Scientific Papers. Series A. Agronomy, Vol. LXV, No. 1, 2022
ISSN 2285-5785; ISSN CD-ROM 2285-5793; ISSN Online 2285-5807; ISSN-L 2285-5785

NEW GENOTYPES OF SWEET SORGHUM AND THEIR BIOMASS YIELDS IN THE SUSTAINABLE AGRICULTURE SYSTEM

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Abstract

The challenges of practicing a sustainable farming system include the use of renewable energy sources, fuels from residual crop biomass or biomass produced for this purpose. From the multitude of crops with high energy potential suitable for cultivation in climatic conditions in Romania, sweet sorghum (Sorghum bicolor (L.) Moench. var. Sacharratum). it proves to be one of the most important species, which is highlighted both by its high capacity to generate high yields, but also by the consistency and quality of fresh biomass production. Due to the stalks whose juice is rich in sugar (12-22% Brix), which can be easily converted into biofuel, either directly by fermentation or indirectly by obtaining alcohol, sweet sorghum is enlarged in culture, with obvious tendencies to increase surfaces on the European continent. The data presented in this paper were obtained from a study conducted on the chernozem soil in the Caracal Plain, in order to identify the ability of new hybrids of sweet sorghum to capitalize the climatic conditions specific to the area and to express their productive potential through high yields of fresh biomass with a high sugar content. The obtained data showed that the most valuable hybrid proved to be SASM 1, with a total biomass production of 88.1 t / ha and a ratio of stem participation to total biomass of 81.3%. The average soluble dry matter content (Brix) determined with the portable field refractometer, in the conditions of 2019 year, was 18.2% for the same hybrid.

Key words: *sweet sorghum, fresh biomass, yields, Brix content.*

INTRODUCTION

Characterized by a high sugar content of the stems and a chemical composition of the grain where starch predominates, sweet sorghum (*Sorghum bicolor* (L.) Moench. var. *Saccharatum*) is one of the most important agricultural sources used for the production of biomass that can be processed and converted. relatively easy in a type of fuel (bioethanol, synthesis gas), vegetable protein, feed or green manure (Reddy et al., 2005, Almodares, 2008, 2009; Matei, 2016; Antohe, 2007). In the current global energy context, green (renewable) energy is a critical source of energy that contributes to energy security, reducing dependence on fossil fuels and greenhouse gas emissions.

Many countries have developed alternative programs for fossil fuel energy in order to reduce dependence in the near future by providing at least 20-30% of them with bioethanol, biogas or biodiesel. Vinutha et al., 2014, shown that for India, more than 6.3 billion liters of ethanol were produced to reach target of replacing 20% of petroleum fuel with biofuel consumption, according to Ethanol Blending Program (EBP).

Sweet sorghum breeding programs have brought to market new genotypes with superior agronomic properties, adapted to various climatic conditions, capable of generating high biomass production and with a higher sugar content in stems than existing ones.

In a study based on multi-trait selection of sweet sorghum genotypes for bioenergy production, da Silva et al., 2020, tested 36 hybrids in two experimental areas of Embrapa Milho e Sorgo, in Sete Lagoas and Nova Porteirinha. The results demonstrated the existence of genetic variability among the genotypes of sweet sorghum, showing the possibility of selecting high-performance genotypes superior. The selection indexes tested were efficient in the selection of sweet sorghum hybrids with higher agroindustrial performance. Also, at least it was possible to identify hybrids of sweet sorghum with high potential for bioenergy production.

Sweet, grain, and dual-purpose sorghums differ in a number of important traits, including biomass production, total solutes in the stem juice and sugar accumulation across the stem. In a study with five sorghum hybrids the obtained results showed that plant height, leaf number, leaf weight, cane yield, and juice yield were positively correlated with the sugar yield in fresh stalks (Kanbar, 2021).

The level of yields and quality of the productions were is influenced by genotypes, technology, environmental conditions, soil quality and harvest time (Soare et al., 2019; Partal et al., 2020; Matei et al., 2021; Velea et al., 2021).

MATERIALS AND METHODS

The research was carried out at Agricultural Research and Development Station Caracal (ARDS), during the 2019 year in the conditions of a chermozem soil, medium rich in nutrient and with a humus content which varied between 3% to 4%. The soil in the arable layer (0-20 cm) has a lutearic texture with a clay content (particles below 0.002 mm) of 36.2%, an apparent density of 1.42 g/cm^3, a total porosity of 47% and one medium penetration rate (penetration resistance of 42 kg/cm^2).

From the point of view of the hydric features of soil in the superficial layer, the wilting coefficient records the value of 12.3%, the field capacity 24.5% and the hydraulic conductivity is 9.2 mm/h.

The main aim of the study was research was to establish the most valuable sweet sorghum hybrid for the area of Caracal Plain, in the above soil conditions. Were experimented four hybrids: 2 typical sweet sorghum hybrids with provenience from the Republic of Moldavia (SASM 1 and SASM 2) and 2 hybrids from the Romanian market - BMR Gold and Supersile 20 - hybrids recommended for silage crops.

The culture was placed in rotation with whiter wheat as previous plant in randomized blocks of three repetitions. The sowing date was realized in the 2th of May with a complete emergence of sweet sorghum plants in 10th of May. The density used was 15 g.s/sq.m on the background of $N_{100}P_{80}K_{80}$ applied before sowing as granulated chemical compounds.

During the vegetation period were made biometrical determinations: height of plants, average leaves number and dimensions, stalks diameters. The total fresh biomass was register in milk maturity stage of plants development, on which occasion the percentage of participation of the main components of biomass was also determined: stems, leaves and panicles.

Also, we registered the sugar content as dry soluble substances (Brix content %) with portable refractometer.

Representative samples of each hybrid were extracted and using an electric roller press device were determinate the sweet juice percent and total amount of juice per hectare for each hybrid tested.

The collected data in the field were analyzed using statistical program of ANOVA.

RESULTS AND DISCUSSIONS

Climatic conditions (Figure 1 and Table 1) during the experiment had an important influence on the evolution of sweet sorghum crop. The recorded data certify that the 2019 year was an excessively hot year. Compared to the normal area, an average temperature of 12.7ºC was achieved, with 2.1ºC higher than the normal range for the area, which is 10.6ºC. Regarding the months of the warm period of the year (April - September) we find that in no month were temperatures lower than the multiannual average. The deviations were positive, ranging from 0.4ºC to 3.1ºC. It is noted as extremely hot in July, August and September, with a thermal surplus between 2.3ºC and respectively 3.1ºC. Also worth mentioning are the many days in July and August when the maximum temperature has exceeded the value of 38ºC and daily ETO had registered values of over 4.8 mm significantly reducing the water from soil. During the vegetation period of sorghum, from May to Octomber (when were made the final determinations), the total of 438.6 mm precipitations, numerically representing a sufficient value for a plant with relatively low requirements compared to the vegetation factor of water. The period of August-September was very poor in precipitation, with a deficit of -49.7 mm and respectively -37.6 mm led to a supplementary stress of sweet sorghum hybrids, having negatively repercussions to the total fresh biomass and sugar content registered in stalks.

Figure 1. Climatic conditions of 2019 year - period of March-November - precipitations and ETO (mm)

Table 1. Climatic conditions of 2019 year - period of January-September - precipitations and ETO (mm)

Year of 2019	Temperature [°C]			Solar radiation [W/m2]	Precipitations [mm]	Wind speed [m/s]		Daily ETO
Month	avg	max	min	avg	sum	avg	max	[mm]
January	-0.85	9.01	-13.47	41	38.6	1.6	8.5	0.2
February	3.42	17.41	-8.19	90	14.2	1.4	8.2	0.4
March	9.4	25.07	-3.96	156	25.2	1.7	9	2.8
April	12.11	27.16	-0.2	167	44.4	1.7	7.8	2.8
May	17.13	30.88	4.45	215	69	1.7	9.2	2.9
June	22.79	34.13	12.87	269	285.8	0.5	6	2.6
July	23.13	38.81	9.62	263	60	0.4	6.2	4.8
August	25.02	38.71	12.5	242	1	0.5	3.6	4.8
September	20.01	35.02	2.74	167	2	0.8	4.9	3.4
Octomber	13.64	54.05	2.15	107	20.8	0.8	7.6	3.4
November	11.4	23.81	2.55	46	74.4	1	5.9	0.5
May-Oct.	*20.26*				*438.6*			
Sum Jan-Nov					635.4 mm			

Morphological features of the sweet sorghum plants were influenced equally by the genetic heritage and the technological measures: plant's density, level of fertilization, water supply level and so on (Drăghici, 1999; Varvel, 2000; Matei, 2020, Paraschivu M. et al., 2021).
In our study, the main morphological features determined in the tested assortment were presented in Table 2.

Table 2. Biometrical measurements of the assortment of sweet sorghum hybrids

Hybrid	Plant's height cm	Stalk diameter (cm)	Av. leaves/ plant	Av. length leaf (cm)	Av. width leaf (cm)
BMR Gold	282	2.03	15.4	70.8	8.4
SAȘM 1	324	2.16	15.2	68.7	7.3
SAȘM 2	305	2.11	15.7	71.4	7.6
Supersile 20	262	1.98	17.7	68.5	7.3
Average	**293**	**2.07**	**16**	**69.8**	**7.6**

Related the height of sorghum plants we can observe that the tallest plants, over 300 cm, were recorded at the Moldavian hybrids, SASM 1 and SASM 2, with 324 cm in case of first hybrid and 305 cm for the second hybrid mentioned. The smallest plants were observed at Supersile 20, of 262 cm, followed by BMR Gold hybrid with a value of 282 cm. In the climatic conditions' of 2019 year, the average/experiment was 293 cm.
Part of the biomass component, the dimensions of stalks have a powerful influence to the final yields of fresh biomass. The tested hybrids generate powerful plants with a diameter of stalk (measured on the middle section of plants) which range between 1.98 cm (Supersile 20) and 2.16 cm (SASM 1). With exception of Supersile 20 hybrid, all of hybrids had over 2 cm in diameter in the middle section of plant. In literature we found similar results of SASM 1 hybrid related the stalk's diameter, with values between 0.7 cm to 2.68 cm (Vladuț et al., 2019).
Guihua et al., 2011, found significative correlation between stalk (stem) diameter (SD) and fresh biomass yield, but no consistently significant correlations with sugar content (SC) in three trials.
Leaves dimensions also contribute on the total fresh biomass yield of sweet sorghum tested hybrids. Related the average numbers of leaves/plant we found a number of over 15 leaves/plant, with the highest number, of 17.7, at Supersile 20 hybrid. The differences between others hybrids were very small, of order of 0.2 to 0.5 leaves/plant.
In our designed experiment the average of length leaf was 69.8 cm. Longer leaves were recorded at SASM 2 hybrid, with a value of 71.4 cm, followed by BMR Gold hybrid with 70.8 cm and others 2 hybrids with almost equal size, of 68.7 cm and respectively 68.5 cm (SASM 1 and Supersile 20).
Regarding the width of the leaves, we record values on tested hybrids from 7.3 cm on SASM 1 to highest values of 8.4 cm at BMR Gold hybrid. For this indicator the average/experiment had a value of 7.6 cm.
The obtained fresh biomass yield of the assortment is presented in Table 3. The productions range between 68.3 t/ha (Supersile 20) to 88.1 t/ha (SASM 1 hybrid).
In comparison with the Control, the average yield/experiment, which realized 77.7 t/ha, with very significand increases in production is highlight only one hybrid, SASM 1, with a positive difference of 10.4 t/ha which exceeds the value of the control with 13.4%.

With positive differences, of 2.7 t/ha, the value of the SASM 2 hybrid is also noticeable, but from the statistically point of view that difference is considered as insignificant.

Table 3. Fresh biomass yield on the assortment of sweet sorghum hybrids

Hybrid	Fresh biomass yield			Signif.
	t/ha	%	Differences	
BRM Gold	74.1	95.4	-3.6	O
SASM 1	88.1	113.4	10.4	***
SASM 2	80.4	103.5	2.7	-
Supersile 20	68.3	87.9	-9.4	OOO
Average	**77.7**	**100.0**	**Control**	**Control**

LSD 5%=3.5 t/ha; LSD 1%=5.8 t/ha; LSD 0.1%=8.7 t/ha

Lower values than the Control were observed at the other two hybrids, with values of 74.1 t/ha in case of BMR Gold hybrid and respectively 68.3 t/ha for Supersile 20 hybrid. Both differences levels of yields were statistically point of view ensured view ensured: significative for BMR Gold and very significant for Supersile 20.

Main components of the fresh biomass on sweet sorghum are: stalks, leaves and panicles. Stalk weight, stalk volume, stalk diameter, and plant height had significantly strong associations with juice yield, which were consistent across different sorghum ideotypes (Carvalho et al., 2017). In order to establish which hybrid is more valuable in our experiment from this point of view we extract samples and separate and registered the main components. The recorded results are presented in Figures 2 and 3.
Stalks percentage rage in our assortment from 72.3% at Supersile 20 hybrid to 81.3% at SASM 1 hybrid. Looking at the figure 2 we can say that the values are closer to the highest, with 79.2 % on SASM 2 hybrid and 78.5% at BMR Gold genotype.

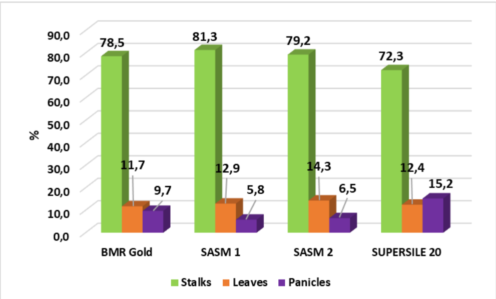

Figure 2. The percentage of biomass components for tested hybrids (%)

The participation percent of leaves to the total fresh biomass realized in the experimented conditions had values between 11.7% at BMR Gold hybrid and 14.3% at SASM 2 hybrid. The other hybrids from the assortment record closer values, of 12.9 in case of SASM 1 hybrid and 12.4% on the Supersile 20 hybrid.
The highest differences of recorded values were observed in case of percentage of leaves, which range between 5.8% at SASM 1 hybrid to 15.2% at Supersile 20 genotype. We must note the lower values recorded by the two hybrids from the Republic of Moldova, a value justified by the fact that they are sterile forms, and in the tested conditions they did not form seeds or accidentally formed small quantities.
If we compare those results with the data from various studies made on this subject, we can say that the results fall within the margin reported by other researchers.

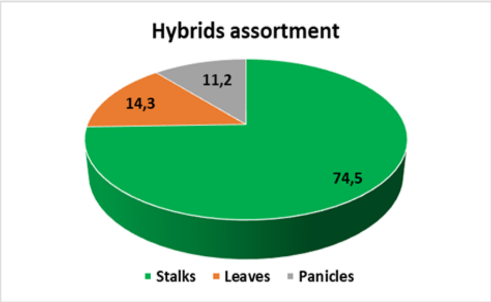

Figure 3. The percentage of biomass components in average/experiment (%)

In average/experiment (Figure 3) the main components are: 74.5% stalks, 14.3% leaves and 11.2% panicles.
Other criteria in order to evaluate the suitability a sweet sorghum hybrid to capitalize the climate and soil conditions in an area is the accumulation of carbohydrates in the stem, but also the quality of the sweet juice (the ratio between reducing and non-reducing sugar, the amount of juice/kg of stalks, the amount of alcohol/ethanol obtained (Băbeanu et al., 2017).
In these conditions we start to determinate the total dry soluble substances (*BRIX content %*) using a portable refractometer (Figure 4) and the results obtained at the assortment of sweet sorghum hybrids are presented in Figure 5.
Determinations of the BRIX content (%) in stalks, carried out in the milk maturity phase of

the grains of sweet sorghum plants, show values which range between 14.3% at Supersile 20 hybrid and 20.1% at BMR Gold hybrid. The Moldavian hybrids, SASM 1 and SASM 2 realized closer values of 18.2% and respectively 17.2%. The average of BRIX content on sweet juice/experiment was 17.5%.

Figure 4. Field aspects from Brix (%) determinations with portable refractometer

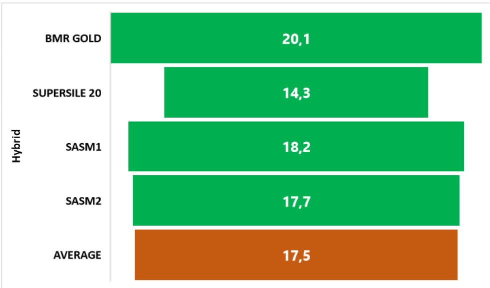

Figure 5. Brix content (%) at sweet sorghum hybrids from assortment

Based on the data collected we go froward and we determined the total yield of juice/ha in relative to the weight of the squeezed stalks for each hybrid from assortment. In order to obtain sweet juice, we used an electric roller press (with 3 tamburs) for squeezing sorghum stalks (Figure 6). Before squeezing the stalks, we remove the leaves from the sorghum plants and also and the final internode of the stalk (near the panicle) due his chemical compositions rich in minerals, which can negatively affect the process of obtaining ethanol.

At worldwide production of cellulosic ethanol fuel and diversify the supply of raw materials include new crops such cassava and sweet sorghum (Sanyuan Tang et al., 2018). In China, in 2020, the total yield of ethanol had reach 4.0 million tons, up 90% related at 2015 year when the production was 2.1 million tons.

The same strategy was observed in USA such an increase of the area of sweet sorghum has already occurred due to the rapid development of ethanol refineries based of grain and sweet juice. This is already demonstrated by a 19% increase in sorghum crop areas in 2007 compared to 2006. This review focuses on the benefits of sorghum as a source of ethanol and its future for mass planting.

Figure 6. Electric roller press for extracting sweet juice

Looking at the data presented in Figure 7, we can observe that the highest quantity of sweet juice was generated by SASM 1 hybrid with almost 30 thousand liters/ha in the mentioned experimental conditions.

Valuable from this point of view proves to be also SASM 2 hybrid, with a total yield of sweet juice of 24.5 thousand liters/ha.

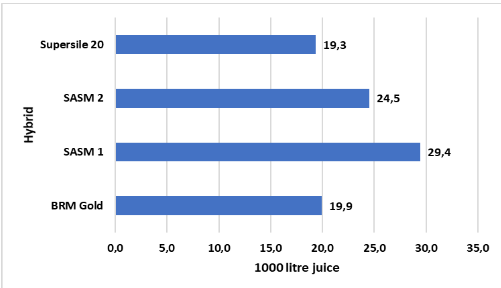

Figure 7. Theoretical estimations of the juice (thousand liters/ha) at sweet sorghum assortment

The others two hybrids had values near the limit of 20 thousand liters/ha (19.9 thousand liters/ha for BMR Gold hybrid and respectively 19.3 thousand liters/ha in case of Supersile 20 hybrid.

CONCLUSIONS

As most important aspects related the goals and results of our experiment, we can synthetize and highlights the most important conclusions, as follow:

- due to its genetic variability, in terms of the sugar and juice content of the stalks, such as total soluble sugars, green stalks yield, amount of juice and grain yield, various research institutes in the country and abroad have created sweet sorghum hybrids capable of achieving good yields in different cultivation conditions;
- in the climatic conditions from ARDS Caracal, in 2019 year, the sweet sorghum plants had good conditions for plant's development, this aspect being found in the measured biometric values;
- the sweet sorghum hybrids tested realized very valuable yields of fresh biomass, almost 90 t/ha, with high percentage of stalks from those, over the values of 80%;
- typical hybrids of sweet sorghum proved to have the most valuable features to produce high biomass yields, but also high efficiency of sweet juice, with very good quality of it due the Brix content of 18-20%.

ACKNOWLEDGEMENTS

The research was done in the activities of the Project no. 9/PCCDI/2018 VALINTEGR supported by Ministry of National Education UEFISCDI, Program PN III 2017- 2020.

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