Original scientific paper
DOI: /10.5513/JCEA01/19.1.2032
Journal of Central European Agriculture, 2018, 19(1), p.142-152

The influence of stages of maturity on the agronomic traits of fibre flax introduced varieties

Utjecaj vremena zriobe na agronomska svojstva introduciranih kultivara predivog lana

Jasminka BUTORAC[1], Ružica BRUNŠEK[2]*, Zvjezdana AUGUSTINOVIĆ[3] and Milan POSPIŠIL[1]

[1] University of Zagreb, Faculty of Agriculture, Department of Field Crops Forage and Grassland, Svetošimunska cesta 25, 10000 Zagreb, Croatia

[2] University of Zagreb, Faculty of Textile Technology, Department of Materials, Fibres and Textile Testing, Prilaz baruna Filipovića 28a, 10000 Zagreb, Croatia, *correspondence: ruzica.brunsek@ttf.hr

[3] College of Agriculture at Križevci, Milislava Demerca 1, 48260 Križevci, Croatia

Abstract

The harvest time of fibre flax is influenced by climatic conditions, varieties, stages of maturity and the crop's final use. In addition, the time of harvesting of fibre flax affects the quality of the fibres. Fibre flax can be harvested in few stages of maturity. So, this paper presents the influence of three stages of maturity (green, yellow and full ripening) on the agronomic traits (stem yield, stem yield after retting, total fibre yield, share of total fibre, long fibre yield, share of long fibre) of five fibre flax varieties. Varieties trials with fibre flax were set up in two years (2010-2011) and in two locations: at the experimental fields of the Faculty of Agriculture in Zagreb on eutric cambisol and of the College of Agriculture at Križevci on pseudogley on level terrain. The trials were carried out according to the randomized complete block design (RCBD) with four replications. According to the results of the two-years research into the agronomic traits of fibre flax, significant differences were established among the varieties and among the stages of maturity under study. The varieties Agatha, Viola and Electra recorded higher values of investigated traits. All varieties achieved higher values of investigated traits at Križevci (production on heavier soil in which some of winter moisture remained available in spring months). The highest values of investigated traits were recorded when the fibre flax were harvested in the green ripening.

Keywords: dry stem yield, *Linum usitatissimum* L., share of total and long fibre, stages of maturity, total and long fibre yield, varieties

Sažetak

Na vrijeme berbe predivog lana utječu klimatski uvjeti, kultivari, vrijeme zriobe i upotrebna vrijednost lana. Također, vrijeme berbe predivog lana utječe na kvalitetu vlakana. Predivi lan može se ubrati u nekoliko zrioba. Stoga, ovaj rad prikazuje utjecaj vremena zriobe (zelena, žuta i puna) na agronomska svojstva (prinos stabljike, prinos močene stabljike, prinos ukupnog vlakna, udio ukupnog vlakna, prinos dugog vlakna i udio dugog vlakna) pet inozemnih kultivara predivog lana. Pokusi s predivim lanom izvedeni su tijekom dvije godine (2010-2011) na dvije lokacije: u Zagrebu na eutričnom smeđem antropogeniziranom tlu i u Križevcima na pseudogleju obrončanom. Pokusi su provedeni prema metodi slučajnog bloknog rasporeda u četiri ponavljanja. Na osnovi dobivenih dvogodišnjih istraživanja agronomskih svojstava predivog lana utvrđeno je da postoje signifikantne razlike između istraživanih kultivara i između različitih zrioba. Kultivari Agatha, Viola i Venica ostvarile su veće vrijednosti istraživanih svojstava. Svi kultivari ostvarili su veće vrijednosti istraživanih svojstava na lokaciji Križevci (uzgoj na težem tlu gdje je zimska vlaga ostala dostupna u proljetnim mjesecima). Najveće vrijednosti istraživanih svojstava ostvarene su kada je predivi lan ubran u zelenoj zriobi.

Ključne riječi: kultivari, *Linum usitatissimum* L., prinos stabljike, prinos ukupnog i dugog vlakna, udio ukupnog i dugog vlakna, vrijeme zriobe

Introduction

Flax (*Linum usitatissimum* L.) is the source of industrial fibres and, as currently processed, results in long-line and short (i.e., tow) fibres. Long line fibre is used in manufacturing high value linen apparel, while short staple fibre has historically been the waste from long line fibre and used for lower value products.

Primary cells in the bast differentiate early in the plant´s life into what are called “primary fibres”, to distinguish them from what are generally accepted as flax fibres which are, in effect, amalgamations of primary fibres cemented to each by pectins. These primary fibres rapidly develop into bundles of several dozen fibres forming a rough interrupted circle in the bast (phloem) of the stem and which surrounds its woody part. The outmost bundles develop first, with the more central ones developing progressively later. The primary fibres elongate very rapidly until the end of flowering and it is at this point that the plant reaches its maximum potential from the point of view of fibre quality, if not quantity. The quality of fibre is therefore essentially determined by the properties of the elementary fibre cells, and the properties of the structure, which make fibre cells into a fibre. At maturity, fibres represent about 25% of the dry weight of the flax stem (Salmon-Minotte and Franck, 2005).

Thus, for example, flax plant has 89 elementary cells at the height of 0.085 m, 138 at the height of 0.248 m, 199 at the time of the appearance of buds, 336 after the end of flowering, and 346 at full maturity (Sizov and Graščenko, 1963).

The harvest time is influenced by climatic conditions, varieties, stages of maturity and the crop’s final use.

Increases in plant height and flowering are promoted by long days (Yanagisawa, 1970). The long day condition enhances the yield of fibres as well as the diameter of the fibre cells, but cell-wall thickness is greater in plants cultivated in shorter days. Under short day conditions, fibres of better quality are obtained.

Croatia has not own fibre flax varieties (Andrassy et al., 2004; Pospišil et al., 2004). The introduced varieties are from Western Europe and these varieties are less suitable for climatic conditions of Croatia (yields and quality are usually lower - Butorac et al., 2006a, 2006b, 2009; Andrassy et al., 2010; Butorac et al., 2011; Šurina et al., 2011; Brunšek et al., 2014; Butorac et al., 2014). The commercialised European varieties are spring varieties adapted to seaside climate and long days. The flax does not tolerate negative temperatures in the beginning of the growth and, on the contrary, high temperatures accelerate maturity of flax and the elongation of fibre does not appear and the quality is reduced. In the lowland continental part of Croatia, flax is sown around the end of March, and growth stage of flowering starts at the end of May (Butorac, 2009).

Flax can be harvested at different stages of maturity (depending upon the colour of the stalk, such as 1. green, 2. yellow, 3. full and over-mature, respectively harvested about 5 days before, about 5 days after, about 14 days after and about 23 days after flowering), it is necessary to indicate that harvesting at the first stage may result in lower seed, stem and fibre yields (Shekhar and Van Sumere, 1992). In addition, during retting and scotching, several problems, such as uneven retting and difficulties in removing the shives may occur. By the second stage of maturity, all fibres in the stem have formed, and as a result, flax should be preferentially harvested at this stage or the third stage.

Fibre fineness, length and strength are the most important processing properties and determine the quality and suitability of flax fibres as a textile raw material for yarn and fabric manufacturing. Harvesting of flax at different maturities provides a diversity of products. Flax that is harvested too early – (green) - produces very fine but weak fibres. On the other hand, in (over-mature flax, the stems) are strong but brittle and produce too high a proportion of undesirable short fibres (Mushtaq et al., 1984). When the flax is yellow, the fibres are long and supple, and therefore ideal for further processing. Therefore, the finest fibres are obtained by harvesting the crop following a full flowering with the stem and leaves green or at medium fibre fineness when half to a third of the seed bolls are yellow and brown with fully developed seeds (Muir and Westcott, 2003).

Therefore, the objective of the investigations was to identify the possibility of the introduction of foreign fibre flax varieties to the continental lowland region of the Northwestern Croatia, and to determine the influence of three stages of maturity on the agronomic traits of fibre flax varieties.

Materials and methods

Varieties trials with foreign fibre flax were carried out at the experimental field of the Faculty of Agriculture of Zagreb (45°49'26" N, 16°02'07" E), on eutric cambisol and at the experimental field of the College of Agriculture of Križevci (46°02'23" N, 16°54'62" E), on pseudogley on level terrain. The trials involved five fibre flax varieties: Viking

(Cooperative Liniere de Fontaine Cany, France), Viola (Van de Bilt Zaden, The Netherlands), Venica (Agritec, Czeck Rep.), Agatha and Electra (Cebecco Seed, Netherlands). The content of the nutrients in the soil and pH values are given in Table 1.

Table 1. The content of nutrients in the soils and pH

Year	P_2O_5 (mg/100 g)	K_2O (mg/100 g)	Total nitrogen (%)	pH (KCl)
		Zagreb		
2010	19.9	19.9	0.12	6.91
2011	22.3	17.2	0.09	6.6
		Križevci		
2010	20.9	19.4	0.09	5.04
2011	12.8	15.8	0.08	4.8

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

Fertilization with 100 kg/ha P (as superphosphate) and 150 kg/ha K (potassium salt) was done within basic tillage. Before sowing 30 kg N/ha (nitrogen) were added before sowing, and 30 kg/ha in a single fertilizer application at the average plant height of 0.1 m.

The trials were laid out according to the randomized complete block design (RCBD) with four replications. The main trial plot size was 10 m^2 (10 rows x 0.1 m row spacing x 10 m length). Sowing was carried out using a plot seeder (Wintersteiger, Austria). Fibre flax seeding was performed on 29th March 2010 and 1st April 2011. Sowing density was 2,500 germinable seeds/m^2.

The agronomic traits investigated were dry stem yield, dry stem yield after retting, total fibre yield, share of total fibre, long fibre yield and share of long fibre. Manual harvest by hand pulling was carried out at three different stages of maturity (green, yellow and full ripening). The harvest time of flax plants is given in Table 2.

Plants were pulled from an area of 1 m^2. Dry stem yield was determined after de-seeding. Flax stems were then placed in tank of water at 30 °C for 4 days under controlled conditions.

After retting stems were 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, whereupon the yields of total and long fibres (using a set of hackling pins), and their respective share, were estimated.

Table 2. The harvest time of flax plants

Stages of maturity	Date of pulling	
	2010	2011
	Zagreb	
Green	15 – 19 June	16 – 20 June
Yellow	23 – 27 June	25 – 29 June
Full	9 – 13 July	11 – 15 July
	Križevci	
Green	17 – 21 June	18 – 22 June
Yellow	26 – 30 June	26 – 30 June
Full	11 – 15 July	12 – 16 July

Data of all the traits studied in each location and year were statistically processed by the analysis of variance. Differences between mean values were analysed using Duncan's multiple range test (Duncan, 1955).

Results and discussion

Statistically significant differences were recorded among the varieties for investigated traits of fibre flax, except for dry stem yield in 2010 at Križevci, for share of total fibre in 2010 at Zagreb and Križevci and in 2011 at Križevci and for share of long fibre in 2010 at both locations (Tables 3 and 4).

In addition, statistically significant differences were recorded among different stages of maturity for investigated traits of fibre flax, except for share of total fibre in both years and locations and for share of long fibre in both years at Zagreb (Tables 5 and 6). 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, Agatha and Electra for two years at Zagreb and one year at Križevci. No significant differences were recorded among these varieties for dry stem yield, except for Electra in 2010 at Zagreb. Viola gave the highest dry stem yield after retting in two years at Križevci and one year at Zagreb. The highest total fibre yield was achieved also by the varieties Viola, Agatha and Electra for two years at Zagreb and one year at Križevci.

No significant differences were recorded among these varieties for total fibre yield. These varieties gave the highest long fibre yield for two years and both locations.

The highest share of total fibre was achieved with the varieties Electra and Agatha at Križevci.

Table 3. Means of agronomic traits of fibre flax in dependence on the varieties in Zagreb during the two growing seasons (2010 - 2011)

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 (%)
			2010			
Viking	6.16b	4.58b	0.95b	20.44a	0.74b	16.44a
Viola	8.34a	6.33a	1.43a	22.82a	1.01a	15.88a
Venica	7.08ab	5.68a	1.17ab	21.22a	0.83ab	14.74a
Agatha	7.8ab	5.74a	1.27ab	21.14a	0.94ab	16.31a
Electra	7.63ab	5.56ab	1.26ab	22.76a	0.89ab	15.86a
			2011			
Viking	4.3c	2.98c	0.8c	27.02b	0.49c	16.64ab
Viola	6.04a	4.27a	1.17ab	27.32b	0.79a	18.54a
Venica	4.49bc	2.9c	1.03bc	35.6a	0.51c	17.7ab
Agatha	6.04a	4.34a	1.43a	32.64ab	0.68b	15.63ab
Electra	5.14b	3.7b	1.26ab	33.85a	0.52c	14.05b

Values within a column marked with the same letter are not significantly different (P<0.05).

Comparing locations, all varieties achieved higher values of dry stem yield, dry stem yield after retting, total fibre yield and long fibre yield in two years and of share of total fibre and share of long fibre in one year at Križevci. The obtained values of studied traits in these varieties resulted from flax production on heavier soil (pseudogley on level terrain), in which some of winter moisture remained available in spring months.

Table 4. Means of agronomic traits of fibre flax in dependence on the varieties in Križevci during the two growing seasons (2010 - 2011)

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 (%)
			2010			
Viking	9.83a	6.5b	1.36c	20.9a	0.82c	12.45a
Viola	10.58a	7.92a	1.6a	20.23a	1.1a	13.8a
Venica	9.93a	7.17ab	1.45bc	20.36a	0.88bc	12.3a
Agatha	10.03a	7.34ab	1.53ab	20.9a	1.02ab	13.85a
Electra	10.14a	7.62a	1.62a	21.45a	0.99ab	13.02a
			2011			
Viking	5.84b	4.25c	1.3b	30.89a	0.77bc	18.64a
Viola	7.31a	5.6a	1.88a	34.17a	0.91a	16.29ab
Venica	6.56ab	5.11ab	1.67a	32.72a	0.73c	14.31b
Agatha	7.17a	5.04abc	1.81a	36.03a	0.88a	17.48ab
Electra	6.49ab	4.49bc	1.53ab	34.24a	0.84ab	18.74b

Values within a column marked with the same letter are not significantly different (P<0.05).

The mean values for total fibre yield, long fibre yield, share of total fibre and long fibre at Zagreb and at Križevci in 2010 were influenced by plant lodging due to rough weather and strong wind at the end of May and at the beginning of June.

The below-means values of the investigated traits, particularly those recorded at Zagreb in 2011, were a consequence of adverse weather conditions during flax growth and development (moisture deficiency throughout the growing period in April (Zagreb 42.1 mm) and in May (Zagreb 45.2 mm), as well as excessively high temperatures in May and June in the intensive flax growth stage – absolute maximum temperature in May was at Zagreb (30.8 °C); and June at Zagreb (32 °C).

The quantity of precipitation in May is crucial for fibre yield and quality in Croatian ecological conditions (Butorac et al., 2009). The plants were shorter. According to previous investigations dry stem yields after retting ranged between 6 and 7 t/ha, total fibre yield between 1.8 and 2 t/ha, share of total fibre between 25 and 30%, long fibre yield between 1.3 and 1.6 t/ha and share of long fibre between 20 and 25% (Pavelek, 2001; Daenekindt, 2003).

The highest values of agronomic traits were achieved in variant where the fibre flax was harvested in green ripening growth stage except for share of total fibre in 2010 at Zagreb and Križevci and for share of long fibre in 2010 at Zagreb (Tables 5 and 6).

Table 5. Means of agronomic traits of fibre flax in dependence of stages of maturity in Zagreb during the two growing seasons (2010 - 2011)

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 (%)
			2010			
Green	9.31a	6.61a	1.42a	20.98a	1.09a	16.67a
Yellow	6.91b	5.9a	1.28a	21.72a	0.97a	16.72a
Full	5.98b	4.22b	0.93b	22.33a	0.57b	14.14a
			2011			
Green	5.86a	4.13a	1.36a	33.15a	0.7a	17.19a
Yellow	5.19ab	3.61b	1.14ab	31.74a	0.59b	16.66a
Full	4.55b	3.17c	0.9b	28.96a	0.49b	15.68a

Values within a column marked with the same letter are not significantly different ($P<0.05$).

No significant differences were recorded among the stages of maturity for share of total fibre in 2010 at Zagreb and Križevci and for share of long fibre in 2010 at Zagreb. The statistically highest dry stem yield in 2010 at Zagreb, dry stem yield after retting in 2011 at Zagreb and long fibre yield in 2011 at Zagreb and at Križevci were achieved in green ripening. On the other hand, the statistically lowest dry stem yield after retting in 2011 at Zagreb, total and long fibre yield in 2010 at Zagreb and at Križevci, long fibre yield in 2011 at Križevci and share of long fibre in 2010 and 2011 at Križevci were achieved in full ripening. The stems were strong but brittle and produce too high a proportion of undesirable short fibres. This is consistent with previous investigations reported in the literature (Mushtaq et al., 1984). For fibre quality, the correct harvesting time is when the stem is yellow and fibre is ideal for further processing. Comparing locations, all stages of maturity were achieved higher agronomic traits at Križevci, except for share of total and long fibre in 2010.

Table 6. Means of agronomic traits of fibre flax in dependence of stages of maturity in Križevci during the two growing seasons (2010 - 2011)

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 (%)
			2010			
Green	11.14a	7.83a	1.63a	20.95a	1.16a	14.83a
Yellow	10.12ab	7.32ab	1.56a	21.47a	1.06a	14.55a
Full	9.06b	6.77b	1.33b	19.89a	0.66b	9.87b
			2011			
Green	7.64a	5.51a	1.93a	35.41a	1a	19a
Yellow	6.66ab	4.92ab	1.65ab	33.87a	0.82b	17.03a
Full	5.71b	4.26b	1.33b	31.56a	0.65c	15.65b

Values within a column marked with the same letter are not significantly different (P<0.05).

Conclusions

The influence of maturation on the agronomic traits of five fibre flax varieties was investigated by flax harvested in three stages of maturity (green, yellow and full ripening) and by estimation dry stem yield, dry stem yield after retting, total fibre yield, share of total fibre, long fibre yield and share of long fibre.

Statistically significant differences were recorded among the varieties for investigated traits of fibre flax, except for dry stem yield in 2010 at Križevci, for share of total fibre in 2010 at Zagreb and Križevci and in 2011 at Križevci and for share of long fibre in 2010 at both locations.

Statistically significant differences were recorded among different stages of maturity for investigated traits of fibre flax, except for share of total fibre in both years and locations and for share of long fibre in both years at Zagreb.

The highest dry stem yield, dry stem yield after retting and total fibre yield was achieved by the variety Viola for two years at Zagreb and one year at Križevci. Varieties Viola, Agatha and Electra gave the highest long fibre yield for two years and both locations. The highest share of total fibre was achieved with the varieties Electra and Agatha at Križevci.

Comparing locations, all varieties achieved higher values of dry stem yield, dry stem yield after retting, total fibre yield and long fibre yield in two years and of share of total fibre and share of long fibre in one year at Križevci.

The highest values of investigated traits were recorded when the fibre flax was harvested in the green ripening. However, no significant differences were recorded for the most investigation traits between green and yellow ripening.

References

Andrassy, M., Pezelj, E., Butorac, J. (2004) Resumption of the production of spinnable flax fibres. Tekstil, 53 (8), 385-391.

Andrassy, M., Šurina, R., Butorac, J. (2010) Influence of agroecological conditions on the properties of flax fibres in Croatia. In: Proceedings of 5th International textile, clothing and design conference. Dubrovnik, Croatia, 3-6 October 2009, Zagreb: Faculty of textile technology.

Brunšek, R., Andrassy, M., Butorac, J. (2014) The revitalization of flax in Croatia. Tekstil, 63 (1-2), 49-58.

Butorac, J., Pospišil, M., Mustapić, Z. (2006a) Some characteristics of European fibre flax varieties. In: Proceedings of 41st Croatian and 1st International symposium on Agriculture. Opatija, Croatia, 13-17 February 2006, Osijek: Faculty of Agriculture Osijek.

Butorac, J., Pospišil, M., Mustapić, Z., Zorić, D. (2006b) Estimation of some important agronomic and morphological traits of fibre flax varieties in different plan densities. Sjemenarstvo, 23 (5-6), 437-445.

Butorac, J., Pospišil, M., Mustapić, Z., Duvnjak, I. (2009) Estimation of agronomic and morphological traits of fibre flax varieties without and with topdressing by nitrogen. Sjemenarstvo, 26 (3-4), 119-129.

Butorac, J. (2009) Fibre flax. In: B. Kugler, ed. (2009) Fibre plants. Zagreb, Croatia: Kugler, 34-67.

Butorac, J., Šurina, R., Andrassy, M., Pospišil, M., Augustinović, Z., Brčić, M. (2011) The influence of vegetation ripening group of fibre flax cultivars on morphological and textile- technological traits. In: Proceedings of 46st Croatian and 6st International symposium on agriculture. Opatija, Croatia, 13-17 February 2011, Zagreb: University of Zagreb, Faculty of Agriculture.

Butorac, J., Brunšek, R., Augustinović, Z., Pospišil, M., Andrassy, M. (2014) The influence of nitrogen on the agronomic traits of fibre flax cultivars. Romanian Agricultural Research, 31, 253-259.

Daenekindt, A. (2003) Belgian flax varieties in 2002. Vlas Berichten, 4, 1-4.

Duncan, D. B. (1955) Multiple range and multiple F tests. Biometrics, 11, 1-42.

Muir, D., Westcott, N. D. (2003) Flax. In: A. D. Muir, N. D. Westcott, eds. (2003) The Genus Linum (Medicinal and aromatic plants - industrial profiles). Canada: CRC Press, 235-268.

Mushtaq, A., Jamil, N. A., Hanif, A. H., Saeed, M. A. (1984) Quality characteristics of various flax (*Linum usitatissimum*) fibres as affected by maturity. Pakistan Journal of Agricultural Research, 5 (1), 18-22.

Pavelek, M. (2001) New varieties – Venica. Czech Journal of Genetics and Plant Breeding, 37, 103-104.

Pospišil, M., Butorac, J., Gojšić, T. (2004) Flax-forgotten but useful culture. Gazophylacium, 9 (3-4), 81-86.

Salmon-Minotte, J., Franck, R. R. (2005) Flax. In: R. R. Franck, ed. (2005) Bast and other plant fibre. Cambridge, England: Woodhead Publishing Limited, 94-175.

Shekhar Sharma, H. S., Sumere, Van C. F. (1992) The biology and processing of flax. Belfast, Northern Ireland: M. Publications.

Sizov, I. A., Graščenko, M. G. (1963) Die Verwendung des ölfaserleins für die faserproduktion. Fibra, 8 (1), 30-36.

Šurina, R., Butorac, J., Andrassy, M. (2011) Dependence of fiber properties on the properties of the flax fibres. Tekstil, 60 (2-3), 87-101.

Yanagisava, U. (1970) Effects of different days lengths on the growth and some properties of fibre cells in the plants, *Linum usitatissimum*. Japanese Journal of Crop Science, 39 (3), 274-278.