The Effect of Polyethylene Film and Polypropylene Non-Woven Fabric Cover on Cobs Parameters and Nutritional Value of Two Sweet Maize (Zea mays L. var. saccharata Bailey) Hybrids

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Abstract: In 2012–2014, at the Research and Didactic Station of the Department of Horticulture at Wroclaw University of Environmental and Life Sciences (51° 19‘06’’ N, 17° 03‘49’’ E), field studies were conducted to evaluate the responses of two sweet maize hybrids to sowing dates (early and optimum) and five methods of maize plant coverings—polyethylene film: perforated (PE), red (PER), green (PEG), polypropylene non-woven fabric (PP), and control (C), with non-irrigation systems. Total yield and morphological characteristics of cobs were compared. In 2012 soluble sugars and carotenoids content were measured. The use of maize cover at the beginning of growth (PE and PER) significantly influenced the number of rows, while PE and PEG increased the number of grains per cob. Covering maize sown at a later date, with polyethylene film and non-woven fabric, ensured better production effects than using such covers after earlier sowing. Signet F1 hybrid was characterized by significantly higher sugar content and Rustler F1 by higher lutein and zeaxanthin levels. The application of the optimum sowing date resulted in a significantly higher yield of cobs, by 11.3%, than after early sowing. The yield increase as a result of the applied covers was higher after sowing at a later date. The content of dry matter in grains was positively correlated with the content of sucrose, glucose, and fructose. The change in carotenoids content also depended on the accumulation of dry matter in the kernels. The study confirmed the correlation of sweet maize accumulated growing degree days (AGDD), and revealed dependence of grain quality on dry matter content in the grain.

Keywords: sweet maize hybrids; plastic cover; cobs yield; biological value; sucrose content; carotenoids content

1. Introduction

The high economic importance of maize, especially sweet maize, is due to its suitability for direct consumption. The main beneficial characteristics of this species include its adequate kernel texture at optimal maturity, its sweet taste, and high biological value (e.g., vitamin C and E content, carotenoids, and mineral salts) [1,2]. The antioxidants content in certain types of maize and its use in the human diet is also important (i.e., its ability to modify the breakdown of sugars as well as its anti-diabetic effects) [3].
Sweet maize (*Zea mays* L. var. *saccharata* Bailey) is a diploid subspecies characterized by enhanced soluble sugar content resulting from a spontaneous mutation within the gene starch synthesis of common maize. This mutation prevents some water-soluble sugars from being converted to starch, being accumulated in the endosperm of the kernels [4,5]. Consequently, this maize produces and retains large amounts of simple sugars and disaccharides in its kernels. Three main groups of genotypes are distinguished: sugary (*su*), sugar enhanced (se), and super sweet or shrunken (*sh2*).

Historically, the first developed sweet maize was the “sugary (*su*)” type. In this type, mutations in the sugary1 (*su1*) gene decrease activity of the isoamylase-type starch-debranching enzyme (ISA1 DBE). It results in decreased concentration of amylopectin, increased concentration of sucrose, and accumulation of the highly branched glucopolysaccharide-phytoglycogen. Another gene affecting starch metabolism, important in sweet maize, is the natural mutation of sugary1 (*su1*)-sugary enhancer1 (*se1*). This recessive modifier of *su1* increases sucrose, maltose, and water-soluble polysaccharides content, and decreases starch content in kernels. Mutation of the Shrunken2 (*sh2*) gene, which is responsible for the synthesis of the large subunit of the heterotetrameric enzyme, adenosine diphosphate glucose pyrophosphorylase (AGPase), determine, to the greatest extent, the quality of super sweet maize and its suitability for consumption in the food industry. *Sh2* mutants contain extremely high levels of saccharose and very low amounts of starch. The majority of the currently grown sweet maize contains this allele [6,7].

Sweet maize hybrids are cobs harvested at the stage of milk maturity, processed in the form of whole cobs—as a vegetable for direct consumption or grains—for the food industry. There is no information in the literature on the effects of polyethylene and polypropylene covers on the carbohydrate content in kernels.

An important group of compounds found in maize are carotenoids, containing a β-ionone ring that is a precursor to vitamin A, which deactivates reactive oxygen compounds [8]. They are important in preventing many diseases, such as cancer and cardiovascular disease [9,10]. Lutein and zeaxanthin (commonly found in maize) are important at reducing the development of two major degenerative eye diseases: cataract and macular degeneration of the retina [11]. Sweet maize is one of the vegetable species with the highest carotenoid content [12]. Lutein and zeaxanthin are the most important compounds of this group and are mainly responsible for the high nutritional and health promoting values of sweet maize. Compared to lutein, zeaxanthin is found in lower amounts in most species (including maize) [2,13]. Nevertheless, maize—along with peppers and orange colored fruit—is a major source of zeaxanthin among vegetables [14,15]. As reported by Aman et al. [13], sweet maize kernels immediately after harvest had a lutein content of 2.34 mg per 100 g in dry matter, while zeaxanthin had 0.92 mg per 100 g in dry matter.

Hybrid differences, harvest dates, and herbicide use are among the factors affecting lutein and zeaxanthin content [12,16–18]. Ibrahim and Juvik [12] found statistically significant differences between the contents of these compounds in different hybrids. By the same token, Gallon et al. [16] evaluated the content of carotenoids; the maximum contents were 62 and 24 µg kg⁻¹ fresh weight, respectively, in the hybrids with increased and standard content. Among agrotechnical factors, delayed harvesting is reported to have a beneficial effect on the content of β-ionone compounds. However, there is no information available in literature about the effect of covering plants with polyethylene films, and polypropylene non-woven fabrics on carotenoid content in kernels.

Maize, as a species native to warmer regions of the world, exhibits high thermal requirements. Thermal conditions during the initial growth period have a decisive impact on the vegetation of these plants. Hybrids that are well-adapted to temperate climate conditions have been developed through intensive breeding efforts [19]. However, low temperatures in early spring, as well as the length of the growing season, may limit the production of sweet maize under these climatic conditions. The time period at which sweet maize is commercially available is important to the profitability of production. Therefore, the date of sowing and the length of the growing season are factors that significantly
affect maize grain yield, market availability, and production efficiency [20]. In experiments conducted by Nagy [21], grain yield was higher when the plant growth period was extended.

Kwabiah [1] and Ahmadet et al. [22] report that the minimum soil temperature during the initial growth period of maize should be above 12 °C. This is beneficial for root system development and nutrient uptake intensity. Various methods are used to accelerate the growth of sweet maize, both in the early growing period and in later stages of development. One is to sow early hybrids that germinate well at lower temperatures and reach harvest maturity quickly. Another way is to use flat covers made of transparent foil or to install low foil tunnels over the maize rows [19,23,24]. The use of flat covers or covers on low support structures during the early growing season is beneficial for improving thermal conditions and accelerating sweet maize growth [25].

According to Waterer [26] and Zandstra et al. [27], increasing soil temperature is more important than protecting against transpiration and water losses in temperate climates. Soil temperature under a transparent film was 2 °F–5 °F higher at sunrise and 4 °F–12 °F higher at noon compared to uncovered soil temperature. Moreover, under warm climate conditions, maize grown under cover germinates, tassels, and matures several days faster than maize without cover [28].

The objective of this three-year study was to determine the effects of a hybrid sowing date, as well as the polyethylene film and polypropylene non-woven fabric covers on the yield, morphological characteristics of sweet maize cobs, and total cob yield. Additionally, in 2012, the effect of the treatments used in the study on kernel quality traits was evaluated, and an analysis of soluble sugars and carotenoids content was performed.

2. Materials and Methods
2.1. Field Experiment
A randomized subblock method of a three-factor experiment was established, with three repetitions, for the years 2012–2014 at the Research and Didactic Station of the Department of Horticulture at Wroclaw University of Environmental and Life Sciences (51°19′06″ N, 17°03′49″ E). The experiment was conducted on soil, degraded chernozems with a calcic level, Gleyic Calcic Chernozems soil (Food Agriculture Organization–World References Base, FAO–WRB) on medium clay. The sweet maize cob morphology parameters, total cob yield, and the biological value of grain of two Shrunken2 (sh2) hybrids were compared (factor I-Hy):

- Signet F1 (very early);
- Rustler F1 (medium early).

Two sowing terms for sweet maize hybrid was tested (factor II-St).
Sowing term of the first date depended on weather conditions, and was sown as early as possible in the spring, after spring soil tillage. The first sowing date was on the 18, 15, and 8 April in 2012, 2013, and 2014, respectively. In each year, the second sowing date was on the same day (25 April). The other information was provided in a study by Adamczewska-Sowińska, Sowiński [24].

Directly after sowing, herbicide was applied (Lumax 537.5 SE) in the amount of 656.3 + 131.3 + 1093.8 g ha⁻¹ terbuthylazine + mesotrione + s-metolachlor, respectively.
Five different covers were tested in a low tunnel as a factor III (Ct):

- Colorless perforated polyethylene foil (perforation of 100 holes per 1 m², each with a diameter of 10 mm) of 0.2 mm thickness (PE);
- Red perforated polyethylene foil (PER);
- Green perforated polyethylene foil (PEG);
- Polypropylene non-woven fabric (with weight of 17 g m⁻²) (PP);
- Control—maize cultivation without cover (K).

After herbicide spraying, metal arches were placed as a tunnel construction, and 200 cm wide strips of foil and non-woven fabric covered two rows of maize, attached to the
ground using metal sticks. The tunnel height was 40 cm. The maize plants were covered for 4–6 weeks (depending on temperature and maize plant height). No treatment was performed in the tunnels until the structures were dismantled.

The size of one plot was 10.5 m$^2$ (7.5 × 1.4 m). Sweet maize was hand sown in spacing at 70 cm × 24 cm (~60,000 per ha).

Weather (rainfall and temperature conditions) during maize vegetation presented from April to August. During the initial period of maize vegetation, soil temperature was measured at a depth of 5 cm using a digital thermometer DT-34 (Termoprodukt, Bielawa, Poland). After removing the covers, air temperature was measured using a Temp Logger AZ8828 (AZ Instrument Corp., Taichung, Taiwan), placed 2 m above the soil surface [24]. The obtained air temperature data were compiled (from the initial growing period plus the temperature of the rest of the sweet maize growing season—the same for all covers). From sowing to the sweet maize harvest (for each combination separately), the following formula was used to calculate the number of days and the number of thermal units ($T_{baseline} = 10 ^\circ C$):

$$AGDD = \sum_{i=0}^{n} \frac{T_{min} + T_{max}}{2} - T_{baseline}$$

where:

- $AGDD$—accumulated growing degree days;
- $T_{min}$—minimum temperature during 24 h;
- $T_{max}$—maximum temperature during 24 h;
- $T_{base}$—base temperature ($10 ^\circ C$).

All maize cobs at maturity stage (milk-early dough grain stage) harvested, counted, selected, and weighted. Marketable maize cob sizes consist of fully developed cobs (filled with grains, 90.0–96.7% on average, as determined from 3 years of research) and no marketable yield (consists of cobs with below standard sizes). Total cob yield are presented in dt per ha and marketable cob yield as the percentage of total yield.

Ten well-developed cobs were taken for the morphological measurements of the cobs. Afterward, husk removing (cob cover leaves) measured the number of kernel rows in a cob, the number of kernels per row, the number of kernels per cob, and finally, in five of them, separate kernels from cobs, for dry matter content analysis. Additionally, in 2012, two samples of grain (50 g of each) were taken in three replications for deep freezing ($−20 ^\circ C$), for nutritional analysis (carotenoids and sugar fraction).

2.2. Analysis of Soluble Sugar Content in Maize Grain

The content of fructose, glucose, saccharose, and maltose, such as trimethylsilyl (TMS) oxime derivatives, was determined by gas chromatography with flame ionization detection (GC-FID), according to Knudsen and Li [29], with minor modifications. Briefly, 50 mg of freeze-dried ground material was extracted with 10 mL of 80% ($v/v$) ethanol at 60 °C for 60 min. with occasional shaking. After cooling and centrifugation, 500 µL of clear supernatant was transferred to 4-mL vials; 200 µL of internal standard (phenyl β-D-glucose, 5 mg mL$^{-1}$) was added, and evaporated to dryness in stream on nitrogen. Dry residues were re-dissolved with 20 µL of dimethyl sulfoxide (DMSO), and 0.5 mL of hydroxylamine hydrochloride (25 mg mL$^{-1}$) in pyridine was added and heated at 75 °C for 60 min., with occasional shaking for conversion of sugars to the oxime derivatives. After cooling, 75 µL of silylating agent Sylon BTZ (Sigma-Aldrich Co., St. Louis, MO, USA) were added and heated at 60 °C for 30 min. After cooling, 1 mL of isoctane and 2.5 mL of deionized water were added and intensively shaken. After separation, the organic layer containing derivatized sugars was transferred to 1.5 mL vials and analyzed with GC-FID. Chromatographic analysis of TMS-derivatives of sugars was conducted using a SRI 8610C gas chromatograph (SRI Instruments, Torrance, CA, USA), fitted with a flame ionization detector (GC-FID) and HTA200 autosampler (HTA s.r.l., Brescia, Italy). Solutes were separated on a BGB-5MS capillary column (30 m, 0.25 mm ID, 0.25 µm),
temperature gradient (from 160 °C to 280 °C, 5 °C min⁻¹). Data acquisition and integration were conducted with the Peak Simple (SRI Instruments, Torrance, CA, USA) version 454 integration program. For the quantitative analysis of sucrose content, the calibration curve was constructed, linear in the range of concentrations 0.1–2.0 mg mL⁻¹ ($r^2 = 0.999$).

### 2.3. Analysis of Lutein and Zeaxanthin Content in Maize Grain

The Panfili method [30] was used to determine the content of lutein and zeaxanthin. Thus, 0.5 g of ground maize was placed in a sealed 15 mL plastic Falcon tube and ethanol solution of pyrogallol (1 mL, $c = 60$ g/L), 95% ethanol (1 mL, $c = 10$ g/L), and aqueous KOH (0.5 mL, $c = 600$ g/L), and mixed thoroughly. The samples were heated in a water bath at 70 °C for 45 min, shaken every 5–10 min, and immediately cooled by placing them in cold water. Then, aqueous NaCl (4 mL, $C = 10$ g/L) was added and the mixture, was extracted twice with 5 mL of hexane: ethyl acetate in a 9:1 (v:v). In order to separate the layers faster, the whole mixture was placed in the refrigerator for about 30 min. The combined organic layers, which were transferred to the pear shape flasks for 25 mL, were evaporated to dryness under the vacuum pump. The residue was dissolved in 2 mL of solvent (acetonitrile: methanol: tetrahydrofuran, 75:20:5 (v:v:v)) and filtered through a 0.45 µm teflon filter into HPLC vials.

HPLC/UV analysis was performed using a Waters apparatus (Waters Corporation, Milford, MA, USA) containing a 2690 separation module and a 996 diode detector, equipped with a Macherey-Nagel Nucleodur 100-5 C18 ec 4.6 × 250 column, thermostated at 5 °C. The eluent was a mixture of acetonitrile: methanol: dichloromethane, 75:20:5 (v:v:v). The quantitative analysis was performed at 450 nm against an external standard, which was a solution of lutein and zeaxanthin. The single analysis time was 20 min. The eluent flow was fixed at 1 mL/min. The areas under the signals from the analytes were taken into consideration.

### 2.4. Statistical Analysis

Sweet maize cob parameters: number of grain rows, number of grains per row and per cob, total yield cobs, percentage of marketable yield, maize grain quality, carbohydrates, and carotenoids content were statistically elaborated by three-way analysis of variance (ANOVA), using Statistica software version 13.1 StatSoft (Krakow, Poland). Mean values were compared using the Tukey test for the level of significance $\alpha = 0.05$.

The sweet maize management (i.e., hybrid type, term of sowing, and type of cover) were entered as a fixed effect in the analysis, and replications and year were considered as random effects. The percentage of marketable cob yield was calculated as the share of marketable yield in the total yield. These values were provided as averages for the treatments (without replications) and were not subject to statistical analysis.

Correlation between AGDD and achieved experimental data were calculated. Pearson correlation between grain dry matter content vs. quality grain parameters elaborated. Only significant correlation was drawn (correlation $v = (n − 2)$, where $n$ = number of observation) as a regression graphs at significance level $\alpha = 0.05$ based on critical values ($v$) for Pearson correlation.

### 3. Results

#### 3.1. Weather Conditions and Vegetation Characteristic

The pattern of weather conditions varied between the years of the study, especially the rainfall (Figure 1). In April and May of 2012, rainfall was at a very low level (15.6 mm and 20.5 mm) and accounted for 42% and 36% of the multiannual average for those months, respectively. In April 2013, rainfall was 60% of the multi-year total, and in May it was at the multi-year average. April and May of 2014 recorded high rainfall, and the total for both months was 63% higher compared to the multi-year average rainfall for that period. Maize emergence, initial growth, as well as later development, was also highly dependent on rainfall occurring at the beginning of the growing season.
Figure 1. Average month temperature and rainfall amount within sweet maize growing vegetation in the years 2012–2014.

The average air temperature in all years of the study was higher than the multiannual average. The most favorable thermal conditions for maize growth, especially at the beginning of the growing season, occurred in 2012. In April (10.7 °C) and May (15.9 °C), the average air temperatures were higher than the multiannual average by 2.5 and 2.4 °C, respectively. Thermal conditions in 2012 influenced the average length of the growing season and contributed to earlier reaching harvest maturity by 7 days than in 2013 and by 10 days than in 2014.

During the growing season, depending on the factors studied, maize plants accumulated an average of 792.9 (Signet F1—very early hybrid) to 952.9 (Rustler F1—medium early hybrid) of AGDD (Table 1). Hybrid differences were found to be the largest, amounting to 20%. Heat unit accumulation between sowing dates differed by 19.8 AGDD (874.6 and 854.8 AGDD at sowing dates I and II, respectively) and between cover types by 63.8 AGDD (831.4 and 895.2 AGDD for non-woven fabric (PP) and perforated film (PE), respectively).

During the research, Signet F1 hybrid was harvested on average after 97 days, while Rustler F1 (medium early hybrid) had a longer vegetation period, on average by 14 days. A similar difference in reaching harvest maturity was found when comparing the effect of sowing dates. With a later sowing date, there was a shortening of the vegetation period by 10 days. The lack of maize cover at the beginning of its growth resulted in a lengthening of the whole vegetation period from 3.4 days (compared to the plots with PE and PER) to 4.0 days (compared to the PP object). Sowing maize at the first and second date produced grain with similar dry matter (DM) content (22.7 and 22.2, respectively). The highest differentiation by 3.1 percent point (p.p.) was between the hybrids.
Table 1. Accumulative growing degree days (AGDD) for sweet maize growing season, vegetation period (in days), and average grain dry matter (DM) content. Average and standard deviation for treatments.

| Treatments          | AGDD       | Growing Days | Grain DM (%) |
|---------------------|------------|--------------|--------------|
| Average for hybrids |            |              |              |
| Signet F1           | 792.9 ± 49.2 | 97.0 ± 8.5   | 21.1 ± 2.8   |
| Rustler F1          | 952.9 ± 47.6 | 109.9 ± 6.2  | 24.2 ± 1.9   |
| Average for sowing term |              |              |              |
| I                   | 874.6 ± 91.7 | 107.4 ± 9.4  | 22.7 ± 2.8   |
| II                  | 854.8 ± 96.7 | 97.4 ± 7.5   | 22.2 ± 3.0   |
| Average for cover type |         |              |              |
| PE                  | 895.2 ± 85.6 | 102.2 ± 8.5  | 22.9 ± 2.5   |
| PER                 | 884.4 ± 87.3 | 102.5 ± 10.3 | 23.9 ± 1.8   |
| PEG                 | 871.6 ± 101.9 | 101.8 ± 10.6 | 22.5 ± 2.6   |
| PP                  | 831.4 ± 95.4 | 101.9 ± 10.9 | 21.7 ± 3.0   |
| K                   | 845.6 ± 99.2 | 105.9 ± 10.3 | 21.4 ± 3.9   |

Colorless perforated polyethylene foil (PE); Red perforated polyethylene foil (PER); Green perforated polyethylene foil (PEG); Polypropylene non-woven fabric (PP); Control (K).

3.2. Cobs Yield and Morphological Parameters

Cob maturity was the primary characteristic that determined the harvest time of sweet maize. An indicator determining the maturity of maize and suitability for consumption and industry was the dry matter content. In the conducted studies, dry matter content ranged from 21.1 (Signet F1) to 24.2% (Rustler F1) (Table 1). It was found that maize grain grown without the use of covers, and covered with non-woven fabric, contained less dry matter, respectively by 2.5 and 2.2 p.p., than after the application of PER. This indicates some differences of cob milk maturity stage at harvest.

The sum of effective temperatures showed a strong effect on biometric cob traits (Figure 2a,b). Significant relationships were demonstrated, finding a positive correlation between AGDD and dry matter content (correlation coefficient $r = 0.590$) (Figure 2a), length of growing season ($r = 0.616$), number of grains per row ($r = 0.685$), and number of grains per cob ($r = 0.357$) (Figure 2b). On the other hand, increasing the sum of heat units had a decreasing effect on the number of rows of grains per cob ($r = −0.437$) (Figure 2a). The strong dependence of cob dry matter content on the sum of effective temperatures was the basis for the analysis of the relationship between dry matter content and biological value expressed in water-soluble carbohydrates and carotenoids. Figures 3–5 show the effect of the amount of DM on the change in the content of these organic compounds.

Based on the investigations conducted, significant differences in the determined morphological parameters of cobs were found among the hybrids (Table 2). Signet F1 hybrid had a significantly higher number of rows in the cob (15.72), while Rustler F1 had a significantly higher number of grains per row (42.77), grains per cob (641.8). Covering maize plants with PE and PER at the beginning of growth significantly increased the number of rows, while PE and PEG increased the number of grains per cob, compared to the control. There was a significant effect of interaction between hybrids and the type of covers applied on the number of grains per cob and between hybrids and sowing date (on the number of grains per row).
Figure 2. Effect of thermal condition presented in accumulated growing degree days of the sweet maize growing period and cob parameters. (a): Accumulated growing degree days (AGDD) vs. dry matter (DM), Number of grain rows in cob. (b): AGDD vs. number of growing days, number of grain per row, Number grain per cob.

Significantly higher cob yield was obtained at the second sowing term, 191.6 dt per ha (compared to 172.1 dt in first sowing date) and after using PE cover (207.6 dt per ha), PEG and PER (182.3 and 181.7 dt per ha), respectively, compared to the control, 161.6 dt per ha (Table 3). A significantly higher cob yield by 24.3% was obtained in the cultivation of Rustler F1 compared with Signet F1 hybrid (Table 3). Delaying maize sowing by 7–14 days, an increase in marketable yield by 8.5 p.p. was observed. A higher marketable yield obtained cultivation Rustler F1 (80.44% on average) compared with Signed F1 65.89%. It turned out that covering maize, sown at a later date with polyethylene film and non-woven fabric, ensured better production effects than using covers after sowing maize at an earlier date.
Table 2. The effect of experimental treatments on the morphological parameters of cobs. Average from years 2012–2014.

| Sowing Term (St) | Cover Type (Ct) | Number of Rows in Cob | Number of Grain in Row | Number of Grain Per Cob |
|-----------------|-----------------|-----------------------|------------------------|------------------------|
|                 | Signet F1       | Rustler F1            | Mean                   | Signet F1              | Rustler F1            | Mean                   |
| I               |                 |                       |                        |                        |                       |                        |
| PE              | 16.07           | 15.58                 | 15.82                  | 37.64                  | 43.44                 | 40.54                  | 605.3                  | 675.6                  | 640.4                  |
| PER             | 15.82           | 15.42                 | 15.62                  | 37.09                  | 43.29                 | 40.19                  | 585.8                  | 668.5                  | 627.1                  |
| PEG             | 15.69           | 15.27                 | 15.48                  | 36.87                  | 43.40                 | 40.13                  | 578.2                  | 664.0                  | 621.1                  |
| PP              | 15.58           | 15.20                 | 15.39                  | 38.04                  | 42.38                 | 40.21                  | 592.9                  | 644.9                  | 618.9                  |
| control         | 15.13           | 14.64                 | 14.89                  | 38.69                  | 42.53                 | 40.61                  | 585.6                  | 623.8                  | 604.7                  |
| mean            | 15.66           | 15.22                 | 15.44                  | 37.67                  | 43.01                 | 40.34                  | 589.6                  | 655.4                  | 622.5                  |
| II              |                 |                       |                        |                        |                       |                        |                        |                        |                        |
| PE              | 16.04           | 14.87                 | 15.57                  | 37.69                  | 42.30                 | 39.53                  | 604.6                  | 629.2                  | 614.4                  |
| PER             | 15.82           | 14.50                 | 15.29                  | 37.93                  | 41.67                 | 39.43                  | 600.8                  | 604.0                  | 602.1                  |
| PEG             | 15.89           | 14.43                 | 15.31                  | 37.80                  | 42.73                 | 39.77                  | 599.4                  | 619.4                  | 607.4                  |
| PP              | 15.71           | 14.97                 | 15.41                  | 38.96                  | 42.80                 | 40.49                  | 612.3                  | 642.0                  | 624.2                  |
| control         | 15.40           | 14.33                 | 14.97                  | 39.22                  | 42.57                 | 40.56                  | 604.5                  | 612.6                  | 607.8                  |
| mean            | 15.77           | 14.62                 | 15.31                  | 38.32                  | 42.41                 | 39.96                  | 604.3                  | 621.5                  | 611.2                  |
| Mean            |                 |                       |                        |                        |                       |                        |                        |                        |                        |
| Mean from hybrids (Hy) | 15.72       | 14.98                 | 37.99                  | 42.77                 | 596.9                 | 641.8                  |

LSD = 0.05 for: Hy
St
Ct
Hy × St
Hy × Ct
St × Ct
Hy × St × Ct
LSD—Least Significant Difference, n.s.—not significant.

Table 3. Total cobs yield (dt per ha) and percentage (%) of marketable cobs yield. Average from years 2012–2014.

| Sowing Term (St) | Cover Type (Ct) | Cobs Yield | Percentage of Marketable Cob Yield |
|-----------------|-----------------|------------|-----------------------------------|
|                 |                 | Signet F1  | Rustler F1                        | Mean                   | Signet F1  | Rustler F1                        | Mean                   |
| I               |                 |            |                                    |                       |            |                                    |                       |
| PE              | 166.8           | 226.8      | 196.8                              | 61.19                 | 78.50      | 69.85                              |
| PER             | 145.0           | 195.8      | 170.4                              | 50.39                 | 82.53      | 66.46                              |
| PEG             | 125.7           | 199.6      | 162.6                              | 56.91                 | 76.61      | 66.76                              |
| PP              | 157.5           | 176.6      | 167.0                              | 65.04                 | 84.37      | 74.71                              |
| control         | 143.9           | 183.2      | 163.6                              | 55.96                 | 77.63      | 66.80                              |
| mean            | 147.8           | 196.4      | 172.1                              | 57.90                 | 79.93      | 68.91                              |
| II              |                 |            |                                    |                       |            |                                    |                       |
| PE              | 227.0           | 209.0      | 218.0                              | 75.36                 | 80.13      | 77.75                              |
| PER             | 164.2           | 221.7      | 192.9                              | 74.47                 | 88.69      | 81.58                              |
| PEG             | 176.3           | 227.6      | 202.0                              | 70.95                 | 74.95      | 72.95                              |
| PP              | 170.2           | 200.7      | 185.5                              | 69.48                 | 88.19      | 78.84                              |
| control         | 139.7           | 179.3      | 159.5                              | 79.12                 | 72.76      | 75.94                              |
| mean            | 175.5           | 207.7      | 191.6                              | 73.88                 | 80.94      | 77.41                              |
3.3. Sugar Content in Maize Kernels

Significant differences in the content of glucose, fructose, maltose, and total sugars were shown between maize hybrids (Table 4). Signet F1 was characterized by higher content of these sugars. The interaction of cover type and sowing date significantly affected sucrose content. Maize plants covered with PE (6.56%) and PP (6.51%) at the first sowing date were characterized by the highest content of this sugar. Following the application of the second date of sowing, the most favorable conditions for the accumulation of this sugar were found in the case of maize without cover (6.96%). A similar relationship was found in the content of total sugars. A greater effect of covers on the change in sucrose content, at the first sowing date, was shown for the Signet F1 hybrid. At the second date of sowing, the most favorable conditions for the accumulation of this sugar were found when plants grew without a cover. In the case of the Rustler F1 hybrid, regardless of the sowing date, the highest content of this sugar was found when plants grew without a cover.

The dry matter content of the kernels was strongly correlated with the sugar concentrations (Figure 3). The increase in the amount of dry matter was positively correlated with the content of sucrose ($r = 0.426$), while a negative correlation was found with the content of glucose ($r = -0.516$) and fructose ($r = -0.587$). The changes in the sugar levels are confirmed by the increasing ratio of sucrose to the sum of glucose and fructose ($r = 0.490$) and the decreasing ratio of fructose to glucose with increasing DM content ($r = -0.470$) (Figure 4). An increase in sucrose/glucose and fructose ratio was found in kernels with higher dry matter content. However, a negative correlation was found between dry matter content and fructose to glucose ratio.

### Table 3. Cont.

| Sowing Term (St) | Cover Type (Ct) | Cobs Yield | Percentage of Marketable Cob Yield |
|-----------------|----------------|------------|----------------------------------|
|                 |                | Signet F1 | Rustler F1 | Mean | Signet F1 | Rustler F1 | Mean |
| mean            | PE             | 196.9     | 217.9     | 207.4 | 68.27 | 79.32     | 73.80 |
|                 | PER            | 154.6     | 208.8     | 181.7 | 82.43 | 85.61     | 84.02 |
|                 | PEG            | 151.0     | 213.6     | 182.3 | 63.93 | 75.78     | 69.86 |
|                 | PP             | 163.8     | 188.7     | 176.3 | 67.26 | 86.28     | 76.77 |
|                 | control        | 141.8     | 181.3     | 161.6 | 67.54 | 75.20     | 71.37 |

Mean from hybrids (Hy) 162.6 202.1 - 65.89 80.44 -

LSDx = 0.05 for: Hy
St 11 n.a.
Ct 11 n.a.
Hy × Ct 18 n.a.
Hy × St n.s. n.a.
St × Ct 17 n.a.
Hy × St × Ct 21 n.a.

dt—decitonnes (hkg); n.a.—not analyzed.
Table 4. The effect of experimental treatments on sugar content in maize grain (% of fresh grain). Average from year 2012.

| Sowing Term (St) | Cover Type (Ct) | Signet F1 | Rustler F1 | Mean | Signet F1 | Rustler F1 | Mean | Signet F1 | Rustler F1 | Mean | Signet F1 | Rustler F1 | Mean | Signet F1 | Rustler F1 | Mean |
|------------------|-----------------|-----------|-----------|-------|-----------|-----------|-------|-----------|-----------|-------|-----------|-----------|-------|-----------|-----------|-------|
|                  | PE              | 7.07      | 6.05      | 6.56  | 0.47      | 0.56      | 0.62  | 0.44      | 0.53      | 0.05  | 0.02      | 0.03      | 7.68  | 6.97      | 7.31      |
|                  | PER             | 6.54      | 6.14      | 6.34  | 0.42      | 0.54      | 0.63  | 0.40      | 0.52      | 0.04  | 0.03      | 0.03      | 7.86  | 6.99      | 7.43      |
|                  | PEG             | 6.40      | 6.49      | 6.44  | 0.42      | 0.60      | 0.78  | 0.40      | 0.59      | 0.05  | 0.03      | 0.04      | 8.02  | 7.34      | 7.68      |
|                  | PP              | 6.85      | 6.16      | 6.51  | 0.46      | 0.54      | 0.62  | 0.44      | 0.53      | 0.04  | 0.02      | 0.03      | 8.14  | 7.09      | 7.26      |
| control          | 4.87            | 6.48      | 5.67      | 0.49  | 0.62      | 0.82      | 0.48  | 0.65      | 0.03      | 0.03  | 0.03      | 6.47      | 7.47  | 6.97      | 7.47      |
| mean             | 6.35            | 6.26      | 6.30      | 0.70  | 0.45      | 0.57      | 0.69  | 0.43      | 0.56      | 0.04  | 0.03      | 0.03      | 7.78  | 7.17      | 7.47      |

II

|                  | PE              | 6.37      | 6.16      | 6.26  | 0.46      | 0.43      | 0.45  | 0.41      | 0.43      | 0.04  | 0.03      | 0.03      | 7.32  | 7.04      | 7.18      |
|                  | PER             | 6.54      | 6.29      | 6.42  | 0.36      | 0.51      | 0.66  | 0.33      | 0.50      | 0.04  | 0.03      | 0.04      | 7.90  | 7.01      | 7.46      |
|                  | PEG             | 5.73      | 6.12      | 5.92  | 0.39      | 0.52      | 0.67  | 0.37      | 0.52      | 0.03  | 0.03      | 0.03      | 7.07  | 6.91      | 6.99      |
|                  | PP              | 5.83      | 6.34      | 6.09  | 0.51      | 0.43      | 0.47  | 0.51      | 0.40      | 0.05  | 0.03      | 0.02      | 6.87  | 7.19      | 7.03      |
| control          | 7.19            | 6.73      | 6.96      | 0.61  | 0.52      | 0.57      | 0.58  | 0.50      | 0.54      | 0.05  | 0.03      | 0.04      | 8.44  | 7.78      | 8.11      |
| mean             | 6.33            | 6.33      | 6.33      | 0.58  | 0.43      | 0.50      | 0.57  | 0.40      | 0.49      | 0.04  | 0.03      | 0.03      | 7.52  | 7.19      | 7.35      |

Mean from hybrids (Hy)

|                  | PE              | 6.72      | 6.10      | 6.41  | 0.56      | 0.45      | 0.50  | 0.43      | 0.48      | 0.04  | 0.02      | 0.03      | 7.85  | 7.00      | 7.43      |
|                  | PER             | 6.54      | 6.21      | 6.38  | 0.39      | 0.52      | 0.64  | 0.37      | 0.51      | 0.04  | 0.03      | 0.04      | 7.88  | 7.00      | 7.44      |
|                  | PEG             | 6.06      | 6.31      | 6.18  | 0.40      | 0.56      | 0.72  | 0.38      | 0.55      | 0.04  | 0.03      | 0.03      | 7.54  | 7.12      | 7.33      |
|                  | PP              | 6.34      | 6.25      | 6.30  | 0.45      | 0.51      | 0.56  | 0.42      | 0.49      | 0.03  | 0.02      | 0.03      | 7.51  | 7.14      | 7.32      |
| control          | 6.03            | 6.60      | 6.32      | 0.69  | 0.51      | 0.60      | 0.70  | 0.49      | 0.59      | 0.04  | 0.03      | 0.03      | 7.46  | 7.63      | 7.54      |

LSDx = 0.05 for: Hy n.s. 0.06 0.44 0.63 0.42 0.04 0.03 - 7.65 7.18 -

St n.s. n.s. n.s. n.s. n.s. n.s. n.s. n.s. n.s. n.s. n.s.

Ct n.s. n.s. n.s. n.s. n.s. n.s. n.s. n.s. n.s. n.s. n.s.

Hy × Ct n.s. n.s. n.s. n.s. n.s. n.s. n.s. n.s. n.s. n.s. n.s.

St × Ct 0.69 n.s. n.s. n.s. 0.77

Hy × St × Ct 0.83 n.s. n.s. n.s. 0.90

Figure 3. Regression curve between grain dry matter (DM) content and sugar content (% of fresh matter).
4. Discussion

Cob morphological traits varied among the hybrids under study. Signet F1 hybrid had a significantly higher number of rows per cob, while Rustler F1 had a significantly higher number of grains per row and per cob. The type of cover significantly differentiated only the number of rows. A study by Ghimire et al. (2020) showed a significant effect of film type on morphological traits, such as cob length, diameter, grain size, and grain formation. Under temperate climate conditions, early maize cultivation was hampered due to low temperatures, frequent high rainfall, and occurrence of cold water stress, from which severe plant pathogen infestation often results [25]. Early sowing of sweet maize is risky, but at the same time preferable, due to its ability to take full advantage of the entire growing season, as well as provide a valuable vegetable earlier to market [5]. Sowing date is also an important part of agronomic management under subtropical climate conditions, affecting yield parameters and directly influencing cob yield [31]. In our study, a higher cobs yield of sweet maize was obtained by sowing it at a later date, at the end of April (an average of 191.6 dt of cobs per ha was harvested from the three years of the study compared to 172.1 dt per ha at an earlier date). A greater difference between the sowing dates (18%) was observed in the very early Signet F1 hybrid, while in the medium-early hybrid, Rustler F1, the yield of cobs was more equal, and for the second sowing date, it was only 6% higher than at the earlier date.

To improve thermal conditions, polyethylene or other polymer film covers are recommended for accelerated harvest and increased yield [32,33]. Ghimire et al. [25], using different biodegradable covers throughout the growing season of sweet maize, obtained a shortening of the maize growing period (to the heading stage, occurring in 50% of plants) within a wide range of 5.5 to 20.4 days. In our study, covers were applied only in the initial period of vegetation, until plants reached 40 cm of height (i.e., for a maximum of 24–45 days, depending on sowing date and thermal conditions). As a result of this treatment, the vegetation period was shortened by 3.4 to 4.1 days compared to the vegetation period of maize without cover. Total effective temperatures were also lower, ranging from

\[ y = -0.011x + 1.2174 \]
\[ r = -0.4 \]

\[ y = 0.3897x - 2.2336 \]
\[ r = 0.4 \]

### Figure 4. Regression curve between grain dry matter (DM) content and sugar ratio (% of fresh matter).

#### 3.4. Carotenoids Content in Maize Kernels

On average, Rustler F1 hybrid has significantly higher content of lutein (7.0 µg g\(^{-1}\) fresh matter), zeaxanthin (3.4 µg g\(^{-1}\) f.m.) and the total of these carotenoids (Table 5). The interaction of the hybrids with the type of covers was evident. In the Signet F1 hybrid, the highest content of lutein (6.0 µg g\(^{-1}\) f.m.) and zeaxanthin (3.0 µg g\(^{-1}\) f.m.), as well as the
total sum of these carotenoids were obtained when the plants were covered with PP in the initial vegetation period. Rustler F1, on the other hand, accumulated the most carotenoids when plants were covered with PER and PEG (11.2 and 11.6 µg g⁻¹ f.m., respectively).

Table 5. The effect of treatments on carotenoid content in maize grain (µg per g of fresh grain). Average from year 2012.

| Sowing Term (St) | Cover Type (Ct) | Lutein | Zeaxanthin | Lutein + Zeaxanthin | Lutein/Zeaxanthin Ratio |
|-----------------|-----------------|--------|------------|--------------------|------------------------|
|                 |                 | Signet F1 | Rustler F1 | Mean | Signet F1 | Rustler F1 | Mean | Signet F1 | Rustler F1 | Mean | Signet F1 | Rustler F1 | Mean |
| I               | PE              | 5.2     | 6.0        | 6.8   | 2.4     | 2.9        | 3.3   | 7.6     | 9.0        | 10.1  | 2.2      | 2.1        | 2.1  |
|                 | PER             | 4.5     | 7.5        | 5.4   | 2.1     | 3.1        | 2.6   | 6.6     | 10.6       | 8.0   | 2.1      | 2.4        | 2.1  |
|                 | PEG             | 5.5     | 8.1        | 5.9   | 2.8     | 3.8        | 2.8   | 8.2     | 11.9       | 8.7   | 2.0      | 2.1        | 2.2  |
|                 | PP              | 5.7     | 5.6        | 5.7   | 2.8     | 2.8        | 2.8   | 8.5     | 8.5        | 8.5   | 2.1      | 2.0        | 2.0  |
|                 | control         | 3.5     | 7.4        | 5.6   | 1.7     | 3.5        | 2.7   | 5.2     | 10.9       | 8.3   | 2.0      | 2.1        | 2.1  |
|                 | mean            | 4.9     | 6.9        | 5.9   | 2.4     | 3.2        | 2.8   | 7.2     | 10.2       | 8.7   | 2.1      | 2.2        | 2.1  |
| II              | PE              | 5.1     | 6.5        | 6.9   | 2.7     | 3.2        | 3.5   | 7.8     | 9.7        | 10.4  | 2.0      | 2.1        | 2.0  |
|                 | PER             | 3.8     | 8.0        | 5.8   | 1.7     | 3.9        | 2.9   | 5.5     | 11.9       | 8.8   | 2.3      | 2.1        | 2.0  |
|                 | PEG             | 5.1     | 7.6        | 6.3   | 2.4     | 3.7        | 2.9   | 7.4     | 11.3       | 9.4   | 2.1      | 2.1        | 2.1  |
|                 | PP              | 6.4     | 7.5        | 5.5   | 3.2     | 3.8        | 2.6   | 9.6     | 11.2       | 8.1   | 2.0      | 2.0        | 2.1  |
|                 | control         | 4.8     | 5.8        | 6.0   | 2.1     | 3.0        | 2.6   | 6.9     | 8.8        | 8.6   | 2.3      | 2.0        | 2.3  |
|                 | mean            | 5.0     | 7.0        | 6.1   | 2.4     | 3.5        | 3.0   | 7.4     | 10.5       | 9.0   | 2.1      | 2.0        | 2.1  |

The interaction of all studied factors was demonstrated for lutein content. In the Signet F1 hybrid, irrespective of sowing date, the highest accumulation of lutein was found when plants were covered with PP (5.7 and 6.0 µg g⁻¹ f.m. for the first and second sowing dates, respectively). In the Rustler F1 hybrid, sown in the first sowing date, the highest content of this component was found when PEG was used (8.1 µg g⁻¹ f.m.), while in the second sowing date, it was observed when plants were covered with PER (8.0 µg g⁻¹ f.m.). All carotenoid content in maize grains were significantly, positively correlated with dry matter content (Figure 5). Correlation coefficient range from r = 0.640 to r = 0.680.

4. Discussion

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Maize is highly thermally demanding; optimal conditions for growth occur when the temperature is above 15–20 °C and growth stunting occurs above 35 °C [34–37]. The use of perforated film in our study at both sowing dates resulted in the greatest output effects. A greater yield increase relative to the control was obtained at the second sowing date (by 37%) than at the first (by 20%). The use of transparent film to cover maize is recommended in a number of regions [38,39]. Under such covers, there are also very good conditions for weed growth due to the simultaneous penetration of radiation and photosynthetically active radiation (PAR) [40]. Therefore, mulches made of black film or so-called selective films that stop PAR radiation, are used in some regions [26]. In our study, the use of red and green foil, which are classified as selective foils (to cover plants), resulted in a higher yield of cobs by 12–13%, respectively, compared to the yield of maize cobs grown without covering.

Sweet maize is harvested when the cobs are physiologically immature, i.e., approximately 20 days after pollination [6]. The biological and consumption value is highest at the milk maturity stage of the grains. Delaying harvesting increases hardness, decreases water-soluble carbohydrate content, increases starch content, and deteriorates kernel palatability. In the study conducted by Liu-Peng et al. [41] and Kumari et al. [42], delaying cob harvest affected dry matter content at harvest, as well as sugar and starch content. A negative correlation was found between delaying harvest date and starch content. In a study by Szymanek et al. [6], maize cobs of sh2 hybrids were harvested from 20 to 32 days after pollination. On average, out of the three hybrids, the dry matter content in kernels increased by 13.7 p.p. (from 26.4 to 40.1%), at the same time, the content of total sugars decreased by 1.4 p.p., and the average starch content increased by the same amount (by 1.4 p.p.). Our investigations showed different results and a positive correlation between the DM content and sucrose concentration. As a result of increasing the DM content from 15 to 29%, the
sucrose content rose by 1.4 p.p. on average. The low dry matter content of the kernels indicates that the cobs were harvested at earlier maturation times than in publications by other authors. Cao et al. [43] report that, from a wide numbers of days (from 14 to 42) after pollination, there is a successive conversion of sucrose to starch.

On the other hand, the increased DM concentration in kernels during the harvest period had a significantly negative effect on the glucose and fructose content of maize kernels. The sugar content of grains, and especially the rate of reduction of simple sugars in grains, is affected by genotype [44,45]. Signet F1 hybrid had substantially higher content of glucose, fructose, maltose, and total sugars than the Rustler F1 hybrid.

The content of carotenoids in maize kernels depends on varietal characteristics and increases with cob maturation [46]. This is confirmed in our study, where grains with higher dry matter content were characterized by higher lutein and zeaxanthin levels. The hybrid Rustler F1, having more intense yellow kernels, was characterized by a higher content of carotenoids. The color of the kernels indicates the carotenoid content, the highest being found in yellow or yellow-orange ones [2,47]. In a study by Baseggio et al. [48], on more than 300 maize lines, lutein content in fresh grain weight ranged from 0.64 to 19.39 µg g⁻¹ fresh weight. Zeaxanthin content, on the other hand, remained in the range of 1.62–10.71 µg g⁻¹ fresh weight. In our study, lutein content ranged from 3.5 to 6.4 and from 5.7 to 8.1 µg g⁻¹ (for Signet F1 and Rustler F1 hybrids, respectively). The zeaxanthin content, on the other hand, was in the range from 1.7 to 3.2 µg g⁻¹ (Signet F1) and 2.8–3.9 µg g⁻¹ of fresh weight (Rustler F1). The study by Calvo-Brenes et al. [49] confirmed the influence of genotype on carotenoid content, but grain maturity and location in the cob also appeared to influence this trait. Regardless of whether the hybrid was biofortified or standard, the highest carotenoid content was found in the top part of the cob. In our study, total carotenoid content increased from 4.7 to 11.7 µg g⁻¹, with an increase in DM content by 15 p.p. (from 10 to 25%).

5. Conclusions

The high biological value of sweet maize, as well as the possibility of supplying it to the market in fresh, canned, or frozen form, is the reason why the production and consumption of this species is increasing in many regions of the world. The biological value is determined mainly by hybrid characteristics. The growing popularity of the shrunken2 (sh2) and sweet enhancer1 (se1) hybrids ensures that maize with a high content of soluble sugars is readily available on the market. Maize, especially hybrids with high sugar content, are characterized by high sensitivity to unfavorable habitat conditions, especially during the early growing season. In addition to hybrid types, the use of covers and the optimum sowing date largely determine the yield and functional characteristics of maize cobs.

It is recommended that sh2 varieties should be grown later after the spring chill has passed. When soil temperature reaches the optimum value (>10 °C), growth of sh2 maize is normal. In temperate climates, sowing should be delayed or covers should be used. For an early, good quality yield of sh2 sweet corn, cultivation should be done according to the recommendations of this study. The transparent perforated film provided the best growing conditions and the highest yield of early sown sweet maize.

The biological value of maize is also determined by the content of lutein and zeaxanthin, which are important in the control of civilization diseases. The study revealed large hybrid differences in biological value. On the basis of the obtained results, it can be concluded that a later harvest of maize cobs affects the change in carbohydrate content (monosaccharide content decreases, sucrose content increases). At the same time, there was an increase in the content of lutein and zeaxanthin, by 150%, when the DM content in grain increased 15 p.p.

The study has confirmed that maize plants exhibit an unfavorable ratio of lutein to zeaxanthin, which in the conducted studies ranged from 2.0 to 2.4. It is therefore necessary to supplement the diet with other products characterized by a high lutein content.
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