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Evaluation of collection specimens of guar (*Cyamopsis tetragonoloba* L.) by economically valuable traits

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Abstract. For effective introduction of guar into production, it is necessary to use varieties adapted to the Southern Steppe of Ukraine, the creation of which is impossible without well-researched collection material, which is relevant and important. Guar is in high demand globally in the food and oil industries, and most importantly, thanks to its ability to symbiotically fix nitrogen, it improves soil quality in a cost-effective and natural way. However, it is a completely new culture for Ukraine. The purpose of this study was to investigate the gene pool of guar plants and identify the best ones with economically valuable traits. The study used field, laboratory, and statistical methods. The results of the study conducted in 2020-2022 helped to identify the best introduced guar samples in terms of tolerance to hot temperatures and the arid climate of the Southern Steppe of Ukraine. The most adapted to this zone are IU07466 Haldi bhati and IU074658 Pusa Naubahar. They formed the maximum yields: IU07466 Haldi bhati – 262.5 g/m^2, IU074658 Pusa Naubahar – 329.0 g/m^2, which is more than 135% compared to the standard. The above-mentioned samples were characterised by a vegetation period of 133.5 days and 129.5 days, respectively, which, on average, over two years of research, exceeded the duration of the "germination – maturation" period of the standard variety IU074657 Ankur by 4.5-8.5 days. The correlation and regression analysis of the data obtained from the study of the introduced samples of the guar gene pool suggested a direct correlation between the weight of seeds per square metre and the number of beans and seeds per plant. The correlation coefficient is 0.997-0.986, respectively. It is recommended to use the identified sources of valuable traits for further effective implementation in the breeding and

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research programmes of scientific institutions to create self-pollinated lines, synthetic populations, varieties adapted to the extreme conditions of the Southern Steppe of Ukraine

Keywords: guar; plant gene pool; length of the growing season; adaptability; productivity

INTRODUCTION

The almost complete destruction of the irrigation system during the war poses a challenge for farmers to introduce crops that are not watered or require minimal irrigation water in the southern region of Ukraine. One of these annual legumes, which is gaining great popularity in the world, is guar (*Cyamopsis tetragonoloba* L.). To grow guar in the south of the country, suitable varieties are required. S. Ismail *et al*. (2019), A. Alshameri *et al*. (2019) argue that guar is relatively drought-resistant compared to many other crops and is well adapted to arid and semi-arid climates with high temperatures, tolerant of saline soils. It is grown in India, Pakistan, the USA (Texas and Oklahoma), Sudan, and Australia. Like other legumes, guar is used in the national economy. M. Shakir *et al*. (2020) indicated that guar cake, similar to soybean meal, is a separate additive to animal food due to its high crude protein content of about 480 g/kg dry matter.

Demand for the crop is growing rapidly around the world due to the use of guar gum in industrial applications such as paper and textiles, ore flotation, explosives, and the oil industry for hydraulic fracturing of oil and gas formations. Q. Zhu *et al*. (2019) note that gum is used to produce about 300 industrial products. R. Kuhns & G. Shaw (2018) report that guar gum is the main derivative of guar, it is obtained from the seeds of the plant *Cyamopsis tetragonoloba* of the *Leguminosae* family. D. Sandhu *et al*. (2021) found that it is a natural high molecular weight polysaccharide, also known as the natural stabiliser E412, an excellent emulsifier, viscosity regulator, and emulsion stabiliser, which is useful for controlling many health problems such as diabetes, heart disease, and colon cancer. Due to its gel-forming properties, guar gum reduces cholesterol and glucose levels.

Recent studies by B. Acharya *et al*. (2022) and D. Sandhu *et al*. (2022) have shown that guar gum can be produced at lower prices than imported gums and produce lower greenhouse gas emissions than existing crops. Given the widespread use of guar and its products in the national economy and the high purchase prices, Ukraine should not be dependent on its imports, considerably saving currency assets. However, this requires having varieties adapted to the region where the crop will be sown. According to Ukrainian scientists R. Vozhegova *et al*. (2022a), the main requirements that breeders have for growing guar in a particular zone are early maturity, productivity, and quality indicators of guar. F. Gresta *et al*. (2018) emphasise that the duration of the ripening period of some guar genotypes can be longer than 160 days, and therefore this should be factored in. S. Thapa *et al*. (2018) recommend sowing guar in crop rotation because of its ability to symbiotically fix nitrogen, improving soil quality in a cost-effective and natural way.

J. Singh *et al*. (2021) claim that 350-400 mm of rainfall during the growing season is sufficient for growing guar. In addition, A. Garcia *et al*. (2023) report that guar can also be implemented in regions with low precipitation (under 400 mm). According to R. Vozhegova *et al*. (2022b), the weather conditions in the southern zone of Ukraine are similar to those where guar is grown: on average, 300-350 mm of precipitation falls per year, with fluctuations over the years from 250 to 650 mm, and the sum of effective temperatures above 10°C is 3,200-3,400°C. Therefore, the study of the guar gene pool and the selection of the best economic traits will allow them to be used to create new varieties, and short-stemmed varieties are suitable for these purposes. Considering the analysis of the above sources, the purpose of this study was to investigate the adaptability of guar collection samples to the natural and climatic conditions of the Southern Steppe of Ukraine and to identify the sources of valuable traits.

MATERIALS AND METHODS

The examination of the collection of new guar samples, their in-depth research in the irrigation conditions of the Southern Steppe of Ukraine and preservation of their authenticity in the face of climate change was a planned research work during 2020-2022 under the state applied task: "To investigate guar samples to create varieties with their further implementation and use in production". The study was conducted at the Breeding Department of the Institute of Irrigated Agriculture of the National Academy of Sciences of Ukraine (now the Institute of Climate-Smart Agriculture of the National Academy of Agrarian Sciences of Ukraine). The subject of the study was the introduced collection samples of guar IU074657 Ankur, IU074658 Pusa Naubahar, IU074659 Maharandi, IU074660 Sheetal, IU074661 Haldi bhati, IU074662 Aryan, IU074663 Tindal, obtained for the study from the National Centre for Plant Genetic Resources of Ukraine. The best samples were submitted for registration to the National Centre for Plant Genetic Resources of Ukraine as valuable samples in terms of morphological, biological, and economic characteristics.

The soil of the experimental plot is dark chestnut medium loamy, with a topsoil containing 2.0-2.2% of total humus, 1.8 mg/kg of nitrate nitrogen, 32.3 mg/kg of mobile phosphorus and 251.0 mg/kg of potassium.

The limiting factor in technological support is insufficient rainfall during the growing season. The specificity of the zone also lies in the rather severe effects of air drought during dry days. Therefore, growing guar in the Southern Steppe zone of Ukraine is possible only under irrigation conditions.

The agrotechnical conditions of the experiments are generally accepted for southern Ukraine (Goloborodko & Kokovkhin, 2014). Its predecessor – winter wheat. 100 kg/ha of ammonium nitrate was applied for pre-sowing cultivation. Sowing was carried out in the first decade of May, when the soil temperature at a depth of 5 cm was 18-20°C. Samples of the collection nursery were sown in single-row plots 5 m long at 100 kg/ha without repetition. The guar variety IU074657 Ankur was used as a standard. After sowing, Hortus herbicide (2 l/ha) was applied to the soil surface. In June, postemergent herbicide Picador was applied (1 l/ha). Between June and September, the area was irrigated 3 times at 400 m^3/ha.

To characterise the weather conditions, the study used data from the Kherson Agrometeorological Station located near the experimental field. The weather conditions during the years of research were typical for the southern region of Ukraine, which facilitated an objective assessment of the introduced material, selection of the best samples by morphological, biological, and economic characteristics (Figs. 1, 2, 3).

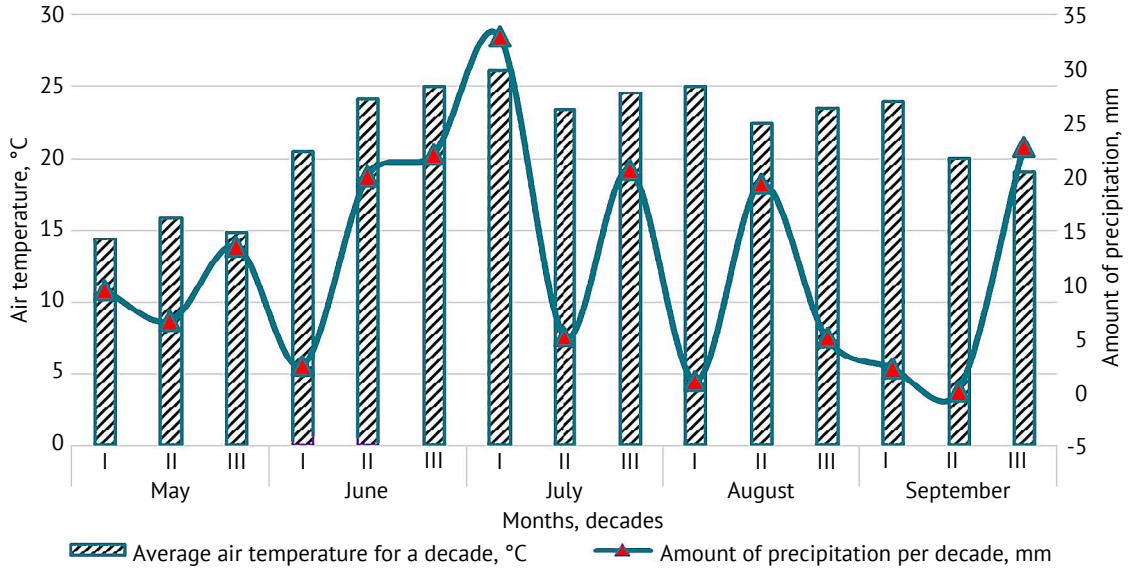

***Figure 1**. Trends in air temperature (°C) and precipitation (mm), 2020*
***Source:** compiled by the authors of this study*

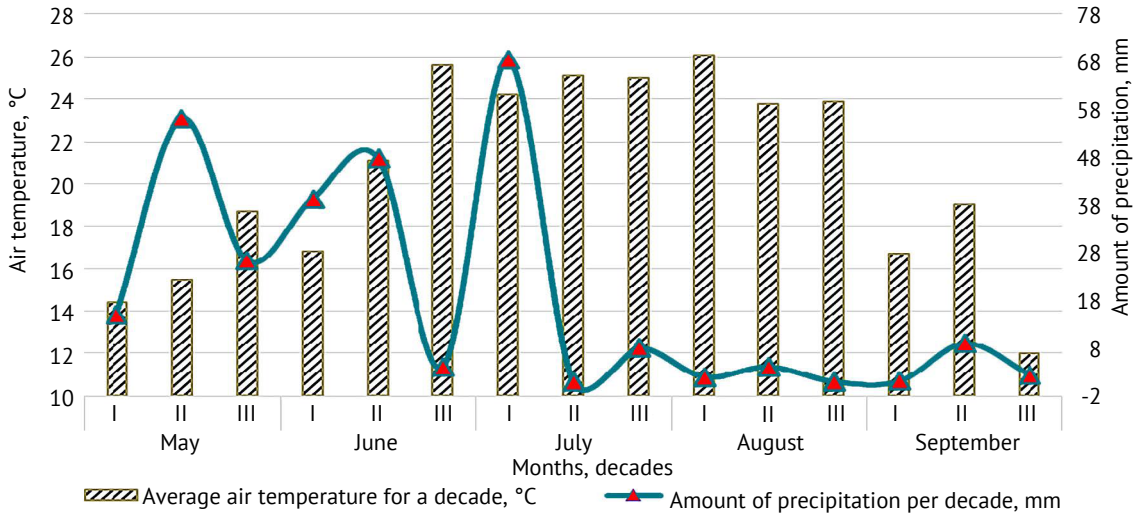

***Figure 2**. Trend in air temperature (°C) and precipitation (mm), 2021*
***Source:** compiled by the authors of this study*

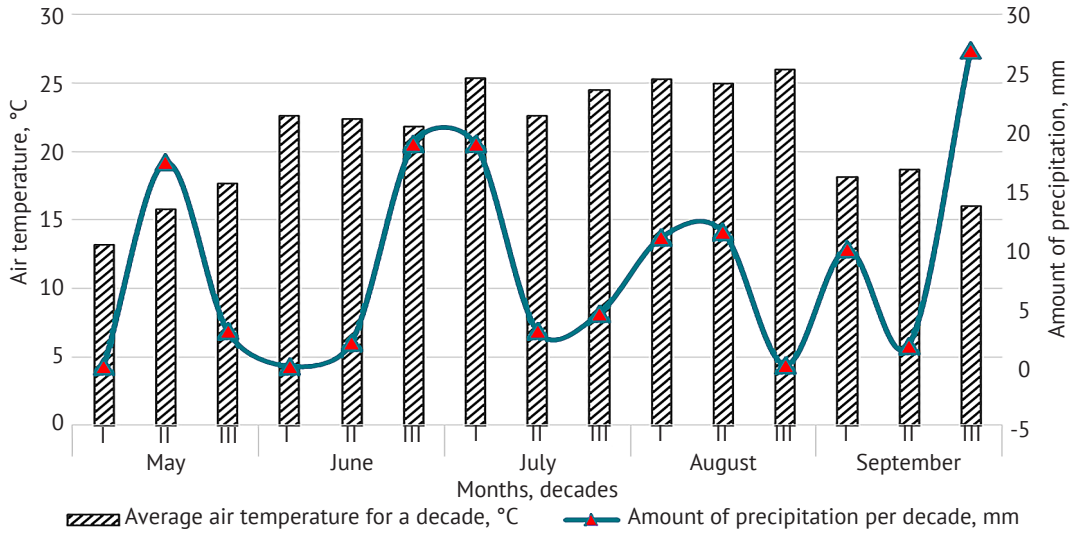

***Figure 3**. Trends in air temperature (°C) and precipitation (mm), 2022*
***Source:** compiled by the authors of this study*

Observations and records were kept during the study (Kobyzieva *et al.*, 2014). The duration of the growing season was determined according to the description of the periods and phenological phases of growth and development of guar plants. The beginning of the phase was considered to be the presence of at least 15% of plants, and 75% of plants were considered to have the full phase (Volkodav, 2001). In the phase of full ripeness in the field, 10 registered plants were measured for plant height and the height of the lower bean attachment above the soil level. The final indicator of such accounting is the average plant height and the height of the lower bean attachment. Once ripe, the guar plants were harvested by hand. Elements of the guar harvest structure were determined according to the methodology of the state variety testing by test sheaves taken from an area of 1 m^2 (Volkodav, 2001). In laboratory conditions, the structural analysis was evaluated according to the following main quantitative traits: "number of beans", "number of seeds" per plant according to the Broad Unified Classifier of the genus *Glycine max*. (L.) Merr. (Kobyzieva *et al.*, 2014).

The seed yield was measured by individual weighing from each plot at the stage of harvest ripeness. After weighing, an average sample of seeds was taken from each plot, followed by determination of their moisture content in the laboratory and conversion to 14% moisture content (Goloborodko & Kokovkhin, 2014). The harvest from each plot was brought to 14% moisture content using formula (1):

$$X = \frac{Ax(100-B)}{100-14}, \quad (1)$$

where X is the grain yield at 14% moisture content t/ha; A is the grain yield without adjustment for moisture content t/ha; B is the grain moisture content at harvest, %.

Statistical analysis of the experimental data and determination of linear correlation coefficients were performed according to the methodology of Goloborodko and Kokovkhin (2014).

RESULTS AND DISCUSSION

According to M. Mahdipour-Afra *et al.* (2021), V. Mealing and A. Landis (2021), the length of the guar growing season is 60-90 days for determinate and 120-150 days for indeterminate varieties. A study of the guar collection in 2020 showed that in the arid climate of the Southern Steppe of Ukraine, some varieties had a longer growing season than soybeans. The shortest, 120 days, was observed in samples Maharandi IU074659, Sheetal IU074660, Tindal IU074663. Under the conditions of 2020, not all the beans formed on the plant ripened in the samples Pusa Naubahar IU074658 and Haldi bhati IU07466, the duration of the growing season of which was 130 days (Table 1).

***Table 1**. Characterisation of guar samples by morphological and biological traits, 2020*

Sample name and registration number	Growing season, days	Height, cm		Quantity, pcs./plant		Seed weight, g	
		plant	lower bean attachment	beans	seeds	per 1 m^2	% to standard
IU074657 Ankur	125.0	46.7	3.0	17.0	56.5	150.0	–
IU074658 Pusa Naubahar	130.0	48.2	3.2	16.6	64.7	210.0	140
IU074659 Maharandi	120.0	43.0	2.2	6.0	23.0	78.0	52

Table 1. Continued

Sample name and registration number	Growing season, days	Height, cm		Quantity, pcs./plant		Seed weight, g	
		plant	lower bean attachment	beans	seeds	per 1 m²	% to standard
IU074660 Sheetal	120.0	44.0	3.1	2.2	4.0	6.0	4
IU074661 Haldi bhati	130.0	42.3	3.2	23.0	102.0	324.0	216
IU074663 Tindal	120.0	33.5	4.0	2.0	13.0	48.0	32

Source: *compiled by the authors of this study*

According to the trait "plant height", almost all guar samples were at the level of IU074657 Ankur and were characterised by small values – 33.5-48.2 cm and had "very small attachment of the lower bean" – 2.2-4.0 cm. Haldi bhati IU074661 stood out for its "very high" productivity, with 102 seeds/plant, and Sheetal IU074660 – for its "very low" productivity, with 4 seeds/plant. "Very high" yields, more than 135% compared to the control, were observed in Pusa Naubahar IU07465 210 g/m² and Haldi bhati IU074661 324 g/m². As Figure 4 shows, the maximum yield was formed by samples with a longer vegetation period of 130 days, namely IU074658 Pusa Naubahar and IU074661 Haldi bhati. On the same samples, a larger number of beans and seeds per plant was observed – 16.6 and 23.0 and 64.7 and 102.0 pieces, respectively.

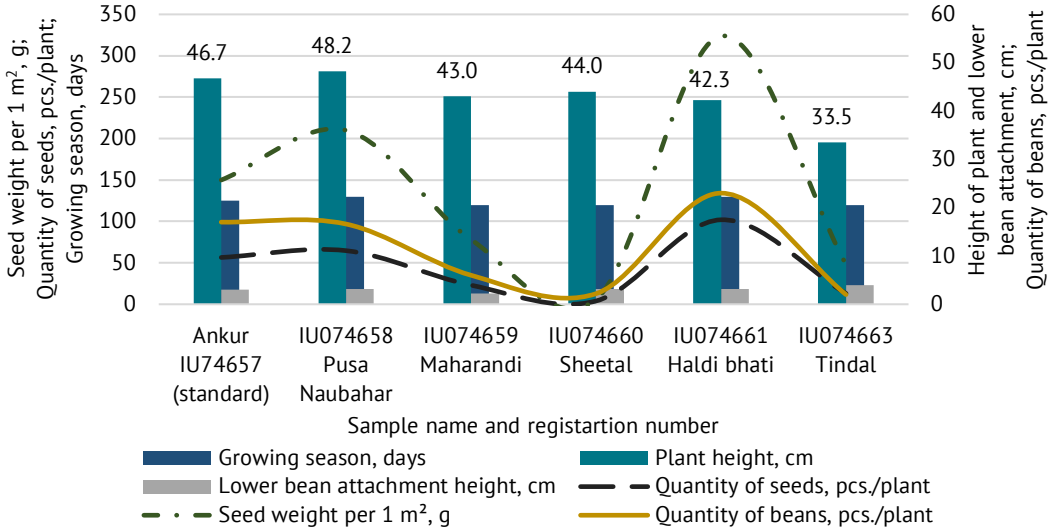

Figure 4*. Dependence of seed weight (g/m²) on morphological and biological traits, 2020*
Source: *compiled by the authors of this study*

Based on the correlation and regression analysis of the research results, it was found that there is a direct correlation between the seed yield per square metre and the number of beans and seeds per plant. The correlation coefficient is 0.994-0.966, respectively (Fig. 5).

The duration of the growing season in 2021 was 7-9 days longer than in 2020 (Table 2).

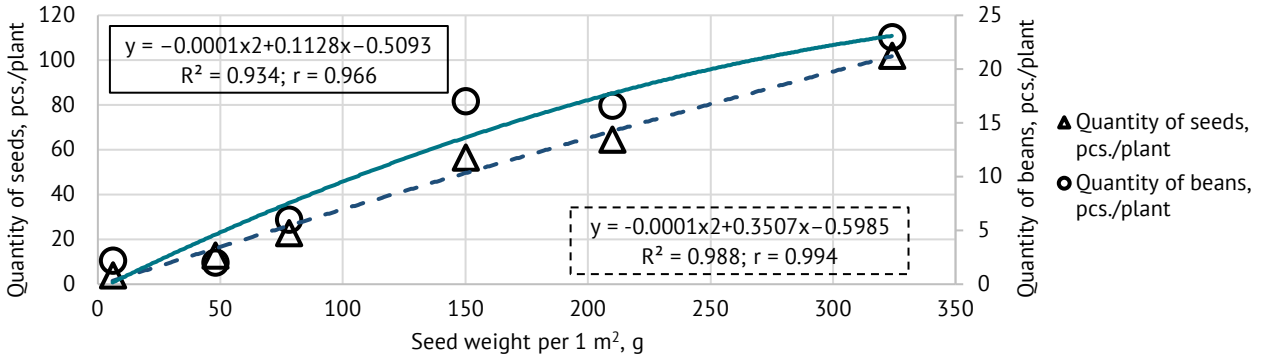

Figure 5*. Statistical model of the dependence of seed weight (g/m²) on the number of beans and seeds per plant, 2020*
Source: *compiled by the authors of this study*

***Table 2**. Characteristics of guar samples by a set of economically valuable traits, 2021*

Sample name and registration number	Growing season, days	Height, cm		Quantity, pcs./plant		Seed weight, g	
		plant	lower bean attachment	beans	seeds	per 1 m²	% to standard
IU074657 Ankur	126.0	46.8	2.9	17.0	56.6	150.1	–
IU074658 Pusa Naubahar	137.0	58.7	5.2	28.6	117.7	315.0	210
IU074659 Maharandi	129.0	49.5	3.4	18.0	59.0	178.0	119
IU074660 Sheetal	129.0	46.1	3.8	10.2	34.0	116.0	78
IU074661 Haldi bhati	137.0	45.3	4.2	29.0	132.0	334.0	223
IU074663 Tindal	129.0	43.2	5.0	17.0	48.0	148.0	99

***Source:** compiled by the authors of this study*

This was facilitated by precipitation of 68.4 mm in the first ten days of July and a drop in average daily air temperatures in September to 12.0-16.0°C. The duration of the vegetation period in the samples IU074657 Ankur was at the level of the standard variety IU074659 Maharandi, IU074660 Sheetal and IU074663 Tindal, which was 129 days. All beans formed on the plant did not ripen in the samples IU074658 Pusa Naubahar and IU07466 Haldi bhati with a growing season of 137 days, but they formed the maximum yield. Samples IU074658 Pusa Naubahar and IU074661 Haldi bhati formed 28.6 and 29.0 beans, which amounted to 117.7 and 132.0 seeds per plant, respectively, and contributed to a remarkably high yield of 315 g/m² and 334 g/m², respectively (Fig. 6).

These indicators exceeded the standard variety IU074657 Ankur by 59.9-72.9%. According to the statistical model of the dependence of seed weight/m² on the number of beans and seeds per plant, presented in Figure 7, there is a direct relationship between these traits: r = 0.976-0.966, respectively.

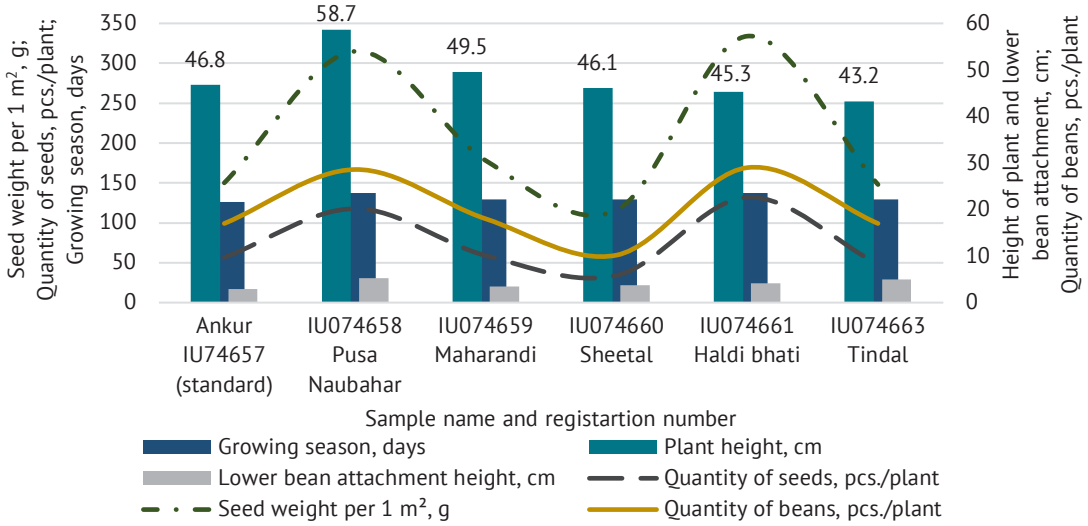

***Figure 6**. Dependence of seed weight (g/m²) on morphological and biological traits, 2021*
***Source:** compiled by the authors of this study*

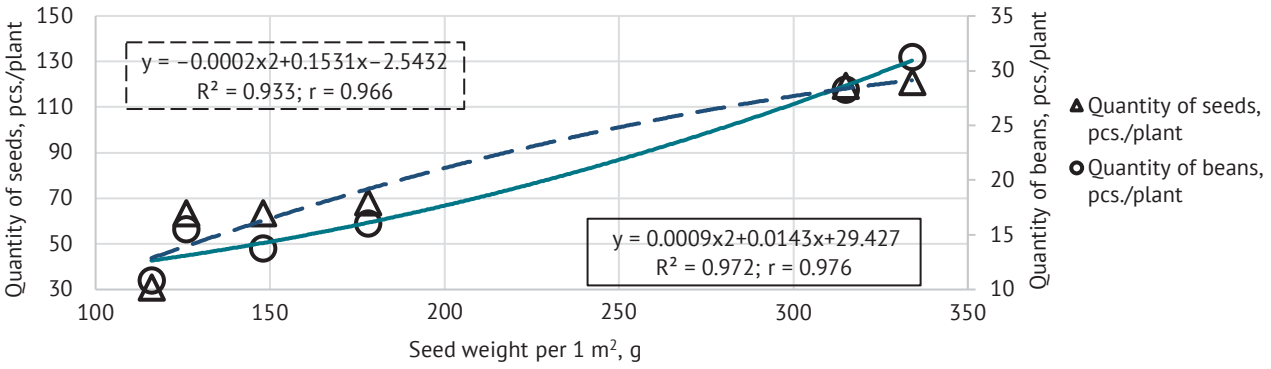

***Figure 7**. Statistical model of the dependence of seed weight (g/m²) on the number of beans and seeds per plant, 2021*
***Source:** compiled by the authors of this study*

The studied collection samples of guar by the trait "plant height" were within 43.2-69.5 cm (IU074661 Haldi bhati, IU074663 Tindal – IU074659 Maharandi, respectively), and the height of bean attachment ranged within 3.0-4.2 cm (IU074657 Ankur – IU074658 Pusa Naubahar, respectively), which corresponds to the gradation "very small" (Table 3).

Three-year studies of guar samples have shown that the length of the plant growing season has a significant impact on the formation of seed mass/m^2. IU074659 Maharandi, IU074660 Sheetal, and IU074657 Ankur were characterised by the shortest parameters of this trait – from germination to maturation, which was 124.5-125.0 days. However, they produced very low yields. The maximum values of this trait were observed in IU07466 Haldi bhati with a growing season of 133 days and in IU074658 Pusa Naubahar, with a growing season of 129.5 days, which is more than 135% compared to IU074657 Ankur, the standard, and amounts to 262.5 g/m^2 and 329.0 g/m^2, respectively. The correlation and regression analysis of the data obtained from the research results of guar collection samples for three years of research suggests a direct correlation between the weight of seeds per square metre and the number of beans and seeds per plant (Fig. 8).

The correlation coefficient is 0.997-0.986, respectively (Fig. 9).

Table 3 *Characteristics of guar samples according to a set of economically valuable traits, average for 2020-2022*

Sample name and registration number	Growing season, days	Height, cm		Quantity, pcs./plant		Seed weight, g	
		plant	lower bean attachment	beans	seeds	per 1 m^2	% to standard
IU074657 Ankur, standard	125.0	46.7	3.0	17.0	56.5	150.0	–
IU074658 Pusa Naubahar	129.5	48.5	4.2	22.6	91.2	262.5	175
IU074659 Maharandi	124.5	69.5	2.8	12.0	41.0	128.0	86
IU074660 Sheetal	124.5	45.0	3.5	6.2	14.0	61.0	41
IU074661 Haldi bhati	133.5	43.2	3.7	26.0	116.0	329.0	220
IU074663 Tindal	129.0	43.2	5.5	17.0	48.0	148.0	99

Source: *compiled by the authors of this study*

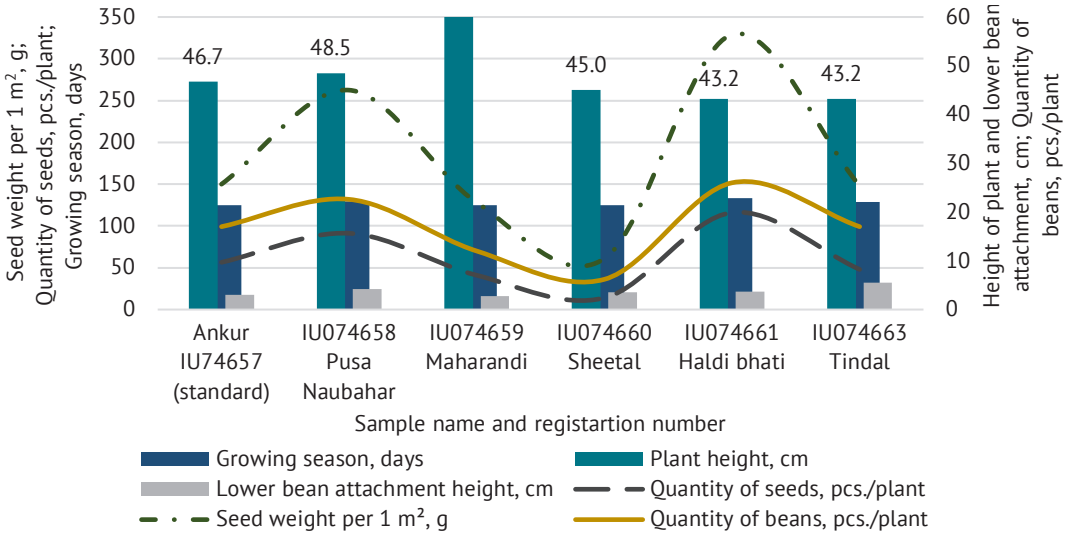

Figure 8*. Dependence of seed weight/m^2 of the studied guar gene pool samples on morphological and biological traits, average for 2020-2022*

Source: *compiled by the authors of this study*

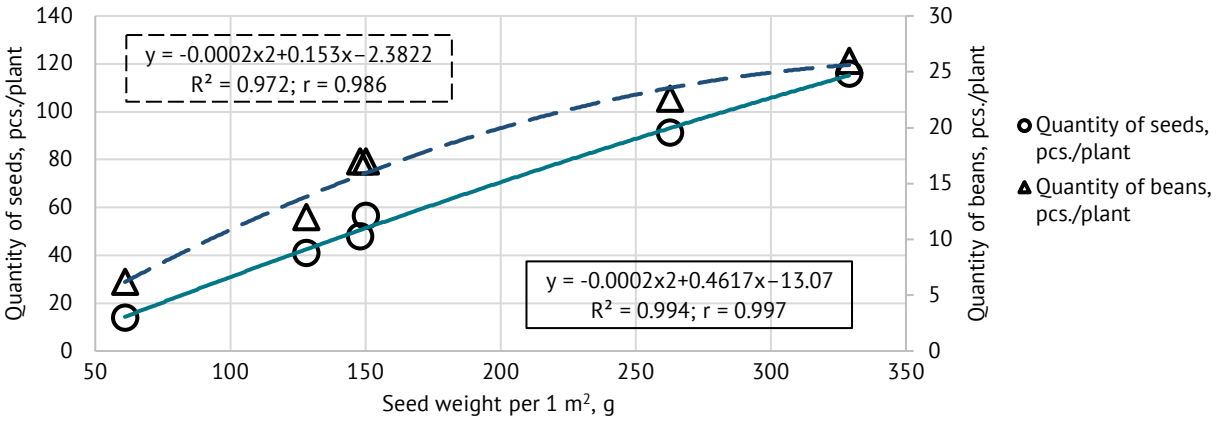

***Figure 9**. Statistical model of the dependence of seed weight/m² on the number of beans and seeds per plant, average for 2020-2022*

***Source:** compiled by the authors of this study*

The best samples of the guar collection IU07466 Haldi bhati and IU074658 Pusa Naubahar, which were the most adapted to the arid climate of the Southern Steppe of Ukraine, were involved in intraspecific hybridisation (Fig. 10).

***Figure 10**. The guar plant on which the hybrid bean was formed*

***Source:** photo taken by the author of this study*

As a result of these crosses, valuable source material was obtained – hybrid combinations Ankur/Pusa Naubahar, Ankur/Maharandi, Ankur/Sheetal, Ankur/Haldi bhati, Ankur/Tindal, Pusa Naubahar/Ankur, Haldi bhati/Ankur for further breeding work. The main producer of guar gum is India, where 80% of the world's acreage is concentrated, followed by Pakistan, which accounts for 15% of the acreage, and the United States (Texas and Oklahoma), which accounts for 5%. Clearly, very few countries produce guar. The Institute of Climate-Smart Agriculture is the only one in Ukraine that studies a crop whose plant sample collection was provided for study by the National Centre for Plant Genetic Resources of Ukraine. Since guar is a completely new crop for Ukraine, current research has focused on the study of relevant genotypes.

The guar gene pool is made up of sample numbers of different ripeness groups. According to two-year observations by R. Vozhegova *et al.* (2022a) on the growth and development of plants, it was found that in the Southern Steppe of Ukraine, where the frost-free period is 180-200 days and the growing season is 225-230 days, they can mature and form high productivity. The findings of the current study are in line with the results of G. Jaramillo *et al.* (2019), M. Amiri *et al.* (2022), who argue that the weather conditions of the year should favour the ripening of guar with a growing season longer than 160 days. However, there is some difference in this regard. Comparison of the duration of the growing season of the samples studied in the southern region of Ukraine on this basis showed that guar ripening occurred earlier than 160 days and was within 124.5-133.5 days.

IU074659 Maharandi and IU074660 Sheetal were characterised by the highest early maturity. However, these samples formed lower yields than those with a longer ripening period – on the reaction of the studied genotypes to irrigation. When growing guar in the southern region of Ukraine, three irrigations were made at a rate of 400 m³/ha. S. Hussain *et al.* (2020) share the same opinion, also recommending three waterings during the guar growing season. R. Shrestha *et al.* (2021) report that guar, as a drought-tolerant crop, can be grown without irrigation. Therewith, the plant produces slightly lower yields. At the same time, S. Ahmadi *et al.* (2017) argue that for normal growth it is necessary to optimise the irrigation regime of the crop. It was found that in the non-irrigated plots, the plants were stressed by drought, which, accordingly, slightly reduced the germination index, germination percentage, and plant height; in the irrigated plots, the above indicators were higher.

The correlation and regression analysis of the average data obtained from the results of research of guar collection samples for three years of study showed

that there is a fairly close positive correlation between the indicators of seed productivity and the number of beans and seeds per plant**.** The correlation coefficient is 0.997-0.986, respectively. Comparable positive correlation values of r = 0.806 between seed yield and the number of pods per plant were obtained by Santonoceto *et al*. (2019). The analysis of literature sources and the results of studying the gene pool of guar plants indicate that guar genotypes are characterised by high drought resistance. Screening genetic resources for this trait seems to be a promising strategy for gaining access to drought-tolerant varieties. The discovery of drought-tolerant genotypes is essential to ensure sustainable guar production.

CONCLUSIONS

As a result of the conducted study, the collection samples of guar (Cyamopsis tetragonoloba *L.) were* evaluated according to economic and morphological-biological characteristics. Studies have shown that *Cyamopsis tetragonoloba* prefers dry or moist soil and can tolerate drought. Therefore, the weather conditions of the Southern Steppe of Ukraine are favourable for the introduction of this crop, which requires a minimum amount of irrigated water. This will be especially important in the post-war period when a significant part of irrigated land will need to be restored. Ukraine will become one of 35 countries in the world where guar will be grown.

According to the analysis of literature sources, it was found that for the effective introduction of guar into production, it is necessary to have varieties adapted to the region where it will be sown. The best specimens in the guar collection have been identified in terms of morphological, biological, and economic characteristics. IU074659 Maharandi, IU074660 Sheetal, and IU074657 Ankur were characterised by the shortest duration of the growing season (124.5-125.0 days). IU07466 Haldi bhati and IU074658 Pusa Naubahar had the highest yields of 262.5 g/m^{2}and 329.0 g/m^2, respectively. Furthermore, the above samples were characterised by an increased number of formed seeds per plant – 91.2 and 116.0 pcs. It was found that there is a fairly close positive correlation between the indicators of seed productivity and the number of beans and seeds per plant: r = 0.997-0.986, respectively.

The scientific enrichment on the effectiveness of involving guar samples adapted to the south of Ukraine in the breeding process was further developed. As a result of intraspecific crossing, it was possible to expand the process of forming hybrid populations of Ankur/Pusa Naubahar, Ankur/Maharandi, Ankur/Sheetal, Ankur/Haldi bhati, Ankur/Tindal, Pusa Naubahar/Ankur, Haldi bhati/Ankur. In future research, the best forms will be selected for desirable economically valuable characteristics such as early maturity, productivity, quality, and ability to fix nitrogen from the air, and further breeding work will be carried out with them.

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CONFLICT OF INTEREST

The authors of this study declare no conflict of interest.

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Оцінка колекційних зразків гуару (*Cyamopsis tetragonoloba* L.) за господарсько-цінними ознаками

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Анотація. Для ефективного впровадження гуару в виробництво, необхідно використовувати сорти, адаптовані до Південного Степу України, створення яких неможливе без добре дослідженого колекційного матеріалу, що є актуальним і важливим. Гуар користується широким попитом у світі в харчовій та нафтовидобувній промисловості, а головне – завдяки здатності до симбіотичної фіксації азоту, покращує якість ґрунту рентабельним і природним шляхом. Проте є зовсім новою культурою для України. Метою наукової роботи було проведення дослідження генофонду рослин гуару та виділити кращі за господарсько-цінними ознаками. В роботі було використано польовий, лабораторний, статистичний методи. Результати проведених досліджень впродовж 2020-2022 рр. дозволили виділити кращі інтродуковані зразки гуару за толерантністю до високої температури та посушливого клімату Південного Степу України. Найбільш приспособленими до цієї зони є IU07466 Haldi bhati та IU074658 Pusa Naubahar. Вони сформували максимальні показники врожайності: IU07466 Haldi bhati – 262,5 г/м^2, IU074658 Pusa Naubahar – 329,0 г/м^2, яка, по відношенню до стандарту, становить більше 135%. Вище згадані зразки характеризувались тривалістю періоду вегетації 133,5 та 129,5 діб, відповідно, що в середньому за два роки досліджень перевищувало тривалість періоду «сходи – дозрівання» стандартного сорту IU074657 Ankur на 4,5-8,5 діб. Кореляційно-регресійний аналіз отриманих даних результатів досліджень інтродукованих зразків генофонду гуару свідчить, що існує пряма залежність між показниками маси насіння з одного метра квадратного та кількістю бобів і насінин на рослину. Коефіцієнт кореляції складає 0,997-0,986, відповідно. Виділені джерела цінних ознак рекомендується використовувати для подальшого ефективного впровадження в селекційні та дослідницькі програми наукових закладів з метою створення самозапилених ліній, синтетичних популяцій, сортів, адаптивних до екстремальних умов Південного Степу України

Ключові слова: гуар; генофонд рослин; тривалість періоду вегетації; адаптивність; продуктивність