

EFFECT OF DIFFERENT SEEDLING GROWING METHODS ON THE SPAD, NDVI VALUES AND SOME MORPHOLOGICAL PARAMETERS OF FOUR SWEET CORN (*ZEAMAYS L.*) HYBRIDS

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The main goal of our investigation was to determine the relationship between different growing methods of sweet corn seedlings and some physiological and morphological parameters of four hybrids in order to get information about the ability of their stress tolerance in a two-year experiment (2019, 2020). Seedlings were grown with and without pre-conditioning. Pre-conditioning is based on growing young plants exposing them to cold stress. Seedling emergence percentage, plant height, total leaf number, the total mass of fresh aboveground biomass, and ear length were determined as well as Soil Plant Analysis Development (SPAD) and Normalized Difference Vegetation Index (NDVI) values. In 2019, the pre-conditioned seedlings were more tolerant to cold stress for most of the tested parameters. Overall, the SPAD and NDVI values of the pre-conditioned seedlings were considered better in both years, however, it was not verified for all the studied hybrids. Among the hybrids, 'Strongstar' had the highest benefit from pre-conditioning compared to the standard growing method in terms of resulting in 17.5% higher plants, 13.1% longer ears, and 10.4% higher SPAD values in 2019. In 2020, when the cold stress was not so dominant, 'Gyöngyhajnal' gained the most from pre-conditioning with 9.7% higher plants, 32% more fresh aboveground biomass, 6.8% longer ears, 3.6% higher SPAD, and 9.3% higher NDVI values. More emphasis should be placed on the choice of stress-tolerant hybrids as well as on the seedling growing method and the date of transplanting to improve adaptation to the more frequent weather extremes.

Key words: sweet corn, seedling growing method, abiotic stress, SPAD, NDVI

In the European Union, France and Hungary are the leading sweet corn-producing countries (Orosz *et al.* 2009). Hungary has excellent soil conditions and the cultivation practices applied are high quality providing prime commodity for the processing industry as well as fresh consumption. Besides the pedological conditions, the climate of the country is also suitable for sweet corn production, even Hungary is located at the northernmost border of the

optimal production area of such a heat-demanding vegetable species (Kristóf & Terbe 2002). Nevertheless, the Central and Eastern European countries are considered a critical area regarding the effects of climate change on agricultural sectors (Ciscar *et al.* 2011; Iglesias *et al.* 2012). Weather extremes are becoming increasingly frequent (Olesen & Bindi 2002) negatively influencing the higher yield variability and the success of agriculture and farmers'

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welfare at local and global scales (Li *et al.* 2017).

The main problem in the production of sweet corn intended for the fresh-vegetable markets is the radical temperature changes in early springtime, which can cause losses of productivity and deterioration in crop quality. As the export from Hungary of early sweet corn is becoming more and more significant, thus it can have a negative impact on the international market (Fruitveb 2019). Abiotic stresses are crucial factors for corn production and impede its extension to new geographical areas. Cold stress – one of these impeding abiotic stress factors – negatively affects corn growth from germination to harvest, resulting in considerable yield depressions. Cold stress harms plant growth and yield due to several abnormalities in physiological, molecular, and biochemical processes (Waititu *et al.* 2021).

Two types of cultivation techniques (growing transplants and sowing under plastic mulch or row covers) are available for the farmers to provide sweet corn ears early in the season. Transplanted or directly-sown (under clear plastic mulch, row covers, or a combination of these) sweet corn can provide benefit for the growers from premium market prices early in the season, therefore gathering information on its performance will be more and more important (Aguayoh *et al.* 1999). Rattin *et al.* (2006) also had the opinion that transplanting the sweet corn would be a prospective alternative to direct seeded. According to Gavric and Omerbegovic (2021), sweet corn is cultivated by raising seedlings in a greenhouse in order to avoid cold stress and they can be transplanted into the fields when the weather conditions are favourable. However, abiotic stresses, such as low temperature, frequently occur recently (Krasensky & Jonak 2012).

The adaptation of crops to the changing climate is considered a major task to mitigate agricultural losses at the global level, therefore agricultural researchers have to deal with this issue (Gaál *et al.* 2014). According to Alcázar *et al.* (2006), plants have to adapt to the environmental fluctuation with their response mechanism, as there is a biological evidence that every plant uses this system to deal with abiotic stress. Generally, this adaptability comes along with changes in their physiological, developmental, and biochemical systems as well. Stress-tolerant plants are essential for agriculture

that needs crops more resistant to environmental stresses, especially to cold shock that causes considerable damages in plants (Hajihashemi *et al.* 2020).

Every technological element used during the cultivation, which improves the physical conditions of the plant, can subserve the tolerance of the plant against biotic and abiotic stress factors. It is necessary to emphasize the monitoring of the physical conditions of the plants, as stress resilience can negatively affect the quality and the quantity of the yield (Dobos *et al.* 2014). We can get information about the physical condition of the crops from their chlorophyll content (Carter 1994), which can be detected with many instruments, nowadays.

In our experiment, we investigated the possibilities of the adaptation to abiotic stress caused by extreme temperature fluctuations that frequently occur during the early sweet corn growing season. Through studying the physiological changes in sweet corn seedlings under low-temperature stress, the biosynthetic mechanism of the plants can be revealed. Exploration of the biosynthetic regulative mechanism can provide guidance for cultivating sweet corn under abiotic stress (Xiang *et al.* 2020).

Our hypothesis was that the pre-conditioned seedlings are more tolerant to stress factors originating from extreme temperature fluctuations after transplantation. Four sweet corn hybrids and two seedling growing methods were studied in two consecutive years. 2019 and 2020 provided a good opportunity to study the effect of various temperature conditions on the efficiency of the investigated seedling growing methods. Cold tolerance is a very important feature of fresh-market sweet corn intended to be sold early in the season. The main goal of our investigation was to determine the relationship between the two different seedling growing methods and cold stress tolerance of four early-maturing sweet corn hybrids by quantifying their SPAD and NDVI values and some morphological parameters.

MATERIAL AND METHODS

Our experiment was set up in the Demonstration Garden and Arboretum (DGA) of the Institutes for Agricultural Research and Educational Farm, University of Debrecen in 2019 and 2020. We test-

ed four early-maturing sweet corn hybrids (F_1), ‘Gyöngyhajnal’ (vegetation period (vp): 69 days), ‘Nugát 72’ (vp: 90 days), ‘Strongstar’ (vp: 69 days) and ‘Sweetstar’ (vp: 73 days). These hybrids are popular among the sweet corn growers in Hungary. In our study, we grew sweet corn seedlings up to their 5th leaf collar (15 by BBCH-scale) phenophase. Previously, the seeds were put into 5 × 5 cm plastic pots containing Kekkilä DSM 3W 25D (pH 5.9) peat medium. Two different growing methods were applied, one with pre-conditioning (PreCon), and one without it (standard=ST). The seedlings ready for transplanting were transplanted into small plots (3.8 × 2.4 m) with 76 cm row and 20 cm plant spacing in a calcareous chernozem soil on 10th April 2019 and on 18th May 2020, respectively. The main soil parameters of the experimental plots were determined according to the Hungarian standards in the accredited laboratory of the Research Institute of Karcag (Table 1).

In our study, we investigated the effect of two different seedling growing methods on some morphological parameters of sweet corn: seedling emergence percentage, plant height, total leaf number, total fresh aboveground biomass, and one of its quality-determining properties (ear (cob) length). The total fresh aboveground biomass was determined at harvesting. Two parameters (SPAD, NDVI) characterizing the relative chlorophyll content of the plants were measured before harvest in both years.

Seedling growing conditions

In the case of the ST method, the seedlings were grown in a heated glasshouse. During germination, the air temperature was maintained at 25°C (which is optimal for sweet corn). After germination, the temperature was reduced to 18–22°C and it was maintained until the end of the 5th leaf collar (15 by BBCH-scale) phenophase.

The PreCon growing method is based on the fact that pre-conditioning before transplantation enhances the adaptive ability of the seedlings to unfavourable conditions. We assumed that they can accommodate sudden cold stress if their temperature requirements are not fully satisfied during the seedling growing period. Therefore, the PreCon seeds were germinated at 10–15°C in a climate chamber. After germination, the young plants were grown in a non-heated plastic tunnel exposing them to cold stress from the early growth stages (at 5–15°C).

The air temperature values were recorded in the meteorological station of the Agrometeorological and Agroecological Monitoring Centre of the Institutes for Agricultural Research and Educational Farm located near the study plot.

The seedlings grown with the two different methods were transplanted into separate plots in 3 replications. The experimental field was very homogenous therefore a non-randomized, systematic design was applied. The seedlings of each investigated hybrid were placed in a double row arrangement within the plots, hence each plot represented one treatment. In both years, we examined 12 individual plants from each treatment and hybrid giving 12 replications for plant height, total leaf number, and total fresh aboveground biomass.

During the two growing seasons, we provided proper crop care for the appropriate development of the plants. Uniform fertilisation was used for each plot: 135 kg/ha nitrogen in the granular ammonium nitrate form was applied 2 times (top dressing), 160 kg/ha phosphorus in triple-super-phosphate form was given once, and 200 kg/ha potassium in potassium sulphate form was applied 3 times (basic dressing, 2 times top dressing), respectively. A foliar fertiliser containing 144 g/ha Zn was also applied 2 times during the vegetation period.

T a b l e 1

Main soil parameters of the experimental plots

pH _(KCl)	Total soluble salt content [w/w %]	CaCO ₃ [w/w %]	Humus content [%]	NO ₂ ⁻ +NO ₃ ⁻ -N [mg/kg]	P ₂ O ₅ [mg/kg]	K ₂ O [mg/kg]
7.7	<0.02	12.9	1.5	2.6	740.0	402.0

Source: Central Laboratory of Research Institute of Karcag.

Mechanical weed control was performed three times each year. We provided the generally applied crop protection, including treatments against European corn borer (*Ostrinia nubilalis*), corn earworm (*Helicoverpa armigera*), and aphids (*Aphidoidea*).

Determination of SPAD

The relative chlorophyll content of the leaves was measured with a SPAD (Soil Plant Analysis Development) 502 relative chlorophyll content meter (Minolta, Japan). This is a compact device, which measures the relative chlorophyll content of plant leaves. Knowing the chlorophyll content, it can be determined when to add fertiliser to produce larger crop yields of higher quality, furthermore, it is also an indication of the plant condition (Konica Minolta 2021). The SPAD values were determined one day before harvest. In our study, the average of 3 measurements on one leaf was considered as one repetition and 12 plants from each treatment were investigated for the SPAD measurements.

Determination of NDVI

We used the Trimble® GreenSeeker® crop sensor to measure plant biomass and display as the Normalized Difference Vegetation Index (NDVI) calculated using the reflectance at 660 nm and using infrared light (770 nm) as a reference. The relative strength of the detected light shows the density of the foliage. The greater the difference between the reflected light signals, the more vigorous the plant is (Trimble 2013). The normalized vegetation index increases with the development of the plant until the population reaches the senescence stage (Raun *et al.* 2005). We determined the NDVI values one day before harvest (the differences in the relative chlorophyll content, as well as the morphological param-

eters of the plants grown in different ways, are the most expressive at the end of the growing season). In our study, the average of 3 measurements on one plant was considered as one repetition and 12 plants from each treatment were investigated for the NDVI measurements.

Statistical and data analysis

The statistical evaluation of the measured data was performed with an SPSS 25.0 software package. The statistical reliability of the differences between the means was tested with Duncan’s Multiple Range test at 5% probability level. The relationship between the examined parameters was determined by calculating the Pearson correlation.

RESULTS

Seedling emergence

The seedling emergence rates determined in 2019 and 2020 are summarized in Table 2.

‘Gyöngyhajnal’ and ‘Nugát 72’ were found not to be sensitive to the seedling growing methods, in both years, regardless of the cold stress showed high emergence rate (near or 100%). ‘Sweetstar’ under ST fully emerged both years, but was sensitive to cold stress, especially in 2020 with 88 emergence percentage only. ‘Strongstar’ had the weakest emergence in both years, even under ST (90% and 85%, respectively), but under PreCon these values were very low (82% and 54%, respectively). Furthermore, we experienced that the germination of ‘Strongstar’ and ‘Sweetstar’ hybrids was slower than that of ‘Gyöngyhajnal’ and ‘Nugát 72’ in both years.

In 2019 the seedling growth was smooth, we

T a b l e 2

Emergence rates of the investigated sweet corn hybrids grown with different methods in 2019 and 2020

Hybrid	Gyöngyhajnal		Nugát 72		Strongstar		Sweetstar	
	ST	PreCon	ST	PreCon	ST	PreCon	ST	PreCon
Growing method	ST	PreCon	ST	PreCon	ST	PreCon	ST	PreCon
Emergence rate	[%]	[%]	[%]	[%]	[%]	[%]	[%]	[%]
2019	100	98	100	98	90	82	100	98
2020	100	100	100	100	85	54	100	88

Note: ST – standard growing method; PreCon – preconditioning.

could plant the seedlings in their 5th leaf collar (15 by BBCH-scale) phenophase uniformly in two separated plots at the same time (10/04/2019). The weather was quite capricious after transplantation in that season (Figure 1), thus providing a good opportunity to study the effect of weather extremes of early springtime, especially cold stress on sweet corn.

Starting on the first day after the transplantation, we observed a longer period with low temperature; the daily maximum values did not reach 20°C, while the minimum values during the nights were around 5°C for several days. On the 19th and 20th of April, we experienced even a more drastic fall in air temperature, the daily minimum value was 1°C on both days. Obviously, such a low temperature causes serious stress to the transplanted seedlings. During the rest of the vegetation period, there were no extreme weather conditions (cold or heat stress) being critical in terms of the normal development of the plants. In 2020 (just like in the previous year), after their germination, the young plants were grown further in a non-heated plastic tunnel from 10th of April. Five days later, we detected –3.6°C minimum temperature outside (Figure 2) that caused 0°C inside the plastic tunnel.

Due to this extreme cold stress, all the young plants were supposed to be lethally damaged. Nevertheless, we detected differences in the cold stress tolerance of the investigated hybrids. As the germination of ‘Strongstar’ and ‘Sweetstar’ hybrids was slower, most of the young plants were under the soil surface (in phenophase 09 by BBCH-scale). Therefore, we could not get any information about the cold tolerance of the seedlings of these two hybrids exposed to extremely low (0°C) temperatures. By that time, the seedlings of ‘Gyöngyhajnal’ and ‘Nugát 72’ reached phenophase 12 (by BBCH-scale), and they were more vulnerable: 25% and 63% of the seedlings survived that cold stress, respectively (Figure 3).

The experiment was restarted by resowing the seeds (from all investigated hybrids) one month later, the new seedlings were planted on 18th May 2020 for both growing methods. After the transplantation in 2020, the minimum and maximum air temperature values were more favourable for the young plants than in 2019 (Figure 4).

Nevertheless, even in the May and June of 2020, several days could be identified with a minimum air

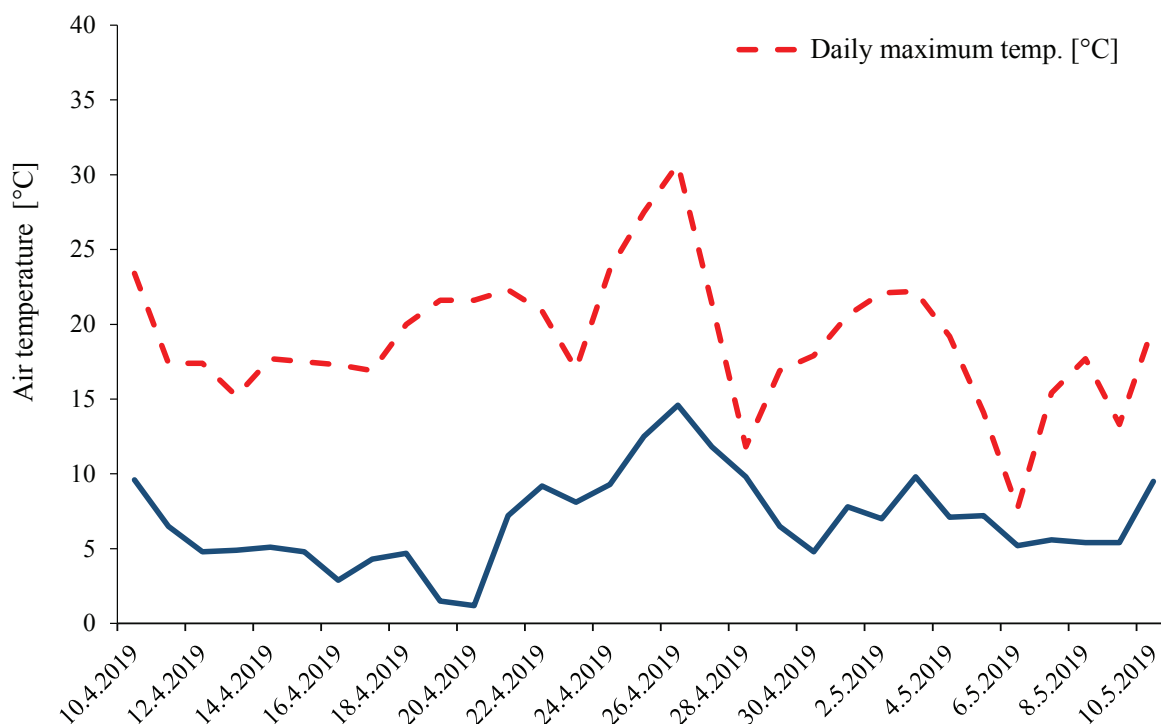


Figure 1. Daily minimum and maximum air temperature values in the 30-day-long period after transplanting in 2019.

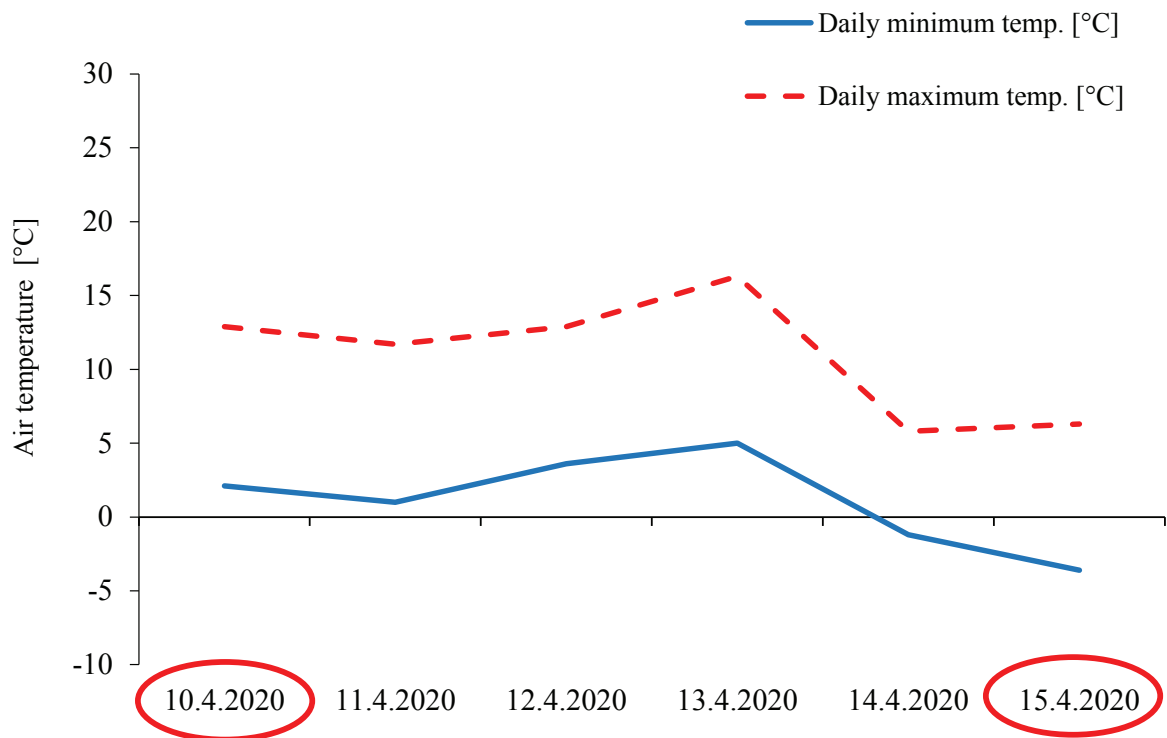


Figure 2. Daily minimum and maximum outside air temperature values in the 5 days while the young plants were in the non-heated plastic tunnel in 2020.



Figure 3. Young plants damaged by cold stress in the non-heated plastic tunnel.

temperature lower than the optimum for the young corn plants: 22nd–24th May and 3rd–4th June with their minimum air temperature around 5°C. We assumed that these days caused cold stress to the young corn plants even at a lower temperature than in 2019.

Effect of the two different seedling growing methods on the SPAD and NDVI values

The SPAD and NDVI values are highly dependent on the plants' genetic background, but also can be modified by the environmental and technological conditions and various stress effects (Lemaire *et al.* 2008). Table 3–4 show the SPAD and NDVI values of the seedlings grown with the two different methods measured before their harvest. The values of the hybrids that have achieved the best results in the various seedling growing methods are highlighted in bold numbers.

In 2019 (Table 3), the PreCon plants showed better SPAD and NDVI values, except for the NDVI

T a b l e 3

SPAD and NDVI values of the investigated sweet corn hybrids grown with different methods in 2019

Growing method	Genotype	SPAD	NDVI
ST seedling growing	Gyöngyhajnal	57.10±0.6 ^{ab}	0.61±0.07 ^{ab}
	Nugát 72	55.40±1.68 ^{bc}	0.50±0.01 ^c
	Strongstar	53.30±1.61 ^c	0.61±0.02 ^{ab}
	Sweetstar	58.12±1.36 ^{ab}	0.64±0.07 ^{ab}
PreCon seedlings	Gyöngyhajnal	57.99±0.91 ^{ab}	0.57±0.01 ^b
	Nugát 72	57.03±2.31 ^{bc}	0.65±0.03 ^{ab}
	Strongstar	58.83±1.14^a	0.67±0.02^a
	Sweetstar	58.08±0.70 ^{ab}	0.66±0.03 ^{ab}

*Values are means ± SD obtained from 12 replicates. The means with the same letters do not differ statistically by Duncan's multiple range test (p ≤ 0.05).

Note: SPAD – values measured with a Soil Plant Analysis Development chlorophyll meter; NDVI – Normalized Difference vegetation Index; ST – standard growing method; PreCon – preconditioning.

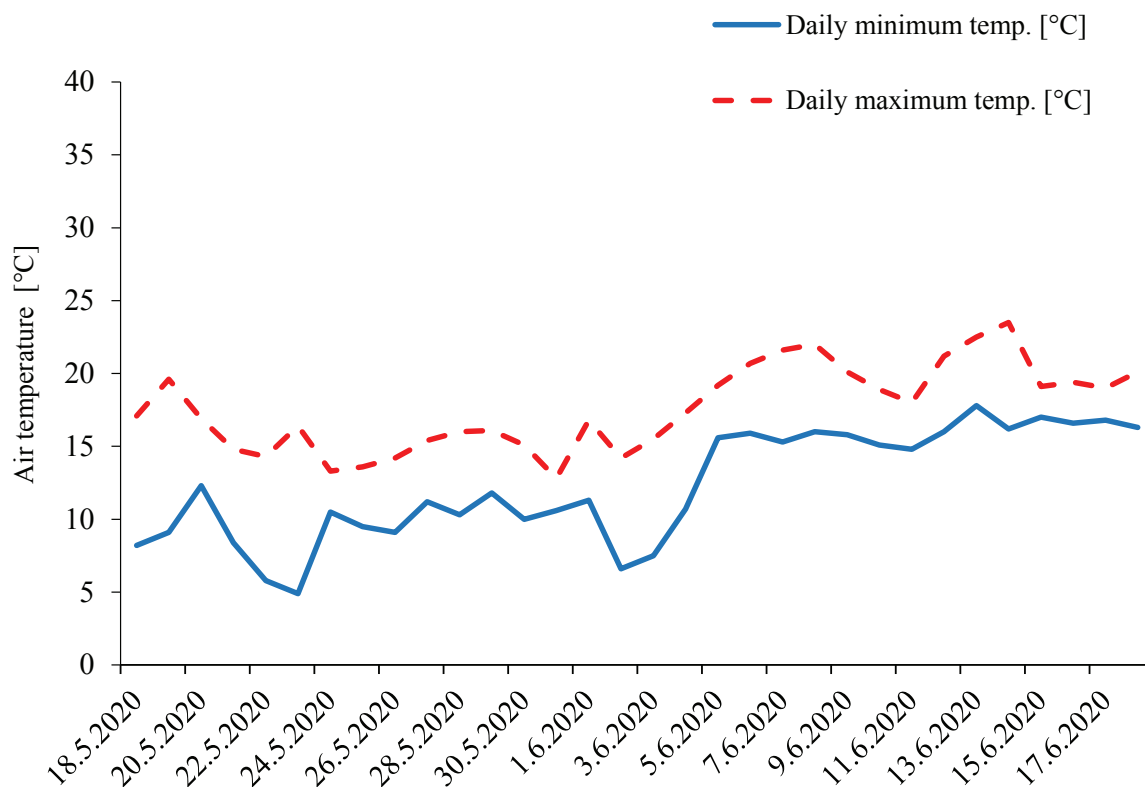


Figure 4. Daily minimum and maximum temperature values in the 30-day-long period after transplanting in 2020.

T a b l e 4

SPAD and NDVI values of the investigated sweet corn hybrids grown with different methods in 2020

Growing method	Genotype	SPAD	NDVI
ST seedling growing	Gyöngyhajnal	56.11±2.3 ^{ab}	0.54±0.05 ^{ab}
	Nugát 72	54.55±1.5 ^b	0.55±0.03 ^{ab}
	Strongstar	51.90±2.8 ^c	0.52±0.04 ^b
	Sweetstar	56.46±2.3 ^{ab}	0.55±0.03 ^{ab}
PreCon seedlings	Gyöngyhajnal	58.11±1.8^a	0.59±0.07^a
	Nugát 72	55.85±2.8 ^{ab}	0.54±0.03 ^{ab}
	Strongstar	55.85±3.4 ^{ab}	0.58±0.06 ^a
	Sweetstar	57.30±3.6 ^{ab}	0.55±0.06 ^{ab}

*Values are means ± SD obtained from 12 replicates. The means with the same letters do not differ statistically by Duncan’s multiple range test ($p \leq 0.05$).

Note: SPAD – values measured with a Soil Plant Analysis Development chlorophyll meter; NDVI – Normalized Difference vegetation Index; ST – standard growing method; PreCon – preconditioning.

of ‘Gyöngyhajnal’. Nevertheless, these differences were not statistically significant for all the cases at 5% significance level ($p \leq 0.05$). Based on the SPAD and NDVI values, PreCon ‘Strongstar’ was the best among the investigated hybrids in 2019.

In 2020, due to the later transplanting, the seed-

lings were not exposed to such extreme cold stress as in 2019 giving the chance to gain information on the efficiency of the two seedling growing methods under mild temperature conditions. The SPAD and NDVI values of the hybrids grown with different methods measured in 2020 are summarized in Table 4.

Just like in the previous year, in 2020, the SPAD and NDVI values of the PreCon plants were better, except for the NDVI value of ‘Nugát 72’. The differences were not statistically significant for all the cases at 5% significance level ($p \leq 0.05$). Based on the SPAD and NDVI values, the PreCon ‘Gyöngyhajnal’ was the best among the investigated hybrids in 2020.

Results of the morphological measurements

Plant height

As cold stress causes disruption in the function of cell membranes and slows down enzymatic processes, it significantly affects plant growth and development. The productivity of sweet corn with the good condition may also be more stable; therefore, the plant height of the hybrids grown with the investigated methods measured directly before harvest is considered a representative parameter (Figure 5).

According to our results, PreCon seedlings produced statistically higher plants in the case of each

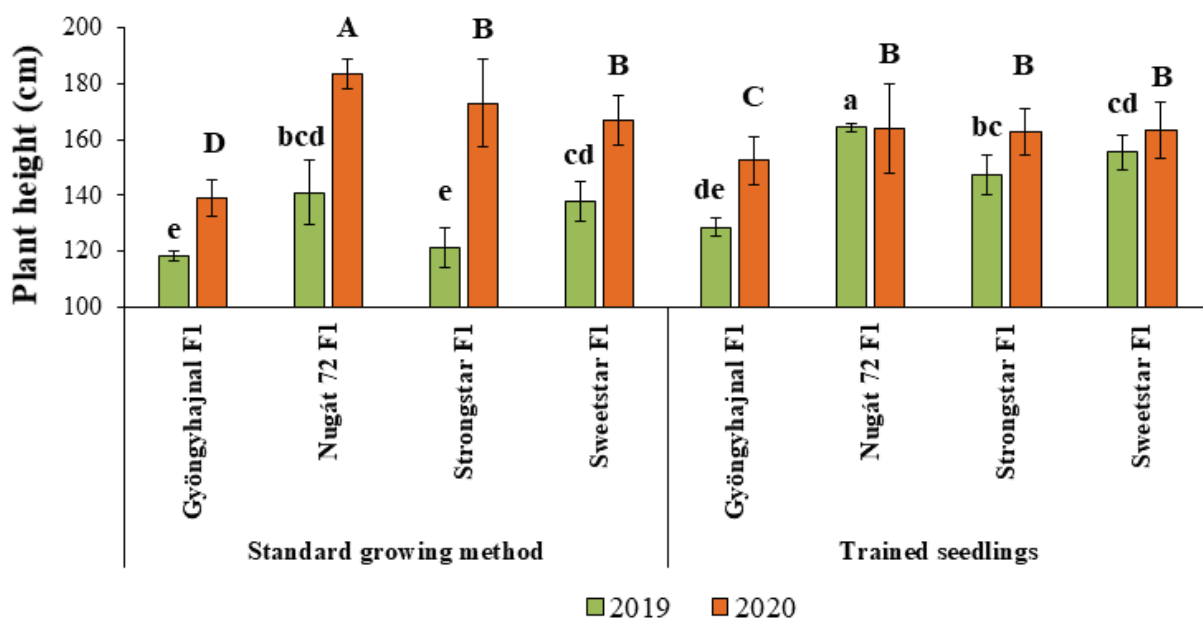


Figure 5. Effect of different seedling growing methods on the plant height of the investigated sweet corn hybrids (mean ± SD, $n = 12$). Minuscule and majuscule letters indicate the significant differences ($p \leq 0.05$) in 2019 and 2020, respectively.

genotype compared to the ones with the conventional (ST) growing method in 2019. Potential plant height is genetically coded, this is proven by trends we found in the plant height measured for the four hybrids treated with the different seedling growing methods. Therefore, this parameter is not suitable to select the best hybrid. Nevertheless, it could be established that ‘Strongstar’ had the largest gain in plant height due to the pre-conditioning just like in the SPAD and NDVI values in 2019.

In 2020, we found the same correlation between the relative chlorophyll content and the plant height: ‘Gyöngyhajnal’ had the highest SPAD and NDVI values associated with the statistically significant gain in plant height due to pre-conditioning. The other three investigated hybrids reacted with loss to pre-conditioning, but the difference was significant only in the case of ‘Nugát 72’.

Total leaf number

The number of leaves of a plant determines the size of the assimilation surface, which determines the amount of water transpired by the plants as well as the amount of absorbed light energy, and thus, the organic matter produced during the vegetation period. As the number of leaves is closely related to the relative chlorophyll content of the

plant, the effect of the investigated seedling growing methods on the average number of leaves was also analysed (Figure 6).

Comparing the seedling growing methods regarding this parameter, we found pre-conditioning against cold stress to be better for ‘Gyöngyhajnal’ (5.3 leaves/plant) and ‘Strongstar’ (6.3 leaves/plant) in 2019. The highest average total leaf number was detected on ‘Nugát 72’ from PreCon seedlings (7.7 leaves/plant). On the base of our results, it can be concluded that the PreCon seedlings had more leaves, but these differences could not be statistically justified unambiguously. In general, the plants grown with the ST method generated more leaves in the second year of the experiment (2020) when extreme cold stress did not occur during the repeated trial. We found statistically significant differences in the total leaf number in the case of ‘Nugát 72’ and ‘Strongstar’ hybrids under ST growing conditions.

Total fresh aboveground biomass

The amount of the fresh aboveground biomass of the plants was also examined in our experiment as a parameter determining the condition and the assimilation surface of the plant (Figure 7). We considered the study of the fresh aboveground biomass important since it can provide information on the

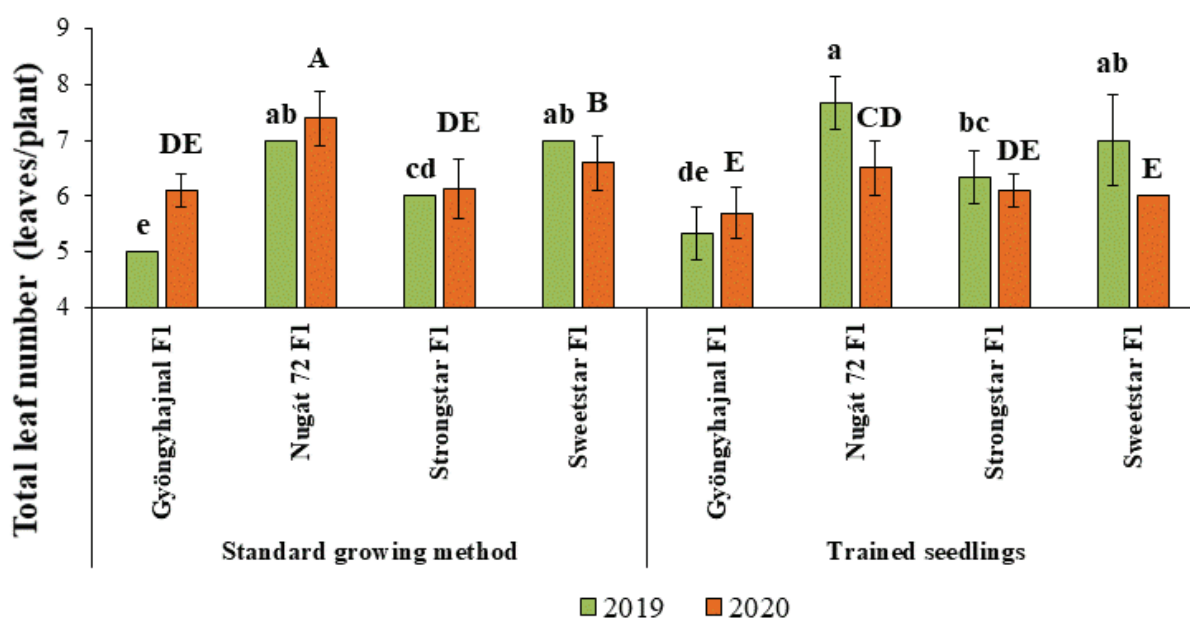


Figure 6. Effect of different seedling growing methods on the total leaf number of the investigated sweet corn hybrids (mean \pm SD, $n = 12$). Minuscule and majuscule letters indicate the significant differences ($p \leq 0.05$) in 2019 and 2020, respectively.

plant growth influencing the role of cold stress.

In 2019, significantly higher ($p \leq 0.05$) weight of sweet corn biomass of the PreCon ‘Nugát 72’, ‘Strongstar’ and ‘Sweetstar’ hybrids was found compared to the weight of the fresh aboveground biomass of these hybrids grown with the ST method. It can be established that ‘Nugát 72’ and the Pre-Con seedling growing method resulted in the best values in the examination of the amount of the total fresh aboveground biomass.

In 2020, ‘Gyöngyhajnal’ produced significantly larger fresh aboveground biomass due to the pre-conditioning. In the cases of ‘Nugát 72’ and ‘Sweetstar’, no significant differences were found between the seedling growing methods meaning that the pre-conditioning did not result in a negative effect on the generation of the fresh aboveground biomass of the plants.

Ear length

The length of the corn ear is also a very important quality parameter for the marketability of sweet corn, which, although genetically limited, can be influenced by the cultivation technology. The results of the ear length examination are shown in Figure 8.

According to the variety descriptions, ‘Gyöngyhajnal’ produces 19.2 cm, ‘Nugát 72’ 19.6 cm, ‘Strongstar’ 21 cm and ‘Sweetstar’ 19 cm long ears on the average. In 2019, the length of the ears of the PreCon seedlings was larger for ‘Nugát 72’ (18.7), ‘Strongstar’ (19.2), and ‘Sweetstar’ (19.5) than of the conventionally-grown seedlings. These three hybrids had similar ear lengths to their characteristic values despite the fact that they suffered from cold stress, not only during the seedling growing but also after transplantation.

While in 2019 there was no effect of the seedling growing method on the ear length of ‘Gyöngyhajnal’, in 2020, when the cold stress was not so intense this hybrid produced significantly longer ears due to pre-conditioning. In contrast, in the cases of the other three hybrids, no significant differences were found between the seedling growing methods. Nevertheless, the PreCon plants had ear lengths closer to their genetically encoded potential.

Correlation analysis

Pearson’s correlation calculation was used to determine the relationships between the values of SPAD, NDVI, total leaf number, total fresh abo-

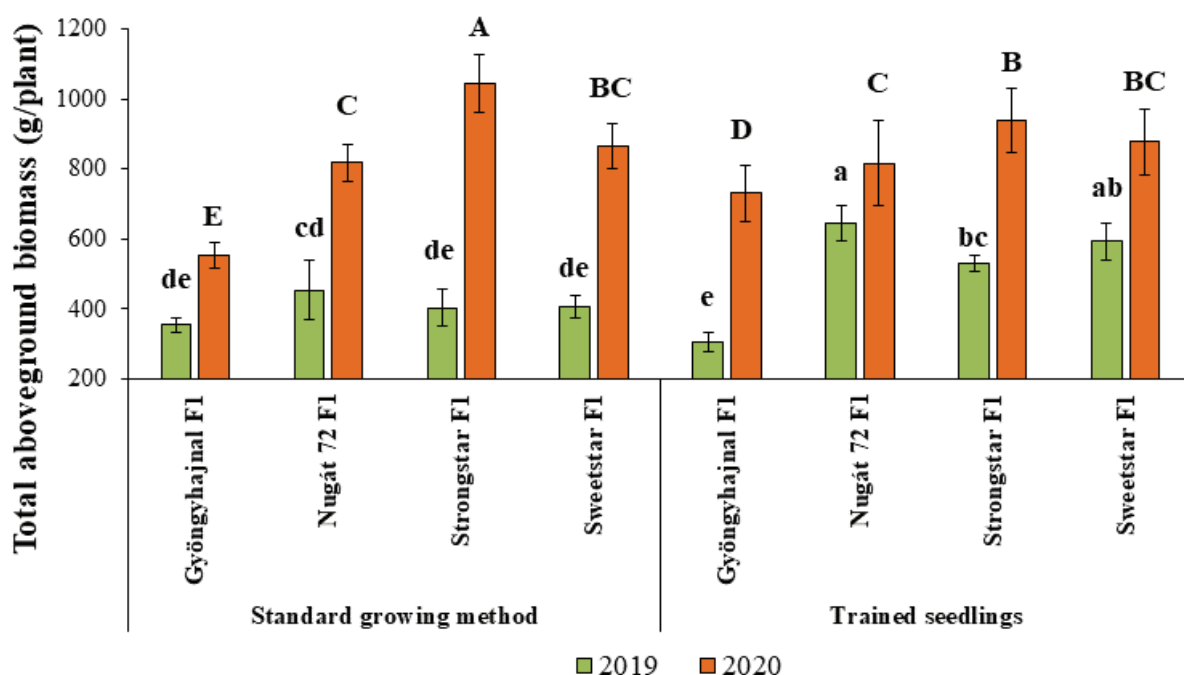


Figure 7. Effect of different seedling growing methods on the total fresh aboveground biomass of the investigated sweet corn hybrids (mean ± SD, $n = 12$). Minuscule and majuscule letters indicate the significant differences ($p \leq 0.05$) in 2019 and 2020, respectively.

veground biomass, and ear length (Table 5). In our study, correlations below 0.4 are considered weak, values between 0.4 and 0.5 are moderate, and correlations above 0.6 are considered close.

In 2019, there was a weak positive correlation between SPAD and NDVI values. The NDVI values had a moderate positive correlation with total leaf number, plant height, and ear length, while a close positive correlation was found between NDVI and fresh aboveground biomass. Total leaf number had a moderate positive correlation with total fresh aboveground biomass, weak positive correlation with ear length, and strong with plant height. Total fresh aboveground biomass had a close positive correlation with ear length and plant height. Furthermore, ear length also positively correlated with plant height in 2019.

In 2020, we found a weak positive correlation between SPAD and NDVI values, just like in the previous year. The correlation between NDVI and all the investigated morphological parameters was weak. Total leaf number had a weak positive correlation with plant height. Fresh aboveground biomass had a moderate positive correlation with ear length. Plant height positively correlated with ear length in 2020.

We found more positive correlations among the investigated parameters in 2019 than in 2020 proving that the first year of the experiment was more suitable to figure out the effect of the investigated growing methods on sweet corn seedlings. In general, it can be established that the morphological parameters characterizing the condition of sweet corn had a medium or close correlation with one another in both years of the experiment even under different weather conditions. Contrary to that, the correlation of SPAD and NDVI values with the morphological parameters was highly influenced by the weather conditions.

DISCUSSION

In boreal and temperate regions, late-spring frosts can be a risky weather phenomenon causing losses in crop yield in North America (Zohner *et al.* 2020) as well as in Europe (Gombos *et al.* 2011). Such weather extremes can have a negative effect on early sweet corn production, therefore, investigating the maximum cold tolerance of sweet corn is a perspective way to deal with this phenomenon. Accord-

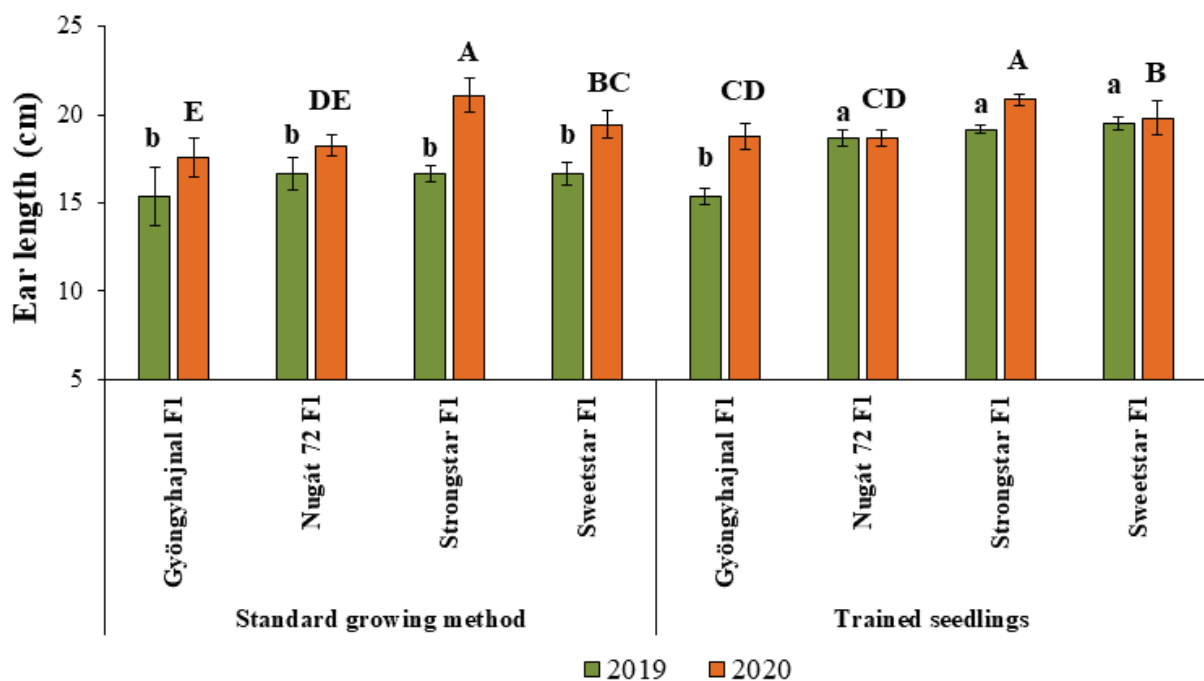


Figure 8. Effect of different seedling growing methods on the ear length of the investigated sweet corn hybrids (mean ± SD, $n = 12$). Minusculer and majusculer letters indicate the significant differences ($p \leq 0.05$) in 2019 and 2020, respectively.

ing to Li *et al.* (2021), cold stresses can cause physiological, molecular, and biochemical changes in plants, negatively affecting cell membrane integrity, metabolic function, seed germination, and seedling emergence. There is a molecular mechanism of corn seed resistance to cold stress at seed germination. Li *et al.* (2021) analysed the global transcriptome of a high-vigour corn variety exposed to cold stress by RNA-sequencing. They identified 9,605 differentially expressed genes between the control and the cold-stressed sample. From an agronomic point of view, the difference we figured out in cold stress tolerance of the investigated hybrids under different growing methods also justified the importance of further studies in this respect.

According to Janda (2007), acclimatization processes are induced by cold stress in most of the plants of the temperate climate zone that ensure resistance against low temperatures and maintain their metabolism. For example, the so-called suboptimal temperature range for the undisturbed development of young corn plants is 15–20°C. If corn plants are growing in the temperature range of 12–15°C,

slight acclimatization is taking place (Janda 1998).

In freezing-stressed plants, photosynthesis is suppressed. Cold stress induces a signalling mechanisms and overexpression of the cold stress-responsive genes that help in the prevention of cold-induced water stress, oxidative stress, and photosynthetic damage (Hajihashemi *et al.* 2020). Based on our results, the SPAD and NDVI values of plants from PreCon seedlings were higher than from seedlings growing with the ST method in both years. The same consequence was published in the study of Molnár *et al.* (2012), they also established that hybrids with higher SPAD and NDVI values (meaning better plant condition) showed higher productivity compared to hybrids with lower values. Based on their research, Wang *et al.* (2016) also revealed a significant relationship between yield and NDVI during the pre-silking period of corn.

Three of the studied morphological parameters (plant height, total leaf number, fresh aboveground biomass) characterizing the condition of the plants also statistically justified the advantage of the Pre-Con seedling growing method in the year 2019 with

T a b l e 5

Pearson’s correlation between the examined parameters in 2019 and 2020

		SPAD	NDVI	Total leaf number	Total fresh aboveground biomass	Ear length	Plant height
SPAD	2019	1	0.25	-0.01	0.11	0.26	0.07
	2020	1	0.13	-0.27 ⁺⁺	-0.10	-0.24 ⁺⁺	-0.18 ⁺
NDVI	2019		1	0.44 ⁺⁺	0.61 ⁺⁺	0.49 ⁺⁺	0.56 ⁺⁺
	2020		1	0.03	-0.01	0.03	0.04
Total leaf number	2019			1	0.48 ⁺⁺	0.34 ⁺	0.60 ⁺⁺
	2020			1	0.53 ⁺⁺	0.60 ⁺⁺	0.36 ⁺⁺
Total fresh aboveground biomass	2019				1	0.66 ⁺⁺	0.86 ⁺⁺
	2020				1	0.12	-0.06
Ear length	2019					1	0.59 ⁺⁺
	2020					1	0.63 ⁺⁺
Plant height	2019						1
	2020						1

⁺Correlation is significant at SE 0.05 level (2-tailed); ⁺⁺Correlation is significant at SE 0.01 level (2-tailed).

Note: SPAD – values measured with a Soil Plant Analysis Development chlorophyll meter; NDVI – Normalized Difference vegetation Index.

extreme temperature fluctuations during the early transplanting period. Similar results were found by Sohag *et al.* (2020) when rice plants were studied under chilling stress. For the two-week-old plants, chilling stress caused stunted growth with visible toxicity along with an increase in oxidative stress markers and osmolytes, and a decrease in chlorophyll. In 2020 with less extreme temporal distribution of air temperature, the ST method resulted in higher values of the morphological parameters except for ‘Gyöngyhajnal’, but the majority of the differences were not statistically significant.

Among the hybrids, ‘Strongstar’ had the highest benefit from pre-conditioning compared to the ST growing method in terms of the SPAD and NDVI values and almost all the investigated morphological parameters in 2019, when the seedlings were exposed to strong cold stress. In 2020, when the cold stress was not dominant due to the delayed transplanting, ‘Gyöngyhajnal’ gained the most from pre-conditioning.

The length of the corn ear is not just a morphological, but also a very important quality parameter of sweet corn. Plants from PreCon seedlings performed better in this marketability trait too. In 2019, the length of the ears originating from the PreCon seedlings was larger for ‘Nugát 72’, ‘Strongstar’ and ‘Sweetstar’ than from the conventionally grown seedlings. These hybrids had ear length similar to their characteristic values although the fact that they faced multiple cold stress. In 2020, only ‘Gyöngyhajnal’ showed better results in this parameter due to pre-conditioning, no significant differences were found for the other three hybrids in this respect, though they had almost reached the ear length values given in the variety descriptions.

CONCLUSIONS

On the base of our experiment, it can be concluded that the morphological parameters characterizing the condition of sweet corn had a medium or close correlation with one another regardless of the weather condition differences detected in the two investigated years. Contrary to that, the correlation of SPAD and NDVI values with the morphological parameters was highly influenced by the weather

conditions. In 2019, when the cold stress was severe, the hypothesis that the pre-conditioned seedlings are more tolerant to stress factors originating from extreme temperature fluctuations after transplantation was verified most of the tested parameters. The plants from the pre-conditioned seedlings were significantly higher, furthermore could be characterized with more leaves, higher fresh aboveground biomass, and ear length.

Our results gained so far are promising and have scientifically established practical soundness as well as aiding the proper hybrid selection of farmers producing sweet corn under agroecological conditions similar to the investigated ones. Nevertheless, further studies are needed as the research of the adaptation to the changing weather conditions is a complex task. More emphasis should be placed on the choice of stress-tolerant hybrids, seedling growing, pre-conditioning, and date of transplanting to improve the adaptation to the more frequent weather extremes.

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