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Wicking Properties of Brassica Fiber in Three Different Growth Stages of Canola Waste Biomass

Laura Soriano
umsoria8@myumanitoba.ca

Dr. Mashiur Rahman
Mashiur.Rahman@umanitoba.ca

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ABSTRACT *Brassica napus* plant (canola biomass) was used as raw material for fibre processing and extraction. An investigation was conducted to determine the wicking behaviour of *Brassica napus (B. napus)* fibre. The wicking property which is an important comfort property of any textile fibre was studied to assess the *B. napus* fibre's feasibility for use in textile applications. Wicking is the procedure by which the fibres in a piece of clothing draw sweat away from the skin and up to the surface of the fabric, permitting dampness to vanish rapidly. A test method was developed to determine the horizontal wicking behavior of single fibres. The wicking property of single fibres was also compared between the different plant growth stages from which the fibre was extracted. The average horizontal wicking rate of *B. napus* from all stages (flowering, seed and mature stage) was found to be 0.184 mm/sec which is much higher than the industry standard (0.08 mm/sec). In addition, the results were compared with cotton, flax and polyester fibres. The horizontal wicking of *B. napus* fiber was faster than polyester but slower than cotton and flax fibres. These results indicate that *B. napus* fibre may have potential applications in the textile industry.

Keywords: Brassica fiber, canola plant, bast fiber, wicking, absorption, Bioquant, enzyme treatment, retting, non-cellulosic material, textile.

INTRODUCTION Canadian-grown canola (*Brassica napus*) contributes $19.3 billion to the national economy yearly creating approximately 249,000 jobs and generating $12.5 billion in wages (Canola Council of Canada, 2015). However, regardless of huge revenue, not all parts of the plant are used as raw material and *Brassica napus* plant remains as waste material on the ground after its seed has been harvested for the production of canola oil. Using waste material as raw material can be of great advantage to industry as it reduces the costs of production implied in the production of new material. The main objective of this research project is to study the wicking property of *Brassica napus* fiber extracted from waste plant material to assess its feasibility for use in textile applications.

Wicking is the capacity of a material to sustain capillary flow (Harnet and Methta, 1984) and it is an important property of textile fabrics as it is the procedure by which the fibers in a piece of clothing draw sweat far from the skin and up to the surface of the fabric, permitting the dampness to vanish rapidly (Webster's Dictionary, 2010). Wicking is therefore an essential property required in order to make performance clothing (sports textiles, hygiene disposable materials and fibrous filters).

The wicking behavior of textile fabrics are well known; the wicking behavior of fabrics varies depending on fiber type (cotton or polyester), fiber variety (cotton – long or short staple; polyester – Dacron, Trevira), fiber cross-section, yarn type (spun or filament), and fabric type (woven/knitted/non-woven) (Simile, 2004). There are no industry standards as to which fiber is best for wicking. Hydrophilic fibers (cotton, flax) absorb water readily but do not give up water quickly; in contrast, hydrophobic fibers (polyester) do not absorb water as much but give up water quickly (Simile, 2004). It seems that hydrophilic polyester and blend of polyester with a hydrophilic fiber is the consensus choice for industry (Tamura, 2010).

There are several standardized test methods and test equipment for the wicking measurement of fabric and yarn (AATCC, 2013; AATCC 2013; Simile, 2004). Therefore, the wicking rate of **fabric** and **yarn** (an arrangement of fibers) is readily available in the literature. However, no test method or measurement techniques are available for studying the wicking rate of **single fibers** *(*as opposed to yarn and fabric). As a result, the wicking properties of *B. napus* fiber have not been assessed and there is no data in the literature.

The major objective of this research is to develop a test method to determine the wicking behavior of single fibers and at the same time to examine the wicking properties of single fiber *B. napus* harvested from different growth stages. It is known that fiber quality of natural fiber is growth stage dependent (Bell and Chen, 2015) and that the moisture absorbency of *B. napus* fiber is about 12-15%, which is higher than cotton and flax (Sevenhuysen and Rahman, 2015). The results will be compared among each growth stage and will also be compared with cotton, flax and polyester materials.

MATERIALS AND METHODS Fiber was extracted from the stem and branches of *B. napus* plants through water retting process. After the fiber was obtained, it was enzymatically treated to remove non-cellulosic material that might inhibit wicking (Shen et al, 2008). Single fibers were subjected to horizontal wicking to assess their wicking properties. Light microscopy, video recording and image analysis software (Bioquant) were used for assessing the wicking rate of individual fibers. The results were compared among the different growth stages from which *B. napus* fiber was obtained with the aim to conclude at which stage single fibers exhibited greater wicking rate.

Materials The stem samples used in this research study were taken from Reston variety of *B. napus* species plants. The plants were grown in the field owned by the Faculty of Agriculture and Food Sciences at the University of Manitoba. Twenty samples of 4 inches in length were cut from plants corresponding to three different growth stages: flowering, seed and mature stage. Samples from seed stage were collected both from larger and smaller diameter stems to further investigate the effect of stem diameter on wicking rate of single fibers. Thick stems were found in the lower part of the plant closer to the roots and thin stems were obtained from the upper part of the plant closer to the branches or at the branches. The average diameter of the thick stems was 8.72 mm ± 2.38 and the average diameter of thin stems was 4.35mm ± 0.71. Cotton fiber, and flax fiber were obtained from Textile Collection (University of Arizona, USA), polyester filament yarn, polyester, cotton and flax spun yarns were supplied by the Test Fabrics (USA).

Retting *B. napus* fiber is contained at the outermost layer of the plant stem and needs to be removed manually from the stem. Retting is the process of loosening the fiber from the stem through bacterial action (Hatch, 2006). Precut samples were conditioned for 48 hours at 20°C and 65% RH.

Retting was carried out by placing the conditioned samples inside beakers containing tap water and were left at room temperature until the fiber was easily separable manually in tap water.

Enzyme Treatment To treat the fiber, the enzyme Pectinase from Aspergillus 3.800 units/ml was used. The treatment was carried out using 4% enzyme solution in water (200 ml water for each treatment). The initial pH of the enzyme solution was 6.5, which was adjusted to 5.8 by using acetic acid (5 drops of 5 g/L acid solution). The enzyme solution and virgin fiber were transferred in a canister and then placed in launderometer. The enzyme treatment was conducted for 90 minutes at 40°C. After enzyme treatment, the fiber samples were washed with hot and cold water and then dried in a conditioned room for 48 hours. The dried samples were kept in sealed bags for subsequent analysis.

Horizontal wicking The plants from which the samples were extracted were obtained from the same cultivar (Reston, *Brassica napus*), however at different growth stages. Therefore, the conditions in which the plant grew were constant across all the samples. The growth stages from which the samples were taken are: seed stage (further divided into thick stem and thin stem samples), flowering stage and mature stage.

Wicking was measured using light-microscopy, video-recording and image analysis software (Bioquant). Single fibers were attached to glass slides. The fibers were positioned horizontally and fully extended across each slide as shown in Figure 1. The fibers were then examined using the microscope with the 4X magnification lens. The length of the fiber and its diameter were recorded using the image software analysis. The Window Image was recorded using Windows Media Encoder program which captures the screen of the image window which displays the microscope output. The image window of the microscope was recorded a few seconds before a drop of Textile Identification Solution (TIS) is placed on top left of the fiber, the image window is captured until the liquid droplet has travelled the across the length of the window. The time the liquid takes to travel the fiber segment which is equivalent to the window is used to calculate the wicking rate.

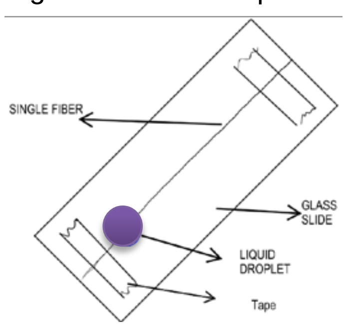

Figure 1. Fiber and glass slide prepared for horizontal wicking experiment

Figure 2. Vertical wicking apparatus

Time Rate Analysis The fiber was examined under 4X magnification lens which has a magnification factor of 4.9505 microns/pixel. The magnification factor was used to convert pixels into units of length. The length of travel which is the segment of fiber that can be observed through the software's image window. The software analysis used (Bioquant) has an image window of 637 pixels equivalent to 3.154 mm of length. This is the maximum length the liquid can be observed traveling horizontally across the window of the image analysis software. It is more convenient to calculate wicking rate with a large length of travel (>3.1mm). However, due to limitations of the available tools, it was not possible to calculate wicking rate of single fibers using a large length of travel.

Vertical wicking Vertical wicking was carried out using *B. napus* fibers from the mature stage plants. Vertical wicking was performed using a bundle of enzyme treated fiber attached to a glass rod in one end and to a small weight (1.75 g) at the other end to keep the fiber bundle straight as shown in the Figure 2. The extended bundle was then positioned inside a beaker with the rod attached on top of the beaker. The beaker was then filled with TIS until a small part of the bundle was submerged. The bundle was left to rest for a couple of hours to observe if vertical wicking occurred.

Statistical Analysis To determine if there is a significant difference in the average wicking rate among each of the growth stages, an analysis of variance (ANOVA) was carried out. The analysis of variance determines if the difference in the average wicking rate among each group is due to the effect of growth stage in the samples or if the difference in average wicking rate is attributed to other factors particular to each single fiber.

RESULTS AND DISCUSSION

HORIZONTAL WICKING RATE The maximum segment of length that liquid can travel horizontally is 3.1 mm which corresponds to the horizontal length of the Image Window of the image analysis software (Bioquant). Even though the maximum length of fiber that liquid can travel is known, measurements of length were obtained for each single fibers as it was observed that some fibers were positioned slightly at an angle on the glass slides. The image analysis software was also used to obtain diameter measurements of each single fiber.

Non-enzymatically treated fibers (untreated fiber) Based on the video recordings of liquid flow, it was observed that for untreated *B. napus* fibers, liquid did not travel in a uniform manner. In untreated fibers, the behavior of the liquid was irregular when traveling across the fiber; varying greatly within the same segment of fiber. The liquid travelled faster in some sections and slower in other sections or stopped altogether at some point of the fiber segment. The irregular behavior of liquid absorption and travel in untreated *B. napus* fiber made it difficult to calculate wicking rate. Therefore, the wicking rate data for untreated fibers could not be determined and only visual observations of the wicking behavior in untreated fibers was noted. The irregular behavior of wicking absorption for untreated *Brassica napus* fiber may be attributed to the presence of non-cellulosic components (lignin, pectin and so forth) in the untreated fibers (Shen et al, 2008).

Wicking rate for enzyme treated fibers The wicking rate of enzyme treated *B. napus* fiber, harvested at different growth stages, was analyzed and calculated in this experiment. In order to understand the effect of plant diameter on wicking rate, seed stage was further divided into fibers obtained from stems of thick diameter and fibers obtained from stems of thin diameter to further investigate wicking rate. Seed stage was selected to further classify the fibers because it is the stage that has the fewer amounts of nodes in its plants. Fewer nodes allow for a greater amount of samples to be extracted without fiber breakage. Other stages such as mature and flowering contained a relatively greater amount of nodes making it difficult to obtain enough longer fiber samples clear of obstructions.

The horizontal wicking rate of *B. napus* fibers for seed stage (thick stem), seed stage (thin stem), flowering stage and mature stage is shown in Tables 1, 2, 3 and 4 respectively. These tables also contain the average wicking rate with standard deviation. The average wicking rate (mm) for seed stage thick stem was the highest (0.235 mm/sec), followed by mature stage (0.203 mm/sec), seed stage thin stem (0.176 mm/sec) and flowering stage (0.120 mm/sec). The average wicking rate was also demonstrated in Figure 3. It can be seen from these tables that the standard deviation for wicking rate is very high, which indicates a greater amount of variation in results. The standard deviations at each of the stages are: 0.121 mm/sec, 0.195 mm/sec, 0.122 mm/sec and 0.189 mm/sec for seed stage thick stem, thin stem, flowering and mature stage respectively.

Tables 1 shows the wicking rate for fiber extracted from thicker diameter stem samples mostly from the bottom of the plant while table 2 shows the rate for smaller stem diameter samples mostly from the plant branches. The average wicking rate for fibre from thicker diameter fibre was found to be higher (0.235 mm/sec ± 0.121) than the fiber from the smaller diameter plant (0.176 mm/sec ± 0.195).

Table 1. Data for seed stage thick stem

Seed stage (thick)			
Length(mm)	Time(s)	Diameter(μ)	Rate(mm/s)
3.154	11	52.61	0.287
3.154	21	84.31	0.15
3.154	17	73.37	0.186
3.154	40	92.88	0.079
3.154	21	156.82	0.15
3.154	9	103.99	0.35
3.154	21	50	0.15
3.154	7	77.66	0.451
3.149	10	111.47	0.315
		Mean	0.235±0.121

Table 2. Data for seed stage thin stem

Seed stage (thin)			
Length(mm)	Time(s)	Diameter(μ)	Rate(mm/s)
3.149	5	101.04	0.63
3.155	27	103.612	0.117
3.154	10	90.98	0.315
2.535	158	94.25	0.016
3.153	36	86.82	0.088
3.147	44	139.95	0.072
3.156	14	104.11	0.225
3.155	38	64.57	0.083
2.698	67	74.94	0.04
		Mean	0.176±0.195

Table 3. Data for flowering stage

Flowering Stage			
Length(mm)	Time(s)	Diameter(μ)	Rate(mm/s)
3.154	12	314.55	0.263
3.156	12	142.19	0.263
3.154	79	104.11	0.04
3.153	69	93.46	0.046
3.153	54	104.44	0.058
3.155	50	119.14	0.063
3.154	152	63.22	0.021
1.866	152	88.42	0.012
3.158	10	90.66	0.316
		Mean	0.120±0.122

Table 4. Data for mature stage

Mature Stage			
Length(mm)	Time(s)	Diameter(μ)	Rate(mm/s)
3.155	23	137.76	0.137
3.154	38	140.64	0.083
3.154	10	144.91	0.315
3.153	29	103.77	0.109
3.154	30	78.67	0.105
2.614	31	80.4	0.084
3.155	5	76.82	0.631
3.156	10	94.22	0.316
3.154	68	67.74	0.046
		Mean	0.203±0.189

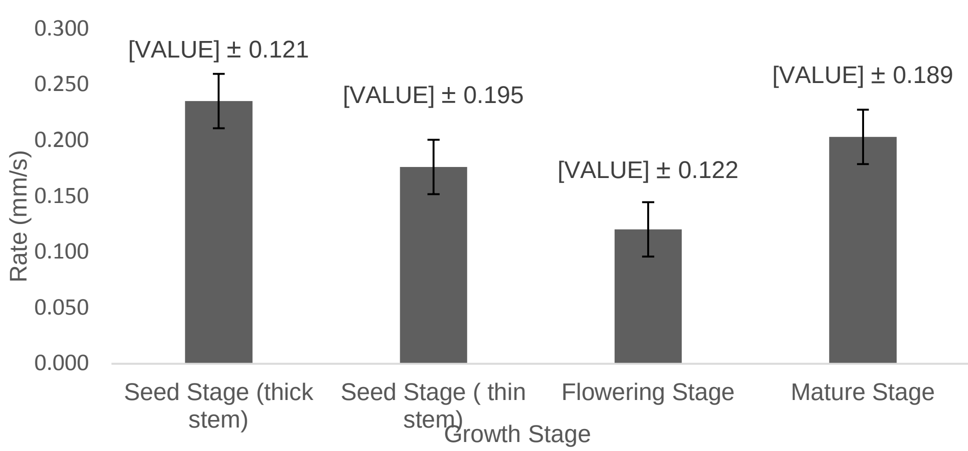

Figure 3 Horizontal wicking rate for enzyme treated *Brassica napus* fiber

Diameter and wicking time The average travel time for fiber from all three growth stages was 38.61 seconds with the fastest time being 5 seconds and the slowest 158 seconds. This is the time required for the liquid to travel the segment of fiber equivalent to the image window taking into account small variations in length due to the fibers not being positioned perfectly horizontally over the glass slide. The time frame for wicking rate is highly variable and there is no clear relationship with time or other fiber attributes such as diameter or stage which is shown in Figure 4.

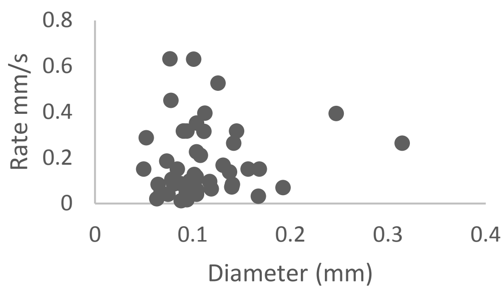

Figure 4. Wicking rate and fiber diameter

Comparison of wicking rate of canola fibers with cotton and flax Cotton and flax fibers are relatively thinner than *Brassica* fiber and were observed with the 100x magnification. In an attempt to establish the wicking rate of single fibers of cotton and flax, single fibers were subjected to the light-microscopy horizontal wicking experiment that canola fibers were subjected to.

Cotton and flax are known to be very absorbent material (Collier and Epps, 1999), fibers are thinner and with a smaller diameter than the *B. napus* fibers. However, during the experiment, cotton and flax fibers absorbed liquid instantaneously without providing a strong visual indicator to account for wicking (Table 5). For *B. napus* single fibers, the liquid can be seen inside the fiber as well as on the surface of the fiber, travelling from one end (left) to the other (Figure 5). The thin flax and cotton fibers gave almost no visual indicators as to when the phenomenon occurred (Figure 6). The cotton and flax fibers instead showed a thin layer of liquid forming on the outside of the whole segment of fiber slightly thickening as time passed. Therefore, it was very difficult to measure the wicking time as not enough visual feedback was obtained. Therefore, the wicking rate was not calculated for single fibers of cotton and flax.

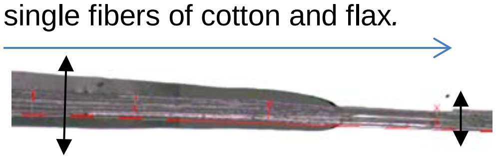

Figure 5. Absorption of liquid by a single Brassica fiber exhibiting visual feedback. (4X magnification) Liquid is absorbed from left to right.

Figure 6. Wetted single Cotton fiber exhibiting no visual feedback. (100X magnification)

An extraordinary phenomenon was observed during the horizontal wicking measurement for *Brassica* fiber. It was noticed that the diameter of single fibers changed as wicking occurred (Figure 5). The fiber became thicker as water approximated and advanced across the single fiber. It was observed that the change in diameter was almost the double of the initial diameter of the fiber. No such diameter increase was observed for cotton, flax or polyester (Figure 6). This may explain the reason for lower wicking rate for *Brassica* fiber as it is known that fiber swelling does not only increases liquid retention in the fibers at the expense of the capillary liquid capacity in interfiber pores, but also complicates the pore structure. This swelling of the fibers can cause closing off of capillaries, which in turn causes the flow in those capillaries to be slow or even stop (Hsieh, 1995).

Despite the fact that horizontal wicking rate for cotton and flax fiber could not be calculated by means of the method used in this study (as cotton and flax fibers showed no liquid absorption visual indicators), an attempt was made to measure the wicking rate for cotton and flax spun yarns as well as polyester spun and filament yarns (Table 5). The wicking rate for polyester filament yarn was very slow as liquid did not travel within 5 minutes of observation. The wicking rate for spun yarns of cotton, flax and polyester is 0.581, 0.645 and 0.206 mm/sec respectively. *Comparing to B. napus* all wicking rates are faster than *Brassica* fiber (0.184 mm/sec).

Table 5. Horizontal wicking for cotton, flax and polyester

Material type	Wicking rate (mm/s)	Comments
Cotton fiber	Not measured	Instantaneous absorption
Cotton yarn	0.581	Fast absorption
Flax fiber	Not measured	Instantaneous absorption
Flax yarn	0.645	Fast absorption
Polyester filament	Not measured	Very slow
Polyester spun yarn	0.206	Slow

VERTICAL WICKING RATE Another experiment was carried out to study vertical wicking behaviour. The aim of this experiment was to observe the wicking of *Brassica* fiber over an extended period of time without the presence of the interacting forces of the glass slide used in the horizontal wicking rate experiment. During vertical wicking, gravity force is the only force opposing capillary action; in contrast, in the horizontal wicking experiment there are no gravity forces opposing capillary action. Vertical wicking testing is commonly performed in commercial fabrics, yarns and other absorbent materials such as paper over which liquid travels many centimeters (Kate and Spade, 2016).

It was found through qualitative observation that the wicking rate was much slower in the vertical setup than in the horizontal setup; liquid stopped after travelling only a few millimeters. Similarly, slower vertical wicking rate was reported by Das et al (2008). Poor vertical wicking properties may be attributed to the presence of non-cellulosic materials (even after enzyme treatment). Further, as it was discussed earlier that the fiber swelling that was observed during horizontal wicking measurement (Figure 5) may be responsible for this behavior (Hsieh, 1995).

ANALYSIS OF VARIANCE (ANOVA) TEST OF SIGNIFICANCE The F of the ANOVA test is the ratio of variance between groups to variance within the groups and the critical value is the point on the ANOVA distribution that is compared to the F value to determine whether to reject the null hypothesis. The null hypothesis of the ANOVA test implies that there is no difference among the mean values of each group. In this experiment the null hypothesis assumes that there is no difference in average wicking rate among the growth stages which indicates that the growth stage has no effect on wicking rate. (Null hypothesis: $\mu 1 = \mu 2 = \mu 3 = \mu 4$). The analysis of variance results is presented in the table below.

Table 5. Summary of statistical results.

Statistical measure	Value
F value	0.83
Critical Value	2.90
Variance between groups	64.07
Variance within groups	823.82
Degrees of freedom (between groups)	3
Degrees of freedom (within groups)	32

The **F** ratio in the ANOVA test of significance is the ratio of two mean square values. An F value of 0.83 was obtained and a critical value of 2.9. In order for the results to be significant and reject the null hypothesis, the F value must be greater than the critical value.

The F value obtained does not exceed the critical value, $F = 0.83 < 2.9$, therefore the difference in wicking rate between each fiber is not significant. The results show a small ratio which means the variation among groups is not more than would be expected to be seen by chance.

If growth stage has no significant effect in the variation of means between groups; it means that the variation in the wicking rate of the fibers may be due to factors common to all fibers such as the presence of lignin and pectin in the fibers or non-homogeneity in the samples. Biological samples are known to be amorphous and non-homogeneous (Hatch, 2006), these characteristics are generally common to all biological samples including fibers; so the variation in wicking rate may be attributed to non-homogeneity rather than growth stage.

LIMITATIONS OF THE EXPERIMENT The method used to assess horizontal wicking rate of *Brassica* single fiber samples contains sources of error due to the effect of the glass slide used in the experiment. Other methods free of forces other than gravity need to be applied to obtain wicking rate and validate the results. Another limitation of the experiment in assessing the feasibility of *Brassica* fiber as textile product is that this experiment measures wicking rate but it does not measure drying rate which is an important parameter for wickability. Lastly, as previously discussed, the length of travel needs to be larger to assess wicking phenomenon over an extended period of time accounting for wicking rate over a larger segment in the fiber. This can be achieved by obtaining a microscope with larger field.

CONCLUSIONS

The method that has been designed and developed in this research project may be used to measure the horizontal wicking of single *B. napus* fibers as well as wicking rate of spun yarn. Ultimately, this method may be used to identify whether or not the non-cellulosic materials were removed from the fibers completely and uniformly. Constant wicking rate over the length of the fiber may indicate that most of the non-cellulosic material was extracted from the fiber while fluctuating liquid absorption may indicate presence of cellulosic material resulting in the determination of wicking rate with different values over the length of the fiber

Statistical significance results show that growth stage has no influence on the horizontal wicking rate of single *Brassica* fiber samples. Difference in wicking rates at each stage and among each fiber sample may be attributed to the amorphous nature of each individual fiber and to the presence of non-cellulosic material not removed by the enzyme treatment (chemical treatment) applied to the fibers.

There was no significant difference found between the wicking rate of fibers obtained from thin diameter stems and from thick dimeter stems. Also, the relationship between fiber diameter and wicking rate is non-linear; it can be concluded from the results that there is no relationship between fiber diameter and wicking rate (Figure 4). This result contradicts the findings of Das et al (2008), who reported an inverse relationship between fiber diameter and wicking rate.

Comparison of the wicking rate of *B. napus* fiber (0.184 mm/sec) to industry standard (0.08 mm/sec) shows that *B. napus* could be used by blending with polyester to achieve acceptable wicking performance (Kate and spade, 2016). However, more studies need to be done to further confirm the results of current studies.

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APPENDIX A – ANALYSIS OF VARIANCE DATA

G1 corresponds to seed stage thick stem, G2 to seed stage thin stem, G3 to flowering stage and G4 to mature stage. The total sum of squares (SST) and the sum of squares within groups (SSW) were calculated to determine the F ratio. For the SST the sum of all data is used.

Table 6. Data for the analysis of Variance (ANOVA) test of significance.

Rate (mm/s)	$(x-\mu)^2$
0.287	10.624
0.150	1.119
0.186	0.003
0.079	10.985
0.150	1.122
0.350	27.799
0.150	1.121
0.451	71.202
0.315	17.217
0.630	199.052
0.117	4.464
0.315	17.354
0.016	28.096
0.088	9.229
0.072	12.578
0.225	1.745
0.083	10.126
0.040	20.561
0.263	6.272
0.263	6.298
0.040	20.661
0.046	19.033
0.058	15.692
0.063	14.535
0.021	26.542
0.012	29.374
0.316	17.452
0.137	2.162
0.083	10.133
0.315	17.342
0.109	5.613
0.105	6.168
0.084	9.869
0.631	200.087
0.316	17.410
0.046	18.848
Sum	887.887

	Rate (mm/s)			
	G1	G2	G3	G4
	Seed thick	Seed thin	Flowering	Mature
	0.287	0.630	0.263	0.137
	0.150	0.117	0.263	0.083
	0.186	0.315	0.040	0.315
	0.079	0.016	0.046	0.109
	0.150	0.088	0.058	0.105
	0.350	0.072	0.063	0.084
	0.150	0.225	0.021	0.631
	0.451	0.083	0.012	0.316
	0.315	0.040	0.316	0.046
μ	0.235	0.176	0.120	0.203

	G1	G2	G3	G4
	$(x-\mu1)^2$	$(x-\mu2)^2$	$(x-\mu3)^2$	$(x-\mu4)^2$
	2.649	205.751	20.352	4.330
	7.236	3.524	20.399	14.390
	2.475	19.371	6.444	12.632
	24.467	25.655	5.550	8.878
	7.242	7.854	3.820	9.572
	13.253	10.963	3.260	14.076
	7.239	2.422	9.891	183.194
	46.323	8.683	11.648	12.689
	6.337	18.481	38.248	24.519
Sum	117.221	302.705	119.612	284.281