https://doi.org/10.26898/0370-8799-2023-4-4 Тип статьи: оригинальная
УДК: 631.633.521 Type of article: original

МИРОВЫЕ ГЕНЕТИЧЕСКИЕ РЕСУРСЫ ЛЬНА КОЛЛЕКЦИИ ВИР В СОЗДАНИИ СОРТОВ ТОМСКОЙ СЕЛЕКЦИИ

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Представлены результаты изучения 30 образцов льна различного эколого-географического происхождения из коллекции Всероссийского института генетических ресурсов растений им. Н.И. Вавилова (ВИР). Исследованы сорта российской селекции – 14, китайской – 6, украинской – 5, французской – 4, белорусской – 1. Установлено влияние генотипов и погодных условий на проявление хозяйственных признаков многофакторным дисперсионным анализом. Полевые исследования проводили в подтаежной зоне Томской области в 2015–2017 гг. Природно-климатические условия соответствовали требованиям возделывания льна-долгунца. Лучшими по общей и технической длине стеблей отмечены сорта китайской селекции Heiya 4 (К-8485), Sxy 7 (К-8689), российский гибрид Томский 16*Успех (К-8544), французский сорт Drakkar (К-8493), украинский – Глазур (К-8695), 66–72 и 60–66 см соответственно, достоверно выше стандарта Томского 16. По содержанию волокна в технической части стеблей (38–40%) лидировали сорта: российской селекции П-3989 (К-8672), А-236 (К-8692), М-249 (К-8693), французской – Alizee (К-8494), Agatha (К-8492), Melina (К-8495), украинской – Вручий (К-8694), достоверно выше стандарта Томского 16. По массе волокна (91–104 мг) – французские сорта Drakkar (К-8493) и Alizee (К-8494), украинские – Вручий (К-8694) и Глазур (К-8695), российские – А-236 (К-8692) и М-249 (К-8693) – достоверно превосходили стандарт Томский 16 на 6–44 мг. Сорта льна российской селекции П-3989 (К-8672), Добрыня (К-8504), А-236 (К-8692), китайской – Heiya 4 (К-8485), Heiya 13 (К-8486), Tyy 13 (К-8687), французской – Agatha (К-8492), Drakkar (К-8493), Alizee (К-8494), Melina (К-8495), украинской – Гладиатор (К-8505) и Вручий (К-8694) – признаны перспективными и включены в селекционный процесс в качестве отцовских родительских форм. Полученный гибридный материал находится на испытании в питомнике отбора с 2017 г. и второго года селекции с 2021 г.

Ключевые слова: лен-долгунец (*Linum usitatissimum* L. *f. elongata*), селекция, коллекция, сорта, продуктивность, волокно, семена, мыклость

WORLD'S GENETIC RESOURCES OF THE VIR FLAX COLLECTION IN THE CREATION OF TOMSK SELECTION VARIETIES

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The results of the study of 30 flax samples of different ecological and geographical origin from the collection of the N.I. Vavilov All-Russian Institute of Plant Genetic Resources (VIR) are presented. The varieties of the Russian selection - 14, Chinese - 6, Ukrainian - 5, French - 4, Belarusian - 1 have been investigated. The influence of genotypes and weather conditions on the manifestation of economic traits by multivariate analysis of variance has been established. Field studies were conducted in the sub taiga zone of the Tomsk region in 2015-2017. Natural and climatic conditions met the requirements for the cultivation of fiber flax. By total and technical stem length the best varieties of the Chinese selection Heiya 4 (K-8485), Sxy 7 (K-8689), the Russian hybrid Tomsky 16*Uspekh (K-8544), the French variety Drakkar (K-8493), the Ukrainian - Glazur (K-8695), 66-72 and 60-66 cm respectively, were significantly higher than the standard Tomsky 16. According to the fiber content in the technical part of the stems (38-40%) the following varieties were the leaders: the Russian selection P-3989 (K-8672), A-236 (K-8692), M-249 (K-8693), the French selection Alizee (K-8494), Agatha (K-8492), Melina (K-8495), and the Ukrainian selection Vruchy (K-8694), were significantly above the Tomsky 16 standard. By the fiber mass (91-104 mg) the French varieties Drakkar (K-8493) and Alizee (K-8494), the Ukrainian varieties Vruchii (K-8694) and Glazur (K-8695), the Russian varieties A-236 (K-8692) and M-249 (K-8693) reliably exceeded the Tomsky 16 standard by 6-44 mg. The flax varieties of the Russian selection P-3989 (K-8672), Dobrynya (K-8504), A-236 (K-8692), the Chinese - Heiya 4 (K-8485), Heiya 13 (K-8486), Tyy 13 (K-8687), the French - Agatha (K-8492), Drakkar (K-8493), Alizee (K-8494), Melina (K-8495), and the Ukrainian Gladiator (K-8505) and Vruchiy (K-8694) were recognized as promising and were included in the breeding process as male seed parents. The resulting hybrid material has been on trial in the selection nursery from 2017 and the second year of breeding from 2021.

Keywords: fiber flax (*Linum usitatissimum* L. *f. elongata*), breeding, collection, varieties, productivity, fiber, seeds, stem slenderness (the ratio between the stem length and the diameter)

Для цитирования: *Попова Г.А., Рогальская Н.Б., Трофимова В.М.* Мировые генетические ресурсы льна коллекции ВИР в создании сортов Томской селекции // Сибирский вестник сельскохозяйственной науки. 2023. Т. 53. № 4. С. 34–47. https://doi.org/10.26898/0370-8799-2023-4-4

For citation: Popova G.A., Rogalskaya N.B., Trofimova V.M. World's genetic resources of the VIR flax collection in the creation of Tomsk selection varieties. *Sibirskii vestnik sel'skokhozyaistvennoi nauki = Siberian Herald of Agricultural Science,* 2023, vol. 53, no. 4, pp. 34–47. https://doi.org/10.26898/0370-8799-2023-4-4

Конфликт интересов
Авторы заявляют об отсутствии конфликта интересов.
Conflict of interest
The authors declare no conflict of interest.

INTRODUCTION

Historically, flax has remained the main and leading fiber and oil crop in Russia for a long time, being highly adapted to cultivation in moderate climates and its specific soil and climatic conditions. Russia has been the largest global producer and exporter of natural flax fiber and fabrics for a significant period. To ensure the country's economic and strategic independence, it is important to preserve domestic cellulose fiber raw materials, which can significantly contribute to cotton import substitution [1]. In modern flax varieties, cellulose can account for up to 90% of the fiber content. Despite the annual decrease in flax cultivation, it remains the main source of annually renewable fibers in the Russian Federation [2, 3].

Modern flax breeding continues to focus on improving the quality of flax products. The success of the breeding work in creating new varieties relies on the effectiveness of a scientifically based approach to the selection of initial material and its evaluation under specific soil and climatic conditions[1].

To enrich the genetic material in flax breeding, the Siberian Research Institute of Agriculture and Peat - branch of the Siberian Federal Scientific Centre of Agro-BioTechnologies of the Russian Academy of Sciences (SibNIISHiT - SFSCA RAS) – is establishing a nursery for the ecological testing using the samples from the main Russian collections of the VIR and the Federal Research Center for Bast Fiber Crops (FRC BFC).

For a long time in Russian flax breeding, including during the development of the first Tomsk varieties, local thickset flax was used as the initial material [4]. In the early 20th century, high-fiber lines were selected from local Siberian flax, which served and continue to serve as genetic material in creating new varieties with increased fiber content. The drawback of the early Siberian varieties was that they had coarse, low-quality fiber, with a long fiber num-

[1]*Pavlova L.N., Gerasimova E.G., Rumyantseva V.N.* Innovative techniques in the selection of fiber flax // Flax breeding: current state and prospects for development: materials of the interregional scientific-practical conference with international participation, dedicated to the 80th anniversary of the Tomsk school of fiber flax breeding. FASO, SibNIISKhit - branch of SFSCA RAS. Tomsk: LLC "Grafika", 2017. pp. 43–46.

ber of 9-10. In the second half of the 20th century, the inclusion of a set of collection samples and varieties from the VIR (N. I. Vavilov All-Russian Institute of Plant Genetic Resources) and the All-Russian Flax Research Institute (VNIIL) allowed for the expansion of genetic diversity and the development of a range of early-maturing Tomsk varieties[2].

The obtained varieties inherited a high fiber content and acquired improved fiber quality (long fiber number of 11-14). Modern Tomsk varieties of flax are included in the State Register of Breeding Achievements of the Russian Federation and are adapted to the Northwestern, Central, Volga-Vyatka, and West Siberian regions, with some varieties being suitable for all regions (for example, Tomich 3, indicating its high adaptive potential).

Modern flax varieties are subject to high requirements for fiber quality, resistance to biotic and abiotic environmental factors, and adaptive potential [5]. Many varieties with high fiber quality indicators have been developed in Russia[3].

The State Register of Breeding Achievements approved for use in the territory of the Russian Federation has been expanded with Tomsk varieties such as Pamyati Krepkova (included in 2012), Tomich (2017), Tomich 2 (2019), and Tomich 3 (2022)[4].

The development of flax varieties with a high fiber content has led to changes towards a deterioration of the structural and morphological qualities of the plants. The increased fiber productivity of the new varieties has resulted in a decrease in technological spinning indicators such as flexibility, fineness, strength, and uniformity of fiber distribution along the stem length, as well as a deterioration in the anatomical structure of the stem, including an increase in the diameter of elementary fibers by almost 50% and a reduction in their length[5] [5].

Researchers have noted a deterioration in the chemical composition of the fiber, as well as a decrease in pectin substances, which affects the spinning properties of the yarn. Therefore, improving the fiber quality in the new varieties is a top priority for Russian breeders.

In addition to these factors, changes in temperature trends have been observed in Siberia since the early 2000s. The climate in the entire subtaiga of the West Siberian Plain has been warming from 1936 to 2015 [6]. During the vegetative period of fiber flax, there is an increasing occurrence of temperature fluctuations and uneven precipitation, especially during critical growth phases. Heavy rains and gusty winds lead to soil overhydration, lodging of flax crops, and the development of diseases, which in turn reduce the quantity and quality of flax products.

The influence of growing conditions on the manifestation of economically valuable traits in flax has been thoroughly studied [7]. The majority of these studies focus on individual factors that affect the physiological processes of plant growth and development. The expression of most traits depends not on a single factor but on the overall system. It has been previously established that the geographical conditions during flax cultivation in different natural-climatic zones influence morphological characteristics. For example, increased temperature and insufficient moisture reduce plant height, fiber yield and quality, seed size, but increase inflorescence length and the number of capsules [8]. Fiber flax plants acquire the habitus of oil flax-intermediate type.

When developing new varieties, it is important to consider their ability to provide high and

[2]Michkina G.A., Rogalskaya N.B., Popova G.A. History of breeding of Tomsk fiber flax. Development of N.I. Vavilov scientific heritage at the present stage: materials of the international scientific conference devoted to the 120th anniversary of the birth of Academician N.I. Vavilov (Novosibirsk, December 19, 2007). Rosselkhozakademia. Siberian Branch. Novosibirsk, 2009. pp. 148–155.

[3]*Kutuzova S.N., Brach N.B., Tikhvinsky S.F., Doronin S.V., Sharov I.Y., Pitko A.G.* Geographical variability of economically valuable traits of flax // Proceedings on applied botany, genetics and breeding. 1991. Vol. 144. pp. 40–48.

[4]The State Register of Breeding Achievements admitted to use (plant varieties): //gossortrf.ru/ wp-content/uploads/2022/06/ Реестр%20на%20допуск%202022.pdf (accessed on 18.11.2022).

[5]*Pavlova L.N.* Variety - the basis of successful development of flax production // The role of flax in improving the habitat and active longevity of man. Materials of the international seminar. Tver, 2012. pp. 51–55.

stable productivity, as well as ecological plasticity and resistance to a complex set of biotic and abiotic environmental factors under unfavorable agroclimatic conditions [8].

Analysis of the results of fiber flax breeding conducted by N.B. Brach[6] and colleagues from 1932 to 2000 demonstrated that increasing the diversity of the initial material allows overcoming undesirable correlations between the traits and achieving a combination of high economic indicators. It has been established that plant length is one of the key traits that influence the mass of technical fiber and fiber content [7]. The most stable indicator, least dependent on weather conditions, harvesting time, and primary processing methods, is the total fiber content (see footnote 3).

Extensive genetic collections of the VIR and the FRC BFC are the only accessible sources of new collection samples and varieties of flax with diverse eco-geographical origins.

The purpose of the research is to study high-fiber samples and varieties of fiber flax from the global collection of the VIR under the conditions of the subtaiga zone of the Tomsk region, focusing on the productivity of flax fiber and seeds, and to identify promising initial material for inclusion in the breeding process.

MATERIAL AND METHODS

The study utilized 30 samples of cultivated flax (*Linum usitatissimum* L.) from the global VIR collection with diverse eco-geographical origins. The samples consisted of 14 Russian varieties, 6 Chinese varieties, 5 Ukrainian varieties, 4 French varieties, and 1 Belarusian variety.

Field research was conducted from 2015 to 2017 at the Bogashevsk branch of the SibNIISHiT – branch of the SFSCA RAS, located in the subtaiga zone of the Tomsk district in the Tomsk region.

The Tomsk region is situated in the taiga zone of the southeastern part of the West Siberian Plain, and its climate is characterized as continental-cyclical [7, 8].

In the subtaiga zone, the frost-free period lasts on average 115 days, and the multi-year sum of average daily temperatures above 10 °C is 1700°; precipitation during the vegetation period amounts to 200-220 mm, approximately half of the annual norm. According to agroclimatic zoning, the research area belongs to the 5th agroclimatic zone and is characterized as moderately warm and moderately humid. The hydrothermal coefficient (HTC) according to T.K. Selyaninov ranges from 1.1 to 1.6 (see footnote 8) [6]. Despite being located in a region with excessive moisture, there can be periods of drought and dry winds. Overall, the agroclimatic resources of temperature and moisture are close to optimal conditions and meet the requirements for cultivating fiber flax.

The analyzed period of the research covers years with different meteorological conditions. In 2015, there was sufficient moisture and thermal resources (HTC - 1.38), while 2016 belonged to the moderately humid type (HTC – 1.14). The highest amount of precipitation occurred in 2017, indicating excessive moisture (HTC – 1.50). Overall, the moisture supply during the vegetation periods was characterized by sufficient moisture and heat for the growth of fiber flax (see fig. 1)[9]. The soil cover of the experimental plots consisted of medium-podzolic loamy soils[10]. The plowed horizon had a weakly acidic to near-neutral soil solution reaction (pH-water: 5.9 – 6.1), and as the horizons descended, the soil contained carbonates.

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[6] *Brutch N., Pavlov A., Porokhovinova E. et. al*. The role of initial material in the results flax breeding in Soviet Union and Russia from 1932 till 2000. // Innovative technologies for comfort: Proceedings of the 4th global workshop (general consultation) of the FAO/ESCORENA European co-operative research network on flax and other bast plants. 7–10 October 2007. Arad, Romania. pp. 43–44.

[7] Agroclimatic resources of the Tomsk region. Reference book. L.: Gidrometeoizdat, 1975. 148 p.

[8] *Azmuka T.I.* Climate Resources. Natural resources of the Tomsk region. Tomsk: Tomsk University Publishing House, 1991. pp. 83–103.

[9] http://www.pogodaiklimat.ru/ Weather and Climate.

[10] *Solovyova T.P., Makeeva E.A., Popova G.A.* The state of agrosulfurous old plowed soils of the Basandaika River / Flax growing: current state and prospects of development: materials of the interregional scientific-practical conference with international participation, dedicated to the 80th anniversary of the Tomsk school of fiber flax breeding. FASO, SibNIISKhit - branch of SFSCA RAS. Tomsk: LLC "Grafika", 2017. pp. 141–149.

The gross humus content in the plowed horizon varied from 4 to 6%. The main soil nutrients, available phosphorus and exchangeable potassium, were present in sufficient quantities for the cultivation of fiber flax (25-27 mg/100 g). Flax is grown in a seven-field crop rotation, with preceding crops being grains such as wheat, oats, and barley.

The analysis of morphological characteristics and determination of fiber content in stems were carried out on the plants grown under field conditions using a square planting method with a feeding area of 2.5 × 2.5 cm in a leveled agricultural background. To assess fiber productivity, the following morphological characteristics were determined: total stem length (distance from the attachment point of the cotyledonary leaves to the beginning of the inflorescence branching (cm), stem diameter (mm), fiber mass (mg), and fiber content (%) in the technical part, determined by the ratio of the fiber mass to the stem mass. The stem slenderness (cm/mm) was determined by dividing the technical stem length by its average diameter[11,12]. Seed productivity was evaluated based on the number of the capsules per plant (pcs.) and the seed mass within them (mg). Fiber extraction was carried out from the dam retting flax straw obtained by thermal retting[13]. The regionally adapted variety Tomsky 16 (T-16) was used as a standard for morphological characteristics that determine fiber or seed productivity. The normality of feature distributions was tested using the Kolmogorov-Smirnov test. One-way analysis of variance (ANOVA) and Duncan's test were used to compare morphological characteristics of hybrids. Multifactorial analysis of variance was conducted to determine the proportion of factor influence.

RESULTS AND DISCUSSION

Drought during critical periods of growth and development of the crop is one of the limiting factors in obtaining a guaranteed high-quality flax fiber yield. The vegetative period of flax from emergence to flowering is critical in terms of moisture requirements. It has been proven that conditions of increased moisture have a positive effect on the quantity and quality of fiber in fiber flax stems [9].

While overall the amount of heat and moisture for the flax crop during the observed years

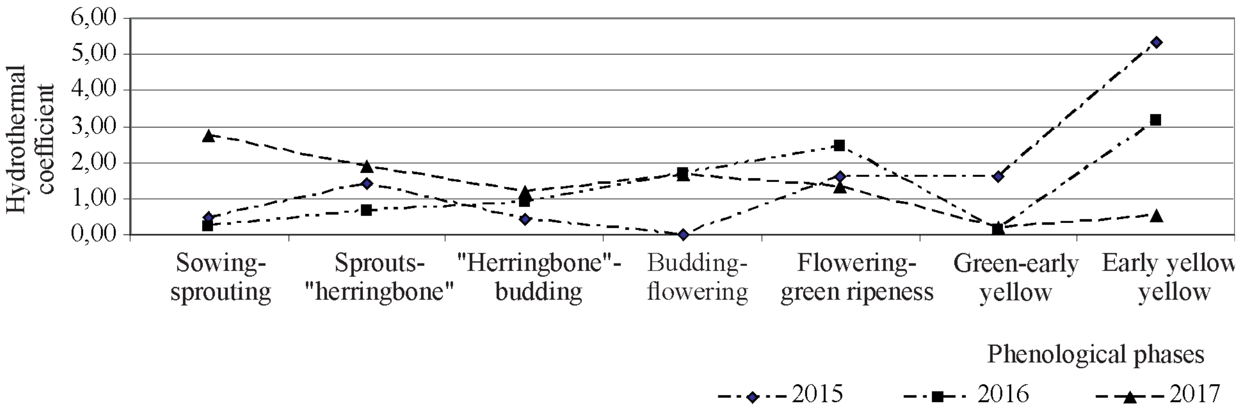

Рис. 1. Гидротермический коэффициент вегетационного периода по фазам роста льна-долгунца в 2015–2017 гг. в Томской области

Fig. 1. Hydrothermal coefficient of the growing season according to the growth phases of flax in 2015–2017 in the Tomsk region

[11]GOST R 52784-2007. Fiber flax. Terms and definitions. Moscow: Standards Publishing House. 2009. 21 p.

[12]*Solov'ev A.Ya.* Flax growing. M.: Agropromizdat, 1989. 320 p.

[13]Methodological guidelines for technological evaluation of flax straw and experiments on primary processing of flax. Torzhok, 1972. 58 p.

(2015-2017) was considered sufficient, the specific distribution of precipitation and temperature regime showed a rather uneven nature. The integral indicator of plant moisture supply assessment (HTC) for the formation of high-stem fiber flax should be in the range of 1.3-1.6[14].

The 2015 vegetation period was characterized by the HTC value of 1.38, indicating sufficient moisture supply and thermal energy, but with an uneven distribution throughout the season during critical phases of flax water consumption. The period of active growth of flax during the "herring bone" stage – flower-bud formation stage, which is crucial for the potential formation of stems and fiber bundles, occurred under insufficient moisture. From sowing to flowering, only 68 mm of precipitation was recorded, with only 9 mm available during the phase of stem formation and fiber deposition, negatively affecting the linear dimensions of the stem and the yield of flax straw.

Optimal conditions for seed productivity are considered to be precipitation during the period after flowering and during the ripening phase (green-yellow ripeness), with a sufficient amount of 70-80 mm. However, there was an excess of precipitation with 120 mm actually recorded. Excessive moisture after flowering prolonged the ripening process and increased the duration of the vegetative period. The conditions of the year differed from the optimal moisture supply due to unfavorable distribution throughout the vegetative period.

In the moderately humid year of 2016, the HTC was 1.14, and the conditions for growth and yield formation of fiber and seeds were similar to the previous year of the study. Insufficient moisture and heat were noted prior to flowering. Elevated air temperatures and the absence of rainfall in June accelerated the passage of the "herring bone" – flower-bud formation stage, and the stem formation occurred under inadequate precipitation conditions. As a result, flax flowering started 5-7 days earlier than the average. The beginning of the first ten-day period of July was characterized by optimal air temperatures and sufficient rainfall, which further contributed to increased seed productivity. The weather conditions in the second ten-day period of July, with high air temperatures (up to 30°C) and almost daily precipitation, led to soil over moistening. Overall, the temperature and moisture conditions during the growth and development periods of flax in the vegetation period of 2016, similar to 2015, did not always correspond to optimal indicators.

The most favorable in terms of moisture should be considered the 2017 vegetation period. Overall, it was characterized as over moistened (HTC – 1.50) with an optimal distribution of temperature and water regimes. Precipitation from sowing to flowering amounted to 143 mm, and after flowering - 63 mm. The weather conditions during the study period allowed for the assessment of the collection material for its adaptability to environmental stress factors.

Frequently, unfavorable conditions occurred during important growth and development phases throughout the vegetation period, which reflected in the morphological characteristics that determine the productivity of flax plants and its linear parameters, such as total and technical plant length, fiber content in the technical part of the stem, flax straw and seed yield.

Important heritably stable morphological characteristics of fiber flax plants, such as total and technical stem length, largely determine the yield of flax straw and its fiber content. Based on the results of the 3-year observations, high-growing varieties of Chinese flax selection were identified, such as Heiya 4 (K-8485), Sxy 7 (K-8689), with a total stem length of 66-72 cm. The Russian hybrid Tomsky 16*Uspekh (K-8544), the French variety Drakkar (K-8493), and the Ukrainian variety Glazur (K-8695) with a total stem length of 67-68 cm significantly exceeded the standard Tomsky 16 (58 cm) by 9-10 cm (see Table 1).

Long fiber, the main product for which flax is cultivated, is formed and contained in the technical part of the stem, which is an important morphological characteristic that determines the linear size of the stem. The length of the technical part of the stem in 17 studied flax

[14]Flax farmer reference book. Moscow: Rosselkhozizzdat, 1969. 215 p.

samples and varieties significantly exceeded the standard Tomsky 16 (52 cm) by 9-10 cm. As in the case with the total plant length, Chinese varieties Heiya 4 (K-8485) and Sxy 7 (K-8689) had the highest values for this important morphological characteristic (technical stem length), they reached the value of 60-62 cm. Russian hybrid Tomsky 16*Uspekh (K-8544), M-249 (K-8693) and the French variety Drakkar (K-8493) - 59-62 cm, the Ukrainian variety Glazur (K-8695) - 58 cm - by 6-10 cm significantly exceeded the standard Tomsky 16 (see Table 1).

An important morphological characteristic that can be used to assess the quality of flax straw and its fiber is the stem diameter. It has been empirically proven that the thinner the stem, the higher the fiber quality. Flax provides high-quality fiber with a stem length of at least 70 cm and a diameter of 1.0-1.2 mm (see footnote 12). All flax samples in the experiment exhibited thin stems (0.92-1.18 mm) and showed slight differences from the Tomsky 16 standard (0.95 mm). The stem diameter of the Russian hybrid Tomsky 16*Uspekh (K-8544), the French variety Drakkar (K-8493) (1.15 mm), and the Ukrainian varieties Vruchiy (K-8694) and Glazur (K-8695) (1.12-1.18 mm) were significantly larger than the standard (see Table 1).

The stem slenderness, which is the ratio of the stem's technical length to its diameter, reaches 600 in tall stems, while for most plants, it does not exceed 300 units. This is one of the significant characteristics that determine the yield and quality of the fiber [7]. As V.N. Ponazhev and E.G. Vinogradova [5] note, modern varieties of flax have experienced a decrease in stem slenderness from 620-650 to 420-450 units. In our case, based on a 3-year study (2015-2017), there were no significant differences from the Tomsky 16 standard (564 units) in the studied samples. All the samples exhibited sufficiently high levels of stem slenderness ranging from 485 to 620 units (see Table 1). Three samples showed a tendency to increase this characteristic compared to the standard: the Russian hybrid (K-8498) with 613 units, the variety Dobrynya (K-8504) with 576 units, and the sample from China, Heiya 4 (K-8485), with 620 units.

The main determining indicator of fiber productivity in flax is the hereditary trait of fiber content in the technical part of the stem, expressed as a percentage. The natural-climatic conditions of the 2017 growing season contributed to achieving the highest fiber productivity and proved to be the most favorable for fiber formation (see Figure 2). The regional variety of fiber flax, Tomsky 16, with high fiber content used as a standard in our case, had a fiber content in the technical part of the stem of 34.8% (see Figure 2a). The highest fiber content, exceeding the standard by 9.9%, was observed in the sample of Russian flax selection P-3989 (K-8692). The French varieties Alizee (K-8494) and Melina (K-8495) also ranked high with fiber content in the technical part of the stems exceeding 40% (Figure 2 в). Slightly lower values (over 38%) were observed in the Russian varieties A-236 (K-8692), M-249 (K-8693), and the Ukrainian variety Vruchiy (K-8694) (see Figure 2a, b). During our 3-year observation period, 14 samples of flax had fiber content in the stems (30-37%) reaching or exceeding the standard level, while 15 samples had significantly lower fiber content (less than 30%) (see Figure 2).

The evaluation of fiber productivity in flax was conducted based on the fiber mass in the technical part of the stem, which ultimately determines the fiber yield. In our case, based on the observations, the majority of the samples and varieties significantly exceeded the Tomsky 16 standard in terms of fiber mass in the technical part of the stem by 6-44 mg (see Table 1). The highest values (91-104 mg) were observed in the French varieties Drakkar (K-8493) and Alizee (K-8494), the Ukrainian varieties Vruchiy (K-8694) and Glazur (K-8695), and the Russian varieties A-236 (K-8692) and M-249 (K-8693).

The conducted analysis of flax productivity showed that the highest values in terms of the number of bolls per plant (2.7-3.3) were observed in the samples of the Ukrainian selection, specifically the variety Kamenyar (K-8556), the Russian hybrid Tomsky 16*Uspekh Uspekh (K-8544), the Belarusian variety Fort (K-8507), and the Chinese varieties Heiya

Табл. 1. Результаты морфолого-структурного анализа образцов льна-долгунца коллекции ВИР в Томской области (среднее за 2015–2017 гг.)

Table 1. Results of the morphological and structural analysis of the flax samples yield from the VIR collection in the Tomsk region (average for 2015–2017)

Number according to VIR catalog	Name	Total length, cm	Technical length, cm	Diameter, mm	Stem slenderness, cm/mm	Fiber weight in the technical part of the stem, mg	Fiber content, %	Number of bolls	Seed weight per plant, mg
Tomsky 16 standard		58	52	0,95	564	60	30	2,1	63
Russian varieties									
K-8498	l-4к-5512*l1-к-5523	62*	55*	0,92	613	43*	24*	1,6	43*
K-8499	к-6083*l-1к-550	64*	56*	1,02	557	56*	23*	2,5	87*
K-8500	l-1к-550*к-6084	57*	50	0,92	555	44*	29*	2,2	67*
K-8504	Dobrynya	59	52	1,04	576	76*	32*	2,4	74*
K-8539	Toast 4* Zaryanka	57*	49	0,98	510	56*	30	2,4	65
K-8540	l 2 Toast*Zaryanka	56*	49	1,00	495	56*	29*	2,5	59*
K-8544	Tomsky 16*Uspekh	67*	59*	1,15*	537	69*	22*	3	116*
K-8557	Alexandrit	62*	55*	1,09	507	87*	33*	2,3	64*
K-8558	Gorizont	64*	56*	1,09	527	84*	30	2,4	69*
K-8671	Vesnichka	61*	53	1,01	537	57*	26*	2,1	52*
K-8672	P-3989	61*	53	1,03	523	84*	37*	2,3	66
K-8673	L-205	62*	54	1,11	500	63*	25*	2,6	83*
K-8692	A-236	64*	57*	1,09	532	91*	33*	2,2	56*
K-8693	M-249	66*	59*	1,07	560	91*	31*	2,4	68*
Chinese varieties									
K-8485	Heiya 4	72*	62*	1,09	620	77*	24*	2,9	76*
K-8486	Heiya 13	61*	51	1,11	485	59	23*	2,6	92*
K-8667	Sxy 20	66*	57*	1,09	543	75*	27*	2,5	73*
K-8687	Tyy 13	62*	55*	1,06	527	58	25*	2,7	82*
K-8688	Lu 1	60*	53	1,04	546	66*	28*	2,2	79*
K-8689	Sxy 7	67*	60*	1,09	565	76*	26*	2,4	69*
Ukrainian varieties									
K-8505	Gladiator	65*	58*	1,08	547	84*	31*	2,3	78*
K-8506	Globus	64*	55*	1,09	512	81*	32*	2,5	88*
K-8556	Kamenyar	61*	53	1,09	497	60	24*	3,3	108*
K-8694	Vruchiy	65*	58*	1,12*	536	97*	32*	2,6	76*
K-8695	Glazur	68*	60*	1,18*	534	96*	28*	2,7	76*
French varieties									
K-8492	Agatha	58	52	1,04	512	84*	34*	2,2	77*
K-8493	Drakkar	67*	61*	1,15*	541	104*	32*	2,1	55*
K-8494	Alizee	64*	58*	1,10	542	99*	33*	2,2	86*
K-8495	Melina	59	53	0,99	542	83*	35*	2,2	72*
Belorussian varieties									
K-8507	Fort	61	53	1,04	523	74*	29*	2,9	76*
mean		62,6	55	1,06	538	74,1	28,9	2,4	74,2
LSD_{05}		0,06	1,8	0,16	88	3,09	0,07	0,25	3,98

* Differences with the standard are reliable at 5% significance level by the Duncan test.

4 (K-8485) and Tyy 13 (K-8687). No statistically significant differences were found among the samples (see Table 1).

The maximum seed productivity values, in terms of seed mass per plant, were recorded for the Russian hybrid Tomsky 16*Uspekh (K-8544) with 116 g, the Ukrainian variety Kamenyar (K-8556) with 108 g, and the Chinese variety Heiya 13 (K-8486) with 92 g. In comparison, the standard variety Tomsky 16 exhibited a much lower value of only 63 g (see Table 1).

The analysis of variance of flax collection samples revealed that the factor "year" significantly influenced the morphological characteristics. It had the greatest impact on the overall length, technical length, and stem diameter, accounting for 75.0%, 69.5%, and 52.6% respectively (see Table 2). The thinnest stems of flax plants were obtained in 2017.

Based on the analysis of field observations of the morphological characteristics of the studied flax samples and varieties, it was determined that the "year" factor had a significant influence (44%) on the stem slenderness trait (see Table 2). Therefore, under the most favorable conditions for the growth and development of flax, which were observed in 2017, samples of flax from China, specifically Lu 1 (K-8688), Sxy 7 (K-8689), Heiya 4 (K-8485), and Sxy 20 (K-8667), exhibited excellent stem slenderness values ranging from 728 to 789 cm/mm.

The Ukrainian varieties Glazur (K-8695) and Vruchiy (K-8694), the French varieties Drakkar (K-8493) and Alizee (K-8494), and the Russian hybrids Tomsky 16*Uspekh (K-8544) and l-4k-5512*l-1 k-5523 (K-8498) exhibited values exceeding 700 cm/mm. Among the samples, 12 had high values (at the level of or above the standard) ranging from 658 to 700 cm/mm. These included the Russian varieties M-249 (K-8693) and A-236 (K-8692), as well as the hybrids l-4k-5512*l-1k-5523 (K-8498) and k-6083*l-1k-550 (K-8499). On the other hand, 10 samples had values below the standard of Tomsky 16 (ranging from 571 to 650 cm/mm).

The analysis of variance indicated that the factors "year" and "genotype" had a strong influence on the characteristics of stem mass and fiber content in the technical part of the stem (see Table 2). These traits were relatively stable and more resistant to the impact of weather conditions.

Furthermore, it was observed that seed productivity, as indicated by the number of bolls and the seed mass per plant, was more dependent on weather conditions (38.8-38.3%) than on genotype (5-8%).

Based on the three-year observations, it was found that the best fiber characteristics were obtained in 2017. Optimal moisture supply from germination to flowering facilitated stem development, the formation of bast fiber bundles, and consequently, increased flax straw and fiber yield. This finding confirms the commonly accepted notion that flax is a moisture-demanding plant, especially during the period from germination to flowering. Optimal moisture conditions are considered to be when precipitation during this period exceeds 100 mm [4]. In 2015 and 2016, the moisture supply during the vegetation period from sowing to flowering was only 68 mm, while in 2017, it was twice as high at 143 mm. According to A.P. Krepkov [4], with a precipitation level of 120 mm and an average temperature of 16.6 °C in July, the maximum straw yield (up to 70 c/ha) and fiber content in the technical part of the stem (38.3%) were achieved.

A.I. Sizov's research [7] demonstrated that ancient varieties of flax, with their wide cultivation range, exhibited less variation in different conditions in terms of morphological characteristics that characterize flax productivity.

Modern flax researchers note that new breeding varieties, despite their high yield potential, have weak genetic protection and adaptability to local soil and climatic conditions, as well as various environmental stresses, resulting in a decrease in the quantity and quality of flax products[15] [8]. Previously, it was believed that

[15] *Pavlova L.N., Aleksandrova T.A., Marchenkov A.N.* Results and priorities of the selection of fiber flax // Results and prospects for the development of breeding, seed production, improvement of cultivation technology and primary processing of fiber flax / Materials of the international scientific-practical conference. Torzhok. 2000. pp. 8–11.

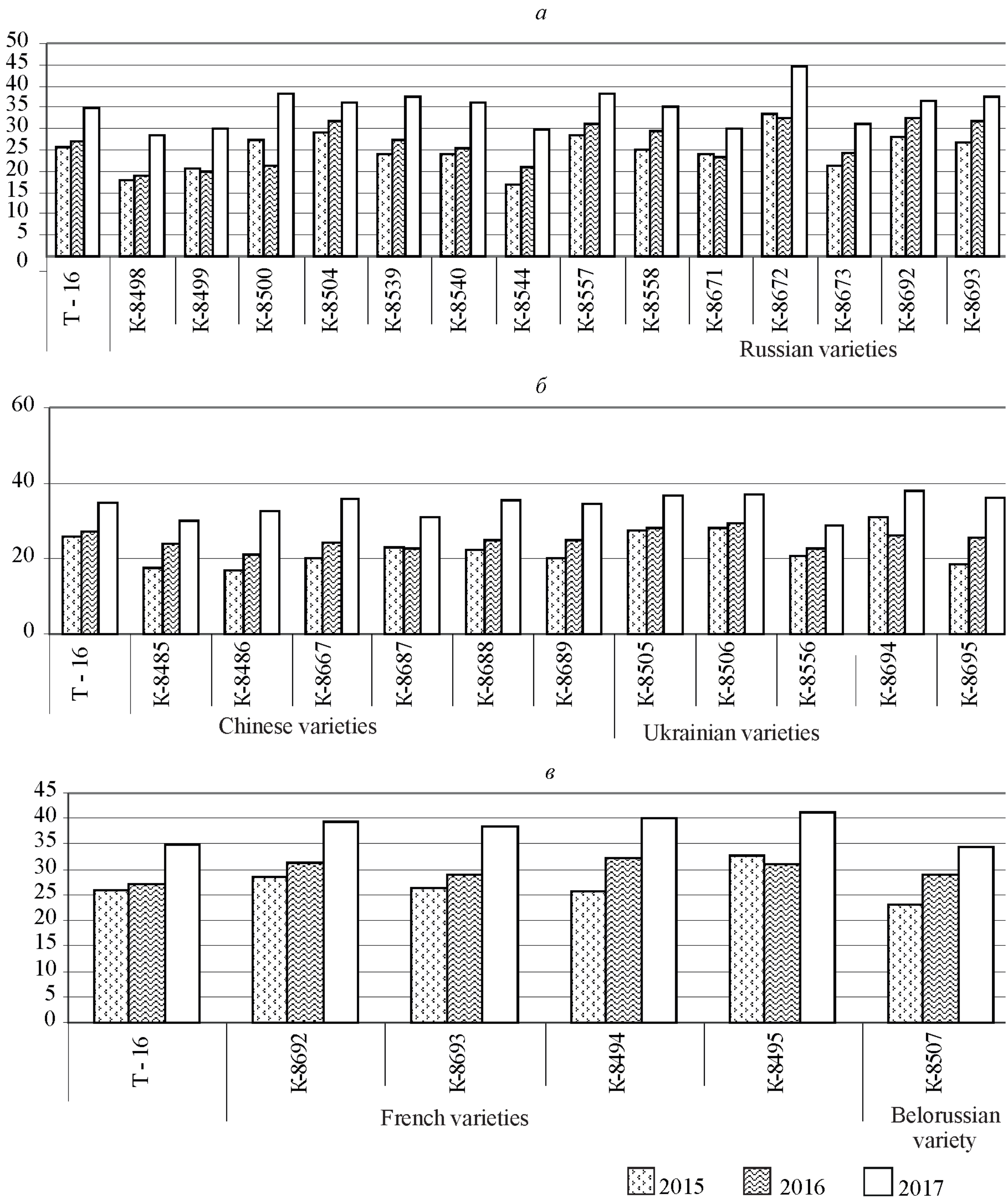

Рис. 2. Содержание волокна в технической части стебля образцов льна-долгунца коллекции ВИР: *а* – российской, *б* – китайской, украинской, *в* – французской и белорусской селекции в 2015–2017 гг., %

Fig. 2. Fiber content (%) in the technical part of the stem of flax specimens from the VIR collection: *а* – Russian, *б* – Chinese, Ukrainian, *в* – French and Belarusian selection in 2015–2017, %

Табл. 2. Влияние факторов «год» и «генотип» на изменение значений морфологических характеристик коллекционных сортов льна-долгунца луночного посева в 2015–2017 гг.

Table 2. Influence of factors "year" and "genotype" on the change in values of morphological characteristics of flax collection cultivars in 2015–2017

Factor	*df*	SS	*F*	*p*	Factor contribution, %
Total stem length, cm					
Genotype	30	37 374	49,7	< 0,05	7,2
Year	2	390 829	7792,1	< 0,05	75,0
Genotype *Year	60	25 127	16,7	< 0,05	4,8
Error	2697	67 637			
Total	2789	520 968			
Technical stem length, cm					
Genotype	30	32 284	46,1	< 0,05	7,6
Year	2	293 493	6285,3	< 0,05	69,5
Genotype *Year	60	33 783	24,1	< 0,05	8
Error	2697	62 969			
Total	2789	422 527			
Diameter, mm					
Genotype	30	10,608	20,2	< 0,05	7,8
Year	2	71,159	2035	< 0,05	52,6
Genotype *Year	60	6,25	6	< 0,05	4,6
Error	2697	47,153			
Total	2789	135,169			
Stem slenderness, cm/mm					
Genotype	30	2 526 481	6,11	< 0,05	3,2
Year	2	34 436 839	1249,48	< 0,05	44,0
Genotype *Year	60	4 075 446	4,93	< 0,05	5,2
Error	2697	37 165 836			
Total	2789	78 204 602			
Fiber weight of the technical part, mg					
Genotype	30	728 716	70,46	< 0,05	19,8
Year	2	1 657 501	2404,02	< 0,05	45,1
Genotype *Year	60	361 288	17,47	< 0,05	9,8
Error	2697	929 751			
Total	2789	3 677 257			
Fiber content, %					
Genotype	30	41 189	181,9	< 0,05	30,8
Year	2	65 222	4319,6	< 0,05	48,7
Genotype *Year	60	7 137	15,8	< 0,05	5,3
Error	2697	20 361			
Total	2789	133 908			
Number of bolls per plant					
Genotype	30	283,91	10,13	< 0,05	5,6
Year	2	1954,4	1046,31	< 0,05	38,8
Genotype *Year	60	282,06	5,03	< 0,05	5,6
Error	2697	2518,87			
Total	2789	5039,24			
Seed weight per plant, g					
Genotype	30	625 400	15,85	< 0,05	8,3
Year	2	2 874 215	1092,62	< 0,05	38,3
Genotype *Year	60	463 214	5,87	< 0,05	6,2
Error	2697	3 547 312			
Total	2789	7 510 140			

Note. *df* - degrees of freedom, SS - sum of squared deviations, *F* - criterion of the ratio of the effect mean squares to the error mean square, *p* - significance of differences.

there was a negative correlation between fiber content in the flax stem and its quality[16,17] [10]. However, based on the observations in 2017, the studied flax samples and varieties exhibited high fiber content and sufficiently high stem slenderness values, suggesting a positive influence of favorable weather conditions during the vegetation period. Previous studies have shown that plant length, both overall and technical, was almost entirely dependent on the sample genotype[18].

The technical stem length parameter has a dual significance. On the one hand, varieties with longer stems can yield higher-grade fibers, but on the other hand, there is a high risk of lodging, leading to a decrease in fiber quality [10]. Grain crop breeding focuses on cultivating dwarf varieties due to their vulnerability to lodging[19] [11]. However, flax breeding is not aimed at reducing plant height. On the contrary, relatively tall plants are desirable to achieve higher yield since fibers are extracted from the stem [12].

In 2016 and 2017, the Russian selection samples l-4k-5512*l-1k-5523 (K-8498), k-6083*l-1k-550 (K-8499), l-1k-550*k-6084 (K-8500), Dobrynya (K-8504), Vesnichka (K-8671), P-3989 (K-8672), L-205 (K-8673), A-236 (K-8692), the Chinese variety Tyy 13 (K-8687), and the Ukrainian variety Gladiator (K-8505) were involved in hybridization as paternal parental forms. The resulting progeny is currently being studied in the hole breeding nursery at the F_5–F_6 selection stage. Over 40 promising hybrids have been advanced to subsequent stages of the breeding process in the second-year nursery from 2021 to 2023.

CONCLUSION

As a result of the conducted research, valuable and adaptable breeding material has been identified for creating varieties with high productivity traits. Chinese selection varieties, namely Heiya 4 (K-8485) and Sxy 7 (K-8689), the Russian hybrid Tomsky 16*Uspekh (K-8544), the French variety Drakkar (K-8493), and the Ukrainian variety Glazur (K-8695) stood out in terms of overall and technical stem length, with measurements ranging from 66-72 cm and 60-66 cm, respectively, significantly exceeding the standard of Tomsky 16 by 9-10 cm.

In terms of fiber content in the technical part of the stem, the leading samples were the Russian selection varieties P-3989 (K-8672), A-236 (K-8692), and M-249 (K-8693), the French selection varieties Alizee (K-8494), Agatha (K-8492), and Melina (K-8495), and the Ukrainian variety Vruchiy (K-8694), with percentages ranging from 38-40%, significantly surpassing the standard of Tomsky 16 (34.8%) by 7.0-9.9%.

The highest fiber mass in the technical part of the stem was observed in the French varieties Drakkar (K-8493) and Alizee (K-8494), the Ukrainian varieties Vruchiy (K-8694) and Glazur (K-8695), and the Russian varieties A-236 (K-8692) and M-249 (K-8693), ranging from 91-104 mg. They significantly exceeded the standard of Tomsky 16 by 6-44 mg.

The flax varieties P-3989 (K-8672) and Dobrynya (K-8504) from the Russian selection, A-236 (K-8692) from the Ukrainian selection, Heiya 4 (K-8485) and Heiya 13 (K-8486) from the Chinese selection, Agatha (K-8492), Drakkar (K-8493), Alizee (K-8494), and Melina (K-8495) from the French selection, as well as Gladiator (K-8505) and Vruchiy (K-8694) from the Ukrainian selection, have been recognized as promising and included in the breeding process as paternal parental forms in hybridization. The obtained hybrid material is currently under evaluation in the breeding nursery since 2017 and the second-year selection nursery since 2021.

[16] *Artemieva A.E.* Chemical composition and technological properties of fiber flax // Proceedings of the Academy of Sciences of BSSR. 1983. N 3. pp. 52–57.

[17] *Boguk A.M., Sosnovskaya M.V.* Selection of fiber flax for increasing fiber content // Selection, seed production and technology of cultivation of bast crops. Moscow, 1985. pp. 45–48.

[18] *Brach N. B.* Intraspecific diversity of flax (*Linum usitatissimum* L.) and its utilization in genetic research and breeding: extended abstract of Doctor's thesis in Biology. St. Petersburg, 2007. 38 p.

[19] *Crook M.J., Ennos A.R.* Stem and root characteristics associated with lodging resistance in four winter wheat cultivars // The Journal of Agricultural Science. 1994. Vol. 123. pp. 167–174. DOI: 10.1017/S0021859600068428.

СПИСОК ЛИТЕРАТУРЫ

1. *Рожмина Т.А., Павлова Л.Н., Понажев В.П., Захарова Л.М.* Льняная отрасль на пути к возрождению // Защита и карантин растений. 2018. № 1. С. 3–8.
2. *Живетин В.В., Гинзбург Л.Н., Ольшанская О.М.* Лен и его комплексное использование: монография. М.: Информ-Знание, 2002. 400 с.
3. *Новиков Э.В., Басова Н.В., Безбабченко А.В.* Лубяные культуры в России и за рубежом: состояние, проблемы и перспективы их переработки // Технические культуры. Научный сельскохозяйственный журнал. 2021. Т. 1. С. 30–40. DOI: 10.54016/SVITOK.2021.1.1.005.
4. *Крепков А.П.* Селекция льна-долгунца в Сибири: монография. Томск, 2000. 183 с.
5. *Понажев В.П., Виноградова Е.Г.* Развитие селекции и семеноводства льна-долгунца – важнейший ресурс повышения эффективности льноводства России // Технические культуры. Научный сельскохозяйственный журнал. 2022. № 1 (3) 2. С. 30–39. DOI: 10.54016/SVITOK.2022.71.55.004.
6. *Ромашова Т.В., Филандышева Л.Б., Юркова К.Д* Анализ динамики временных характеристик сезонов года в подтайге Западно-Сибирской равнины за период с 1936 по 2015 г. // Геосферные исследования. 2017. № 3. С. 16–25. DOI: 10.17223/25421379/4/3.
7. *Брач Н.Б., Шаров И.Я., Павлов А.В., Пороховина Е.А.* Разнообразие признаков льна, связанных с формированием волокна, и влияние условий выращивания на их проявление // Экологическая генетика. 2010. Том. 8. № 1. С. 25–35.
8. *Степин А.Д., Рысев М.Н., Кострова Г.А., Рысева Т.А., Уткина С.В.* Основные направления и результаты научных исследований Псковского НИУ по селекции льна-долгунца // Известия Великолукской ГСХА. 2019. № 2. С. 14–21.
9. Эколого-генетические основы селекции льна-долгунца: монография. Тверь: Тверской государственный университет, 2009. 272 с.
10. *Павлов А.В., Брач Н.Б., Пороховина Е.А., Кутузова С.Н.* Образцы льна-долгунца китайской селекции как источник хозяйственно ценных признаков // Труды по прикладной ботанике, генетике и селекции. 2015. Т. 176. № 1. С. 68–75. DOI: 10.30901/2227-8834-2015-1-68-75.
11. *Oladokun M.* Structural development and stability of rice *Oryza sativa* L. var. Nerica 1. // Journal of Experimental Botany. 2006. Vol. 57. P. 3123–3130. DOI: 10.1093/jxb/erl074.
12. *Goudenhooft C., Bourmaud A., Baley C.* Flax (*Linum usitatissimum* L.) Fibers for Composite Reinforcement: Exploring the Link Between Plant Growth, Cell Walls Development, and Fiber Properties // Frontiers in Plant Science. 2019. Vol. 10. P. 411. DOI: 10.3389/fpls.2019.00411.

REFERENCES

1. Rozhmina T.A., Pavlova L.N., Ponazhev V.P., Zakharova L.M. Linen industry on the way to revival. *Zashchita i karantin rastenii = Plant Protection and Quarantine,* 2018, no. 1, pp. 3–8. (In Russian).
2. Zhivetin V.V., Ginzburg L.N., Ol'shanska O.M. *Flax and its complex use.* Moscow, Inform-Znanie, 2002, 400 p. (In Russian).
3. Novikov E.V., Basova N.V., Bezbabchenko A.V. Bast crops in Russia and abroad: the state, problems and prospects of their processing. *Tekhnicheskie kul'tury. Nauchnyi sel'skokhozyaistvennyi zhurnal = Technical crops. Scientific agricultural journal,* 2021, no. 1, pp. 30–40. (In Russian). DOI: 10.54016/SVITOK.2021.1.1.005.
4. Krepkov AP. *Breeding of fiber flax in Siberia.* Tomsk, Tomsk university, 2000. 186 p. (In Russian).
5. Ponazhev V.P., Vinogradova E.G. The development of selection and seed production of flax is the most important resource for improving the efficiency of flax growing in Russia. *Tehnicheskie kul'tury. Nauchnyj sel'skohozjajstvennyj zhurnal = Technical crops. Scientific agricultural journal*, 2022, vol. 1 (3), part 2, pp. 30–39. (In Russian). DOI: 10.54016/SVITOK.2022.71.55.004.
6. Romashova T.V., Filandysheva L.B., Yurkova K.D. Analysis of the dynamics of time characteristics of the seasons of the year in the sub-boreal forest (sub-taiga) of the west Siberian plain in the period from 1936 to 2015. *Geosfernye issledovaniya = Geosphere Research*, 2017, no. 3, pp. 16–25. (In Russian). DOI: 10.17223/25421379/4/3.
7. Brutch N.B., Sharov I.Y., Pavlov A.V., Porokhovinova E.A. Diversity of flax characters associated with fibre formation and environmental influence on their formation. *Ekologicheskaya genetika = Ecological genetics*, 2010, vol. 8, no. 1, pp. 25–35. (In Russian).
8. Stepin A.D., Rysev M.N., Kostrova G.A., Ryseva T.A., Utkina S.V. The main directions and results of scientific research on flax breeding of the Pskov National Research University. *Izvestiya Velikolukskoi GSKHA = Izvestiya of Velikiye*

Luki State Agricultural Academy, 2019, no. 2, pp. 14–21. (In Russian).
9. *Ecological and genetic bases of flax breeding.* Tver, Tver State University Publ., 2009. 272 p. (In Russian).
10. Pavlov A.V., Brutch N.B., Porokhovinova E.A., Kutuzova S.N. Fibre flax accessions of Chinese breeding as sources of valuable agronomic characters. *Trudy po prikladnoi botanike, genetike i selektsii = Proceedings on applied botany, genetics and breeding*, 2015, vol. 176, no. 1, pp. 68–75. (In Russian). DOI: 10.30901/2227-8834-2015-1-68-75.
11. Oladokun M. Structural development and stability of rice *Oryza sativa* L. var. *Nerica 1*. *Journal of Experimental Botany*, 2006, vol. 57, pp. 3123–3130. DOI: 10.1093/jxb/erl074.
12. Goudenhooft C., Bourmaud A., Baley C. Flax (*Linum usitatissimum* L.) fibers for composite reinforcement: Exploring the link between plant growth, cell walls development, and fiber properties. *Frontiers in Plant Science*, 2019, vol. 10, pp. 411. DOI: 10.3389/fpls.2019.00411.

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Дата поступления статьи / Received by the editors 28.02.2023
Дата принятия к публикации / Accepted for publication 13.04.2023
Дата публикации / Published 22.05.2023