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YIELD OF BROOMCORN (*SORGHUM VULGARE* VAR. *TECHNICUM* [KÖRN.]) CULTIVATED IN SOUTHERN BULGARIA

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ABSTRACT

A three years' comparative trial was conducted in Agricultural Experimental Station in the Eastern Rhodopes – Kardzhali, Bulgaria to assess the productive potential of five broomcorn genotypes – cultivar Prima and populations S14, G16, L18 and MI16N. Fresh biomass yield was formed by two to three cuttings per season, depending on annual precipitation quantities. The average duration for cutting formation for the region is from 35 to 45 days. When grown in Southern Bulgaria (Kardzhali region) broomcorn landraces can produced up to 9974 kg/da fresh biomass and up to 1977 kg/da dry mass, depending on the cultivation year. The highest yield of fresh and dry biomass was obtained from the local population MI16N, which exceeds the standard variety Prima from 131.8% to 185.1% and an average of 159.1%. This study demonstrates the potential of growing broomcorn for fodder in the conditions of Southern Bulgaria.

Key words: broomcorn, *Sorgum* spp., *Sorghum vulgare* var. *technicum* [Körn.]), yield.

INTRODUCTION

Frequent extreme droughts in recent decades with increasing intensity and duration appear as limiting factors in a number of sectors and systems of the human environment and represent challenge for risk analysis and management, because impacts (in intertwined systems) can propagate through multiple sectors including fodder production (Raza et al. 2019; Niggli et al., 2022). To minimize the impact in agricultural practice, various techniques and methods are used: technological (agricultural practices, managerial decision, etc.), biological (early ripening varieties, early sowing dates, etc.) etc., however they often are ineffective and can partially compensate for the consequences of pronounced climatic anomalies (Liliane et Charles, 2020). There is an active demand from agricultural producers for cost-effective alternative forage crops, due to a large consumption of fresh and dry biomass feed for feeding farm animals (Pastorelli et al., 2022).

On the other hand, the drive for ecological production, technologies and products in modern agriculture leads to a renewed interest in unique agricultural crops that are not necessarily related to food production, such as broomcorn (*Sorghum vulgare* var. *technicum* [Körn.]) (Sikora and Berenji, 2011; Berenji et al., 2013). *Sorghum vulgare* var. *technicum*, as annual grass belonging to genus *Sorghum*, is a promising crop with a number of advantages in adverse climate conditions: tolerates air and soil drought, performs low soil quality requirements (salinity, acidity, shallow, low productive soils as well as slopes), exerts more effective CO_2 intake, needs lower input for cultivation, etc. Consequently, these advantages increase biodiversity, lower greenhouse gas emissions, enhance climate change mitigation and thus protect the environment. (Borrell et al., 2000; Berenji et al., 2011; Sikora et al. 2013; Brdar-Jokanovic and Sikora, 2020). The variety possesses typical ecological plasticity and sustainable yield (2-3 cuts for vegetation period), which allows formation of above-ground biomass in the period of summer depression of perennial fodder grasses. The number of cuttings is relatively reduced from fresh biomass, but despite this, remains relatively high compared to other forage cereal grasses in dry conditions (Chamble et al.,1995; Stefan, 2015; Mulatu and Kifle, 2016). In addition, broomcorn multiple applications (as fodder or industrial crop) as well as its allelopatic potential justifies it as a promising crop for balanced field rotation schemes, both in conventional and organic agriculture (Berenji and Dahlberg, 2004, Berenji et al., 2011; Sikora et al., 2016; Sikora et al. 2018).

In the past, in Bulgaria broomcorn was used for fodder production but in limited regions without further distribution (Mazdrakov, 1937). Possible reasons for that could be scars scientific data and lack of cultivars and cultivation technologies (Marinov-Serafimov et al., 2020). Thus, the aim of our study was to select a promising broomcorn landrace for fodder production by evaluating their productivity in Kardzhali region, Southern Bulgaria – an area with distinctive dry climate during crop vegetation.

MATERIAL AND METHODS

A field experiment was set up at Agricultural Experimental station in the Eastern Rhodopes – Kardzhali, which is located near town of Dzhebel, Bulgaria. The region is in the Southern xerothermal zone, where cinnamon forest soils are typical. The upper soil layer is very low in humus (2.0%), with low nitrogen and phosphorus content, and high potassium content. The physical qualities of the soil are very unfavourable with low water penetration and with high clay content. The climate is typically southern – in winter precipitation is mostly rain, while summer is hot and dry.

The agroclimatic profile of Eastern Rhodopes’ mountains region is characterized by lowmountainous terrain with dense hydrographic network. The mean annual air temperature is 12-13° C at lower parts, and 10° C – at higher planes. The lower planes are warmer, with higher moisture deficit. The sum of active temperatures is 3700 - 4100° C, which provides excellent conditions for agriculture. The atmospheric moisture balance in April – September in the Eastern Rhodopes is restrictive – from -200 to - 450 mm, which determines hot, dry summer with unequal rain distribution – so called “xerophytic” climate (Sapundzhiev et al. 2016).

The trial was conducted for three years (2019-2021) and included five variants – a cultivar Prima as a standard and four broomcorn landraces, gathered in several regions in Bulgaria. The compared variant are as follows:

Table 1. Broomcorn accessions

Name or code	Plant height	panicle position	Panicle class	Origin
Prima	medium high	curved	I	Institute of field and vegetable crops, Novi Sad, Serbia
S14	low	curved	I	a local population from Southeastern Bulgaria
GL15A	medium high	standing	II	
PL16	medium high	standing	II	populations from Central and Northern Bulgaria
MI 16N	low	curved	I	

The trial was designed as blocks (1 block – 1 variant) with 0.25 cm between rows at density 25-30 000 plants per da in three replications. Each year, two to three cuts are performed at BBCH 47-51 growth stage (flag leaf sheath opening – beginning of heading) according to the classification of growth stages of mono- and dicotyledonous plants - BBCH scale (Meier, 2001). Productivity was evaluated by analysing the following parameters:

1. yield of fresh biomass per variant per cut and in total (kg/da);
2. yield of dry biomass per variant after drying of fresh biomass to absolutely dry matter (kg/da);

3. relative share of cuts to total yield of fresh biomass (%);
4. fresh weight to dry weight ratios (FW/DW) by cuts and in total biomass for vegetation.

For analyses of climatic conditions were used primary climatic data (monthly precipitation (mm) and mean air temperature (t,^{0}C), gathered from Synoptic station – Kardzhali, at the National institute of meteorology and hydrology in Bulgaria. As norm was considered data registered for 1960-2000 period. To classify the climate of the area, the DeMartonne index was applied (De Martonne, 1920). It is a complex indicator which depicts the moisture conditions of studied area for certain period of time (Croitoru et al., 2013).

Hierarchical cluster analysis (Hair et al., 1987) was used to identify the similarity groups across samples using software STATISTICA 10. To ensure that yield results of broomcorn accessions were significant, an one-way analysis of variance (ANOVA) was used. Low significant differences (*LSD*) with a 0.05 significance level was used to determine the differences in yield of fresh and dry biomass. Different letters describe significant differences between groups of columns. The calculations were made using the software product STATGRAPHICS Plus for Windows and graphs were made using Microsoft Office Excel, 2010.

RESULTS AND DISCUSSION

Evaluation of influence of main climatic indices (precipitation and monthly air temperature) reveals that for trial years the conditions were relatively favourable for broomcorn growth and development (Table 2). Even though the soil water deposit depends on the winter precipitation, which was scarce for Kardzhali, primary influence on the emergence of broomcorn in spring and its subsequent growth, have the climatic conditions during season (April - September). The mean monthly air temperature in trial period was higher than the norm with +2.0 to +2.9^0 C, which qualifies it as abnormal. Precipitation amounts varied according to the year of study. In 2019 and 2020 vegetation precipitation amounts exceeded the norm with 19 - 29%, but in 2021 they were only 70% of norm.

Table 2. Climate data for 2019 - 2021 vegetation period (IV – IX) of broomcorn for Kardzhali region.

Years	**Months**						**Mean IV – IX, t ^{0}C**
	IV	V	VI	VII	VIII	IX	
	Mean monthly air temperature. t^0 C						
2019	12.2	17.0	22.3	23.5	24.9	20.0	**20.0**
variation, + -	*0.5*	*-0.5*	*1.3*	*0.4*	*2.4*	*1.8*	*2.9*
2020	10.3	16.1	19.0	23.7	24.3	20.9	**19.1**
variation, + -	*-1.4*	*-1.4*	*-2.0*	*0.6*	*1.8*	*2.7*	*2.0*
2021	10.0	17.4	21.2	25.7	25.1	18.3	**19.6**
variation, + -	*-1.7*	*-0.1*	*0.2*	*2.6*	*2.6*	*0.1*	*2.5*
norm (1964- 2000) °C	11.7	17.5	21.0	23.1	22.5	18.2	**17.1**
	Monthly amount of precipitation. mm						**Sum IV –IX, mm**
2019	116.8	82.8	89.6	51.3	39.0	1.3	**380.8**
variation, %	*236.4*	*132.1*	*139.6*	*89.8*	*93.3*	*3.0*	*119.7*
2020	143.0	75.2	141.2	0.0	14.9	35.9	**410.2**
variation, %	*289.5*	*119.9*	*219.9*	*0.0*	*35.6*	*83.5*	*128.9*
2021	67.9	71.9	45.0	0.8	31.2	5.0	**221.8**
variation, %	*137.4*	*114.7*	*70.1*	*1.4*	*74.6*	*11.6*	*69.7*
norm (1964- 2000) °C	49.4	62.7	64.2	57.1	41.8	43.0	**318.2**
	De Martonne aridity index						**I_{DM} IV - IX**
2019	63.1	36.8	33.3	18.4	13.4	0.5	**25.4**
2020	84.5	34.6	58.4	0.0	5.2	13.9	**28.2**
2021	40.7	31.5	17.3	0.3	10.7	2.1	**19.6**
norm (1964- 2000) °C	27.3	27.4	24.9	20.7	15.4	18.3	**21.9**

Source: Synoptic station Kardzhali, NIMH

Notably, rain amounts in 2019 were relatively evenly distributed throw-out the year which possibly allowed the formation of third cut in broomcorn variants, which happened only this year. Applying the De Martonne index may be concluded that the experimental period is characterized with diversity in aridity with 2021 being the driest of them. Thus, 2019 and 2020 are classified as semi-humid, and 2021 – as semi-arid (Table 2).

Despite climate variations all broomcorn variants formed biomass, mostly in two cuts per season. The productivity of fresh biomass is shown both per cuts as well as total per vegetation for the trial period in Table 3. The highest yield in all growing years was recorded for accession MI16N – it exceeds the standard Prima with 30-103%. It is followed by L18 and G16, whose total fresh mass yield outmatched the standard with 20- 30% depending on the year. It should be noted that in 2021, which was the driest of trial period, MI16N formed yield that exceeds the standard Prima most – with 103%, which could be one indicator for better drought resistance of that genotype.

The highest mean fresh broomcorn biomass was harvested in 2020 – 9973.8 kg/da. It was formed in two cuts (April – June) at abnormal quantities of precipitation - (19.9 – 189.5% of norm). In 2019 and 2021 the mean biomass of all variant was relatively less and equal – 6575.5 kg/da and 6519.7 kg/da.

Table 3. Fresh biomass (kg/da) from broomcorn variants in 2019-2021 period

Accessions	Cuts, kg/da						Total, kg/da	
	I	% *St*	*II*	% *St*	*III*	% *St*	Total	% *St*
				2019				
Prima(*St.*)	2394.4bc	100.0	2626.7a	100.0	691.1a	100.0	5712.2ab	100.0
S14	1388.9a	58.0	2684.4a	102.2	612.7a	88.6	4686.0a	82.0
G16	2933.3c	122.5	3300.0ab	125.6	873.8ab	126.4	7107.1ab	124.4
L18	2073.3ab	86.6	3444.4ab	131.1	882.2ab	127.7	6400.0ab	112.0
MI 16N	3942.2d	164.6	3977.8b	151.4	1052.2b	152.3	8972.2b	157.1
Average	***2546.4***	***106.3***	***3206.7***	***122.1***	***822.4***	***119.0***	***6575.5***	***115.1***
				2020				
Prima(*St.*)	7506.7a	100.0	1128.9a	100.0	-		8635.6a	100.0
S14	8128.9ab	108.3	1454.4ab	128.8	-		9583.3a	111.0
G16	8784.4ab	117.0	1276.7a	113.1	-		10061.1a	116.5
L18	8506.7ab	113.3	1697.8ab	150.4	-		10204.4a	118.2
MI 16N	9253.3b	123.3	2131.1b	188.8	-		11384.4a	131.8
Average	***8436.0***	***112.4***	***1537.8***	***136.2***			***9973.8***	***115.5***
				2021				
Prima(*St.*)	4217.8a	100.0	582.2a	100.0	-		4800.0a	100.0
S14	4862.2abc	115.3	741.1a	127.3	-		5603.3ab	116.7
G16	4484.4ab	106.3	918.9ab	157.8	-		5403.83a	112.6
L18	5328.9bc	126.3	1364.4b	234.4	-		6693.3ab	139.4
MI 16N	5751.1c	136.4	3132.2c	538.0	-		8883.3b	185.1
Average	***5141.6***	***120.0***	***1347.8***	***231.5***			***6276.7***	***130.8***

Mean values, followed by different letters are statistically different at P = 0.05

The ranking results on broomcorn variants according to their dry mass are similar to those obtained for fresh biomass (Table 4). The highest values were recorded for MI16N, again it exceeded the standard with 37-84% depending on year of cultivation. Here, however, the second place is hold by G16 in 2019 and 2020, and S14 in 2021.

Table 4. Dry biomass (kg/da) from broomcorn variants for 2019-2021

Accessions	Cuts, kg/da						Total, kg/da	
	I	% *St*	*II*	% *St*	*III*	% *St*	Total	% *St*
				2019				
Prima(*St.*)	563.8abc	100.0	587.8ab	100.0	152.9ab	100.0	1304.5ab	100.0
S14	329.2a	58.4	532.4a	90.6	115.7a	75.7	977.4a	74.9
G16	775.8bc	137.6	883.7c	150.3	169.9ab	111.1	1829.4ab	140.2
L18	496.7ab	88.1	681.1abc	115.9	161.4ab	105.6	1339.2ab	102.7
MI 16N	845.1c	149.9	747.3bc	127.1	195.8b	128.0	1788.1b	137.1
Average	***602.1***	***106.8***	***686.4***	***116.8***	***159.1***	***104.1***	***1447.7***	***111.0***
				2020				
Prima(*St.*)	1282.7a	100.0	193.3a	100.0	-		1475.9a	100.0
S14	1663.7b	129.7	297.2a	153.8	-		1961.0a	132.9
G16	1746.5b	136.2	259.6a	134.3	-		2006.1a	135.9
L18	1493.6ab	116.4	298.3a	154.3	-		1791.9a	121.4
MI 16N	2152.8c	167.8	495.5b	256.4	-		2648.3a	179.4
Average	***1667.9***	***130.0***	***308.8***	***159.8***			***1976.6***	***133.9***
				2021				
Prima(*St.*)	1061.1ab	100.0	165.5a	100.0	-		1226.5a	100.0
S14	1225.6ab	115.5	146.3a	88.4	-		1371.8a	111.8
G16	1030.7a	97.1	165.6a	101.1	-		1196.3a	97.5
L18	1053.8ab	99.3	308.6ab	186.5	-		1362.3a	111.1
MI 16N	1351.8b	127.4	658.7b	398.0	-		2010.5a	163.9
Average	***1144.6***	***107.9***	***288.9***	***174.6***			***1433.5***	***116.9***

Mean values, followed by different letters are statistically different at P = 0.05

Variation in the relative share of cuts among the years and broomcorn variants is depicted in figure 1. As noted previously, only in 2019 all variants formed three cuts. The distribution was uneven – the second cut is the highest – from 46-57% of total yield, the third cut – the lowest – 11-13% of total. In 2020 and 2021 the cuts were two, with first prevailing - in most variants over 80% of the total annual biomass. This coincides with precipitation periods – usually in years with late summer drought the formed second cut mass is lower than the one, harvested in early summer. The exclusions are in 2021, when G16 and MI16N formed first cut subs. 76 and 65% of the total biomass yield. It should be noted the ability of these two variants to form biomass in the unfavourably dry conditions in late summer of 2021.

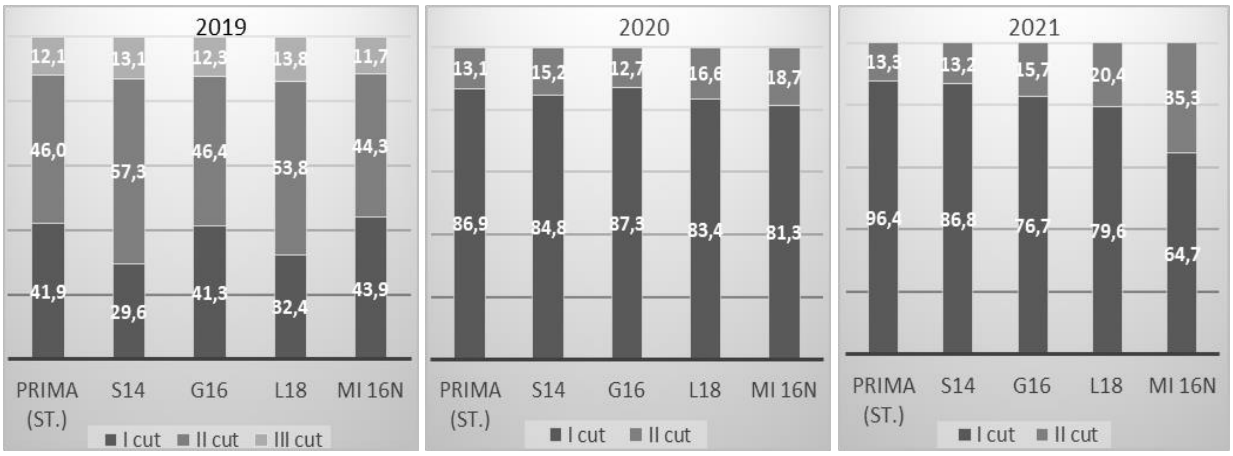

Figure 1. Relative share (%) of cuts per total yield for vegetation of broomcorn variants, harvested in 2019-2021

Vegetative biomass, and more specifically fresh weight (*FW*) and dry weight (*DW*), ratio will improve understanding of total yield for vegetation period and traits such as drought tolerance and water use efficiency. The fresh weight: dry weight ratio (FW/DW of broomcorn accessions) is related to both, accessions and environment in years of the study (Figure 2, Table 5).

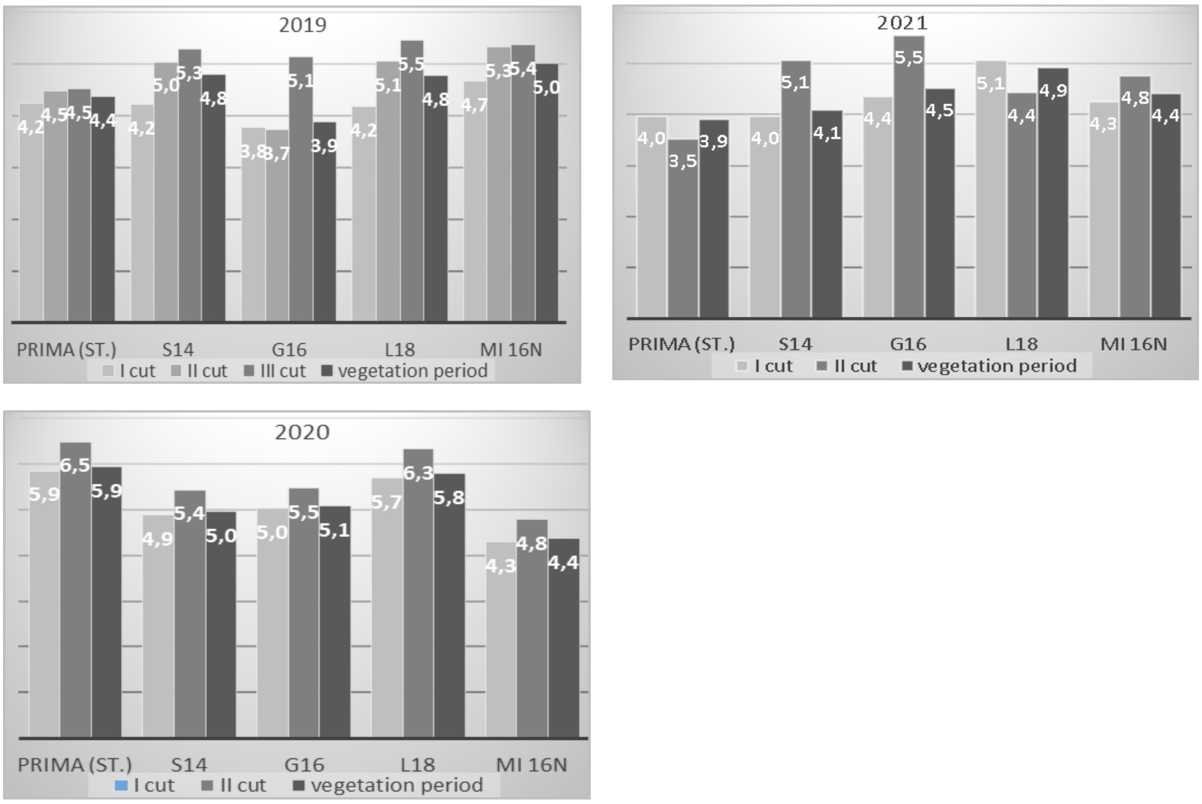

Figure 2. *FM/DM* ratio of broomcorn variants by cuts and years of cultivation

Table 5. Average *FM/DM* ratio data of broomcorn variants for cultivation years (2019-2021).

Accessions	***FW/DW* ratio**			
	2019	**2020**	**2021**	***AVG***
Prima (St.)	4.4	5.9	3.9	***4.7***
S14	4.8	5.0	4.1	***4.6***
G16	3.9	5.1	4.5	***4.5***
L18	4.8	5.8	4.9	***5.2***
MI 16N	5.0	4.4	4.4	***4.6***
AVG	***4.6***	***5.2***	***4.4***	

The highest *FW/DW* ratio for all broomcorn landraces was calculated for 2020– 5.2. This higher fresh biomass yield was formed in year with abnormal precipitation level, which is most probable explanation for it. In 2019 and 2021 *FW/DW* ratio was lower, but similar – 4.6 and 4.4.

FW/DW ratio presented significant differences among broomcorn accessions. The lowest dry matter content was registered for L18 for trial years, which indicates for better drought resistance and more effective utilization of air and soil moisture. For the rest of variants was recorded relatively high dry matter content – MI16N and S14 with lowest ratio, thus showing appropriate variants for hay production.

Figure 3 shows a hierarchical cluster analysis of the data in Table 3 and 4 – fresh and dry biomass yield of all variants. The first group includes standard Prima and local population S14. These accessions can be taken as relatively close. In another cluster, G16 and L18 stand out with higher productivity compared to the standard. Local population MI16N with the highest productivity of fresh biomass is singled out. These data analyses once more confirm the advantageous quantities of accession MI16N when grow in Southern Bulgaria. In addition, cluster analysis provides significant additional information on the studied broomcorn accessions and their targeted use in forage production.

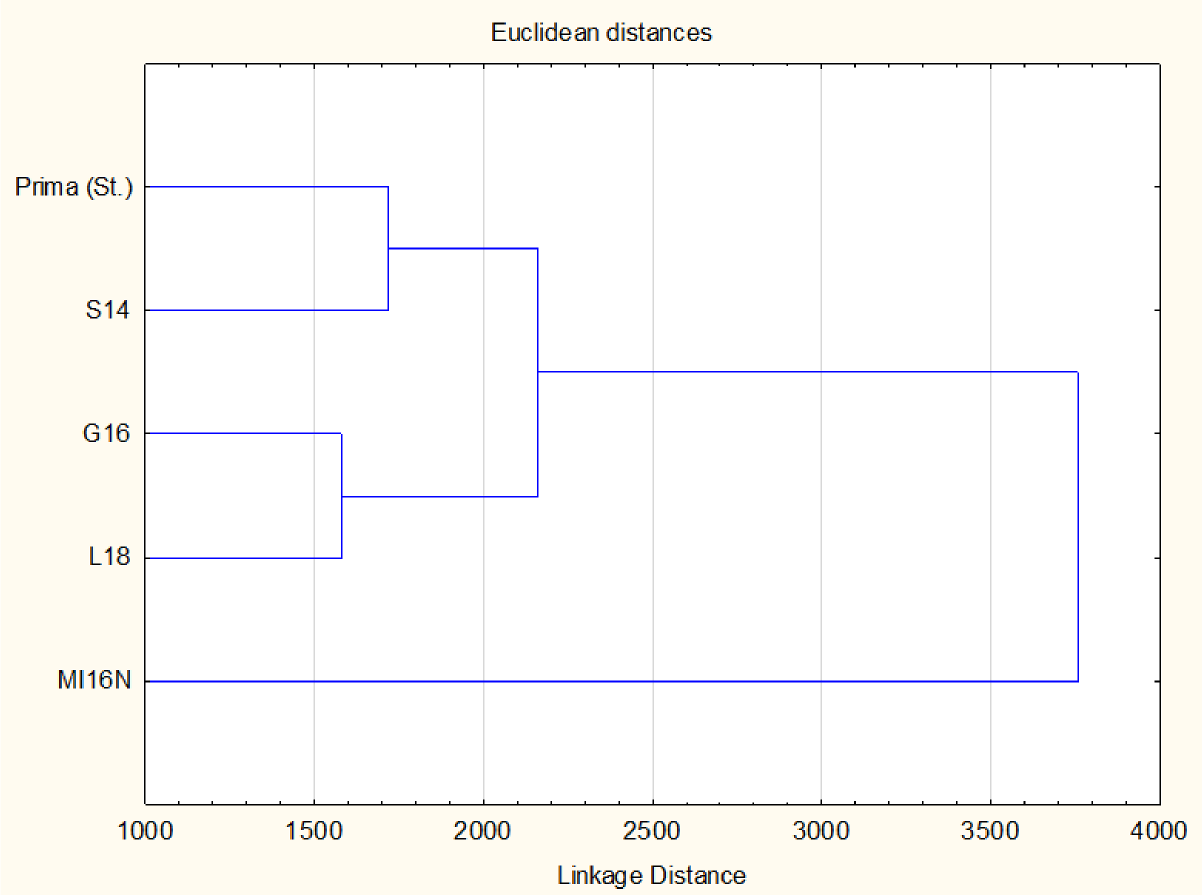

Figure 3. Dendrogram of broomcorn accessions by fresh and dry biomass productivity.

CONCLUSIONS

The presented study analyses the possibilities for growing broomcorn (*Sorghum vulgare* var. *technicum* [Körn.]) for fodder production. When grown in Southern Bulgaria (Kardzhali region) broomcorn landraces can produce up to 9974 kg/da fresh biomass and up to 1977 kg/da dry mass, depending on cultivation year. Precipitation amounts and their distribution were the factor that determines the quantity and quality of broomcorn biomass.

Among the tested accessions MI16N performed best for the study period – MI16N produced the highest yield of fresh (131.8 to 185.1%) and dry biomass (137.1 to 179.4%) compared to standard Prima.

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