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Bioethanol Producing from Sorghum Crops

Valentina Gamayunova*, Lyubov Khonenko, Oleg Kovalenko

Mykolaiv National Agrarian University

54008, 9 Georgiy Gongadze Str., Mykolaiv, Ukraine

Abstract. The relevance of the article lies in a comprehensive analysis of the trend in the production of biofuels from crop products in Ukraine and other countries of the world. The purpose of the research was to justify on the basis of research by both their own and many authors that sorghum varieties are extremely important in cultivation due to changes in soil and climatic conditions. When conducting research, we used generally accepted methods, techniques and DSTU, in particular: the method of comparison, analysis and synthesis, laboratory and field. Computer methods of information processing and visualization of research results using the Microsoft Office program were also used. According to the results of research, it was found that with less favorable temperature conditions and moisture supply in 2020 yr., grain sorghum crops formed a yield depending on the hybrid in the range of 2.1-6.9 t/ha, in a more favorable year for these indicators in 2021 yr. it was at the level of 6.9-14.5 t/ha, and on average for two years it was in the range of 4.5-10.7 t/ha. Performance stability was determined in the U 60117 IG and Bianca hybrids. On average, over two years, the theoretical yield of biofuels, depending on the hybrid, ranged from 2216 up to 5199 l/ha with a starch content in the grain of more than 75%. The highest estimated alcohol yield per unit area was in the grain sorghum hybrid U 60116 IG, which combines a stable yield (10.7 t/ha) with a high starch content in the grain (75%). Treatment of sugar sorghum crops with biologics and microfertilizers had a positive effect on the yield of structural units per hectare: compared to the control, the yield of leaves during organic balance processing increased by 2.66 t/ha, the yield of panicles – by 1.56 t/ha, and stems – by 3.64 t/ha. The increase in the conditional yield of sugars relative to the control of treatment with Quantum microfertilizers was 0.354 t/ha, organic balance – 0.417 t/ha, and with their combined action – 1.143 t/ha, which was the maximum value

Keywords: grain sorghum, sugar sorghum, yield, starch yield, biofuel yield, energy efficiency

INTRODUCTION

In recent years, due to the increase in the population, the expansion of large cities and rising living standards, the demand for traditional energy resources has been growing, which in turn leads to increased global pollution, reduction of natural resources and productive areas, as well as the extinction of certain plant and animal species [1]. At the same time, the use of non-traditional and renewable energy resources, in particular bioethanol can significantly mitigate the negative effects associated with increased fossil energy production [1-3].

Bioethanol is a refined ethyl alcohol made from biomass or raw ethyl alcohol for use as biofuels. It is usually classified as a first-generation biofuel. The main advantage of bioethanol over gasoline as an energy source is its relatively low cost and the absence of harmful emissions into the atmosphere. For the production of bioethanol, agricultural crops with a high sugar or starch content are used [4]. The addition of bioethanol to gasoline increases the oxygen content, which makes it to achieve more complete combustion of gasoline, while reducing CO_2 emissions [5].

Among the many crops which are suitable for the production of bioethanol, one of the most promising crops is sorghum, which has a high photosynthetic efficiency and it can form a powerful energy biomass in a short time [6]. Sorghum, in particular, can also be grown in meadows and pastures, where it is capable of producing high levels of yields. In addition, a small seeding rate and later sowing dates make sorghum an indispensable insurance crop.

A special feature of this crop is its high drought resistance, which is quite important for arid areas of the steppe zone, where other cereals greatly reduce the

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yield [7; 8]. The emergence of modern varieties and hybrids of sorghum with fundamentally new characteristics regarding the content of sugar-containing substances, effective use of their genetic potential require improving the system of selection and rational placement in a certain soil-climatic zone, taking into account biological characteristics, adaptability, agroecological plasticity and reaction to growing conditions [9; 10].

LITERATURE REVIEW

Biofuels are usually obtained from plant or animal biomass, which provides a viable energy source a number of studies have shown that energy plants can reduce greenhouse gas emissions [11]. According to foreign researchers [12], the most common biomass for fuel production is corn, wheat, sugar cane, sugar beet and sorghum.

These sources provide great potential for both replacing conventional fuels and reducing polluting emissions. Due to the increasing global demand for alternative energy types, the prospects for growing sorghum varieties have been increasing in recent years. In addition, sorghum crops are highly adaptable to drought, high air temperatures and soil salinity. These characteristics make the crop ideal, especially in changing climatic conditions and a suitable raw material for sustainable biofuel production [7; 13].

However, its yield varies depending on the variety or hybrid, growing conditions (soil, water, climate, pests and diseases, etc.) and elements of agricultural technology [14-16]. At the same time, compared to corn and sugar beets other agricultural crops, sorghum uses significantly less moisture and nutrients due to the favorable combination of its agrotechnical and technological characteristics [7; 10]. Sorghum requires an average of 300 parts of water per unit of dry matter, wheat – 515, barley – 545, sugar beet – 470. Sorghum consumes 300 kg of water for the formation of 1 kg of dry matter, and corn consumes 388 kg, which makes it one of the best raw materials in the production of biofuels [17].

Sorghum contains the huge share of energy (65-75%) in substances which are easily converted to ethanol. In sugar sorghum, this substance is a sugar complex in the juice of the stem, and in grain sorghum it is starch. The starch yield from grain sorghum (70-74%) is significantly higher than that of corn (67-72%). If stems and grain are used for the production of bioethanol, its volume can reach 7.000 liters per year per hectare [18].

In the United States, sorghum is one of the main crops from which bioethanol can be produced, and its yield is 25-30% higher than that of corn and wheat. As for sorghum in Ukraine, the production of this crop allowed our state to enter the top ten producing countries in the world, but in terms of export volume, according to estimates of the US Department of Agriculture, Ukraine is one of the first in the world out of five major exporters [19; 20].

Now for the production of biofuels at agricultural biogas plants, corn silage is most widely used [13; 21], the main advantage of which over other substrates is that it guarantees stable production of biogas and methane, it greatly facilitates the dosage of the substrate into the fermentation chamber and it stabilizes the operation of the cogeneration plant.

Due to the warming climate, corn growing areas are decreasing and sorghum is becoming an alternative crop for the production of biofuels and biogas. Sorghum is more resistant to drought than corn, and its biomass yield is higher in years with low rainfall. Sorghum is more tolerant of changing environmental conditions, and its production is less energy-intensive compared to corn [22]. This is an extremely important factor, since energy crops must have a positive energy balance, that is, they are characterized not only by high biomass yields, but also by low energy costs associated with technological operations for cultivation.

According to G. Popova [23], sorghum, as an energy and fodder crop, is of significant practical interest for agriculture in general and especially for arid regions of Ukraine. It exceeds the level of yield of corn and is able to provide high yields in this zone. The positive properties of sorghum culture include the fact that it is unpretentious to soil fertility.

The introduction of innovative sorghum cultivation technologies is important not only in the agronomic aspect, but also from an economic point of view. In recent years, intensive sorghum cultivation technologies based on the use of low-molecular synthetic heterocyclic compounds derived from various classes have attracted considerable attention as effective and environmentally friendly substitutes for phytohormones and traditional plant growth regulators. The main advantages of using these compounds in agricultural practice are their wide specificity of action on various types of agricultural plants and high physiological activity at low concentrations (10^{-8M}-10^{-12M}) compared to phytohormones or their synthetic analogues, which show physiological activity at higher concentrations – 10^{-4M}-10^{-6M}. The use of synthetic compounds in low concentrations prevents environmental pollution in comparison with chemical mordants and existing plant growth regulators, which are used in significantly higher concentrations and have a longer half-life [24].

Now one of the directions of increasing the productivity of field crops, in particular sorghum, restoring fertility and improving the soil is mycorization. As established by studies [25], inoculation of sorghum seeds (8 g/kg) with a mycorrhizal fertilizer preparation of American production Bioarsenal contributed to an increase in grain yield by 0.6-0.8 t/ha.

In the last decade, the United States, Australia, Canada and Brazil, as well as Ukraine, have started introducing the technology of introducing biochar – activated charcoal from agro-biomass (sorghum, corn, hemp and energy perennials) into the soil since 2021. This organic substance is chemically neutral, is able to absorb and retain moisture and nutrients well, absorb and neutralize harmful chemicals, reduce the acidity of the soil (increasing pH from 3.9 to 5.1) and increase the accumulation of carbon in it [26]. Depending on the soil and climatic conditions, the efficiency of the biochar varies [27].

Further research of the proposed technological solutions is a climate-oriented innovative agricultural technology for growing sorghum crops using biotechnological alternatives and biologically active nanomaterials.

Growing sorghum on an optimal nutritional background increases both productivity and the main indicators of economic efficiency, in particular, the growth of production and the level of profitability [8; 21; 28].

The purpose of the study is an analytical review of the world production of bioethanol and the feasibility of growing the most productive varieties and hybrids of sorghum crops in the Southern steppe of Ukraine in order to switch from traditional energy sources to renewable ones, to analyze bioenergy opportunities and prospects for their use for the effective development of the country's agricultural sector.

MATERIALS AND METHODS

Field research was conducted in 2020-2021 yrs at the experimental sites of the Educational, Scientific and Practical Center of the Mykolaiv National Agrarian University. The area of the sown area is 90 m^2, the accounting area is 25 m^2, and the repetition rate is three times. The climate is continental, it is characterized by sharp and frequent fluctuations in annual and monthly air temperatures, significant heat reserves and aridity. Soil-southern heavy loamy slightly saline chernozem.

Its predecessor is winter wheat. Agricultural cultivation techniques are generally accepted for the Southern steppe zone of Ukraine. After harvesting, the plant residues were treated with Ecostern stubble biodestructor (1.5 l/ha) with the addition of urea 5.0 kg/t of straw at a working solution consumption of 300 l/ha, they were earned with a heavy disc harrow BDT-7 to a depth of 12-14 cm. In autumn, plowing was carried out (25-27 cm). In spring, $N_{30}P_{30}K_{30}$ (2 centners/ha of nitroammofoski) was applied for cultivation. Sorghum was sown in the second decade of May with a row spacing of 70 cm with a domestic Klen-2.8 seed drill.

Seed treatment of Advanta Seeds sorghum hybrids was carried out before sowing with Quantum microfertilizer (4.0 l/t) and organic balance battery preparation (1.0 l/t). During the growing season (the tillering phase and the release of plants into the tube), the crops were fed with a mixture of these preparations (4.0 l/ha Quantum + 1.0 l/ha Organic balance). Sugar sorghum seeds were not processed, only top dressing of crops was carried out according to the experiment scheme in the tillering phase and the beginning of stemming with Quantum microfertilizer (4.0 l/ha), Organic balance (1.0 l/ha) both separately and together. Before the 3-5-leaf phase, crops were treated with the herbicide Pik (15-20 g/ha), and Karate Zeon insecticide (0.2 l/ha) was used against aphids if the harm threshold was exceeded. The density of plants for the harvesting period was 120 thousand/ha for grain sorghum, 130 thousand/ha for sugar sorghum. The yield was determined from the accounting area of the plot, followed by its recalculation per hectare.

2020 yr. was a dry year with 240 mm of precipitation during the growing season, which is 89% of the long-term average. Average daily temperatures from January to July 2020 were significantly higher than the long-term average. Spring was early, but prolonged. From the second half of summer to the beginning of autumn 2020, there were prolonged droughts with little precipitation and high temperatures. For almost the entire growing season of sorghum in 2021yr., including during critical periods of crop growth and development, on the contrary, the water regime was optimal – precipitation provision was 163% of the average annual norm.

The calculation of the economic efficiency of sorghum varieties was carried out using standard technological maps developed for the Southern steppe of Ukraine. When planning and conducting research, we were guided by generally accepted guidelines and manuals [29; 30]. For detailing the object and subject of the research, theoretical and methodological generalization of the obtained results, the abstract method is applied, in particular its techniques – induction and deduction, analysis and synthesis. The main research methods were: field experiments to determine the impact of technology on the growth and development of sorghum plants; laboratory, in which the sowing qualities of seeds, the chemical composition of raw materials, the content of starch and sugars in plants were determined; mathematical and statistical, dispersive – to assess the reliability of experimental data; calculation-comparative – to establish the economic and bioenergetic efficiency of the studied factors.

RESULTS AND DISCUSSION

The global biofuel market replaces 2.32-5.0% of oil consumption, using more than 71 million hectares of arable land. The world production of biofuel in 2018 was 154 billion liters. In the context of biofuels, ethanol production is higher than biodiesel. The main producers of ethanol are the United States (2018: 54% share), the main raw material is corn, and in Brazil (2018: 30% share), the main raw material is sugar cane [31].

One of the key global levers for reducing CO_2 pollution from transport is the development of the biofuel market. However, in 2020 yr., due to the coronavirus pandemic in the United States, the production and consumption of ethanol tended to decrease. Global biofuel production fell to 151 billion liters in 2020, down 6% from 161 billion liters in 2019, according to an annual report published by the International Renewable Energy Agency (IRENA). Bioethanol production fell by 8%, while biodiesel production was relatively stable. In 2020, the US and Brazil remained the leading global producers of bioethanol, accounting for a combined 83% of global production [32].

In 2021/2022 MR, due to unfavorable weather conditions and a smaller area of plantations, the production of ethanol from sugar cane decreased, in particular in Brazil by 10% – to 26.78 billion liters, but ethanol produced from corn increased by 15% – to 3.47 billion liters [33].

Ethanol is produced from a variety of raw materials, especially agricultural products such as corn and straw in the United States and China, sugar cane pulp and straw in Brazil, and molasses in India. About 80% of the world's ethanol production is used as fuel, while the rest (20%) is used for industrial purposes. Almost 60% of ethanol is produced from corn, 25% from sugar cane, 7% from molasses, 4% from wheat, and the rest from other cereals, such as cassava and sugar beet. The share of second-generation non-food ethanol production is insignificant (0.4%, 0.4 billion liters/year), although it is expected in the EU and US countries it is expected to increase significantly in the future and may double by 2023 yr. [34].

Raw materials for use are determined by the climatic conditions of a given country or region. It was found that the production of ethanol from sugar cane is 50-60% cheaper than from corn. In our opinion, in 2021-2022, the difference between the costs of growing these crops and the production of bioethanol from these raw materials in connection with the increase in the price of energy carriers had a growing tendency. According to [35], the cultivation of sugar cane requires less chemicals, in particular pesticides and fertilizers, and the production of bioethanol from it provides the highest energy balance and reduces the cost of fuel produced by six times compared to corn, especially in South American countries. It is expected [34] that by 2029, sugar cane production will increase by 25%, while corn production will decrease by 14%. It was also determined that in economic terms, sugar cane was the best option compared to crops such as corn or sugar beet, but significant government support could increase the competitiveness these cultures, especially in the EU and the United States, which explained why the United States became the world's largest producer of ethanol.

Pro-Consulting conducted a study of the alcohol and bioethanol market, which presented the main trends, capacity, dynamics and structure in the alcohol and bioethanol market in Ukraine and the EU [36].

The European biofuel industry is mainly limited to two separate sectors: such as bioethanol and biodiesel, which do not rely on the same raw materials for fuel production. In the EU, bioethanol is produced mainly from cereals and sugar beet derivatives. Wheat is used in Northwestern Europe, while corn is used in Central Europe and Spain. The use of sugar beet covers France, Germany and Belgium [5]. Today, in Europe and in the world, the processes of starting the production of second-generation bioethanol, which is obtained from non-food cellulose raw materials, such as wood, grass energy crops, straw, corn, etc., are becoming increasingly [37]. In 2020, the EU, according to USDA estimates, produced 25 million liters of cellulosic bioethanol. In post-Soviet countries, cereals and potatoes were traditionally used for the production of ethyl alcohol at various times. However, during this period, the production of bioethanol from sugar-containing material had the lowest cost (Table 1).

Table 1. *Efficiency of bioethanol production from various raw materials in post-Soviet countries*

Raw materials	Volume of production from the area 1 ha, m^3	Cost dollars/m^3
Sugar beet	2.5-3.0	300-400
Sugar cane	3.5-5.0	160
Corn	2.5	250-400
Wheat	0.5-2.0	380-400
Potatoes	1.2-2.7	800-900
Sugar sorghum	3.0-5.0	200-300

Source: *[18]*

A comparative analysis of various types of raw materials for the production of ethanol shows that it is the cheapest for the use of sugar cane as 160 dollars for 1 m^3, for sugar sorghum it is 200-300 dollars and for corn grains it is 250-400 dollars per 1 m^3.

Sorghum is a valuable biological raw material for the production of ethanol. From 1 ton of sorghum grain, you can get 650-700 kg of starch or 300-350 liters of alcohol, which is 35 liters more than from 1 ton of corn. Calculations [20] have determined that existing varieties and hybrids of sugar sorghum can provide sugar production at the level of 2.8-3.0 t/ha on non–irrigated land and 4.5-5.0 t/ha on irrigated land. Due to the fact that sugar beet is practically not grown in the south of Ukraine, sorghum can significantly replenish sugar reserves.

In Ukraine, more than 4 million hectares of land are concentrated, which, due to degradation and salinization, it is advisable to withdraw from intensive cultivation [13].

Calculations prove that [18] about 200 tons of sugar can be obtained from an area of 100 hectares of sugar sorghum (with an average green mass yield of 30.0 t/ha and 18% sugar content). In some years, it is quite possible to get up to 100 tons of green mass from 1 ha of sugar sorghum without watering. Ukraine has existing capacities and schemes for processing this biomass for feed, food and energy needs.

In Ukraine, it is most appropriate to place sugar sorghum in the southern and eastern zones of the country, since the area of sugar sorghum cultivation for syrup production is limited by the temperature potential. The high sugar content in plants accumulates only in the southern zone of Ukraine, where the average annual sum of active temperatures exceeds 2800-3000°C. [18; 20]. When a smaller amount of temperatures is set, the rate of sugar accumulation decreases. In the years of research (2020-2021 yrs.), the sum of positive temperatures as of August 31st was in the range of 3171-3334°C. A peculiar distribution of heat and moisture during the year and growing season was noted in 2020 yr. In ten months, only 320.2 mm of precipitation fell, which was by 60 mm less than the long-term average. In addition, the distribution of precipitation throughout the year was extremely uneven. The main part of precipitation fell by mid-summer, in the period from the second decade of May to the second decade of June (Table 2).

Table 2. *Agrometeorological conditions for conducting research according to the NNPC MNAU weather station*

Month	Average monthly rate air temperature, °C			Average monthly rate amount of precipitation, mm			Average monthly rate air humidity, %		
	2020 yr.	2021 yr.	Average perennial	2020 yr.	2021 yr.	Average perennial	2020 yr.	2021 yr.	Average perennial
January	0.39	-1.13	-3.6	24.2	67.0	25	85.98	92.72	84
February	2.65	-1.25	- 3.0	52.8	33.4	21	85.21	88.49	81
March	6.98	3.01	2.3	9.8	26.8	23	67.31	80.31	77
April	9.26	7.88	9.6	5.0	47.0	30	52.21	77.68	67
May	13.93	14.95	16.3	49.2	61.6	40	70.13	77.80	64
June	21.88	20.20	19.9	90.2	104.8	67	69.01	80.76	62
July	24.13	24.79	22.9	28.4	82.6	47	52.52	65.0	59
August	23.08	23.27	22.0	7.0	19.0	37	48.55	60.48	60
September	19.54	15.36	16.9	36.6	32.4	28	54.81	61.63	66
October	14.73	9.32	10.8	39.6	48.4	35	81.77	69.03	74
November	4.43	5.72	3.8	1.6	39.2	27	85.69	91.86	85
December	3.79	2.70	1.3	17.2	47.0	29	91.57	91.67	87

Source: *compiled according to the author's research*

Weather conditions in 2021 were more favorable in terms of temperature conditions and providing crops with moisture. Analysis of the weather conditions of the study years, as noted above, showed that they were quite contrasting and significantly differed from the long-term average parameters, which affected the productivity of the studied hybrids of sorghum grain selection Advanta Seeds (Table 3).

Table 3. *Yield of sorghum hybrids of grain selection Advanta Seeds, t/ha*

Name of hybrid	Yield		Average for two years
	2020	2021	
ADV G 1329	3.2	7.3	5.3
Yankee	5.8	9.6	7.7
Sentinel	2.4	7.8	5.1
Bianca	6.1	13.3	9.7
MR Eclipse	4.3	8.5	6.4
MR Bazley	2.1	6.9	4.5
U 60116 IG	6.9	14.5	10.7
U 60117 IG	6.3	13.8	10.1
HIP_{05}, т/га	0.45	0.74	

Source: *compiled according to the author's research*

Calculations of the theoretical yield of alcohol from hybrids of sorghum grain selection Advanta Seeds, studied by us during 2020-2021 yrs. in the experimental field of the Scientific, Educational and Practical Center of the Mykolaiv National Agrarian University, are shown in Table 4.

Table 4. *Grain yield, starch content and theoretical alcohol yield from grown products of Advanta Seeds sorghum hybrids (average for 2020-2021 yrs.)*

Hybrid, sample	Grain yield, t/ha	Starch content, %	Theoretical* alcohol yield from 1 ha, l
ADV G 1329	5.3	74	2541
Yankee	7.7	74	3691
Sentinel	5.1	76	2511
Bianca	9.7	75	4713
MR Eclipse	6.4	76	3151
MR Bazley	4.5	76	2216
U 60116 IG	10.7	75	5199
U 60117 IG	10.1	75	4907

Note: ** – the theoretical yield of anhydrous alcohol from 1 ton of starch was 71.98 dcl.*
Source: *compiled according to the author's research*

The hybrid of grain sorghum U 60116 IG, which combined a constant yield (10.7 t/ha) simultaneously with a high starch content in the grain (75%), was determined to be the most optimal in terms of ethanol yield per unit area (5199 l/ha). Research also found that depending on the background of nutrition, sugar sorghum hybrids were able to accumulate sugars in the stems in different ways. The highest indicator was formed according to the variants of the experiment in the phase of milk-wax ripeness of grain by a hybrid Medoviy (Table 5).

Table 5. *The content of total sugars in sugar sorghum stalks in the phase of milk-wax ripeness of grain, depending on the studied factors (average for 2020-2021 yrs), %*

Foliar top dressing * (factor B)	Variety/hybrid (factor A)			Average by Factor B	Average by research
	Silo 700 D (St)	Medoviy	Troistiy		
Control	14.1	15.5	15.4	15.0	15.5
Qu	14.3	15.9	15.8	15.3	
OB	14.5	15.7	15.6	15.3	
OB + Qu	14.9	17.1	16.7	16.2	
Average by factor A	14.5	16.1	15.9	**15.5**	

Note: ** – Qu – microfertilizer Quantum; OB – preparation Organic Balance; OB+Qu – joint use of the preparation Organic Balance and microfertilizers Quantum*
Source: *compiled according to the author's research*

The increase in the sugar content in the stems, compared to the control, when treated separately with Quantum microfertilizer or Organic Balance preparation averaged 0.2% and 0.4% over the years of research, respectively, and the combined use of Organic Balance and Quantum microfertilizer as 0.8 %. It was found that to a greater extent this indicator depended on the genetic characteristics of the sorghum-hybrid composition.

An integral indicator which characterizes the efficiency of growing sugar sorghum for energy purposes is the yield of biofuels (bioethanol, biogas, solid biofuels) and energy yield [1; 32]. According to literature sources, as well as the results of research conducted at the Institute of Bioenergetic Crops and Sugar Beet (IBC&SB), it was found that the juice from sugar sorghum stalks contained on average about 15% dry matter, of which 13% was sucrose, 1% was monosaccharides and 1% of other dry substances (starch, minerals) [17; 31]. Thus, bioethanol from sugar sorghum juice is produced mainly from sucrose. The bioethanol yield can be calculated using the formula (1):

$$M = \frac{U \bullet n \bullet S \bullet b \bullet k}{100} \quad (1)$$

where, M – yield of bioethanol from 1 ha of sugar sorghum, t/ha; U – yield of stems, t / ha; n – juice yield factor, n=0.5; S – total sugar content in juice, %; b – the yield factor of bioethanol from sucrose, b=0.53; k – the factory yield coefficient of bioethanol, k=0.9.

To calculate the yield of bioethanol, it is proposed to use the formula of alcoholic fermentation:

$$C_{12}H_{22}O_{11} + H_2O = 4C_2H_5OH + 4CO_2 \quad (2)$$

According to the formula, the yield of bioethanol from sucrose is 53%, the remaining 47% is carbon dioxide. Therefore, the coefficient b, which characterizes the yield of bioethanol from sucrose, which dominates the juice of sugar sorghum stalks, is 0.53. With modern processing technologies in plants, bioethanol losses are assumed at the level of 9...15%, so the coefficient of factory yield K is proposed to be taken as 0.9. Juice from sugar sorghum stalks is obtained mainly using roller presses. The juice yield is about 50% (i.e., n=0.5) of the stem yield, or 75% of the moisture available in the stems. According to the results of research, the indicators of conditionally calculated ethanol yield for the cultivation of sugar sorghum against the background of joint top dressing of crops with Organic Balance and Quantum microfertilizer are shown in Table 6.

***Table 6.** Yield and sugar content in stem juice and theoretical alcohol yield from sugar sorghum (average for 2020-2021 yrs.)*

Variety, hybrid	Yield of stems, t/ha	Sugar content in the juice of the stems, %	Alcohol yield from 1 ha, l	
			by methodology IBC&SB	Theoretical*
Silo 700 D (st)	25.0	14.9	1789	2194
Medoviy	49.3	17.1	2412	4965
Troistiy	37.9	16.7	1811	3728

Note: ** – the theoretical yield of anhydrous alcohol from 1 ton of invert sugar is 58.9 dkl*
Source: *compiled according to the author's research*

To determine the energy yield from bioethanol obtained from one hectare of sugar sorghum crops, it is necessary to multiply the calculated mass of bioethanol by its energy intensity according to Formula 3:

$$Em = M \cdot em \tag{3}$$

where, Em – energy output, Gj/ha; M – bioethanol yield from 1 ha of sugar sorghum, t/ha; em – energy intensity of bioethanol, Gj/t (25 Gj/t).

Thus, from 1 ha of sugar sorghum sowing with a stem yield of 25-49.3 t/ha and a juice sugar content of 14.9-17.1%, you can get from 1.8 tons up to 5.0 tons of bioethanol, which is equivalent to 45 to 125 Gj of energy.

According to the definitions [13; 16], this indicator may be significantly higher in sugar sorghum as an energy raw material compared to other agricultural crops used for the production of alternative energy sources.

The coefficient of energy efficiency of sugar sorghum cultivation in the MNAU National Research Center also depended on the studied factors (Table 7).

***Table 7.** Coefficient of energy efficiency of sugar sorghum cultivation depending on the studied factors (average for 2020-2021 yrs.)*

Foliar top dressing* (factor B)	Hybrid (factor A)			Average by factor B	Average by research
	Silo 700 D (St)	Medoviy	Troistiy		
Control	5.6	8.9	8.3	7.6	7.9
Qu	6.0	9.2	8.9	8.0	
OB	6.0	9.2	8.9	8.0	
OB+Qu	5.9	9.0	8.9	7.9	
Average by factor A	5.9	9.1	8.7	7.9	

Note: ** – Qu – microfertilizer Quantum; OB – preparation Organic Balance; OB+Qu – application of the preparation Organic Balance and microfertilizers Quantum*
Source: *compiled according to the author's observations*

Indicators of the energy efficiency coefficient in our studies ranged from 5.6 up to 9.2. On average, for two years of cultivation, this indicator was 2.8-3.2 units of hybrids Troistiy and Medoviy was higher compared to the Silo 700 d variety. when processing crops with microfertilizer Quantum, the energy efficiency coefficient increased by 0.4 units, with Organic Balance it increased by 0.4, and when processing both of these preparations together it increased by 0.3.

According to the results of research by G.M. Kaletnik, the domestic market of bioethanol can reach 800-1200 thousand tons per year, as provided that it replaces 10-15% of the hydrocarbon part of gasoline consumed in Ukraine [3; 19]. The European Space has even greater potential for bioethanol exports. The export of transport ethanol may become a serious source of currency and an environmentally friendly energy commodity of Ukraine on the international fuel market in the future.

Currently, the world has the necessary production potential and developed technologies that make it possible to produce technical hydrolyzed alcohol. However, hydrolysis technologies are based on the use of sulfuric acid, which is why they are environmentally harmful. It is necessary to improve existing technologies for obtaining transport ethanol and develop modern more environmentally friendly ones. Moreover, from an energy and economic point of view, grain ethanol surpasses all types of fuel from raw materials, and ethanol obtained from biomass is the next significant step forward. Therefore, it is necessary to search for new biologically safe raw materials sources of sucrose and starch. In this regard, interest in sorghum (grain and sugar) crops will constantly grow.

CONCLUSIONS

The duration of droughts is one of the most serious problems of the impact of climate change on agriculture, both at the regional and global levels. As one of the best solutions to this problem is the selection of crops which are characterized by high yields and drought resistance. Such a crop is sorghum, which has many advantages in terms of cultivation, storage, threshing, use for food preparation and biofuels.

According to the results of variety testing of hybrids of sorghum grain selection Advanta Seeds, it was found that on average for two years their yield of hybrids ranged from 4.5 t/ha up to 10.1 t/ha. During 2021 yr., the weather conditions were more favorable, which made it possible to form a harvest of 6.9 up to 14.5 t/ha. The maximum yield was provided by the U 60116 IG hybrid as 14.5 t/ha, it was also determined to be high in the U 60117 IG and Bianca hybrids, while the yield was lower in other hybrids studied. The best hybrid in terms of ethanol yield per unit area (5199 l/ha) was identified as grain sorghum U 60116 IG, which combined a high yield (10.7 t/ha) with a simultaneously high starch content in the grain (75%).

Sugar sorghum, as a promising bioenergetic crop, is able to form high and stable yields of raw materials under extreme growing conditions, favorably distinguished by drought resistance, salt tolerance, and economical consumption of moisture. This crop can provide a stable base for bioenergy in the conditions of the Southern steppe of Ukraine. From 1 ha of sugar sorghum crops with a stem yield of 25-49.3 t/ha and a juice sugar content of 14.9-17.1%, you can get from 1.8 tons up to 5.0 tons of bioethanol, which is equivalent to 45 to 125 Gj of energy.

Research with sorghum culture should be continued and deepened. After all, every year there are new drugs, varieties and hybrids, as well as changes in climate and soil fertility.

You should also take into account the results of recent scientific research, including on Nanotechnologies, which were obtained in Ukraine and other countries of the world. Carry out their production verification and enter them. This will significantly increase the area of grain growing and thereby ensure Ukraine's energy independence.

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Виробництво біоетанолу із соргових культур

Валентина Василівна Гамаюнова, Любов Григорівна Хоненко, Олег Аналолійович Коваленко

Миколаївський національний аграрний університет
54008, вул. Георгія Ґонґадзе, 9, м. Миколаїв, Україна

Анотація. Актуальність статті полягає в комплексному аналізі тенденцій виробництва біопалива з продукції рослинництва в Україні та інших країнах світу. Метою досліджень було на основі досліджень як власних, так і багатьох авторів обґрунтувати виняткову важливість сортів сорго у вирощуванні у зв'язку зі зміною ґрунтово-кліматичних умов. При проведенні досліджень використано загальноприйняті методи, методики та ДСТУ, зокрема: метод порівняння, аналізу та синтезу, лабораторний та польовий. Також використовувалися комп'ютерні методи обробки інформації та візуалізації результатів дослідження за допомогою програми Microsoft Office. За результатами досліджень встановлено, що за менш сприятливих температурних умов та вологозабезпеченості у 2020 р. посіви сорго зернового формували врожайність залежно від гібриду в межах 2,1–6,9 т/га, у більш сприятливий рік за цими показниками у 2021р. вона була на рівні 6,9–14,5 т/га, а в середньому за два роки – в межах 4,5–10,7 т/га. Стабільність продуктивності визначали у гібридів U 60117 IG та Б'янка. У середньому за два роки теоретична врожайність біопалива залежно від гібриду коливалася від 2216 до 5199 л/га при вмісті крохмалю в зерні понад 75%. Найвищий розрахунковий вихід спирту з одиниці площі мав гібрид зернового сорго U 60116 IG, який поєднує стабільну врожайність (10,7 т/га) з високим вмістом крохмалю в зерні (75%). Обробка посівів цукрового сорго біопрепаратами та мікродобривами позитивно вплинула на врожайність структурних одиниць з гектара: порівняно з контролем урожай листя за органобалансової обробки підвищився на 2,66 т/га, урожай волоті – на 1,56 т/га. /га, а стебла – на 3,64 т/га. Приріст умовної врожайності цукрів відносно контролю за обробки мікродобривами Квантум становив 0,354 т/га, органічного балансу – 0,417 т/га, а за їх сумісної дії – 1,143 т/га, що було максимальним значенням

Ключові слова: зернове сорго, цукрове сорго, урожайність, вихід крохмалю, вихід біопалива, енергоефективність