Flax breeding: goals, methods, variety realization

Dr. Sofija Jankauskienė

Upytė Experimental Station
of the Lithuanian Research Centre for Agriculture and Forestry
Lithuania

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Overview:

- Flax presentation
- Description of flax breeding
- Flax breeding goals
- Flax breeding methods

Steps of variety realization:

- Collection – a source of initial breeding material (flax germplasm)
- Creation of breeding lines
- Selection and testing of breeding lines
- Registering of new varieties
The Linaceae family comprises of 22 genera of which genus *Linum* is the most well-known.

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.
Flax was already grown 6,000-8,000 years ago in Egypt and Sumaria, and belongs (together with barley and wheat) to the oldest cultivated plants.
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.
Since the domestication of flax, there has been a preference for growing flax either for its fiber or oil. But selection depends on the geography also. 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. Countries with cooler climate grow fibre flax, and linseed is grown in more southern countries.
Linum usitatissimum L. – cultivated flax –

could be:

- Flax and linseed;
- Winter or spring type.

While Linum usitatissimum is an annual crop species, the wild forms can also be:

- biannual or
- perennial
Linum grandiflorum Desf., Linum perenne L. and Linum flavum L. serve as ornamentals.
I – fibre flax  
II - III - intermediate  
IV - linseed
Flax (*Linum usitatissimum* L.)

- Seed
- Stems
- Fibre (long and short)
- Shives
- Chaff
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.
Plant breeding was started already 10,000 years ago by selecting the best plants in the field and it is defined as identifying and selecting desirable traits in plants and combining these into individual plant.

Traditional flax breeding was based on mass selection. Around 1900, pedigree selection of flax was introduced.

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

Since 1900, Mendel's laws of genetics provided the scientific basis for plant breeding.
Ceccarelli (2015) described three main phases of flax breeding:

1) generating genetic variability (making crossings, inducing mutation, introducing exotic germplasm, using genetic engineering techniques);

2) selection and testing (which terminates with the identification of potential cultivars);

3) release, distribution, and adoption of new cultivars (the yield testing in multienvironment trials).
As all traits of a plant are controlled by genes located on chromosomes, plant breeding can be considered as the manipulation of the combination of chromosomes.

Each species has a characteristic number, size, shape, etc., of the chromosomes that is represented by a diagram called ideogram.

The number of chromosomes of the *Linum* species show a wide range varying from 2n=16 to 2n=72.

*Linum usitatissimum* L. and its wild relatives contain 2n=30 chromosomes (is a diploid).

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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.
Starting from the beginning of the XX century many new tools have been applied to broaden the breeding possibilities. Mutagenesis (chemical or physical, even site-directed mutagenesis of plant genes), molecular marker–assisted selection with genetic engineering, etc. could be also applied for breeding purposes, but did not replace the conventional breeding methods. Conventional breeding techniques are still in breeders’ toolbox however such breeding methods are time consuming since need at least 15 years for variety development.
Flax breeding goals

The objective of flax breeding is to obtain improved varieties, adjusted to the demands of farmers, processors and consumers.
Practice classes
Weightman and Kindred (2005) describe the obvious phenotype for an ideal flax variety (ideotype) (for every country it could be different) which would include high fiber yield, high seed yield, synchronous maturation of fiber quality and seed yield, good lodging resistance and early enough maturity date to allow sufficient retting with minimized risk of loss to bad weather.

However, flax processors might summarize as follows: a variety which yields a high proportion of fibre, where the fibre separates easily from the core and bark, and can be processed quickly to give a low content of shives. The fibre would be colourless, and these characteristics should be stable over sites and seasons.

The consumer wants to be healthy and feel comfortably when wearing linen clothes, sleeping in linen bed, consuming oil or seeds, or other products, etc....
It is a very hard task for flax/linseed breeders to combine all desired features in one genotype.

Thus breeding targets depend on breeders’ program selection.

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.

Fibre yields can be dependent on weather and also, crucially, the degree of retting...

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.
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) (emasculcation and artificial pollination);
- Mutation (natural, chemical, physical);
- Haploidisation;
- Biotechnology;
- Gene transfer;
- etc.
Selection

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.
Hybridization

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.
Inter varietal crossing:

- Simple crossing \([A \times B]\) (emasculated and artificial pollination)
- Back crossing \([A \text{ or } B \times F_1]\) (crossing of \(F_1\) 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)

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\begin{array}{c}
\text{A} \\
\text{♀} \\
F_1 \\
\text{B} \\
\text{♂}
\end{array}
\]
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 colchicine, 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.
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.
Fibre flax breeding (variety realization) 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,
9) VCU and DUS tests
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.
In conventional breeding programmes, it takes approximately ten to fifteen (could be even 25) years to develop a new flax variety. Genetic engineering, biotechnology could shorten time neccessary for variety development.

To obtain a sufficiently homozygote line, it takes ten or more successive selfing generations.
Prosperous breeding lines are tested for Value for Cultivation and Use (VCU) in few locations (at the State Plant Variety Testing Stations).

The initial registration of varieties is normally carried out by a plant breeder (or an agent) in the respective EC member state.

Assuming that a variety meets certain requirements for distinctiveness, uniformity and stability (so called DUS tests) and show value for cultivation and use (VCU), it can then be entered on the National List, and would normally proceed to be registered on the EU Common Catalogue.
A lot of flax and linseed varieties are developed and registered (191) at the EC Common catalogue of varieties of agricultural plant species for 2014 (33rd complete edition) (2014/C 450/01).

60 of them are marked as fibre flax and 71 – as linseed type.
Thank you for attention!