

THE INFLUENCE OF BASE TEMPERATURE ON SWEET SORGHUM PRODUCTION IN HUNGARY

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Abstract

In order to reach the goal determined by the 2009/28/EU directive sorghum production for energy purposes can be an adequate method. Efficient sorghum production is based on the consideration of the climatic aspects. An advantage of sorghum is appearing in the field of drought tolerance. The foundation of sorghum's great drought tolerance is the high heat demand which must be fulfilled.

The heat demand varies from 8 °C to 15 °C, so that based on the meteorological data recorded in the period of 1997-2016 the Effective Heat Unit varied between 627 °C and 2097 °C. Base temperature has a remarkable impact on the length of the vegetation period as well. Depending on this value the potential length of the vegetation period can vary from 123 days to 153 days. The sugar accumulation curve of a sorghum hybrid is also an important aspect of efficient bioethanol production where length of the vegetation period is an essential factor.

Key words: base temperature, heat unit, sweet sorghum, sugar accumulation, bioethanol

INTRODUCTION

The 2009/28/EU directive appropriates the increase of the rate of renewable energy up to 20% in communal energy consumption of the EU countries by 2020 in order to support the broader dissemination of renewable energy. In 2012 the share of renewable energy sources in the Central and Eastern European Countries ranged from 9.6% to 35.8% and in the case of four countries the share of renewable energy sources was below the average of EU-28 which was 14.1% (IEPP, 2014). Regarding the Central and Eastern European Countries natural gas is the main source of energy in Hungary, Latvia, Lithuania and Slovakia, while coal is a notable energy source in Bulgaria, Czech Republic, Poland and Romania in addition high energy dependency often reveals in the Region (IEEP, 2014). Agricultural lands are finite hence the competition for arable lands can be increase between the sectors of food- and energy production (Smith et al., 2010). One way to prevent food vs fuel competition is to cultivate biomass crops on marginal areas (e.g., dry environments) that are not currently being used for the production of food crops.

Sorghum species can be excellent crops for biomass energy production in the Central and Eastern European Region, especially sweet

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sorghum (*Sorghum bicolor* (L.) Moench), which is a widely used basic material for bioethanol production in the world regarding the high sugar content accumulated in the juice of the stem (Bryan, 1990; Billa et al., 1997; Dolciotti et al., 1998; Barbanti et al., 2006; Zhao et al., 2009).

Sorghum is a very prospective crop in Hungary due to its great tolerance against drought and unfavorable soil conditions, which are actual problems in the Hungarian agriculture (Nagy et al., 2014). It was an important and widely adapted crop grown between 40 °N and 40 °S of the Equator in the 20th century (Doggett, 1988). Due to the effective sorghum breeding processes and the climatic adaptation of this plant the geographical boundaries of sorghum production have been expanded in the recent decades. Hungary was formerly considered to be the northern border of sorghum production (Chrappan et al., 1997). Nowadays several publication report about the effective sorghum production from countries northern than Hungary (Idziak et al., 2013; Pazderu et al., 2014; Adamčík et al., 2016).

The general heat unit of sorghum usually varies between 2600 °C and 3300 °C (Faragó, 1975; Horváth, Mikes, 1981; Késmárki, 2005). This parameter is often in correlation with the length of the vegetation period, which varies between 90 and 300 depending on the variety, with the most frequent range being 150–200 days (Craufurd et al., 1999; FAO, 2000; Geleta, Labuschagne, 2005).

The base temperature of the grown sorghum variety is a determinative factor of the climatic adaptation. By this parameter the effective heat unit can be calculated which is the useful heat amount for the crop during vegetation period. According to Monk, 1977, Angus et al., 1981 and Gerik et al., 2003 the base temperature of sorghum is 10 °C while this parameter ranged from 8.3 °C to 12.2 °C in the report of Craufurd et al., 1999. According to Parthasaranthi et al., 2013 this value varies between 8 °C and 10 °C.

In this study the impacts of the base temperature on the potential length of vegetation period of sweet sorghum hybrids were evaluated. Based on the meteorological data of the period from 1997 to 2016 the probability of risks caused by cold temperature were determined appearing either in the beginning or in the end of the vegetation period. The optimal length of the vegetation period of sweet sorghum within the Hungarian conditions were calculated and the shape of the refractometric dry material (Rdm) content accumulation curve of six sweet sorghum hybrids were determined.

MATERIAL AND METHOD

This research work was carried out in the Research Institute of Karcag in Hungary (N 47° 23', E 20° 56', Above Mean Sea Level: 87 m). Meteorological parameters were recorded with 10 minutes frequency by a

VAISALA QLC-50 automatic meteorological meter. Based on the recorded data between 1997-2016 the dates of frost appearing in late spring and early autumn were selected. The calculated dates were classified with 5 days and the occurrence frequencies were determined focused on the investigated period, so as, to determine the risks caused by the length of the vegetation period.

Effective Heat Units (EHU) were determined by Eq. 1. Calculations referring to the period from 20th of April to 10th of October. In the case of EHU values the base temperature has ranged from 8 °C to 15 °C with 0.5 °C scale.

$$EHU = i \sum_{1}^n \frac{(T_{i,MIN} + T_{i,MAX})}{2} - T_B; \quad \text{Eq. 1.}$$

where:

$T_{i,MIN}$: daily minimum temperature (°C)

$T_{i,MAX}$: daily maximum temperature (°C)

T_B : base temperature (°C)

n: length of vegetation period (day)

The field experiments were fixed on the plant growing sites of the Research Institute of Karcag. The soil type of the non-irrigated production areas were Haplic phaeozem (WRB). Field experiments were carried out between 25th of April and 31th of November in 2008-2016 so as, to evaluate six sweet sorghum hybrids. The average annual precipitation was 549.5 mm and annual average temperature was 11.5 °C respectively. During the sowing the applied row space was 76.2 cm, the distance of the plants was 5 cm and the depth of sowing was 5 cm as well. The plant stocks were free of weeds, pests and pathologic symptoms. As fertilizer ammonium - nitrate was used added to field before sowing with the dose of 100 kg/ha.

Refractometric dry matter content, which is in a strict correlation with sugar content (Izsáki, 2004; Liu et al., 2008; Kawahigashi et al., 2013) was determined by refractometer weekly in the period of August – November of each evaluated hybrid. Measurements were based on the juice pressed out from the internodes between the 3. and 4. nodes of the stalk. Based on the measured Refractometric dry matter contents, the shapes of the Rdm content curves were determined by polynomial regression analysis. Calculations and data management were done by MS Office Excell while statistical analyses were performed by using R software with R Studio user service (R Core Team, 2018).

RESULTS AND DISCUSSION

Based on the meteorological data recorded in the surveyed two decades the Effective Heat Unit varied between 627 °C and 2097 °C. By

taking into consideration that sorghum varieties can be characterized with different base temperature, remarkable distinctness appear in the field of the useful amounts of heat. According to this result the value of base temperature of a sorghum variety is a determinative factor of sorghum production within Hungarian climatic conditions.

If a sorghum variety can be characterized with a base temperature of 8 °C, the average effective heat unit is about 1810 °C, while in the case of 15 °C base temperature useful heat sum is only 761°C, which is not enough to produce sorghum with a low level of climatic risks (Table 1).

Table 1

Effective Heat Unit and length of vegetation period in case of different base temperature stages

T _B	Effective Heat Unit (°C)				Length of vegetation period (days)			
	Mean	SD	Min	Max	Mean	SD	Min	Max
8	1810	145.58	1563	2097	152.9	0.22	152	153
8.5	1735	145.19	1493	2021	152.9	0.22	152	153
9	1660	144.83	1423	1946	152.9	0.45	151	153
9.5	1584	144.45	1353	1870	152.5	0.83	150	153
10	1509	144.04	1284	1795	152.2	1.06	150	153
10.5	1434	143.5	1215	1719	151.4	1.5	148	153
11	1359	142.94	1147	1644	150.6	2.03	146	153
11.5	1285	142.19	1079	1568	149.9	2.17	146	153
12	1211	141.23	1011	1493	148.7	2.62	144	153
12.5	1139	140.1	945	1417	146.8	3.41	140	153
13	1067	138.67	879	1343	144.8	3.63	138	151
13.5	996	136.96	814	1268	142.1	4.61	131	151
14	926	134.89	751	1195	139.4	4.95	129	149
14.5	859	132.77	690	1122	136.8	5.63	126	148
15	791.81	130.47	627	1052	133.4	6.2	123	143

Base temperature has a remarkable impact on the length of the vegetation period as well. Depending on this value the potential length of the vegetation period can vary from 123 days to 153 days. By increasing the value of base temperature the standard deviation and range values of EHU are increasing as well which phenomenon reflects on the climatic risk of sorghum with high heat demand.

Sorghums are basically sown in the beginning of May and harvested in the beginning of October. This is a short period for this plant, so that a higher heat demand can be provided by choosing varieties with a lower base temperature.

If the vegetation period is longer a high risk factor is appearing due to the probability of cold temperature in the late spring or early autumn.

Regarding the evaluated two decades the latest frost in spring were observed in the period of the 10th of March and 25th of April, while 55 % of the total registered latest frost were registered in April. The late spring frost were appeared nine times (45 %) in the period from 10th of April to 25th of April hence the probability of late spring frost is the highest in these days. Considering this fact lengthening the vegetation period by sowing in an early time is not a prospective method. Frost can cause serious damage on sorghum plants, therefore a remarkable risk is appearing if the vegetation period is expanded by sowing before May (Fig. 1).

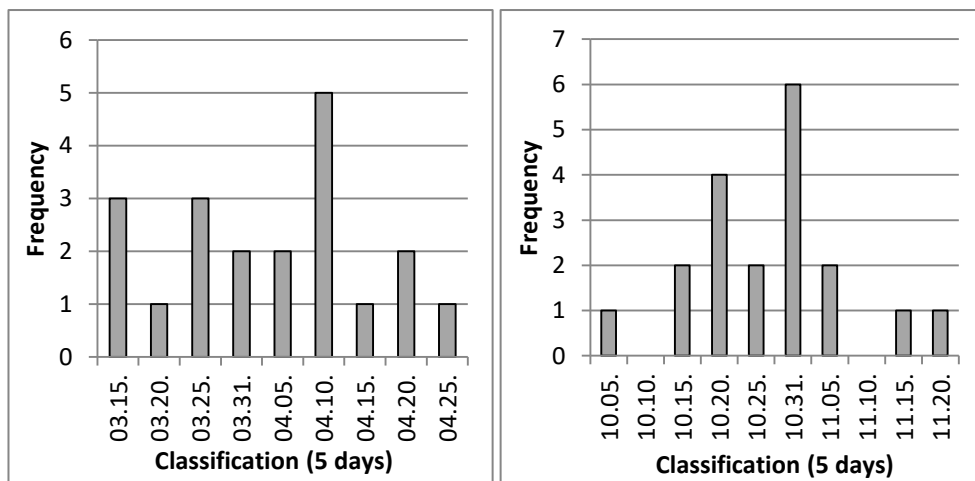


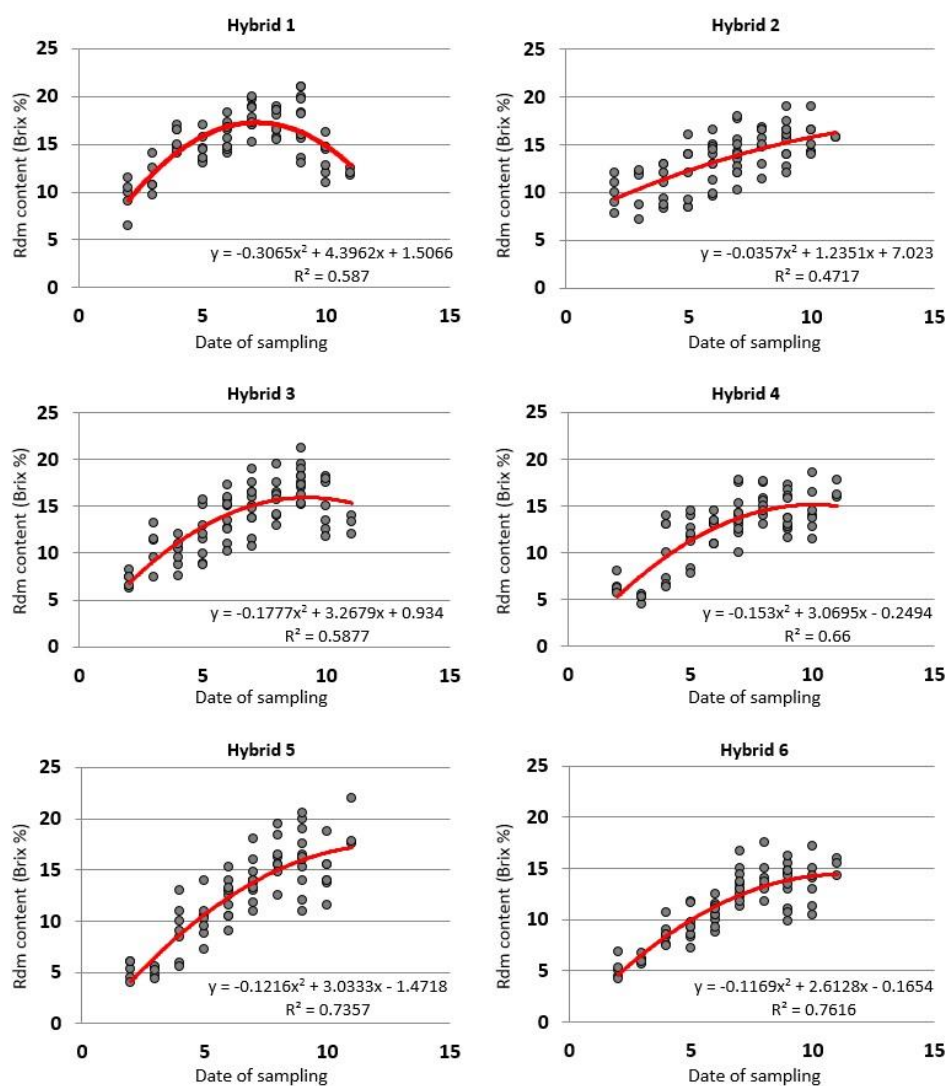
Fig. 1. The frequency of late spring frost (left) and early autumn frost (right) in spring (days)

Early frosts in autumn can cause serious problems as well, which is a remarkable risk factor if considering the fact that 75 % of the earliest frosts were registered in October. Thus, the extension of the vegetation period in autumn is also fraught with risk.

By the viewpoint of bioethanol production early autumn frost can be very harmful by the sugar loss caused by the chilling injury. This sugar loss can be remarkable, because sorghums usually reach the maximum amount of sugar content in the stage of waxy maturity. The sugar accumulation curve is in coherence with the length of the vegetation period, so that the shape of the accumulation curve is also typical for each hybrid. This can be a very important characteristic of a variety regarding the purposes of sugar production.

The shape of these curves were different in every cases, hence the dynamic of sugar accumulation in the stalks were different. The Rdm

accumulation curve of Hybrid 1 achieved the peak point in the mid of October, while peak point was reached of the Rdm accumulation curve of Hybrid 3 in the beginning of October (Fig. 2). In every other cases the top of the curve were hit in November. These hybrids have a longer vegetation period than 180 days, which is not fit for the Hungarian climatic conditions. In Hungary harvesting sweet sorghum in November is unfavorable, because in this case the risks of frost damage are enhanced. Thus, early maturity hybrids are acceptable for growing in Hungary.



0: aug. 0 – 9 3: szept. 0 – 9 6: okt. 0 – 9 9: nov. 0 – 9
 1: aug. 10 – 19 4: szept. 10 – 19 7: okt. 10 – 19 10: nov. 10 – 19
 2: aug. 20 – 31 5: szept. 20 – 30 8: okt. 20 – 31 11: nov. 20 – 31

Fig. 2. Rdm accumulation curves in the case of the investigated sweet sorghum hybrids

However differences in the shape of the Rdm accumulation curves can be beneficial as well. If the goal of the sweet sorghum growing is to produce sugar, the application of hybrids with different length of vegetation period can be effective so as to maximize sugar yields. Thus in the field of bioethanol production an enhanced amount of alcohol can be produced by an extended harvesting period. In this case, by dividing the production site to separated fields growing early and medium maturity hybrids an increased sugar yield can be provided.

CONCLUSIONS

According to this survey, it can be set out that sorghum can be an adequate crop to produce biomass for bioenergy purposes, considering the impacts of climate change. In this point of view, the drought tolerance of sorghum is a determinative aspect, but on the other hand the heat demand of a sorghum hybrid must be fulfilled in order to produce sorghum efficiently. The heat demand of a sorghum is depending on the base temperature of cultivated variety. Base temperature is usually varies from 8 °C to 15 °C. If the base temperature is high, the production possibilities are unfavorable due to the low heat sum, which can be useful for the plant. Thus, sorghum hybrids characterized with 10 °C or lower base temperature can be prospective within the Hungarian climatic conditions.

The length of the vegetation period is an important factor as well. Based on the meteorological data of the investigated two decades frosts can cause serious damage on sorghum lands. Spring frosts and autumn frosts can also appear during the vegetation period of sorghum, which can results serious yield and sugar loss.

In order to produce sugar from sorghum the shape of the sugar accumulation curve is an important aspect. By considering the sugar accumulation curve, sorghum based bioethanol production can be fitted to the climatic conditions, moreover by choosing adequate hybrids a longer harvesting period can be maintained with the maximum sugar amount.

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