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EXPERIMENTAL PAPER

Characterisation and evaluation of morphological trials, biological features and seed yield of 23 flax accessions (*Linum usitatissimum* L.) of different geographical origins

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Summary

Introduction: The Institute of Natural Fibres and Medicinal Plants (INF&MP) is involved in the protection of the genetic resources of flax (*Linum usitatissimum* L.) and hemp (*Cannabis sativa* L.). In 1998–2000, the INF&MP conducted research titled "Collection and evaluation of flax and hemp cultivars and ecotypes". Poland participates in the programme, financed by the Ministry of Agriculture and Rural Development because our country has signed the Convention on Biological Diversity.

Objective: The objective of the research was the evaluation of the genetic resources of 23 accessions of flax. The characteristics data for flax accessions are presented according to traditional methodology and according to the methodology for developing the International Flax Data Base.

Methods: Field trials were carried out in 1998–2000 in the experimental station in Wojciechów, located in the Opolskie region. The objective was to evaluate the morphological traits, biological features and seed yield of 23 accessions of flax. The research included the following genotypes of *Linum usitatissimum* L. according to type of use: 12 linseed varieties, three landraces, one accession of unknown type of use, six fibre varieties and one genotype of both types of use.

Results: The total plant length of *Linum* was short for 12 accessions of flax, medium short (7) and medium (4). The technical length was short (17 accessions), medium short (3) and medium (3). The stem thick-

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ness for all accessions was medium, i.e. between 1.2 and 2.0 mm. The panicle length was short (12 accessions), medium (10) and long (1). A number of primary lateral branches of the stems of all flax accessions was medium (4–8 branches). The 1000 seed weight was low for 21 accessions of flax and very low in two genotypes: Currong and UKR 97 104. The size of the corolla (flower) was small (9), medium (12) and large (2) – varieties: Martin and Maxigold. The petal colour of the corolla was blue (11), light blue (8) and white (4) – Crystal, Hella, Kreola, Achay.

Conclusions: Morphological characterisation of the stamen showed that accession K-1390 was segregating because the anther colour was bluish and greish. The highest resistance to lodging was observed for Abby, Peak and Olinette. The following accessions of flax were very resistant to *Fusarium*: Martin, UKR 97 269, Kijewskij and Ukraińskij 3; resistant to *Fusarium*: Abby, Peak, Olinette, Crystal, Gold Merchant, Currong and Ukraińskij 2. The following varieties were very susceptible to *Fusarium*: Hella, Kreola, Maxigold and Achay. These varieties should not be used for cross breeding. The best average seed yield in 1998–2000 in Wojciechów was found in the following accessions of flax: Abby (191%), Gold Merchant (162%), Currong (161%), Olinette (151%), PEAK (148%), UKR 97 269 (148%), Crystal (138%), Ukraiński 3 (132%), Martin (130%), Pacific (110%) and Ukraiński 2 (103%). These varieties are particularly valuable for flax breeders.

Key words: ***genetic resources, flax, Linum usitatissimum L., morphological traits, biological features, seed yield***

Słowa kluczowe: ***zasoby genetyczne , len, Linum usitatissimum L., cechy morfologiczne, cechy biologiczne, plon nasion***

INTRODUCTION

Since 1982, the Institute of Natural Fibres, now the Institute of Natural Fibres and Medicinal Plants (INF&MP) has been responsible for collecting the genetic resources of the *Linum* genus. Since then the institute has been conducting a research programme aimed at collecting, identifying and keeping alive the genetic resources of *Linum* sp. and, also, since 1998, of *Cannabis* sp. [1]. Each accession in the collection was tested in a three-year trial at the experimental station in Wojciechów, located in the Opolskie region.

Presently, the flax collection of the INF&MP Gene Bank comprises 829 accessions, including wild forms and landraces, primitive and advanced cultivars as well as varieties and breeding lines. World gene banks maintain about 48,000 accessions of cultivated flax, of which some 10,000 might be unique [2]. The collection is part of the Polish Gene Bank and Database, supervised and partially financed by the Polish Ministry of Agriculture and Rural Development [3]. The Program for Genetic Resources of Cultivated Crops Protection is a consequence of implementing the resolutions of the Convention on Biological Diversity [4-7]. In 1992, the Convention on Biological Diversity was signed by 167 countries.

Protection of the genetic resources of *Linum* is very important because flax is the richest source of α-linolenic acid, which prevents civilisation diseases [8, 9]. Providing the body with α-linolenic acid (omega-3) is very important because there are very few food sources of this compound. In addition, only plants can synthesise it. In food products α-linolenic acid is present in very small amounts but linoleic fatty acid in very large quantities. The diet consumed in the countries of Western Europe provides the body with far too much linoleic fatty acid (di-saturated), since most vegetable oils contain very large amounts of this acid. Eating too much linoleic acid contributes to inflammation in the body. Supplementing the human diet with α-linolenic acid prevents the diseases of civilisation. Flaxseed oil contains the most omega-3 of all plant and animal food sources. Currently cultivated Polish varieties have a natural (traditional), pro-health composition of fatty acids in seed oil with a very large amounts of α-linolenic acid, which is very deficient in the human diet. However, there are also some of new varieties of flax (*Linum usitatissimum* L.) with low α-linolenic acid on the market. Unfortunately, according to the regulations, there is no need to separately put the content of tri-unsaturated α-linolenic acid (omega-3) and di-unsaturated linoleic acid (omega-6) on labels. The sum of both fatty acids, di-unsaturated fatty acid (linoleic; omega-6) and tri-unsaturated fatty acid (α-linolenic; omega-3), given as the total content of polyunsaturated acids, is the same in both so-called high-linolenic varieties and in low-linolenic varieties or products (where

α-linolenic fatty acid is only 3% fat) [10]. A German doctor has successfully treated people with cancer using linseed oil obtained from conventional varieties with a high content of α-linolenic acid from the omega-3 family. However, the effect of α-linolenic acid is most proven for counteraction of cardiovascular diseases. The α-linolenic fatty acid is part of cell membranes. It is characterised by a *cis* spatial structure, which results in its semipermeability. Large amounts of omega-3 fatty acids are needed for building the brain, too. Therefore, including it in the daily diet prevents skin problems and brain diseases like depression.

In the studies by Obiedzińska *et al.* [11] the content of α-linolenic acid in flaxseed oil is 51.8–60.4%. Similar results of 52.7% were obtained by Mińkowski *et al.* [12]. In a study of 16 genotypes of flax, the content of α-linolenic acid was from 50.9 to 59.2% [13]. In a study of nine accessions from the Polish Flax Collection, the range of variability of α-linolenic acid content in seed oil was even higher: from 48.9 to 59.9% [10].

Another group of bioactive compounds of great importance for health are lignans, with the content in flax definitely higher than in other food sources. Lignans are a group of polyphenolic compounds with antioxidant activity that has a beneficial effect on, for example, ovarian cancer, breast and prostate cancer or diabetes because they are phytoestrogens.

Other important bioactive compounds found in oil from linseed or flax seeds that counteract the ageing of the body (antioxidant) are tocopherols and sterols. The content of total tocopherols in cold press flax seeds oil is 840 mg in one kg of oil and the content of total sterols is 689 mg in 100 g of oil [11]. In turn, other compounds that the body can get from eating ground flax seeds are selenium, copper, zinc, manganese and iron ions. These compounds help the body fight free radicals enzymatically, because they form important antioxidant enzymes. Endogenous amino acids (peptides) are bioactive compounds also necessary for health. Dietary fibre found in flax seeds also has a very significant impact on the immune systems of humans and animals through interaction in the gastrointestinal tract. Consuming flax seeds, which contain a lot of dietary fiber, increases the pro-health bacterial flora. Restoring the tradition of flax cultivation in Poland and the tradition of consuming flaxseed varieties of high-linolenic varieties would be very important for the health of the society [8, 14]. Consumers are increasingly interested in the use of *Linum* seeds in their daily diet [15].

MATERIAL AND METHODS

The Program for Genetic Resources of Cultivated Crops Protection in Poland is coordinated by the Plant Breeding and Acclimatization Institute National Research Institute (PBAI), which has established the Polish Gene Bank. Flax has a long history of cultivation in warm and cool temperate climate regions [16]. The genetic resources of flax, gathered in the Polish Gene Bank, come from different geographical regions of the world. New flax objects come directly from the breeders sometimes by way of exchange or they are collected during field expeditions. The collected accessions are stored as seeds in the National Centre for Plant Genetic Resources at the PBAI in Radzików, near Warsaw. The genotypes are stored in chambers maintained at a constant temperature of 0°C [17]. The accessions of flax are tested in tree vegetation seasons. The morphological and botanic traits, growth stages and economic value of cultivars and lines were tested.

In 1998–2000 an experiment was conducted on 23 accessions of flax sown in the field in Wojciechów, in the Opolskie region (near Kluczbork) on small plots (1.6 m^2). After two years of vegetation, 50 g of seeds were sent to long-term storage at PBAI. Moreover, in the case of Gold Merchant, Vitagold, Diane, UKR 97 130 and Viola accessions, part of the seed yield after 1999 was dedicated to regeneration, due to the very small quantity of seeds in the collection. The results of the research are the result of a three-year study of plots of 18 accessions of flax and two-year study of five flax varieties: Gold Merchant, Vitagold, Diane, UKR 97 130 and Viola.

Passport data of the flax accessions is shown in table 1. Twelve varieties of linseed flax were investigated: Abby, Peak and Gold Merchant from Great Britain, Olinette, Pecyfic and Royale from Denmark, Crystal from the Netherlands, Hella, Kreola, Martin and Maxigold from Germany, Currong from Russia and one accession, Achay, from Afghanistan characterised for both types of use. The evaluation was also made for one accession (unknown accession name) from Russia (K-1390) (type of use – unknown) and for the six varieties of fibre flax: Vitagold from Germany, Diane and Viola from the Netherlands, Kijewskij, Ukraińskij 2, and Ukraińskij 3 from Ukraine and three accessions of fibre flax from an expedition organised in 1997 (Ukraine): UKR 97 104, UKR 97 130, UKR 97 269. A summary of the meteorological data in the growing seasons in 1998, 1999 and 2000 is presented in Tables 2, 3 and 4.

Table 1.

The passport data of 23 accessions of flax (*Linum usitatissimum* L.)

1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.
INF00685	Abby	POL026	19980217	GBR	3	*Linum*	*usitatissimum*	POL003	linseed	166178
INF00686	Peak	POL026	19980217	GBR	3	„	„	POL003	linseed	166179
INF00687	Olinette	POL026	19980218	DNK	3	„	„	POL003	linseed	166180
INF00688	Pacific	POL026	19980218	DNK	3	„	„	POL003	linseed	166181
INF00689	Royale	POL026	19980218	DNK	3	„	„	POL003	linseed	166182
INF00690	Crystal	POL026	19980309	NLD	3	„	„	POL003	linseed	166183
INF00691	Hella	POL026	1998----	GER	3	„	„	POL003	linseed	166184
INF00692	Kreola	POL026	1998----	GER	3	„	„	POL003	linseed	166185
INF00693	Martin	POL026	1988----	GER	3	„	„	POL003	linseed	166186
INF00694	Maxigold	POL026	1998----	GER	3	„	„	POL003	linseed	166215
INF00695	Gold Merchant	POL026	19980327	GBR	3	„	„	POL003	linseed	166188
INF00696	(K-1390)	POL026	1998----	RUS (RUS 001-VIR)	-	„	„	POL003	unknown	166187
INF00697	Currong	POL026	1998----	RUS (RUS 001-VIR)	3	„	„	POL003	linseed	166189
INF00698	Vitagold	POL026	1998----	GER	3	„	„	POL003	fibre	166190 165849
INF00699	Achay	POL026	1998----	AFG	-	„	„	POL003	both types	166191
INF00700	Diane	POL026	2004----	NLD	3	„	„	POL003	fibre	166192
INF00701	UKR 97 104	POL003	19970903	UKR	2	„	„	POL003	fibre	166193
INF00702	UKR 97 130	POL003	19970904	UKR	2	„	„	POL003	fibre	166194
INF00703	UKR 97 269	POL003	19970908	UKR	2	„	„	POL003	fibre	166195
INF00704	Viola	POL026	19980309	NLD	3	„	„	POL003	fibre	166196
INF00705	Kijewskij	POL026	1998----	UKR (SUN 160)	3	„	„	POL003	fibre	166197
INF00706	Ukraiński 2	POL026	1998----	UKR (SUN 160)	3	„	„	POL003	fibre	166198
INF00707	Ukraiński 3	POL026	1998----	UKR (SUN 160)	3	„	„	POL003	fibre	166199

1. Accession number – number of accessions of flax
2. Accession name – name of accessions of flax
3. Institution code – code of the institution that collected the accessions
4. Acquisition date – date of accession was included in the flax collection
5. Country of origin
6. Origin (type of accession based on its originating): 2 – landrace , 3 –cultivar, – unknown
7. Genus: *Linum*
8. Species: *Linum usitatissimum* L.
9. Institute code –code of the institution where the accessions are stored
10. Type of use: linseed, fibre, both types, unknown
11. Collecting number (number of National Centre for Plant Genetic Resources – PBAI Radzików)

Table 2.

Summary of meteorological data for 1998 growing season – experimental station in Wojciechów

The decade	Rainfall [mm]						Temperature [°C]											
	III	IV	V	VI	VII	VIII	III		IV		V		VI		VII		VIII	
							Average	Min.	Average	Min.	Average	Min.	Average	Min.	Average	Min.	Average	Min.
I	45.0	–	21.1	35.0	37.5	4.5	3.6	–0.6	11.0	6.5	14.9	9.0	22.2	19.6	15.5	13.0	20.4	17.1
II	12.4	14.0	–	1.6	44.1	21.5	1.6	–3.8	7.2	4.2	16.7	13.4	15.3	12.4	18.2	13.9	20.4	12.6
III	–	2.2	7.7	34.1	121.2	29.1	4.6	–2.4	15.3	8.4	16.6	12.6	17.5	14.7	20.0	17.4	12.5	10.5
Total rainfall [mm]	57.4	16.2	28.2	70.7	202.8	55.1	–	–	–	–	–	–	–	–	–	–	–	–
Average temperature month [°C]	–	–	–	–	–	–	3.3	–	11.2	–	16.1	–	18.3	–	17.9	–	14.8	–
Average for many years	34.5	42.3	63.7	49.7	86.8	66.8	2.5	–	7.6	–	13.6	–	17.3	_	18.7	–	18.0	–

Table 3.

Summary of meteorological data for the 1999 growing season – experimental station in Wojciechów

The decade	Rainfall [mm]						Temperature [OC]											
							III		IV		V		VI		VII		VIII	
	III	IV	V	VI	VII	VIII	Average	Min.	Average	Min.	Average	Min.	Average	Min.	Average	Min.	Average	Min.
I	40.0	6.5	-	28.6	1.6	2.6	6.2	2.6	11.5	8.3	11.6	7.4	18.4	16.5	-	-	21.0	18.2
II	-	60.1	62.2	40.3	48.5	20.2	1.3	-2.6	8.7	7.0	14.4	12.6	17.3	16.5	-	-	17.6	15.3
III	6.5	14.0	37.0	79.4	6.5	3.5	8.3	4.8	10.9	7.8	18.5	16.5	16.8	13.0	20.7	17.6	17.0	12.5
Total rainfall [mm]	46.5	80.6	99.2	148.3	56.0	26.3	-	-	-	-	-	-	-	-	-	-	-	-
Average temperature month [°C]	-	-	-	-	-	-	5.3	-	10.4	-	14.8	-	17.5	-	-	-	18.5	-
Average for many years	34.8	43.1	64.4	60.6	86.3	66.0	2.6	-	7.7	-	13.6	-	17.3	-	18.4	-	18.1	-

Table 4.

Summary of meteorological data for the 2000 growing season – experimental station in Wojciechów

The decade	Rainfall [mm]						Temperature [°C]											
							III		IV		V		VI		VII		VIII	
	III	IV	V	VI	VII	VIII	Average	Min.	Average	Min.	Average	Min.	Average	Min.	Average	Min.	Average	Min.
I	69.3	10.7	32.0	44.5	20.9	0.6	4.1	0.8	6.9	0.4	17.9	14.7	18.8	14.3	18.6	16.1	18	15.6
II	26.3	14.0	21.0	4.0	102.9	13.7	2.6	1.3	13.2	7.4	18.6	13.2	20.4	16.2	13.3	11.3	22.8	19.3
III	31.1	–	56.2	4.8	75.7	19.5	7.0	3.4	10.5	15.3	13.3	10.0	17.4	15.6	16.5	14.0	18.2	14.6
Total rainfall [mm]	126.7	24.7	109.2	53.3	199.5	33.8	-	-	-	-	-	-	-	-	-	-	-	-
Average temperature month [°C]	-	-	-	-	-	-	4,7	-	12.9	-	16.5	-	18.9	-	16.2	-	19.6	-
Average for many years	36.6	42.7	65.3	50.7	88.5	65.4	2.6	-	7.8	-	13.7	-	17.3	-	18.0	-	18.1	-

The morphological traits, biological features and seed yield were investigated according to quantitative descriptors (traditional methodology). The following morphological traits: total plant length, technical length, stem thickness, panicle length, number of primary lateral branches, size of the corolla and 1000 seed weight were characterised according to the methodology for the development of the International Flax Database (IFDB), using the ' state descriptor' [18-20].

The following state descriptors, according to J. Nozkova, for the seven morphological traits, listed below, were used [20]:

1. Total plant length
short: 310–649 mm
medium short: 650–769 mm
medium: 700–879 mm

2. Technical length
short: 250–549 mm
medium short: 550–649 mm
medium: 650–749 mm

3. Stem thickness
thin: <1.2 mm
medium: 1.2–2.0 mm
thick: > 2.0 mm

4. Panicle-like size
short: 7–21% of plant's natural height
medium: 22–34% of plant's natural height
long: 35–48% of plant's natural height

5. Number of (primary lateral) branches
low: <4

medium: 4–8
high: >8

6. Size of corolla (diameter of opened flower)
small: 10.0–15.9 mm
medium: 16.0–21.9 mm
large: 22.0–27.9 mm

7. 1000-seed weight
very low: <4.50 g
low: 4.5–7.49 g
medium: 7.50–10.49 g

Differences in the characterisation descriptors and evaluation between the traditional methodology and IFDB methodology were described by Silska and Praczyk [21]. This article also shows the characterisation and evaluation for flax according to both methodologies.

The following morphological descriptors, described plants, stems, panicles, flowers, reproductive organs and seeds, were investigated according to both methodologies (IFDB, traditional):
1. PLANT – Plant growth habit (prostate, spreading, semi-erect, erect)
2. PLANT – Plant life cycle (annual, biennial, perennial)
3. STEM – Plant's natural height = total plant length [cm] (tab. 5)
4. STEM – Stem length = technical length [cm] (tab. 5)
5. STEM – Stem thickness [mm] (tab. 5)
6. PANICLE – Panicle length [cm]; Panicle-like size [%] (tab. 5)
7. PANICLE – Number of primary lateral branches (No) (tab. 5)
8. FLOWER – petal colour of corolla (at the fully opened flower stage) (tab. 5)
9. REPRODUCTIVE ORGANS – Stamen: anther colour (tab. 5)
10. REPRODUCTIVE ORGANS – Stamen: filament colour (tab. 5)
11. REPRODUCTIVE ORGANS – Carpel: style colour (at base) (tab. 5)
12. SEED – 1000 seed weight [g] (to two decimal places) (tab. 5)

The following morphological traits and biological features were only investigated according to the IFDB methodology:
13. FLOWER – Size of corolla (tab. 5)
14. VEGETATION PERIOD – sowing: beginning of flowering (tab. 6)
15. VEGETATION PERIOD – sowing: yellow maturity (tab. 6)

The following biological and agricultural traits were investigated according to the traditional methodology:
16. Resistance to *Fusarium oxysporum* f. sp. lini [1–9° on COBORU scale] (tab. 6)
17. Resistance to lodging [1–9° on COBORU scale] (tab. 6)
18. Seed yield of plots [g] (tab. 7)
19. Seed yield of plots [%] from the average of all plots] (tab. 7)
20. Seed yield of plots [%] – average from 1998–2000 for 18 accessions of flax; average from 1998–1999 for five accessions (Gold Merchant, Vitagold, Diane, UKR 97 130, Viola)

The results were calculated as the average of 20 plants. Resistance to lodging and resistance to disease – *Fusarium oxysporum* f. sp. line – for IFDB is different compared to the evaluation used in INF&MP, where 1–9° on COBORU (Central Research Center for Varieties of Cultivated Plants) scale was applied [21].

In our examination it was not possible to evaluate the economic traits used in the methodology for the International Flax Database, because our seed plots were 1.6 m^2. For IFDB, the seed plots should be 10 m^2. The work presents seed yield from the plots in grams and as a percentage of the average yield of all accessions of flax in a given year. Table 7 presents too the average seed yield, expressed as a percentage, from 3 years (1998–2000) of research for 18 accessions and 2 years of research (1998-1999) for 5 accessions (Gold Merchant, Vitagold, Diane, UKR 97 130, Viola).

Ethical approval: The conducted research is not related to either human or animal use.

RESULTS

Morphological features were investigated according to the descriptors for characterisation and evaluation for the International Flax Database (IFDB) [18, 19]. State descriptors are evaluated in the "Descriptor list for flax (*Linum usitatissimum* L.)" [20].
The plant growth habits for all accessions of flax were erect. The plant life cycles of all genotypes of flax was annual.
The morphological characteristics and valorisation of 23 accessions of flax are shown in table 5. According to the IFDB, the total plant length refers to the plant's natural height and the technical length is the

Table 5.

The morphological characteristics and valorisation of 23 accessions of flax (*Linum usitatissimum* L.) in Wojciechów (1998–2000)

Accession number	name	Stem						Panicle				Flower		Reproductive organs			Seed	
		Total plant length		Technical length		Stem thickness		Panicle length and like size		Number of branches		Size of corolla	Petal colour of corolla	Stamen		Carpel	1000-seed weight	
		[cm]	state descriptor	[cm]	state descriptor	[mm]	state descriptor	[cm]	state descriptor	number	state descriptor	state descriptor	colour	anther colour	filament colour	style colour	[g]	state descriptor
INF00 685	Abby	62.1	short	55.5	medium short	1.4	medium	6.6	short	4.8	medium	medium	blue	bluish	blue	blue	5.07	low
INF00 686	Peak	56.2	short	42	short	1.7	medium	14.4	medium	6.3	medium	medium	blue	bluish	blue	blue	6.27	low
INF00 687	Olinette	65	medium short	47.9	short	1.9	medium	17.7	medium	5.5	medium	medium	light blue	greyish	white	blue	5.77	low
INF00 688	Pacific	63.7	short	50.6	short	1.8	medium	13.2	short	4.8	medium	medium	light blue	bluish	white	white	6.42	low
INF00 689	Royale	58	short	45.6	short	1.5	medium	12.4	short	7.8	medium	medium	light blue	bluish	white	blue	6.1	low
INF00 690	Crystal	64.2	short	52	short	1.7	medium	12.3	short	5.4	medium	small	white	yellowish	white	yellow	7.6	low
INF00 691	Hella	66.8	medium short	47.9	short	2	medium	14.9	medium	5.6	medium	small	white	yellowish	blue	blue	6.25	low
INF00 692	Kreola	60	short	38.3	short	1.8	medium	22.4	long	6.2	medium	small	white	yellowish	blue	blue	7.04	low
INF00 693	Martin	57.9	short	44.8	short	1.8	medium	13.1	medium	5.6	medium	large	light blue	bluish	blue	blue	7.84	low
INF00 694	Maxigold	63.5	short	45.1	short	1.9	medium	18.4	medium	7	medium	large	blue	bluish	blue	blue	5.07	low
INF00 695	Gold Merchant	56.6	short	39.2	short	1.6	medium	14.2	medium	7.1	medium	medium	blue	bluish	blue	blue	4.85	low
INF00 696	(K-1390)	62	short	44.5	short	1.7	medium	17.5	medium	7	medium	medium	light blue	bluish and greyish	blue	blue	4.85	low
INF00 697	Currong	72.4	medium short	55.5	medium short	1.7	medium	16.9	medium	6.3	medium	medium	light blue	bluish	blue	blue	4.25	very low
INF00 698	Vitagold	62.5	short	40	short	1.5	medium	15.5	medium	5.1	medium	medium	light blue	bluish	blue	blue	5.18	low
INF00 699	Achay	66.5	medium short	59.1	short	1.8	medium	14.6	medium	5.2	medium	small	white	bluish	white	white	4.52	low
INF00 700	Diane	87.5	medium	65	medium	1.9	medium	10	short	4.7	medium	small	blue	yellowish	blue	blue	4.5	low
INF00 701	UKR 97 104	83.4	medium	67.1	medium	1.9	medium	16.3	short	5.1	medium	medium	blue	bluish	blue	blue	3.75	very low
INF00 702	UKR 97 130	74.1	medium short	54.1	short	1.6	medium	9.2	short	4	medium	small	blue	bluish	blue	blue	4.5	low
INF00 703	UKR 97 269	60	short	47.3	short	1.5	medium	12.8	short	5.8	medium	small	blue	bluish	blue	blue	4.72	low
INF00 704	Viola	74.1	medium short	49.2	short	1.7	medium	9.2	short	6.7	medium	medium	blue	yellowish	blue	blue	6.7	low
INF00 705	Kijewskij	79.3	medium	65	medium	1.8	medium	14.3	short	5.2	medium	medium	blue	bluish	blue	blue	4.57	low
INF00 706	Ukraiński 2	66	medium short	52.2	short	1.8	medium	13.8	short	6.2	medium	small	blue	bluish	blue	blue	4.75	low
INF00 707	Ukraiński 3	78.4	medium	63	medium short	1.8	medium	15.4	short	5.1	medium	small	light blue	bluish	blue	blue	5.12	low
	Min.	56.2	short	38.3	short	1.4		6.6	short	4.7	-	small	-	-	-	-	3.75	very low
	Max.	87.5	medium	67.1	medium	2.0		22.4	long	7.8	-	large	-	-	-	-	7.84	low

Table 6.

The morphological characteristics and valorisation of 23 accessions of flax (*Linum usitatissimum* L.) in Wojciechów (1998–2000)

Accession number	Accession name	Vegetation period – according International Flax Data Base												Resistance to abiotic factors – lodging			Resistance to biotic factors – *Fusarium*		
		Sowing – beginning of flowering						Sowing – yellow maturity											
		1998		1999		2000		1998		1999		2000		1998	1999	2000	1998	1999	2000
		days	state descriptor	days	state descriptor	days	state descriptor	days	state descriptor	days	state descriptor	days	state descriptor	(1–9 on COBORU scale)			(1–9 on COBORU scale)		
INF00 685	Abby	45	short	53	medium	49	short	105	medium	95	short	117	medium	9	9	7	8	8	9
INF00 686	Peak	50	short	43	short	46	short	105	medium	95	short	117	medium	9	9	5	8	9	9
INF00 687	Olinette	51	short	54	medium	47	short	108	medium	95	short	117	medium	9	9	3	8	8	9
INF00 688	Pacific	49	short	51	short	49	short	106	medium	93	short	112	medium	9	7	6	8	6	9
INF00 689	Royale	47	short	47	short	49	short	102	short	93	short	112	medium	8	5	3	6	5	9
INF00 690	Crystal	47	short	49	short	48	short	105	medium	101	short	112	medium	9	9	8	8	9	9
INF00 691	Hella	50	short	49	short	52	short	102	short	93	short	115	medium	8	1	3	8	1	3
INF00 692	Kreola	48	short	49	short	59	medium	102	short	93	short	115	medium	3	9	5	5	1	3
INF00 693	Martin	51	short	55	medium	50	short	112	medium	101	short	110	medium	9	7	5	9	9	9
INF00 694	Maxigold	51	short	52	short	52	short	106	medium	93	short	115	medium	9	7	3	4	1	3
INF00 695	Gold Merchant	49	short	52	short	-	-	105	medium	93	short	-	-	9	3	-	9	8	-
INF00 696	(K-1390)	47	short	48	short	45	short	105	medium	107	short	102	short	2	6	3	6	5	8
INF00 697	Currong	46	short	44	short	47	short	105	medium	101	short	103	medium	7	9	2	9	8	9
INF00 698	Vitagold	50	short	52	short	-	-	105	medium	107	medium	-	-	2	7	-	7	4	-
INF00 699	Achay	49	short	48	short	53	short	105	medium	107	short	102	short	5	8	9	5	1	3
INF00 700	Diane	51	short	55	medium	-	-	101	short	93	medium	-	-	9	8	-	9	1	-
INF00 701	UKR 97 104	46	short	45	short	49	short	101	short	94	medium	111	medium	7	4	8	9	3	9
INF00 702	UKR 97 130	48	short	45	short	-	-	101	short	95	short	-	-	3	5	-	8	4	-
INF00 703	UKR 97 269	48	short	45	short	43	short	101	short	107	short	104	medium	3	8	2	9	9	9
INF00 704	Viola	48	short	50	short	-	-	101	short	93	short	-	-	8	9	-	7	3	-
INF00 705	Kijewskij	48	short	52	short	48	short	101	short	101	medium	104	medium	8	8	3	9	9	9
INF00 706	Ukraiński 2	47	short	48	short	44	short	101	short	101	short	110	medium	6	8	3	9	8	9
INF00 707	Ukraiński 3	48	short	49	short	45	short	107	medium	107	short	108	medium	9	7	3	9	9	9
Min.		45		43	short	43	short	101	short	93	short	102	short	2	1	2	4	1	3
Max		51		55	medium	59	medium	108	medium	107	medium	117	medium	9	9	9	9	9	9

Table 7.

Seed yields of 23 accessions of flax (*Linum usitatissimum* L.) in Wojciechów (1998–2000)

Accession number	Accession name	Seed yields of plots [g] – 1.6m²			Seed yields of plots [%] – the percentage of average yield in 1998, 1999, 2000 and 1998-2000			
		1998	1999	2000	1998 (average yield – 256 g) [%]	1999 (average yield – 88 g) [%]	2000 (average yield – 143 g) [%]	average from 1998, 1999, 2000 [%]
INF00685	Abby	420	173	303	164	197	212	191
INF00686	Peak	250	175	209	98	199	146	148
INF00687	Olinette	290	160	224	113	182	157	151
INF00688	Pacific	350	56	185	137	64	129	110
INF00689	Royale	210	64	168	82	73	117	91
INF00690	Crystal	230	189	158	90	215	110	138
INF00691	Hella	210	1	19	82	1	13	32
INF00692	Kreola	160	1	11	62.5	1	8	24
INF00693	Martin	300	154	139	117	175	97	130
INF00694	Maxigold	70	3	40	27	3	28	11
INF00695	Gold Merchant	460	127	-	180	144	-	162
INF00696	(K-1390)	180	48	155	70	55	108	78
INF00697	Currong	400	140	240	156	159	168	161
INF00698	Vitagold	110	44	-	43	50	-	46.5
INF00699	Achay	230	2	11	90	2	8	33
INF00700	Diane	190	49	-	74	56	-	65
INF00701	UKR 97 104	290	22	120	113	25	84	74
INF00702	UKR 97 130	150	56	-	59	64	-	61.5
INF00703	UKR 97 269	350	164	175	137	186	122	148
INF00704	Viola	210	54	-	82	61	-	71.5
INF00705	Kijewskij	250	94	133	98	107	93	99
INF00706	Ukraiński 2	270	79	162	105	90	113	103
INF00707	Ukraiński 3	310	162	130	121	184	91	132
Min.		70	1	11	27 (Maxigold)	1 (Hella, Kreola)	8 (Kreola, Achay)	11 (Maxigold)
Max		460	189	303	180 (Gold Merchant)	215 (Crystal)	212 (Abby)	191 (Abby)
Average yield		256	88	143				

same as the stem length.

The total plant length of 23 accessions of flax ranged from 56.2 cm (Peak – linseed) to 87.5 cm (Diane – fibre). The technical length ranged from 38.3 cm (Kreola – linseed) to 67.1 cm (UKR 97 104 – landrace). The thickness of the stem in the middle of the technical length of all accessions was medium (IFDB) and ranged from 1.4 (Abby – linseed) to 2 mm (Hella – linseed).

The minimum panicle length was 6.6 cm (Abby – linseed) but the maximum was 22.4 cm (Kreola – linseed).

The evaluation results of the total plant length were as following: short (310–649 mm) – 12 accessions; medium short (650–769 mm) – 7 accessions; and medium (700–879 mm) – 4 accessions of flax. Evaluation of the technical length gave the following results: short (250–549 mm) – 17 accessions; medium short (550–649 mm) – 3 accessions; and medium (650–749 mm) – 3 accessions of flax. The panicle-like size [20] was short (7–21% of plant's natural height) for 12 accessions of flax, medium (22–34% of plant's natural height) for 10 and long (35–48% of plant's natural height) for 1 accession of flax (Kreola – linseed).

The number of primary lateral branches of inflorescence (stem) of all accessions of flax was medium (4–8 branches).

The size of the corolla was small for 9 accessions, medium for 12 and large for 2 accessions of linseed (Martin and Maxigold).

The petal colour of the corolla flower was blue in 11 accessions of flax, light blue in 8 genotypes and white for 4 accessions (Crystal, Hella, Kreola, Achay).

The 1000-seed weight was low for 21 accessions of flax and very low for 2 genotypes (Currong and UKR 97 104).

Table 5 also presents the characteristics of the

reproductive organs: stamen – anther colour (at the top) and filament colour; and the characteristics of the carpel – style colour (at the base). These traits are very important for identifying accessions of flax. Morphological characterisation of the stamen shows that accession K-1390 is segregating because the anther colour is bluish and greish.

The study was aimed at the evaluation of resistance of flax accessions to *Fusarium* (biotic factors), according to a 1–9 COBORU scale and resistance to lodging (abiotic factors), according to a 1-9 COBORU scale (tab. 6). The highest resistance to lodging was found in linseed varieties: Abby, Peak, and Olinette. The following varieties were very resistant (9) to *Fusarium*: Martin, UKR 97 269, Kijewskij and Ukraiński 3; and resistant (8) were Abby, Peak, Olinette, Crystal, Gold Merchant, Currong and Ukraiński 2 (tab. 7). Of the 23 accessions of flax, the most susceptible to *Fusarium* were the following varieties: Hella, Kreola, Maxigold and Achay.

The results of seed yield from the 1.6 m^2 plots, as a percentage of average yield in each year (1998, 1998, 2000), are shown in table 7. In the group of 12 linseed flax accessions and Achay (both types) the highest average seed yield characterised the following accessions: Abby (191%), Gold Merchant (162%), Currong (161%), Olinette (151%), Peak (148%) and Crystal (138%). The lowest average seed yield characterised Maxigold (11%), Kreola (24%), Hella (32%) and Achay (33%). In the group of ten flax accessions (fibre and unknown) the highest average seed yield was observed for the following accessions: UKR 97 269 (148%), Ukraiński 3 (132%), Ukraińskij 2 (103%) and Kijewskij (99%).

DISCUSSION

Flax is both types: fibre and linseed plant. This species is characterised by high variability of genotypes. Tall plants, with a long stem from which the long fibre is extracted, are characterised by a short panicle with a small number of branches and, therefore, a small seed yield. In turn, short genotypes with short stems, from which a short fibre is obtained, are characterised by a panicle longer than in fibre genotypes of flax with more numerous panicle branches with seed bags and a higher seed yield. Tall plants of flax represent fibre type of use , shorter plants of flax represent the linseed type of use (linseed genotypes). Plants of *Linum* with a morphological shape characteristic of genotypes of the fibre type are gradually transformed into fibre-linseed forms and forms with a morphological shape characteristic of flax with an linseed type of flax. Flax plants with an intermediate morphological features between the two types of use are variously called in the literature: mixed type of use, dual purpose, both types of use.

The Institute of Natural Fibres and Medicinal Plants takes part in the development of the International Flax Data Base (IFDB). Creating the IFDB, based on new criteria, will allow for easier and faster analysis of the morphological, biological and agronomic characters of accessions of genus *Linum*. It is important for breeders, because it will make it possible to select genetic materials for breeding purposes [22, 23]. For example, industrial crops in Lithuania are analysed at the Lithuanian Institute of Agriculture and experimental stations deal with flax and potatoes [24].

Therefore, some of morphological traits were evaluated according to the methodology of the development of IFDB. Development of the IFDB, based on the descriptors adopted by the European Cooperative Programme for Crop Genetic Resources Networks – ECP/GR) for Plant Genetic Resources for Textile Crops Working Group – allows easier and faster analysis of the morphological, biological and agricultural genotypes of the genus *Linum* [21]. Breeders will be able to choose the most suitable components as biological characteristics, such as resistance to lodging and resistance to *Fusarium* (*Fusarium oxysporum f. sp. lini)*, or morphological ones, for example 1000 seed weight, stem length, become available.

Taking into account the use of the seeds in the cultivation of flax, and other pesticides should not be applied, especially on seed plantations [25]. Therefore, the determination of linseed resistance to *Fusarium* in the breeding linseed material is of special importance. Due to very unfavourable atmospheric conditions in 1999, testing for resistance to *Fusarium* could be run in real-life conditions.

After a three-year study cycle for *Fusarium* resistance conducted on a field infected with *Fusarium*, the accessions were classified as follows: Gold Merchant and Martin – very resistant; Abby, Peak, Olinette and Achay – resistant; Currong and Vitagold – medium resistance [25]. Identical results were obtained in the 1998–2000 study for Martin, Abby, Peak and Olinette. Similar results to those obtained in the field infected with *Fusarium* were observed for two accessions of flax: Gold Merchant (very resistant – field infected with *Fusarium*: resistant) and Currong (medium resistance – field infected with *Fusarium*: resistant). However, Achay was classified as of medium resistance [17] in the 1998–2000 study on susceptibility to *Fusarium*.

It was observed that for 18 flax plants the length of the growing season from sowing to the beginning of flowering was short in the years of the study. For five accessions of flax in one year, the growing season from sowing to beginning of flowering was medium and in the remaining years it was short. The valorisation of the growing season from sowing to the beginning of yellow maturity was more varied. In 1999 and 2000, the length of the growing season from sowing to the beginning of yellow maturity was medium.

There was no dependence on the fact that accessions of the fibre type of use have thinner stems than linseed accessions of flax.

In the group of 23 accessions, there was not one genotype with a very low number of branches (less than four) and with a very high number of branches (more than four).

In 1999, the precipitation in June amounted to 150% of the long-term average and at the end of the month lodging and *Fusarium* wilt were observed. The quantity of seed in 1999 was very low because of very unfavourable vegetative conditions. The highest yields were obtained in accessions: Crystal (189 g), Peak (175 g), Abby (173 g), UKR 97 269 (164 g), Ukraiński 3 (162 g), Olinette (160 g), Martin (154 g), Currong (140 g) and Gold Merchant (127g). On the basis of research carried out in Italy with lineseed flax for four years, it was found that it showed great adaptability to the conditions of a given cultivation year, which resulted in partial compensation between the individual components of the seed yield structure [26].

Based on the experience from 15 cities in Germany, the plasticity in the development of linseed was also found to be very ductile, because the yield of this plant was strongly dependent on the local habitat conditions [27].

In a study conducted in Wojciechów each year, a different variety achieved the highest yield of seeds from the plot: in 1998 – Gold Merchant, in 1999 – Crystal, in 2000 – Abby. The Abby variety, which had the highest average yield of seeds from three years, is characterised by the thinnest stems and the shortest panicle of the 23 genotypes of flax.

The Polish Flax Collection is a reservoir of seeds with a very high content of α-linolenic acid [10, 29]. Seeds of the so-called traditional varieties and cold pressed linseed oil from such seeds counteract the following health problems: atherosclerosis, arterial hypertension, high cholesterol, breast, prostate, colon and other cancers [29, 30]. Flax also prevents diabetes, metabolic syndrome, problems during menopause, skin problems including atopic dermatitis. Regular consumption of flax seeds with a naturally high content of α-linolenic acid also prevents dangerous diseases of the nervous system such as depression or Alzheimer's disease. In addition, α-linolenic acid, whose very important food source is *Linum,* is needed for pregnant women, because the health of the developing child depends on it [31]. The α-linolenic fatty acid is essential for proper development of the brain and eyes. These are not all health problems that can be avoided by including flax (*Linum usitatissimum* L.) in the diet. We're trying to get scientists interested in studying the genetic resources of flax. Currently, flax accessions are a research material for the study of the content of lignans and other valuable bioactive compounds [32].

Detailed information can be found in articles by Polish and foreign researchers, for example [33-35].

CONCLUSIONS

1. In our investigation the most useful flax accessions for breeders were: Abby, Gold Merchant, Currong, Olinette, UKR 97 269, Crystal, Ukraiński 3, Martin, Gold Merchant and Peak.
2. *Linum* is characterised by a high variability of morphological, biological and agricultural features.
3. The largest variation of the tested flax accessions was observed in the yield of seeds and in resistance to abiotic (lodging) and biotic (*Fusarium*) factors.
4. The yield of seeds very much depends on the weather conditions. Meteorological conditions in 1998 were the best for flax vegetation and in 1999 were the worst in terms of seed yield.
5. Based on the field experiment carried out in the years 1998–2000 in Wojciechów, 23 accessions of flax can be divided into three groups: recommended for breeding, not distinguished in terms of any traits important for breeders, and those to be eliminated as a starting material for breeding.
6. Recommended for breeding are varieties distinguished by a very high yield, whose average of the average yield in the years 1998–2000 was over 100%. These are the following 11 varieties: Abby (linseed), Gold Merchant (linseed), Currong (linseed), Olinette (linseed), Peak (linseed), UKR 97 269 (landrace), Crystal (linseed), Ukrainian 3 (flax), Martin (linseed), Pacific (linseed) and Ukrainian 2 (flax).

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