Theses of Doctoral (PhD) dissertation

EVALUATION OF BIOLOGICAL BASIS AND ITS INNOVATIVE USE IN PRECISION SWEET CORN (ZEA MAYS CONVAR. SACCHARATA KOERN.) GROWING

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1. INTRODUCTION AND OBJECTIVE

Corn has been cultivated in the America for thousands of years. Sweet corn is characterized by a mutation on chromosome 4 that causes the recessive allele to be expressed instead of the dominant allele. The conversion of sugar in the seeds into starch does not occur, but is partially inhibited. This results that the starch content of sweet corn is lower while the sugar content is higher compare t corn, so it is sweeter and more tender (Daniel, 1978, Revilla et al., 2021). The quality of sweet corn is primarily determined by its sugar content, which varies depending on the hybrid. nay shows diversity (Abadi and Sugiharto 2019).

The global sweet corn production area is approximately 1,6 million hectares with a production of approximately 20 million tons and an average yield of 13,029 tons/ha (Anonymous, 2020). Due to its prominent role in feeding the world's population and the rapid increase in its production, corn has become one of the most important crops in the world (Nagy 2021). To achieve adequate yield and crop security, it is of paramount importance to select the best hybrids which suits the production goals and given high production under pressure ecological conditions, the harmonious nutrient supply is essential. The growing population makes a stable, increasing the volume of corn production inevitable. Sweet corn is a widely consumed grain throughout the world, and its crop contains abundant nutrients (proteins, carbohydrates, minerals), dietary fiber, and phytochemicals, including carotenoids (Parra et al., 2007). Sweet corn is of paramount importance as a healthy food, and its role in the food industry is continuously increasing, primarily due to its nutritional value (Swapna et al., 2020).

Sweet corn is grown in the largest area in Hungary, Tiszántúl, including in Hajdú-Bihar County. Unlike the more important vegetable crops, its cultivation area has not decreased even today, 30,000 - 35,000 hectares. The most significant producers are the USA, the European Union, and Thailand. Hungary's sweet corn production is also among the leading countries in international terms. We are the largest sweet corn-growing country in the European Union, ahead of France. A significant part of the domestic production is utilized by canneries, a smaller part by the refrigeration industry, but its consumption as fresh goods is also increasing year by year. Hungary ranks second in the world in sweet corn exports after the USA. It has become one of the most widely processed food industry raw materials in our country. The demand for sweet corn is increasing, the annual harvest is 500,000 tons, 90-95% of its is exported to abroad. In order to minimize the production costs and ensure high-quality sweet corn, the basis of cultivation is provided by precise planning and cultivation, for which the optimal basis is provided by knowledge of the growing time of different sweet corn hybrids. In Hungary, primarily Australian and American hybrids are grown. In order to achieve a successful yield, breeding companies provide the length of the growing time in days or broken down into heat units.

In connection with the research program of the Kerpely Kalman Doktoral School we set the goals:

- In field sweet corn experiments, we will determine the effects of different vintages (2020,2021,2022) on corn yield and content values.
- During the research, efficiency parameters were determined based on the annual available water (rainwater + irrigation water) quantities and the useful heat amounts.
- the yield and yield component results of normal sweet and supersweet sweet corn hybrids in the years studied and their averages using statistical analyses.
- We examine and evaluate the mineral, lutein and xanthophyll contents of raw grains, taking into account aspects of healthy nutrition.
- We determine the ratios of kernels, cobs and husks, which are important from the perspective of food processing.
- Our research aims to identify molecular biological markers of lutein biosynthesis in sweet corn hybrids. monitoring , with targeted gene expression studies, in the generative phase of plants
- a difference in arbuscularity between different sweet corn hybrids. in mycorrhizal colonization.

2. **MATERIAL AND METHOD**

2.1. Location and circumstances of the experiment

The leaf, fruit and root samples required for the experiments were collected from the Demonstration Garden of the Böszörményi út Campus of the University of Debrecen, which is located at 47.5524502, 21.5999328. The experimental area is a leached lime-sediment chernozem soil with extremely good water and nutrient management parameters. The average pH value of the top 1 meter layer of the soil is 7.59 units. The Arany type binding number is 45.8 (*Table* 1).

Table 1. Main chemical properties of the soil of the studied area in the upper 0-100 cm section (Debrecen, 2021)

Chemical property	Value
Carbonated lime (m/m%)	15,33
Humus (m/m%)	3,35
Total salts soluble in water (m/m%)	0,0065
Magnesium (potassium chloride soluble) (mg/kg of air)	435,5
Sulfur (potassium chloride soluble) (mg/kg of air)	7,97
Nitrogen nitrite+nitrate (potassium chloride soluble) (mg/kg air volume)	5,27
Phosphorus pentoxide (ammonium lactate soluble) (mg/kg of air)	343,8
Potassium oxide (ammonium lactate soluble) 8mg/kg of air)	274,68
Sodium (ammonium lactate soluble) (mg/kg air volume)	54,23

Source: Demeter et al. 2021

2.2. Meteorological conditions

The weather of the experimental years was evaluated using the measurement data of the automatic meteorological station operating on the Böszörményi campus of the University of Debrecen. For the growing season (April-September), we evaluated the temperature and precipitation conditions on a monthly basis. For comparison, we used climate data from the 30-year period between 1981-2010, and we also examined the weather of the winter semesters.

In 2020, 261 mm of precipitation fell during the (previous) winter semester. A large amount of precipitation fell during the growing season, with 447 mm significantly exceeding the multi-year average. Precipitation fell mostly in the three summer months, with the highest amount in July (149 mm), ensuring favorable water supply during the phenological phases that are crucial for the crop (flowering, fruit setting, grain filling).

The 2021 growing season started similarly to the previous year, with adequate soil moisture conditions. The weather was cool for the season throughout April and May, with below-average precipitation in April (33 mm) and average precipitation in May (66 mm). A definite turn in the weather occurred in June. The first month of summer was characterized by significantly warmer weather than usual and little precipitation fell (6 mm) (Gombos and Nagy 2022).

In 2022, an even more severe drought occurred than in the previous year. After a very dry growing season, only 150 mm of precipitation fell in the winter semester. April was on average rainy, but after that, every month until August was extremely dry. A total of 66 mm of precipitation fell in the three summer months, which is 115 mm below average. The summer months showed positive temperature anomalies of 3.4, 2.4, and 2.9°C, respectively (Gombos and Nagy 2023).

2.3. Laboratory methods

2.3.1. Sampling, sample preparation

Leaf, root and fruit samples for our studies were collected from the beginning of the generative stage of sweet corn until harvest. The samples were collected from the uppermost, fully developed leaves and from corn kernels cut from the crops. During the sampling, in order to protect the RNA, we performed on-site freezing in liquid nitrogen, then the replicates were stored at -80 °C until the studies.

2.3.2. RNA isolation, cDNA synthesis

The homogenization of the samples and subsequent RNA isolation were performed under liquid nitrogen due to the degradability of the polymer giant molecule. Total RNA was extracted using the MN - Nucleo Spin RNA Plant, Mini Kit for RNA following the manufacturer's instructions. The quality of the extracted ribonucleic acid (RNA) was checked after gel electrophoresis with 1% by separation on agarose gel. During the electrophoresis, DNA fragments were separated according to their length and visualized using integrating compounds and UV light. Subsequently, the A260/A280 and A260/A230 ratios were evaluated spectrophotometrically. In the next step, Thermo Scientific RevertAid First Stand cDNA synthesis kit and Random hexamer Using primers, 20 µL of complementary DNA (cDNA) was prepared.

2.3.3. Quantitative PCR

The cDNA for quantification by Thermo We used quantStudio 5 to make Applies Using Biosystems TM SYBR TM Select Master Mix dye preparation. The different PCR products of primer sets were subjected to melting curve analysis (Melting Curve Analysis) to detect the presence of non-specific ampicons and primer dimers.

2.3.4. Evaluation and sequencing of reference genes

Housekeeping genes are a group of constitutively expressed genes. They encode essential functions for all cells. They are expressed in every cell of an organism, regardless of tissue type, developmental stage, cell cycle state, or external signal (Kozera and Rapacz 2013). Their presence is essential for maintaining basic cellular functions. Based on literature data, the reference genes with which we compared gene expression differences in our studies encode actin (ACT), tudin (TUB), ubiquitin (UBI), and a thioredoxin -like gene (TLG) (*Table* 2*).*

Table 2. *Household verbs included in our* studies

GENE	Forward primer sequence	Reverse primer sequence
TUB	AGAACTGCGACTGCCTCCAAAGG	AGATGAGCAGGGTGCCCATTC
ACT	CATGGAGAACTGGCATCACACCTT	CTCTCTGTTGGCGACACGACTCA
UBI	GTTTAAGCTGCCGATGTGCCTG	GACACGACTCATGACACGAACA
TLG	GGACCAGAAGATTGCAGAAG	CAGCATAGAGACAGGAGCATTG

Source: *Mesiass et al. 2014*, Own edit

2.3.5. Evaluation of carotenoid pathway genes by real-time PCR

He et al. 2019, we examined and validated known molecular biological markers. For lutein biosynthesis gene *expression*, 8 pairs of primers and 6 target genes were selected for preliminary studies (PSY, PDS, ZDS, LCYB, LCYE CYP97C). Specific primers for amplification of carotenoid- related maize genes (Sigma-Aldrich) are listed in (*Table 3*). Our results show that our reactions are efficient, and melting point curve analysis shows that there are different products.

Table 3. Primer sets *used for gene expression studies of the carotenoid pathway*

Gén	Forward Primer Sequence (5′–3′)	Reverse Primer Sequence (5′–3′)
PSY	CATCTTCAAAGGGGTCGTCA	CAGGATCTGCCTGTACAACA
PDS	GAAATCATCGATGCAACTATGGAA	CTTCGATAGGTGACCTTTGGA
ZDS	GTGTGGTAAAGATCGGACAA	AGAGAGTTGCTCCTTCCAT
LCYB	CATCGTAAGGTTCCTCGACA	ATGCCGAAGCAGAAGAACTC
LCYE	TTTACGTGCAAATGCAGTCAA	TGACTCTGAAGCTAGAGAAAG
CYP97C	GTTGACATTGGATGTGATTGG	AACCAACCTTCCAGTATGGC

Source: *W. He et al., 2019*, Own editing

2.3.6. Element determination by laboratory testing method

The hybrids that we examined under laboratory conditions from samples which was taken at harvest at the Agricultural Instrument Center of the Faculty of Agriculture, Food Science and Environmental Management of the University of Debrecen. The plants were randomly selected for the sampling required for the statistical analysis of their content values. The samples required for laboratory tests were transported in liquid nitrogen and then stored at -84 °C until testing. In order to determine the element, the drying of the sweet corn hybrids grains took place at a gentle, low temperature. The drying took place at 50°C and then the samples were stored at 24°C until processing. After collection, the samples were immediately processed in a drying cabinet (Binder FD 720 heat chamber) with maximum air speed (El- Abady, 2014). In order to determine the elemental content of the samples, 0,5 g of the prepared eye samples were weighed and then 5 ml of distilled cc. HNO_3 and 3 ml of 30% H_2O_2 were added to the samples. After sealing, the samples were destroyed in four steps with an ETHOS Plus Milestone microwave destroyer according to the Application Note 076 method. In the next step, the containers containing the destroyed samples were cooled down and then poured into a 50 ml volumetric flask. The measurements were made with an ICAP 7000 spectrophotometer (Thermo Scientific), during which we measured the spectral lines with wavelengths characteristic of each element.

To determine the amount of carotenoids (lutein, zeaxanthin), the method of Moros et al. (2002) was used. The samples were ground with the addition of dry ice and stored at -18 °C until the test. During the test, 0,6g of ground sample was weighed into a 50 ml centrifuge tube and after adding 6 ml of 100% ethanol , the samples were vortexed for 30 seconds and then sonicated in a cooled ultrasonic bath for 5 minutes. In the next step, 3 ml of 10% ethanol was added. NaCl solution and 10 ml hexane, then the samples were vortexed again for 30 seconds. The samples were centrifuged at 5000 rpm for 3 minutes until the phases separated. The upper, hexane phase was transferred to an evaporating tube. The hexane separation was repeated twice more until the lower aqueous-alcoholic phase became colorless. The collected hexane fractions were evaporated to dryness under a nitrogen stream at room temperature in the dark. 2 ml of 0,1% Butyl Hydroxyl Methanol (MeOH) containing toluene (BHT) was added, vortexed and sonicated, then the solution was filtered through a 0,22 μm syringe filter into an HPLC vial. Samples were stored at -18 °C until high-performance liquid chromatography (HPLC) analysis.

The kernel samples were ground in the presence of dry ice, after which approximately 1/3 of the ground sample was placed in a 40 ml EPA vial. The samples were stored in an open container at room temperature until the dry ice sublimed, and the weight of the vial was weighed. The vials were then placed in a vacuum oven at 70 °C using a vacuum of 500 mbar, then after 3 hours the vacuum was reduced to 100 mbar and dried overnight. After removing the vials from the oven, they were hermetically sealed and cooled back to room temperature to determine their exact weight.

2.4. Hybrids tested in the experiment

For our studies, four different genotypes of sweet corn hybrids were selected in each of the three experimental years (*Table 4)*. Of the four hybrids tested, the laboratory results of the normal sweet Honey and the supersweet GSS6924 hybrids provided a reliable basis for comparison, and for detailed statistical evaluations

Table 4. *Sweet* corn *hybrids 2020-2022*

Notation	2020	2021	2022
	Hybrids		
H1	Honey normal sweet (Martonvásár)	Honey normal sweet (Martonvásár)	Honey normal sweet (Martonvásár)
H2	GSS6924 supersweet (Syngenta)	GSS6924 supersweet (Syngenta)	GSS6924 supersweet (Syngenta)
H3	Dessert R80 super sweet (Unicorn)	Dessert R80 super sweet (Unicorn)	Dessert R80 super sweet (Unicorn)
H4	SV1899 Superédes (Seeds)	SV1899 Superédes (Seeds)	SV1899 Superédes (Seeds)

2.5. Experimental production technology, 2020, 2021, 2022

In all three experimental years, for all four sweet corn hybrids tested, the seed number sown was 55,000/ha. The sowing dates were 2020.05.22, 2021.04.29, 2022.05.12. The implemented precision production technology was supplemented with drip irrigation.

Elements of the technology:			
2019.09.12	Mud crushing	2021.04.29	Sowing
2019.10.15	Autumn plowing	2021.05.21	Weeding
2020.03.28	Ploughing work	2021.08.20	Harvest
2020.04.03	Fertilizer spreading	2021.11.03	Crushing
2020.05.20	Seedbed preparation	2021.11.09	Stem splitter Natur NOVA, MCIRO
2020.05.22	Sowing	2021.11.10	Dial
2020.06.05	Weed control	2021.11.17	Relaxation
2020.06.29	Interrow cultivation	2021.11.24	Ploughing
2020.08.19	Harwest	2022.03.10	Failure to plow
2021.03.09	Soil sampling (0-30 cm)	2022.04.11	Fertilizer spreading -
2021.03.18	Soil sampling (0-200 cm)	2022.04.11	Combinatorization after fertilizer application
2021.03.30	Fertilizer spreading	2022.05.02	Soil sampling
2021.03.30	Combinatorics afrer fertilizer application	2022.05.12	Sowing
2021.04.23	Showing with a spade harrow	2022.05.27	Weeding
2021.04.26	Combine befor sowing	2022.07.31	Roofing

The herbicide agent used during the experiment was Laudis 5 l/ha. Continuous water supply was ensured by a controllable drip irrigation system. The irrigation water was 45 mm in 2020; 268 mm in 2021; 304mm in 2022. In the experiment, the N fertilizer also contained Mg (Table *5*) .

Table 5. *Fertilizer used in the experiment (kg/ha)* 2020-2022

Year	**N**	**CaO**	**Mg**
2020	80	21	15
2021	90	23	16
2022	101	26	18

2.6. Statistical methods

Fisher 's least significant difference (LSD) test was used to determine significant differences between different values. The correlation between variables was characterized by the Pearson correlation coefficient. This correlation matrix was used as the starting point for the principal component analysis. The applicability of principal component analysis (PCA), a multivariate statistical procedure, was determined by the Kaiser - Mayer - Olkin test (Dzhuiban and Shirkey 1974). The critical value of the test is 0,5. If any variable MSA (Measure of Sampling Adequacy) value exceeds this value, suitable for analysis. The number of principal components was set so that the variance coefficient of the correlations was above 80%. Components with eigenvalues less than one were ignored and were only used in the representation. During the correlation analysis, the following abbreviations were used: plant height (nm), stem diameter (stem), yield (term), tube diameter (tube length), grain weight (grain), cob (cob) and for minerals magnesium (Mg) potassium (K), iron (Fe), phosphorus (P), calcium (Ca), zinc (Zn). Statistical evaluation of the experimental results R 3.2.4. We characterized the results in a statistical environment (Teams 2016a), using the RStudio (Team2016b) graphical interface, the " gplots " (Warnes et. al., 2015), "car" (Fox and Wesiberh 2011) and " agricole " (De Mendiburu , 2016) packages, and Minitab LLC. (PA, USA) and statistical software.

2.7. Mycorrhizal colonization study

Mycorrhizal colonization in roots is determined by a special ink/ vinegar staining procedure , during which subsamples taken from stored samples are boiled in 10 % KOH, then further boiled in 5 % acetic acid solution in 5% ink. After washing with water, they are washed in 10% acetic acid solution. Finally, thirty 1 cm root pieces per sample are placed on a microscope slide. Colonization is estimated microscopically, based on the method of Trouvelot et al. (1986), during which the total colonization of the root and the arbuscule and vesicle content within the colonized root fragment are estimated for each root piece. The total colonization value is 0-5, and the arbuscule and vesicle content is estimated between 0-3.

Parameters characterizing mycorrhizal colonization:

- F%: The mycorrhizal frequency, the percentage of the root piece with any colonization.
- M%: The total intensity of colonization in the entire root, i.e. how widespread the colonization is in the root.
- A%: The intensity of arbuscular colonization in the entire root.
- V%: The intensity of vesicle colonization in the entire root.

3. RESULTS

3.1. Comparative results of sweet corn hybrids in 2020

2020 was a good, average year for sweet corn. Significant precipitation fell from the harvest of the previous crop to the time of sowing, 261 mm. The raw yield of the H1 hybrid was 16.146 tons per hectare, in a favorable year (*Figure 1*). The raw grain yield rate showed an average result, 51% (*Figure* 2). The raw yield of the H2 hybrid was the most favorable of the hybrids tested, 17.187 t/ha. The raw grain rate was also outstanding, 57% (9.22 t/ha). The cob rate was also favorable, 39% and the cob rate was 7%. The raw yield of the H3 hybrid was the smallest (16.545 t/ha). The grain (52%) and cob (40%) were average, and the cob rate (8%) was more favorable. The results of the H4 hybrid, despite the excellent vintage, can be considered average. The raw yield was 16.771 tons and the raw grain yield was 8.843 tons per hectare. The grain (53%) and cob (38%) ratio were favorable, but the husk (9%) ratio was the highest.

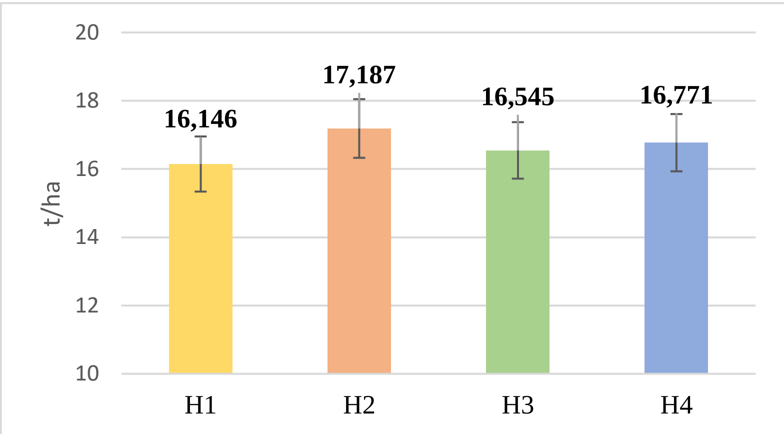

Figure 1. Raw yield of *sweet corn hybrids (tube+cob) t/ha Debrecen*, 2020

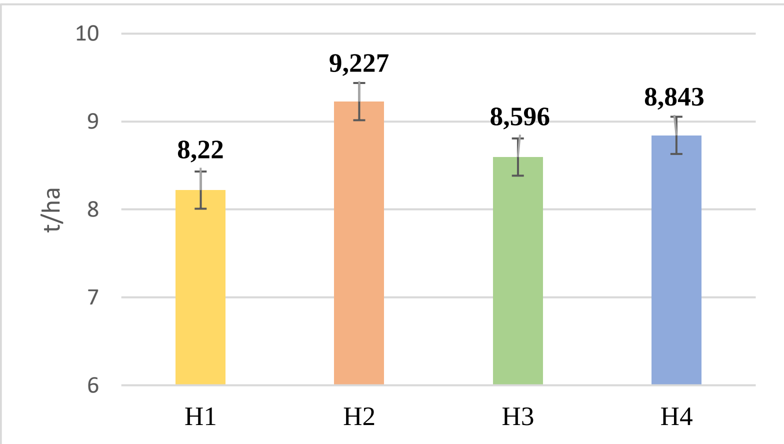

Figure 2. *Raw grain* yield of sweet corn *hybrids, t/ha Debrecen, 2020*

3.2. Comparative results of sweet corn hybrids in 2021

2021 proved to be an above-average, favorable year for sweet corn production. 246 mm of precipitation fell from the time of pre-crop harvest to the time of sowing. The H1 hybrid has a raw yield of 17.621 t/ha (*Figure 3*) and a grain yield of 9.185 t/ha (52%) which is considered average (*Figure 4*). The cob quantity is high (40%), the cob ratio is average (8%). The H2 supersweet hybrid has the highest raw yield, 18.486 t/ha. The raw grain yield ratio is excellent, 57% (10.557 t/ha). The cob ratio is the lowest, the most favorable (36%), and the cob ratio is also the lowest (7%). The H3 hybrid has the lowest raw yield among the four hybrids (16.841). The ratio of raw grain (53%) and cob (38%) was also favorable. The amount of cob was average (9%). The yield of raw grain per hectare of the H4 hybrid (17.294 tons) was average. The ratio of grain (51%) and cob (39%) was more favorable, but the cob ratio was the highest (10%), which is in line with the processing industry data.

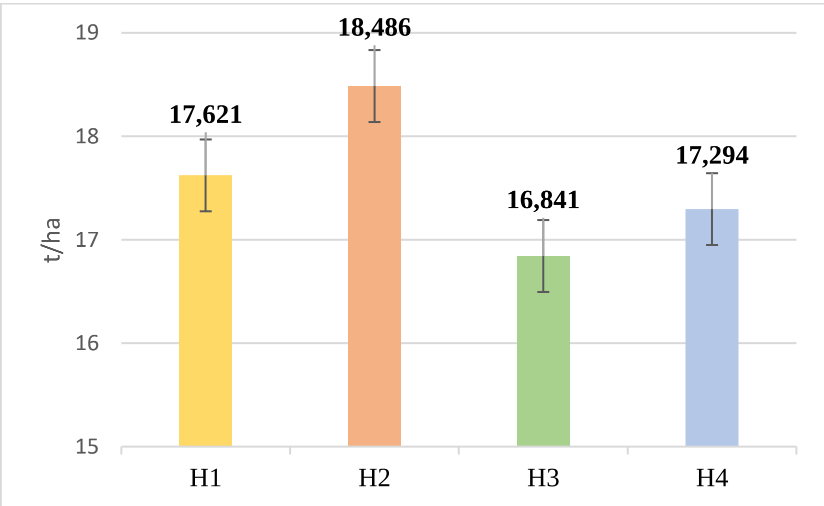

Figure 3. Raw yield of *sweet corn hybrids (tube+cob) t/ha Debrecen*, 2021

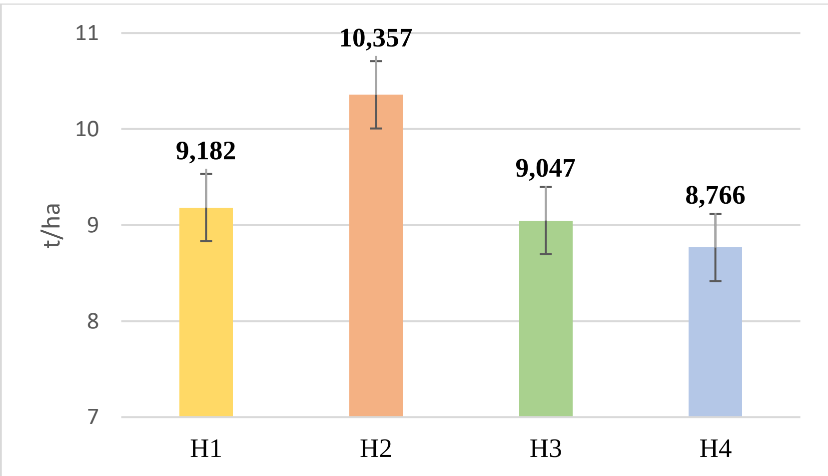

Figure 4. *Raw grain* yield of sweet corn *hybrids, t/ha Debrecen, 2021*

3.3. Comparative results of sweet corn hybrids in 2022

2022 was extremely unfavorable for sweet corn production, including supersweet hybrids. Only 150 mm of precipitation fell between the harvest of the previous crop and sowing. The H1 normal sweet sweet corn hybrid performed very well in the severe drought year. Its raw yield (*Figure* 5) was particularly outstanding (15.978 t/ha), however, the grain yield (*Figure 6*) ratio (44%) was very unfavorable, at 6.952 tons per hectare, which is considered an average result. The cob ratio (46%) is very high, and the cob ratio is the highest (10%). The H2 supersweet sweet corn yield is low due to the severe drought (11.359 t/ha), despite this, the raw grain yield (6.067 t/ha) ratio is favorable at 53%. The cob ratio is average (8%). The H3 hybrid has the lowest raw yield, 10.635 t/ha. The raw grain yield (5.564 t/ha) and its ratio are favorable (52%). The cob ratio is average (39%) and the cob ratio is also (9%). The raw yield of H4 supersweet sweet corn, considering the national averages, is not unfavorable (11.054 t/ha). However, the raw grain yield (5.540 t/ha) is only 50%, and the cob ratio is also unfavorable, above average (41%).

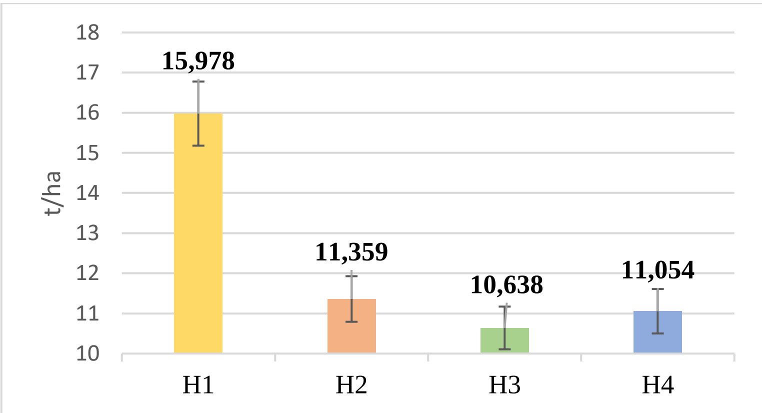

Figure 5. Raw yield of *sweet corn hybrids (tube+cob) t/ha Debrecen,* 2022

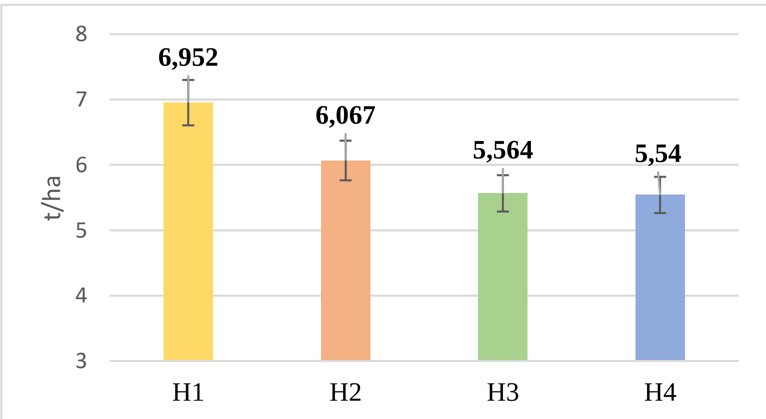

Figure 11. *Raw grain* yield of sweet corn *hybrids, t/ha Debrecen, 2022*

3.4. Evaluation of the results of normal sweet and super sweet sweet corn hybrids in different vintages (2020, 2021, 2022)

The yield results and content values of normal sweet (H1) and supersweet (H2) sweet corn hybrids were examined and compared in three different years. In 2020, both the amount and distribution of precipitation and temperature conditions were average, and in 2021 they were adequate. The year 2022 was severely drought-prone, with unfavorable precipitation and high temperature values. The results of normal sweet and supersweet sweet corn hybrids showed a significant difference in the three years examined. In 2021, in the case of normal sweet sweet corn, compared to the drought year (2022), the raw yield (cob + cob) was 10% higher , and the raw grain yield (9.185 t/ha) was 32% higher . The amount of cobs did not differ significantly, but the cob was more favorable (-16%). Compared to the data of the drought year, the mineral content showed significantly higher values: +5% K, +6% Ca, +7% Mg, +8% Zn. The sugar content was 35% higher and the lutein content was 27%. The yield of supersweet sweet corn in 2021 (18,486 t/ha) exceeded the drought-affected 2022 results by more than 60%. The largest loss due to the drought was in the raw grain yield (-74%). The ratio of cobs (+49%) and cobs (+50%) was also unfavorable in 2022. The plants were 13% lower on average. Examining the content values, we found that Mg and Zn decreased significantly by 6 - 6%, and K by 9%. Smaller but not significant values were shown for: Ca, Fe and P. The sugar content (-22%) and lutein (-51%) were significantly lower. A new result is that the Hungarian-bred normal sweet hybrid has a better adaptability to unfavorable vintages than the supersweet hybrid. In 2020, the normal sweet sweet corn hybrid. The content of Ca (+71%) and Fe (+12%) was significantly higher. The contents of K, Mg, Zn and P did not differ reliably. The sugar content (+10%) and lutein (+11%) were reliably high in the more favorable vintage. In 2020, compared to the 2022 vintage, the results of super sweet sweet corn showed significantly higher values, except for the tube diameter and Ca content. Compared to the raw yield measured in 2022 (11.359 t/ha), the yield was 51% higher in 2020. As a result of the more favorable vintage, the raw grain yield (9.227 t/ha) was also excellent, exceeding the result of 2022 by 47 %. The high yield was accompanied by larger cobs (51%) and larger cobs (+40%) and the plants were taller (+14%). The effects of the drought were also reflected in the nutrient values, with Fe and Zn being 9% and Zn being 9% lower, Mg being 18% lower, and K being 20%. Lutein concentration was also significantly lower (31%).

3.5. Evaluation of vintage effect

The effects of vintage, we found that in all of the years examined, both lutein and zeaxanthin contents were significantly different. Both lutein and zeaxanthin synthesis decreased under the influence of drought. The detrimental effect of drought was greater in the normal sweet corn hybrid.

In summary, we performed correlation assessments based on the measured parameters in the average of genotypes and years, taking into account the strengths of the correlations.

yield showed a strong positive correlation with grain weight, cob, sucrose, lutein . There was a medium positive correlation with the contents of lutein, K, Mg, Zn, P, zeaxanthin, a weak positive correlation with the contents of Fe, fructose and only a weak negative correlation with the contents of Ca.

Grain weight was positively correlated with all parameters to varying degrees. Grain weight showed a strong positive correlation with sucrose, lutein, zeaxanthin, a moderate positive correlation with cob, Fe, K, P, and a weak positive correlation with cob, Mg, Ca, Zn, and fructose contents.

Cob and husk parameters showed similar correlation values. Cob had a strong positive correlation with husk, Mg, Zn values, weak positive correlation with K, P, fructose, sucrose, lutein, zeaxanthin and weak negative correlation with Ca, Fe.

The correlation of the parameters of the cob was hardly different from the data of the cob, except that the cob showed a moderate negative correlation not only for Ca but also for Fe.

the correlation analysis of the mineral elements , we found that there was a strong positive correlation between Ca values and Fe, K data, Fe with K , lutein , K with lutein , Mg with Zn , Zn with fructose, P with sucrose, lutein , zeaxanthin. We found a weak positive relationship between the majority of the mineral elements, and in some cases a very weak negative relationship. A strong negative relationship was found only in the case of Ca, in the case of Mg and Zn. There was a strong positive relationship between fructose and sucrose and zeaxanthin, between sucrose and lutein, and between lutein and zeaxanthin.

3.6. Sweet corn hybrids evaluation of molecular biological markers

The necessary leaf, fruit and root samples for the laboratory tests were collected from the field sweet corn experiments in the demonstration garden of the Böszörményi út Campus of the University of Debrecen. In order to preserve the RNA content of the samples, they were frozen on site in liquid nitrogen, and then the replicates were stored at -80 ◦C until the test were stored.

Total RNA was extracted using the MN- NucleonSpin RNA Plant, MiniKit for RNA was extracted using.

Housekeeping genes consist of a group of constitutively expressed genes. They encode essential functions for all cells. They are expressed in every cell of an organism, regardless of tissue type, developmental stage, cell cycle state, or external signal. Based on literature data, the reference genes with which we compared differences in gene expression during our studies encode actin (ACT), tudulin (TUB), ubiquitin (UBI), and a thioredoxin -like gene (TLG).

3.7. Root staining and arbuscular assessment of mycorrhizal colonization intensity

Based on the results, we could establish that there were differences in the degree of colonization between the individual sweet corn hybrids. In the case of F%, M% and A%, the H3 hybrid showed higher values, and the lowest values were shown in most cases by the H4 hybrid. In the case of V%, the picture was more mixed, but the V% values were lower and the amount of aporia in the root can also modify the results when evaluating the amount of vesicles. In the case of F%, M% and A%, similar differences were measured between the hybrids in the samples sown at the two times, which confirms the significance of the differences between the hybrids

4. CONCLUSIONS AND RECOMMENDATIONS

Sustainable food systems simultaneously consider healthy nutrition and the protection of natural ecosystems from economic, environmental and social perspectives (Alcamo et al., 2003).

According to Szakály (2024), a food consumption structure cannot be considered sustainable if the nutrient density of the food is insufficient and causes deficiency diseases. Two key dimensions are the environment and health. The consumption of fruits, vegetables and legumes must double in order for the diet to bring health and environmental benefits to people in the future. This statement is also true for sweet corn, because currently the average domestic consumption per capita is only 2 kg per year. Sweet corn consumption is beneficial for the human body and could be part of the diet all year round. With its regular consumption, the development of many diseases can be prevented, its vitamin, mineral and fiber content is high, however, the general public opinion is that its sugar content is high, therefore its consumption is contraindicated, this opinion is not credible. For comparison, while a tube of sweet corn contains 6-7 g of sugar, a medium banana contains 15 g.

The meteorological database of the three years studied (2020, 2021, 2022) allowed the evaluation of the yield results and quality parameters of four sweet corn hybrids in three years (average, favorable, drought). Similar to the research of Hudák and Gombos (2023), we started the analysis of the vintage effects by evaluating the water supply in the period from the harvest of the previous crop to the time of sowing and proved that this period is extremely important due to the recharge of the deeper layers of the soil. In the years studied, the year 2021 was the most favorable in terms of water supply during the emergence period. In contrast, in 2022, only 150 mm of precipitation fell in the period from the harvest of the previous crop to sowing, and the unfavorable vintage effects are also confirmed by the work of Gombos and Nagy (2021). After that, we performed a detailed analysis of the growing seasons in all three years. The vintage effect can be well characterized by the useful heat amounts required for female flowering from emergence: 485 HU in 2020, 637 HU in 2021 and 668 HU in 2022. The most important indicator of the vintage is the raw yield. The average of the four hybrids examined was 16.662 t/ha in 2020, 17.561 t/ha in 2021 and 12.257 t/ha in 2022. The most important result for the processing industry is the raw grain yield, which showed the same vintage effect as the tube + pod data. The raw grain yield per hectare was 8.722 tons in 2020, 9.338 tons in 2021 and 6.031 tons in 2022.

performed a comparative evaluation of the four different genotype sweet corn hybrids. The highest raw yield (tube + cob) was achieved by the normal sweet (H1) hybrid over a three-year average (16.582 t/ha). Among the supersweet hybrids, the results of H4 and H2 (15.039 - 15.677 t/ha) did not differ significantly. The H3 supersweet sweet corn yielded one ton less raw yield (14.675 t/ha). The raw grain yield results were different, with the H2 supersweet sweet corn hybrid (8.551 t/ha) outperforming the H1 normal sweet hybrid (8.118 t/ha). The raw grain yield of the H3 and H4 supersweet sweet corn hybrids did not differ reliably over a three-year average (7.716 - 7.736 t/ha). Our results are consistent with the results of Pepó et al. (2019) and Demeter et al. (2020) regarding the ecological sensitivity of hybrids.

The results of the comparative analysis of the genotypes, based on the aggregated data of different years (drought, average, favorable), were consistent with the findings of Horváth et al. (2021), especially regarding the parameters of the adverse effects of drought. The water utilization capacity of the genotypes was characterized by specific values. A database was created from the three-year results of the raw grain yield of each genotype and the amounts of water (precipitation + irrigation water) available over the three years.

According to our research results, the supersweet (H2) sweet corn hybrid had the best water utilization, producing 21 kg of raw kernels with 1 mm of water. The normal sweet (H1) hybrid also had a favorable water utilization, based on a three-year aggregate database (19.8 kg of raw kernels / 1 mm of water). The efficiency of the H3 and H4 (supersweet) hybrids was lower and did not differ reliably from each other (18.8 - 18.9 kg of raw kernels / 1 mm of water). The relationships were consistent with the research results of Samarah et al. (2009), especially with regard to the relationships between genotypes and water stress , the wider database (yield results, internal values) of the H1 (normal sweet) and H2 (supersweet) sweet corn hybrids enabled a reliable statistical evaluation of the research results and studies.

Based on the results of field experiments, we evaluated the correlations between vintages and hybrid x vintage relationships. According to our research results, vintage had a significant effect on yield results. The results confirm the vintage effect analyses of Ilker (2011) and Nagy et al. (2021). The yield of the normal sweet hybrid was significantly the highest in 2021, compared to which we harvested more than one ton per hectare in 2020 and nearly two tons less in 2022 in the drought year. The supersweet hybrid showed similar correlations in the studied vintages, with the difference that the impact of the drought was more severe, yield results were 6 - 7 t/ha lower. The higher genetic yield was coupled with poor drought tolerance.

Based on our experimental results, we evaluated the yield parameters important for the processing industry in different years. The results of the raw grain weight of the normal sweet sweet corn hybrid in more favorable years were 8-9 tons per hectare. The raw grain weight of the supersweet sweet corn hybrid exceeded 10 t/ha in a favorable year, but in the drought year, due to unfavorable conditions, we measured a value four tons lower. The greater sensitivity of supersweet sweet corn to climatic conditions is also proven by the interval of the standard deviation of the grain weight data. According to the values of the variance analysis, the differences between years and hybrids were also significant. The different effects of years on the raw yield results of sweet corn hybrids with different genotypes were measured by Marshall and Tracy (2003) and Mousavi et al. (2024). The hybrid x year effect also differed reliably.

Normal sweet and supersweet sweet corn hybrids, we found that the largest differences were shown by the raw cob weight values, both between the vintages and the hybrids. From an economic point of view, a smaller cob weight is more favorable during food processing. According to Nagy et al. (2023), the ratio of yield elements differs from year to year for each sweet corn hybrid.

Based on the results of the analysis of variance, we determined that the cob weight of normal sweet and supersweet sweet corn hybrids was significantly different between the hybrids in 2022, the drought year. The cob weight of supersweet sweet corn was significantly, by 39%, more favorable than that of the normal sweet hybrid. Sweet corn producers transport the fresh crop to the processing plant in tubes and cobs. It is beneficial for both parties if producers use high-yielding, high-quality sweet corn hybrids, preferably with a low cob weight. The cob weight basically depends on the genotype of the sweet corn hybrid grown and the vintage effect is also significant. Based on the analysis of variance, we determined that the cob weight of the normal sweet sweet corn hybrid was significantly (by 40-60%) higher in the drought year. The two hybrids differed reliably in the average of the years examined.

We found, in agreement with the research results of Aylswirth (1986) and Szabó et al. (2021), that the difference between years is significant. However, the fresh kernel weight of supersweet sweet corn is reliably and significantly lower in both favorable and unfavorable, drought years.

Sweet corn hybrids and its phenological survey data were also statistically evaluated. The height of the plants showed significant differences in the years examined, but the two hybrids did not differ in the average of three years. The difference between the years was significant in the average of the two hybrids. According to Ge et al. (2012) and Daryanto et al. (2016), the year, primarily heat stress in critical phenophases, causes significant differences in the phenometric data of the plant. The normal sweet sweet corn plant stand was the highest in 2021, in the favorable year (280 cm). However, due to drought, a significantly lower stand height (200 cm) was measured for the normal sweet hybrid. According to the values of the variance analysis, the differences between years and hybrids showed significant differences only in the drought year, 2022, in the case of both the normal sweet and super sweet hybrids.

The stem diameter data, based on statistical evaluation, show higher values for both types of hybrids in favorable years than in drought years. In the three years examined, the average stem diameter data showed a significant difference. In three years, the stem diameter data of the two hybrids examined belonged to two reliably different groups. One group consisted of the stem diameter data of the normal sweet in 2020, and both hybrids in 2021, while the other group consisted of the stem diameter data of the supersweet in 2020 and both types of hybrids in the drought year (2022).

In the tube length data of the normal sweet and super sweet sweet corn hybrids. All three year effects were also reliable. Based on the significance values, the differences between years and hybrids showed reliable differences, except for the tube length values measured in normal sweet 2020 and super sweet 2021.

Compared to the tube length, the tube diameter depended less on the vintage, although the average of the years studied significantly differed between the normal sweet and supersweet sweet corn hybrids, but the vintage effects did not show a reliable difference in 2020 and 2022. According to the values of the analysis of variance, the differences between years and hybrids showed a reliable difference only between 2021 and 2022, taking into account the values of both hybrids.

Field sweet corn experiments provided reliable parameters for content values, and we examined the relationship between vintages and hybrid x vintages using our own data. Gu et al. (2015), Xiong et al. (2017), Ray et al. (2019), who showed a significant correlation between mineral content and year in their research. According to the results of the variance analysis, in the average of the years examined, the Ca, Fe, K, Mg, Zn content of normal sweet and supersweet sweet corn differed significantly, except for the P content. Evaluating the year effects, we found that the Fe, K, and Mg contents did not differ reliably, but in the drought year (2022), they differed reliably from the content values measured in the previous two years.

The sugar content of sweet corn is an important consideration for growers when choosing hybrids. The sugar content of sweet corn hybrids and its changes have been widely researched (Long 1988, Marshall and Tracy 2003). Our research results coincide with the interactions determined by Huzsavi et al. (2021). We examined the fructose and sucrose content of normal sweet and super sweet sweet corn at harvest. According to the values of the variance analysis, the fructose content of normal sweet and super sweet sweet corn differed significantly in the average of the years studied, but the sucrose content did not. Evaluating the vintage effects, we found that the studied vintages had a significant effect on both fructose and sucrose contents. In more favorable vintages, we measured reliably higher sugar contents. In our experiments, drought significantly reduced sugar contents; compared to 2021, fructose was 2,2% lower in 2022 and sucrose was 6,6 %.

Lutein and zeaxanthin content of sweet corn from the perspective of healthy nutrition. The use of research results in healthy nutrition and medicine is gaining more and more ground. Rosen et al. (2018) patented the therapeutic administration of zeaxanthin against tumor cells. The importance of fresh sweet corn in healthy nutrition is increasing (Erdal et al., 2011).

Lutein content of normal sweet and supersweet sweet corn differed reliably in the average of the years studied, but the zeaxanthin content did not. When evaluating the effects of the vintage, we found that in all of the years studied, both lutein and zeaxanthin contents were significantly different. Under the influence of drought, both lutein and zeaxanthin synthesis decreased, showing significantly lower values. The detrimental effect of drought was greater in the normal sweet sweet corn hybrid.

5. NEW SCIENTIFIC RESULTS

1. Based on our research results, we determined that, on average over the three years studied, the grain yield and content values of supersweet sweet corn hybrids are more favorable. The raw grain yield is 6% higher, the Ca content is 20% higher , the Fe content is 10% higher, the K content is 12% higher, and the lutein content is 16% higher than that of normal sweet sweet corn.

2. A particularly important result for food processing is that – on average over three years – the ratio of kernel: cob (59:41) and husk (7.7%) of the supersweet sweet corn hybrid is reliably more favorable than that of the normal sweet sweet corn hybrid (kernel: cob= 54:46, husk 9.5%).

3. We demonstrated the effect of different vintages on the raw grain yield of sweet corn hybrids. We determined the parameters characteristic of the utilization of the available water (precipitation + irrigation water). For 1 mm of water, 24 kg of raw grain yield was obtained in a more favorable vintage, 22 kg in an average vintage, and 14 kg in a drought year. Analyzing the useful heat amounts, we determined that 95 HU in an average vintage, 108 HU in a favorable vintage, and 139 HU in a drought year were required for 1 ton of raw grain yield.

4. Correlations between parameters measured in the field experiment We evaluated the strength of the correlations based on correlation analyses. Sweet corn yield showed a strong positive correlation with grain weight, cob, sucrose, lutein. There was a medium positive correlation with starch, zeaxanthin and the elements Mg, K, P, Zn. There was a weak positive correlation with fructose and iron content and only a weak negative correlation with Ca content.

Methodological result

During our studies, we monitored the sweet corn hybrids with targeted gene expression studies. molecular biological markers of lutein biosynthesis in the generative phase of plants. We have proven that our methods for sample collection, RNA isolation and quantification are suitable. The three reference genes: ACT (actin), TUB (tubulin) and UBI (ubiquitin) specific PCR reactions showed satisfactory results. We have identified the genes of the carotenoid / lutein biosynthesis pathway. Our results provide an opportunity for efficient, bulk sample processing and evaluation.

In our studies, there were differences in the degree of colonization among sweet corn hybrids. In the case of F% (*The mycorrhizal frequency, the percentage of the root piece with* *any colonization*), M% (*The total intensity of colonization in the entire root, i.e. how widespread the colonization is in the root.*) and A% (*The intensity of arbuscular colonization in the entire root.*) similar differences were measured between the hybrids in the samples taken at the two time points , which proves the differences between the hybrids.

6. PRACTICAL UTILIZATION OF THE RESULTS

1. Our experimental results prove that when choosing the sweet corn hybrid to be grown , it is necessary to take into account the most important production (main crop, secondary crop, staggered crop) and processing and commercial (fresh consumption, canning, refrigeration) fundamental aspects.

2. Based on our research results, we have determined that the cultivation of normal sweet corn hybrids with better stress tolerance is justified if the cultivation technology is semi-intensive, the spring warming of the soil is slow and the primary goal is early fresh consumption.

3. When using precision cultivation technology, it is recommended to choose the supersweet hybrids that are best suited to the growing location and farm conditions. Irrigation is essential.

4. New supersweet sweet corn hybrids with high quality, adequate mineral content and significant amounts of lutein and xanthophylls helps to promote healthy nutrition. It is necessary to provide a wider range of reliable professional results that support sweet corn consumption.

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8. PUBLICATION LIST

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A PhD értekezés alapjául szolgáló közlemények

Magyar nyelvű tudományos közlemények hazai folyóiratban (7)

1. **Bakos, Z.**, Sidahmed, H. M. I., Nagy, J.: A Honey csemegekukorica (Zea mays L. convar. saccharata Koern) hibrid ásványianyag-, foszfor-, kálium-, magnézium-, cink- és vastartalmának elemzése.
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További közlemények

Magyar nyelvű tudományos közlemények hazai folyóiratban (1)

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Idegen nyelvű absztrakt kiadványok (3)

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