from 6.12 mm (term I) to 4.07 mm (term III) (Tab. 38). No significant statistical differences were observed between the mean values of deformation for harvest terms II and I.

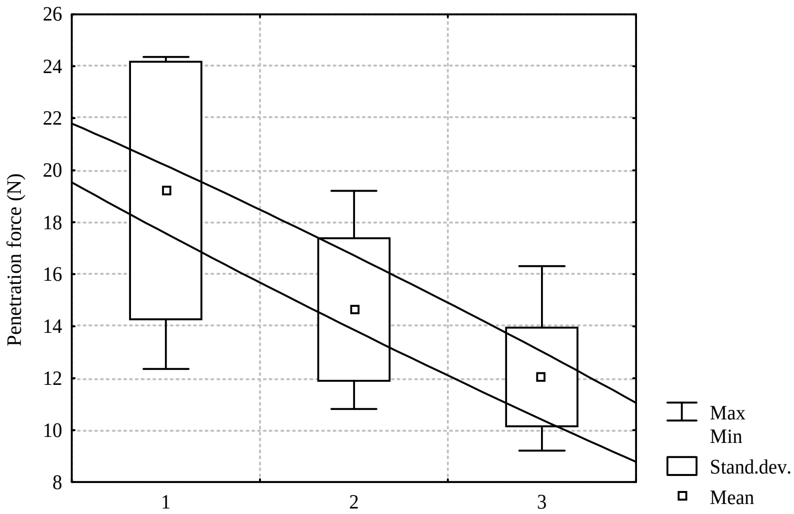

Fig. 80. Penetration force for different harvest terms: 1 – term I, 2 – term II, 3 – term III

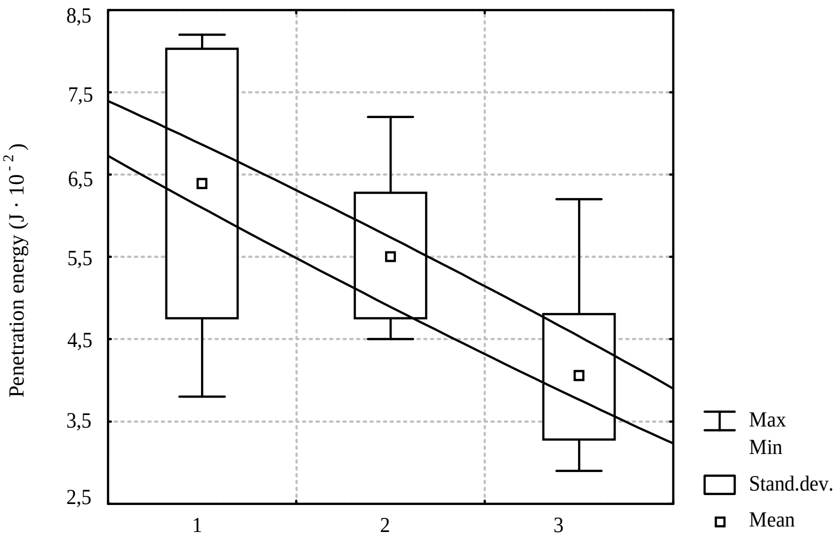

Fig. 81. Penetration energy for different harvest terms: 1– term I, 2 – term II, 3 – term III

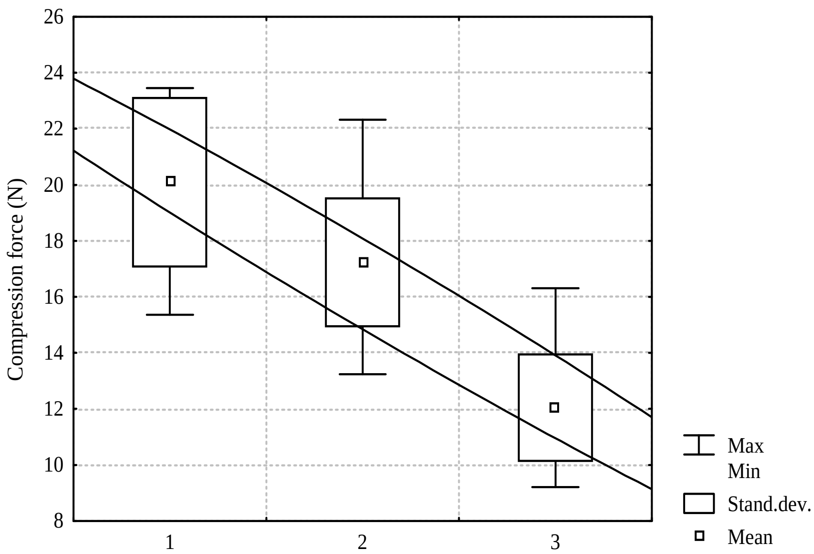

Fig. 82. Pressing force for different harvest terms: 1– term I, 2 – term II, 3 – term III

In the case of compression tests of individual kernels, for mean values of force for harvest terms II and I no significant statistical differences were found. The mean compression force values varied within the range from 20.12 (term I) to 12.05 N (term III) (Fig. 82). In the case of the mean values of compression energy, which varied from 0.031 (term I) to 0.023 J (term III) (Fig. 83), statistical insignificance occurred between the mean values for harvest terms II, and I and for terms II and III. The mean values of the modulus of elasticity fell within the range from 4.08 (term I) to 2.94 MPa (term III), and those of deformation - from 4.96 (term I) to 3.43 mm (term III) (Tab. 38). For the modulus of elasticity, the differences between harvests term II, and I and for the deformation – between terms II and III were statistically insignificant.

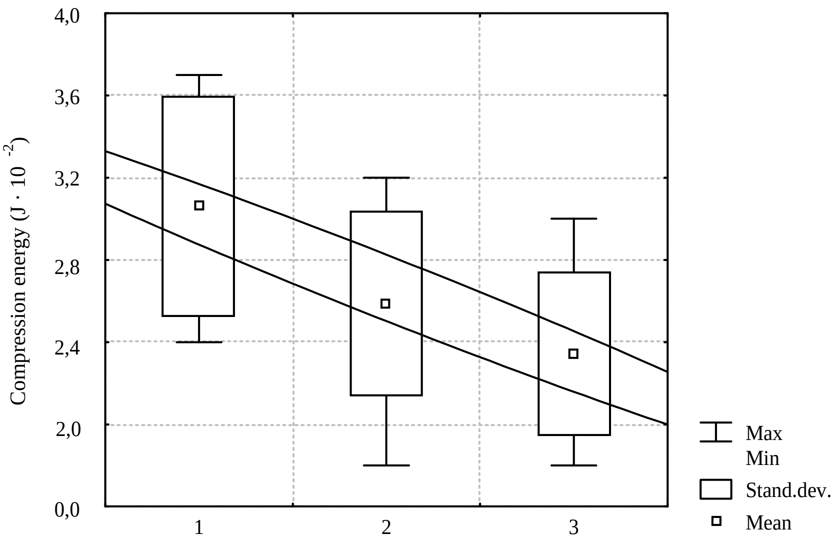

Fig. 83. Pressing energy for different harvest terms: 1– term I, 2 – term II, 3 – term III

The mean measurement values obtained in harvest term I decreased by 42% in harvest term II, and by 70% in term III in the case of the cutting force, and by 28% and 39%, respectively, for the penetration force and by 15% and 40% for the compression force. In the case of energy determinations, a decrease was observed in the mean values - by 53% (term II) and by 70% (term III) in the cutting tests, by 14% (term II) and 36% (term III) in the penetration tests, and by 16% (term II) and 26% (term III) in the compression tests. The values of the modulus of elasticity decreased, in accordance with the above relation, in the cutting test by 29% (term II) and 35% (term III), in the penetration test from 28% (term II) to 58% (term III), and in the compression test - from 10% (term II) to 28% (term III) as compared to the values of the modulus for the first harvest term.

Table. 38. Values of elasticity modulus and deformation obtained for tests of strenght

Contents	Min.	Max.	Mean	stand.	95% conf. Int.
The cutting test – term I					
Modulus of elasticity, (MPa)	2,83	11,91	5,94	2,57	4,57-7,31
Deformation, (mm)	7,69	18,23	13,37	3,42	11,55-15,14
The cutting test – term II					
Modulus of elasticity, (MPa)	3,25	5,26	4,20	0,66	3,85-4,55
Deformation, (mm)	11,87	17,50	15,22	1,86	14,23-16,21
The cutting test – term III					
Modulus of elasticity, (MPa)	2,29	5,68	3,85	1,03	3,15-5,55
Deformation, (mm)	5,95	14,71	12,14	2,09	11,77-13,86
The penetration test – term I					
Modulus of elasticity, (MPa)	4,50	11,30	8,14	2,49	5,04-11,23
Deformation, (mm)	4,20	7,80	6,12	1,35	4,44-7,79
The penetration test – term II					
Modulus of elasticity, (MPa)	4,25	7,25	5,83	0,86	5,35-6,31
Deformation, (mm)	4,36	7,63	5,84	1,01	5,28-6,41
The penetration test – term III					
Modulus of elasticity, (MPa)	2,54	4,36	3,40	0,63	3,06-3,74
Deformation, (mm)	3,21	5,58	4,07	0,65	3,72-4,41
The compression test – term I					
Modulus of elasticity, (MPa)	3,26	5,26	4,08	0,75	3,15-5,01
Deformation, (mm)	3,24	6,25	4,96	1,12	3,57-6,34
The compression test – term II					
Modulus of elasticity, (MPa)	3,23	4,15	3,68	0,34	3,74-3,56
Deformation, (mm)	2,48	4,88	3,60	0,80	3,74-3,31
The compression test – term III					
Modulus of elasticity, (MPa)	2,45	3,56	2,94	0,29	2,78-3,09
Deformation, (mm)	2,45	5,02	3,43	0,80	3,02-3,85

The mean values of deformation obtained in the cutting tests increased by 14% (for harvest term II) and decreased by 9% (for term III) as compared to those for harvest term I. A decrease was also recorded in the penetration tests – by 4.4% (for harvest term II) and by 34% (for term III), and in the compression tests – by 27% (for term II) and by 31% (for term III).

Decrease in the measurement values with delay in the cob harvest time (though not always statistically significant) is related to changes occurring in the structure of the kernel parenchyma. This is affected by the phase of kernel ripeness, which is manifested mainly in a decrease in kernel moisture, and in increasing share of starch at the cost of sugars (both reducing sugars and saccharose). Kernel moisture decreased by about 6% in the case of harvest term II and by about 10% in the case of harvest term III, with respect to the value in harvest term I. In relation to the harvest in term I, there was a decrease in the content of reducing sugars by about 17% for harvest term II, and by about 27% for harvest term III, a decrease in the content of saccharose by about 32% for term II and by about 44% for term III, and an increase in the content of starch by about 21% for harvest term II and by about 82% for harvest term III (Tab. 37).

Kernels with reduced moisture and increased content of starch have much lower values of the mechanical properties, hence the lower amount of energy required for kernel cutting off the cob. This may be caused by a decrease in the turgor of the kernels, or also in the elasticity of the seed cover, as evidenced for instance by the decrease in the modulus of elasticity. Both the critical cutting force and the critical force of kernel penetration of cracking are preceded by considerable plastic deformation. As a consequence, this is reflected in higher values of force required to overcome the critical point, for kernels from harvest time III, and I with relation to harvest terms II at the cost of greater deformation.

9.1.3. Evaluation of the Process of Sweet Corn Kernels Cutting off

Sweet corn cobs for the processing industry are subjected to mechanical processing consisting in kernel cutting off from the cob cores. Among the requirements concerning the quality of the cut material one should enumerate, among other things, smooth cut surface and even length of kernels, lack of mechanical damage, and low level of losses in mass and in the content of nutritional components [7].

Statistical analysis showed that in the case of mean values of the degree of kernel mass cutting off there is significant statistical differentiation. Mean values of the degree of kernel mass cutting off from cob cores (Fig. 84) varied within the range from 55.6% (term I) to 64.7% (term III). In the case of mean values of electric energy consumption (Fig. 85), power consumption (Fig. 86) and process efficiency

(Fig. 87), on the difference between harvest terms III and I was statistically significant. The values varied as follows: for energy consumption - from $2.75 \cdot 10^{-4}$ kWh (term I) to $2,09 \cdot 10^{-4}$ kWh (term III), for power consumption - from 0.72 kW (term I) to 057 kW (term III), and for efficiency - from 65.5 cobs/min (term I) to 73.5 cobs/min (term III). The differences in the mean values of the share of kernels of inferior quality (Fig. 88), which varied from 21.8% (term I) to 14,0% (term III), were not statistically significant between the harvest terms II and III.

The decrease in energy consumption by 24% and in power consumption by 21% resulted from the change in the turgor of the kernels. This can be interpreted in a way similar to that in the description of the energy of cutting, penetration and compression of kernels on the strength tester under quasi-static conditions.

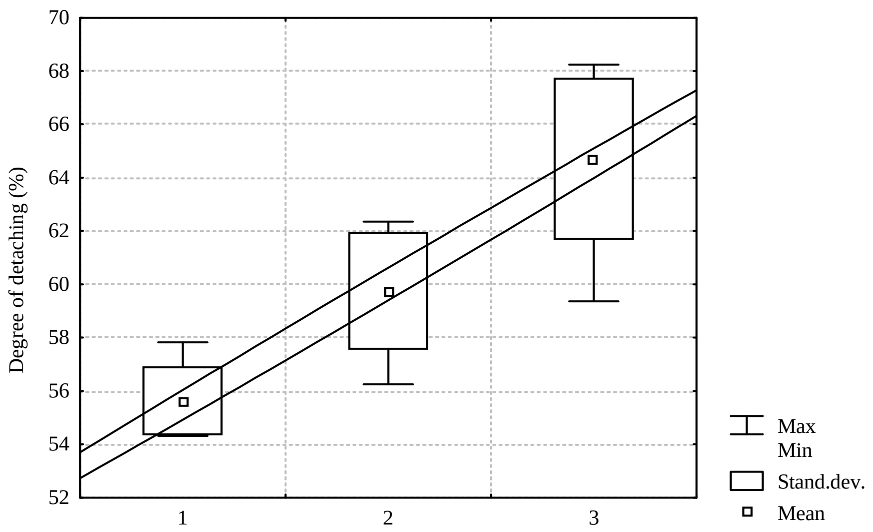

Fig. 84. Degree of kernel mass cutting for different harvest terms: 1– term I, 2 – term II, 3 – term III

The decrease in kernel turgor with delay in the harvest time has also a favorable effect on the degree of kernel mass cutting off, as well as on the quality and efficiency of the cutting process. Change in the consistency of sweet corn kernel parenchyma, caused by ripening, causes a decrease of kernel moisture and of the content of mealy starch. Such consistency of the parenchyma prevents mass losses both in the course of kernel cutting and as a result of kernel transport during the technological processes related to kernel processing and contact with water (rinsing, sorting, blanching). The lower energy consumption in the process of cutting kernels from harvest times II and III, resulting from the reduced cutting resistance, causes an increase in the efficiency of the process.

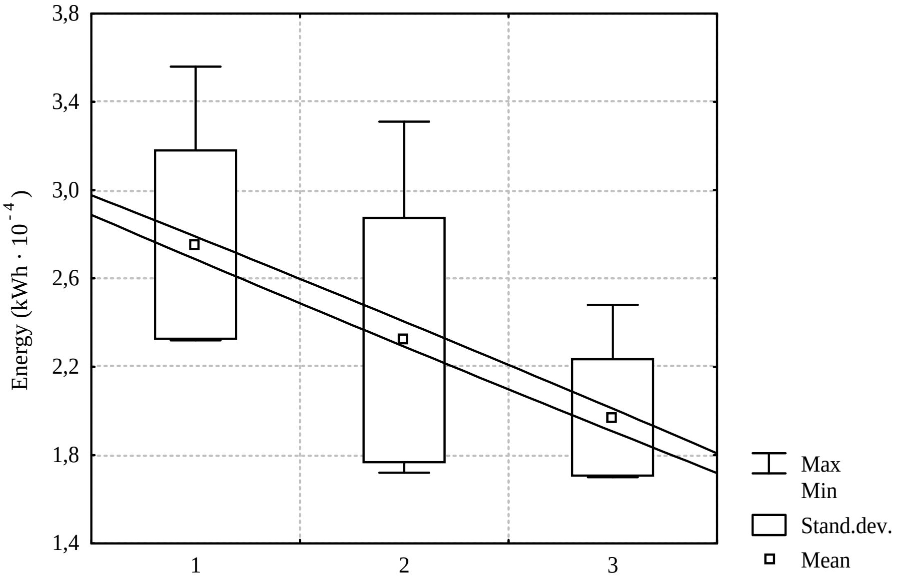

Fig. 85. Cutting energy for different harvest terms: 1– term I, 2 – term II, 3 – term III

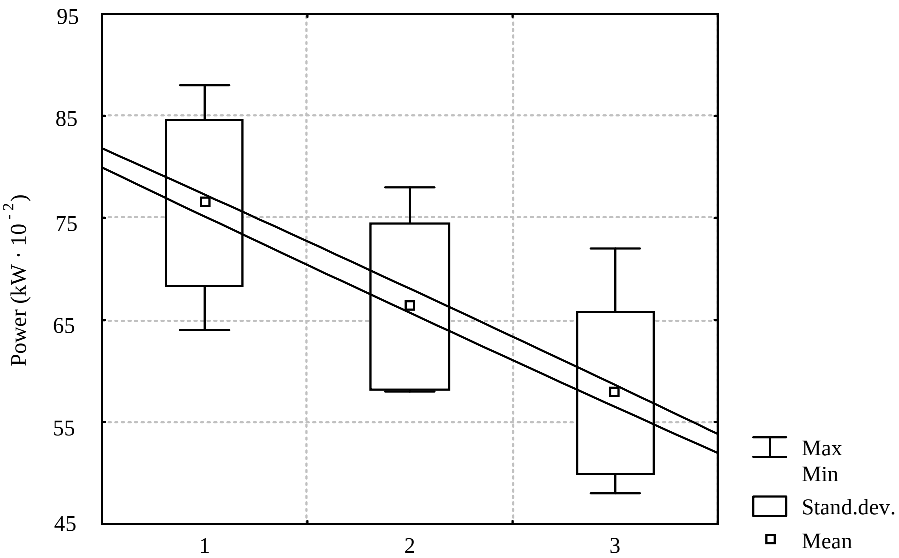

Fig. 86. Cutting power for different harvest terms: 1– term I, 2 – term II, 3 – term III

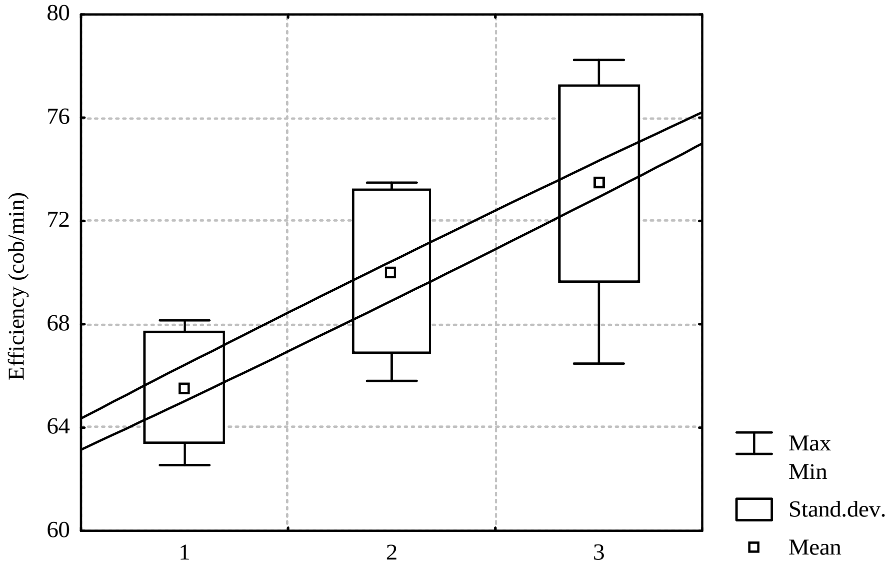

Fig. 87. Cutting efficiency for different harvest terms: 1– term I, 2 – term II, 3 – term III

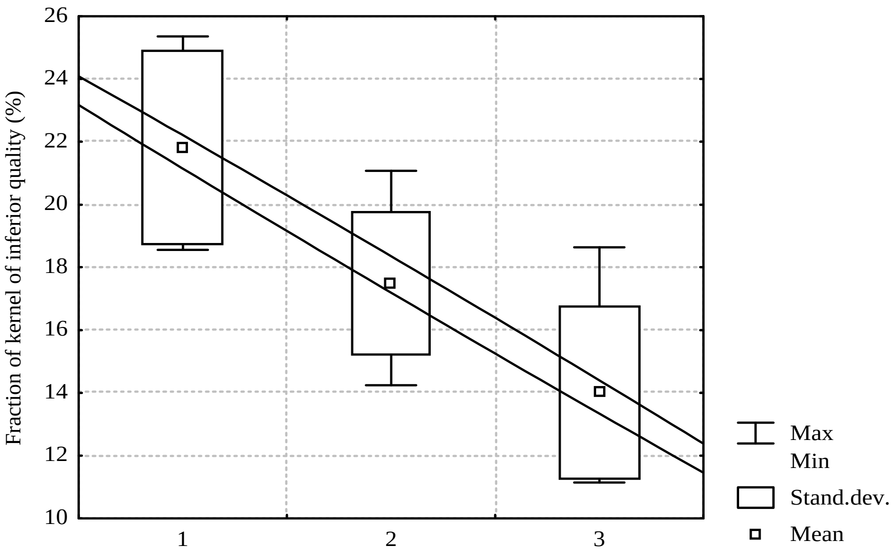

Fig. 88. Part of kernels of worse quality for different harvest terms: 1– term I, 2 – term II, 3 – term III

9.2. EFFECT OF STORAGE AND BLANCHING CONDITIONS ON THE MECHANICAL PROPERTIES AND ON THE CUTTING PROCESS OF SWEET CORN KERNELS

Sweet corn attains its consumption and processing ripeness within 24 to 28 days from blooming, that is from the appearance of stigmates. A visible symptom of ripeness is the browning of the stigmates. The kernels assume yellow-gold colouring and are in the phase of late milk ripeness. The period of corncobs suitability for consumption is relatively short – cobs get over-ripe fairly quickly, especially at high temperature. The process of over-ripening, which consists in the transformation of sugars into starch, is delayed in cobs stored with the cover leaves unresolved, and in cool conditions [154].

In order to estimate the effect of storage conditions on the possibility of extending the period of corn suitability for processing, tests were performed, consisting in storing corncobs for 7 days under the following conditions:

- conventional storage - temperature approx. 20^0C (barn, umbrella roof),
- refrigerated storage - cold storage room, temperature approx. 2^0C,
- soaking in water - temperature approx. 20^0C.

Immediately after harvest the mechanical properties of cobs at late milk ripeness phase were compared, as well as those of cobs after blanching. Corncob blanching was made in a 4-minute water bath with a temperature of 80-90°C. After the blanching, the cobs were cooled to a temperature of about 20°C and dried.

9.2.1. EFFECT OF STORAGE CONDITIONS ON THE MECHANICAL PROPERTIES OF SWEET CORN KERNELS

To estimate the effect of storage conditions of cobs after harvest, penetrometric tests were performed in which the force of kernel penetration was determined. Also recorded in the tests were the deformation of the seed cover at the point of penetration and the energy corresponding to the work of seed cover penetration with a penetrometer with a diameter of 2 mm, and calculation was made of the modulus of elasticity of kernel parenchyma, indicating the level of its turgor.

The tests were performed on corn cobs that were divided into three parts in order to allow estimation of the effect of storage conditions on the particular batches of kernels - those from the cob tip area (conical in shape and with the largest number of unripe kernels), from the central cob section (cylindrical in shape and well filled with well formed kernels), and from the cob base part, where the kernels are the most ripe but also characterized by varied mechanical properties.

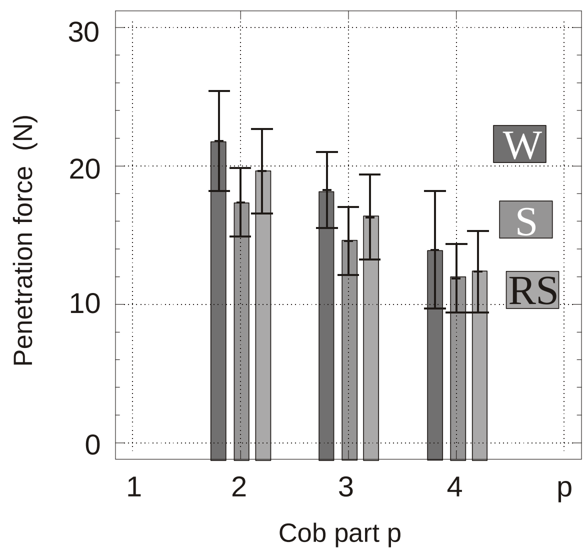

Fig. 89. Force at penetration of seed cover. W – wetted cobs, S – cobs from regular storage and RS – cobs from refrigerated storage

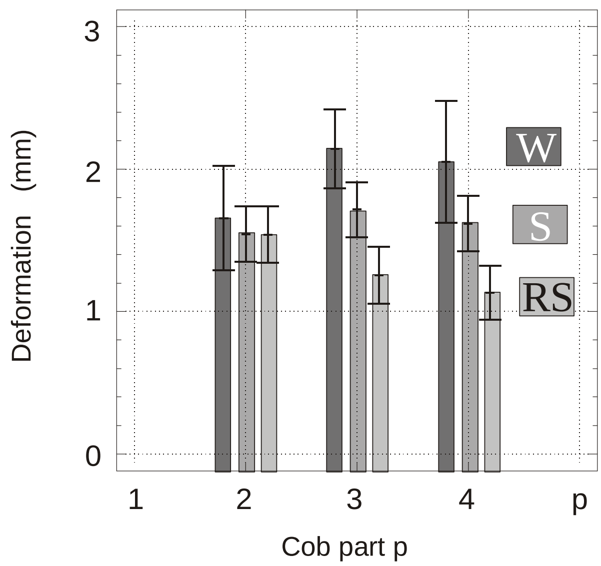

Fig. 90. Deformation at penetration of kernel. W – wetted cobs, S – cobs from regular storage and RS – cobs from refrigerated storage

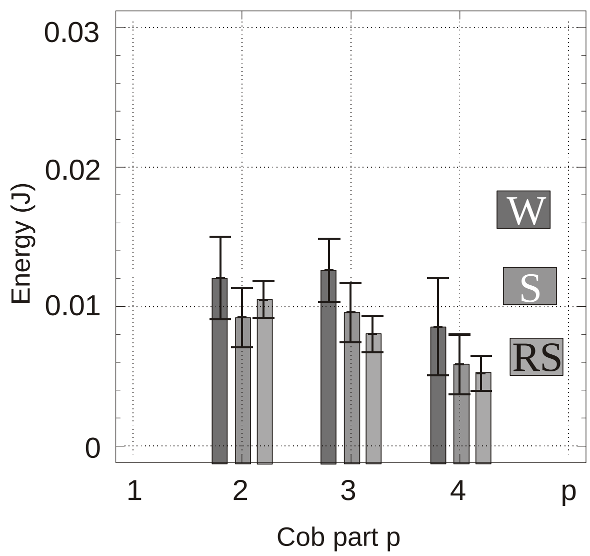

Fig. 91. Energy at penetration of kernel. W – wetted cobs, S – cobs from regular storage and RS – cobs from refrigerated storage

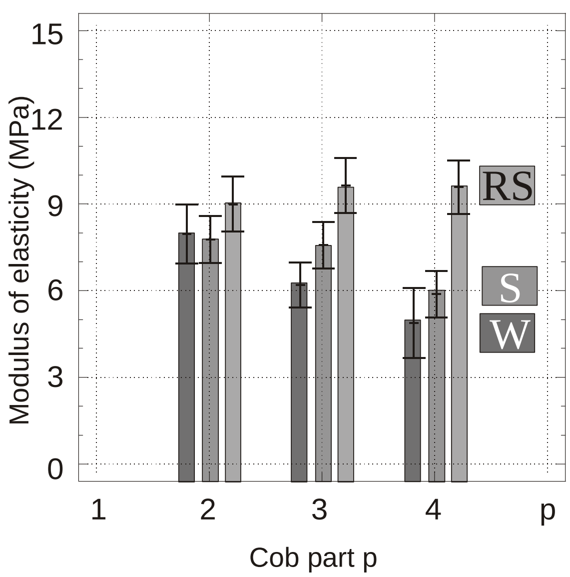

Fig. 92. Modulus of elasticity of kernel. W – wetted cobs, S – cobs from regular storage and RS – cobs from refrigerated storage

It was observed that the force of seed cover penetration differentiated the mechanical properties of kernels from particular sections of the cob and was indicative of the effect of the storage methods or conditions applied (Fig. 89). Cob soaking (wetting) causes a differentiation of the force required to penetrate seed cover, but also the strongest lowering of its strength for kernels from the base section of the cob (14.02 N), which may be related to filling with water kernels that are already well formed. For comparison, for wetted kernels from the tip part of the cob the value exceeded the level of 19.83 N. The values of standard deviation (Fig. 89) indicate that significant differences were observed for the extremes of the cob, and in a majority of cases differences in the strength of kernels from the central sections of the cob did not differentiate their strength relative to kernels from the edge areas.

When recording kernel deformation, or rather the deformation that corresponds to seed cover penetration with a penetrometer, it can be observed (Fig. 90) that kernels from the tip section of the cob, frequently neither fully formed nor ripe, are not prone to differentiation as a result of 7 days of storage, irrespective of whether they are stored in refrigerated room at 2^0 C or under traditional conditions at 20^0 C. However, an effect of kernel wetting can be observed as increase in deformation (2.03 mm) of kernels from the central section of the cob. The effect is related to softening of the seed cover of ripe kernels, but on the other hand refrigerated storage increases the turgor of such kernels, which is manifested in the decrease of the deformation value to 1.12 mm. Kernels from all the cob sections, stored under traditional conditions (barn, umbrella roof), are characterized by similar deformation values of from 1.42 mm to 147 mm.

Analyzing, in Figure 91, the values of energy determined in the course of seed cover penetration, one can observe that refrigerated storage causes a decrease in the energy values and has a homogenizing effect on the material (lower values of standard deviation), which effectively provides a valuable practical indication of a drop in energy requirements for the process of kernel cutting off from cobs after their refrigerated storage.

Plotting the modulus of elasticity of sweet corn kernels in Figure 92, one can observed that kernel wetting causes a loss of kernel elasticity, that is causes kernel flabbiness, while corn cobs stored under refrigerated conditions have kernels whose elastic properties remain on a constant level (9.02-9.45 MPa) irrespective of what cob section the kernels come from.

The observed differences in the mechanical strength of kernels from corn cobs stored under different conditions, i.e. soaked with water, and stored in refrigerated rooms or traditionally, indicate the necessity of verifying all the studied factors in the course of kernel cutting off from cobs and of comparing the results with those obtained for cobs directly after harvesting as well as after blanching. It can be observed from Figure 93 that kernel cutting directly after harvest requires the highest expenditure of energy (0.034 J). Refrigerated storage causes a reduction of that value to 04.07 J, though the differences are not statistically significant. This is related to the behaviour of the modulus of elasticity under those conditions, which has been demonstrated earlier in Figure 92. Cob storage under traditional conditions, as well as cob wetting, causes flabbiness of kernels and a reduction of their elasticity in the case of 7-day storage at a temperature of 20°C, but also a loss of elasticity of the seed cover of wetted kernels. In both instances this is manifested through decreased energy requirements for kernel cutting off from cob cores.

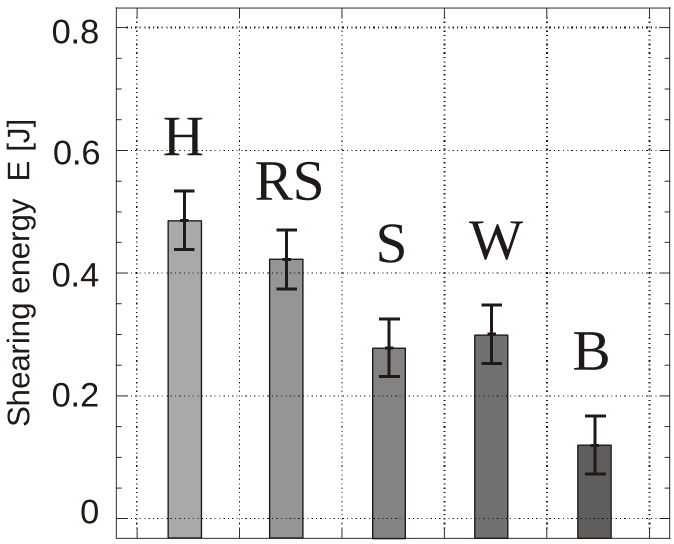

Fig. 93. Energy of kernel cutting off from cob core. H– after harvest, W – wetted cobs, S – cobs from regular storage, RS – cobs from refrigerated storage and B – after blanching

As follows from Figure 93, kernels from cobs subjected to the process of blanching need lower energy expenditure for the kernel cutting process (0.27 J), which provided an inducement for a broader study of the process of cutting of blanched kernels (sections 9.2.3 and 9.2.4) and of their mechanical properties (section 9.2.2).

9.2.2. Effect of Blanching on the Mechanical Properties of Kernels

One of the stages of the technological process of corn kernel production is kernel blanching. The fundamental objective of the process is the deactivation of tissue enzymes responsible for biochemical transformations that determine, among other things, changes in the tissue texture. Blanching causes also a change in the consistency of the kernel parenchyma, resulting in coagulation of starch which, in the case of non-blanched cobs, is lost in the course of kernel processing [4]. Moreover, at later stages of kernel processing (especially rinsing), it reduces juice seepage and - therefore - losses of valuable nutritional components.

The losses mentioned above are related both to the morphological features of cobs and the size and mechanical strength of kernels, and to the parameters of the process of kernel cutting, i.e. the geometry of the cutter knives, rotary speed of the knife head, and linear speed of the cob feeder. One of the methods that permit considerable limitation of the losses is the application of blanching prior to the process of kernel cutting off, instead of blanching of kernels already cut as it is frequently done in practice [73,75].

Sweet corn cobs for the processing industry are frequently subjected to machining consisting in kernel cutting off from cob cores. Among the requirements concerning the quality of raw material detached in this manner one should mention, among other things, smooth cut surface and even length of kernels cut off, lack of mechanical damage to the kernels, and low level of losses in kernel mass and in the content of nutritional components [73].

In view of the necessity of reducing the losses, both qualitative and quantitative, that occur in the process of kernel cutting off from cobs, cobs collected at the stage of late milk ripeness were subjected to 4-minute blanching in a water bath of a temperature of 80-90°C. After the blanching, the cobs were cooled down at ambient temperature (approx. 22°C), and dried. Determination of the effect of blanching on selected mechanical properties of kernels was performed on sweet corn cobs of Helena variety. To examine the effect of blanching on the mechanical properties of kernels, kernel cutting, penetration and compression tests were performed, comprising measurements of the values of force, modulus of elasticity, deformation, and energy for the particular tests. That stage of the study was also realized with the help of the Instron 6022 strength tester, at measurement head speed of 50 mm/min. The cutting and penetration tests were made on cob samples (with a length of 5 cm) taken from the central section of the cob. Also, the content of dry mass in corn kernels was determined, in accordance with the dryer-weighing method as per the standard No. PN-90/A-75101.03.

Analyzing the results obtained, presented in Figures 94-99 and in Table 39, we can state that blanching is an operation that causes a decrease in the mean values of the mechanical properties of sweet corn kernels, as well as in energy consumption.

In the shear test of corn kernels, the value of the shearing force varied from 19.8 to 53,5 N for non-blanched cobs and from 12.1 to 38,9 N for cobs subjected to blanching. The shearing energy formed ranges of values from 0.0 to 0.33 J (non-blanched cobs) and from 0.09 to 0.31 J (cobs after blanching). The mean values of kernel shearing force were 34.5 N for the non-blanched cobs and 26.0 N for the cobs after blanching (Fig. 94), while those of the shearing energy were 0.21 and

0.18 J, respectively (Fig. 95). This means that, as a result of blanching, the value of the shearing force decreased by about 25%, and that of shearing energy by approximately 14%. Standard deviation for the shearing force was 7.83 (non-blanched cobs) and 8.20 (cobs after blanching), and that for shearing energy – 0.073 and 0.072, respectively.

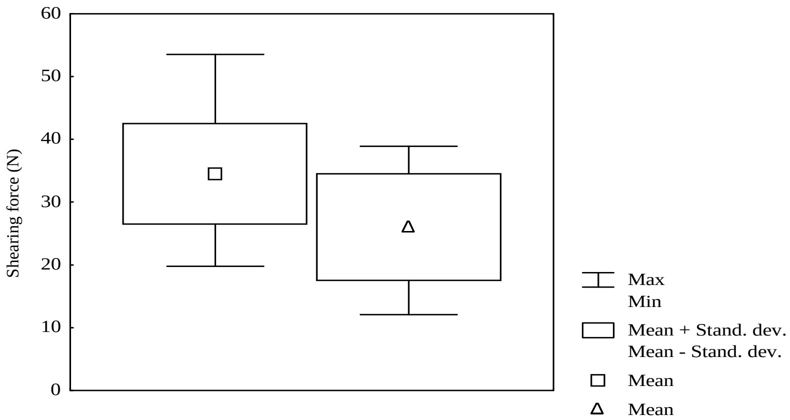

Fig. 94. Shearing force of no-blanching (☐) and blanching (Δ) kernels

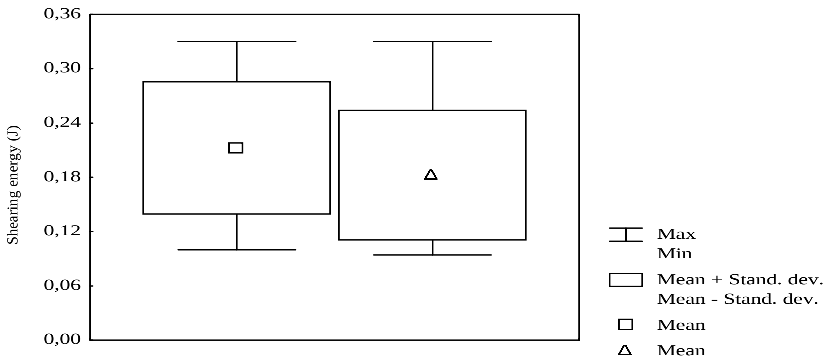

Fig. 95. Shearing energy of no-blanching (☐) and blanching (Δ) kernels

In the kernel penetration test, the value of the penetration force varied from 9.1 to 12.5 N for the non-blanched cobs, and from 7.1 to 11.2 N for the cobs after blanching. The values of penetration energy fell within the range of 0.027–0.041 J (non-blanched cobs) and 0.018–0.037 J (blanched cobs). The mean values of corn kernel penetration force were 11.1 N for non-blanched cobs and 9.5 N for cobs after blanching (Fig. 96), while of the penetration energy was 0.34 J and 0.28 J, respectively (Fig. 97). In this case the mean value of the penetration force decreased by about 15%, and that of penetration energy by nearly 18%. Standard deviation for the penetration force was 0.84 (non-blanched cobs) and 0.89 (cobs after blanching), and for penetration energy – 0.006 and 0.003, respectively.

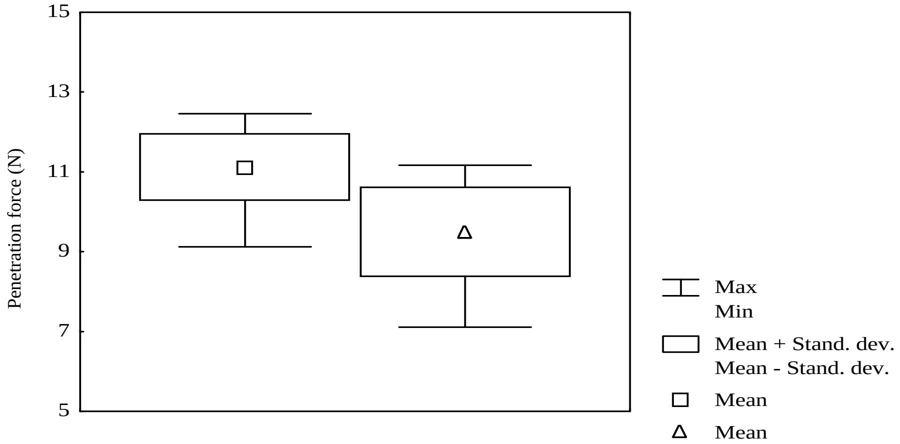

Fig. 96. Penetration force of no-blanching (☐) and blanching (Δ) kernels

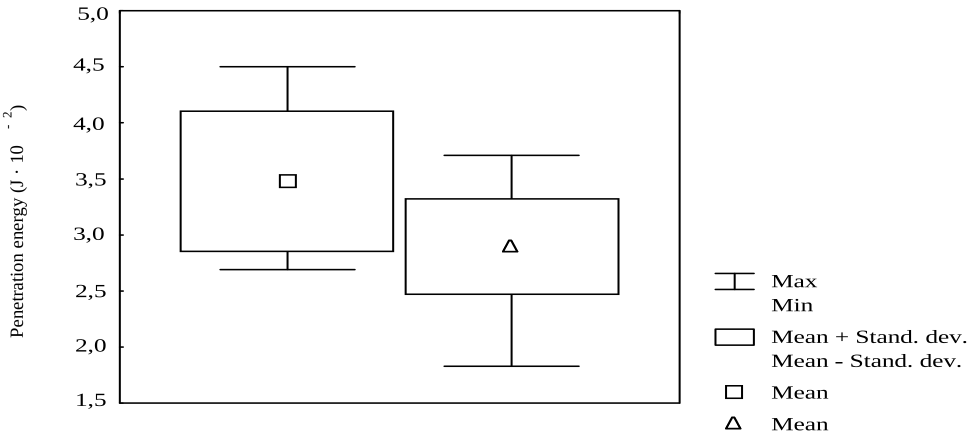

Fig. 97. Penetration energy of no-blanchng (☐) and blanching (Δ) kernels

In the kernel compression test, in turn, the values of force vary from 22.6 to 58.4 N for the non-blanched cobs and from 12.6 to 64.9 N for the cobs after blanching. The compression energy values fell within the range of 0.015–0.046 J (non-blanched cobs) and 0.011–0.062 J (cobs after blanching). The mean values of compression force were 39.1 N for the non-blanched cobs and 30.2 N for the cobs after blanching (Fig. 98), while those for the compression energy were 0.027 J and 0.026 J, respectively (Fig. 99). Therefore, the values of the compression force decreased by about 23%, and that of compression energy by about 4%. Standard deviation for the compression force was 9.79 (non-blanched cobs) and 12.84 (cobs after blanching), and for the compression energy – 0.008 and 0.013, respectively.

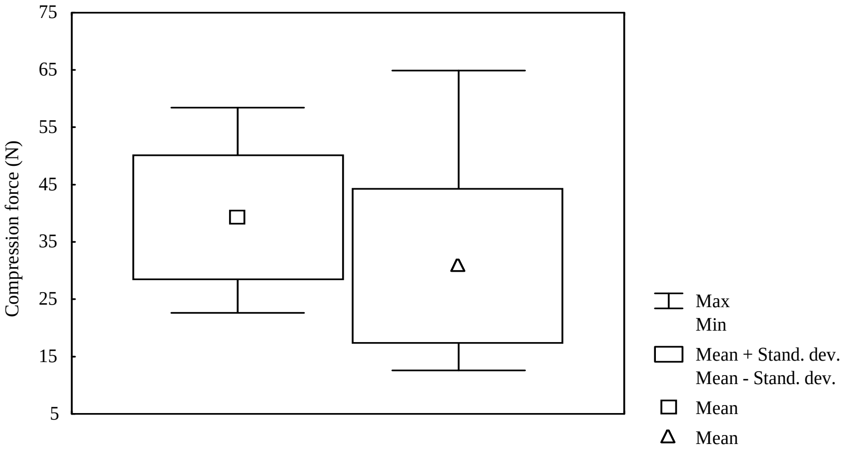

Fig. 98. Compression force of no-blanching (☐) and blanching (Δ) kernels

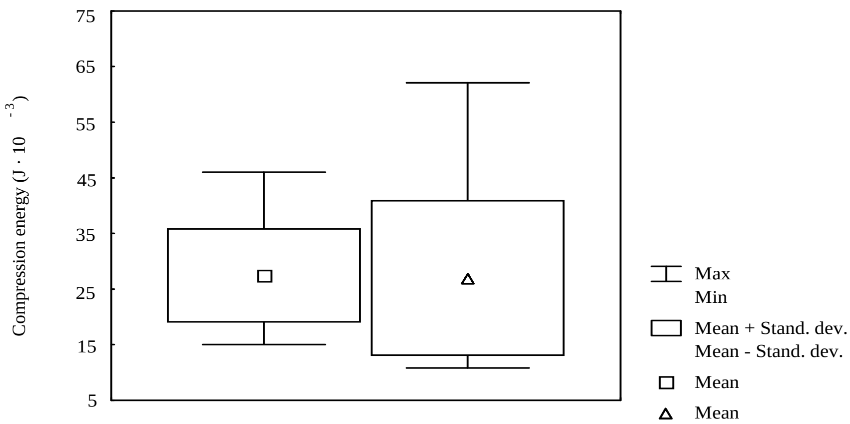

Fig. 99. Compression energy of no blanching (☐) and blanching (Δ) kernels

Table 39 presents the results of the tests for the modulus of elasticity and of deformation, obtained form the non-blanched and blanched cobs, and the doped strength tests. In the case of the shearing test, the mean value of the modulus of elasticity for the non-blanched cobs decreased by 31%, and that of deformation by 54.5%, with respect to the cobs subjected to blanching.

In these of the penetration test, in turn, the value of the modulus of elasticity for non-blanched cobs decreased by 8.5%, and that of deformation by about 22%, with relation to the cobs after blanching, while in the case of the compression test performed for sweet corn kernels the corresponding levels of reduction were 32.4% for the modulus of elasticity, and 4% for the value of deformation.

Table. 39. Modulus of elasticity and deformation obtained in test of strenght

Contents	Min.	Max.	Mean.	Stand. dev.
Test of cutting – no-blanching cobs				
Modulus of elasticity (MPa)	0,09	5,09	2,58	1,24
Deformation (mm)	2,81	3,95	3,45	0,83
Test of cutting – blanching cobs				
Modulus of elasticity (MPa)	1,56	2,36	1,78	0,34
Deformation (mm)	1,76	1,88	1,57	1,67
Test of penetration – no-blanching cobs				
Modulus of elasticity (MPa)	5,68	7,67	6,69	0,66
Deformation (mm)	1,27	2,21	1,43	0,81
Test of penetration – blanching cobs				
Modulus of elasticity (MPa)	1,70	9,71	6,12	1,38
Deformation (mm)	1,21	2,41	1,12	0,53
Test of compression – no-blanching cobs				
Modulus of elasticity (MPa)	0,56	1,47	1,02	0,25
Deformation (mm)	1,53	2,28	2,02	0,19
Test of compression – blanching cobs				
Modulus of elasticity (MPa)	0,41	0,88	0,69	0,11
Deformation (mm)	1,73	2,39	1,94	0,20

The tests presented above showed that blanching has a significant effect on the values of the analyzed mechanical properties of sweet corn kernels. In comparison to the strength tests of shearing, penetration and compression performed on the non-blanched kernels, there was a reduction in the shearing force by about 25%, in the penetration force by about 15%, and in the compression force by about 23%.

The process of blanching caused a significant reduction in energy consumption for kernel shearing (by about 14%), penetration (by about 17%) and compression (by about 4%), and the corresponding levels of reduction for the modulus of elasticity were approximately 31%, 8% and 32%, while those for deformation - approximately 55%, 22% and 4%.

The tests showed that the change in the consistency of the kernel parenchyma that resulted from the application of blanching caused a decrease in the hardness and in the elasticity of the kernel seed cover, and both during the shearing test and after kernel shearing no parenchyma seepage was observed (neither juice nor solid parts). Sheared kernels were characterized by smooth and even cut surface, and by the absence of mass losses.

9.2.3. Effect of Blanching on Cutting Efficiency and Kernel Quality

In practice we frequently encounter situations where blanching is applied to kernels already cut off the cobs. The advantage of this solution is the fact that such blanching requires the use of blanching vessels of smaller volume, as well as the reduction in the quantities of blanching agents required (water, steam). Cob blanching prior to kernel cutting off results in relatively high mass efficiency and better taste qualities of the kernels. The time of blanching is usually related to what the kernels are to be used for (frozen products, canned products), and to the cob size. Kernels for freezing are usually blanched for a longer time (6 to 11 min), while those for canned products for only 2 to 4 min) [27]. Blanching, as an operation affecting the mechanical properties of kernels, required also to verified for its effect on the degree of kernel cutting off and on kernel quality.

Sweet corn cobs collected in the phase of late milk ripeness were subjected, like in the preceding phase of the study (section 9.2.2.), to 4minute blanching in a water bath of about 80°C. After the blanching, the cobs were cooled down at ambient temperature (approx. 22°C), and then dried. The control sample was made up of cobs not subjected to the process of blanching. This phase of the study was performed on samples of 5 cobs of sweet corn each. The sweet corn used was the Jubilee variety, and the tests were made in 6 replications. Classification of kernels into two quality classes was made on a sample of 250 kernels.

The main study concerned with measurement of the degree of kernel mass cutting off and with kernel quality was preceded with determination of the fundamental physical properties of the cobs. Kernels were cut off by means of the FMC Corn Cutter, with standard rotary speed of the knife head – 167.5 $rad \cdot s^{-1}$ and linear speed of cob feeder of 0.31 $m \cdot s^{-1}$.

The degree of kernel mass cutting off S_{od} was determined in two stages. In the first, the mass of kernels cut off M_{od} was calculated with the help of the formula (14):

$$M_{od} = \frac{(m_k - m_r)}{m_k} \quad (\%) \tag{14}$$

where:

m_k – cob mss before the process of kernel cutting off (g),
m_r – cob core mass after kernel cutting off (g).

and in the second the value obtained from the formula (15) was related to the biological yield of the kernels W_b:

$$S_{od} = \frac{M_{od}}{W_b} \cdot 100 \quad (\%) \tag{15}$$

Such a procedure of calculation resulted from the problem of collecting all the kernels cut off, that in part were scattered over the elements of the cutter, and from losses of juice and solid fractions, as well as from the difficulty with determining what part of the kernels remained on the cob core after the cutting process. The mass of the material tested was determined with the help of a WPE 2000p balance with the accuracy of ± 0.1g.

The quality of the cut kernels was determined on the basis of scanning the cut surface, attention being paid to the smoothness of the cut surface and to kernel mass reduction. The condition of the cut kernel section was adopted as the index of the quality of kernel cutting off. Kernel cutting quality was accepted as good is the section surface was smooth and no mass losses were visible. Every other appearance of the section surface qualified the kernel as being of inferior quality. The share of such kernels, U_{zg} , was calculated from the formula:

$$U_{zg} = \frac{n_l - n_{zd}}{n_l} \cdot 100 \quad [\%] \tag{16}$$

where:

n_{zd} – number of kernels of good and inferior quality [pcs.],
n_l – number of kernels of good quality [pcs.].

On the basis of the measurements and of an analysis of variance it can be stated that blanching had a significant effect on the values studied. The degree of kernel mass cutting for the blanched kernels varied within the range from 63.0 to 65.9% and had a mean value of 64.1%, while the corresponding values for the control sample (non-blanched kernels) were from 54.2 to 58.6% (mean value of 56.0%) (Fig. 100).

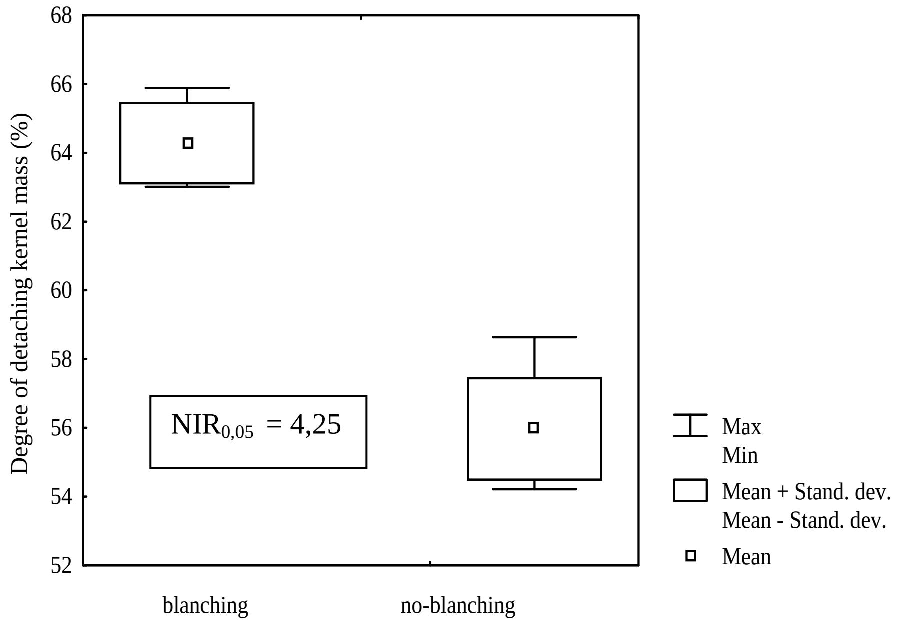

Fig. 100. Degree of kernel mass cutting from blanching and no-blanching cob

Similar advantages following from the process of cutting blanched kernels as opposed to non-blanched kernels can be seen in the assessment of the quality of the kernel section surface. The share of kernels of inferior quality varied from 3.7 to 9.9% and had a mean value of 6.6% for blanched kernels, and from 19.5 to 24.4% (mean value of 20.8%) in the case of the non-blanched kernels (Fig. 101).

The measurement values obtained were characterized by a relatively low measure of scatter. The values of standard deviation fell within the range from 2.2 to 2.8% for the degree of kernel mass cutting off, and from 2.9 to 3.4% for the share of the fraction of inferior quality kernels.

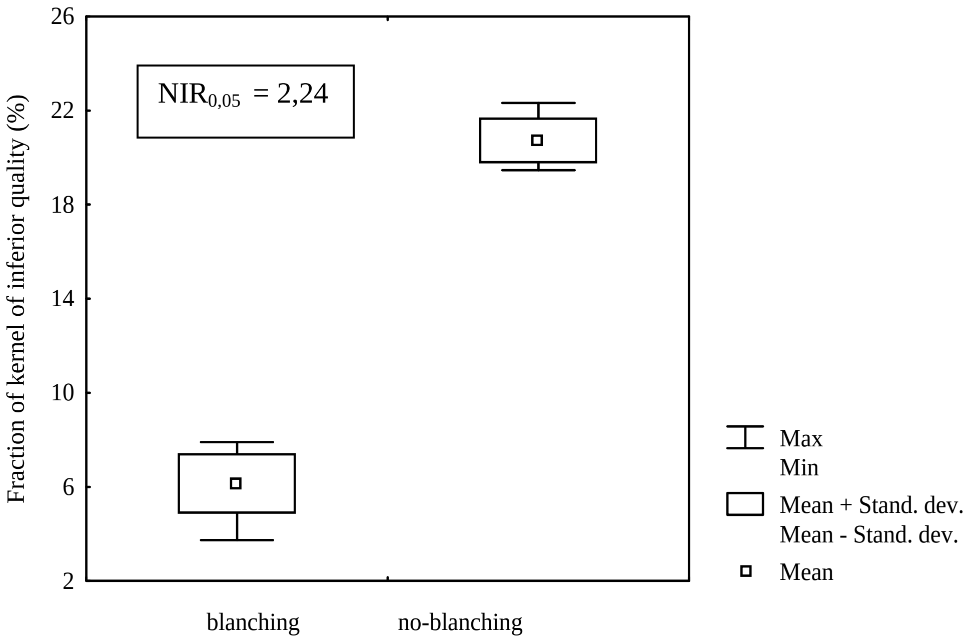

Fig. 101. Fraction of inferior quality of blanching and no-blanching cob

The cutting process of blanched kernels was characterized by relatively low losses of kernel mass. In relation to the biological yield of the kernels, the level of losses was about 11%, while the level of losses for non-blanched kernels was about 23%. These values are significant in that they mainly concern the kernel germ which is the most valuable part of the kernel in terms of its nutritional value. It is also in the germ that the greatest amounts of sugars are accumulated.

Blanched kernels are characterized by better taste, and their cutting off efficiency is higher by from about 7.1 to 26.1%. Also notable is the fact that short blanching (up to about 10 min.) does not cause any notable reduction in the content of sugars. The lower losses result mainly from the change in the consistency of the kernel parenchyma, as well as from the reduction in kernel turgor and in the hardness and elasticity of the seed cover. The change in the structure of the parenchyma, which is primarily responsible for the reduction of its qualitative and quantitative losses, has also an improving effect on the quality of kernel cutting. This is evidenced by the share of kernels of inferior quality which is lower by about 14%.

Blanching had a significant increasing effect on the degree of kernel mass cutting, by about 12% with relation to the non-blanched cobs, and a favorable effect on the efficiency and quality of the cutting process. The share of the inferior quality kernel fraction decreased by about 14%. The process of blanched kernel cutting, as opposed to non-blanched kernels, was characterized by absence of extract seepage, and therefore improved the nutritional quality of the kernels.

9.2.4. EFFECT OF COB BLANCHING ON THE ENERGY CONSUMPTION AND EFFICIENCY OF THE KERNEL CUTTING PROCESS

In the first phase, the basic physical properties of cobs were determined, and in the second – the energy requirements and the efficiency of the process of kernel cutting. That phase of the study was realized on a measurement stand that consisted of the FMC Corn Cutter model 3AR and a system for time and energy consumption recording - Lumel PP83. To continue the study, it was necessary to examine the effect of corncob blanching on the energy consumption and the efficiency of the process of kernel cutting. Blanching was applied to cobs collected at the phase of late milk ripeness. Tests were also made on cobs blanched for 4 minutes in a water bath with a temperature of 80-90°C, subsequently cooled down, like in the preceding phase of the study, at ambient temperature and then dried. Tests on the measurement stand were made for husked corncobs of the Jubilee variety, on samples of 5 cobs each in 6 replications.

The measurements were realized at the basic rotary speed of the knife head – 167.5 rad/s and at linear speed of the cob feeder of 0.31 m/s. Power consumption recording was begun once the kernel cutter reached stable operating speed. On the basis of processed measurement data, the values of energy consumption in the process of kernel cutting were determined, for non-blanched E_{nb} and blanched E_b kernels, as well as of the energy consumption for idle run of the cutter E_j (kWh/kg). The efficiency of the kernel cutting process was determined on the basis of the quotient of the kernel mass obtained to the recorded time of its cutting by the knife head of the cutter.

Analysis of the results obtained showed that blanching significantly affected the energy consumption in the process of mechanical kernel cutting off corncobs. The course of power consumption for the corncobs studied is presented in Figure 102.

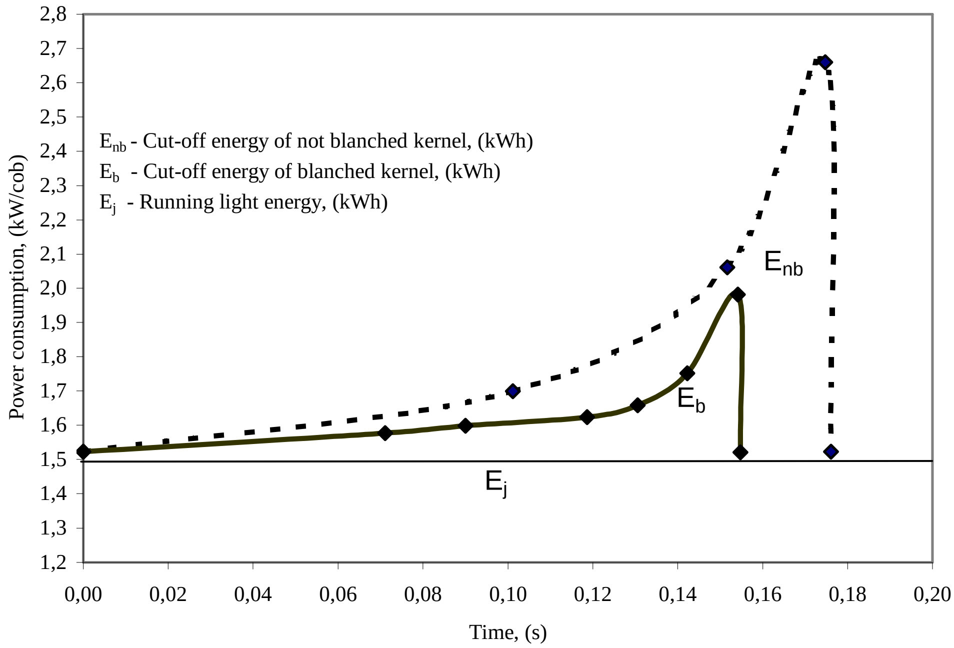

Fig. 102. Course of power consumption during cutting process of no-blanching E_{nb} and blanching E_b kernels

As follows from Figure 103, the total power consumption as well as energy consumption is higher in the cutting process of non-blanched kernels. The mean power consumption obtained for non-blanched kernels cutting was at the level of 2.26 kW/cob, while in the case of blanched kernels it was 1.82 kW/cob.

Such a decrease in power consumption by about 20% resulted from a reduction in the duration of the cutting process by about 12.5%. The resultant increase in cutting process efficiency was also reflected in the total energy consumption of the kernel cutting process which for the non-blanched kernels was 3.09 kWh/cob, and for the blanched kernels – 1.88 kWh/cob (Fig. 104). The efficiency of the kernel cutting process was approximately 97 cobs/min for the non-blanched cobs, and about 111 cobs/min for the blanched cobs (Fig. 105).

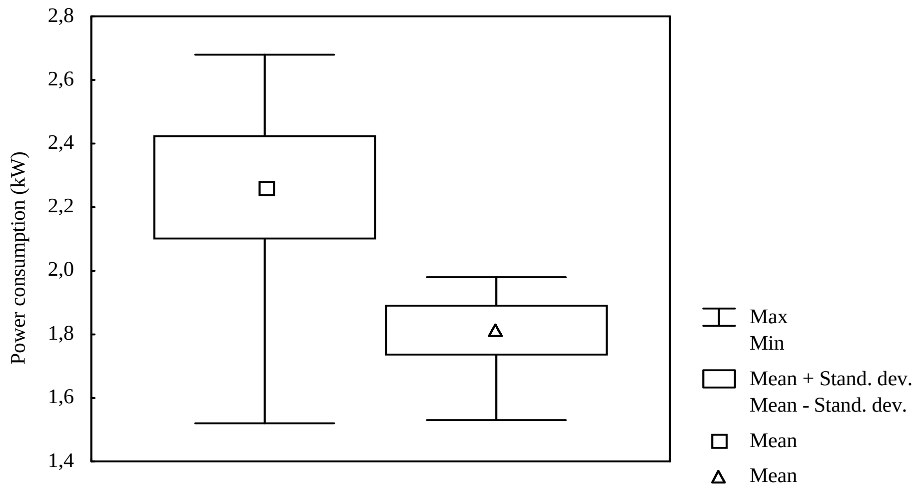

Fig. 103. Power consumption of cutting process for no-blanching (☐) and blanching (Δ) kernels

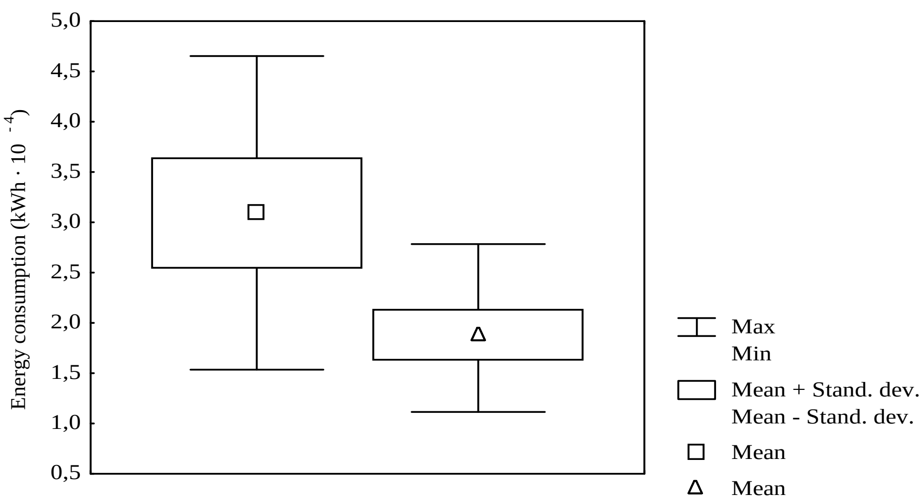

Fig. 104. Energy consumption of cutting process for no-blanching (☐) and blanching (Δ) kernels

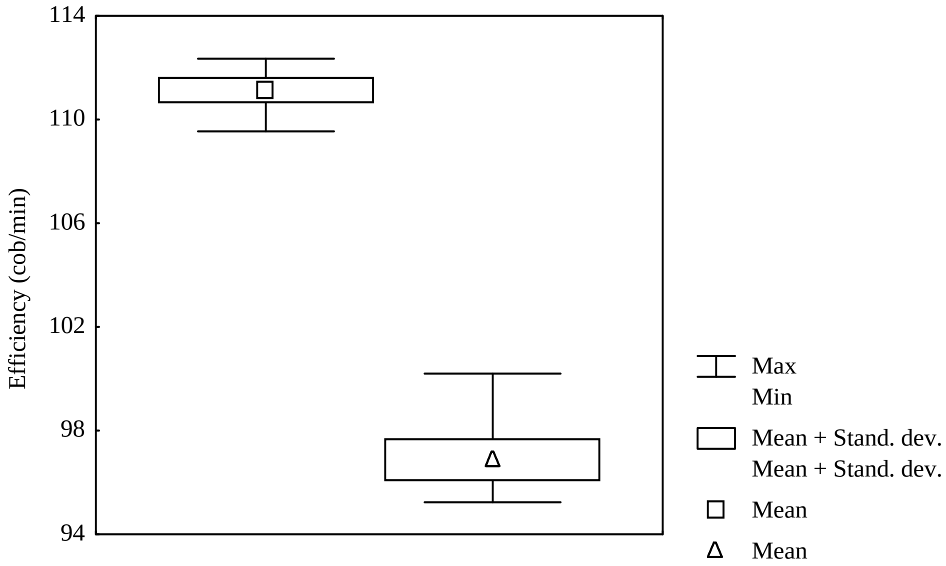

Fig. 105. Efficiency of cutting process for no-blanching (☐) and blanching (Δ) kernels

Blanching had a significant reducing effect on the energy consumption of the process of kernel cutting from corncobs. A decrease of about 40% was recorded in the energy consumption, with a simultaneous increase of about 13% in the efficiency of set corn kernel cutting with relation to the non-blanched cobs. The reduction in energy consumption and the increased efficiency of the kernel cutting process in the case of the blanched kernels could have been related to the change in the consistency of the kernel parenchyma, as well as to the decrease in the hardness and elasticity of the seed cover. The increase in the cutting process efficiency and the reduction of energy consumption by about 40% may also be caused by changes in the internal structure of the kernels and decreased turgor and elasticity of the kernels, and reduced strength of the kernel seed cover.

9.3. POSTHARVEST COOLING FREEZING AND HANDLING OF SWEET CORN*

Sweet corn is a highly perishable crop. When produced for commercial markets, it must be cooled immediately and thoroughly after harvest to protect its quality. It must be kept cool until it reaches the consumer. Mishandling sweet corn causes serious and irreversible deterioration in quality and loss of sweetness and tenderness. Because temperatures are usually high in midsummer when sweet corn is harvested, growers, shippers, and processors must have access to cooling equipment and must have knowledge of proper cooling and handling methods. Only careful attention to postharvest handling procedures can ensure buyer satisfaction and marketing success. Frequently storage life of sweet corn is 5 to 7 days for standard varieties and 8 to 12 days for supersweet varieties. Preferred cooling method is hydrocooling or icing [180].

This chapter acquaints growers, shippers, and processors with energy-efficient cooling and handling methods useful in preserving the quality of fresh sweet corn.

9.3.1. HARVESTING AND HANDLING

Careful supervision of harvesting -- whether done by hand or machine -- results in fewer problems at the packing shed. Whenever possible, sweet corn should be harvested early in the morning when its moisture content is high. Also, the pulp temperature may be as much as 20°C lower at dawn than at midday. Harvesting in early morning is thus a good way to reduce cooling loads and save energy.

After harvest, the ears are normally transported to the packing shed in bulk trucks or trailers. Pulp temperatures at harvest are often higher than 30°C. At these temperatures, bulk lots of uncooled sweet corn will rapidly overheat because of the heat produced by respiration. (The respiration rate of sweet corn is among the highest of common fruits and vegetables; in fact, its rate is about eight times higher at field temperatures than at 0°C.)

If harvested ears are to be left in bulk trucks or trailers for more than an hour, they should be kept from direct sunlight and cooled with a steady flow of well water to remove as much of the field heat and heat of respiration as possible.

Water should be evenly distributed throughout the load with sprinklers to ensure complete coverage at the rate of approximately 1 liter of water per 1 kilogram of corn per hour. For example, a truck containing 5 tons of freshly harvested sweet corn would require approximately: 5000 liters of water per hour. Well water temperatures during the summer average about 15°C, low enough to reduce markedly the total cooling load and thus the cost of subsequent refrigeration.

The care given sweet corn during harvesting should be matched by the attention it receives during packing. At the packing shed, sweet corn should be trimmed uniformly to eliminate flag leaves and long shanks. If left on the ear, they will cause packaging problems and induce further moisture loss. Objectionable kernel denting may occur with a moisture loss of 2 percent or less. Only first-quality sweet corn devoid of defects and of uniform maturity, color, shape, and size should be selected and packed. Any ears exhibiting signs of disease or mechanical or insect damage should be discarded along with any ears that lack adequate shuck coverage.

Most sweet corn in US is packed in wirebound crates holding 42 pounds net weight. Cabbage bags containing 4 1/2 to 5 dozen ears and wax-impregnated cartons containing 50 pounds net are also used. New growers should always consult with buyers to determine what type of shipping container they prefer. Buyers often perceive produce shipped in non-standard containers to be of lower quality than that shipped in standard containers.

9.3.2. Cooling and Storage

The taste and quality of sweet corn depends heavily upon its sugar content, which rapidly decreases after harvest if ears are allowed to remain at field temperatures. By lowering the temperature, the conversion of sugar to starch may be substantially slowed but not completely stopped. Loss of sugar is about four times as rapid at 10°C as at 0°C.

Newer supersweet cultivars contain over twice as much sugar as standard varieties and are more forgiving of delayed cooling and mishandling. For maximum quality and value, however, sweet corn must be continuously and properly refrigerated from harvest until it reaches the consumer.

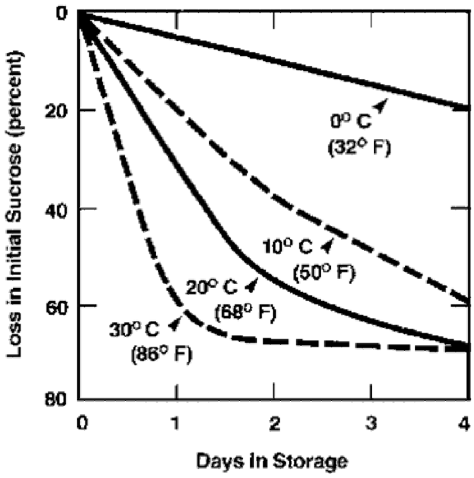

Figure 106. Loss of sugar during storage at four different temperatures. (Source: USDA handbook No. 66: The Commercial Storage of Fruits, Vegetables, and Nursery Stocks.)

Figure 106 demonstrates the effect of various storage temperatures on loss of sweetness. The ideal cooling process for sweet corn removes field heat rapidly and reduces the temperature to near 0^{o}C. This is done in a two-stage process starting with hydrocooling of either packaged or loose corn. Hydrocooling by drenching or immersing in near-freezing water is effective in removing the critical highest heat (the upper two-thirds, or three-quarters of the difference between the harvest temperature and the water temperature). Because the rate of heat transfer is proportional to the temperature difference, hydrocooling removes heat much faster at the start of the cycle than at the end.

The nomograph in Figure 107 illustrates this point. For example, assume that the temperature of a load of sweet corn packed in wirebound crates before cool-ing is 25^{o}C and the temperature of the hydrocooler water is 4-5^{o}C. Draw a straight line from the 80-degree mark on the left side of the chart to the 36-degree mark on the right side. The nomograph shows that it will take 25 minutes to remove the first 20 degrees of field heat and nearly 65 *additional* minutes to remove the second 20 degrees of heat. Thus it would be unduly expensive and time-consuming to hydrocool sweet corn for longer than 20 to 30 minutes.

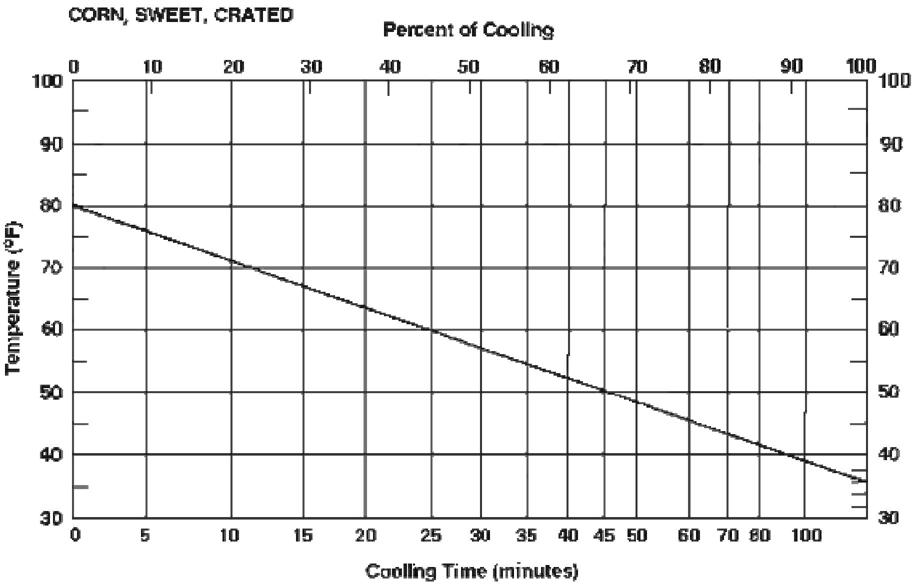

Figure 107. Hydrocooling nomograph for sweet corn in wirebound crates. (Source: USDA Marketing Research Report No. 637. Hydrocooling Vegetables.)

An alternative is to top ice the packaged sweet corn during shipment and store it with large amounts of crushed ice to remove the remaining heat and minimize respiration heat. Enough ice should be placed in each crate to remove the remaining field heat above 0°C and adsorb the heat of respiration plus the heat infiltrating into the transport vehicle or storage building. One kilogram of ice for each 5 kilograms of sweet corn is usually adequate.

Under optimum storage conditions (low temperature and high humidity), sweet corn may not be stored for longer than 5 to 8 days without significant loss of quality. Supersweet varieties seem to maintain an acceptable level of sweetness for a longer period in storage, but reliable information on the rate of quality loss is not available. Loads should be inspected frequently and a suitable fungicide material should be added to the hydrocooler water to prevent disease infestation.

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* This chapter based on the publication [180] which was prepared by M. D. Boyette, L. G. Wilson, E. A Estes, from the North Carolina Agricultural Extension Service of the North Carolina State University at Raleigh, North Carolina Agricultural and Technical State University at Greensboro. For complete information on hydrocooling, refer to Agricultural Extension Service publication AG-414-4, Maintaining the Quality of North Carolina Fresh Produce: Hydrocooling. For information on top icing, refer to Agricultural Extension Service publication AG-414-5, Maintaining the Quality of North Carolina Fresh Produce: Top and Liquid Ice Cooling.

LABOUR EXPENDITURE, COSTS AND EFFECTS IN SWEET CORN PRODUCTION

The lack of traditions in the cultivation of the plant, and of adequate amount of specialized equipment for cob harvesting and processing cause that the technologies currently used for the production of sweet corn kernel are frequently highly expensive and energy consuming. This results from the considerable financial expenditure borne at the particular stages of the technologies used. In this study an attempt has been made at determining the levels of labour and energy expenditure involved in the production of sweet corn kernel. The evaluations were made on the basis of the technologies of manual and mechanized harvest of corncobs.

10.1. ANALYSIS OF LABOUR EXPENDITURE FOR SWEET CORN PRODUCTION

The level of labour expenditure for sweet corn production depends primarily on the kind of production technology employed and on the level of crop yields obtained. Soil tillage, seed sowing and plant care measures are similar in all the technologies available, and the levels of labour expenditure is also similar. The greatest differences in labour can be observed in the case of different methods of cob harvest and transport. For the calculation of labour expenditure involved in sweet corn kernel production the following formula was applied [17]:

$$N_r = \frac{\sum_{i=1}^{n} L_i}{F} \ (\mathrm{rbh \cdot ha^{-1}}) \qquad (17)$$

where:

N_r – labour expenditure, (rbh·ha^{-1}) (rbh – man-hour)
L_i – number of man-hours per operation, (rbh·ha^{-1})
i – item number of successive technological operation, i = 1-n
F – sweet corn cultivation area, (ha)

Table 40 presents the level of labour expenditure involved in the production of sweet corn kernel with hand and combine harvesting of cobs. Cob yield adopted for the calculations was 12 t·ha^{-1}. Figure 108 presents the structure of direct labour expenditure in cob harvest by hand, and Figure 109 – the corresponding labour structure in the case of combine harvest of corncobs.

Table 40. The size of labour expenditures defeated for hand and combine harvest of sweet corn cobs [57]

Contents	Manual cobs harvesting		Combine cobs harvesting	
	rbh·ha^{-1}	rbh·t^{-1}	rbh·ha^{-1}	rbh·t^{-1}
The expenditures of totality labour	195,2	16, 27	49,7	4,14
– tillage and seasoning soil	12,6	1,05	12,6	1,05
– fertilization and plants' protection	9,4	0,78	9,4	0,78
– sowing of seeds	3,2	0,27	3,2	0,27
– harvesting of cobs	145,0	12,08	5,0	0,42
– transportation of cobs	6,2	0,52	2,7	0,22
– processing of cobs	18,8	1,57	16,8	1,40

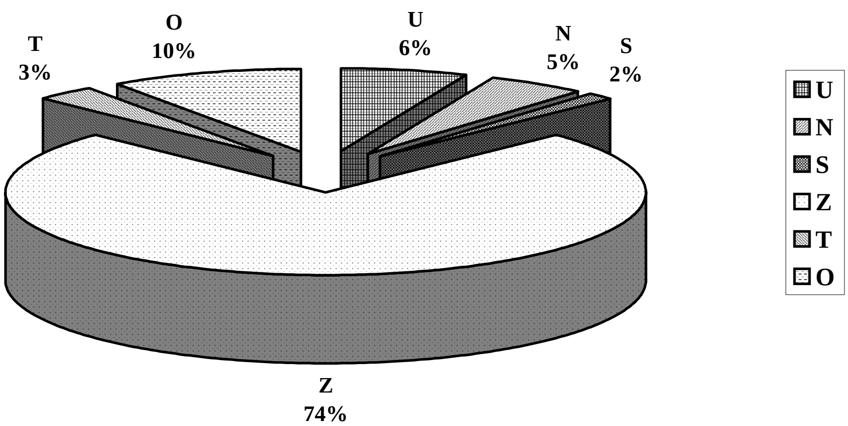

Fig. 108. The structure of labour for hand harvestring of cobs: U – tillage and seasoning soil, N – fertilization and the plants' protection, S – sowing of seeds, Z – gathering of cobs, T – transportation of cobs, O – processing of cobs [91]

Data presented in Table 14 and in Figures 108 and 109 indicate that in the case of technology with sweet corn cob harvesting by hand the labour expenditure is four-fold higher as compared to the labour expenditure in technology with combine harvest of cobs.

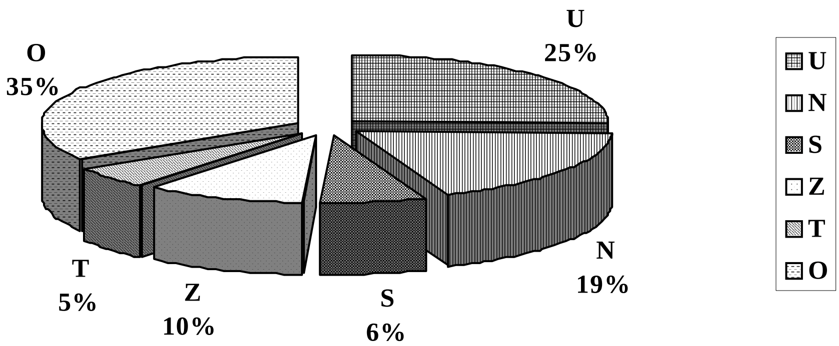

Fig. 109. The structure of labour expenditures for combine harvesting of cobs: U – tillage and seasoning soil, N – fertilization and the plants' protection, S – sowing of seeds, Z – harvesting of cobs, T – transportation of cobs, O – processing of cobs [91]

Overall labour expenditure in the technology with cob harvesting by hand is very high in comparison to that for combine harvest. In both cases the same variants of tillage, fertilization and sowing were used. The greatest difference in labour is related to the process of cob harvest (140 $rbh \cdot ha^{-1}$) and cob transport (3.5 $rbh \cdot ha^{-1}$). With cob harvesting by hand, the labour involved just in cob picking from the plants amounted to about 74% of all the labour involved in the whole process of corn production. This follows from the fact that with cob picking by hand the cobs, as a rule, are carried to the edge of the field by the pickers themselves or by helpers, which is a factor absent from combine harvesting, where cobs are automatically loaded onto means of transport. Moreover, cobs harvested by combine have fewer cover leaves, which reduces the level of labour necessary for processing.

10.2. ANALYSIS OF ENERGY CONSUMPTION IN SWEET CORN PRODUCTION

The amounts of mechanical and electric energy consumed in the particular technological operations were calculated according to the relation:

$$N_e = \frac{\sum_{i=1}^{n} M_i \cdot K \cdot L_1}{Q_z} \text{ (kWh·t}^{-1}\text{)} \qquad (18)$$

where:

N_e – expenditure of mechanical and electric energy, (kWh·ha^{-1})
M_i – nominal power of tractor, (kW)
K – index of tractor power utilization, K = 0,6-0,9
L_i – number of man-hours for given operation, (rbh·ha^{-1})
i – item number of successive technological operation, i = 1-n
Q_z – yield of corncobs, (t·ha^{-1}).

Like in the case of calculation of labour expenditure, a comparison was made of the mechanical and electric energy consumption in the process of sweet corn production with hand and combine harvest of cobs. The results are presented in Table 41 and in Figures 110 and 111.

Table 41. The size of mechanical and electrical expenditures defeated for hand and combine harvest of sweet corn cobs [91]

Contents	Manual cobs harvesting		Combine cobs harvesting	
	kWh·ha^{-1}	kWh·t^{-1}	kWh·ha^{-1}	kWh·t^{-1}
The expenditures of totality labour	662,2	55,18	916,9	76,41
– tillage and seasoning soil	340,8	28,40	340,8	28,40
– fertilization and plants' protection	106,5	8,88	106,5	8,88
– sowing of seeds	44,3	3,69	44,3	3,69
– harvesting of cobs	0,0	0,00	284,7	23,72
– transportation of cobs	98,2	8,18	75,2	6,27
– processing of cobs	72,4	6,03	65,4	5,45

As follows from the presented data, energy expenditure in the technology with hand harvest of cobs is approximately 1.5-fold lower compared to that in the technology with combine harvest of cobs. This is related to the fact that cob harvest by hand does not require the application of additional sources of energy.

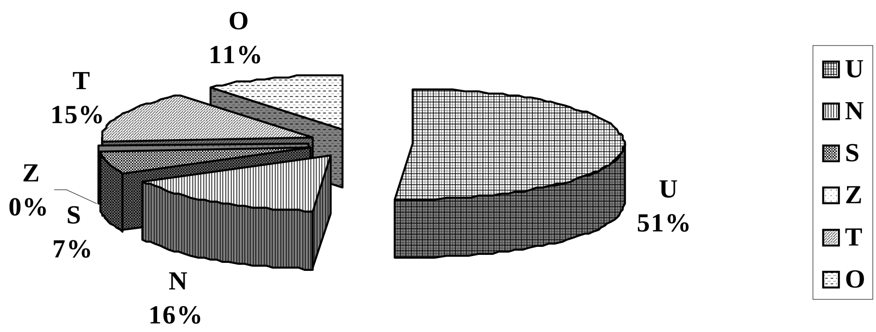

Fig. 110. The structure of enegetic expenditures for hand harvesting of cobs: U – tillage and seasoning soil, N – fertilization and the plants' protection, S – sowing of seeds, Z – harvesting of cobs, T – transportation of cobs, O – processing of cobs [91]

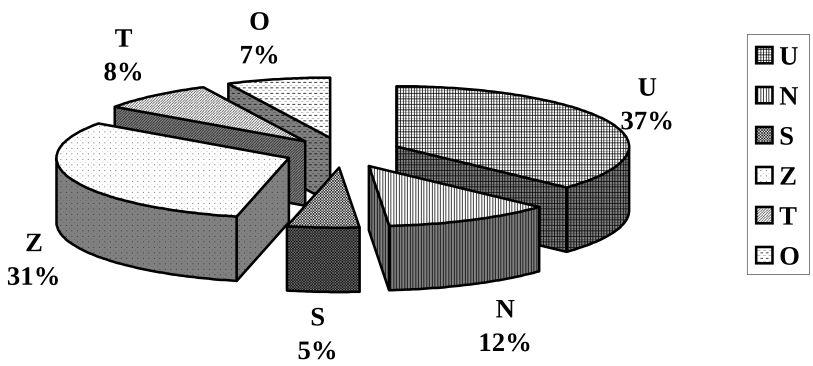

Fig. 111. The structure of enegetic expenditures for combine harvesting of cobs: U – tillage and seasoning soil, N – fertilization and the plants' protection, S – sowing of seeds, Z – harvesting of cobs, T – transportation of cobs, O – processing of cobs

Comparing the structure of energy expenditure in the two technologies, the greatest amounts of energy were spent on soil tillage and seasoning (51% in the case of cob harvest by hand and 37% in the case of combine harvest of cobs). This was related to the use of traditional technology of soil tillage and preparation for seed sowing a considerable part of the energy expenditure (about 31%) was related to the mechanical harvest of cobs in the case of the combine technology. In the case of the technology with hand harvest of cobs, higher energy expenditure was related to cob transport and processing. The remaining elements of energy expenditure, related to fertilization and plant protection, were on a similar level in both the technologies. Overall, much greater amounts of energy were consumed by the combine harvest of cobs, even though cob harvest by hand involved increased energy expenditure on cob transport and processing.

10.3. ECONOMIC EVALUATION OF SWEET CORN PRODUCTION

Studies conducted hitherto on the economic effectiveness of sweet corn production indicate that sweet corn is one of the more profitable crops. In most cases, income per one hectare of sweet corn plantation exceeds the economic effects from the production of wheat, rape, potatoes, or sugar beet [86,149].

In recent years, a considerable deterioration has been observed in the profitability of the production of various crop plants. Such a situation forces the producers to search for crops that will bring in more income. Species and varieties of plants that are less known are more rarely grown may fetch relatively high prices on the market, and thus increase the income from agricultural production and stimulate increase in the level of production. Sweet corn is such a plant that begins to find a place in the Polish agriculture and processing. Whether it is grown for direct consumption or for the processing industry, sweet corn does not essentially differ in the methods of cultivation from fodder corn, but the methods of harvesting, utilization and marketing, as well as the economic effects obtained, are notably different.

The profitability of sweet corn production is very high, in spite of the high level of expenditure involved. It is, however, strongly related to the direction of crop utilization and to the level of crop yields obtained. Direct retailing by the producer allows the possibility of negotiating the selling prices, which affects the level of income generated, as opposed to wholesale delivers for the processing industry, where the buyer dictates the price. Individual selling of corn cobs is burdened with a high level of commercial risk, as the demand is not guaranteed, as well as involves higher levels of costs related to stages harvest, storage, and transport over sometimes considerable distances.

Under favorable conditions, one hectare of sweet corn plantation can yield 50–60 thousand cobs, which is equivalent to 12–15 tons. Crop yields on such a high level can be obtained with favorable weather conditions and perfect cultivation technique. However, one should consider the fact that some of the cobs produced may be outside of the quality classification and their commercial value will be considerably lower. Therefore, sweet corn crop yields at the level of 10 tons or 40 thousand cobs per hectare should be accepted as more realistic and possible to achieve under average soil and climatic conditions [57,87,88,147].

To analyze the profitability of sweet corn production, we present, in tabulated form, the material and labour expenditure involved, together with its structure, as well as the level of income obtained through selling to the processing industry and to the fresh produce market for direct consumption. The calculation was made for 1 hectare of sweet corn plantation, at current levels of costs and prices, with the following assumptions:

- Biological yield of sweet corn of 10 tons or 40 thousand cobs.
- Selling price to processing plant at 420 PLN·t^{-1}.
- Mean selling price of 1 corncob at 0.65 PLN·pc^{-1}.
- Labour expenditure for hand harvest of about 140 rbh·ha^{-1} at labour cost of 10 PLN·ha^{-1}.
- Cost of qualified seed, for sowing with relation to MTN and at plant density of 80 thousand plants·ha^{-1}, i.e. 360 PLN·ha^{-1}.
- Cost of mechanized harvest, at combine productivity of 0.2–0.4 ha·h^{-1}, i.e. 3 h·ha^{-1} x 220 PLN·h^{-1} = 660 PLN·ha^{-1}.
- Cost of cob storage in refrigerated storage room for 12 days, i.e. 12 days x 24 h x 4 kW of refrigeration system power x 0.36 PLN/kWh – average unit price of electric power = 415 PLN.
- Costs of marketing and selling, searching for potential buyers, delivery to distant localities, with goods sold within 20 days at cost of one day at 150 PLN.
- Percentage of well formed and kernelled cobs in the whole crop are usually 60–80%. Value taken for the calculation - 40000 cobs x 70% = 28000 cobs of full market value.
- Fertilization and plant protection: cost of fertilizers - 500 PLN. Cost of herbicides - 150 PLN.

The costs and their structure, the income, the rate of return, and the profitability of sweet corn production are characterized by the data in Table 42. The data show that the production of sweet corn, both for the processing industry and for the fresh produce market, brings income at the rate of return of 168% and 281%, respectively, and its profitability is higher by about 110% in the case of selling to the fresh produce market as compared to deliveries for the processing industry. The rate of profitability was calculated as the ratio of income from selling sweet corn production from 1 ha to the costs incurred for the production.

Table 42. The costs accounting of sweet corn production on delivery for processing industry or on market to direct consumption [57]

Contents	Selling of cobs, (PLN)		Structure of costs, (%)	
	for processing	vegetable on market	for processing	vegetable on market
1. Costs of materials, (PLN)	1010,-	1010,-	40,1	15,6
– sedes,	360,-	360,-	14,3	5,6
– NPK fertilizers,	500,-	500,-	19,8	7,7
– herbicides,	150,-	150,-	6,0	2,3
2. Costs of equipment labour, (PLN)	1510,-	5465,-	59,9	84,4
– tillage,	200,-	200,-	7,9	3,1
– seasoning,	150,-	150,-	5,9	2,3
– fertilization and spraying,	120,-	120,-	4,8	1,9
– seeds sowing,	80,-	80,-	3,2	1,2
– land tax,	100,-	100,-	4,0	1,5
– harvesting,	660,-	-	26,2	-
– manual harvest,	-	1400,-	-	21,6
cobs storage in refrigerator,	-	415,-	-	6,4
– selling costs	200,-	3000,-	7,9	46,4
3. Total costs, (PLN)	2520,-	6475,-	100,0	100,0
4. Price of the sale, (PLN)	0,42 PLN/kg	0,65 PLN/pcs	-	-
5. Value of the crop, ($PLN \cdot ha^{-1}$)	4200,-	18200,-	-	-
6. 3/4 Index of defrayment – 3/4	6,0 t	9962 pcs.	60,0	35,6
7. Costs of production, (PLN) - 12/10000 kg, - 12/28000 lub – or - 12/40000 szt. – pcs	0,25 $PLN \cdot kg^{-1}$	0,16 PLN/pcs. 0,23 PLN/pcs. 0,16 PLN/pcs 0,23 PLN/pcs	-	-
8. Profit with ha – 5/3	1680,-	11725,-	16,2	617,1
9. Profitability (%)	168,0	281,0	-	-
10. Rate of sale rentability – 8/5	40,0	64,4	-	-

The profitability of sweet corn production, that is net profit was calculated as the difference between the sale income from one hectare and the total costs incurred in a given production cycle, where it reached the value of 1680 $PLN \cdot cob^{-1}$ when the produce was sold to the processing industry and as much as 11725 $PLN \cdot ha^{-1}$ when the produce was sold to the fresh produce market for direct consumption. The calculated cost of production per crop yield unit, as the ratio of total costs incurred and the amount of crop yield obtained, is

0.25 PLN·cob^{-1} when selling to the processing industry and 0.16 PLN·cob^{-1} when cobs are sold for direct consumption.

Also calculated was the index of cost return, as the minimum crop yield that guarantees the recovery of the costs incurred. It is the ratio of the total costs of production to the selling price. When the corn was sold to the processing industry the index was 6.0 t, and when cobs were sold for the fresh produce market for direct consumption it was 9962 sweet corn cobs. Another index calculated in the analysis was the rate of profitability on sales, as the ratio of net profit obtained from 1 ha to the crop yield – income from sells of product from 1 ha. In this situation, with product sold to the processing industry the value of the rate of return was 40%, and when the produce was sold to the fresh market it was 64.4%. The index of profitability provides information on the percentage of net profit in the selling value of the goods. A lower value of the index means that a greater volume of product has to be sold to obtain a certain level of profit. A higher value of the index means better economic effectiveness of production.

The presented economic parameters of the example calculation indicate clearly the very high profitability of sweet corn production for the fresh product market, where the income from 1 hectare, at about 12 thousand PLN, is almost 7-fold higher than the income achieved from selling to the processing industry that was about 1700 PLN·ha^{-1} and constituted only 14.3% of the income achieved in the former case. Somewhat different relations were observed in the analysis of the index of profitability, where the differences in the values of the index are not so vastly divergent as in the case of the income, the index values being 168% with product selling to the processing industry and 281% when the cobs are sold to the fresh produce market for direct consumption.

The drop of the index of profitability in the latter case is the result of incurring very high total costs of production, in which major item in the cost structure is the cost of marketing and sales at 46.4% of the total costs of production. The index of cost return illustrates the minimum level of production that guarantees recovery of expenditure – costs of production. With product being sold to the processing industry, that minimum level of production is 6000 kg, which is 60% of the crop yield obtained, while when the produce is sold to the fresh market the minimum is 9962 cobs, which constitutes 35.6% of the crop obtained, adopted for the calculations in accordance with item 9 of the assumptions. It should be noted that the value of the parameter is significantly affected by the unit price obtained for the product; the price level being dependent on the market conditions i.e. the levels of demand and supply.

A much lower effect is that of costs of production which are basically constant in terms of their level and structure. The cost of production of a unit of marketable crop is illustrated by the level of expenditure per unit of production which, with the product being sold to a processing plant, amounts to

0.25 PLN·kg^{-1}, and when selling to the fresh produce market 0.16 PLN·cob^{-1}and is lower by as much as 0.09 PLN per a single production unit.

The presented economic parameters clearly show, in each of their elements, the profitability of sweet corn production with an indication in favor of deliveries to the fresh produce market for direct consumption, where income per 1 ha is the highest and the remaining economic indices are also considerably better than in the case of corn deliveries to the processing industry. It should be noted that the analysis did not include the element of commercial risk which is very high in the case of deliveries to the fresh produce market. Moreover, the culture of sweet corn consumption in this country is not stabilized as yet, and the persisting stereotypes may considerably reduce the net income and the attractiveness of the other economic indices.

According to Warzecha (154), the technology of sweet corn production is similar to that for fodder corn. However, he points out to certain differences, such as separation (about 300 m) from fodder corn plantations and separation between fields of sweet and very sweet corn varieties, as potential cross-pollination would result in strong deterioration of the quality of the material produced. Sweet corn has higher thermal requirements during seed germination than fodder corn, and of the varieties with regular or enhanced sugar content. Optimum sowing time for sweet corn is from 5th to 20th May. Lower plant density is recommended - 5 to 6 plants per 1 m^2 (50-60 thousand per 1 ha). Sweet corn is sown less deep than fodder corn; in more cohesive soils about 3-4cm, in lighter soils down to 5 cm. To recapitulate, costs of sweet corn cultivation are considerably higher than for fodder corn. Expenditure per 1 ha is about 3-4 thousand PLN. Approximately 50% of the costs is the cost of seed whose price can be up to 150 PLN·kg^{-1}. Also cob harvesting is very expensive, usually by hand and multiple in the Polish conditions, as cob ripening is not uniform. Prior to taking the decision to grow sweet corn one has to have a market secured for the product, as during the relatively short period of time of cob ripening the supply of cobs is so high that there is now way to utilize them all and rapidly they lose their taste qualities and technological value.

Hence a very important element of sweet corn cob production profitability, apart from the productivity per hectare and the level of expenditure, is the price that can be obtained in the market, irrespective of the form of sale. The possibility of selling the product and obtaining a good price should be the deciding element in the process of deciding on starting sweet corn production.

Chapter 11

SWEET CORN IN HUMAN NUTRITION*

Corn is a tall cereal plant consisting of strong jointed stems supporting large ears containing kernels. Out of the different types of corn grown, sweet corn is one of the most popular varieties for human consumption. Sweet corn is a good source of vitamin A, magnesium, and potassium, and is often considered to be a vegetable, rather than a grain. This confusion is probably due to the fact that it is eaten fresh like a vegetable. When harvested at the proper ripeness, the kernels of sweet corn are tender and have a sweet, juicy taste. The three types of sweet corn that are readily available are white corn (white kernels), yellow corn (yellow kernels), and a hybrid of both white and yellow, often referred to as peaches and cream or butter and sugar corn. Sweet corn can be processed into syrup, sugars used as sweeteners in soft drinks, starch, and cereals.

During the summer months when it is available fresh, it is most often cooked and eaten on the cob. Sweet corn is also cut off the cob and eaten as a vegetable side dish or added as an ingredient to other dishes, such as soups, stews, casseroles, and salads. The corn can be cut from the cob, raw or cooked, and then preserved by canning or freezing for future use.

Sweet corn is at its best during the late summer months to early fall. An exception to that is in Florida where sweet corn is harvested from fall to spring. To receive the best flavor from sweet corn, it should be eaten as soon as possible after it is picked because the sugars will begin to convert to starches as soon as it has been picked.

When selecting, look for husks that have good green coloring with pale colored silk. To check the freshness, pull the top of the husk away from the ear and pierce a kernel with your fingernail. If the kernel releases a slightly cloudy juice it is typically a fresh batch. If the kernels are dented or discolored, the corn is not fresh. Avoid sweet corn with dried or dark colored silk or discolored husks. Buying sweet corn from a road side stand may result in corn that has lost much of its sweetness from being exposed to high temperatures. The high temperatures will rapidly convert the corns sugar to starch, causing it to lose some of its sweet flavor.

* Kitchen advice, kitchen techniques and all about sweet corn in this chapter is prepared by Hormel Foods (source: www.hormel.com)

11.1.Varieties

Yellow Sweet Corn

The largest portion of the different varieties of sweet corn are yellow sweet corn. All the kernels on the cob are yellow in color. The size of the cob and the corn's taste will vary between different varieties. Most commercially grown sweet corn is yellow.

Peaches and Cream Corn

Peaches and Cream corn, also referred to as butter and sugar, differ from the other varieties in that it contains both white and yellow kernels. White and yellow kernel sweet corn is not generally grown for commercial use. It is more often found at local markets.

White Corn

White sweet corn varies from the others in that it has all white kernels. It has the same sweet and juicy flavor as the yellow corn and the peaches and cream corn. It is used in the same manner as yellow corn. White sweet corn is not generally grown for commercial use. It is more often found at local markets.

11. 2. Storage

To store corn, leave the corn in the husk and refrigerate as soon as possible. If corn has been husked, place it in a plastic bag and store in the refrigerator. It is best to eat it as soon as possible. Corn cut off the cob can be frozen for 6 months to a year.

11.3. Sweet Corn Preparation

11.3.1. Shucking - Removing the Husk from the Sweet Corn

Shuck the corn by peeling back the husk and completely removing it. Remove the thin silk that runs along the kernels of the corn. Remove excess silk with a vegetable brush or with a damp paper towel.

Break or cut off any remaining corn stalk. The corn is now ready to cook. Remove silk when shucking corn by using a damp paper towel for collecting the silk. Moisten the paper towel and hold the towel against the cob, moving the towel down the cob and allowing the silk to stick to the towel. This method works well for removing small strands of silk that often adhere to the cob after the leaves are removed. This method protects the kernels by not having to use other methods of removal that cause damage.

Fig 112. Removing excess silk with a vegetable brush or with a damp paper towel.

11.3.2. Removing Kernels from the Cob

The sweet corn kernels can be removed from the cob and cooked as a side dish or added as in ingredient in other dishes. The kernels are also cut off the cob to be canned or frozen so they can be stored for future use.

Remove kernels by standing the ear of corn upright on a cutting board. Using a sharp utility or chef's knife, cut the kernels straight down along the corn cob to free numerous rows of kernels at the same time.

Fig 113. Removing kernel by cutting

11.4. Cooking Corn on the Cob

The most popular way to eat sweet corn is on the cob. It is generally husked before cooking but can be cooked using methods that call for the husks to be left on. When boiling sweet corn, avoid adding salt to the water because it will cause the corn to toughen when it cooks. Also, it is important to cook the corn only until it is tender. Overcooking will cause the corn to lose its sweet flavor and will cause the kernels to become tough. The instructions below show several methods that can be used for cooking corn on the cob.

11.4.1. BOILING - METHOD 1

This method works well when cooking larger quantities of corn on the cob. Place shucked corn into a large pot and cover with cold water. Add a tablespoon of sugar to keep corn sweet and tender. Cook corn over high heat and when water comes to a rapid boil, the corn is done. Do not overcook. Remove from the heat, drain, and serve. Corn can stand in the hot water (away from heat) for 5 or 10 minutes.

Fig. 114. Cooking larger quantities of corn on the cob

11.4.2. BOILING – METHOD 2

This method also works well when cooking larger quantities of corn on the cob.

Add enough water to a large pot to cover corn when it is added. Be sure you do not add too much so that the water overflows when the corn is added. Add a tablespoon of sugar if desired.

Bring the water to a full boil and then add the corn to the water.

Fig. 115. Cooking by adding the corn to the boiling water

Allow the water to come back to a boil and then cover and turn off the heat. Allow the corn to stand in the hot water for 5 to 7 minutes. Do not overcook. Remove finished corn from the cooking water and serve while warm.

11.4..3. BOILING – SMALL QUANTITIES

This method works best when cooking smaller quantities of corn on the cob.

Place water in a deep skillet. Add at least an inch of water but do not add too much that the water will overflow when corn is added. Add approximately ½ tablespoon of sugar to the water. Do not add salt.

Fig. 116. Cooking in the flat pot

Bring the water to a boil. Place shucked corn into the skillet. The corn does not have to be completely covered.

Allow the water to come back to a boil and then cook the corn for 5 to 7 minutes, depending on desired tenderness. Turn once half way through cooking time. Do not overcook. Remove corn from the cooking water and serve while warm.

Fig. 116. Turning cobs through cooking time

11.5. MICROWAVE

Microwaving corn on the cob is a quick simple method to use when cooking only a few ears of corn. The cooking time will vary slightly depending on the strength of the microwave. Microwaving eliminates the time necessary to boil the water for cooking the corn on the stove top but if microwaving more than 3 or 4 ears, it may be just as fast to use one of the boiling methods.

11.5.1. MICROWAVE - HUSKS ON

Pull back the husks about three quarters of the way down the ear and then remove the silk After the silk is removed, pull the husks back up around the ears.

Place the ears in a pan of water and allow to soak for 20 to 30 minutes.

Place wet corn on a paper towel in the microwave. Microwave on high from 3 to 5 minutes. Turn cobs and microwave an additional 3 to 5 minutes, depending on desired tenderness.

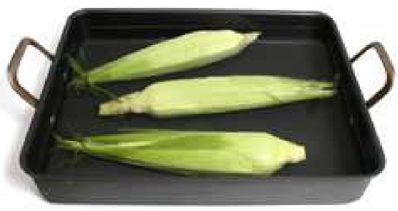

Fig. 117. Soaking cobs in a pan of water

After the corn is done cooking in the microwave, remove the ears and allow to stand for 1 minute before serving.

When ready to serve, remove the husks from the ears of corn. Husks should be easy to remove. Serve with butter and favorite seasoning.

Fig. 118. Removing husks from cobs

11.5.2. MICROWAVE - BAKING DISH

Place husked ears of corn in a baking dish that is microwave safe and add some water, approximately 2 to 3 tablespoons.

Cover ears of corn tightly with plastic wrap. Microwave for 6 minutes and then remove from the oven. Pull back the plastic wrap, being careful of any steam escaping, and then turn ears over.

Fig. 119. Covering cobs with plastic wrap

Replace the plastic wrap and return the corn to the microwave to cook for an additional 5 minutes.When done, allow corn to stand in the microwave for 2 or 3 minutes. Remove from the microwave and carefully remove the plastic wrap.

Remove the corn from the baking dish and serve while warm.

Fig. 120. Preparing cobs for additional cooking in the microwave

11.5.3. MICROWAVE – INDIVIDUALLY WRAPPED

Fig. 121. Wraping each corn in a damp paper towel or wax paper and removing paper before serving while are warm

Rinse ears of shucked corn and wrap each ear in a damp paper towel or wax paper. Microwave on high for 3 or 4 minutes. Turn cobs and microwave for an additional 3 to 4 minutes, depending on desired tenderness. When the corn is done, allow it to stand for 1 minute before eating. Remove the paper towels or wax paper and serve while warm.

11.6. GRILLING SWEET CORN

11.6.1 HUSKS ON - METHOD 1

Fig. 122. Pelling back the husk whithout removing it from the cob

Fig. 123. Preparing corn for soaking before grilling

Peel back the husk without removing it from the corn cob. Remove the thin silk that runs along the kernels of the corn. Remove excess silk with a vegetable brush or with a damp paper towel. Fold husk back. Secure husk with kitchen twine. Soak the corn in water for 1 to 3 hours before placing on the grill.

Fig. 124. Turning cobs on grill throughout cooking time

Fig. 125. Serving after grilling

Place prepared corn on the grill directly over medium heat. Cook 20 to 30 minutes, turning frequently throughout cooking time. Corn is done when it starts to steam.

When done, the husks will be charred but the corn inside the husks will be sweet and tender with a nice roasted flavor.

11.6.2 Husks On - Method 2

1. Using a kitchen scissors, trim excess silk from the end of the corn.
2. Soak corn in cold water for a minimum of 1 hour.
3. Before placing on grill, shake to remove excess water.
4. Grill for approximately 25 to 30 minutes, turning frequently.
5. The husk and any remaining silk is removed after grilling. Use heat resistant gloves to protect your hands.

11.6.3. Husks Off – Method 1

Shuck the corn as shown above by peeling back the husk and completely removing it. Remove the thin silk that runs along the kernels of the corn. Remove excess silk with a vegetable brush or with a damp paper towel. Break or cut off any excess corn stalk.

Fig. 126. After spreading butter and seasoning, wraping each ear tightly with the aluminium foil

Fig. 127. Puncturing the foil before grilling

Wrap each individual ear in aluminum foil. Spread softened butter on the ear and then season as desired. After spreading butter and seasoning, wrap each ear tightly with the foil. Puncture the foil to allow excess steam to escape while grilling. Place the foil wrapped corn on the grill directly over medium heat. Cook for 20 to 30 minutes, turning frequently throughout cooking time.

Remove corn from the grill and carefully open the foil wrap. Check corn for doneness. If it is not done, wrap the ear back up and place it back on the grill for 4 or 5 additional minutes.

Fig. 128. Additonal 5 minutes grilling

11.6.4. Husks Off - Method 2

Fig. 129. Pulling husks back

Fig. 130. Spreading butter mixture on the ear of corn

Fig. 131. Grilling directly over medium heat

Mix 6 tablespoons of softened butter with 1 clove of garlic (minced) and 1 to 2 tablespoons of minced parsley. Stir butter mixture until smooth and then spread lightly on the ear of corn.

Place corn on the grill directly over medium heat. Arrange so that the husks hang off the edge of the grill or place foil under the husks in the area the husks will be placed. This will prevent them from burning. Cook for 10 to 12 minutes. Turn the corn frequently during the cooking time. Brush ears with the remaining butter mixture as they are cooking.

Fig. 132. Turning corn during the grilling time

When the corn is done the ears will be golden brown. Remove from the grill and serve while warm.

11.7. FREEZING SWEET CORN

Husk and clean silk from corn as shown above in Sweet Corn Preparation. To freeze 2 to 2 ½ dozen ears of corn, you will need the following ingredients:

- 14 cups of corn cut from the cob (24 to 30 ears of corn)
- ¾ cup sugar
- 1/8 cup salt
- 7 cups water

Fig. 133. Removing kernels by cut off

Fig. 134. Filling pot with kernels

Remove kernels by standing the ear of corn upright on a cutting board or inside a pan that can be used to catch the corn as it is cut off. Using a sharp utility or chef's knife, cut the kernels straight down along the corn cob to free numerous rows of kernels at the same time. Measure out 14 cups of the cut kernels and pour them into a large pot. Add the sugar and salt to the corn.

Pour in 7 cups of water. Adjust amount of water to just cover corn. Stir well to mix all ingredients together. Bring corn mixture to a boil. Boil 1-5 minutes to desired tenderness.

Fig. 135. Adjusting water to cover corn

Fig. 136. Quick cooling of corn on large sheet

Allow corn to cool. Spreading corn onto a large cookie sheet will cool the corn quicker.

Scoop corn into plastic freezer bags, include a small amount of the remaining water mixture in each bag. Seal bags tightly and then flatten corn filled bag and place in freezer. Flattening the bags will allow them to stack neatly in the freezer.

Fig. 137. Preparing bags for freezing

TIPS

With a permanent marker, write the date the bag of corn was frozen for future reference.

- Do not add salt to the water when cooking sweet corn because the salt will toughen the corn. Add a little sugar to the water to boost the flavor.
- Sweet corn will lose its sweetness much faster if stored at room temperature compared to storing in the refrigerator. Do not husk before storing in the refrigerator. Husk just before preparing. It is best to eat it as soon as possible after it has been picked.
- Two to three medium ears of corn are equivalent to approximately 1 pound, depending on ear size. Two medium ears equal approximately 1 to 1 1/2 cups of kernels.
- If harvesting your own sweet corn, it is best to pick it early in the morning and eat it as soon as possible. If not cooking it soon after it is picked, store in the refrigerator until ready to cook.

CHAPTER 12

SUMMARY AND CONCLUSIONS

The use value of sweet corn, resulting from its high nutritional values, taste qualities, and extensive possibilities of application, fully justifies the sense of increasing the area of its variation. The search for new and more efficient methods of harvest at simultaneous assurance of favorable economic effects and high quality requirements for the sweet corn cobs and kernel produced, become a necessity.

Sweet corn cobs harvested for the processing industry are subjected to machining consisting in the kernel cutting off from cob core. Since a considerable part of sugars is cumulated in the lower part of the kernel, it is recommended to cut kernels off cobs as close to the core as possible. The irregular shape of kernels and their low content of dry mass (approx. 27%) are the reason for frequent mechanical damage to kernels. Kernels, especially those located at extreme parts of the cob, differ in their size and hardness. Also the shapes of cobs (cylindrical or tapered) and their variable size (variety-related) make the detachment of kernels more difficult. Hence the process of kernel cutting off from cob cores is a major problem for the processing industry.

The research problems set for this study have been verified through experimentation and with statistical methods, with the help of methodology and test equipment developed for the purpose. The verification of the research problems was based on analyses of the following:

a) in quasi-static tests:

- values of shearing force at three points on kernel length, designated as: measurement position 1 (2/3 from kernel base), measurement position 2 (at kernel base) and measurement position 3 (at cob core), depending on the corn variety,
- values of shearing, penetration and compression force for kernels from four locations on cob length, designated as: measurement position 1 (lower), measurement positions 2 and 3 (cob center), and measurement position 4 (upper), depending on the corn variety,
- loading head speeds within the range from 0.002 to 0.3 $cm \cdot s^{-1}$,

b) in dynamic tests:
– values of shearing force at measurement position 2 on kernel length and at measurement position 2 on cob lengths,
– cob sample speeds of rotation in the range from 130.9 to 194,7 rad·s^{-1} and travel speeds of knife from 0.005 to 0.015 m·s^{-1},

c) in tests on kernel cutter:
– energy consumption of kernel cutting process at measurement position 2 on kernel length and at measurement positions 1, 2, 3, and 4 on cob length, and the quality of the material obtained (share of kernels of inferior quality, amount of kernel mass detached),
– rotary speeds of knife head in the range from 167.5 to 301.2 rad·s^{-1} and linear speeds of cob feeder from 0.31 to 0.92 m·s^{-1}.

Experiments performed under quasi-static conditions showed that the variables studied have a significant effect on changes in the mechanical properties of kernels, i.e. on the shearing, penetration and compression forces, and on the modulus of elasticity and on relative deformation. Changes in the values of the mechanical properties also affected the values of shearing, penetration and compression energy.

In the dynamic tests, shearing force measurements were made at various speeds. The measurements showed that the application of different combinations of cob sample and knife speeds could provide a criterion for the estimation of changes in the shearing force which affects the energetic quality of the process of kernel cutting off. The measurement results obtained indicate considerable variation relative both to the character of their action and to their values. The strength properties reached their highest values in the case of kernels sweet in the lower part of the cob, and the lowest – for kernels from the tip section of the cob. This can be attributed to the varied degree of kernel ripeness and to varying kernel sizes. Kernels from the lower part of the cob, as opposed to the others, are characterized by strong irregularity both in terms of kernel shape and in its setting in the cob. This is an especially unfavorable feature for the process of kernel cutting off on kernel cutters. It has a negative effect on the quality of the material cut off (the condition of the cut section surface) and on the quality of the cutting process (energy consumption).

A similar relationship was observed on the kernel length. In their lower part kernels were characterized by higher hardness than in the upper, which resulted from greater content of fibrous parts, and from the presence of hard and fibrous fragments of the core (husks). In their lower part, kernels are characterized by smaller section area, which is also reflected in increased hardness. These observations are particularly significant in the context of mechanical kernel cutting off under industrial conditions.

Due to the design limitations of the copying-cutting assembly of corn cutters, and to the variability of the morphological features of corn cobs and kernels, to ensure that the actual point of kernel cutting did not diverge significantly from the value set (assumed), the process of kernel cutting in the tests on corn cutters was conducted only on central sections of cobs, with cylindrical shape, i.e. at measurement position 2. The data acquired support those observations, and moreover permit practical improvement of the quality of raw material obtained and a reduction in the energy consumption of the kernel cutting process through increasing the working speeds of corn cutters. Higher working parameters, i.e. higher rotary speed of the knife head and higher speed of cob feeding, result in an increase in the kernel mass cut off. This relationship can be attributed to greater plastic deformation of kernels with high moisture which, at low speeds of cob feeding and knife head rotation are subject to greater deformation in the course of the cutting process. The cutting of such kernels causes shallower cut on the kernel side opposite to the knife blade, and thus the loss of a part of the plant material. At higher cob feeding speeds, and especially at higher knife head rotations, the process of kernel cutting off cob cores is more accurate.

The morphological features of corncobs have a strong effect on the amount of kernel mass cut off. The two-year study on three sweet corn varieties indicates the existence of considerable variability both within a single variety and between different varieties. The variability was observed already at the stage of the physical and chemical tests. The feature, though unfavorable for the kernel cutting process itself, may be a criterion for the selection of sweet corn varieties for processing. Chemical tests, which due to the quality of the material should not be considered in the case of corn kernels separately from the physical properties, showed differentiation in the content of sugars on the length of the kernels. Sugars (especially saccharose) affect the characteristic taste of sweet corn kernel. Limitation of mass losses also entails an increase in the amount of sugars in the material cut, and thus improves the taste quality of the kernels.

On the basis of the laboratory and stand tests and the measurement results obtained, statistical analyses and review of literature of the subject, strength tests on corn kernels, as well as analysis of labour and energy expenditure, the following conclusions can be formulated:

1. The results of studies on the mechanical properties of sweet corn kernels indicate the existence of a strong relation between the parameters analyzed, and the location of kernels on the cob and place of kernel cutting off the cob core.
2. The results of experimental tests showed that the values of the shearing and penetration force and energy are the highest in the case of kernels located on the lower part of the cob, and decrease towards the tip of the cob.
3. All the studied strength properties of sweet corn kernels depend significantly on the variety properties. Moreover, the force and energy values recorded in shearing and penetration tests increase as the kernel cutting zone shifts towards the cob core.

4. Increase in the speed of knife action on the materials studied, both under quasi-static and dynamic conditions, has a significant decreasing effect on the values of all the parameters studied. This results from the decrease in cutting resistance with increasing speed of knife action on the material studied.
5. The quantity and quality of the kernels cut off depend largely on the cutting speed, as well as on other factors, such as cob feeder speed, variety, kernel location on the cob, and kernel-cutting zone.
6. Correct run of the kernel cutting process (smooth cut surface) ensures the lowest cutting resistance possible. Any divergence will result in considerable deformation of the cut surface (crimps and breaks) and in an increase in cutting resistance.
7. Increase in the speeds of the knife head and the cob feeder results in a decrease in the unit energy of cutting by an average of about 76% (from 92 to 40%), in the share of kernels of inferior quality by about 70% (from 81 to 66%), and in an increase in the kernel mass cut off by about 40% (from 23 to 58%).
8. The shape and regularity of corncobs has a strong effect on the kernel mass obtained in the process of cutting. In the case of cob shapes close to cylindrical (Candle) the highest values of kernel mass cut off were obtained, and the quality of the kernel cutting off process was the best.
9. Kernel cutting as close to the cob core s possible entails not only an increase in the kernel mass obtained, but also in the content of sugars which is relatively the highest in that part of the kernels.
10. The mathematical models obtained create the possibility of providing an explanation for the effect of the variables studied on the course of the process of corn kernels cutting off from cob cores, and can constitute a basis for the optimization of the process, the criteria for such optimization being energy consumption and quality of the material obtained.
11. The results obtained in the study can be used in practice, as the experiment performed showed the possibility of increasing the effectiveness of kernel cutting off through altering the operation parameters of the corn cutter.
12. It is justified to undertake comprehensive studies on the strength properties of sweet corn kernels of different varieties, with special emphasis on the effect of those properties on the quality of the material obtained.
13. Analysis of the level of energy expenditure for sweet corn production shows that soil tillage is the most energy-consuming operation. Both in the variant with cob harvesting by hand and in that with mechanized cob gravest the level of energy expenditure was about 340 $kWh \cdot ha^{-1}$. Fertilization, plant protection and seed sowing required much lower levels of energy expenditure (150 $kWh \cdot ha^{-1}$). The corresponding energy expenditure for cob transport and processing was on a similar level (140-170 $kWh \cdot ha^{-1}$).

14. The high purchasing cost of corncob harvesting machines causes that under the conditions of farms involved in small-scale production of the plant cob harvesting by hand is commonly employed. The level of labour expenditure in cob harvest by hand constituted about 74% (i.e. 145 rbh·ha^{-1}) of the total labour expenditure for the whole production process. With small cultivation areas, that method of cob harvest is still the most economical and guarantees high quality of the material obtained. Combine harvesting of corncobs, on the other hand, requires high levels of energy expenditure (150 kWh·ha^{-1}).
15. Combine harvest of sweet corn ensures higher levels of productivity and permits the cutting of cobs at their optimum phase of ripeness, which in the case of this crop plant is of special importance. The latest engineering solutions employed in the design of sweet corn combines ensure material quality on a level similar to that obtained in cob harvesting by hand. A very important role in combine harvesting of sweet corn is played by the proper selection of varieties whose cobs ripening is uniform and which can be harvested in a single pass of the combine. Currently available are sweet corn varieties whose percentage of cobs ripening at the same time exceeds 95%.
16. The quantity and quality of sweet corn kernels cut off depend largely on the kernel moisture and time of harvest, the location of kernels on the cob, the speed of cob feeding to the cutter head, and on the speed of kernel cutting off from the cob cores. Lower kernel moisture (approx. 69%), related to later time of cob harvest, and relatively low working speed of the knife head of the cutter (approx. 167 rad·s^{-1}) result in considerable deterioration in the quality of the material obtained and in an increase in cutting resistance. The kernel mass obtained was also strongly affected by the size and shape of cobs. In the case of close to cylindrical, the highest kernel mass and the best kernel quality were obtained.
17. The time of harvest and the related dry mass content, as well as the variety, are the factors with the strongest influence on the mechanical parameters determined in the strength tests (force, modulus of elasticity, deformation) and on the energy consumption. A similar relationship was observed for the values determined in the process of kernel cutting off on the corn cutter (degree of kernel mass cutting, quality of kernel cut surface, cutting process efficiency and energy consumption).
18. In view of the large number of new hybrid varieties of sweet corn that appear on the market, it is recommended to conduct strength tests to determine their suitability for mechanical harvest and processing of cobs.

Corn, also called maize, is one of the world's major cereal crops and, we are used as flour to make bread, to produce breakfast cereal, to make popcorn and, of course, sweet corn is grown and sold as a vegetable. Sweet corn cobs are long (20-25 cm) and cylindrical in shape. Inside the husks are parallel rows of golden-yellow seeds with soft threads running from the seeds to the top of the cob. The kernels have soft skins and are sweet and milky inside. For optimum quality, harvest of standard sugary cultivars begins when kernels reach 70-75% moisture. For preservation the sweet corn is cut-off from the cob.

Sweet corn is valuable plant about universal use in man's nourishment. The lack of gluten, what is near growth of number of alimentary allergies sweet corn's essential feature it can significantly influence on growth her consumptions. In turn the growth of demand can influence on enlargement surface of her sowings. Climatical requirements and soil they are on majority of area of Poland profitable for her tillage, and therefore to possibly sweet corn's production with success realized on terrain of whole country.

Sweet corn's tillage fully provides market at present, which they are small with regard on lack of consumers' habits. The economic regards about range of the sweet corn's tillage in Poland do not it decide, or else the productive possibilities of farms. The size of production be dependent on first of all from demand as well as utilization possibility of the got crop. The barrier restrictive the production this also lack of well organized guided the sweet corn's national of the raw material market as well as insufficient development of processing industry and cooling.

The requirements in presented monograph were introduced agrotechnical of the sweet corn's tillage as well as profile of accessible changes on our market. Methods of harvesting of corn cobs' and technique of their processing were have talked over also. Analyses' of mechanical process of separation of from cores of cobs as well as estimation of efficiency production the kernel this plant in Poland were executed also.

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CHAPTER 13

COLOUR PHOTO APPENDIX

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(source: www.hartungbrothers.com/imagegallery)

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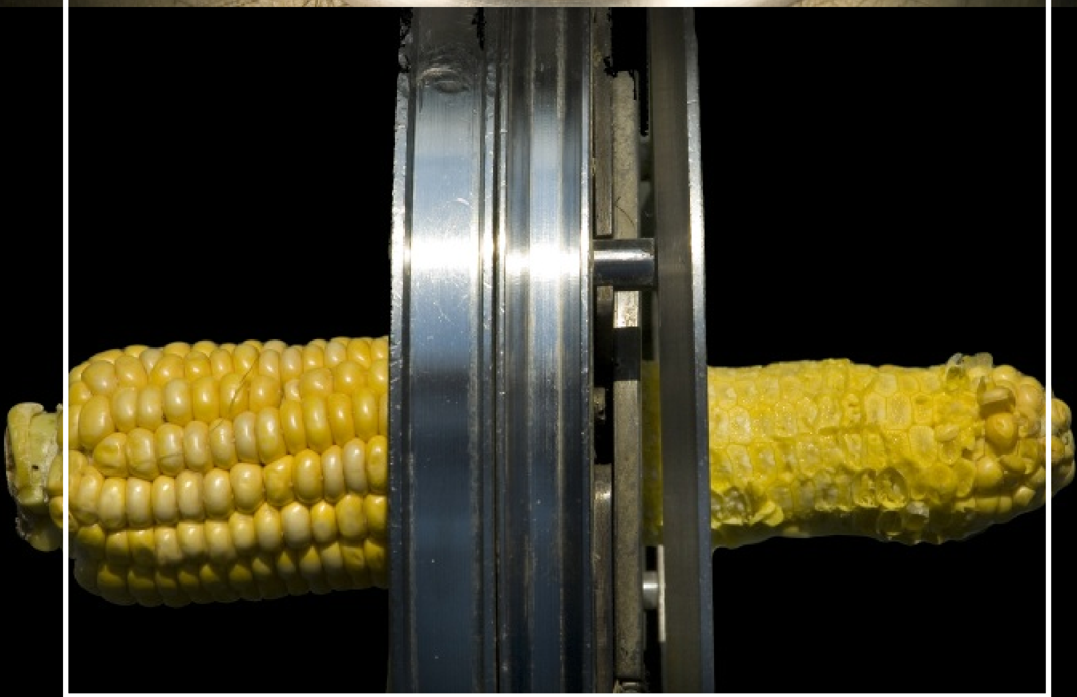


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LIST OF PHOTOGRAPHS PRESENTED IN APPENDIX*

* All photo in appendix, except pages: 218, 222, 223 and 231, are performed and digitally developed by Bohdan Dobrzański, III

ABSTRACT

This is a book about sweet corn. Sweet corn belongs to the species as a most remarkable cereal grain, *Zea mays* L., or maize, or as it is better known in North America, corn. The authors describes origin of sweet corn and its economic significance, beginnings of sweet corn cultivation and the World's leading producers and exporters of fresh and processed sweet corn. Raw material overview covers market trends and development, the market in majors producers. Production, supply and demand consumption and trade, as well as, directions of use and nutritional value of sweet corn kernels are also presented. Agricultural requirements for sweet corn cultivation, climatic and soil requirements, tillage and fertilization, sowing and plant care are discussed, as well. The readers can find characterization of sweet corn varieties including: sweet (sugary) varieties, varieties with increased (enhanced) content of sugars, super sweet varieties. As an example is shown Syngenta list of varieties such as: sweet corn varieties, yellow, white and bicolor sweet corn hybrids and supersweets hybrids, as well as, TripleSweet with comparison to others varieties and explanation what is a TripleSweet.

Sweet corn kernel structure, chemical composition, and sensory qualities are submitted in connection with standards, definitions, test procedures, estimation of physical and chemical properties of sweet corn. Mechanical properties of sweet corn kernels, the methods of study under quasi-static conditions at shearing, penetration and compression test, as well as study at dynamic conditions are presented, too. Energy consumptions, measurement of kernel cut-off process efficiency and method for the measurement of the degree of corn kernel mass detachment are indicated as useful for the measurement of the share of kernel fractions and kernel quality at cut-off process.

Sweet corn cob harvest and sweet corn cob processing technology, corncob husking equipment, cutters and equipment for cut-off the sweet corn kernel are presented. The effect of harvest time on quality, physical properties and detachment process of sweet corn kernels its quality and sugar content, the effect of storage and blanching conditions on the mechanical properties and on the cutting process of sweet corn kernels, cutting efficiency and kernel quality, effect of cob blanching on the energy consumption and efficiency of the cutting process are described, also. Postharvest cooling freezing and handling of sweet corn, labour, costs and effects in sweet corn production, and some utilization ways (Baking, Boiling, Grilling, Microwave) of sweet corn in human nutrition and tips for preparation of dishes with sweet corn kernel as a major ingredient are shown. The monograph is decorated and equipped with colour photo appendix, presenting sweet corn on the field, and at harvest and processing. Anyone interested in any aspect of sweet corn research and development, marketing, utilization, etc., should find this book useful.

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