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SWEET SORGHUM (*SORGHUM BICOLOR* (L.) MOENCH) GENOTYPES ASSESSMENT FOR FOOD, FODDER, AND ENERGY VALUES IN NORTHERN KAZAKHSTAN

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SUMMARY

Sweet sorghum (*Sorghum bicolor* L.) is an unusual crop in Northern Kazakhstan. For its introduction in the region, seven sweet sorghum cultivars and two hybrids with a shorter vegetation period achieved cultivation and evaluation from 2020 to 2022 in the Northern Kazakhstan region**.** The results identified responsive genotypes to the new climatic conditions during the vegetation period. The biomass fodder values analysis referred to its chemical composition. The cultivar Volzhskoe 51 showed distinction by having a higher crude protein and fat content. Based on the acquired findings, sweet sorghum becomes highly recommendable for introduction as a fodder culture. The water-soluble sugar content determination in the central stem juice employed the refractometric method. Cultivars Kapital and Sevilia showed higher water-soluble sugars contained in the stem juice. The established fractional composition used high-performance liquid chromatography. Likewise, cultivars with a prevalent mono- and disaccharide content succeeded in attaining isolation. Depending on the fractional composition, the study proposes a possible direction of sugar-sorghum juice processing for producing bioethanol and dietary food syrup. The results obtained contribute to further work on developing local sweet sorghum cultivars.

Keywords: Sweet sorghum (*S. bicolor* L.), biomass yield, chemical composition, metabolizable energy, sugars in stem juice, silage, syrup, bioethanol

Key findings: The presented study identifies the sweet sorghum (*S. bicolor* L.) cultivars capable of producing higher yields in Northern Kazakhstan. Biomass chemical composition and fractional analysis of stem juice show prospective use of the crop for forage, food syrups, and bioethanol.

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INTRODUCTION

The agricultural sector occupies most of Kazakhstan, about 2 million km^2, which makes up 77% of the sector's area and employs 25% of its labor resources (Fernandez *et al*., 2020). However, the majority of cultivated lands sit in Northern Kazakhstan. With a geographical position in the continent center, Kazakhstan has a climate with piercing variability. Meteorological conditions are characteristically lacking moisture (up to 350 mm of precipitation per year), heat deficit, and a short frost-free period (Karatayev *et al.*, 2022).

Moisture is an essential and viable factor limiting crop cultivation in the region. Long-term past field analysis strongly correlated Kazakhstan's precipitation and crop yields (Kariyeva *et al.*, 2012). Against increasing climate aridization, the traditional maize (*Zea mays* L.), a silage crop, provides insufficient stable yields in Northern Kazakhstan (Salikhov *et al.*, 2018). The maize's high demand for moisture and soil fertility makes its cultivation costly and decreases livestock farming profitability (Getachew *et al.*, 2016). Introducing less popular cultures that are genetically resistant to environmental stress factors is one of the possible solutions to these problems (Avetisyan *et al.*, 2020).

Among such crop plants, sweet sorghum (*Sorghum bicolor* L.) is a distinctly more drought-resistant plant than maize crops (Zegada-Lizarazu *et al.*, 2012). Tolerance to drought conditions is due to the origin of sorghum from the arid lands of Southern Africa and Eastern Asia. After being domesticated in the Savanna of Eastern Sudan in 4000 BC, sorghum's introduction in more than 100 countries with diverse climatic conditions prevailed (Venkateswaran *et al.*, 2019; Nasiyev *et al.*, 2021). A unique feature of sweet sorghum is its multi-purpose use, i.e., as feed for farm animals, foodstuffs, and biofuels (Maftuchah *et al.*, 2022).

Sorghum is a C4 plant with high photosynthetic activity. Based on the climatic conditions, it can generate even more biomass than maize (Xie and Xu, 2019). Moreover, the silage made from sweet sorghum is also equal in nutritional value to maize forage. With the high water-soluble sugar concentration in the stem juice and the simplicity of its extraction, sweet sorghum is a promising potential source of raw materials for producing bioethanol (Mathur *et al*., 2017). Past research indicated that in sorghum stem juice, the water-soluble sugar content greatly varies, ranging from 7% to 21% (Jia *et al*., 2013; Vinutha *et al*., 2014).

Bioethanol has a first-generation (1G) biofuel classification produced through alcoholic fermentation (Bertrand *et al*., 2016). It serves as engine fuel in its pure form or blended with gasoline to reduce the environmental load and improve the octane rating. Sarsenbaev *et al.* (2013) studies revealed the bioethanol obtained from sweet sorghum by fermentation grown in Southeast Kazakhstan had the scheme "Stem biomass – juice – syrup – bioethanol." The estimated yield per 1 ha amounts to 1,260 L. Up to 8000 L of ethanol can come from 1 ha of sweet sorghum, about twice as much as the potential yield of ethanol obtained in maize crops.

Furthermore, improved methods of sugar solution purification allow the use of sweet sorghum syrup for food purposes (Hryhorenko *et al*., 2021). Sorghum syrup is not harmful and contains various nutrients and antioxidants (McGinnis and Painter, 2020). Unlike sugars in sugarcane and sugar beets, mainly sucrose, sorghum syrup also contains soluble starch, glucose, and fructose (Appiah-Nkansah *et al*., 2019). Sorghum has higher proportions of glucose and fructose, rich minerals and phenolics, and good antioxidant properties than sugarcane syrup (Asikin *et al.*, 2018). These qualities make sweet sorghum syrup more advantageous for producing beverages and food products, including dietary and children's meals (Sadikova and Dodaev, 2020).

In the Northern Kazakhstan regions, one of the vital factors hampering the introduction of sweet sorghum is the limited high-yielding cultivars and hybrids obtained from the local selection. For sorghum breeding and seed production in Kazakhstan, the only institution involved is in the Almaty region, southeast of the country (Zhapayev *et al*., 2023). The southeast climate allows for cultivating late-ripening sorghum genotypes notable for their massive habitus and higher productivity (Baiseitova *et al*., 2021). However, the late-maturing sorghum genotypes have insufficient time to mature before autumn frosts in the Northern regions. Sorghum harvest should begin at the milky-wax ripeness stage to obtain a better dry matter (DM) concentration and silage quality (Qu *et al*., 2014). The early-maturing sorghum genotypes have fewer studies in Northern Kazakhstan, which constitutes the relevance of this study. In this connection, the goal of the potential research was to assess the productivity and biochemical composition of the biomass of sugar sorghum cultivars and hybrids created in climatic conditions similar to those in Northern Kazakhstan and to determine the sector of their use in this region.

MATERIALS AND METHODS

The experimental plot sat in the moderately humid and warm agricultural zone of the Akmola region in Northern Kazakhstan. Agrometeorological conditions considered data from the weather station in Kokshetau, located close to the experimental plot. The research covered the years 2020–2022.

The meteorological conditions of this agricultural zone are sharply continental. According to the Meteorological Station, Kokshetau, Kazakhstan, the spring observed with rapid soil warming ranged from +18 °C to +22 °C, with the return of subzero temperatures recorded according to average annual data in the last days of May. In autumn, short-term frosts (-3 °C to -5 °C), according to the average yearly data, come in the first 10 days of September, then replaced by a long period with active temperatures. Heavy precipitation in the first 10 days of July was also a natural phenomenon.

The soils of the experimental fields comprised medium-humus and medium-loamy ordinary chernozem, with the thickness of the arable horizon (20–22 cm). The soils were low in phosphorus and high in potassium, typical for the prime zonal soils of this agricultural zone. The easily hydrolyzed nitrogen, phosphorus, and potassium contents were 153.0, 16.7 mg/kg, and 666.0 mg/kg, respectively, with humus at 4.6% and soil pH of 7.5–7.6.

Meteorological conditions

Relative to average summer conditions, the 2020 crop season was relatively arid based on generally accepted criteria (Figure 1). Dry

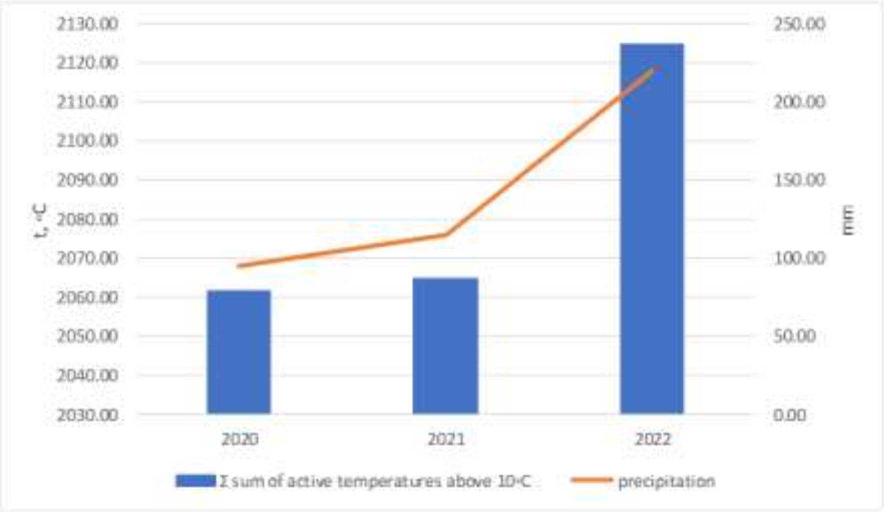

Figure 1. Hydrothermal conditions in 2020–2022 (meteorological station in Kokshetau).

conditions were most intense in May and June, and the precipitation from May 25 to June 30 was only 4.5 mm. However, the productive moisture reserves in the pre-sowing period were sufficient to obtain better sprouts and rooting. Across the entire vegetation period, rainfall amounted to 89.6 mm, including 51.8 mm in July. The sum of active temperatures (above +10 °C) for the sowing-harvesting period was 2063.8 °C, below the long-term average. The first autumn frost recording on September 9 is the day the harvest commenced.

In 2021, the steady warming of the soil to biologically active temperatures was notable at the end of May, with sowing on May 26. Generally, the crop season was dry, relatively cold, and more prolonged than the previous year. With a comparatively late soil warming and the onset of stable active temperatures in May, the sum of active temperatures during the growing season of sweet sorghum remained at the level of the previous year due to the arrival of a warm front with effective temperatures in September and a moderately late onset of autumn frosts, the first of which was on September 21. The timing of the harvest coincided with this date. On precipitation timing, 2021 also matched the previous year's summer months. Maximum precipitation (44.1 mm) was evident in the first 10 days of July.

The 2022 vegetation period was distinct from previous years by having more uniform and abundant precipitation, especially in July, with more than half of summer rainfall. The first short-term frost down to -3 °C occurred on September 23, much later than the average multiyear date. Thus, the vegetation period extended and exceeded the mean long-term level of active temperatures. In general, 2022 had better precipitation during the growing season. Data analysis suggested that the hydrothermal conditions during 2020–2022 were of typical nature in this agricultural zone.

Seed material

The sweet sorghum genotypes promising for Northern Kazakhstan require total active temperatures from 1,900 °C to 2,500 °C to reach milky-wax ripeness for silage harvesting. These genotypes have early-maturing, mid-early, and mid-maturing classifications. Specimens with longer growing seasons appeared not suitable for cultivation in the agroclimatic resources of this region. The nine sweet sorghum genotypes selected for testing succeeded in development under similar climatic conditions. The sweet sorghum cultivars Kapital, Volonter, Chaika, Sakhara, Flagman, Sevilia, and Volzhskoe 51, and hybrid Kalibr attained production at the Russian Research and Design-Technological Institute of Sorghum and Corn (Saratov, Russian Federation). The sweet sorghum hybrid, Slavianskoe Priusadebnoe (SP), approved for cultivation in the Akmola region, served as a standard for comparison (All-Russian Research Institute of Sorghum and Soybean, Rostov-on-Don, Russian Federation). The State Register of Breeding Achievements has no Kazakh sweet sorghum cultivars registered in the Akmola region.

Research procedure

All the sweet sorghum experiments ran on soil plots with a weed-free predecessor. The plot area was 28.0 m^2. In the experiments, the repetition of the randomized plots was threefold. Sowing used a hand seeder. The sowing method was wide-row sowing with a 70-cm row spacing. Yield accounting followed a continuous weighting method across all the plots in all experiments per hectare. The dry biomass weight measurement engaged drying weighted samples in a desiccator at 65 °C. The biochemical analysis of the dry matter proceeded in the certified laboratory, Agro Complex Expert. The mass fraction of the protein's estimation analyzed the total nitrogen content in the sample and the crude protein by the calculation method, using the coefficient 6.25, with the same process applied to crude ash, fiber, and fat content (Baidalin *et al.*, 2017).

Estimating the nutritional value of feed measured the gross and metabolizable energy. Calculating the total energy content in the dry matter of the feed followed the formula based on the chemical analysis of the feed.

$$\text{GE MJ/kg} = 23.95 \times CP + 39.77 \times CF + 20.05 \times CFb + 17.46 \times NFE$$

Where: CP – crude protein (kg), CF – crude fat, CFb – crude fiber, NFE – nitrogen-free extractives (NFE=100%-CP-CF-CFb-CA), and CA – crude ash.

Next, metabolizable energy (ME) calculation used the following equation:

$$\text{ME MJ/kg} = \frac{0.73 \times GE}{DM} \times (DM - CFb \times 1.05)$$

Where: GE – gross energy and DM – dry matter content.

Sugar content measurement by refractometry used a refractometer model IRF-454B2M. Taking three samples in each replication happened before harvesting. Stem juice extraction came from 4 to 5 internodes of the core stem. Glucose, fructose, and sucrose contents' analysis by liquid chromatography used a Shimadzu LC-20AD Prominence chromatograph with a refractometer detector. The eluent used was a mixture of CH_3CN and H_2O (80%:20%), the flow rate was 0.5 ml/min, the injected sample volume was 10 µl, the column temperature was 40 °C, and the column Nucleodur - 5 µm, 110 Å, 4.6×150 mm (Macherey-Nagel). The procedure utilized the isocratic mode. The concentration of compounds' detection by absolute peak area calibration compared the peak area of the analyte with the peak area of a standard analyte sample of known concentration. Analytical expressions of the correspondence between the monosaccharide and its peak area concentration on the chromatogram reached establishment. The calibration graphs showed the linear dependence of the peak area on the monosaccharide concentration.

Statistical analysis

Statistical processing of experimental data is advanced using the AgCStat software package integrated into Microsoft Excel. The variability of biochemical analysis values resulted from calculating the mean, the coefficient of variation (V%), and the standard error $S\bar{x}$. Identifying significant differences between the variants by yield appeared by calculating the least significant difference (LSD_{05}), recognized as relevant at a 5% level.

RESULTS

The results of formulating the green mass (GM) yield of different sweet sorghum cultivars appear in Table 1. The cultivar Volzhskoe 51 stood out in the experimental results, even exceeding the standard cultivar (SP) by 23.3% on average, with the lowest deviation in 2020 (7.8%) and the highest in 2021 (58.9%). This contrast can be due to the responsiveness of this cultivar to improving climatic conditions during the vegetation period compared with the standard. In particular, in the intense dry year of 2021, cultivar Volzhskoe 51 had about an equal yield as in the previous year and a more favorable year.

The sweet sorghum hybrid Kalibr also became distinct by biomass productivity, forming a biomass yield higher than the standard by 7.8%–28.6%. The average sugar sorghum yield was 15.5 t/ha in 2020, while 12.2 t/ha and 13.71 t/ha in 2021 and 2022, respectively. In 2021, the lower biomass yield can refer to insufficient rainfall in spring and in the first half of summer. The sorghum cultivars, viz., Kapital, Chaika, Sakhara, and Flagman, provided stable productivity. The maximum difference among the rates of different years in these cultivars was 1.95–3.17 t/ha. Significant differences in yield were evident between the sorghum cultivars Volonter (10.66–15.48 t/ha) and Sevilia (8.69–13.08 t/ha), amounting to 4.82 and 4.39 t/ha, respectively.

Table 1. GM yield of sweet sorghum, t/ha (2020–2022).

Genotype	2020	2021	2022	Mean	Deviation from St.
SP (st)	17.35	10.95	14.35	14.22	
Kapital	12.33	10.72	13.59	12.21	-2.01
Sevilia	13.08	9.62	8.69	10.46	-3.76
Chaika	15.00	12.16	14.11	13.76	-0.46
Volzhskoe 51	18.92	17.40	16.26	17.53	+3.31
Volonter	15.48	10.66	11.15	12.43	-1.79
Kalibr	18.70	14.08	15.55	16.11	+1.89
Sakhara	14.30	12.24	15.41	13.98	-0.24
Flagman	14.28	12.36	14.31	13.65	-0.57
F_{05}	7.39	24.27	2.58	7.41	
LSD_{05}	2.57	1.40	7.46	2.28	

Table 2. Chemical composition of sweet sorghum genotypes, % (2020–2022)

Genotype	Crude protein	Crude fat	Crude fiber	Crude ash	NFE	Ca	P	Ca:P
SP (st)	5.12	1.66	24.30	5.83	63.12	0.47	0.28	1.68:1
Kapital	6.13	2.27	22.10	6.02	63.46	0.44	0.32	1.38:1
Sevilia	5.88	2.79	21.10	4.66	65.58	0.31	0.3	1.03:1
Chaika	5.90	2.46	20.90	6.04	64.73	0.52	0.29	1.79:1
Volzhskoe 51	6.74	2.84	22.90	5.42	62.07	0.39	0.35	1.11:1
Volonter	5.61	2.42	23.90	5.76	62.31	0.36	0.49	0.73:1
Kalibr	5.07	2.67	23.50	5.78	62.94	0.46	0.31	1.48:1
Sakhara	5.39	2.36	22.80	5.43	64.02	0.37	0.29	1.28:1
Flagman	6.33	2.58	23.50	6.12	61.48	0.37	0.42	0.88:1
Mean	5.80	2.45	22.80	5.67	63.3	0.41	0.34	–
V, %	9.6	14.4	5.3	8.0	2.1	16.2	21.0	–
$S\bar{x}$	0.19	0.12	0.40	0.15	0.44	0.02	0.02	–

Studying the raw protein in the biomass of sweet sorghum revealed its amount varied from 5.07% to 6.74% (Table 2). The average crude protein content was 5.80%. The protein content measurement depended on the vegetation conditions. The highest protein in the studied collection was apparent in the cultivar Volzhskoe 51 (6.74%), which was 31.6% higher than the standard (SP). The highest content (above 6%) was also indicative in the sorghum cultivars Flagman and Kapital. Hybrid Kalibr was at the standard level of this parameter. However, the variability of this characteristic across the sorghum genotypes was low (V = 9.6%).

In sorghum biomass, the fat content reached 1.66% to 2.84%. Among the studied sorghum cultivars, the variability for fat averaged at V = 14.4%. However, the highest fat amount occurred in the biomass of cultivar Volzhskoe 51 (2.84%), which was 71.1% higher than the standard genotype SP. The optimal share of the crude fibers established in the presented study ranged from 20.9% to 24.3%, based on the sorghum genotypes, with a lower variability (V = 5.3%). However, the highest percentage of fibers emerged in the standard cultivar, SP (24.3%), with the lowest demonstrated by the sorghum cultivar Chaika (20.9%).

In the biomass of various sorghum genotypes by years, the range of crude ash content was from 4.66% to 6.12%. The cultivar Flagman gave the highest ash content, whereas the lowest was with the cultivar Sevilia. The standard hybrid SP had an ash content of 5.83%, while the parameter variability was low (V = 8.0%). The average nitrogen-free extractives (NFE) content for the study period varied from 61.48% to 65.58% in the sweet sorghum biomass. However, the lowest NFE content was visible in the sorghum cultivar Flagman, with the highest NFE demonstrated by Sevilia. The average NFE content across the examined cultivars and hybrids was 63.30%. Sorghum genotypes revealed nonsignificant differences for NFE, and the variability of the genotypic values was low (V = 2.1%).

The calcium content varied from 0.31% to 0.52% in the green biomass, and the average parameter variability was V = 16.2%. The leading sorghum cultivar for calcium content was Chaika, while the lowest amount resulted in the cultivar Sevilia. The phosphorus content ranged from 0.28% to 0.49% among the studied sorghum cultivars and hybrids. However, the highest phosphorus content was apparent in the Volonter cultivar, with the lowest value in the standard cultivar SP. Among the sorghum cultivars, the variability of the average phosphorus values was high (V = 21.0%). The Ca:P ratio was closer to 1.5:1, detected in the sorghum hybrids SP and Kalibr and the cultivars Kapital and Chaika (1.38:1 to 1.79:1). Low calcium versus phosphorus values emerged in the sorghum cultivars Volonter and Flagman (0.73 and 0.88:1, respectively).

For dry matter (DM), the metabolizable energy (ME) content reached 9.67–10.34 MJ/kg, and in green mass (GM), the said range was 2.66–3.51 MJ/kg (Table 3). The value of ME per unit area ranged from 36.17 to 58.94 GJ/ha. A higher accumulation of gross and metabolizable energy per unit area and yield was evident in the sorghum cultivar Volzhskoe 51 and hybrid Kalibr. However, the lower values came from the cultivars Volonter and Sevilia. The gross energy (GE) ranged from 65.15 to 106.34 GJ/ha.

Table 3. Bioenergetic evaluation of sweet sorghum genotypes (2020–2022).

Genotype	Metabolizable energy content per 1 kg, MJ		Accumulation of metabolizable energy, GJ/ha (DM)	Accumulation of gross energy, GJ/ha
	DM	GM		
SP (st)	9.67	2.66	38.19	70.21
Kapital	10.02	3.29	40.19	71.72
Sevilia	10.34	3.51	37.02	65.14
Chaika	10.19	3.12	43.21	75.8
Volzhskoe 51	10.08	3.33	58.94	106.34
Volonter	9.83	2.89	36.17	66.15
Kalibr	9.88	3.20	52.09	94.77
Sakhara	9.98	3.13	43.62	78.56
Flagman	9.89	3.11	42.63	77.52
Means	9.99	3.14	43.56	78.47

Table 4. Sugar content in stem juice (2020–2022).

Genotype	2020	2021	2022	Means	Deviation from st
SP (st)	12.36	12.76	9.33	11.48	
Kapital	16.12	15.67	14.60	15.46	+3.98
Sevilia	14.24	17.11	15.67	15.67	+4.19
Chaika	12.39	13.84	10.13	12.12	+0.64
Volzhskoe 51	13.11	14.96	12.77	13.61	+2.13
Volonter	13.64	12.57	12.67	12.96	+1.48
Kalibr	12.49	14.98	12.43	13.30	+1.82
Sakhara	14.31	16.67	13.90	14.96	+3.48
Flagman	15.09	14.80	11.53	13.81	+2.33
Means	13.75	14.82	12.56	13.71	
V, %	9.54	10.59	16.2	10.55	
$S\bar{x}$	0.44	0.52	0.68	0.48	

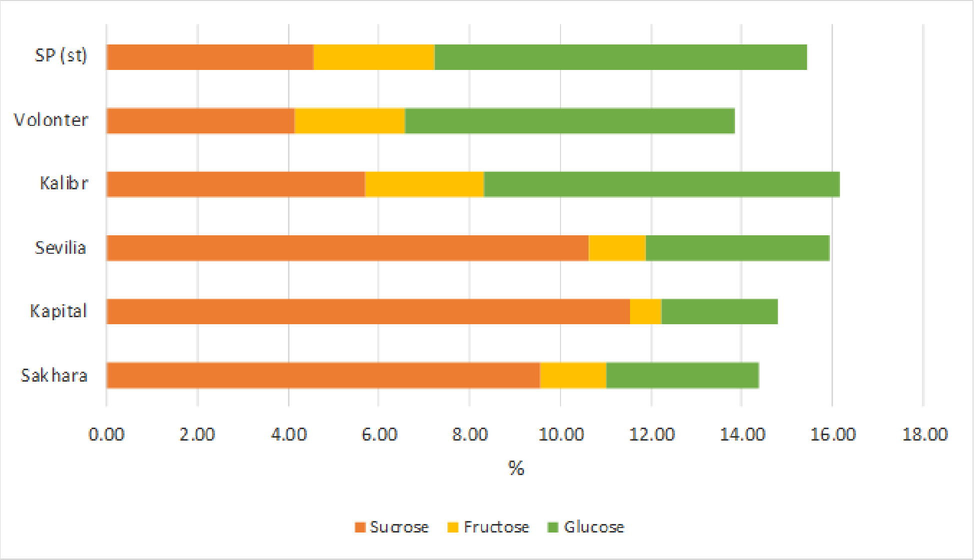

Figure 2. Fractional composition of stem juice sugar, 2021.

In the sorghum cultivars and hybrids, the average sugar content varied from 11.48% to 15.67% in the stem juice, with the highest value observed in the cultivar Sevilia and the lowest in the standard hybrid SP, and the difference between these genotypes was 3.98% (Table 4). On sugar content in the stem juice in 2020–2022, the leading sorghum cultivars were Sevilia (15.67%), Kapital (15.46%), and Sakhara (14.96%). However, the cultivars Volzhskoe 51, Flagman, Volonter, Chaika, and the hybrid Kalibr had values close to 12.12% to 13.61%. With the higher sugar content yield in stem juice, these promising sorghum cultivars attained recommendations for producing sugar-containing products and bioethanol.

The sweet sorghum genotypes selected for the high-performance liquid chromatography were the cultivars Volonter, Sevilia, Kapital, Sakhara and the hybrids Kalibr and SP. Cultivar Kapital was notable with the highest sucrose content (11.54%) and low monosaccharides content (0.68%), fructose (0.60%), and glucose (2.58%) (Figure 2). Given the predominance of the disaccharide in sorghum stem juice, this cultivar can be productive for processing into sugar-containing products and bioethanol. The predominance of sucrose content was also prominent in the sorghum cultivars Sevilia and Sakhara. The standard hybrid SP has a fractional composition opposite that of the cultivar Kapital. The standard has almost twice the sucrose as in Kapital, and the glucose was 72.8% higher. Furthermore, the standard has the highest fructose content (2.66%). The values close to the standard hybrid were visible in the sorghum hybrid Kalibr and the cultivar Volonter, which also had a lower sucrose proportion than glucose and fructose. With superior sugar compositions, these sorghum cultivars can also efficiently produce dietary syrups. The mean values of these parameters were highly variable, i.e., sucrose (V = 42.34%), fructose (V = 44.48%), and glucose (V = 44.85%).

DISCUSSION

The feed value detection is primarily by its crude protein content, which includes nitrogen-containing compounds made up of combinations of 20 different amino acids (Nasiyev *et al.*, 2022). The crude protein requirement of the animals depends on several factors, i.e., dairy cows require 13% to 16% crude protein in the DM of their diet (Imaizumi *et al.*, 2010). The research results for raw protein content in the sorghum biomass were similar, coming from different countries with varying genotypic traits. In their ecological study, Yücel and Erkan (2020) reported a protein content of 4.08% to 5.22%, depending on the sweet sorghum genotypes. Research of a collection of sweet sorghum in the USA showed higher variability for protein content, ranging from 0.6% to 8.0% (Stefaniak *et al*., 2012).

Fats are another essential component of the animal diet. Fats are esters of fatty acid glycerides and act as energy and heat sources in the body. Fat content in the diet of dairy cattle averages 3%–5%. In the presented study, the variability of fat indices corresponds to the results obtained by past researchers in cultivating sweet sorghum in different agroclimatic conditions. For example, in China, Li *et al*. (2021) reported that the crude fat content in the biomass of the sweet sorghum cultivar LiaoTian-1 averages 2.05% (in inflorescences – 2.63%, in leaves – 2.53%, and in stems – 0.98%). A study of the fodder qualities of local sweet sorghum cultivars cultivated in Bulgaria demonstrated a crude fat yield of 2.30% to 2.39% (Enchev, 2021).

Fiber is an indispensable component of the animal diet, especially for ruminant animals. Fiber promotes better digestion and normalization of gut functions and contains vitamin B. However, the high fiber content can have a negative effect on the flavor and digestibility of feed. The industry standard for silage in Kazakhstan states that the crude fiber content for class 1 should be no more than 28%. All the sorghum genotypes studied in this research also did not surpass this raw fiber level. Fiber content conditioning has many factors, viz., genotypes, harvesting phase, and mineral nutrition levels. For example, the tests in Pakistan showed the crude fiber content in seven sorghum genotypes ranged from 29.05% to 31.50% (Ayub *et al*., 2012). In Sudan, the unrefined fiber content in 11 sorghum cultivars scored from 32.0% to 45.0% (Ahmed *et al*., 2019).

Ash content is another indicator of interest in the feed. Crude ash indicates the mineral contents, which can be endogenous or exogenous. Endogenous (internal) minerals appear in the composition of plants, such as, calcium, phosphorus, potassium, and magnesium. These minerals have nutritional value for animals. In contrast, exogenous minerals are external pollutants, i.e., particles in soil, sand, and dirt. Ash content over 10% typically points to the feed as polluted. The prevailing results also fall within the safe range. In addition, assessments of the crude ash content in sorghum biomass in other geographic regions also showed similar values. In Indonesia, the raw ash content in four sorghum genotypes amounted to 8.25% to 9.11% (Harmini *et al*., 2022). A comparison of the chemical composition of self-pollinated and hybrid sorghum lines in India showed the crude ash content ranged from 10.0%±1.2% to 13.0%±1.6% (Singh *et al*., 2022).

As noted earlier, exogenous minerals, such as calcium, are nutritionally valuable to animals. The required content of calcium in cow diets is 0.18% for DM. In addition to calcium, beneficial minerals in plants include phosphorus. Phosphorus is often comparable with calcium because the two minerals work together in bone formation. Approximately, 80% of the body's phosphorus exists in bones and teeth. Feed specialists recommend 0.22%–0.28% phosphorus in ruminant diets. Based on these data, all the sugar sorghum genotypes in the studied collection cover the animal’s calcium and phosphorus requirements. An equally important aspect is the calcium-to-phosphorus ratio. For ruminants, the recommended Ca:P ratio ranged from 1.5:1 to 2:1. However, most of the studied sorghum genotypes comply with the balance of 1.5:1.

The increase in NFE content in fodder, which occurs as plants grow and age, caused a reduction in the digestibility of nutrients (Blokhina, 2014). Analysis of literary sources reveals similar data on the amount of NFE recorded by researchers in other ecological zones. In the Volga region of Russia, in the sorghum cultivar Volzhskoe 51, the NFE content was 63.4% (Zhuzhukin and Garshin, 2016). In Japan, the amount of NFE in chopped plants was 53.1%, sorghum silage was 48.5%, and as a standard, scientists indicate a value of 57.0% (Sun, 2010).

Therefore, a recommendation to evaluate the nutritional quality and balance of feeds by gross (GE) and metabolizable (ME) energy yield is necessary. The metabolizable energy concentration in the feed, calculated in MJ and GJ according to the International System of Units, is of considerable importance in farm animal feeding (Kutuzova *et al*., 2021). Studies suggested that energy yield per unit area of sweet sorghum in regions with differing bioclimatic potential depends mainly on the genetic makeup of the genotypes. For example, Duborezov *et al*. (2022) concluded that an alternative to maize is sweet sorghum close to maize based on metabolizable energy content in DM and yield per unit area but higher in sugar content.

Comparing the present and past findings revealed a low accumulation of saccharides. It can correlate with the deficit of active temperatures, which is a limiting factor for heat-loving crops in the northern regions of Kazakhstan. Kapustin *et al*. (2022) recorded a positive correlation between saccharide content and air temperature. The accumulation of sugars by plants depends on various factors, such as, climatic conditions, genotypic characteristics, field operations, and agricultural engineering (Reddy *et al*., 2014; Rifka *et al*., 2020). Depending on the di- and monosaccharides contained in the sorghum juice, it is possible to recommend specific genotypes for further processing. Producing glucose-fructose and high-fructose food syrups recommends using sorghum genotypes with high monosaccharide content. In turn, the sorghum genotypes with predominant sucrose are more desirable for processing into crystalline sugar or bioethanol since the fractional composition of the sugars is unnecessary for technical production.

Sweet sorghum can form a high biomass yield with less heat and moisture. An influential factor is selecting cultivars and hybrids with a short vegetation period. Assessing the sorghum biomass biochemical components indicated that the cultivars high in protein are Volzhskoe 51, Flagman, and Kapital (over 6%). The leader by fat content in the biomass is the cultivar Volzhskoe 51 with 2.84%, compared with just over 2% in most other genotypes. The optimal percentage of raw fiber is gainful for all genotypes, meeting quality standards. Crude ash values do not exceed 10%, which proved optimal by world standards. The cultivar Chaika stood out with a calcium content of 0.52%, with the highest phosphorus content in Volonter (0.49%). The Ca:P ratio close to the norm is evident in the hybrids SP and Kalibr and the cultivars Kapital and Chaika. The content of NFE is within the norm for all the studied genotypes. The best nutritional value due to the accumulation of gross energy per unit area emerged from the cultivar Volzhskoe 51 (106.34 GJ/ha) and the hybrid Kalibr (94.77 GJ/ha). On metabolizable energy content per 1 kg, the genotypes displayed nonsignificant differences. Assessment of total sugar content by refractometry showed the highest content of water-soluble sugars in the core stem juice from genotypes Sevilia (15.67%), Kapital (15.46%), and Sakhara (14.96%).

CONCLUSIONS

The study of fraction composition by high-performance liquid chromatography of stem juice samples allows for determining further processing directions. High sucrose content paired with low monosaccharide amounts is evident in the sweet sorghum cultivars Kapital, Sevilia, and Sakhara, making them more suitable for producing crystalline sugar and bioethanol. The hybrids SP and Kalibr and the cultivar Volonter are higher in monosaccharides, which are preferable for healthier food syrups production. Proceeding from the study of accumulated sugars, different sorghum cultures attained recommendations for varying uses, such as silage mixed with hard-to-silage crops and producing sugars and ethanol in Northern Kazakhstan. Finally, the highlighted genotypes of sweet sorghum are the best source materials for developing local cultivars.

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