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# EVALUATION OF SWEET SORGHUM (*SORGHUM BICOLOR*) HYBRIDS AS BIOENERGY FEEDSTOCKS IN RELATION TO CLIMATIC ASPECTS

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***Abstract***

*In this study, biomass yield and sugar content, and bioethanol potential of six sweet sorghum hybrids were considered to assess the potential role of the genotype in the performance of sorghum. Yield and sugar content values were investigated in relation to the climatic aspects according to the Ellenberg and the Pálfai drought indices, and the effect of drought on biomass yield and sugar content was evaluated to reveal the dominant factor determining the bioethanol yield. Results proved that sweet sorghum holds a significant potential in the semi-arid regions to enhance the amount of the produced bioethanol e.g. in the EU, even though, considering the climatic characteristics of each year, sometimes extreme differences have been found that had a significant impact on its production. However, considering the performance of the hybrids, significant differences were found for both the green yield (5.5 t ha$^{-1}$) and the sugar content (0.79 Brix %) under similar weather conditions, but sugar content for any of the selected hybrids had no relationship with the drought indices, though, seasonal impact was proved. In contrary, biomass yield showed significant relationship with the Pálfai drought index, suggesting that annual water shortage results in lower sorghum yield in the investigated semi-arid region as the determinative factor. Hybrids of the sweet sorghum showed high but different biofuel potential under the same, extreme climatic conditions via their biomass production variation, thus their field specific experimental testing is advisable to find the best performing ones in this context.*

**Key words:** sweet sorghum, hybrids, bioethanol, climatic conditions, drought indices

## INTRODUCTION

Among other uses, bioethanol is used as fuel additive mixed with conventional gasoline at various percentages; E10 is compatible with most petrol-driven cars used in Europe, while E85 requires dedicated flex fuel vehicles. Compared to the unblended fuel, it reduces carbon monoxide emission and improves fuel octane, produces lower carbon dioxide, as well as hydrocarbon and nitrogen-oxides emissions, and therefore it may be one of the most widespread biofuels in the coming period (Nguyen, Li, 1991; Zhang et al., 2003; IEA, 2008; Mojovic et al., 2012; Littlejohns et al., 2018). This is also supported by the fact that since 2002 the use of biofuels

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and bioethanol in the European Union has been intensively increasing (Eurobserver, 2017).

To reach the goal given by the 2009/28/EU directive, both maize and sorghum are considerable crops to produce bioethanol. However, sorghum better tolerates the unfavourable climatic conditions, especially drought (Jóvér et al., 2018; Wagle et al., 2018).

Sorghum as a prosperous bioethanol feedstock is still intensively investigated (Blaskó et al., 2008; Mojovic et al., 2012; Daliva-Gomez et al., 2011; Goshadrou et al., 2011; Briand et al., 2018; Jiang et al., 2019).

Ethanol yield for sweet shorgum was found, generally between 1,000-7,000 L ha$^{-1}$, according to Mojovic et al., 2012, the average ethanol yield for sweet sorghum hybrids are above 1,700 L ha$^{-1}$. Briand et al., 2018 found hybrids with theoretical ethanol yield from 1,000 to 1,149 L ha$^{-1}$, which was ca.1/3 that of grain corn grown in the same period in the same region with the yield of 6.6-9.1 t ha$^{-1}$. However, Zhao et al., 2009 reported 4,045 L ha$^{-1}$ for another genotype, while Tang et al., 2018 found a higher performing hybrid in China with 14,913 L ha$^{-1}$.

Sugar content of the juice can achieve 16 – 20 %, predominantly containing glucose, fructose and sucrose, e.g. Briand et al., 2018 reported 13.1 - 15.1 °Bx, though, e.g. Reddy et al., 2005 reported even 23 °Bx for sweet sorghum.

Nevertheless, biomass yield is the other factor determining feasibility of ethanol production from plant species; field experiments suggest 30-120 t ha$^{-1}$ biomass yield, depending on the environmental conditions and genetic performance (Roman et al., 1998; Dolciotti et al., 1998; Woods, 2001; FAO, 2002; Classen et al., 2004; Anderson, 2005; Briand et al., 2018; Almeida et al., 2019).

Though, the origin of the sorghum species is uncertain, e.g. Linné, 1753 reported India as their genetic center, while Vavilov, 1949, 200 years later suggested rather Sudan and Ethiopia, there is a common agreement that sorghum is a warm season crop, thus its integration into crop rotation in areas posed to drought risk has considerable perspective (Tuinstra et al., 1997; Lux et al., 2002; Jóvér et al., 2019).

According to Dar et al., 2018, sweet sorghum with high adaptability to drought, saline, alkaline and water logging conditions, can be preferable under hot and dry climatic conditions regarding both economic and environmental considerations as it has higher energy output than sugarcane, sugar beet, maize or wheat. However, significant differences for the traits related to bioethanol potential for 30 hybrids investigated by Silva et al., 2018, and further 102 genotypes assessed by Habyarimana et al., 2018 showed differentiated behaviour under different environmental conditions, particularly temperature and humidity characterizing the fields of the experiments.

As for the latest relevant review by Appiah-Nkansah et al., 2019, crop improvement programs have intensively enhanced sweet sorghum cultivars, producing hybrids with higher yields, higher sugar concentrations, and increased periods of industrial use, the agronomic production systems are evolving, and although it was economically viable to produce sweet sorghum in certain geographic regions, other places showed otherwise.

Economically, however, biofuel potential of sorghum is dependent on both biomass and sugar content in contrary to maize where grain yield determines the feasibility. Moreover, hybrids are expected to show differences in both factors when exposed to climatic stress, but with different contribution.

The aim of the study was to quantify the variability of the parameters determining the feasibility of bioethanol production in relation to different climatic conditions, for selected sorghum hybrids grown in the Great Hungarian Plain that represents semi-arid, arable lands with meadow chernozem soil type.

## MATERIAL AND METHOD

### ***Field experiment design***

The soil type of the experimental site was heavy textured meadow chernozem. The fore crops were winter cereals. And, considering the agro-techniques, ploughing in autumn, tooth harrow in spring were applied, and seedbed preparation was done by combinator.

Grain sorghum was planted between 25 April and 5 May in the years of 2010-2015 with planting distance of 5 cm, row distance of 70 cm, and depth of 4,6 cm by using a HEGE 95 type single-row planter. As part of the seedbed preparation, 100 kg ha$^{-1}$ N was added in form of ammonium-nitrate, then process was completed by using a combined tillage equipment. The six selected forage sorghum hybrids subject to the investigation for their bioethanol potential are listed in the common catalogue of varieties of agricultural plant species in the EU.

Whole plant samples from 4 m$^2$ area of each parcel were taken from mid-August by every 10 days till harvesting, in two parallel. After measuring the fresh biomass, samples were shredded by using an AL-KO dynamic H 1600 shredder, then dried in a Nüve FN 400 dry heat sterilizer at 105 °C until constant weight, in four replications to calculate the moisture content of the sorghum. Bagasse and juice were separated by using a Bologna S.T.M. AMP/E 50/2 type press machine, then the bagasse was dried at 105 °C until constant weight.

The refractive dry matter content of the diluted phase obtained from the stalk of the sweet sorghum hybrids was determined by a refractometer as Brix value closely correlating with the actual sugar content (Liu et al., 2008; Kawahigashi et al., 2013). The refractive dry matter content was determined by four parallel measurements per sampling area.

### *Calculation of the potential ethanol yield*

Potential ethanol yields for the hybrids investigated were calculated according to the recommendation of the Energy Institution of Japan, 2006 (Eq.1).

$$EP = s * dm * cf * fe * g \qquad \text{q.1}$$

where: $EP$ is the sugar-based ethanol potential in L ha$^{-1}$,
$s$ is the sugar content in %,
$dm$ is the dry matter yield in t ha$^{-1}$,
$cf$ is the conversion factor with the value of 0.51,
$fe$ is the fermentation efficiency with the value of 0.85, and
$g$ is the density of ethanol equal to 0.79 kg L$^{-1}$ at 25 °C.

### *Climatic assessment method*

The weather conditions at the experimental site were monitored by a Vaisala QLC 50 data logger, recording of 10 minutes frequency. Total annual precipitation as well as annual mean temperature data were calculated, and their impact on the yield and sugar content of the investigated sorghum hybrids was tested by analysis of variance. Based on the weather data, drought indices according to Ellenberg (Eg.2) and Pálfai (PaDI) (Eq.3) were calculated. The Ellenberg index shows the probability of drought for July.

$$EQ = (T07/Pann)*1000 \qquad \text{q.2}$$

where: $EQ$ is the Ellenberg index,
$T_{07}$ is the mean temperature for July, and
$P_{ann}$ is the total annual precipitation.

$$PaDI_o = \frac{\left[\sum_{i=apr}^{aug} T_i\right] / \ 5*100}{c + \sum_{i=oct}^{sept}(P_i * w_i)} \qquad \text{q.3}$$

$$PaDI = PaDI_o * k_1 * k_2 * k_3$$

Where: $PaDI_0$ is the Pálfai drought index in °C/100 mm,

$T_i$ is the monthly mean temperature between April and August in, °C,

$P_i$ is the monthly mean precipitation between October and September in mm,

$w_i$ is a weighting factor,

$c$ is a constant (10 mm),

$k_1$ is temperature correction factor,

$k_2$ is precipitation correction factor, while

$k_3$ is precipitation correction factor for the previous 36 months.

### *Statistical analyses*

Two-way ANOVA test was used to determine differences among the evaluated parameters in the context of hybrids and season impacts. To quantify the extent of the linear relationship between the bioethanol potential and measured parameters. Pearson correlation was calculated and, linear regression analysis was used to determine the relationships between the drought indices and the evaluated parameters.

## RESULTS AND DISCUSSION

### *Variation of sugar content and biomass yield by sorghum hybrids*

In case of yields, significant differences were found among the evaluated hybrids, highest values were found for the Hybrid 5 and Hybrid 1 hybrids, while the least favorable values were found for the Hybrid 2 (Figure 1).

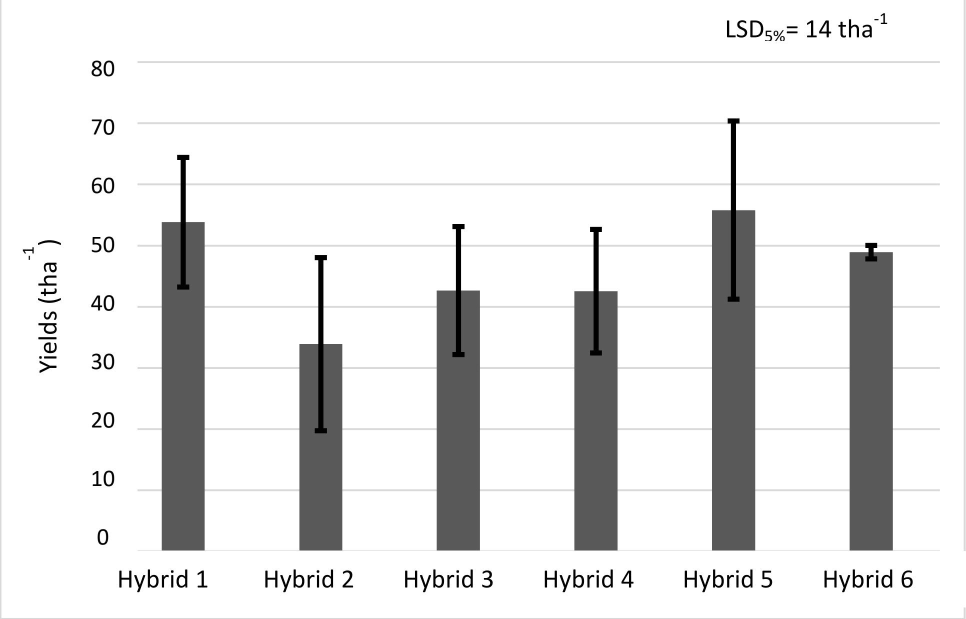

Fig. 1. Yields of the investigated sorghum hybrids

Based on the analysis of variance, the least significant difference ($p \leq 0.05$) among the hybrids was 14 t ha$^{-1}$. The $LSD_{5\%}$ value can be considered very significant, especially in the view of the fact that the average sweet sorghum yield in Hungary is around 40 - 60 tons per hectare. This suggests that, assuming nearly the same soil characteristics, there is a significant difference among the investigated genotypes, which can be a considerable element of adaptation to the varying climatic conditions.

Evaluating the measured parameters by the season impact, values showed significant differences due to the different experimental years. This observation is also supported by the results of ANOVA, significant difference among the experimental years was 5.5 t ha$^{-1}$. Consequently, we found that in addition to the differences among the examined genotypes, the climatic conditions of the different years can further significantly influence yields (Table 1).

*Table 1*

Yields in the experimental years

| Experimental year | Yields | Group |
|---|---|---|
| 2013 | 52.1 | a |
| 2010 | 49.4 | a |
| 2012 | 48.1 | ab |
| 2015 | 42.9 | bc |
| 2014 | 41.6 | c |
| 2011 | 39.9 | c |

The maximum sugar content was found 15.25 Brix% for Hybrid 6 and 14.5 Brix% for Hybrid 4. For all other hybrids, the sugar content was above 15 Brix%. We found that this parameter also produced the most favorable values for Hybrid 1 and Hybrid 5, as the average maximum sugar content was 17.8 Brix% and 19.1 Brix%, respectively (Figure 2).

It should be noted that the sugar content of a sweet sorghum hybrid is an evaluation criterion for biofuel utilization, and there was a significant difference among the evaluated hybrids ($LSD_{5\%} = 1.52$ Brix%). In addition to the maximum sugar content, moisture content and yield at harvest are also considerable factors. The moisture content of the harvested samples was 70 % on average, and there was no significant difference among the hybrids.

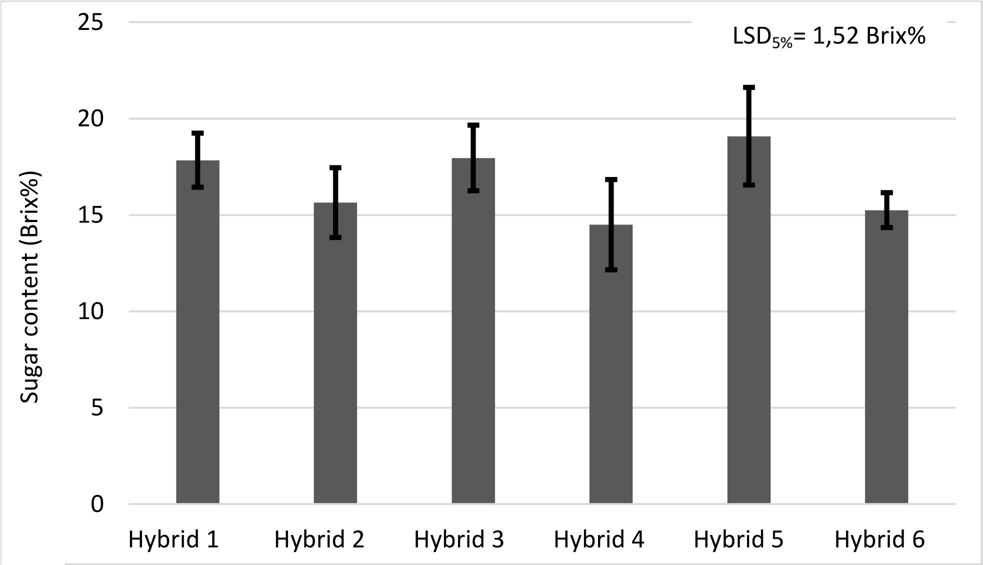

Fig. 2. Sugar contents of the evaluated hybrids

As a result of the different experimental years, the measured sugar content also shows significant differences. According to the ANOVA, significant differences among the evaluated parameters ($LSD_{5\%}$ = 0.76 Brix%) proved that seasonal impacts on the sugar content are notable (Table 2).

*Table 2*

Sugar contents in the experimental years

| Experimental year | Average sugar content | Group |
|---|---|---|
| 2013 | 18.81 | a |
| 2014 | 17.54 | b |
| 2015 | 16.65 | c |
| 2012 | 16.15 | cd |
| 2011 | 15.83 | de |
| 2010 | 15.30 | e |

As a conclusion, both biomass yield and sugar content are significantly different for all the investigated sorghum hybrids, thus, even under similar environmental conditions, genotypes are expected to have different performance.

### *Relation of biomass yield and sugar content to drought indices*

Based on the calculated drought indices, there was not consistent relationship between the sugar content and the index values for the experimental period.

However, a negative regression ($R^2$ = 0.42) was found between the PaDi drought index and the green yield values. Based on the findings, according to the PaDI index of the years with moderate drought (2012, 2014, 2015), where the index value was between 6 and 8, a slight decrease in green yield of sugar sorghum was assumed.

This means that although sorghum, as a drought-tolerant plant, well tolerates hot days in lack of precipitation in summer, these unfavorable climatic conditions result in lower yields than those grown in more favorable years (Figure 3).

In the case of the Ellenberg index, the relationship between index values and yields was not detectable, thus there was no consistent relationship between the index values and the green yields ($R^2$ = 0.05) (Figure 4). This is presumably because the Ellenberg index is calculated based on the average monthly temperature in July of the current year, while the PaDI is based on longer time periods.

The results of Starggenborg et al., 2008 showed that grain sorghum had a yield and economic advantage over corn in dryland regions because of better drought and temperature tolerance, which is in coherence with the above mentioned results. However Assefa, Staggenborg, 2010 reflected that sorghum yields under dryland conditions are much less than irrigated sorghum yields, which support the negative correlation of sorghum yields with PaDi.

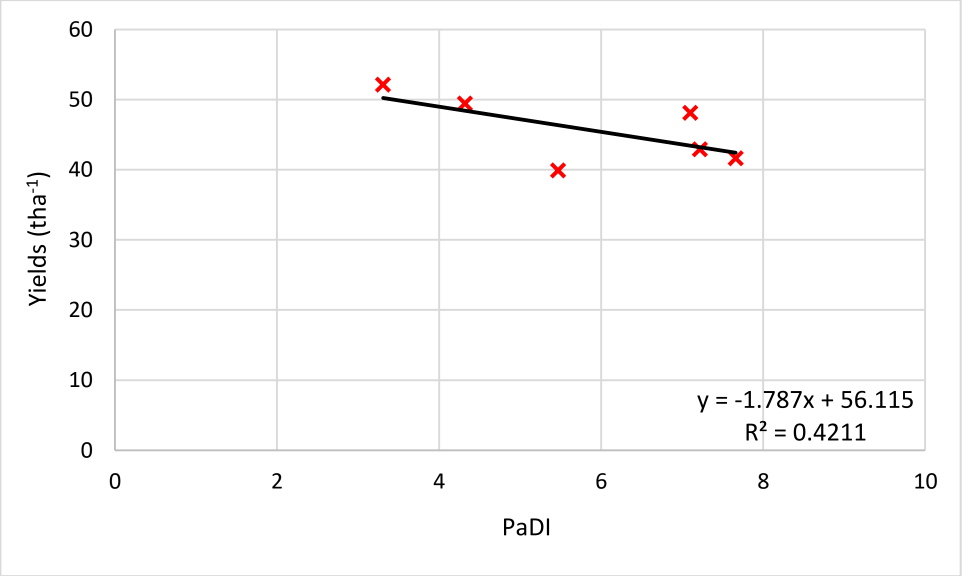

Fig. 3. The relationship between PaDI and average sorghum green yields

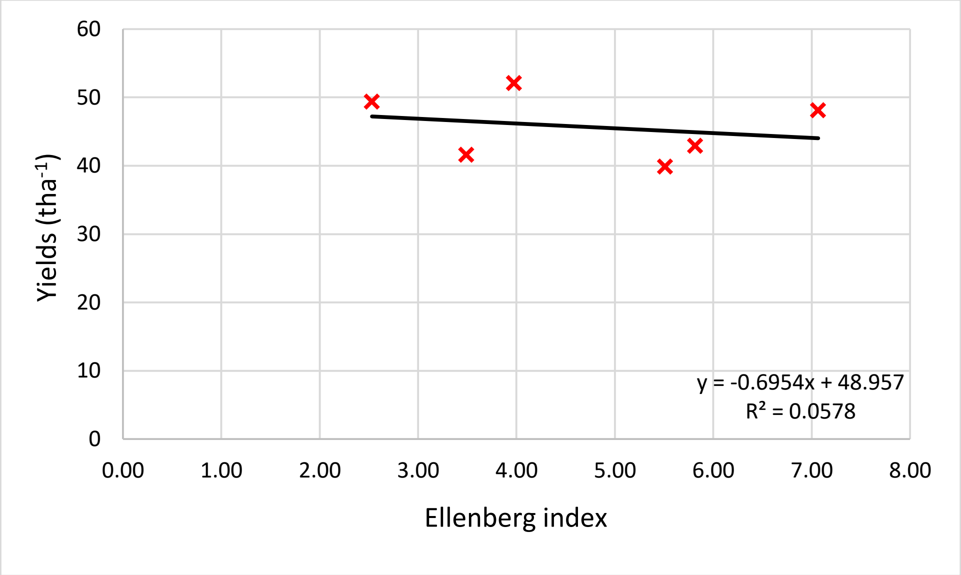

Fig. 4. The relationship between Ellenberg Index and average sorghum green yields

The results confirm that the sorghum can survive drought in the summer and then regenerate. Regarding the relationship between PaDI and green yields, in some cases a decrease in sweet sorghum yields in a water-scarce year can be expected, especially if it occurs at a critical phenological stage of the plant. The results are in coherence with the results of Abdulhamid et al., 2011, who set out that water (precipitation, relative humidity) can be a determinative factor of sorghum production, if water shortage appears in a critical vegetation stage such as germination phase.

If these drought indices values are compared to the maize yields registered in Hungary (Table 3) by the Central Statistical Agency, there are no consistent relationships among maize yields and PaDI ($R^2$=0,01) (Figure 5). This phenomenon is probably resulted by the fact that the calculation method of PaDI is based on annual data, while the calculation method of Ellenberg index focuses on the lack of precipitation in July. Thus these two drought indices put the emphasis on different drought phenomenon.

*Table 3*

Maize yields in Hungary according to the Central Statistical Agency

| Years | Average yield (t ha$^{-1}$) |
|---|---|
| 2010 | 6.47 |
| 2011 | 6.50 |
| 2012 | 4.00 |
| 2013 | 5.44 |
| 2014 | 7.82 |
| 2015 | 5.79 |

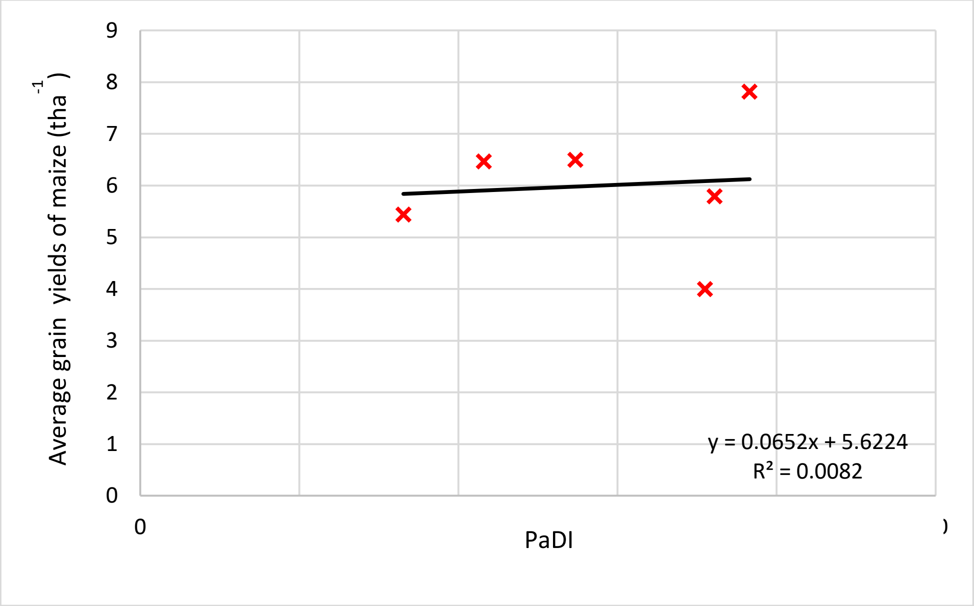

Fig. 5. The relationship between PaDi and average maize grain yields

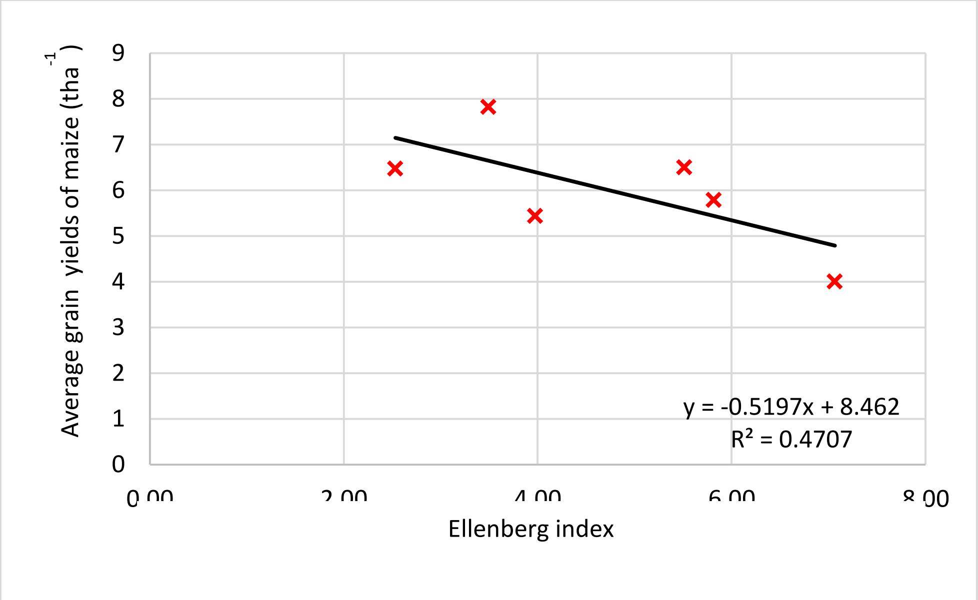

Fig. 6. The relationship between Ellenberg Index and average maize grain yields

However, a negative regression was found between Ellenberg index and maize yields ($R^2$ = 0,47) resulting from that the most critical period for maize by the viewpoint of water shortage is the generative vegetation phase, which is factor in the index (Figure 6.). Thus, sweet sorghum hybrids as a potential bioethanol commodity can tolerate water shortage in July in contrary to maize. Within Hungarian conditions, precipitation shortage usually appears during summer, therefore sorghum production can be an adequate choice to adapt climate change.

### *Differences in the bioethanol potential of sorghum hybrids*

According to the measured data, significant differences were also found in the sugar-based bioethanol potentials. The Least Significant Difference among hybrids was 745 l ha$^{-1}$. Based on the analysis, the hybrids can be ranked according to Table 4, where each letter marks hybrids that can be distinguished by significant difference. There is no significant difference ($p \leq 0.05$) for hybrids with the same lettering.

*Table 4*

Hybrid groups based on the average bioethanol potentials

| Hybrid | Average bioethanol potential (lha$^{-1}$) | Group |
|---|---|---|
| 5 | 2460 | a |
| 1 | 2432 | a |
| 3 | 1716 | ab |
| 4 | 1429 | b |
| 2 | 1205 | b |
| 6 | 1189 | b |

Based on the calculated bioethanol potentials, this value was found to show a strong correlation with the yield of the given hybrid, while the correlation with the sugar content is moderate. This finding was based on the value of the Pearson correlation coefficient, which demonstrated a significantly stronger linear relationship between bioethanol potential and green yield ($R = 0.73$) than in the bioethanol potential – sugar ratio, where this coefficient was $R = 0.38$. Based on this, it can be concluded that a decrease in the bioethanol potentials of sugar sorghum is assumedly caused by drought in the semi-arid regions, typically by decreasing yield rather than sugar content.

## CONCLUSIONS

Considering the variation of sugar content and biomass yield by the investigated sorghum hybrids, both biomass yield and sugar content are significantly different for all the hybrids, thus, even under similar environmental conditions, genotypes are expected to have different performance.

Sugar content for any of the hybrids had no relationship with the drought indices both according to Ellenberg and Pálfai, suggesting that drought itself has moderate effect on the sugar content of the sorghum.

However, ANOVA confirmed the difference in sugar content due to the season impact.

Considering the biomass yield, it did not show relationship with the Ellenberg index, while Pálfai drought index showed significant relationship, thus water shortage has negative impact on the bioethanol yield produced from sorghum, though, compared to maize, where summer drought is a determinative factor, the impact is expected less significant.

When compared the impact on bioethanol yield for sorghum, green yield is the determinative factor, while sugar content variation does not considerably affect it. Finally, Pálfai drought index values showing strong relationship with biomass yield suggest that annual water shortage results in lower sorghum yield in the investigated semi-arid region.

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