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The Influence of Water Hardness on the Agronomic Traits of Foreign Fibre Flax Varieties in the Republic of Croatia
Vpliv trdote vode na agronomske lastnosti tujih sort vlaknatega lanu v Republiki Hrvaški

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Abstract
The amount and quality of fibres depend on a whole range of factors, the most important being variety, agroecological conditions, agrotechnics and the degree of fibre flax plant maturity, the purpose for which flax is grown, retting and processing. The retting of fibre flax is the most complex stage in the processing of flax into fibre. The aim of this study was to gain knowledge about the acclimatization ability of foreign varieties that can potentially be adapted to climatic in Republic Croatia. Therefore, this paper presents the results of achieved agronomic traits (dry stem yield, dry stem after retting, total fibre yield, long fibre yield, share of total fibre and share of long fibre) of five foreign varieties of fibre flax. The selected varieties were retted in very soft, medium hard and hard water. Variety trials with fibre flax were set up over three years (2012–2014) at two locations (Zagreb) on anthropogenized eutric cambisol and (Križevci) on pseudogley on level terrain. The trials were carried out according to the RCBD in four replications. According to the results of the three-year research into the agronomic traits of fibre flax, significant differences were identified among the varieties studied. The varieties Agatha, Viola and Electra recorded the highest values of studied traits. Statistically significant differences were only recorded among different water hardness for long fibre yield in 2012 and share of total fibre in 2013 in Zagreb. The highest yields and share of fibres were recorded when the fibre flax was retted in very soft water.
Keywords: agronomic traits, fibre flax, varieties, water hardness

Izvleček
Količina in kakovost vlaken iz vlaknatega lana sta odvisni od vrste dejavnikov, med katerimi so najpomembnejši sorta, agroekološke razmere, agrotehnika, stopnja zrelosti stebel, namen uporabe, godenje in predelava. Godenje stebel vlaknatega lana je najzahtevnejša faza v celotnem procesu predelave stebla v vlakno. Cilj teh študij je pridobiti znanje o aklimatizacijskih sposobnostih tujih sort, ki se potencialno lahko prilagodijo podnebnim razmeram Republike

Hrvaške. V tem članku so zato predstavljeni rezultati doseženih agronomskih lastnosti (pridelek suhih stebel, suhih stebel po namakanju, skupni pridelek vlaken, pridelek dolgih vlaken, delež vseh vlaken in delež dolgih vlaken) petih tujih sort lanu, namenjenih za pridobivanje vlaken. Stebla izbranih sort so bila namakana v zelo mehki, srednje trdi in trdi vodi. V raziskavo so bili zajeti sortni poskusi iz treh let (2012–2014) na dveh lokacijah, in sicer na antropogeni evtrični rjavi prsti v Zagrebu in na psevdogleju na ravnih terenih v Križevcih. Poskusi so bili izvedeni v naključnih blokih v štirih ponovitvah. Glede na rezultate triletnega raziskovanja agronomskih lastnosti lanu so bile med obravnavanimi sortami ugotovljene pomembne razlike. Najboljše preiskovane lastnosti so zabeležili pri sortah Agatha, Viola in Electra. Statistično značilne razlike so bile zabeležene med različnimi trdotami vode le za donos dolgih vlaken v letu 2012 in v deležu vseh vlaken v letu 2013 v Zagrebu. Največji pridelek in največji delež vlaken sta bila zabeležena pri namakanju lanenih stebel v zelo mehki vodi.
Ključne besede: agronomske lastnosti, lan za vlakna, sorte, trdota vode

1 Introduction

A review of available literature covering the fields of textiles and agriculture showed insufficient cooperation among researchers, particularly with a focus on flax and flax fibres. There is thus a need for an interdisciplinary approach to research, taking into account agricultural and textile knowledge. Twenty years ago, collaboration between researchers at the Faculty of Agriculture and Faculty of Textile Technology, University of Zagreb, was established with the aim of reviving flax production in Republic Croatia, and defining and improving the quality of flax fibres.

Setting the yield and quality parameters of fibre flax depends on many factors, such as soil-climatic, breeding-genetic and anthropogenic factors. Furthermore, the quality of fibres depends on a combination of a number of properties that in turn depend on the variety characteristics of plants, their growing conditions, harvesting technology and retting process, and raw material processing methods. One of the most important factors that determines the quality of long flax fibres is the retting process. Traditional retting methods include dew retting and water retting. Alternative methods include mechanical decortication, and chemical, heat, and enzymatic treatments [1]. In addition, ultrasound retting has been used for fibre flax in recent years [2]. Water retting is one of the best but also one of the most expensive flax fibre production methods. In principle, the method is analogous to stream retting but the flax stems are retted for four to seven days depending on the quality of the flax in heated tanks or pits maintained at 40 °C. Warm water retting, which can be used all year round, normally results in finer fibres of better quality than those produced by dew retting [3]. The advantage of water retting over dew retting is that it is more easily controlled and avoids the risk of the crop being spoilt by inclement weather during the weeks that it lies on the ground [4]. However, it also has serious disadvantages. The main disadvantage is that the water in which the straw has been steeped is highly polluted and in Europe must be treated before being discharged as wastewater. It has almost completely disappeared in Western Europe and in most Eastern European countries, but is still widely practised in China and Egypt. It also requires high water treatment maintenance and the costs are very high.

In Croatia, after the fibre flax pulling during July, the weather conditions (warm and dry) are not suitable for dew retting. Therefore, the fibre flax was traditionally retted in Croatia in rivers, lakes and ponds until the Second World War, and after the war in pools and tanks with cold or warm water. Today, small quantities of water-retted flax are still produced in Croatia. According to Pasković, [5] the quality and yield of fibre depends on water hardness, while bleaching also affects the colour and the characteristics of flax fibres. If the water is softer, the retting of flax fibres is faster and produces the highest quality, characterized by good fineness, strength, softness and whiteness. In the lowland continental area of Croatia, where fibre flax is grown, the natural water that is used for retting is medium hard to hard. In Croatia, there are only a few studies dealing with the retting of fibre flax in different water hardnesses [2, 6, 7].

The commercial breeding of fibre flax started in Europe at the end of the 19th century. Before Western European varieties became available, European varieties of seeds were imported from Russia. Cross breeding is still the main breeding method for fibre flax [8]. The main task of the breeding programme is to develop flax genotypes that are

highly productive (both fibre and seeds) and highly adaptable to changing environmental conditions [9]. Standard European varieties are spring varieties adapted to the coastal climate and long days. At the beginning of the growth cycle, the flax plant does not tolerate negative temperatures, while excessively high temperatures accelerate the maturation of flax plants and there is no elongation of fibres, which ultimately reduces the quality of fibres. According to Rossini and Casa, [10] warm and dry weather conditions, predominant from late spring onwards, cause the excessive shortening of the growing cycle of spring crops, which results in lower yield and poorer seed and fibre quality. The environment has a strong influence on crop success, with some varieties showing more year-to-year stability than others [11]. According to the Liebieg's law, weather conditions (precipitation) represent the main limiting factor that frequently affects flax yield in many regions of Europe [12].
Fibre flax is traditionally cultivated in most parts of Croatia. In the lowland continental area of the country, flax is sown around the end of March, while the growth stage of flowering starts at the end of May [13]. The Croatia has no indigenous fibre flax varieties [14, 15]. Introduced varieties are from Western Europe and are less suitable for the climatic conditions of Croatia (yields and quality are usually lower) [16–24]).
The aim of these studies was to determine the agronomic traits (dry stem yield, dry stem yield after retting, total fibre yield, share of total fibre, long fibre yield and share of long fibre) of five fibre flax varieties that were retted in very soft, medium hard and hard water over three years at two locations. The obtained results will be of great importance for gaining knowledge about the acclimatization ability of foreign varieties that can potentially be adapted to the climatic conditions of Croatia.

2 Materials and methods

Variety trials with fibre flax were carried out in the experimental fields of the University of Zagreb Faculty of Agriculture (45°49'26" N, 16°02'07" E) on anthropogenized eutric cambisol, and of the College of Agriculture in Križevci (46°02'23" N, 16°54'62" E) on pseudogley on level terrain from 2012 to 2014. The trials involved five varieties: Viking (Cooperative Liniere de Fontaine Cany, France), Viola (Van de Bilt Zaden, Netherlands), Venica (Agritec, Czech Republic), and Agatha and Electra (Cebecco Seed, Netherlands). The content of the nutrients in the soil and pH values for both locations are given in Table 1.
Weather conditions were also monitored during the flax growing season for all the years and both locations (Tables 2 and 3).
Fertilization with100 kg/ha P (as superphosphate) and 150 kg/ha K (potassium salt) was carried within basic tillage for both locations. A total of 30 kg of N/ha (nitrogen) was added before sowing, as well as 30 kg/ha in a single fertilizer application at the average plant height of 0.1 m. The trials were designed according to the randomized complete block design (RCBD) with four replications. The main trial plot size was 10 m^2 (10 rows × 0.1 m row spacing × 10 m length). Sowing was carried out using a plot seeder (Wintersteiger, Austria). Fibre flax seeding was performed on 28 March 2012, 12 April 2013 and 14 April 2014. Sowing density was 2,500 germinable seeds/m^2.
The agronomic traits studied were dry stem yield, dry stem yield after retting, total fibre yield, share

Table 1: Content of nutrients in soils and pH

Year	Location	P_2O_5 (mg/100 g)	K_2O (mg/100 g)	Total nitrogen (%)	pH - 1M KCl (1:2.5)
2012	Zagreb	32.20	27.0	0.13	7.31
2013	Zagreb	34.54	25.0	0.11	6.20
2014	Zagreb	37.03	16.2	0.12	7.09
2012	Križevci	28.39	19.05	0.10	5.42
2013	Križevci	21.47	16.67	0.12	4.84
2014	Križevci	29.19	25.31	0.10	6.05

P_2O_5, K_2O – Al method; Total nitrogen – HRN ISO 13878:2004; pH – HRN ISO 10390:2004

Table 2: Mean monthly absolute minimum and maximum air temperatures (°C) and mean monthly precipitation amounts (mm) for 2012, 2013 and 2014 for Zagreb (Meteorological and Hydrological Services of the Republic of Croatia)

Year	Month	Mean monthly air temperature (°C)	Absolute minimum air temperature (°C)	Absolute maximum air temperature (°C)	Mean monthly precipitation amounts (mm)
2012	March	9.4	–3.1	23.9	4.5
	April	12.5	–2.3	30.5	51.3
	May	16.7	3.3	29.3	81.8
	June	22.0	7.0	35.3	127.9
2013	March	4.9	–4.8	17.9	121.7
	April	13.0	–1.2	29.2	56.1
	May	16.3	6.8	28.9	94.0
	June	20.0	8.4	33.6	48.7
2014	March	10.8	0.3	23.6	21.0
	April	13.3	2.5	25.0	70.4
	May	16.2	3.2	29.0	145.0
	June	20.2	8.8	33.9	147.0

Table 3: Mean monthly absolute minimum and maximum air temperatures (°C) and mean monthly precipitation amounts (mm) for 2012, 2013 and 2014 for Križevci (Meteorological and Hydrological Services of the Republic of Croatia)

Year	Month	Mean monthly air temperature (°C)	Absolute minimum air temperature (°C)	Absolute maximum air temperature (°C)	Mean monthly precipitation amounts (mm)
2012	March	9.2	−4.1	23.0	2.4
	April	12.2	−4.0	29.6	34.6
	May	16.1	1.4	29.5	99.4
	June	21.5	5.4	34.6	65.6
2013	March	4.2	−6.0	17.5	132.1
	April	12.3	−0.9	28.1	47.1
	May	15.8	5.9	29.1	108.2
	June	19.5	7.5	34.2	44.4
2014	March	10.3	–3.1	23.3	14.7
	April	12.7	1.9	24.4	56.5
	May	15.4	3.0	29.3	118.3
	June	19.8	9.2	34.1	99.4

of total fibre, long fibre yield and share of long fibre [13]. Manual harvest by hand pulling was carried out at yellow-green ripening and an area of 1 m^2. Dry stem yield was determined after de-seeding. Flax stems were then placed in a tank of water (very soft, medium hard and hard – Table 2) at 32 °C for three days (72 hours) under controlled conditions. Retted stems were then removed from the tank. They were dried at 60 °C for 30 hours and weighed. A scutching machine was used to separate straw (woody matter) from fibre, where the yields of total and long fibres (using a set of hackling pins), and their respective share, were estimated.

The water hardness is expressed in German degrees of hardness (°dH) and in ppm (determination by titration with 0.1 M HCl with methyl orange indicator) (Table 4).

Table 4: Hardness of water retting

Water	German degrees of hardness (°dH)	ppm
Very soft	0.8–1.5	14–26
Medium hard	5.2–5.7	88–98
Hard	15.5–21	263–357

Data regarding all of the traits studied were statistically processed using analysis of variance (two-factor trial – variety and water hardness) separately for each year and each location. Differences between mean values were analysed using Duncan's multiple range test [25].

3 Results and discussion

Statistically significant differences were recorded among the varieties for the studied traits of fibre flax, except for total fibre yield, share of total and long fibre in 2014 in Zagreb, share of total fibre in 2012 and 2014 in Križevci, all studied traits in 2013 in Križevci and dry stem yield in 2014 in Križevci (Tables 5 and 6). In addition, statistically significant differences were only recorded among different water hardnesses for long fibre yield in 2012 and share of total fibre in 2013 in Zagreb (Tables 7 and 8). No significant interaction was recorded for any traits or any location, so interactions were not included in the factors shown here and were not discussed any further. Accordingly, the factors affected the studied traits independently.

The highest dry stem yield was achieved by the varieties Viola in 2012 and 2013 in Zagreb, Venica in 2013 in Križevci and Agatha in 2014 at both locations (Tables 5 and 6). Viola gave the highest dry stem yield after retting in two years in Zagreb and Križevci, and Electra in one year in Zagreb. The highest total fibre yield was achieved by the varieties Viola in 2012 at both locations, in 2013 in Zagreb, and Agatha in 2014 in Križevci and Electra in Zagreb. Also, Viola gave the highest long fibre yield in 2012 and 2013 in Zagreb and Agatha in 2012 in Zagreb, and in three years in Križevci. However, Venica gave the highest share of total fibre in two years in Zagreb and one year in Križevci. The highest share of long fibre was achieved by the variety Agatha in 2012 in Zagreb, in 2013 at both locations and in 2014 in Križevci.

Comparing locations, all varieties achieved higher values of dry stem yield, dry stem yield after retting, total fibre yield, share of total fibre and long fibre yield in two years at Križevci. The higher values in Križevci were also the result of flax production on heavier soil (pseudogley on level terrain), in which some winter moisture remained available in April and at the beginning of May (Tables 2 and 3). According to previous studies of these varieties, dry stem yields after retting ranged between 4.5 and 9.0 t/ha, total fibre yield between 1.5 and 3.8 t/ha, share of total fibre between 25 and 45%, long fibre yield between 1.3 and 2.0 t/ha, and share of long fibre between 20 and 25%, depending on climatic conditions [11, 26–32].

The growth of flax plant is usually monitored in terms of accumulated temperature or effective cumulative temperature [33]. It was determined that optimum fibre richness is reached around an accumulated temperature of 850-1100 °C, which is a favourable condition for harvest. Higher accumulated temperatures (> 1100 °C) were found to be ineffective for the improvement of fibre richness. Higher accumulated temperatures cause lignin generation within the plant, and pose problems during the retting and mechanical separation of fibres. In our studies (Tables 2 and 3), excessively high temperatures in some years at the end of April and at the beginning of May in the intensive flax growth stage (absolute maximum temperature was recorded in April in Zagreb (30.5 °C) and in May in Zagreb (29.3 °C) accelerated the maturity of flax, and the elongation of fibre did not appear and the yield and quality was reduced. The annual precipitation also influenced the growth of fibres. It has been suggested that precipitation should be about 110-150 mm [28] during the growing period.

The below-mean values for dry stem yield after retting, total fibre yield, long fibre yield and share of long fibre in 2012 and 2014 in Zagreb and in 2013 in Križevci were influenced by plant lodging due to poor climatic conditions and strong winds at the end of May (in 2014 in Zagreb and in 2013 in Križevci) and at the beginning of June (in 2012 and 2014 in Zagreb), and excessive precipitation in May (in 2014 in Zagreb (145.0 mm); in 2013 in Križevci (108.2 mm) and in June (in 2012 and 2014 in Zagreb (127.9 mm and 147.0 mm) (Tables 2 and 3).

Table 5: Means of agronomic traits of fibre flax, depending on the varieties in Zagreb (2012, 2013 and 2014)

Year	Varieties	Dry stem yield (t/ha)	Dry stem yield after retting (t/ha)	Total fibre yield (t/ha)	Share of total fibre (%)	Long fibre yield (t/ha)	Share of long fibre (%)
2012	Viking	4.20b	3.20b	1.13b	35.27b	0.38b	11.71ab
	Viola	4.73a	3.86a	1.55a	40.18ab	0.50a	13.07ab
	Venica	4.27a	3.31b	1.35ab	41.14a	0.41ab	12.54ab
	Agatha	4.51a	3.39b	1.38ab	40.52ab	0.50a	14.81a
	Electra	4.71a	3.94a	1.53a	38.85ab	0.43ab	11.12b
2013	Viking	8.65b	6.23d	1.99b	32.34b	0.58c	9.42c
	Viola	12.77a	10.36a	3.66a	35.43b	1.41a	13.77b
	Venica	8.81b	6.69cd	2.31b	35.14b	0.93b	14.32ab
	Agatha	9.08b	7.76bc	3.29a	42.78a	1.40a	18.13a
	Electra	11.98a	8.92b	3.33a	37.70b	1.22ab	13.61b
2014	Viking	6.06b	3.70b	1.12a	30.65a	0.33c	9.10a
	Viola	8.65a	5.45a	1.36a	25.30a	0.54a	10.03a
	Venica	6.26b	3.73b	1.21a	32.76a	0.44b	11.96a
	Agatha	8.84a	4.21b	1.28a	31.53a	0.49ab	12.26a
	Electra	7.88ab	4.58ab	1.45a	32.65a	0.55a	12.47a

Values with the same letter are not significant at a level of 5%. As the significance values decrease, the letters descend, as they are in alphabetical order.

Table 6: Means of agronomic traits of fibre flax dependent on the varieties in Križevci (2012, 2013 and 2014)

Year	Varieties	Dry stem yield (t/ha)	Dry stem yield after retting (t/ha)	Total fibre yield (t/ha)	Share of total fibre (%)	Long fibre yield (t/ha)	Share of long fibre (%)
2012	Viking	8.43b	5.63b	1.63b	29.43a	0.47c	8.43b
	Viola	11.21a	8.10a	2.46a	31.63a	0.80a	10.35ab
	Venica	8.47b	5.55b	1.80b	32.58a	0.66ab	12.00a
	Agatha	9.68ab	6.86ab	2.18a	31.96a	0.82a	11.92a
	Electra	11.27a	7.68ab	2.43a	31.97a	0.55bc	7.35b
2013	Viking	4.94a	4.33a	1.84a	44.42a	0.47a	10.68a
	Viola	5.05a	4.36a	1.87a	43.62a	0.61a	14.04a
	Venica	5.33a	4.50a	1.89a	44.79a	0.60a	13.74a
	Agatha	4.92a	4.08a	1.83a	45.47a	0.67a	15.91a
	Electra	4.78a	4.05a	1.83a	47.53a	0.52a	12.89a
2014	Viking	9.18a	4.91b	1.93b	39.63a	0.57d	11.94d
	Viola	9.52a	6.54a	2.30ab	35.62a	1.15b	17.74bc
	Venica	9.39a	5.41ab	2.05ab	38.35a	0.75c	14.25cd
	Agatha	10.41a	6.08ab	2.49a	41.36a	1.33a	22.15a
	Electra	9.85a	6.20ab	2.43a	39.43a	1.30a	21.17ab

Values with the same letter are not significant at a level of 5%. As the significance values decrease, the letters descend, as they are in alphabetical order.

The highest values for all studied traits (Tables 7 and 8) were achieved when the plants were retted in very soft water. This does not apply for dry stem yield in 2013 and 2014 and dry stem yield after retting in 2013 in Zagreb, and share of total fibre in 2012, dry stem yield, long fibre yield and share of long fibre in 2013 in Križevci. These values were not significantly higher than the values when plants were retted in very soft water. During retting, it was observed that the maceration process was faster in softer water. This is consistent with previous studies reported in the literature [2, 5–7].

4 Conclusion

On the basic of the results obtained, the following conclusions can be drawn:

- Statistically significant differences were recorded among the varieties for the studied traits of fibre flax, except for total fibre yield, share of total and long fibre in 2014 in Zagreb, share of total fibre in 2012 and 2014 in Križevci, all studied traits in 2013 at Križevci and dry stem yield in 2014 in Križevci.
- Statistically significant differences were only recorded among different water hardnesses for long fibre yield in 2012 and share of total fibre in 2013 in Zagreb.

Table 7: Means of agronomic traits of fibre flax, depending on water hardness in Zagreb (2012, 2013 and 2014)

Year	Water hardness	Dry stem yield (t/ha)	Dry stem yield after retting (t/ha)	Total fibre yield, t/ha	Share of total fibre (%)	Long fibre yield (t/ha)	Share of long fibre (%)
2012	Very soft	4.50a	3.61a	1.45a	40.12a	0.49a	13.72a
	Medium hard	4.45a	3.54a	1.37a	39.03a	0.45a	12.92a
	Hard	4.49a	3.47a	1.33a	38.43a	0.39b	11.31a
2013	Very soft	10.01a	7.86a	3.08a	39.67a	1.12a	14.39a
	Medium hard	10.37a	7.85a	2.82a	36.03a	1.11a	14.28a
	Hard	10.40a	8.27a	2.85a	34.54b	1.08a	12.88a
2014	Very soft	7.58a	4.44a	1.37a	32.01a	0.49a	11.60a
	Medium hard	7.64a	4.35a	1.25a	29.71a	0.47a	11.00a
	Hard	7.40a	4.22a	1.23a	30.02a	0.45a	10.89a

Values with the same letter are not significant at a level of 5%. As the significance values decrease, the letters descend, as they are in alphabetical order.

Table 8: Means of agronomic traits of fibre flax dependent on the water hardness in Križevci (2012, 2013 and 2014)

Year	Water hardness	Dry stem yield (t/ha)	Dry stem yield after retting (t/ha)	Total fibre yield, t/ha	Share of total fibre (%)	Long fibre yield (t/ha)	Share of long fibre (%)
2012	Very soft	10.07a	6.89a	2.17a	31.63a	0.70a	10.45a
	Medium hard	9.74a	6.84a	2.12a	31.64a	0.66a	10.13a
	Hard	9.63a	6.56a	2.00a	31.27a	0.61a	9.45a
2013	Very soft	4.96a	4.49a	1.95a	45.80a	0.57a	12.68a
	Medium hard	5.05a	4.21a	1.79a	44.40a	0.59a	14.22a
	Hard	5.01a	4.10a	1.81a	45.30a	0.56a	13.46a
2014	Very soft	9.75a	5.96a	2.33a	39.66a	1.06a	17.62a
	Medium hard	9.61a	5.84a	2.23a	38.66a	1.02a	17.40a
	Hard	9.66a	5.69a	2.15a	38.32a	0.99a	17.33a

Values with the same letter are not significant at a level of 5%. As the significance values decrease, the letters descend, as they are in alphabetical order.

- No significant interaction was recorded for any traits or any location.
- The varieties Agatha, Viola and Electra recorded the highest values of studied traits.
- Comparing locations, all varieties achieved higher values of dry stem yield, dry stem yield after retting, total fibre yield, share of total fibre and long fibre yield in two years in Križevci.
- The highest values for all studied traits were achieved when the plants were retted in very soft water. This does not apply for dry stem yield in 2013 and 2014 and dry stem yield after retting in 2013 in Zagreb, and share of total fibre in 2012, dry stem yield, long fibre yield and share of long fibre in 2013 in Križevci.
- Croatia has extremely hard water, and it would be most economically advantageous to use hard water for flax retting. The results obtained in this research show that the retting process was faster in softer water, making that process a little more expensive. The presented research will therefore be continued and expanded.
- The obtained results are of great importance because they provided valuable knowledge about the acclimatization ability of foreign cultivars that can be potentially adapted to the climatic conditions of Croatia, which will ensure raw materials for making ecologically valuable products.

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