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RESEARCH ARTICLE OPEN ACCESS

Biological potential of castor bean (*Ricinus communis L.*) and safflower (*Carthamus tinctorius L.*) under Ukrainian conditions☆

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Abstract – To diversify agricultural production and introduce new valuable oilseed crops in Ukraine, it is necessary to conserve, study, and develop oilseed collections as a basis for breeding. Oilseed collections and breeding programs have been conducted at the Institute of Oilseed Crops for many years. The research was carried out using classical field experiments over several growing seasons. The results demonstrate the diversity and size of the castor bean and safflower collections, reveal the yield potential of the most promising accessions, and compare the quantitative and qualitative characteristics of accessions of different origins and breeding backgrounds. Under the conditions of the Zaporizhia region, the best castor bean accessions achieved yields of up to 2.96 t/ha, oil content of up to 61%, and ricinoleic acid content of up to 92%. The best safflower accessions yielded up to 3.05 t/ha, with oil content up to 38%, thousand-seed weight up to 55 g, protein content up to 20%, and hull content up to 55%.

Keywords: oil content / oil composition / morphological traits / castor bean / safflower

Résumé – Potentiel biologique du ricin (*Ricinus communis* L.) et du carthame (*Carthamus tinctorius* L.) en conditions de culture ukrainiennes. Afin de diversifier la production agricole et d'introduire de nouvelles cultures oléagineuses d'intérêt en Ukraine, il est nécessaire de conserver, d'étudier et de développer des collections de plantes oléagineuses servant de base à la sélection variétale. Des collections d'oléagineux et des programmes de sélection sont menés depuis de nombreuses années à l'Institut des Cultures Oléagineuses. Les recherches ont été réalisées au moyen d'expérimentations classiques au champ sur plusieurs saisons de culture. Les résultats démontrent la diversité et l'ampleur des collections de ricin et de carthame, mettent en évidence le potentiel de rendement des accessions les plus prometteuses et comparent les caractéristiques quantitatives et qualitatives des accessions selon leur origine et leur contexte de sélection. Dans les conditions de la région de Zaporijjia, les meilleures accessions de ricin ont atteint des rendements allant jusqu'à 2,96 t/ha, une teneur en huile pouvant atteindre 61% et une teneur en acide ricinoléique jusqu'à 92%. Les meilleures accessions de carthame ont atteint des rendements allant jusqu'à 3,05 t/ha, avec une teneur en huile pouvant atteindre 38%, un poids de mille graines jusqu'à 55 g, une teneur en protéines jusqu'à 20% et une teneur en coques jusqu'à 55%.

Mots-clés : rendement / teneur en huile / caractères morphologiques / ricin / carthame

☆ Contribution to the Topical Issue: "Oilseeds in Ukraine / Oléoprotéagineux en Ukraine".
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Highlights

- Oilseed collections and breeding programs have been conducted at the Institute of Oilseed Crops for many years. The results demonstrate the diversity and size of the castor bean and safflower collections, reveal the yield potential of the accessions, and compare the quantitative and qualitative characteristics of accessions of different origins.

1 Introduction

Ukraine is characterized by fertile soils and a relatively warm climate suitable for the cultivation of a wide range of agricultural crops, particularly oilseeds. However, oilseed production is currently dominated by sunflower, soybean, and rapeseed, while flax and mustard are cultivated only on relatively small areas. At the same time, climatic and soil conditions allow for the expansion of the range of oilseed crops grown in the country.

The Institute of Oilseed Crops of the National Academy of Agrarian Sciences of Ukraine has long been engaged in the conservation of genetic resources, breeding, and development of cultivation technologies for oilseed crops. Since its establishment in 1991, numerous varieties, lines, and hybrids have been developed. Owing to the work of the Institute, the cultivation of oilseed flax and mustard has been revived in Ukraine.

The Laboratory of Genetics and Genetic Resources maintains collections of oilseed crops that are either rarely grown or not cultivated at all in Ukrainian agriculture. The laboratory collection includes 1,890 accessions representing 16 crops, including 306 castor bean and 62 safflower accessions. Castor bean and safflower are thermophilic crops of southern origin that differ in agronomic requirements and intended use.

In recent decades, castor bean has attracted increasing global interest. The crop is studied by researchers worldwide due to its wide range of applications; castor oil is an important industrial raw material for numerous products, from polymers to cosmetics (McKeon *et al.*, 2014). Castor oil is unique among oilseed crops because of its exceptionally high ricinoleic acid content, exceeding 90% (Landoni *et al.*, 2023), which determines its suitability for technical applications. Castor oil has more than 700 industrial uses, and global demand is increasing by 3–5% annually. Extensive collections of castor bean genetic resources are conserved in more than 50 gene banks worldwide, although detailed information on these collections remains limited (Anjani, 2012.).

Understanding the yield components is crucial for the successful development of castor bean (Ricinus communis L.) cultivars adapted to different growing systems and regions. Castor bean cultivation in Texas (USA) has been reported to yield 2758 kg/ha of BRS Nordestina under irrigation (Severino *et al.*, 2012). In Mexico, 937.1 kg/ha was obtained (Armendáriz *et al.*, 2015). In India, 2.13 t/ha was obtained under irrigation and it was found that the content of ricinoleic acid is higher under rainfed agroecological conditions (Ramanjaneyulu *et al.*, 2013).

It is well known that castor bean hybrids have been developed that exhibit heterosis in yield and may show higher potential (Neto *et al.*, 2022). Traditional breeding methods have successfully developed about 40 high-yielding hybrids and varieties with built-in resistance to major pests and diseases in India (Lavanya *et al.*, 2018). The breeder reports of some hybrids developed in China indicate a potential yield of more than 4 t/ga.

Potential directions for breeding improvement have been identified; in particular, it has been shown that selecting plants with longer main panicles, relatively tall plants and a larger number of primary branches can increase yield (Yeboah *et al.*, 2022). The number of seeds per inflorescence and the weight of 1000 seeds show a positive effect on yield (Xishun *et al.*, 2006).

Safflower, in contrast to castor bean, is well adapted to arid steppe and desert environments. Ongoing climate warming and increasing aridity, including in Ukraine, necessitate adaptation of crop production systems. Ongoing climate change requires adaptation of agricultural production systems, particularly crop production, to increasingly arid conditions. Although irrigation can significantly improve crop performance, it is not feasible to supply all agricultural land with irrigation. Therefore, safflower becomes a promising and important crop under such conditions.

Safflower is a plant of the Asteraceae family that is similar in seed composition to sunflower, and can be grown where sunflower lacks moisture. In the south of Ukraine, there have been successful attempts to expand safflower cultivation: in the Kherson region in particular. In areas of fields without irrigation there, very few crops can be successfully cultivated. Among spring crops, flax and safflower were primarily cultivated, most often the crop rotation for them was based on winter grain crops. However, due to the war, these developments have largely been lost, except for publications and collections that were maintained at the Institute of Oilseed Crops of the NAAS. Over the years of the institute's work, four varieties were created, which were in the Register of Plant Varieties of Ukraine and were grown in small quantities.

This crop is successfully cultivated in Turkey (El Bey *et al.*, 2021), Greece (Dordas and Sioulas, 2008) and other arid countries. The results of the study of safflower collections with genetic mapping and the identification of candidate genes related to the biosynthesis of unsaturated fatty acids and lipid accumulation are already known (Li *et al.*, 2021; Fan *et al.*, 2023). Safflower has also been proposed as a unique plant for the purification of soils from salinity and heavy metals (Ciaramella *et al.*, 2022). There are winter-hardy safflower specimens that can be sown in autumn and survive the winter (Cullerne *et al.*, 2021). In general, winter safflower has been recognized as suitable for cultivation throughout the Mediterranean region, where it provided an average yield of 1.775 t/ha (Zanetti *et al.*, 2022).

Despite the demonstrated global potential of castor bean and safflower, these crops are not yet widely cultivated in Ukraine. Therefore, the purpose of this study was to evaluate the quantitative and qualitative indicators of a wide range of castor and safflower samples as a basis for breeding in Ukrainian agroecological conditions.

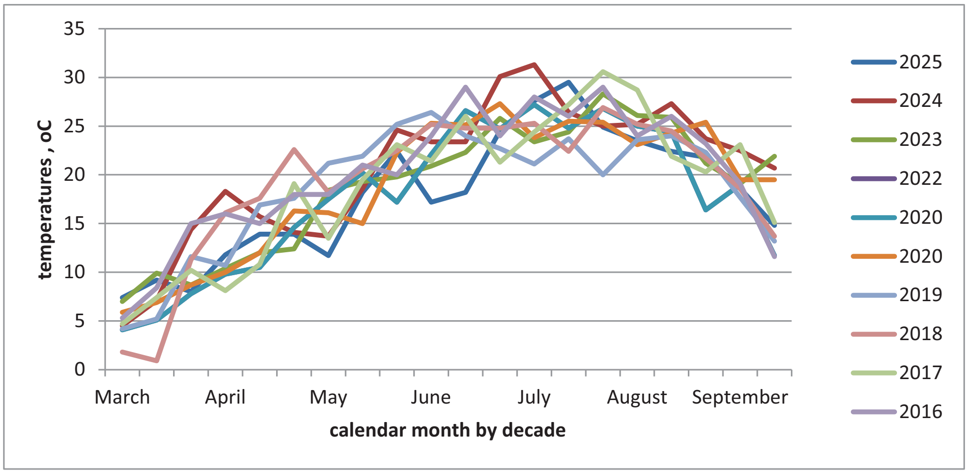

Fig. 1. Ten-day temperatures of the growing season in Zaporizhia.

2 Materials and methods

2.1 Climatic conditions

The climatic conditions of Southern Ukraine are characterized as warm and arid. Figure 1 presents graphs of decadal air temperatures during the growing seasons over the last 10 yr. As shown in the figure, temperatures suitable for the cultivation of most late-season crops (above 15 °C) are observed from April to September. For crops such as castor bean, temperatures below 15 °C cause severe chilling stress and promote the development of Fusarium diseases, while frosts may sometimes completely destroy crops. Long-term observations indicate a high probability of spring frosts in late April. Consequently, only four favorable months, or approximately 120 days, remain for the cultivation of heat-loving crops. Most accessions, breeding varieties, and hybrids of annual crops such as castor oil plant, sesame, peanut, chufa, and others correspond to this duration of the growing season.

The second important factor for crop introduction is moisture availability, especially during the growing season. Figure 2 presents the total amount of precipitation for the conditional growing season from March to September. Although most oilseed crops are not usually sown in March, precipitation during this month reflects the availability of soil moisture before sowing. As shown in the figure, annual precipitation varies considerably: in the driest years it amounts to only 124 mm, whereas in the wettest years it reaches up to 425 mm. The long-term 30-year average annual precipitation is 305 mm; however, during the last 10 yr it has decreased to 279 mm.

This clearly indicates a significant tendency toward a decreasing in precipitation. In addition, rainfall is distributed very unevenly throughout the growing season. For example, over the last 10 yr of research, 2 yr with the highest moisture supply and one extremely dry year were selected and are presented in Figure 3. It is evident that in one of the relatively wet years, despite the high total annual precipitation, spring months were characterized by almost complete absence of rainfall. Such limited spring precipitation negatively affected plant development. In contrast, in 2018, precipitation occurred in March, while subsequent rainfall was observed only at the end of June and in mid-July, which also created unfavorable conditions for the development of many crops. The extremely dry year of 2025 deserves special attention, as even the total amount of precipitation was insufficient to meet the water requirements of most crops, regardless of theoretically optimal monthly distribution.

The third component of growing conditions is soil. Ukrainian soils are generally fertile; in particular, the Zaporizhzhia region is characterized by typical chernozem soils. In general, Ukrainian soils are characterized by moderate humus content, with a humus horizon of 75–85 cm and up to 4% humus in the upper soil layer. At the experimental fields of our institution, humus content ranges from 3.3% to 3.9%. The results of cultivation and introduction experiments with numerous species indicate the feasibility of growing a wide range of crops under these conditions.

2.2 Materials and experiments

2.2.1 Castor bean

The Ricinus communis plant contains toxic and allergenic protein compounds, in particular ricin and agglutinin (RCA), which necessitates adherence to standard biosafety measures when working with plant material during cultivation, collection, and laboratory processing.

The castor bean collection of the Institute of Oilseed Crops of the NAAS currently comprises approximately 300 accessions and was formed on the basis of the global collection of the N.I. Vavilov Institute of Plant Genetic Resources, as well as materials obtained from Ukrainian research institutions. Long-term studies of the collection based on morphological traits have been conducted for about 20 yr (Odynets, 2017). Castor seeds retain their germination for a long time, so only a portion of the collection is grown each field season. All data were used to describe the general collection, and for quantitative indicators presented in the tables, data from the specific study years were used. The experimental material included 208 samples, most of which are lines, 6 old varieties and 4 commercial hybrids of Chinese

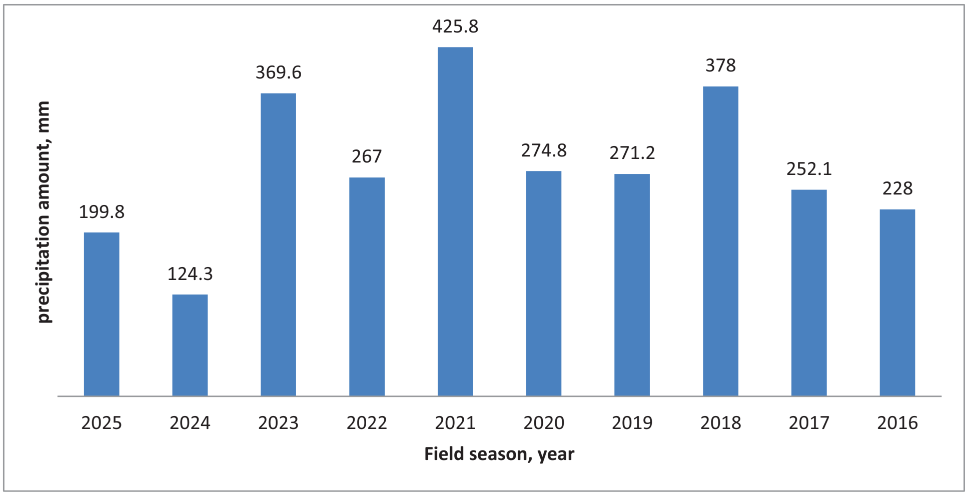

Fig. 2. Total precipitation (mm) for March-September of each research year in Zaporizhia.

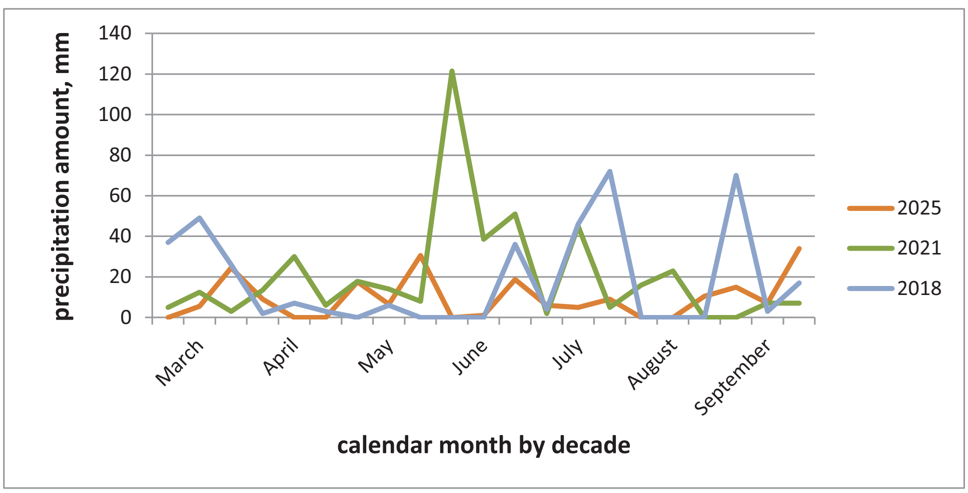

Fig. 3. Precipitation during the growing season in Zaporizhia, for the most contrasting years of cultivation.

origin. During long-term cultivation in Ukraine, some accessions originally maintained as populations became stabilized lines through repeated self-pollination.

We did not have the opportunity to grow the entire collection annually on large plots and establish its yield. However, in 2015, four production castor hybrids were received from the Zibo Academy of Agricultural Sciences: No. 5, 6, 8, 9. This allowed us to investigate their yield under our experimental conditions in 2015–2016 and compare them with several of our samples and varieties.

Field experiments were conducted at the experimental fields of the Institute of Oilseed Crops (Zaporizhia). Soil preparation followed conventional practices, including plowing and pre-sowing cultivation. Castor bean was sown manually at a spacing of 0.7 × 0.7 m, with two plants per hill and a final density of 40,000 plants per hectare. Plot size was 9.8 m^2 for collection evaluation and 29.4 m^2 for yield assessment with three repetitions. Yield and quality studies were conducted mainly in 2015, 2016, and 2018, while descriptive observations continued until 2023.

2.2.2 Safflower

The collection of safflower (Carthamus tinctorius) consists of 58 accessions of various origins. Among them, more than half are of Ukrainian origin and developed by our institute (Fig. 4). Some accessions had a local origin, while others were obtained from international collections many years ago. Over time, these materials were subsequently stabilized as populations or lines.

Five accessions from the collection are varieties of our own selection: Zhivchyk, Lahidny, Sonyachny, Astor, Dobrynya. The collection also includes accessions that had varietal origin: Gila, Safflire, Orange de Marocco, Milyutinsky 114. Unfortunately, these accessions exhibited segregation for certain traits. Most of the collection are lines created by self-pollination of various materials, including from crosses. During the growing season, the accessions differ in phenology within a range of 10–14 days. This is most clearly observed during plant flowering, when 50% of each sample flower from June 24 to July 10. Full ripening occurs from August 1 to 25. Moreover, in most years of cultivation it occurs simultaneously in most accessions. Only in some years, the insufficient moisture in

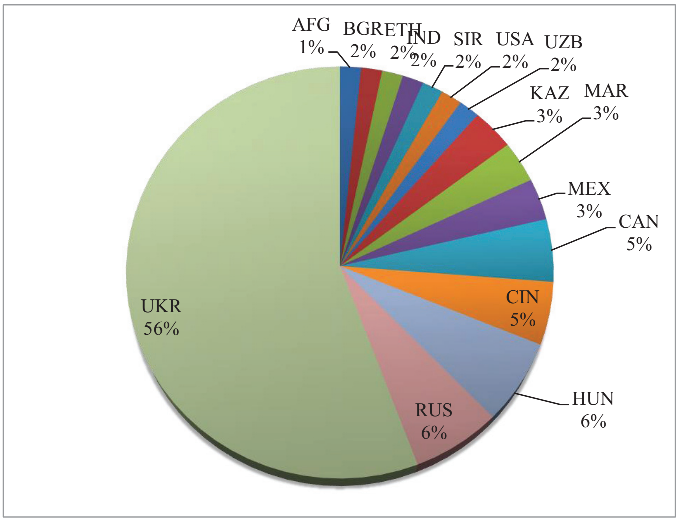

Fig. 4. Distribution of safflower collection by origin.

August delays ripening and distinguishes the accessions from each other.

Safflower was sown in the spring in the collection plots manually, in a row method with a row spacing of 0.35 m and a row length of 2 m. The area of the plots was at least 1.4 m2, in some experiments up to 4.2 m^2. The studies were conducted from 2011 to 2025. Each sample was studied for at least 3 yr.

Individual insulators for safflower were made of SUF No. 30, and insulators for castor bean were made of dense parchment.

2.3 Measurements

Measurements of individual plants of both crops were carried out on at least five plants annually using a ruler. Seeds were threshed using a small-plot combine harvester, each sample was cleaned separately using an οη-flow system, seeds were counted manually, and yield and thousand-seed weight were calculated. Yield data and seed analysis were recorded from the total plot area. But seeds for future sowing were always obtained from isolated plants.

To obtain average values, the results of at least 3 yr of research were used. The collection was described using UPOV methods (International Union for the Protection of New Varieties of Plants, 2018, 2023). The oil content in the seeds was determined in the analytical laboratory of the Institute of Oilseeds using the DSTU method (DSTU 7577:2014 Oilseeds. Determination of oil content by extraction method in a Soxhlet apparatus: [Actual from 2014-01-01] / Editor. – K: Derzhstandart Ukrainy, 2014. – P. 23.). The composition of oilseeds was also determined in the laboratory using DSTU 30418-96. (DSTU 30418-96 Vegetable oils. Method of fatty acid composition determination: [Actual from 1996-01-01] K: Derzhstandart Ukraíni, 1996. P 8).

The content of total protein in plant raw materials was determined by the Kjeldahl method. (DSTU ISO 20483:2016 Cereals and legumes. Determination of nitrogen and crude protein content by the Kjeldahl method (ISO 20483:2013, IDT)). The institute's laboratory does not have the capacity to determine individual types of proteins, including those of castor bean.

Statistical analysis was performed using standard methods implemented in Microsoft Excel, and ANOVA analysis was also performed using the online tool Online Statistics Calculator. Statistical analysis was performed using standard methods implemented in Microsoft Excel, and ANOVA1 analysis was also performed using the online tool Online Statistics Calculator2 (https://statisty.app/?utm_source=chatgpt.com).

3 Results and discussion

3.1 Castor bean collection

The main issue for any crop introduced into agricultural production is yield. In 2015, four production castor hybrids were received from the Zibo Academy of Agricultural Sciences: No. 5, 6, 8, 9. This allowed us to study their yield in our conditions in 2015–2016 and compare them with several of our genetic resources and varieties. The selection of four Chinese commercial hybrids (No. 5, 6, 8, 9) was based on their claimed high yield potential and adaptability, allowing comparison with locally adapted genetic resources in Ukrainian agroclimatic conditions. The results of the study of yield on the plots are presented in Table 1. Yield was estimated from 28 m^2 plots arranged in a completely randomized design with three replicates and a plant density of 40,000 plants per hectare. The obtained yields were not high. However, this allowed the identification of more productive and better-adapted accessions for the steppe zone of Ukraine. The results of the analysis of variance (ANOVA) showed a statistically significant effect of the variety factor on yield ($F(21) = 22.37$; $p < 0.01$).

The highest yield of 2.96 t/ha was found in the sample Selection No. 38 developed by our institute, which had a ricinoleic acid content of 91% and the highest oil content of 63%. Typically, castor oil contains 87–90% ricinoleic acid (Landoni *et al.*, 2023), however, under our conditions, castor oil samples have from 63% ricinoleic acid to 91%. This may be attributed to growing conditions; however, this aspect has been insufficiently studied. The results of studying castor oil in Chile in areas with a lack of moisture showed an oil content of 42–54%, which is significantly lower than our results of 50 to 63%. The ricinoleic acid content in them was 72–92%, which is close to our results: 74–92%. (Román-Figueroa *et al.*, 2020)

The yield of Chinese hybrids was relatively low. The highest was 1.1 t/ha for hybrid No. 5. The productivity of Chinese hybrids in our agroclimatic conditions was significantly lower than the yield indicated in advertising materials, which indicates a strong interaction of genotype × environment. The conditions of the Zaporizhia region cannot, as it turned out, provide high yields of the tested hybrids; this is likely due primarily to the lack of moisture in the soil and possibly to other conditions. In the best years, yields of up to 2 t/ha were observed under production conditions.

Among the accessions grown in the experiment, historical varieties Shcherbinovskaya and Kubanskaya 15, a variety of the Institute of Oilseed Crops selection Khortytska 3, which was in the Register of Varieties of Ukraine since 2001, are presented. The data obtained indicate that the old varieties had

Table 1. Results of castor oil testing at the Institute of Oilseeds of the National Academy of Sciences of Ukraine, Zaporizhia, 2015–2016.

	name	Seed oil content ± SE, %	Protein content ± SE, %	Ricinoleic acid content ± SE, %	Yield assessment ± SE, т/g	Weight 1000 pcs ± SE, g
1	K828	50.0 ± 2.5	18.5	81.0 ± 1.5	2.08 ± 0.12	243 ± 2.4
2	Kubans′ka 15	52.8 ± 2.1	19.7	82.2 ± 1.0	0.71 ± 0.05	351 ± 5.7
3	Khortyts′ka 3	53.6 ± 1.4	18.9	84.1 ± 1.7	2.48 ± 0.11	268 ± 6.3
4	K42	53.8 ± 1.7	18.4	90.3 ± 0.9	1.52 ± 0.15	218 ± 10.1
5	PRL10	55.0 ± 1.8	18.3	84.9 ± 0.9	2.47 ± 0.13	209 ± 5.4
6	K183	55.5 ± 1.3	18.2	82.1 ± 1.7	2.64 ± 0.20	204 ± 4.9
7	Shcherbynovskaya	56.2 ± 1.8	18.8	82.3 ± 1.0	1.14 ± 0.14	238 ± 4.2
8	VNYYMK 165	56.7 ± 2.0	17.,9	74.2 ± 1.0	1.48 ± 0.10	229 ± 7.8
9	Kytays′ka 9	57.1 ± 1.4	16.2	92.1 ± 1.2	1.07 ± 0.09	255 ± 2.9
10	41307	57.5 ± 1.9	18.4	86.0 ± 1.1	2.95 ± 0.21	529 ± 4.6
11	M203	57.6 ± 1.9	18.2	83.6 ± 1.6	0.56 ± 0.07	219 ± 6.1
12	Kytays′ka 5	57.8 ± 1.8	19.7	85.7 ± 1.2	1.11 ± 0.03	319 ± 9.6
13	M103	58.1 ± 2.0	18.7	88.3 ± 1.3	1.21 ± 0.09	236 ± 11.2
14	Kytays′ka 6	58.1 ± 1.6	18.1	86.7 ± 1.6	0.75 ± 0.08	249 ± 10.8
15	464	58.9 ± 1.9	18.7	87.3 ± 1.1	2.63 ± 0.20	245 ± 5.3
16	K 451	59.1 ± 1.6	18.4	84.1 ± 1.1	2.64 ± 0.21	324 ± 7.0
17	PRL 09	60.6 ± 2.4	18.1	89.3 ± 1.7	2.31 ± 0.15	260 ± 6.5
18	Kytays′ka 8	61.4 ± 2.4	17.4	84.9 ± 1.0	1.09 ± 0.11	276 ± 7.1
19	K 1181	61.9 ± 2.3	18.4	86.0 ± 1.0	2.22 ± 0.15	218 ± 4.8
20	Petrovskaya	62.5 ± 2.0	18.6	89.4 ± 1.4	2.28 ± 0.13	287 ± 5.4
21	K 903	63.8 ± 2.4	18.2	88.6 ± 1.5	2.32 ± 0.13	547 ± 6.5
22	Otbor 38	63.8 ± 1.6	17.6	91.3 ± 1.4	2.96 ± 0.20	218 ± 9.3
	Type III Sum of Squares	1034.56	65.83	1358.8	77.45	1075461.19
	df	21	21	21	21	21
	Mean Squares	49.26	3.13	64.75	3.69	51212.44
	F	95.56	83.49	53.88	22.37	87.67
	$p <$	0.001	0.001	0.001	0.01	0.001
	η^2	0.97	0.94	0.95	0.82	0.95

a rather low yield, which may be due to the difficulties of preserving the variety in the system of genetic resources. However, the variety Khortytska 3, the seed production of which was carried out until recently by the Institute of Oilseeds, showed a high average yield of 2.48 t/ha, which is 0.6 t/ha higher than the average in the experiment.

The field-measured yield of castor bean in our conditions is close to 1 t/ga. Under the climatic conditions of the region, yield formation in castor bean largely depends on moisture availability during the first half of the growing season. Favorable moisture conditions promote the development of a well-formed main raceme, which contributes significantly to yield formation. However, secondary racemes often fail to fully develop due to either insufficient time for maturation under cooler conditions or rapid desiccation during hot and dry periods in the second half of the growing season. The latter scenario is observed more frequently. Therefore, breeding efforts have focused on the development of creating single-raceme forms, in which lateral branches are not formed. There are eight such specimens in the collection: K130, K374, K1427, K1372, K1074, K1080, K1126, K385.

The main collection of the Institute of Oilseeds is studied for potential yield at each reseeding. It is calculated by the weight of the main racemes from three plants in terms of the number of racemes per hectare. Such calculations considerably overestimate actual field yield. But with such a calculation it really turns out that a lot of castor oilseed accessions can provide 4 tons per hectare. So in 2018, with the yield calculated in this way, it was observed that five accessions had more than 4 t/ga: K1181, K451, K464, K472, and I 556861.

A study of the yield of castor bean varieties Gromada, Khortytska 3, and Khortytska 1 in the agrotechnical experiment of our institute, conducted in 2000–2002, showed a yield within 1.43–1.77 t/ha (Vasylenko, 2003). These years were wetter and more favorable in terms of weather conditions than 2015–2016. Therefore, the presence of a higher yield is understandable.

The second important component is seed oil content. Román-Figueroa, S. *et al.* (2020) indicate a typical oil content of 45–51%. However, in our studies, this trait for castor oil is always very high, almost always above 50%. This characteristic may negatively affect the mechanization of its harvesting and cleaning. According to the results of the study of the processing of castor oil and feed, one of the main challenges is the high oil content with a low content of carbohydrates, in particular cellulose (Shevchenko *et al.*, 2009). In our collection, the oil content was measured in the experiment with production hybrids and in most of the collection

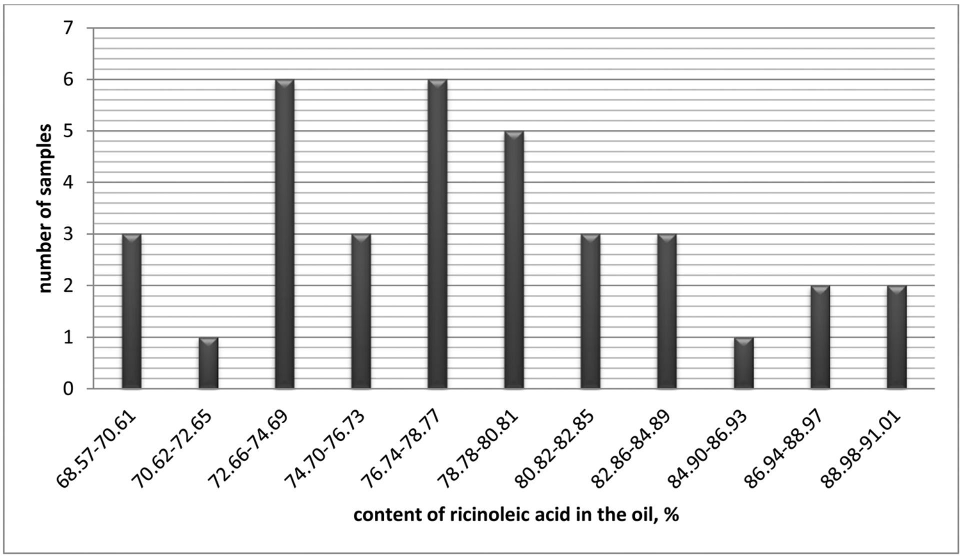

Fig. 5. Percentage distribution of castor oil collection samples by the content of ricinoleic acid in the oil.

accessions. In the experiment on the yield of 2015–2016 (Tab. 1) the oil content ranged from 50% to 63.4%. The highest oil content among Chinese hybrids was obtained in hybrid 8 (61.4%). However, many accessions fall within the margin of measurement error. The accessions with oil content higher than 61% were: K 1181, Petrovskaya, K903 and a sample of our own selection Otbor No. 38.

Therefore, it is not considered necessary to conduct breeding work to increase the percentage of oil content. One of the important issues of the prospects of the crop is the quality of the product. Castor oil has a unique composition, namely ricinoleic acid, which is not found in other oil crops. It provides important technical characteristics. In our study, fatty acid composition was determined according to DSTU 30418-96 (DSTU 30418-96 Vegetable oils. Method of determination of fatty acid composition: [Actual from 1996-01-01] K: Derzhstandart Ukraíni, 1996. P 8) in seeds of the harvest of 2015, 2016, 2018. According to the average indicators, values ranged from 68.57% to 91.01% (Fig. 5). Measurement error was generally within 3%, but the smallest significant error according to all studies was 4.6%. The identified potential for obtaining high-quality raw castor oil in the under the conditions of the Zaporizhia region was found to be sufficient. Thus, Roman-Figueroa, C. and co-authors (Muñoz-Alcayaga *et al.*, 2023) in studies in the Chilean climate found a ricinoleic acid content of 87 to 89%. Therefore, our results indicate a wider genetic diversity of the collection.

Another important indicator of the presence of diversity is the mass of 1000 seeds. In studies of collections, variability was determined from 217 to 388 g (Nagarajan, 2019), from 223 to 565 g (Setayeshnasab, 2024). In our collection there are specimens with a mass of 1000 seeds from 140 to 508 g, although the main part – about 75% of the genetic resource – is in the range of 221–303 g. Our results are slightly lower than those reported by other researchers, but which may reflect less favorable growing conditions in Zaporizhia than in the study regions. Seed size is one of the important indicators by which castor oil subspecies are distributed. The Chinese subspecies is characterized by smaller seeds than the Indian subspecies, and the weedy subspecies of castor oil has the smallest seeds. The distribution of genetic resources by size is presented in Figure 6.

Accessions with very large seeds are usually less numerous than accessions with medium-sized seeds. Therefore, all created varieties and tested hybrids usually have not the largest mass of 1000 seeds, but somewhere up to 350–400 g no more.

According to the study of castor oil, a basic collection of 208 accessions originating from 34 countries was created. The collection describes 23 morphological traits with 103 gradations of their manifestation according to the UPOV methodology (International union for the protection of new varieties of plants, 2018) (Fig. 7).

The castor bean collection was characterized based on morphological traits: stem height and color, stem wax coating, stem height, stem: number of nodes to the central cluster, capsule size, capsule color, capsule cracking pattern, capsule spikiness, cluster: by shape, cluster by density, seed color, seed: corunculus by size, duration of the growing season, anthocyanin color of young leaves, petiole length, leaf blade length, leaf blade width, number of leaf blade blades, inflorescence length, female flowers: color of pistil before pollination. Morphological traits were also taken into account: number of clusters of the 2nd order, cluster by length of the productive part, seed size, yield, weight of 1000 seeds, oil content.

For all the characteristics of the VOS, standard accessions of various manifestations were selected. The most important characteristics for obtaining a high stable yield are the height of the plants, the number of clusters, and their size. Accordingly, in the collection, the number of clusters of the 2nd order is divided into three groups: small (1 pc) - K 374 (UE0300172), Olesya (UE0300122); medium (2–4 pcs) - Khortytskaya 3 (UE0300009), Kubanskaya 15 (UE0300010); large (>5 pcs) - Ophelia (UE0300017), Osennyaya rhapsody (UE0300323).

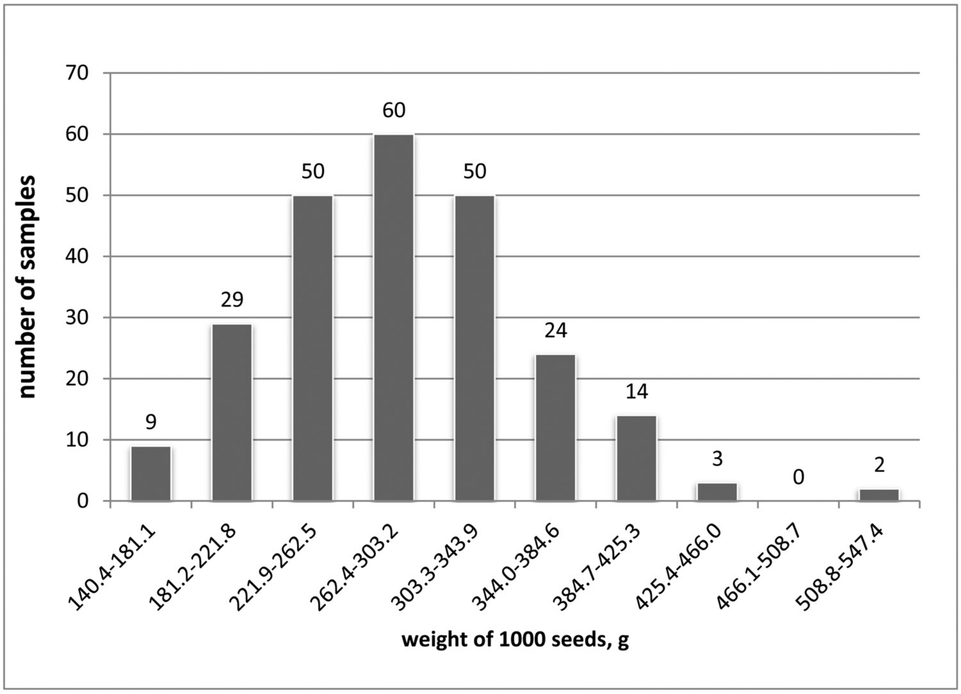

Fig. 6. Percentage distribution of castor bean collection accessions by weight of 1000 seeds.

The size of the cluster by the length of the productive part had five gradations: very short (<10 cm) - K735 (UE0300183), K386 (UE0300070); short (11–20 cm) - Khortytska 3 (UE0300009), Kubanskaya 15 (UE0300010); medium (21–30 cm) - Petrovskaya (UE0300004), Ofelia (UE0300017); long (31–40 cm) - K165 (UE0300043), K 93 (UE0300147); very long (>40 cm) - K 955 (UE0300195), K 409 (UE0300080).

The total number of castor oilseed accessions in the collection of the Institute of Oilseeds of the National Academy of Agrarian Sciences of Ukraine, formed as of 2025, is 300 accessions. Every year, selected accessions are re-sown to restore germination and described. Based on the results of these descriptions, a database was created, according to which valuable accessions individual morphological traits, with valuable quantitative indicators, resistance to fusarium wilt were selected.

The collection of the Institute of Oilseed Crops of the NAAS contains accessions of the source of the trait of early maturity, lack of branching, large panicle, female type of panicles (sterility for use in hybrids), etc. The available material allows creating new varieties and hybrids of castor oil adapted to cultivation in the conditions of southern Ukraine and cooperating with institutions of other countries at a decent level.

3.2 Safflower collection

When growing safflower in Zaporizhia, agroecological conditions correspond well to the biological requirements for this plant. In very humid conditions, the vegetative parts are severely affected by the septoria fungus, which leads to the drying of the plant at any stage of development. Such conditions occur in Zaporizhia no more than once every 10 yr: very humid late June - early July occurs, which can result in almost complete crop loss. In other climatic conditions, safflower is well adapted for the climate. In particular, a cool spring for the development of safflower plants, and a dry hot summer are optimal for plant development.

The usual weather conditions of Zaporizhia provide safflower yields of about 2 t/ga the worst weather conditions, as for example, in 2012, when due to drought, sunflower failed completely, and oilseed flax reached only 10 cm in height, the safflower variety Zhivchik had a plant height of 50 cm and provided a yield of 1.2 t/ha.

The general yield characteristics of the best safflower accessions are presented in Table 2. According to the obtained yield data, the most productive were the accessions Krasnotsvetushchy, K497, K69, which showed a yield of 3 t/ha. They were also characterized by an early flowering date of June 28 - July 1. Later-ripening accessions do not fully realize their yield potential and, as mentioned above, often dry out (ripen) all at the same time.

In Greek studies of safflower, when using nitrogen fertilizers, yields of up to 3 t/ha were obtained (Dordas and Sioulas, 2008) and twice as low (Papadopoulos *et al.*, 2023). In our experiments, fertilizers were not applied at all, therefore the obtained yield of individual accessions of 3 tons should be considered sufficient for the introduction of this crop into cultivation.

The data presented in Table 2 also show the characteristics of the plant that affect the possibilities of harvesting. First, all safflower in the steppe zone of Ukraine has an average plant height of 50 to 105 cm and a height of the lower lateral branch from 22 to 64 cm. This arrangement is well suited to conventional direct harvesting. Other researchers noted the


УКРАЇНА

СВІДОЦТВО

про реєстрацію колекції генофонду рослин в Україні

№ 291

На підставі повноважень, наданих Українською академією аграрних наук, Інститут рослинництва ім. В.Я. Юр'єва, Національний центр генетичних ресурсів рослин України видав це свідоцтво на ознакову колекцію генофонду рицини звичайної, що включає 228 зразків. Зразки колекції походять з 34 країн.

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Fig. 7. Certificate of registration of the basic castor oil collection.

difference in safflower under the influence of agroecological conditions only in plant height, while yield was at the same level of 1.4 t/ha (Licata *et al.*, 2023). In a study of only two varieties Olas and Linas, plant height fluctuations from 82.3 to 158.7 cm were noted, and the number of baskets per plant from 4.15 to 9.47 pieces. (El Bey *et al.*, 2021).

The number of capitula is a highly variable trait, which depends on the density of the plants, but with normal sowing in our accessions values ranged from 6 to 33 lateral capitula. The diameter of the basket in the collection was observed from 18 to 37 mm on average per sample. The diameter of the basket was measured only on the largest basket of one plant, which was usually central, or adjacent to the central one, as we observed injury or absence of the central basket. High-yielding accessions were characterized by a capitulum diameter of at least 25 mm, but the largest basket size does not always correspond to high yield and the largest size of 33 mm was observed in several late-ripening accessions that cannot show their potential in our conditions. Such accessions mainly leave the rosette stage later, have dark green and large leaves.

In the collection, safflower accessions differed quite a lot in the weight of 1000 seeds. From a rather small 30 g to the largest, which in some years was as much as 71 g in breeding specimens 92/1a and D6 (Fig. 8). In studies by other authors, the variability of this indicator was significantly lower, from 34.65 to 47.69 g (El Bey *et al.*, 2021)

Important for future cultivation is the presence of seed quality. Qualities include huskiness, oiliness and oil composition. We also studied these parameters during the years of cultivation. The general definition of oiliness in seeds shows variability in different accessions in individual years from 11% to 38%. Other researchers observed oil content from 20.6 to 41.07% (El Bey *et al.*, 2021; Licata *et al.*, 2023; Thoday-Kennedy *et al.*, 2023; Erbas *et al.*, 2024).

In terms of oil composition, the analyses show mainly the classic oil content, where the content of oleic acid ranges from 8 to 17%, linoleic from 74 to 84%, palmitic from 3.8% to 7%. In small quantities of less than 1%, linolenic and myristic acids are also observed. When determining acids, myristic is quite volatile and is well determined in fresh accessions. Other studies show the presence of a high-oleic type of oil in safflower up to 74.5% (Thoday-Kennedy *et al.*, 2023). Unfortunately, no such accessions were obtained in our collection. Individual plants that showed an increased content of oleic acid did not show stable expression and, accordingly, the highest content of oleic acid in individual accessions only approached 40%.

In 2016–2017, an experiment was conducted to determine the content of the main classes of substances in seeds: protein, carbohydrates, fat, husk and the composition of acids in the oil. Several of the most interesting accessions from this experiment and their results are presented in Table 3.

This table presents selected accessions of our own selection, which had the most interesting results. Thus, the lowest huskiness was found in 48% in sample 129/k. In the experiment with 32 accessions studied for huskiness, an average huskiness of up to 61% was observed. At that time, the carbohydrate content obtained from a portion of ground seeds ranged from 39 to 50%. No accessions with reduced husk content were identified in our collection, as reported by URIE, AL (URIE, 1986). The protein content was in the range from 13.8 to 20.0%. The accessions were selected for their oil content during the selection process, so oil content in the presented accessions started from 24%. The highest oil content was observed in the Zhivchik variety, which was in the register of plant varieties of Ukraine until 2025. The yield in 2016–2017 for the selected accessions was quite moderate, the highest at 1.95 t/ha was observed in the Hercules sample. But the most interesting selected accessions were in terms of oil composition. It was observed Sample 16 had less linoleic acid and up to 30% oleic acid.

According to the general characteristics, the Hercules sample was found in 2016–2017 with a high yield, husk content of 51%, and oil content of 27%. The subsequent crosses and selections allowed creating a new safflower variety Dobrynya.

Selected lines developed through breeding and supported by genetic resources allowed creating a genetic collection of safflower by morphological characteristics, which contains 25 accessions originating from 4 countries and information was provided on 24 characteristics and 71 gradations. The conducted studies on the genetics of morphological traits were published as separate studies (Leus and Vedmedeva, 2012; Leus, 2015, 2016) and summarized in a monograph

Table 2. The best yielding safflower samples from the IOC NAAS collection, average data for 2015, 2016, 2024, 2025.

Accessions name	ACCENUMB	Yield assessment ± SE т/g	Head diameter ± SE, sm	Place of attachment of the first branch above the ground ± SE	Plant height ± SE, sm	Number of head per plant ± SE	Weight 1000pcs ± SE,g
BPK 2	UE0900049	1.72 ± 0.38	3.2 ± 0.05	46 ± 6.7	80 ± 4.2	8 ± 1.1	46 ± 1.7
K120 (K-250)	UE0900024	1.95 ± 0.51	2.5 ± 0.07	46 ± 3.9	98 ± 2.0	15 ± 1.5	40 ± 1.8
K503	UE0900066	2.01 ± 0.55	2.8 ± 0.07	68 ± 4.1	92 ± 2.4	8 ± 1.5	55 ± 4.2
Obrazets 14	UE0900020	2.17 ± 0.66	2.8 ± 0.08	42 ± 2.8	93 ± 1.8	14 ± 0.9	42 ± 1.2
Belotsvetkovyy ne kolyuchiy	UE0900035	2.30 ± 0.51	2.7 ± 0.16	42 ± 5.6	79 ± 6.8	19 ± 4.1	37 ± 1.1
K515	UE0900027	2.30 ± 0.58	3.1 ± 0.06	47 ± 7.4	90 ± 2.2	13 ± 2.5	56 ± 3.9
Solnechnyy 3	UE0900017	2.31 ± 0.15	3.1 ± 0.06	28 ± 3.4	84 ± 2.1	12 ± 1.4	39 ± 2.3
K140	UE0900025	2.33 ± 0.50	2.8 ± 0.06	37 ± 5.7	90 ± 2.3	14 ± 1.5	55 ± 0.9
K504	UE0900058	2.39 ± 0.25	2.5 ± 0.09	63 ± 2.3	92 ± 1.8	14 ± 2.3	40 ± 1.0
K533 Gila	UE0900064	2.47 ± 0.59	2.7 ± 0.08	50 ± 6.0	83 ± 1.4	7 ± 1.2	47 ± 1.3
K549 Safflire	UE0900063	2.50 ± 0.51	2.5 ± 0.09	37 ± 4.9	81 ± 3.7	12 ± 2.7	52 ± 3.6
Saflor 180	UE0900006	2.52 ± 0.58	3.1 ± 0.14	32 ± 4.8	98 ± 1.8	33 ± 0.9	50 ± 2.3
Chimkent	UE0900067	2.52 ± 0.48	2.6 ± 0.05	41 ± 2.8	75 ± 0.7	11 ± 0.3	44 ± 0.6
Dobrynya	UE0900053	2.54 ± 0.20	2.6 ± 0.05	55 ± 3.6	90 ± 2.3	13 ± 3.7	52 ± 3.6
K331 Orange de Marocco	UE0900062	2.59 ± 0.55	2.5 ± 0.04	48 ± 5.3	90 ± 1.4	8 ± 0.0	45 ± 2.1
K501	UE0900059	2.70 ± 0.21	2.6 ± 0.08	59 ± 5.3	105 ± 2.6	12 ± 3.6	39 ± 2.0
K463	UE0900061	2.94 ± 0.56	2.7 ± 0.08	44 ± 2.2	82 ± 1.5	9 ± 1.2	29 ± 3.2
Gerkules	UE0900050	3.00 ± 0.39	2.9 ± 0.04	47 ± 3.3	86 ± 2.7	11 ± 1.4	29 ± 3.4
Krasnotsvetushchiy	UE0900019	3.00 ± 0.26	2.7 ± 0.06	45 ± 2.4	93 ± 2.3	14 ± 0.9	27 ± 3.0
K497	UE0900060	3.05 ± 0.15	2.9 ± 0.05	59 ± 4.9	95 ± 1.4	9 ± 0.6	29 ± 1.7
K69 (K-569)	UE0900023	3.05 ± 0.55	2.7 ± 0.08	29 ± 3.1	83 ± 2.6	22 ± 1.2	38 ± 3.4
Type III Sum of Squares		11.13	14.76	15967.3	18446.77	8550.99	5560.64
df		20	20	20	20	20	20
Mean Squares		0.56	5.7	665.3	376.46	181.94	427.74
F		4.08	9.65	3.12	15.1	15.86	19.06
$p <$		0.001	0.01	0.001	0.001	0.001	0.001
η^2		0.58	0.58	0.26	0.88	0.89	0.79

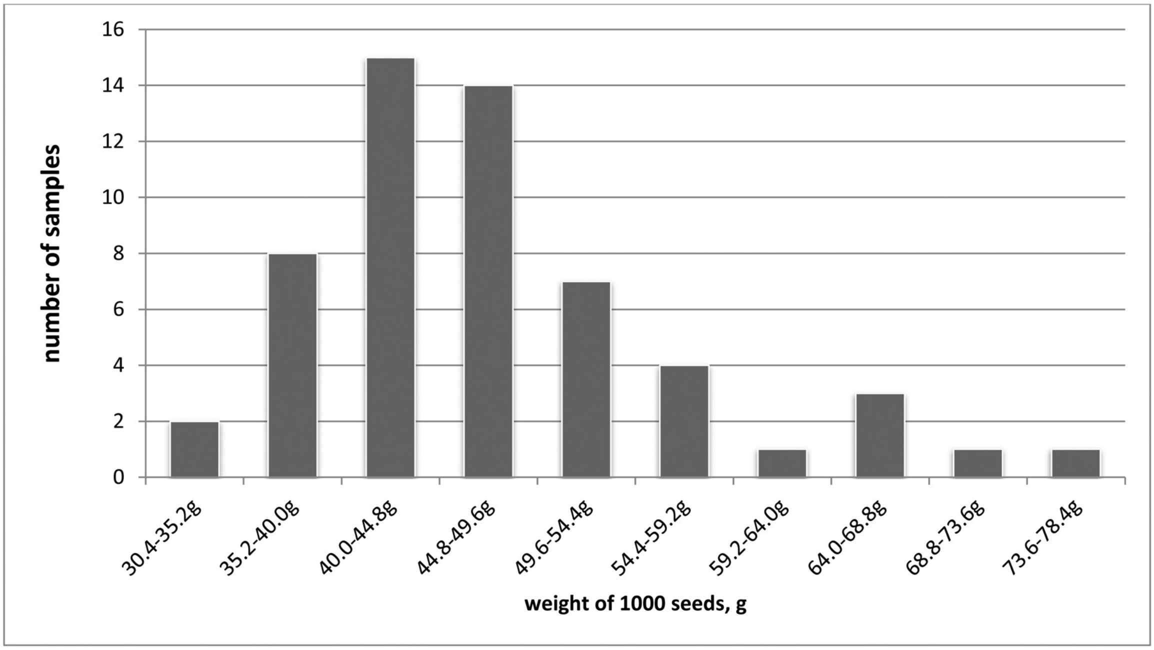

Fig. 8. Distribution of safflower collection by weight of 1000 seeds.

Table 3. Composition of safflower seed samples from the 2016–2017 seed quality experiment.

0	Yield assessment т/ga	Seed oil content, %	Palmitic acid content in oil %	Stearic acid content in oil, %	Oleic acid content in oil, %	Linoleic acid content in oil, %	Protein content, %	Carbohydrate content in seeds, %	Seed huskiness, %
129/к	0.60 ± 0.13	33 ± 1.8	5 ± 0.3	1 ± 0.0	10 ± 0.8	83 ± 1.2	18.7 ± 0.8	39.0 ± 0.9	48 ± 0.4
Bogatyr	1.22 ± 0.29	28 ± 1.0	7 ± 0.2	2 ± 0.1	15 ± 0.7	76 ± 1.0	20.0 ± 0.4	49.4 ± 0.7	54 ± 0.6
Gerkules	1.95 ± 0.39	27 ± 2.2	6 ± 0.2	1 ± 0.2	13 ± 0.9	80 ± 1.1	13.8 ± 0.7	47.9 ± 0.8	51 ± 0.3
Zhivchik	1.10 ± 0.27	32 ± 0.2	7 ± 0.4	2 ± 0.1	14 ± 0.5	78 ± 0.9	14.6 ± 0.3	45.2 ± 0.8	49 ± 0.3
Lagidnyy	1.72 ± 0.60	24 ± 4.1	6 ± 0.6	2 ± 0.3	11 ± 2.6	63 ± 5.1	15.1 ± 0.9	50.5 ± 0.9	53 ± 0.4
Obrazets 16	1.30 ± 0.35	29 ± 1.8	8 ± 0.4	4 ± 0.7	30 ± 0.5	57 ± 0.5	15.3 ± 0.5	43.8 ± 0.9	50 ± 0.4
Solnechnyy	1.10 ± 0.26	26 ± 4.6	6 ± 0.4	1 ± 0.2	12 ± 3.1	61 ± 4.5	16.2 ± 0.4	47.2 ± 0.9	52 ± 0.3

(Vedmedyeva *et al.*, 2022). As a result of this work, a number of lines with morphological marker traits with an established inheritance pattern were created: with red flower corolla color (Rosochka, BOPK2, Rassvet, 129/k); with dark orange flower corolla color (Ogonyok, Kurchavy); with light orange flower corolla color (Iskorka); with three types of yellow flower color (Medovyi, Medovyi 1, 157/1, Salyut); with white flower corolla color (Belotsvetkovyi Nekolyuchy); with pale yellow flower corolla (Yantar); with light green leaf color (Honey, Curly); with green leaf color (Rosochka, 157/1, Salyut); prickly with sharp leaflets of the wrapper and sharp leaves on the stem (BOPK2); non-thorny with round leaflets of the wrapper and round leaves on the stem (Rosochka); non-thorny with sharp leaflets of the wrapper and sharp leaves on the stem (Iskorka, Belotsvetkovy non-thorny); non-thorny with round leaflets of the wrapper and sharp leaves on the stem (Salyut, Rassvet); weakly prickly with thorns at the ends and along the edge of the leaf and sharp leaflets of the wrapper and sharp leaves on the stem (Kurchavy); weakly spiny with spines at the ends of the leaf and sharp leaflets of the wrapper and leaves on the stem (157/1).

Table 4 presents examples of the source of the corresponding manifestation of morphological characters.

In world research and publications, there are known publications on establishing the inheritance of individual traits (Narkhede *et al.*, 1984; Golkar *et al.*, 2009;Golkar and Karimi, 2019), which have never been published in the form of collections. Therefore, our generalized collection is quite interesting material for future selection.

4 Conclusions

The study summarizes long-term collection and breeding research on castor bean and safflower conducted at the Institute of Oilseed Crops of the NAAS. Both crops demonstrate high potential for cultivation under conditions of climate change. Safflower can provide stable yields of

Table 4. List of characteristics by which a genetic collection was created by morphological characteristics.

VOS /UPOV	Characteristics	Degree of manifestation	Note	Example varieties	ACCENUMB
8/6	Time of flowering	early	3	Ogonok	UE0900040
		medium	5	Solnechnyy	UE0900017
		late	7	Salyut Belotsvetkovyy nekolyuchiy	UE0900035
		very late	9	C-1 N4	UE0900011
9/*	Plant: height of first branching point	very short	1	Ogonok	UE0900040
		short	3	Belotsvetkovyy kolyuchiy 157/1	UE0900032 UE0900046
		medium	5	Solnechnyy	UE0900017
		tall	7	Belotsvetkovyy nekolyuchiy Rozochka	UE0900035 UE0900038
		very tall	9	Salyut	UE0900051
10/7	Plant: height	very short	1	Ogonok 157/1	UE0900040 UE0900046
		short	3	Herkules	UE0900050
		medium	5	Solnechnyy Lagidnyy	UE0900017 UE0900052
		tall	7	Iskorka Kurchavyy	UE0900043 UE0900044
		very tall	9	Salyut 129/к	UE0900051 UE0900045
11/8	Plant: length oflongest side branch	short	3	Rozochka Salyut	UE0900038 UE0900051
		medium	5	Lagidnyy Ogonok Bogatyr'	UE0900040
		long	7	Rassvet	UE0900042
*	Upper leaf: number of spines	absent or very few	1	Rozochka Belotsvetkovyy nekolyuchiy	UE0900038 UE0900035
		few	3	Ogonok	UE0900040
		medium	5	BPK2 Syria Aleppo	UE0900049 UE0900030
		many	7	129/к	UE0900045
12/9	Petal: color	white	1	Belotsvetkovyy kolyuchiy	UE0900032
		yellow	2	Medovyy C-1 N3	UE0900039 UE0900010
		orange	3	Ogonok	UE0900040
		червона	4	Rozochka	UE0900038
14/11	Leaf: length	medium	5	Л64	UE0900041
		long	7	129/к	UE0900045
15/12	Leaf: width	medium	5	Л64	UE0900041
		broad	7	129/к	UE0900045
18/15	Leaf: number ofspines	absent or very few	1	Zhyvchyk	UE0900033
		very many	9	C-1 N3	UE0900010
20/17	Bract: length	short	3	Salyut	UE0900051
		medium	5	Bogatyr'	UE0900048
		long	7	K-569 Kurchavyy 89/1	UE0900031 UE0900044 UE0900047

Table 4. (continued).

VOS /UPOV	Characteristics	Degree of manifestation	Note	Example varieties	ACCENUMB
21/18	Bract: width	medium	5	Bogatyr'	UE0900048
				Salyut	UE0900051
		broad	7	K-569	UE0900031
				89/1	UE0900047
22/19	Bract: ratio length/width	low	3	Salyut	UE0900051
		c medium	5	Bogatyr'	UE0900048
		high	7	Kurchavyy	UE0900044
23/20	Bract: number of spines	absent or very few	1	Zhyvchyk	UE0900033
		few	3	89/1	UE0900047
		medium	5	157/1	UE0900046
		many	7	BPK2	UE0900049
		very many	9	C-1 N3	UE0900010
*	Inflorescence: shape of involucral bracts	sharp	1	Belotsvetkovyy nekolyuchiy	UE0900035
				Ogonok	UE0900040
		rounded	3	Rozochka	UE0900038
24/22	Petal: change of color	absent	1	Belotsvetkovyy kolyuchiy	UE0900032
		present	9	K 262, Milyutinskiy 114	UE0900016
25/22	Seed: 1000 seedweight	very low	1	Belotsvetkovyy nekolyuchiy	UE0900035
		low	3	L64	UE0900041
		medium	5	Iskorka	UE0900043
				Medovyy	UE0900039
		high	7	C – 1 5, 129/K	UE0900012
					UE0900045
		very high	9	Bogatyr'	UE0900048
				Herkules	UE0900050
26/*	Seed: by size	low	3	C-1 N3	UE0900010
		medium	5	Belotsvetkovyy kolyuchiy	UE0900032
		high	7	Bogatyr'	UE0900048
28/*	Seed: oil content	low	3	K569	UE0900031
		high	7	C – 1 5	UE0900012
*	Head: diameter	low	1	Belotsvetkovyy kolyuchiy	UE0900032
				Iskorka	UE0900043
		large	3	BPK2	UE0900049
*	Head: number per plant	few	1	C – 1 5	UE0900012
		many	3	Salyut	UE0900051
*	Plant: number of first-order branches	few	1	Bogatyr'	UE0900048
		many	3	L64	UE0900041
*	Plant: number of leaves on main stem	few	1	BPK2	UE0900049
		many	3	129/K	UE0900045UE0900051
				Salyut	
13/10	Leaf: intensity ofgreen colour	very dark	5	Belotsvetkovyy nekolyuchiy	UE0900035
		medium	3	Ogonok	UE0900040
		light	2	Medovyy	UE0900039

* There is no description of the feature in the documents.

edible oil under arid conditions, while castor bean offers a unique source of technical and medicinal oil with exceptional fatty acid composition. The evaluated collections constitute a valuable foundation for future breeding and international cooperation.

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Conflicts of interest

The authors declare that they have no conflicts of interest concerning this work.

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