Aspects of conventional flax breeding

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The origin of flax (*Linum usitatissimum* L.) is uncertain. Some authors consider *L. bienne* as the progenitor of small seeded flax, originating from Kurdistan and Iran, whereas others consider *L. angustifolium* containing high oil content and seed weight, as progenitor, originating from the Mediterranean region.

While *L. usitatissimum* is an annual crop species, the wild forms can also be biennial or perennial.
Domestication

Since the domestication of flax, there has been a preference for growing flax either for its fiber or oil. In the Western region of Eurasia, flax is mainly grown for its fiber, whereas in the Eastern region of Eurasia flax is grown for its oil.
Flax was already grown 6000-8000 years ago in Egypt and Sumaria, and belongs (together with barley and wheat) to the oldest of cultivated plants.

The distribution of flax from the Near East into Europe is well documented. It is considered that flax cultivation in Western Europe (the Netherlands, Northern France, Belgium and Switzerland) started about 5000-3000 BC when semi-nomads, originating from the Middle East, settled in Flanders and introduced flax cultivation.
Taxonomy

The Linaceae family comprises of 22 genera of which genus *Linum* is the most well-known. The more than 200 species present in the genus *Linum* are divided in five subsections (*Linum*, *Dasylinum*, *Linastrum*, *Syllinum* and *Cathartolinum*).

Only some species from the section *Linum* are used for agronomical purposes. Cultivated flax (*L. usitatissimum*) is commercially grown for its fiber and linseed oil. *Linum grandiflorum* Desf., *Linum perenne* L. and *Linum flavum* L. serve as ornamentals.
Flax (Linum usitatissimum L.)

- Seed
- Stems
- Fibre (long and short)
- Shives
- Chaff
I – fibre flax
II - III - intermediate
IV - linseed
The number of chromosomes of the *Linum* species show a wide range varying from $2n=16$ to $2n=72$.

*Linum usitatissimum* and its wild relatives contain $2n=30$ chromosomes (is a diploid).
Fibre flax and linseed

The dual purpose of flax was already known in ancient times. In ancient Egypt, linen (derived from the fiber) was used for wrapping the royal mummies and additionally linseed oil was used to embalm the bodies of deceased Pharaohs.

For a long time flax has been cultivated as a dual-purpose crop, but nowadays fiber flax and linseed represent different gene pools.
Nowadays flax (Linum usitatissimum L.) is grown commercially for two products, fiber and seed.

Due to selective breeding two distinguishable cultivar groups have developed and are grown as different crops, fiber flax and linseed.

Fiber flax has a long unbranched growth habit, whereas linseed (oil flax) is much shorter and highly branched.
Fiber flax is bred for its long stem containing long fibers and is mainly grown in Russia, China, Egypt and near the North-western European coast, whereas linseed was deliberately bred for short and highly branched plants to increase the number of flowers (enhanced seed production). The main purpose of the fiber is the production high quality linen whereas linseed oil originating from the seeds has many industrial applications, e.g. paints, linoleum, ink, etc.
Characteristics

Flax (*Linum usitatissimum* L.) is an erect, herbaceous annual plant.

*L. usitatissimum* has a short tap root with fibrous branches which may extend 90-120 cm in light soils. Leaves are simple, sessile, linear-lanceolate with entire margins, and are borne on stems and branches. The inflorescence is a loose terminal raceme.
Flowers are borne on long erect pedicels, are hermaphrodite, and are composed of five sepals, five petals, five stamens, and a compound pistil of five carpels each separated by a false septum. The fruit is a capsule, composed of 5 carpels and may contain up to 10 seeds. The seed is oval, lenticular, 4-6 mm long with a smooth, shiny surface, brown to light-brown or yellow in colour.

Seeds contain 35-45 % oil and 20-25 % protein.
Flax is a highly self-fertilizing (self-pollinating) annual herbal plant. The pollen is viable for only a few hours, from the time of anther dehiscence until about the time the petals dehisce - between 4 and 7 hours. As the flower opens, the anthers come together and form a cap over the stigma.

The natural crossing in flax ranges from 0-5 %, there being variation among genotypes. Cross pollination may occur via honey bees or by artificial means.
The beginning of flax breeding

Similar to most agricultural crops, commercial breeding of flax started at the end of the 19th century.

Traditional flax breeding was based on mass selection. Around 1900, pedigree selection of flax was introduced in the Netherlands by prof. Broekema which later resulted in the high performing high yield or well performing cultivars.
Plant breeding is defined as identifying and selecting desirable traits in plants and combining these into one individual plant.

Since 1900, Mendel's laws of genetics provided the scientific basis for plant breeding. As all traits of a plant are controlled by genes located on chromosomes, conventional plant breeding can be considered as the manipulation of the combination of chromosomes.

In general, there are three main procedures to manipulate plant chromosome combination. **First**, plants of a given population which show desired traits can be selected and used for further breeding and cultivation, a process called (pure line-) selection. **Second**, desired traits found in different plant lines can be combined together to obtain plants which exhibit both traits simultaneously, a method termed hybridization. Heterosis, a phenomenon of increased vigor, is obtained by hybridization of inbred lines. **Third**, polyploidy (increased number of chromosome sets) can contribute to crop improvement. **Finally**, new genetic variability can be introduced through spontaneous or artificially induced mutations.
Flax breeding goals

The objective of breeding flax is to obtain improved varieties, adjusted to the demands of farmers, processors and consumers.
When talking about fibre flax, the most important aims are to increase fibre yield, fibre quality, lodging resistance and disease resistance.

Flax is not an easy crop to breed, because most of these characters have a low heritability and are difficult to evaluate.

Furthermore, in field trials a large quantity of seed is needed while, compared to cereals, the multiplication rate of flax is relatively low.

Moreover, different users in subsequent processing steps put different demands on the flax quality, while various fibre products such as yarns, cloths and other industrial applications also lead to varying demands on quality aspects.
Fiber flax and linseed are two distinct cultivar groups, grown for the production of fiber and linseed oil respectively.

Some breeding goals are important for both cultivar groups, for example resistance to pathogens and resistance to lodging.

Fiber content, and resistance to *Fusarium* and scorch are the most important breeding goals for fiber flax, whereas seed yield, fatty acid composition and resistance to rust (*Melampsora lini*) and *Fusarium* are important for linseed breeding.
Main breeding aims of **linseed** in the Czech Republic are:
- fat yield (seed yield x fat content in the seed),
- resistance to diseases (*Fusarium oxysporum* f. sp. *lini*, *Alternaria linicola*, *Colletotrichum lini*, *Rhizoctonia linicola*, *Oidium lini*),
- resistance to lodging, and
- fatty acid content.

Main breeding aims of **fibre flax** in the Lithuania are:
- high yields,
- high fibre yield and quality,
- resistant to lodging,
- less susceptible to fungal diseases,
- Short or moderately long vegetative growth period,
- well adapted to Lithuania’s soil and climate conditions.
Flax breeding methods:

Nowadays, several breeding methods are available, but the pedigree method (hybridization) is the most common one used in flax breeding.

- Selection (individual; mass) (onetime; multiplex) (positive; negative);
- Inter-varietal crossing (hybridization) (pedigree selection) (emasculiation and artificial pollination);
- Mutation (natural, chemical, physical);
- Haploidisation;
- Biotechnology;
- Gene transfer;
- etc.
Selection is the most ancient and basic procedure in plant breeding. It generally involves three distinct steps. First, a large number of selections are made from the genetically variable original population. Second, progeny rows are grown from the individual plant selections for observational purposes. After obvious elimination, the selections are grown over several years to permit observations of performance under different environmental conditions for making further eliminations. Finally, the selected and inbred lines are compared to existing commercial varieties in their yielding performance and other aspects of agronomic importance.
The most frequently employed plant breeding technique is hybridization. The aim of hybridization is to bring together desired traits found in different plant lines into one plant line via cross-pollination.

The first step is to generate homozygous inbred lines. This is normally done by using self-pollinating plants where pollen from male flowers pollinates female flowers from the same plants. Once a pure line is generated, it is outcrossed, i.e., combined with another inbred line. Then the resulting progeny is selected for combination of the desired traits.

If a trait from a wild relative of a crop species, e.g., resistance against a disease, is to be brought into the genome of the crop, a large quantity of undesired traits (like low yield, bad taste, low nutritional value) are transferred to the crop as well. These unfavorable traits must be removed by time-consuming back-crossing, i.e., repeated crossing with the crop parent.
Polyploidy

Most plants are diploid. Plants with three or more complete sets of chromosomes are common and are referred to as polyploids. The increase of chromosomes sets per cell can be artificially induced by applying the chemical colchicin, which leads to a doubling of the chromosome number.

Generally, the main effect of polyploidy is increase in size and genetic variability. On the other hand, polyploid plants often have a lower fertility and grow more slowly.
Induced mutation

Instead of relying only on the introduction of genetic variability from the wild species gene pool or from other cultivars, an alternative is the introduction of mutations induced by chemicals or radiation. The mutants obtained are tested and further selected for desired traits. The site of the mutation cannot be controlled when chemicals or radiation are used as agents of mutagenesis. Because the great majority of mutants carry undesirable traits, this method has not been widely used in breeding programs.
With mass selection, individual plants are selected on the basis of their phenotype without knowledge of their genotypic constitution. Therefore, this method is only useful for properties with a high heritability, as in flax for plant height, and selection for fibre quality in progenies from crosses between fibre flax and linseed.

The pedigree method is generally used for breeding self-pollinating crops; individual plants are evaluated on the basis of the results of their progenies.

However, for flax this method has two disadvantages. In early generations there are no, or only a few, easily selectable traits. For instance low heritable characters such as fibre yield cannot be evaluated before F7 or F8, when enough seed becomes available for trials. This means loss of time and, even more important, a loss of genetic variability. In early generations the sowing of plants in low densities is inevitable to speed up multiplication. This introduces the possibility of misinterpretation in the evaluation of traits during these early generations; their expression can also be affected by the plant morphology, such as stem diameter.
Inter varietal crossing:

- simple crossing \([A \times B]\) (emasculaion and artificial pollination)
- back crossing \([A \text{ or } B \times F\ 1]\) (crossing of F1 generation with one of parental forms)
- reversed (reciprocal) crossing \([A \times B], [B \times A]\) (crossing of parental forms in both directions)
- cyclic crossing (1 variety to be crossed with series of other varieties)
In conventional breeding programmes, it takes approximately ten to fifteen (could be even 25) years to develop a new flax variety. To obtain a sufficiently homozygote line, it takes ten or more successive selfing generations.
Fibre flax breeding could be carried out according to the following scheme:

1) nurseries of initial material (collection, hybrids, mutants),
2) breeding nursery,
3) hybrids nursery,
4) selection nursery,
5) control nursery,
6) initial variety trials,
7) competitive variety trials;
8) multiplication of perspective varieties and farm scale trials
In the nursery of initial material the varieties and accessions are sown in very small plots (of 0.2-1.0 m²), and in the breeding, selection and control nurseries – in the plots of 0.2-4.0 m².

In the control nursery flax is sown already in 4-5 replications.
Initial and competitive variety trials involve 3-4 replications; the size of a record plot is 11.2 and 16.0 m², respectively. Flax is sown at a seed rate of 25 million seed per hectare, 10 cm space between rows.

Insecticides are sprayed against flax flea beetles, and herbicides are used to control weeds.

During vegetative growth period of flax, the phenological observations are conducted; resistance to lodging and the incidence of fungal diseases on flax etc. are assessed.
Collection – a source of initial breeding material (flax germplasm)

In recent years it has become more difficult to breed new fiber flax cultivars with a better fiber quality, increased fiber yield and the required resistances, due to repeated use of modern cultivars as crossing parents. Experts dealing with testing plant cultivars for Distinctness, Uniformity and Stability (DUS) criteria have noticed that the morphological variation between new cultivars has decreased. This points towards a narrow genetic basis of modern flax cultivars.

Generally, the collection of various flax accessions is a basis of initial breeding material straight-forwarded to successful flax breeding. Before starting crossing, screening large numbers of prospective parents should be done.
Firstly, the accessions of the collection should be carefully investigated with aim to know what of them are valuable for breeding programs. Beside of this, flax collection serves as collection of genetic resources which variability should be studied and preserved.

The amount of accessions of *Linum ussitatissimum* L. in the collection is not stable; it is changing due to introducing new accessions or discarding of some breeding lines as well as of knelling or some accessions. Valuable breeding lines or other accessions from breeding, selection process could be transferred to flax collection also.

Valuable flax accessions are transferred to Gene bank.

The exchange of flax seed accessions between breeders from various countries is going on continually.
Flax breeding in Lithuania; developed varieties

Fibre flax breeding was started in Lithuania in 1922 (beginning at Dotnuva breeding station; later on flax breeding was carried out at Savitiškis experimental station, and since 1965 this work is continued at the Upytė Experimental Station of the Lithuanian Research Centre for Agriculture and Forestry (former URS of LIA)).
Since 1922 to 2005, eighteen fibre flax varieties have been developed with the main aim to increase fibre yield per hectare, fibre quality (being suitable for textile purposes), flax resistance to lodging and diseases.
Considering growing interest in healthy life, healthy nutrition, linseed breeding was also started in Lithuania.

Since 2005 to 2012, three fibre flax (‘Dangiai’ ‘Snaigiai’ ‘Sartai’) and three linseed varieties (‘Edita’ ‘Rasa’ ‘Rūta’) were developed.
In Western Europe, flax breeding is performed primarily by private companies.

In Eastern Europe, most of the flax breeding efforts are carried out by public institutions.
Sources from 2010 report that flax breeding efforts are concentrated in France, the Netherlands and in the United Kingdom.

In the Netherlands, the major flax breeding programs are lead by van de Bilt Zaden & Vlas B.V., Wiersum B.V. Landbouwbureau, and Limagrain Nederland;

In the United Kingdom by Agrifusion, John Turner Seed Developments, and Limagrain UK, all, of which, are private firms.

In France, the major flax breeding private companies are GIE Linea, Agri Obtentions, and Laboulet Semences. GIE Linea consists of a private company, LIN2000, and three flax stripping cooperatives. In a partnership between the Institute National de la Recherche Agronomique (INRA) (the leading European agricultural research institute) and LIN2000, GIE Linea was entrusted with the task of conducting flax breeding, in particular, to produce cold tolerant flax varieties.
In recent years, the companies based in France have combined their research and breeding efforts through partnerships, with INRA playing a major role as a supplier of the genetic material for these projects.

France’s flax breeding industry is also characterized by the involvement of cooperatives. The leading cooperatives are Terre de Lin and Cooperative Liniere de Fontaine Cany. Terre de Lin has been in operation for more than 50 years and currently has a research team of seven people.
Flax breeding efforts in the Czech Republic, have historically been carried out at individual state research stations which were subsequently consolidated into the state breeding enterprise (Institute) OSEVA in Prague in 1977. The purpose of this consolidation was to combine genetic research, plant breeding and seed production under a single organizational umbrella.

In 1993, the Czech research breeding environment witnessed a dramatic change with public research institutes, specializing in particular crops, evolving into limited liability companies (Ltd.). The public flax breeding institute was transformed into ‘AGRITEC, Research, Breeding, and Services Ltd.’, a principal flax breeding program in Czech Republic that operates as a private non-profit institution. All potential profits generated by AGRITEC must be completely reinvested in research. AGRITEC partners with the national breeding companies Selgen a.s. and SEMO.
Flax and linseed breeding in **Poland** is carried out at the Institute of Natural Fibres & Medicinal Plants and Poznań Branch of Plant Breeding and Acclimatization Institute.

In **Lithuania**, flax breeding has been on-going since 1922. Since 1965, flax breeding has been performed at the Upyte Research Station of the Lithuanian Institute of Agriculture (nowadays – LRCAF).

In **Romania**, flax breeding is carried out at Agricultural Research Station Livada.

In **Russia**, the main flax breeding agencies are: All-Union Research Institute of Flax, Kaluga Research and Development Agro-Industrial Institute, Viatka State Academy of Agriculture, Pskov Research Institute of Agriculture, Smolensk Region A. Engelgardt State research station, Tomsk Region State Agricultural Research Station and some others.
Substantial progress has been made in China during the last several years both in biotechnological and traditional methods of breeding resulting in the registration of several fibre or linseed varieties. The major breeding research efforts are located at the Flax Research Institute under the Academy of Agricultural Sciences of Heilongjiang Province and The Institute of Industrial Crops in Heilongjiang, Hunan.
Figure A. Number of registered flax varieties developed by *private* sector, 1990-1999

Source: (Galushko V., Ryan C. D. Intellectual property rights (IPRs) and knowledge sharing in flax breeding, 2010)
Figure B. Number of registered flax varieties developed by *private* sector, 2000-2008

Source: (Galushko V., Ryan C. D. Intellectual property rights (IPRs) and knowledge sharing in flax breeding, 2010)
Figure C. Number of registered flax varieties developed by *public* sector, 1990-1999

Source: (Galushko V., Ryan C. D. Intellectual property rights (IPRs) and knowledge sharing in flax breeding, 2010)
Figure D. Number of registered flax varieties developed by *public* sector, 2000-2008

Source: (Galushko V., Ryan C. D. Intellectual property rights (IPRs) and knowledge sharing in flax breeding, 2010)
Flax varieties in EC Common catalogue of varieties of agricultural plant species

A lot of flax and linseed varieties are developed and registered (172) at the EC Common catalogue of varieties of agricultural plant species for 2012 (30th complete edition). 70 of them are marked as fibre flax and 77 – as linseed type.
Thank you for attention!