Bast fibre content, fibre yield and fibre quality of different linseed genotypes

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Linseed (Linum usitatissimum L.) grown for seed does not compete well with flax in fibre yield, but as a by-product of seed production its stems could be used in non-woven products. With the aim of discovering suitable linseed genotypes to be cultivated in Finland, Finnish linseed cv. Helmi was compared with ten other linseed genotypes and one flax cultivar for stem yield, bast fibre content in stem, stem length and diameter and bast fibre yield. In addition, breaking tenacity and elongation at break of the fibres were determined. The experiments were conducted in 1996–1997 at the Agricultural Research Centre (MTT) in Jokioinen, Finland (latitude 60°49′ N). Bast fibre content averaged 16.9% and breeding line Bor 18 had significantly higher bast fibre content than cv. Helmi. Bast fibre yield averaged 301 kg dry matter ha\(^{-1}\). Compared with cv. Helmi, breeding lines Bor 15 and Bor 18 and cvs. Flanders and Gold Merchant produced significantly higher fibre yield. The median for breaking tenacity varied among the genotypes between 41 and 67 cN/tex and the median for elongation at break between 3.5 and 6.8%. Finnish breeding line Bor 18 is recommended for cultivation as dual-purpose linseed in Finland.

Key words: breeding lines, cultivars, dual-purpose use, fibre elasticity, fibre strength, Linum usitatissimum L., plant fibres, stems

Introduction

Linum usitatissimum L., is generally cultivated either for fibre production using flax cultivars or for seed production using linseed cultivars. Recently, the dual-purpose use of both seed and stems has been studied for example by Kaul et al. (1994) and Foster et al. (1997). The optimum stage for fibre harvest is past at seed maturity and 79

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the fibre is not suitable for traditional textile use, but perhaps it could be processed and used in the new non-woven products. One of the advantages of linseed fibre is that retting of stems is not required, as stems are ready for breaking immediately after drying (Reijonen 1998).

At the moment, only a limited amount of information is available concerning the physical properties and processing of linseed fibres (Reijonen 1998). In fact, until now, besides the preliminary study of Mäkinen (1998), nothing has been published about the bast fibre content in stem or the fibre yield of either Finnish linseed genotypes or the non-domestic cultivars grown in Finnish conditions. To provide new information on the topic, this paper reports on stem yield, bast fibre content in stem, stem length and diameter, bast fibre yield, breaking tenacity of the fibres and elongation at break of the fibres.

Material and methods

Experimental procedure

Linseed bast fibres were studied in field experiments carried out in 1996–1997 at the Agricultural Research Centre (MTT) in Jokioinen, Finland (latitude 60°49’ N). The experiments were laid out in a randomized complete block design with four blocks. Cvs. Helmi (FIN), Gold Merchant (UK) and Norlin (CAN) and breeding lines Bor 13 and Bor 18 (FIN) were included in the experiments in both years, whereas cvs. Flanders (CAN), Laser and Linus (UK), linseed breeding lines Bor 02, Bor 15 and Bor 20 (FIN) and flax cv. Martta (FIN) were included in only one or the other growing season. In 1997, the fourth block of the experiment was discarded due to poor establishment. Weather data, agronomic details and determination of stem yields are described by Sankari (2000).

Just before seed threshing, plant samples were pulled to determine the plant stand density (Sankari 2000). From among these plants, 25 plants in 1996 and ten in 1997 were randomly chosen for measurements of stem length (from root collar to the top of the plant) and stems diameter at the middle of the plant. Three measurements for each plant were taken in 1996. Five of the measured plants in 1996 and ten plants in 1997 were used for the bast fibre content in stem, the bast fibre content in stem was doubled in 1997 to obtain more reliable results, as has been discussed in Bredemann (1942).

For plant material, a selection of bast fibres from 12 stems per plant was made. The fibres were first cut at root collar and capsules of stems were removed. Stem samples were weighed before retting, and two more crashed stems were used to determine the moisture content in stems by oven drying at 105°C for 24 h. Heads were cut and the remaining ones were used to determine the bast fibre content in stem by removing them with an intense jet of water to remove non-fibrous material such as pieces of epidermis and parenchyma from bast fibres.

For analysis of fibre quality, twelve air-dry stems of each genotype from one of the replicates in 1996 were randomly selected from among the plants chosen for plant density determinations. Bast fibre strings about 20 cm in length and 1–2 mm in width were separated by hand from the middle part of stems. Fibre quality was determined at the Tampere University of Technology, Institute of Fiber, Textile and Clothing Science. First the fibre strings were boiled for 10 minutes in a 2% NaOH solution and then rinsed with an intense jet of water to remove non-fibrous material such as pieces of epidermis and parenchyma from bast fibres. The fibres were dried naturally at room temperature for several weeks, after which the dry weight of the fibres was determined by oven drying at 60°C for 17 h. The bast fibre content in stem (%) was calculated by dividing the fibre dry weight by the dry weight of the stems (fibres yield (%) = fibre dry weight x 100 / dry matter in stem weight).

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made shorter and then by hand and the fibre fractions (i.e. length-related mass) was determined with a textometer (Lenzing AG). A test to allow calculation of breaking tensile of the fibres, breaking energy of the fibres (cN/tex), i.e. maximum breaking force applied to a test specimen carried to rupture, divided by the linear density, and elongation at break of the fibres (%) was determined at a test specimen at break testing machine, OCT device (Altgärtner & Wyss). The total gauge length was 26 mm and the constant rate of extension (CRE) was applied was 20 mm min$^{-1}$.

Statistical methods

The data for the two years were analysed together with the MIXED procedure of SAS Statistical Software (SAS Institute Inc. 1992). Before the analysis, accuracy of the data, with the assumption of equal variance, was checked with the Box-Cox plots. The normality of the data was checked with stem and leaf display and with normal probability plots. The normality of the data was assessed by stem and leaf display and with normal probability plots. The stem yield, bast fibre content in stem, stem length and diameter and bast fibre yield were analysed by applying mixed models. The genotype was analysed as a fixed effect, whereas year and replicate nested in years were analysed as random effects. Because the Finnish cv. Helmi dominates the present cultivation area for linseed in Finland, the ten other linseed genotypes and one flax cultivar were compared with cv. Helmi. For this comparison, the ESTIMATE statement of the MIXED procedure was used to produce t-type contrasts and t-type 95% confidence intervals.

The data for breaking tenacity and elongation at break of the fibres were obtained from just one replicate in 1996. For comparison of the genotypes, therefore, the UNIVARIATE procedure (SAS Institute Inc. 1991) was applied to produce the parameters median (middle value to be measured), 25th percentile (first quartile, i.e. value is greater than 25 per cent of the values to be measured) and 75th percentile (third quartile).

Results and discussion

The average stem yield was 2018 kg dry matter ha$^{-1}$ (standard deviation, SD, 428) in 1996 and 1640 kg dry matter ha$^{-1}$ (SD 737) in 1997. The overall mean for stem yield was 1820 kg dry matter ha$^{-1}$ (S.E.M. 66). The difference in stem yield among the genotypes was statistically significant ($F_{11,42} = 4.93$, $P<0.001$). Five genotypes, inclusive of Finnish breeding lines Bor 15 and Bor 18 and non-domestic cvs. Flanders, Gold Merchant and Norlin, produced significantly higher stem yield than cv. Helmi.

Besides stem yield, bast fibre content is needed in the determination of bast fibre yield. Bast fibre content averaged 16.2% (SD 1.4) in 1996 and 17.4% (SD 2.3) in 1997, and the overall mean for bast fibre content in stem was 16.9% (S.E.M. 0.7). The difference in bast fibre content among the genotypes was statistically significant ($F_{11,42} = 15.45$, $P<0.001$). However, only breeding line Bor 18 exhibited significantly higher fibre content in stem than cv. Helmi. Examination of the 95% confidence interval revealed that the true difference in fibre content between these two genotypes varied from an insignificant difference of 0.1% up to 1.9%. It is noteworthy that the non-domestic cultivars Flanders, Laser and Linus did not differ significantly from cv. Helmi, and cv. Norlin had significantly lower bast fibre content in stem. Mäkinen (1998) reports average values of bast fibre content of a little under 15% in unretted fibres.
ted stems of cvs. Helmi and Norlin, and over 20% for flax cv. Martta. The stubble height at which the stems were cut for this determination was not announced. In my study, where fibre content was determined for stems cut at root collar, bast fibre content of flax cv. Martta did not differ significantly from that of cv. Helmi, while bast fibre content of cv. Norlin was significantly lower (Table 1).

Stem length and stem diameter were determined in order to examine the relationship between these plant characters and fibre content in stem. Kaul et al. (1994) have reported a positive correlation between plant height and fibre content in stem and fibre yield for Linum usitatissimum genotypes. Similarly, Turner (1987) concluded that thin flax stands with fine and tall stems produce high fibre yields with good fibre quality. In the present study, stem length averaged 65.9 cm (SD 6.2) in 1996 and only 51.6 cm (SD 4.6) in 1997. The overall mean for stem length was 58.9 cm (S.E.M. 5.5). The difference in stem length among the genotypes was statistically significant (F11,39 =25.04, P<0.001): linseed genotypes Bor 15, Bor 18 and Norlin and flax cv. Martta had significantly higher stem lengths in comparison with cv. Helmi (Table 2).

Stem diameter averaged 1.9 mm (SD 0.2) in 1996 but was only 1.5 mm (SD 0.1) in 1997. The overall mean was 1.7 mm (S.E.M. 0.2). The difference in stem diameter among the genotypes was significant (F11,39 =11.06, P<0.001), and cvs. Flanders, Gold Merchant, Norlin and Martta produced significantly thicker stems than cv. Helmi (Table 2).

In regard to the linseed genotypes Bor 13, Bor 18, Helmi and Norlin, all of which were measured for stem length and stem diameter in both experimental years, scatter plots of the yearly average fibre contents against yearly average stem lengths and stem diameters showed the fibre content in stems of all these genotypes to increase as the stem length and stem diameter decreased (Fig. 1). Although all four cultivars exhibited the same behaviour, data from just two experimental years, i.e. two scatter plots per genotype, are insufficient for hard conclusions. The combination of long stem length and thick stem diameter in 1996 did, however, produce clearly higher fibre content in stem than did the...
combination of short stem and thin stem diameter in 1997.

Mäkinen (1998) determined the fibre content in stems in the same plants that were cut at harvest at an unknown stubble height to determine stem yield, so that the calculated fibre yield per hectare would be a realistic approximation of the true value. In my study, the fibre content was determined in the whole stem, while the stem yield was determined in stems harvested at 5 cm stubble height. Since the fibre yields for the different genotypes were determined from fibre content and stem yield in a similar way, the comparisons between cv. Helmi and the other genotypes are meaningful. However, the calculated fibre yields per hectare are probably somewhat lower than the true values, which would be obtained if stems for fibre content analysis had been cut at 5 cm stubble height. This conclusion assumes that the fibre content along linseed stem varies in a similar way to that of fibre hemp (Cannabis sativa L.).

Werf et al. (1994) divided hemp stems into ten sections of equal length and found that the bast fibre content at the base of the stem was lower than the average for the whole stem. Calculated bast fibre yield averaged 324 kg dry matter ha⁻¹ (SD 63) in 1996 and 280 kg dry matter ha⁻¹ (SD 113) in 1997. The overall mean was 301 kg dry matter ha⁻¹ (S.E.M. 11), which was clearly lower than the fibre yield for linseed reported by Easson and Molloy (1996). According to Kämmerling (1990), harvest method has an effect on flax fibre yield; the loss in fibre yield averaged 19% when the flax stubble was left in the field instead of the whole plant being pulled.

In the present study, the difference in bast fibre yields among the genotypes was significant (F11,42 = 3.52, P = 0.002). Relative to cv. Helmi, breeding lines Bor 15 and Bor 18 and non-domestic cvs. Flanders and Gold Merchant produced significantly higher fibre yields (Table 1). Examination of the lower limit of the 95% confidence interval of these four genotypes suggested that the true differences between them and cv. Helmi may be insignificant in practice (Table 1). The upper limit of the 95% confidence interval, in turn, showed true fibre yields almost 200 kg higher for these genotypes than for cv. Helmi. Such yield increases would be of practical importance. The yields also ap...
proached the natural fibre yield range of 451 and 837 kg ha⁻¹ reported by Easson and Molloy (1996). Caution is needed in the comparison, however, as materials and methods were not reported in the earlier study.

Use of linseed fibre is being considered for several products, but as yet our knowledge of the physical properties of linseed fibre is inadequate. Compared with other natural fibres and most man-made fibres, fibres of Linum usitatissimum are relatively inelastic and constant in shape. Depending on the end use, these characteristics may be either advantageous or disadvantageous (Mäkinen 1998). In the present study, breaking tenacity (cN/tex) and elongation at break (%) of the fibres were analysed as fibre quality indicators. Measurement of fibre fineness (dtex) was required for the calculation of breaking tenacity. According to Herzog (1989), the fineness of flax bast fibre bundles varies from 10 to 200 dtex, whereas that of a single fibre varies from 1 to 8 dtex. The fineness values obtained in the present study varied between 13.6 and 66.8 dtex, and it was concluded that the breaking tenacity of the fibre bundles, not that of single fibres, had been measured at Tampere. Fineness varies with the shape and length of single fibre cells, the number of single fibre cells in the fibre bundle and the processing method (Mäkinen 1998). The wide variation in the values of fibre fineness in this study can be attributed to the hand treatment of the fibre string samples.

The parameter median for breaking tenacity of the fibres varied from 41 to 67 cN/tex, depending on the genotype (Fig. 2a). The median for cv. Helmi was one of the lowest. The line segments in Figure 2 represent the interquartile range inside of which 50% of the observations of each genotype are included. Judging from the lengths of the segments, the fibre quality was highly heterogeneous, especially for breeding lines Bor 13 and Bor 15. Linseed cv. Norlin and flax cv. Martta showed the best fibre uniformity, but even then the range of the fibre strength was wide, about 30 cN/tex. According to Herzog (1989), the strength of a good quality flax bast fibre, expressed as cN/tex, should be at least 60. Kromer et al. (1995) report that the strength of unretted flax fibre bundles is double...
that of retted bast fibre bundles. However, the factor responsible for fibre strength is not entirely clear. Thus, in the study of Meijer et al. (1995) the strength of unretted flax fibres varied between 30 and 40 cN/tex, while that of water retted fibres was higher and that of field retted fibres lower. Furthermore, Mäkinen (1998) reported highest strength of linseed fibres for unretted and field retted stems and lowest values for flax derived from stems at seed maturity. It is reasonable to assume that fine retted or field retted fibres become coarse and cracked by the time the seed of flax is harvested and the fibres are unsuitable for linen making. It bears notice that unretted flax fibres are not always suitable for linen making. This was observed in linseed experiments carried out in 1998 at Jokioinen, when, as a result of a wet and long growing time, the fibre bundles in the stems became grey and loosened from the stems before seed maturity. According to Meijer et al. (1995) and Easson and Molloy (1996), over-retting of fibres causes weakening of the fibres. If flax remains unretted, however, as probably most often is the case for linseed stems at seed harvest, the flax fibres that are obtained are coarse owing to the inadequate separation of fibres from the surrounding parenchyma and from the bundles (Meijer et al. 1995). It can be concluded that fibres of linseed stems at seed harvest may be used in partly retted, according to the weather and time of harvest, manner. Fibre quality was also determined by measuring the elongation at break. Elongation affects the physical properties and shape constancy of a product (Mäkinen 1998). The median for elongation of the fibres varied from 3.5 to 6.8% depending on genotype (Fig. 2b). A comparison of the median values shows flax cv. Martta and linseed cv. Gold Merchant to have the greatest elongation of fibres. Mäkinen (1998) reports average values between 3 and 4% for unretted fibres of cvs. Helmi, Norlin and Martta. In my study, the lengths of the line segments in Fig. 2b show the fibres of cv. Martta and breeding line Bor 18 to be the most uniform ones, while those of cv. Helmi and breeding line Bor 15 show an especially wide variation in elongation at break of the fibres.
ment there is no demand for linseed fibre in Fin-
land, the total bast fibre yield of 585 200 kg dry
matter ha\(^{-1}\) would be obtained yearly if 2200
hectares were planted to linseed, as in 1997, and
the average fibre yield was the value obtained
for cv. Helmi in this study. The area planted to
linseed varies from year to year, however, and
owing to the clearly higher seed than fibre pro-
ductivity of linseed, the area used in cultivation
merely will be the seed production. If the
average seed production already coincides with
the current area, the area of linseed for the purpose of pro-
ducing more fibre would merely be the average
seed production.

Early maturity and both high seed and high
bast fibre yield of linseed genotypes were of interest
in an earlier study (Sankari 2000), where linseed
breeding lines Bor 15 and Bor 18 were recom-
mended for cultivation for dual-purpose use in-
stead of the commonly cultivated cv. Helmi.
The additional results of the present study con-
cerning the linseed bast fibres show that the Fin-
nish breeding lines Bor 15 and Bor 18 and non-
domestic cvs. Flanders and Gold Merchant all
produce significantly higher fibre yield than cv.
Helmi. However, linseed genotypes Bor 15 and
Flanders were included in the fibre analysis in
just one year and the data are thus too few to be
taken as the basis for recommendation of suit-
bility for dual-purpose use. The fibre quality
was more heterogenous for these two genotypes
than for breeding line Bor 18. Late maturing
non-domestic linseed cultivars are always a risk
for the Finnish farmer as long as the price for
harvested seed is based on quality indicators,
such as the chlorophyll content in the seed oil.
Cvs. Flanders and Gold Merchant cannot be rec-
nommended for cultivation in Finnish conditions,
therefore. The Finnish linseed breeding line Bor
18 (Boreal Plant Breeding, Finland), on the
other hand, is unhesitatingly recommended for a
new commercial cultivar to be cultivated as a
dual-purpose linseed in Finland.

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