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Pre-breeding, Breeding and Farming for Flax Production in Russia. Igor Uschapovsky, The All-Russian Research Institute for Flax Production (VNIIML) Komsomolsky pr., 17/56 Tver, 170041 Russia
Research on Accumulation Pattern of \( \alpha \)-linolenic Acid Flax Seed Development

Zhao Dang\(^{1,2} \), Jia Sun\(^3 \), Junsheng Song\(^1 \), Rongkai Hao\(^1 \), Wenjuan Li\(^2 \), and Limin Wang\(^2 \)

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Abstract

Flax (\textit{Linum usitatissimum} L.) is an important oil crop in Northwestern and Northern China. Its \( \alpha \)-linolenic acid content is 45%-60%. This article presents an analysis on fatty acid composition of three varieties with different \( \alpha \)-linolenic acid contents by a gas- chromatograph, in order to understand \( \alpha \)-linolenic acid accumulation pattern in the development of flax seeds. Accumulations of stearic acid, oleic acid, and linoleic acid occurred in the early development. Linolenic acid content significantly increased from the beginning of seed development and slightly decreased around 30-40 days after seeding, followed by an increase again. This fact indicated that linolenic acid has been accumulated from early seed development to maturity. A correlation analysis among content of various fatty acids during seed development was conducted to understand the relationship among different types of fatty acids. Results showed that the contents of palmitic acid, stearic acid, oleic acid and linoleic acid were positively correlated with each other, but were negatively correlated with linolenic acid. Besides, fruit size (diameter), fresh weight, dry weight and the dry/fresh weight ratio of three varieties were scored. Results indicated that fruit size increased mainly at the beginning of the development and remained stable or even reduced slightly during the mid-late stages of seed development. This was the same among three varieties. Fruit’s fresh weight increased from the beginning to harvest, while the dry weight increased at the beginning and decreased in a later stage. Dry/fresh weight ratio increased during the whole process. This implied that fruit dry matter accumulated mainly in prometa phase of fruit development.

Characterization of Flax Germplasm for Resistance to Fusarium Wilt

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Abstract

Fusarium wilt caused by the fungus \textit{F. oxysporum} f. sp. \textit{lini} (FOL) is a major disease affecting flax (\textit{Linum usitatissimum} L.) worldwide. Historically, this was a devastating flax disease in North America during the early and mid- 20th century resulting in high yield losses and causing fields to be unfit for flax production “flax sick fields”. This study aimed at identifying phenotypic differences among recombinant inbred lines (RIL) from a cross between resistant and susceptible parents, and to identify Quantitative Trait Loci (QTL) linked to resistance. The RILs were challenged with three FOL isolates under controlled growth cabinet conditions and to natural inoculum in fusarium wilt nurseries at Morden, Manitoba and Saskatoon, Saskatchewan. Disease severity was determined and the area under the disease progress curve (AUDPC) was calculated. The RIL populations varied in response from resistant to highly susceptible, indicating that resistant to wilt in the resistant parent is probably polygenic. The analysis of the QTL is under way to determine the association with phenotypic data of the RILs.
Flaxseed and Buckwheat Supplemented Diets Altered Bacterial Populations in the Cecum and Feces of Mice

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Abstract
Depending on the host’s dietary intake, bacterial populations in the gastrointestinal tract can vary in abundance and diversity. The objective of this research was to determine the growth and diversity of bacteria in the cecum and feces following flaxseed and buckwheat supplemented diets. Seventy-two C57BL/6J male mice were randomly assigned into one of the following diet groups and fed for eight weeks: Group 1 (45% Kcal fat, control); Group 2 (45% Kcal fat, 10% whole flaxseed); Group 3 (45% Kcal fat, 6% defatted flaxseed); Group 4 (45% Kcal fat, 4.5% flaxseed oil); Group 5 (45% Kcal fat, 10% buckwheat); and Group 6 (control diet, 16.4% Kcal fat, pair-fed to group 2). At week nine, fecal and cecum samples were collected for bacteria isolation. Significant differences in bacterial growth in the cecum (p < 0.0348) and feces (p < 0.0033) were observed among treatment groups. The whole flaxseed and buckwheat groups showed the most growth and bacterial diversity of Enterobacteriaceae, including Serratia liquefaciens, Enterobacter cloacae, Pantoea agglomerans, etc. while the flaxseed oil and high fat diets had the least. In conclusion, whole flaxseed and buckwheat supplementation altered bacterial growth and diversity in the cecum and feces of mice.

Survey of Lignan Content in Commercially Available Flax and Flax Supplements

Gerard Engelen

Abstract
A small study on lignan content of commercially available flax supplements, flax meal and seed was initiated at our laboratory. Eight different flax supplements were purchased from one online source. Five of the flax supplements were in gel caps and were of different brands; the flax oils were different brands as well. Additionally, we tested lignan content in 6 flax seed samples and one flax meal sample. Lignan was not found in any of the gel caps (containing flax oil) or flax oil samples. However, lignan was found in flax seed and meal samples. Lignan and oil content varied among seed samples. We conclude that, based on the flax oil and gel caps we tested, these do not provide additional health benefits from lignan. However, flax meal and flax seed are a rich source of lignan, thus providing additional health benefit to the consumer.
Cloning and Expression Analysis of Male Sterility Related MS2-F Gene in Flax (Linum usitatissimum)

Siqin Bateer, Zhang Hui, Jia Xiao-yun, Gao Fengyun, Ren Long-mei, and Li Qiang
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Abstract
A cDNA of 1911 bp, homologous to MS2 in Arabidopsis thaliana, named MS2-F was cloned from flower buds of flax (Linum usitatissimum). It contained an ORF of 1608 bp, the deduced amino acids sequence of the gene included two male sterile conserved domains: NAD-binding domain and male sterile C-terminal domain. The gene was exclusively expressed in tapetum during tetrad and microspore periods in flax anther, and probably be involved in the formation of sporopollenin which is a major component of young microspore exine wall during flax pollen development. Genomic DNA fragment of the gene was 2696 bp in size and contained 8 introns and 9 exons.
The TUFGEN Project

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Abstract

The Total Utilization Flax GENomics (TUFGEN) project was a large scale project (~11.5M) funded by Genome Canada and multiple co-funders that ran over four years, ending in September 2013. In Canada, 14 principal investigators from four universities, Agriculture and Agri-Food Canada and the National Research Council were involved. The Canadian co-funders included the provincial governments of Saskatchewan, Alberta and Manitoba, Agriculture and Agri-Food Canada, Agricultural Bioproducts Innovation Program, Agriculture Development Fund, Alberta Department of Energy, Alberta Ingenuity Fund, Canada Foundation for Innovation, Flax Council of Canada, Manitoba Flax Growers Association, National Research Council, Saskatchewan Flax Development Commission, the University of Alberta and Western Economic Diversification. The project also had international collaborators from India and funding from the Indian Agricultural Research Institute and Department of Biotechnology. TUFGEN encompassed five main activities: (1) Gene and genome sequencing, (2) Genetic and physical mapping, (3) Gene Characterization, (4) Genomics applications for flax genomics improvement and (5) GE3LS, i.e., Genomics-related ethical, environmental, economic, legal and social activities. A strong bioinformatics component permeated activities 1 to 4 while activity 5 provided an umbrella for them. The project significantly contributed to the development of highly qualified personnel including several graduate students and post-doctoral fellows. Nearly 100 scientific articles in peer-reviewed journals, 15 book chapters and four books have been published to date. The following details some of the most significant outcomes of the project.
Suppression of Lung Cancer Cell Proliferation and Migration \textit{in vitro} by Flaxseed-derived Lignans

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Abstract
In the United States, lung cancer is the leading cause of cancer-related deaths. The American Cancer Society estimates that 224,210 new cases of lung cancer will be reported in 2014 and 159,260 Americans will die from lung cancer this year. The risk for developing lung cancer and the progression of existing lung cancer can be reduced by lifestyle changes such as minimizing smoking and eating a healthy diet. Consumption of functional foods such as flaxseed may provide numerous health benefits to individuals including anticancer properties. Research has shown that enterodiol (ED) and enterolactone (EL), lignans that are derived from flaxseed lignans, have anticancer effects for breast, colon, and prostate cancer, but less is known about their effects on lung cancer. Here, we present \textit{in vitro} data demonstrating the anticancer effects of lignans for non-small cell lung cancer (NSCLC). For this study, A549 NSCLC cells were treated with increasing concentrations (0-100 μM) of ED and EL, and the resulting effects on cell proliferation and migration were evaluated. EL inhibited the growth of A549 cells in concentration- and time-dependent manners, while, ED showed no growth-inhibitory effects for A549 cells. EL also impaired the ability of the lung cancer cells to migrate in a wound healing assay. The findings from this study suggest that EL has potential anticancer properties for NSCLC.

Updates on Pasmo Disease and Control Using Fungicide Applications

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Abstract
Pasmo is a major disease affecting flax \textit{(Linum usitatissimum L.)} worldwide including Canada and USA, and reduces yield and quality of seed and fibre. Efforts to identify sources of resistance to this pathogen resulted in identifying several flax genotypes with field resistance and some are resistant to 1, 2, 3 and/or 4 specific isolates of the pathogen. These resistant genotypes may possess race-specific genes for resistance to pasmo. The efficacy of several fungicides have been evaluated under field conditions and most fungicides used proved effective in reducing the disease by 30-60% and improve yield by 15-25% over a four-year period.
Optimizing Flaxseed Milling Using a Hammer Mill

Elena De La Peña, Frank Manthey, and Clifford Hall

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Abstract
Two flaxseed milling experiments were conducted using a hammer mill. The objective of the first experiment was to evaluate the effect of hammer speed (2,400, 4,000, 5,600 and 7,200 rpm) and screen mesh size (1.7 mm/0.065 in, 2.8 mm/0.109 in and 4.8 mm/0.187 in) combinations on the yield and particle size of the fine flaxseed fraction obtained after milling. The objective of the second experiment was to determine the effect of flaxseed moisture content (6.5, 8.5 and 10.5%) and seed temperature (18, -7 and -23°C) on the yield and particle size of the fine flaxseed fraction obtained after milling. Fine flaxseed production was maximized at 7,200 rpm, using the 2.8 mm screen, and when samples with 6.5% moisture content had a seed temperature of 18°C.

Impact of Hammer Speed, Screen Mesh Size, and Seed Temperature and Moisture on Oxidative and Hydrolytic Stability of Hammer Milled Flaxseed

Cassandra Hillen, Elena De La Peña, Mary Niehaus, Frank Manthey, and Clifford Hall III

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Abstract
The stability of flaxseed is dependent on the storage environment along with the surface area exposed to oxygen. Surface areas of particles are dependent on hammer speed and mesh screen size and need to be investigated. Furthermore, seed milling temperature and moisture may influence surface area and ultimately oxidative stability. Therefore, the objective of this study was to assess oxidative and hydrolytic stability of flaxseed milled under various conditions. Peroxide value (PV) and free fatty acids (FFA) were determined on oil obtained from hammer-milled flaxseed over a ten-month storage period. The screen mesh size did not affect the hydrolytic rancidity of milled flaxseed as indicated by similar FFA at each of the sampling dates. However, the PV of the flaxseed obtained from the smallest (1.7 mm) screen was higher than flaxseed from the other screens. Mill speed seed temperature did not impact either PV or FFA. In contrast, milled flaxseed obtained from high seed moisture contents (10.5 %) did have higher FFA contents, indicating greater susceptibility hydrolytic rancidity. Combination of low moisture flaxseed with a cold (-7 °C) temperature milled through a 0.187 inch (4.8 mm) screen at 7200 rpm resulted in a milled flaxseed with the least amount of oxidation and hydrolytic rancidity over the 10 month storage period.
Integrated Methods of Linseed Cultivation in Poland

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Abstract
The research results of the improvement of integrated methods of linseed (flax) [Linum usitatissimum L.] cultivation are presented. Cultivar potential and growing method efficacy for integrated farming was evaluated. Research factors were: linseed cultivar, sowing technique and density as well as non-chemical methods of plant protection. Polish cultivars Bukoz, Jantarol, Oliwin, and Szafir were cultivated. Two sowing densities (40 kg ha$^{-1}$ and 60 kg ha$^{-1}$) and two row widths (12.5 cm and 25 cm) were used. The best seed yield was obtained from cultivar Bukoz, cultivated with a sowing density of 60 kg ha$^{-1}$ and a row width of 25 cm. The cultivar with the shortest growing period was Szafir, followed by Bukoz, Jantarol, and Oliwin. There were no observed differences between cultivars in fat content, fatty acid composition and heavy metal level in linseed yield. The subjects of research in non-chemical plant protection were: 1) organic seed dressings, 2) post emergent bio-technical products with insect repellent and disease control properties. The feedstock for these products are essential hemp oil used as an active ingredient (a.i.) and non-chemical emulsible vegetable oils, used as synergents increasing the efficacy of a.i. Organic seed dressing Eco-Hemp-Mix, showed a positive effect on growth, development, and linseed seed yields. For effective non-chemical weed control, repeated weeding is mandatory during the first vegetation period from plant emergence until when plants are 20 cm tall.

Oil Content and Fatty Acid Composition of Oil Flax under Different Ecological Environments in China

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Abstract
The influence of Genotype, Environment, and Genotype × Environment on the fatty acid composition of the oils from oilseed flax (Linum usitatissimum L.) genotypes grown in northwest and north China was evaluated in China. The flax cultivar ‘Longya 8’, four land races, and seven new lines were grown under six various agro-ecologies regimes from northwest to north China. The amounts of the linolenic, oleic, linoleic, stearic, and palmitic fatty acids from the flaxseed oil were determined using gas chromatography (GC). In this study, we found that two new lines, FX-16 and TY-58, were significant higher in oil and exceeded Longya 8 in oil content ($P<0.01$). The oil content of flaxseeds was significant more than others locations in Zhangbei and Yili ($P<0.01$). Linolenic acid content was the highest at Zhangbei and Yili. ‘Zhangya 2’ had the highest linolenic acid content of all cultivars. Meanwhile, we found that the correlation of linolenic with the other fatty acids were inconsistent under different ecological environment. In conclusion, the present study indicates that fatty acid composition of the oils from oilseed flax is influenced by genotypes and environmental factors.
Genetic Diversity and Structure of the *Fusarium oxysporum* f.sp. *lini* Populations on Linseed (*Linum usitatissimum*) in China

Hui Zhang and Ziqin Li*

Inner Mongolia Academy of Agricultural & Animal Husbandry Sciences, China

**Abstract**

The genetic diversity of specific *Fusarium oxysporum* f.sp. *lini* from six provinces in China was investigated using molecular markers, inter-simple sequence repeats (ISSR). Based on the morphological features and the internal transcribed spacer (ITS) sequences, 96 isolates were identified as *Fusarium oxysporum*. The 96 isolates were amplified by PCR with 12 ISSR primers. The number of bands amplified by each primer ranged from 43 to 142, with sizes ranging from 250 to 4500 bp. A total of 800 bands were observed, out of which 797 were polymorphic (99.6%). The percentage of polymorphic loci varied from 17.25% in Gansu and Inner Mongolia to 33.75% in Sinkiang. Nei’s gene diversity index (h) ranged from 0.0428 in Gansu to 0.0666 in Sinkiang, and Shannon’s information index (I) ranged from 0.0675 in Gansu to 0.1117 in Sinkiang. The genetic identity using the Nei’s genetic identity varied from 0.9643 between the populations from Hebei and Gansu to 0.9844 between the populations from Sinkiang and Shanxi. Unweighted pair group mean analysis (UPGMA) cluster analysis, as indicated by the Nei’s genetic distance, showed the distances ranging from 0.0158 between the populations from Sinkiang and Shanxi to 0.0364 between the populations from Hebei and Gansu. The six populations were clustered into three subgroups. The Gansu population was clustered into one subgroup, the same as the Inner Mongolia population. The four other populations were clustered into the third subgroup. The Nei’s GST (0.2972) and gene flow among populations (Nm =1.1825) revealed large gene exchanges among populations.

Aster Yellows Disease in Flax

Khalid Y. Rashid

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**Abstract**

Aster Yellows (AY) caused by a Phytoplasma and affects >300 plant species including flax (*Linum usitatissimum* L.). AY has been considered a minor disease that affects flax causing flower buds to become vegetative with star-shape appearance and produces no seed. The phytoplasma is transmitted by several species of leafhoppers mostly by the six-spotted leafhopper *Macrosteles fascifrons*. Annual surveys have been conducted since 1988 of 60-100 flax fields in Manitoba and Saskatchewan, Canada. In 2012, AY was present in flax, 60% of surveyed fields with trace to 5% plants affected in comparison with a 5-30% of the fields and trace to 1% incidence in the previous 10 years. Major epidemics of AY were recorded in 1953-1957 with 90-100% prevalence and 5-15% incidence. The high prevalence and incidence of AY in flax has been attributed to the early migration of the six-spotted leafhopper coinciding with the spring warm weather. Presently, there is no recommendation to control this disease.
Flow and Agglomeration Properties of Semolina and Whole Wheat Flour Fortified with Flaxseed Flour

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Abstract
An experiment was conducted to determine the angle of slide and repose, and wet agglomeration of semolina and whole wheat flour blends fortified with flaxseed flour and hydrated to different moisture contents. Determination of angle of slide and repose for samples hydrated at 10, 15, 20, 25, 30 and 32% moisture content was performed on both a stainless steel and an aluminum surface. For the determination of the wet agglomeration, samples were hydrated at 30, 31, 32, 33, and 34% moisture content. Samples with whole wheat flour had a greater angle of slide and repose. Incorporation of flaxseed flour in the formulation resulted in increased angle of slide. Samples flowed better on aluminum than on stainless steel. Extreme dough agglomeration was observed with samples containing semolina and fine flaxseed hydrated above 31% moisture; whereas limited agglomeration was detected for whole wheat samples with or without flaxseed flour.

Use of Bio-based High Functionality Polyols in Polyurethane/Flax or Glass Fiber Composites

Nassibeh Hosseini, Chad A. Ulven, Dean C. Webster and Thomas J. Nelson
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Abstract
There is a growing interest in the use of natural fibers as reinforcement in polymer composites due to depletion of oil and gas in petroleum resources. Some advantages of using natural fibers other than their renewability and biodegradability include global accessibility and relatively low cost. In this study flax fiber is used as the reinforcement for a novel highly functional plant oil-based polyols, Methoxylated Sucrose Soyate Polyols (MSSP). The novel MSSP were cross-linked with isocyanate to formulate MSSP-based polyurethane (PU) thermosets. Compression molding process was used to make composite panels out of MSSP-based polyurethane and flax fiber reinforcement of about 50 vol %. Properties of the MSSP-based PU thermosets and its corresponding flax fiber reinforced thermoset composites were assessed by tensile, flexural, and interlaminar shear strength (ILSS). The MSSP-based PU resin reinforced with 50 vol % unidirectional E-glass fiber mats was tested as a reference. Specific mechanical properties of the flax fiber reinforced bio-based PU composites were found to compare favorably with those of glass. By using flax fibers and bio-based PU resin in the composite, almost 87% (wt %) of the flax/MSSP-based PU is renewable resources. High mechanical properties in flax fiber reinforced MSSP based PU composites can be attributed to high functionality and rigid compact chemical structures of MSSP oligomers in polyol resin.
Surface treatment of flax fiber

Ali Amiri & Chad Ulven, Mechanical Engineering Department, North Dakota State University
This material is based upon work supported by the National Science Foundation, EPSCoR, and the State of North Dakota.

Abstract
Natural fibers have a great potential to be used as reinforcement in composite materials. Cellulose being a critical constituent of natural fibers provides us with unquestionable advantages over glass fibers. With lower density and higher toughness, comparable strength and stiffness, lower cost, being biodegradable and renewable, and less abrasive to equipment and tooling would be other advantages compared to glass fibers or other synthetic fibers. Increasing and modifying the adhesion between fiber and matrix has been subject of many studies. In this study impact of two methods of fiber treatments on mechanical properties of resultant composites has been investigated. First, the effect of enzyme treatment of fiber was studied. Then, effect of four different mechanical processes on mechanical properties of subsequent composites was examined.

Effect of Different P Level on P Nutrient Transferring, Distribution and P Utilization Efficiency of Oil Flax

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Abstract
In order to achieve higher yields, producers often apply large amounts of P (P) fertilizer, which can result in the accumulation of P in the soil, contaminating the environment and reducing the utilization efficiency of P fertilizer. This research was set up to determine the effect of P fertilization on the P nutrient transfer, distribution and P utilization efficiency of oil flax (Linum usitatissimum L) during two growing seasons. The factorial field trials were conducted according to a randomized complete block design with three replications in the growing seasons 2011 and 2012, respectively. The oil flax cultivar ‘Baxuan 3’ and four levels of P fertilization (0, 35, 70 and 105 kg P₂O₅ /hm²), that is, no P, low P, medium P and high P was tested in both growing seasons. This experiment of two years indicated that different P application rates affected P nutrient uptake, transformation and accumulation at different growth stages. Besides, P accumulation increased significantly (P<0.05) in different organs compared with the treatment without P fertilizer application. The P translocation from leaf to seed in oil flax, medium P increasing 54.9%-73.8% and 8.2%-10.0% (P<0.05), compared with low P and high P, respectively. The 20.5%-35.9% of P accumulation in seeds were transferred from the leaf. The P accumulations mainly occurred during reproduction development stages. The proportion of P accumulation at reproduction development stages occupied 79.0%-92.2% of all growth stages in oil flax plant. The maximums of P fertilizer recovery efficiency and agronomic efficiency were 20.2%-20.5% and 7.30 kg/kg-7.44 kg/kg, respectively; and when the P (P₂O₅) application rate was 70 kg/hm². The grain yield improvement complied with increasing P application rates, increased range from 28.96% to 31.46%. The recommendation of P fertilizer rate for oil flax was 70 kg/hm² (P₂O₅) under climate conditions of the experimental area are based on synthesize grain yield, P fertilizer recovery efficiency, P agronomic efficiency and environment pollution,
Principal Component Analysis on Agronomic Characters of Flax

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Abstract
In this paper 17 traits from parents commonly used in recent flax (*Linum usitatissimum* L.) hybrid breeding, were analyzed utilizing the F test. Nine of traits were screened, namely flowering period, plant height, technical length, the effective branch number, effective boll number per plant, grain number and weight of single plant, 1000-seed weight and kernels from one fruit. Using principal component analysis, results showed the accumulated percentages of eigenvalue from plant height, effective branch number, effective boll number, and 1000-seed weight were all over 90%, plant height was the first principal component, and the effective branches and boll numbers were all the second principal component, followed by 1000-seed weight. These traits, which are key characters, always play an important role during the breeding of differently new varieties.

Pre-breeding, Breeding and Farming for Flax Production in Russia

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Abstract
The flax (*Linum usitatissimum* L.) research and breeding programs at the state research organizations of the Russian Academy of Science have the responsibility to breed new flax cultivars for producers in all flax growing regions of the Russian Federation. Historical strict dividing for fiber and oil flax production resulted in two separate types of breeding and farming. At the pre-breeding stage fiber and oil flax varieties are crossed within the specific type only. One of the big source of genetic variability is present in collections of the Vavilov’s Institute in St.-Petersburg, the Flax Institute in Torzhok, and the Oil Crops Institute in Krasnodar. Traditional methods for breeding of new cultivars are classical crosses and selection for outstanding agronomic traits and biotic and abiotic stress factors. Biological potential of new cultivars is quite high and favorable conditions can realize the high yield. The State Commission for Breeding conducts 3-yr multi-location tests of new lines within many different climatic and soil zones in order to understand the genotype × environment interaction patterns. From 49 fiber flax and 20 oil flax varieties presented in the State List of Recommended varieties for the Russian Federation (for 2014) the majority is from Russian origin. However, some farming difficulties in many common flax growing farms decreased the realization of the cultivars' genetic potential and the income from the breeding’s innovation is lower than anticipated. Federal and regional programs for flax crop development aim to create marketing conditions and positive motivation for farmers to grow fiber and oil flax.