A New Generation of Textile Fibre from Canola Biomass and the Impact of Cultivar on Fibre Quality

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1. Introduction

Not all fibres can be classified as textile fibres. A textile fibre must possess important properties, such as fibrous structure, spinnability, strength, fineness, colour, and the ability to react with acid or alkali. The quality of a cellulosic bast fibre may vary due to the intrinsic variabilities of its natural components such as fibrous nature, the morphology of the fibre bundles inside plant stems, cellulose, and lignin (Rowell, Han and Rowell, 2000; Bonatti et al., 2004). Examples of such bast fibres are jute, hemp, flax, and ramie (Bergfjord and Bodil, 2010) that vary from each other regarding cellulosic content as well as in many physical and chemical properties.

Canola (*Brassica napus*), a lignocellulosic (Tofanica et al., 2011) bast fibre is the third most produced oleaginous plant in the world, ranks third worldwide as a source of vegetable oil and accounts for 16% of vegetable oil consumption all around the world after soybean (33%) and palm oil (34%) (Daun, Hickling and Eskin, 2011; Info-Prod Research, 2010; FAOSTAT, 2009; Edwards, 1967; Badani et al., 2006). Canada is one of the biggest producers of canola in the world. The major use of canola is for edible oil production; the plant stems are considered waste material after the harvest of the seeds for extraction of edible oil. Sevenhuysen and Rahman (2016) have recently manufactured textile grade fibres from these waste stems of canola plants.

No previous research work has been conducted on the effect of different canola cultivars on the physical properties of the fibres for industrial applications, such as fibre density, diameter, and tensile strength. Hence, this research work attempts to investigate the effect of different canola cultivars on the textile fibre properties.

Cromack (1998) investigated five different cultivars of hemp (Fedora 19, Felina 34, Uniko B, Futura 77, and Komopoliti) to determine the effect of cultivars on fibre yield (%) and found that there is an influence of cultivars on fibre yield. Cultivar Komopoliti had the highest fibre yield (3.48 ton ha^{-1}) and cultivar Felina 34 had the lowest (1.34 ton ha^{-1}) among all the five cultivars with a seeding rate of 400 seeds/m^2. Similarly, variations among cultivars reveal variations in productivity and physical properties in cotton (Farag and Elmogahzy, 2009) and flax (Salmon-Minotte and Franck, 2005). Four major cultivars of cotton of commercial importance are grown around the world; *Gossypium hirsutum* (*G. hirsutum)* (commonly known as “American Upland” or “Long-Staple/LS” cotton) with fibre length of 0.875 to 0.938 inches; *G. barbadense* (commonly known as “American Pima” or “Extra-Long Staple/ELS” cotton) with fibre length of 1.25 to 1.188 inches; and *G. herbaceum* and *G. arboretum* with comparatively shorter fibre length of 0.5 to 1.0 inch (Messiry and Abd-Ellatif, 2013). Even more, fibres obtained from same bolls of any plant of cotton may have a tendency to differ in length, diameter, and also fibre strength (Farag and Elmogahzy, 2009). Longer fibre length and finer diameter cottons are considered higher quality fibres. Salmon-Minotte and Franck conducted research on ten different cultivars of flax and concluded that productivity is dependent on the cultivar, likewise, cultivar Ariane showed very good productivity, whereas cultivar Nynke showed medium productivity (2005). These facts led to the hypothesis to be addressed in this current research that different cultivars of canola may have different textile fibre properties.

Canola, with a cellulosic content of 61.3% (Tofanica et al., 2011) has the potential to become a dominant textile fibre much as cotton and polyester. Since cotton requires an estimated of 550-950 litres/m^2 of water for its cultivation (World Wildlife Fund, 2000), canola could be an alternative fibre to cotton that does not involve huge water consumption because the fibre would be produced from the waste stems of the oil seed production. Furthermore, canola does not depend on global petrochemical production as polyester does (Watts, 2009). The current research discusses the effect of four different canola cultivars (HYHEAR 1, Topas, 5440, 45H29) on the textile fibre properties of canola fibre, such as moisture regain, fibre diameter, fibre density, fibre and tensile strength.

2. Materials and methods

2.1. Materials

2.1.1. Plant materials

Four different cultivars of canola (*Brassica napus*) were used in this research work: HYHEAR 1, Topas, 5440, and 45H29. One hundred (100) plants per cultivar were germinated inside a growth room *(Fig 1.1)* of Department of Plant Science, University of Manitoba (day temperature: 22°C; night temperature: 17°C). At the two-leaf-stage, the plants were transplanted to larger plastic pots (5.75 inches in height) and placed inside the greenhouse of Crop Technology Centre (CTC) of University of Manitoba. Full grown plants *(Fig. 1.2)* were harvested on the 116th day inside the greenhouse. Following harvesting, plant samples were brought to the Textile Laboratory in the Department of Biosystems Engineering at the University of Manitoba (U of M) and were water retted in either a vertical or horizontal orientation to determine retting time and fibre yield (%). The physical properties of the fibre, such as diameter, density, tensile strength, and thermal resistance were investigated in the Textile Laboratory (U of M) and the FibreCITY lab at Composites Innovation Centre (CIC), Winnipeg, Manitoba Canada.

Fig. 1.1 Plants in growth room (144 hours).

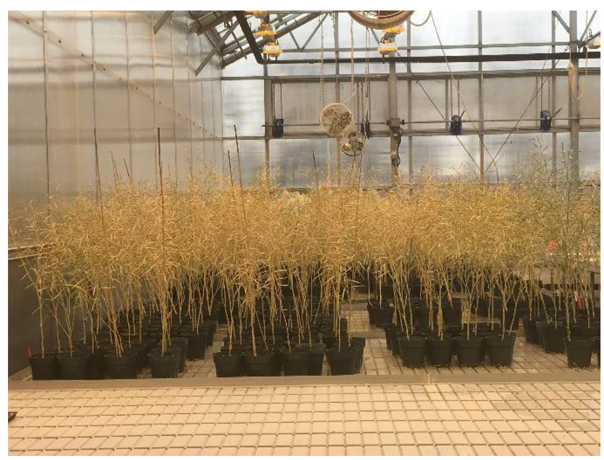

Fig. 1.2 Plants ready to be harvested.

2.1.2. Chemicals

NaOH (Sigma-Aldrich Corporation); CH_3COOH (Sigma-Aldrich Corporation); glycerin (Ricca Chemical Company); AATCC 1993 WOB (without optical brightener and without phosphate) standard detergent (Testfabrics, Inc); and Tubingal 4748 (CHT BEZEMA) were used in this research work.

2.2. Methods

2.2.1. Retting for canola fibre extraction

The 400 plants (100 plants per cultivar) were distributed into three segments to conduct three water retting experiments: Stem set #1, #2, and #3. Before starting the water retting, all the stem samples were oven-dried at 105°C for 8 hours inside an incubator to avoid any variations of moisture content according to ASTM D2495-07 (2012) standard. The stem samples of Stem-set #1 and #3 were set horizontally *(Fig. 1.3)* in the retting water. However, the stem samples for Stem-set #2 were set vertically (*Fig. 1.4*) in the retting water. Retting was conducted at room temperature for all stem sets.

Each of the cultivar samples namely HYHEAR 1, Topas, 5440, and 45H29 were water retted in four different water baths of 5000 ml each. Water was added as needed during the retting process to maintain a constant water volume of 5000 ml in the water bath. A circular lid, with a weight on top, forced the stems to be completely immersed in the water to ensure adequate retting. A small space was kept open for air to pass. Each of the retting water baths was monitored daily to determine the end point of retting. Gradual progress was observed to the end point of the retting process, where fibres were naturally coming away from the stem exterior *(Fig. 1.5)*.

Fig. 1.3 Horizontal set-up of stems.

Fig. 1.4 Vertical set-up of stems.

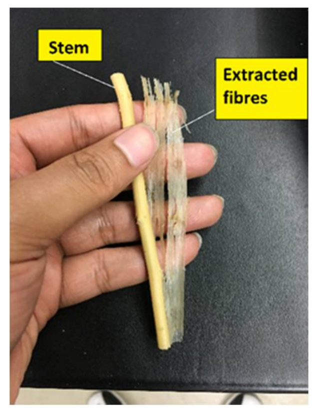

Fig. 1.5 Canola fibre extraction from the stem.

2.2.2. Fibre yield (%) and moisture regain (%) measurement

The extracted fibres were washed and dried at room temperature followed by 8-hour oven drying at 105°C inside an incubator, and the oven dried fibres were reweighed. Fibre yield (%) and moisture regain (%) of the extracted fibres were calculated using the following equations *(Eqn. 1.1)* and *(Eqn. 1.2)*.

$$\text{Fibre yield (\%)} = \left[100 \text{ x } \frac{\text{The weight of virgin-retted dried fibres after oven drying}}{\text{The weight of dried stems (unretted) after oven drying}}\right]\% \text{ ..... } \textit{Eqn. 1.1}$$

$$\text{Moisture regain (\%)} = \left[100 \text{ x } \frac{\text{The weight of moisture in the fibre}}{\text{The weight of oven dried fibre}}\right]\% \text{ ..... } \textit{Eqn. 1.2}$$

2.2.3. Surface modification of virgin-retted fibre

This treatment is a three-step surface modification model of chemical treatment processes for canola fibres for improved fibre quality. This model involves three consecutive treatment steps of the virgin-retted canola fibres obtained from Stem-set #2: alkaline scouring of virgin-retted canola fibres (1st step); acidic treatment of the alkali-scoured canola fibres (2nd step); and finally softening treatment of the acid-scoured canola fibres (3rd step).

Alkaline scouring involves treating the virgin-retted fibres obtained from Stem-set #2 with 400 ml solution of 5% NaOH and a 0.5% wetting agent (glycerin), at 60°C for 60 minutes. After this treatment, the fibres were rinsed for 15 minutes in distilled water and dried at room temperature. Acidic scouring involves treating the alkali scoured fibres (Step 1) with 400 ml solution of 4% acetic acid solution at 60°C for 30 minutes; then the fibres were rinsed for 30 minutes in distilled water and dried at room temperature. In the softening treatment, the acid scoured fibres (Step 2) were treated with 400 ml solution of 10% Tubingal 4748 softener at 40°C for 30 minutes at an acidic pH 4.5 (controlled by acetic acid). The softened fibres were rinsed for 15 minutes in distilled water and dried at room temperature.

2.2.4. Fibre diameter measurement

The diameter measurement method was based on quantitative image analysis. At Composites Innovation Centre (CIC), the diameter of the 10% softener treated fibres was assessed using FibreShape software (Innovative Sintering Technologies, Switzerland). The test equipment is comprised of a flatbed scanning system connected to a computer with FibreShape software for diameter analysis. The fibres were individualized *(Fig. 1.6, Fig. 1.7)* as much as possible using a fine comb prior to being placed on the scanning plate of the flatbed scanner for imaging.

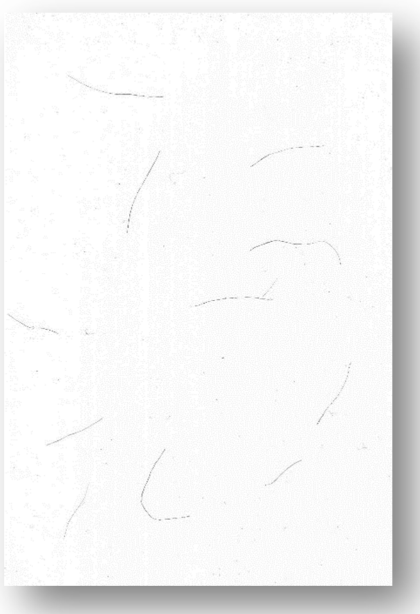

Fig. 1.6 Scanned image of HYHEAR 1 fibres (N=34).

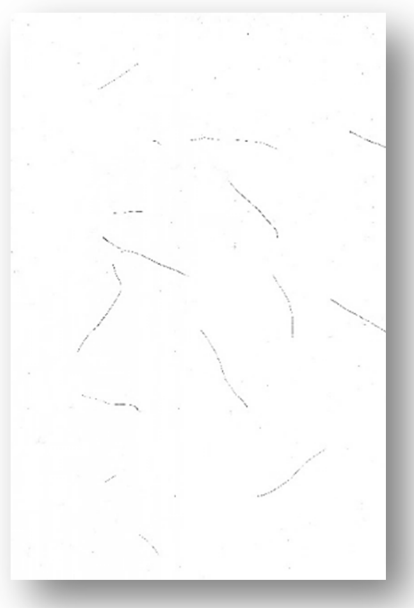

Fig. 1.7 Scanned image of Topas fibres (N= 22).

2.2.5. Fibre density measurement

At Composites Innovation Centre (CIC), the density of the 10% softener treated fibres was assessed using a Quantachrome Ultrapyc 1200e Automatic Gas Pycnometer (Quantachrome Instruments). After the fibre sample was weighed using an electronic balance, it was loaded into a cell of known volume, and the cell wass loaded into the gas Pycnometer. This Pycnometer accurately and precisely measures the volume of the fibre specimen through N_2 gas displacement. Once the sample is loaded into the chamber of Pycnometer, N_2 gas is introduced to pass into the sample chamber to fill the void volume of the chamber including the tiny pores of the sample. The corresponding pressure is also measured by the Pycnometer. The difference between the void volume of empty cell chamber and the new void volume is the volume of the sample solid phase. The weight of the sample is measured using an electronic balance before loading it inside the Pycnometer. Therefore, the density of the specimen is determined by dividing the weight of the sample by its volume.

2.2.6. Fibre tensile strength measurement

In the humidity chamber (temperature: 23.0°C; relative humidity: 50.0%) of the Department of Plant Science of University of Manitoba, the breaking load of 10% softener treated fibres was measured according to ASTM D1445-12 (2012) standard using a Pressley Fibre Bundle Strength Tester (Manufacturer: SDL Atlas Instrument; Model F215). Strength Index, breaking tenacity, and tensile strength was calculated using the following formula equations *(Eqns. 1.3, 1.4, 1.5)*.

Strength Index $\left(\frac{\text{lb}}{\text{mg}}\right)$ = Breaking Load (lb)/ Mass of specimen (mg) ….. *Eqn. 1.3*

Breaking Tenacity $\left(\frac{\text{gram.force}}{\text{tex}}\right)$ = 6.8 x Strength Index ….. *Eqn. 1.4*

Tensile strength (MPa)=9.807 x Fibre density $\left(\frac{\text{gm}}{\text{cc}}\right)$ x Breaking tenacity ($\frac{\text{gram.force}}{\text{tex}}$) ..... *Eqn. 1.5*

3. Results and discussions

3.1. Effect of cultivars on water retting time

Table 1.1 displays the retting time for three different Stem-sets of four cultivars. For Stem-set #1 and #2, all the stems were taken out at the same time after the retting point was reached for most of the stems in the whole batch. However, for Stem-set #3, each individual stem was investigated twice a day and was taken out when an individual stem reached its retting point as discussed later in this section. Therefore, in *Table 1.1*, the results for retting time of Stem sets #1 and #2 and the mean (± standard deviation or SD) retting time for Stem-set #3 are given. It was found that for Topas, the retting time was the shortest over all three stem sets *(Table 1.1)*. For Stem-set #1, Topas (263 hours) showed the lowest retting time, and HYHEAR 1 (393 hours) the highest; for Stem-set #2, Topas showed the lowest retting time (312 hours), and every other cultivar showed the same retting time (419.5 hours). For Stem-set #3, once again Topas showed the lowest average retting time 140.71 (±27.48) hours, and 5440 the highest 335.74 (±96.35) hours.

Table 1.1 Retting time (hours) of the four cultivars of Stem-sets #1, #2, and #3.

	Retting time (hours)			
Stem-set#	**HYHEAR 1**	**Topas**	**5440**	**45H29**
1	393	263	309	351
2	419.5	312	419.5	419.5
3	164.27 (±41.75)	140.71 (±27.48)	335.74 (±96.35)	239.86 (±63.38)

Table 1.2 shows the summary of the retting times for individual stems used in the retting experiments of Stem-set #3. The symbol n represents the total number of stems used in retting for each cultivar, and the symbol 'N' represents the number of different water retting times obtained for individual cultivars. Highest retting time for the last stems was for cultivar 5440 at 412.5 hours (n=21, N=7), and HYHEAR 1 demonstrated the least at 222 hours (n=37, N=4) followed by Topas at 223 hours (n=35, N=4). Statistical analysis showed no significant difference ($p > 0.05$) among the different retting times (N) observed for each cultivar during the water retting of Stem-set#3 *(Table 1.2)*. This phenomenon depicts that it may be difficult to obtain any statistically significant difference among the retting times for different canola cultivars without knowing the true end point of retting.

Table 1.2 Retting time (hours) of 140 stem specimens of four cultivars from Stem-set #3.

Cultivars	**HYHEAR 1 (n=37, N=4)**		**Topas (n=35, N=4)**		**5440 (n=21, N=7)**		**45H29 (n=47, N=9)**	
	Stem #	Retting hours	Stem #	Retting hours	Stem #	Retting hours	Stem #	Retting hours
	1-19	126	1-26	127	1	128.5	1-6	126.5
	20	150	27-30	151	2-3	152.5	7	150.5
	21-30	198	31-34	199	4	200.5	8-18	198.5
	31-37	222	35	223	5	224.5	19-27	222.5
					6-8	364.5	28	270.5
					9-19	388.5	29-40	294.5
					20-21	412.5	41-43	318.5
							44-45	342.5
							46-47	366.5
Mean	164.27 (±41.75)		140.71 (±27.48)		335.74 (±96.35)		239.86 (±63.38)	

3.2. Effect of cultivars on fibre yield (%)

Table 1.3 contains the mean (± standard deviation) value of fibre yield (%) obtained from water retting experiments in two different orientations for each of the four cultivars and three stem sets (Stem-set #1, Stem-set #2, and Stem-set #3). It can be seen that overall horizontal orientation of the stems during the water retting produced a higher yield (%) than the vertical orientation.

Mean fibre yield (%) was calculated from the fibre yield (%) of Stem-sets (#1, #2, #3) for both stem orientations that have been detailed in *Table 1.3*. Cultivar 45H29 produced the highest average yield (%) [10.41±1.87], while 5440 produced the lowest average yield (%) [9.11±2.13]. However, statistical analysis revealed no significant differences in the fibre yield (%) of the four cultivars ($F_{statistical} = 0.33 < F_{critical} = 4.07$; $p > 0.05$).

Table 1.3 Fibre yield (%) and stem orientation during water retting of Stem-set #1, #2, and #3.

Stem-set #	**Stem orientation**	**Fibre yield (%)**			
		HYHEAR 1	**Topas**	**5440**	**45H29**
1	Horizontal	11.04	10.46	10.65	12.06
2	Vertical	7.56	9.22	6.69	8.39
3	Horizontal	9.51	9.14	10.01	10.79
Mean		9.37 (±1.75)	9.60 (±0.74)	9.11 (±2.13)	10.41 (±1.87)

After completing the retting of Stem-set #1, it was observed that small woody particles or contaminants were clinging to the retted fibres causing entangling of fibres and producing bundles of fibres. Hence, the retting time was intentionally extended during the retting of Stem-set #2. As a result, the fibres were more individualized, softer, and the woody contaminants were highly removed during the fibre extraction, which may be due to degradation from prolonged exposure in water. Otherwise, there was a higher tendency of woody contaminants entangling with the fibres and preventing the formation of a single fibre entity.

This is an important factor because the contaminants may have prevented the softening chemicals from getting into the fibre interior; consequently, retting time for Stem-set #2 was intentionally increased for each cultivar *(Table 1.3)*. The extended retting time produced softer and flexible fibres *(Fig. 1.9)* for Stem-set #2 compared to the fibres *(Fig. 1.8)* extracted from Stem-set #1. However, extending the retting time has a drawback, which is a decrease in fibre yield (%). It was observed that a few fibres from Stem-set #2 were over retted and of these over-retted fibres, some degraded into the water causing a lower fibre yield (%) compared to Stem-set #1 *(Table 1.3)*. From this observation, it was decided to observe the retting time *(Tables 1.2)* of each individual stem used for Stem-set #3. However, as it can be seen that extended retting time can produce a fibre with better surface quality which is a requirement for use in textile applications and assessment of their physical properties, therefore only fibres of Stem-set #2 were treated with different surface modification techniques using enzymes and different chemicals to attribute different physical properties. On the contrary, fibres of Stem-set #1 and #3 were not used for any assessment due to their stiffness or gummy attributes despite showcasing higher fibre yield (%). The approach used for Stem-set #3, which involved monitoring retting of individual stems, would not be practical in an industrial setting. For large scale fibre production the processing would be done as a batch, similar to Stem-set #1 or #2. Therefore, the approach for Stem-set #1 or #2 is more representative of industrial processing compared to Stem-set #3.

Fig. 1.8 Extracted virgin-retted fibres from Topas of Stem-set #1.

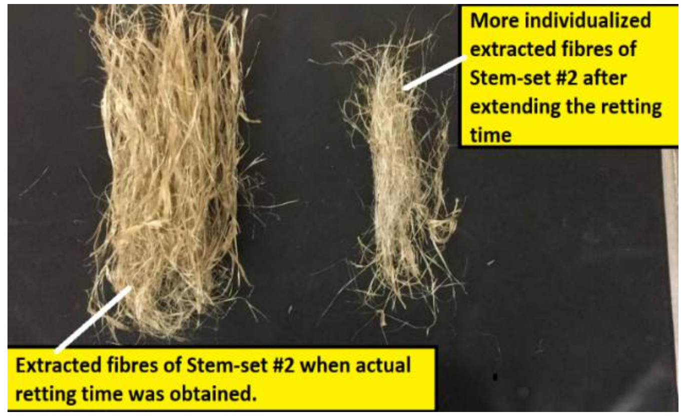

Fig. 1.9 Extracted virgin-retted fibres from Topas of Stem-set #2.

3.3. Effect of cultivars on textile characteristics of canola fibre

3.3.1. Effect of surface modifications on fibre flexibility, softness, and single-fibre entity

Virgin retted fibre is not suitable for fibre property evaluation due to inherent stiffness, harsh hand-feel, and absence of single fibre entity. Hence, the virgin-retted fibres were treated with 10% softener (detailed in section 2.2.3). The 10% softener treatment produced fibres (*Fig. 1.10*) that possess single fibre entity, flexibility, and softness. Hence, throughout this research paper, only the 10% softener treated fibres were used to investigate the textile fibre properties (diameter, density, tensile strength, thermal heat resistance) of the four canola cultivars.

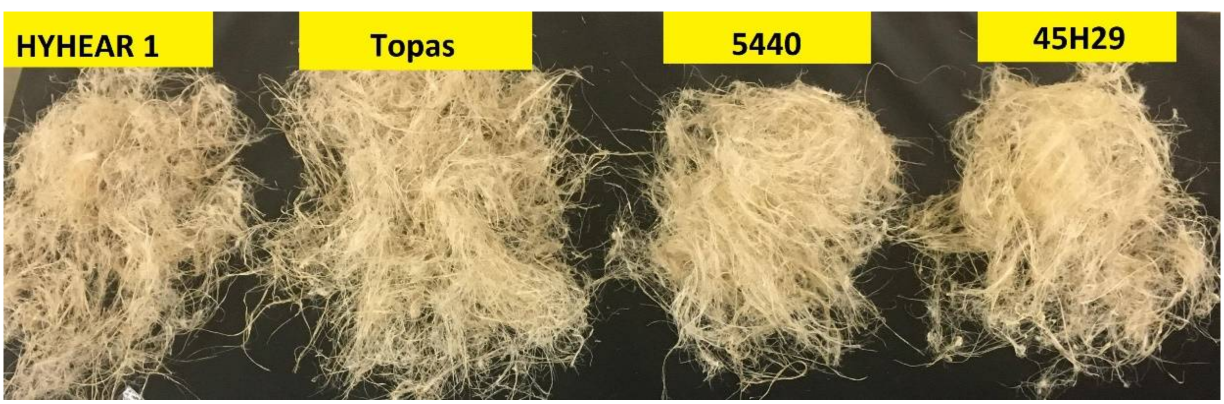

Fig. 1.10 10% softener treated fibres (from left to right- HYHEAR 1, Topas, 5440, 45H29).

3.3.2. Moisture regain of canola fibre

The mean and standard deviation (in parentheses) value of the moisture regain (MR) (%) of virgin-retted fibres for the four cultivars is shown in *Table 1.4*. It can be seen that for Stem-set #1, HYHEAR 1 showed the highest (14.36%) moisture regain, and Topas showed the least (12.48%). For Stem-set #2, HYHEAR 1 showed the highest (14.59%) moisture regain and

45H29 showed the least (7.43%). For Stem-set #3, 5440 showed the highest (9.45%) moisture regain and Topas showed the least (7.22%). However, statistical analysis (ANOVA) showed no significant difference among the means ($F_{statistical} = 0.67 < F_{critical} = 4.07$; $p > 0.05$).

Table 1.4 Moisture regain (%) of the canola fibres of the four cultivars in Stem-sets (#1, #2, #3).

Cultivars	**Moisture regain (%) of the canola fibres**				
	Virgin-retted fibre				**Softened fibre**
	Stem-set #1	**Stem-set #2**	**Stem-set #3**	**Mean**	
HYHEAR 1	14.36	14.59	8.65	12.53 (±3.37)	7.61
Topas	12.48	8.45	7.22	9.38 (±2.75)	6.03
5440	13.82	7.70	9.45	10.32 (±3.15)	7.20
45H29	13.24	7.43	7.27	9.31 (±3.40)	7.13

Table 1.4 also displays the moisture regain (%) of the 10% softener treated fibres of the four cultivars. It was found that HYHEAR 1 showed the highest MR that is 7.61% and Topas showed the least, which is 6.03%. By comparing the MR of virgin fibres and 10% softener treated fibres, it can be seen that MR is comparatively lower for all the chemically treated fibres than for the virgin-retted fibres. One possible reason for this low moisture regain can be the increased hydrophobicity of the canola fibres after softening treatment. A recent research work revealed that moisture regains of cotton fibre is reduced when treated with a cationic hydrophobic softener (Parvinzadeh et al., 2010).

3.3.3. Diameter of canola fibre

Table 1.5 contains the mean fibre diameter (dia) and standard deviation in parentheses, number of specimens (N), minimum and maximum diameter (dia) of the four cultivars as determined by FibreShape analysis. It can be seen that Topas showed the highest mean fibre diameter (97.34µm ± 27.86, N=22) and 5440 showed the lowest fibre diameter (75.69µm ± 21.96, N = 22). No significant differences among the fibre diameter of these four cultivars ($F_{statistical} = 1.00 < F_{critical} = 2.69$; $p > 0.05$) were found after conducting ANOVA test.

Table 1.5 Diameter (µm) of the 10% softener treated fibres of the four cultivars.

	Diameter (µm) of the softened fibres			
Cultivars	HYHEAR 1	Topas	5440	45H29
N (no of specimens)	34	22	22	37
Minimum dia	30.39	33.35	27.32	26.11
Maximum dia	213.60	146.67	109.25	240.90
Mean dia	80.47 (±35.24)	97.34 (±27.86)	75.69 (±21.96)	88.26 (±39.50)

A boxplot and whisker diagram *(Fig. 1.11)* was constructed to investigate the consistency of the fibre diameter among the cultivars. It can be seen from *Fig. 1.11* that 50% of fibre diameter (Q2 and Q3) for HYHEAR 1 is between 45.68 and 92.91 µm; 55.66 and 101.44 µm for Topas; 42.99 and 86.04 µm for 5440; and 53.74 and 99.11 µm for 45H29. Of the four full box plot-whiskers, 5440 is the most congested, followed by Topas, which means the fibre diameters of these two cultivars vary least and are more uniform than HYHEAR 1 and 45H29. This is also evident from the standard deviation of individual diameters, which are ±21.96 for 5440 and ±27.86 for Topas.

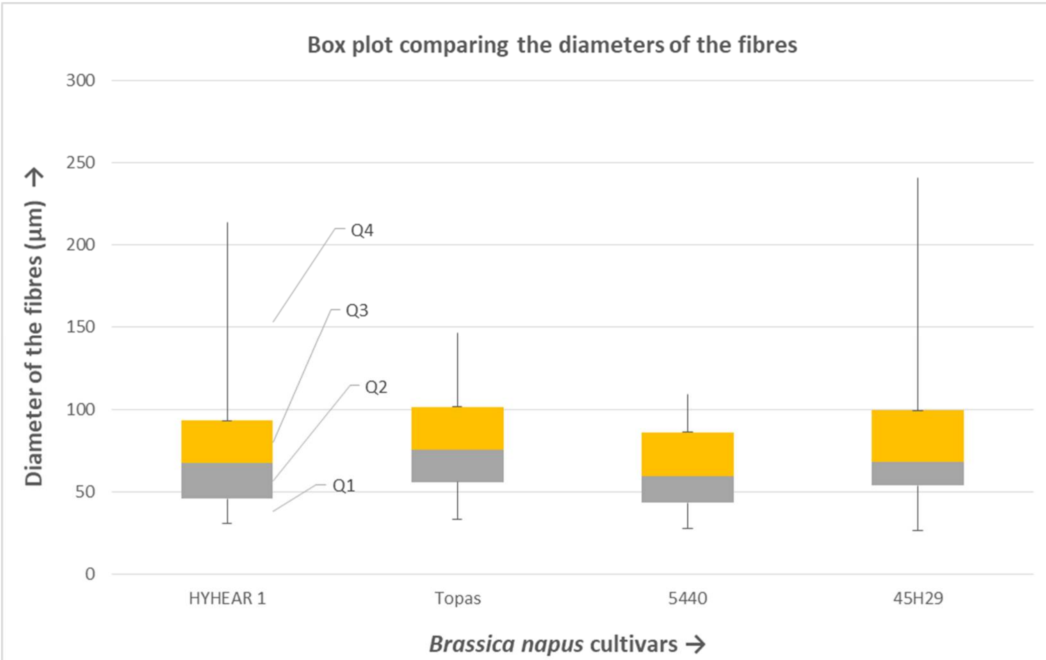

Fig. 1.11 Box-plot and whisker diagram of the single fibres of the four cultivars.

45H29 has the highest width of box plot-whisker followed by HYHEAR 1, which means these two cultivars have higher variations as shown by their standard deviations, which are ±39.50 for 45H29 and ±35.24 for HYHEAR 1. 25% of the fibres of 5440 had lower diameters in comparison to other cultivars, followed by HYHEAR 1, 45H29, and Topas if compared by their respective Q1 (25 percentiles) from the Box-plot diagram. The diameter is more variable in the upper diameters (Q4) level for every cultivar except 5440. As a result, it can be said that 5440 has the most consistent and dependable data set.

3.3.4. Density of canola fibre

Table 1.6 contains the mean density of the 10% softener treated fibres of the four cultivars, as determined using a Pycnometer. The mean and standard deviation value was obtained from seven (n= 7) individual readings per cultivar, which was taken into consideration to calculate the mean value of the density of the fibres.

It can be seen from *Table 1.6* that the densities range between 1.34 gm/cc and 1.43 gm/cc for the four cultivars, with 45H29 having the highest density (1.43±0.0011 gm/cc) and HYHEAR 1 the lowest (1.34±0.009 gm/cc). Statistical analysis (ANOVA test) shows the significant difference among the mean densities of these four cultivars ($F_{critical}$= 3.01 < $F_{statistical}$= 10547.53 and p < 0.05).

Table 1.6 Density (gm/cc) of the 10% softener treated fibres of the four cultivars.

Cultivar	**Mean density (gm/cc)**	**Standard deviation**	$\mathbf{F_{critical}}$	$\mathbf{F_{statistical}}$	***p*-value**
HYHEAR 1	1.34	0.0009			
Topas	1.36	0.0007	3.01	10547.53	0.00
5440	1.38	0.0007			
45H29	1.43	0.0011			

Since significant variation among the fibre densities was identified, a Scheffe test was conducted to find the difference in density between cultivar pairs, and the results are tabulated in. *Table 1.7*, where the Scheffe critical value was found 9.03.

Table 1.7 Scheffe test to compare the difference between pairs of means of fibre density.

Group 1	**Group 2**	**Scheffe statistical**	**Significant variation**
HYHEAR 1	Topas	1335.74 (>9.03)	yes
HYHEAR 1	5440	5013.26 (>9.03)	yes
HYHEAR 1	45H29	28567.65 (>9.03)	yes
Topas	5440	1173.51 (>9.03)	yes
Topas	45H29	17548.79 (>9.03)	yes
5440	45H29	9646.24 (>9.03)	yes

The results show that there is a significant difference between every pair of means of fibre densities; the cultivars can be ranked from the least to most dense in the following order: HYHEAR 1> Topas> 5440> 45H29. Considering fibre density, it can be stated that canola fibre is the lightest (1.34-1.43 gm/cc) of all the natural cellulosic fibres. For instance, the density of cotton is 1.52-1.56 gm/cc, 1.44-1.50 gm/cc for jute, 1.48-1.49 gm/cc for hemp, and 1.48-1.50 gm/cc for flax (Kozlowski, 2012a). Flax density of 1.50 g/cc was also confirmed by CIC using gas Pycnometer (Truong et al., 2009).

3.3.5. Tensile strength of canola fibre

Table 1.8 displays the comparative studies of the breaking load, fibre weight, strength index, breaking tenacity, and tensile strength of the 10% softener-treated fibres which have been obtained from six (n= 6) individual test readings per cultivar.

It can be seen from *Table 1.8* that Topas had the highest mean breaking tenacity (13.15 gram-force/tex) and HYHEAR 1 showed the lowest mean breaking tenacity (8.72 gram-force/tex) among softened fibres. Strength index variation caused the variation of breaking tenacities among the fibres than their corresponding mean breaking loads. *Table 1.8* reveals that Topas had the highest strength index (1.93 lb/mg) followed by 45H29 (12.51 lb/mg) and HYHEAR 1 had the lowest (1.28 lb/mg) strength index.

Table 1.8 Breaking load (lb), fibre weight (mg), strength index (lb/mg), breaking tenacity (gram-force/tex), and tensile strength (MPa) of the 10% softener-treated fibres of the four cultivars.

Cultivars	**Mean breaking load** (lb)	**Mean fibre weight** (mg)	**Mean strength index of fibre** (lb/mg)	**Mean breaking tenacity of fibre** (gram-force/tex)	**Mean tensile strength of fibre** (MPa)
HYHEAR 1	10.68	8.34	1.28	8.72	114.74 (±34.42)
Topas	10.99	5.69	1.93	13.15	175.46 (±51.08)
5440	9.88	7.01	1.41	9.57	129.35 (±11.67)
45H29	11.48	6.24	1.84	12.51	175.20 (±24.22)

Further, the tensile strength of the softened fibres was determined using the value of density and breaking tenacity of the fibre using *Eqn. 1.5. Table 1.8* displays that Topas showed the highest tensile strength: 175.46 (±51.08) MPa and HYHEAR 1 showed the lowest: 114.74 (±34.42) MPa. ANOVA statistics showed that there is a significant difference among the means of the fibre tensile strength of the four cultivars ($F_{critical}$= 3.10 < $F_{statistical}$= 5.22; $p < 0.05$). Since significant variation was identified among the means of the tensile strength of the fibres, a Scheffe test was conducted to find the difference in mean tensile strength between cultivar pairs.

Results of the Scheffe test showed that there is a significant difference in tensile strength between HYHEAR 1 and Topas ($S_{critical}$= 9.30 < $S_{statistical}$= 9.80) as well as between HYHEAR 1 and 45H29 ($S_{critical}$= 9.30 < $S_{statistical}$= 9.71). However, there is no significant difference in tensile strength between HYHEAR 1 and 5440 ($S_{critical}$= 9.30 > $S_{statistical}$= 0.57); between Topas and 5440 ($S_{critical}$= 9.30 > $S_{statistical}$= 5.65); between 5440 and 45H29 ($S_{critical}$= 9.30 > $S_{statistical}$= 5.58); and between Topas and 45H29 ($S_{critical}$= 9.30 > $S_{statistical}$= 0.00).

4. Conclusion

The nature of canola as a new-frontier natural fibre offers considerable innovative potential as canola retains all the natural properties of a cellulosic fibre. In this current study, HYHEAR 1 exhibited the highest moisture regain among all the cultivars followed by 5400 for both virgin-retted and softener treated fibres. 5440 and Topas displayed the most uniform fibre diameter among all the cultivars. It was revealed that HYHEAR 1 was the most light-weight fibre among all the cultivars followed by Topas according to the observed value of fibre density. Further, Topas showed superior tensile strength among all four cultivars. It appears that canola fibre possesses superior fibre properties to cotton, such as moisture regain of virgin-retted canola fibre is higher than cotton, and the density of softener treated canola fibre is lower than cotton fibre. The density of fibre has enormous implications in many textile and smart textile applications. For example, in aerospace or automotive applications, lightweight fibre reinforced composites will reduce fuel consumption and related fuel costs. Therefore, canola fibre composites can be a lightweight alternative to other currently-used fibre composites.

There are numerous theoretical relationships noticed in the current study. For example, the highest fibre yield% (10.41 ± 1.87) was obtained for 45H29 which might have been related to the highest fibre density (1.43 ± 0.0011 g/cc). Similarly, softener treated HYHEAR 1 shows the largest moisture regain (7.61 %) and lowest fibre density (1.34 ± 0.0009 g/cc). A fibre that has lower density accommodates a higher degree of amorphousness in its interior which ultimately leads to the tendency of a higher degree of moisture absorption (Morton and Hearle, 2008). Furthermore, assuming that all other parameters are constant, fibre with a larger diameter will have a higher breaking strength. In this regard, Topas displays the highest mean diameter (97.34 ± 27.86 µm) as well as the highest strength index (1.93 lb/mg) among all the four cultivars. 45H29 also has the second largest diameter (88.26 ±39.50 µm) as well as second largest strength index (1.84 lb/mg) among the cultivars.

It was observed that during the matured retting of Stem-set #1, not all fibres were retted at once as well as not all stems produced fibres that are free from hard woody contaminants. To overcome these two problems, retting time for Stem-set #2 was extended beyond typical maturation. As a result of the extended retting time of the stems (Stem-set #2), the extracted fibres were soft and flexible; however, the fibre yield (%) was dropped down due to over retting of some fibres. To overcome these challenges, different retting approach was adopted for Stem-set #3 which involved investigating the retting time of individual stems instead of the whole batch. The fibres from this retting process were much superior to the fibres obtained from Stem-sets #1 and #2. However, this method is tedious and not suitable for industrial applications.

Future work should concentrate on developing a standard methodology to determine the degree of retting or end point of canola fibre retting which can be the determination of stem strength loss and caustic weight loss of fibres as suggested by Brown et al., (1986). Further investigation into the structure and properties of canola fibres should broaden the current state of knowledge to develop strategies towards building precise textile fibre properties with the desired fibre flexibility. Consequently, canola will find application not only for textiles but also for technical textiles.

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