Assessing the effects of planting density and variety on seed and fibre production of flax (*Linum usitatissimum)*

Kayla Buttress

Department of Sustainable Agriculture and Food Systems

Kwantlen Polytechnic University

Advisors: Michael Bomford, Kathy Dunster

December 13, 2024

ABSTRACT

Flax is a versatile crop known for its dual-purpose in producing oil-rich seed as well as fibre which can be processed into linen material. Rising concerns about local food production and general sustainability of the textiles industry highlight the importance of local production and optimization of cultivation practices to ensure profitability. One of the key factors influencing seed and fibre yield is planting density. An experiment was conducted using a completely randomized design to test the effect planting density has on the production of seed and fibre. An increase in seed and fibre yield as well as stem length was observed with increased planting densities.

Key Words: fibre production; flax; linen; seed yield

INTRODUCTION

History of flax

Flax (*Linum usitatissimum*) is a resilient and versatile annual plant cultivated for its oil-rich seed as well as fibre that can be made into linen. With archaeological evidence of flax use dating back to before 6000 B.C. (Jhala and Hall 2010), the persistence of this crop reflects its value to humans throughout history. Phylogenetic evidence indicates that flax was originally cultivated for its value in oil (Allaby et al. 2005). Mummies wrapped in linen fibre have been unearthed in Ancient Egypt, providing archaeological evidence of the fibre use of flax dating back to approximately 4500 BC (Jones et al. 2014). While the exact centre of origin for *Linum usitatissimum* is unknown, it is proposed that either the Mediterranean or Southwest Asia are likely the regions where this species was first domesticated (Millam et al. 2005).

Brought to Canada in 1617 by Louis Hébert, *L. usitatissimum* is thought to first have been established at the present site of the Québec City courthouse (Kenaschuk and Rowland 1995). Records from 1720 report that New France (early Québec) produced 25 tonnes of flax seed (Kenaschuk and Rowland 1995). Over time, flax production spread west with migrating European settlers and by 1875, flax was being cultivated in western Canada (Kenaschuk and Rowland 1995). Production thrived in the prairie provinces where Russian settlers began intensive fibre flax production as early as 1899 (Kalmakoff 2023). The fibre flax industry migrated with the Russian settlers who introduced linen production into British Columbia between 1908 and 1913 where flax mills were built in Grand Forks and other communities in the Kootenay region (Kalmakoff 2023).

Flax production in Canada

Seed production

Today, flax production in Canada is concentrated in the prairie provinces of Alberta, Saskatchewan, and Manitoba (Saskatchewan Flax Development Commission n.d.). In these regions, *L. usitatissimum* is commercially cultivated exclusively for seed and oil production. Canada is the largest producer of flaxseed, representing approximately 40% of global yield (Saskatchewan Flax Development Commission n.d.). Recommended seeding rates are between 44 and 56 kg per hectare (Manitoba Flax Growers Association n.d.). Farmers can expect a yield of between 1300 and 2000 kg of seed per hectare of flax grown (Rowland 2013; Saskatchewan Flax Development Commission n.d.).

Flax yield in Canada decreased by 43% between the 2022-23 and 2023-24 growing seasons from 473 kt to 273 kt (Beckman 2024). This is the lowest yield since 1967-68. There was a 23% decrease in the total harvested area as well as a 25% decrease in the yield per hectare (Beckman 2024). In 2022-23, farmers were able to earn an average price of $635 per tonne while in 2023/24, that price decreased to $581 per tonne and is expected to decrease further in the 2024-25 season (Beckman 2024). Domestic use of flax has a projected approximate economic value for the 2024-25 season of $52,290,000 CAD while exports are valued at $145,250,000 CAD (Beckman 2024).

Flax seed production involves a straightforward process of removing bolls, containing up to ten small seeds, from the end of stalks that can grow up to 60 cm tall (Rowland 2013; Deckers et al. 2023). Traditionally, this process is done by hand using a metal comb. Seed bolls are then crushed to separate plant material from the seeds. Plant material can be removed from the seed using two containers and wind to blow away the lighter chaff while pouring seed slowly from one container into the other, leaving the heavier seeds behind. This process is known as winnowing.

Flax seeds are prized for their high fat content, containing approximately 40% oil, and 25% protein (Rowland 2013). Flax seed oil, also known as linseed oil, is used in oil-based paints, in the production of linoleum flooring, as well as in wood sealants (Canadian Food Inspection Agency 2012). Flax seeds may also be consumed as a health product due to their high concentration of omega-3 alpha linolenic acid and polyphenols (Canadian Food Inspection Agency 2012).

Fibre production

Although there are many small-scale flax fibre production guilds throughout Canada, there is no recognized commercial market for domestic linen production. The total area dedicated to fibre flax production in Canada is estimated to be less than four hectares (Tancock 2024).

The small-scale production of linen fibre is a multistep process involving many terms specific to the production of flax. When grown for fibre production, *L. usitatissimum* is harvested by pulling, as opposed to cutting, to ensure the length of the fibre contained inside the stalk is preserved. After pulling, stems are air dried to remove moisture. It is after this step that seed bolls are removed, although when grown on a larger scale, harvesting seed is not considered as fibres are of highest quality before seed reaches maturity.

Stems are then retted, either in fields or submerged in water. Retting is the process of breaking down the outer plant material, known as the shive, to release the inner fibres. Breakdown is completed by degradation, or rotting, via microorganisms (Reda et al. 2024). After retting, stems are thoroughly dried and rigid stalks are crushed using specialized equipment known as a flax break. This breaks up rigid stems so that the shive is more easily able to be removed when scutched.

Scutching is the process of beating stems with a dull, typically wooden blade known as a scutching knife to knock off most of the shive material. After most of the shive has been removed, the fibre becomes readily visible. Fibres are then brushed using a hackle. Hackling separates long fibre, known as line, from short fibres, known as tow. Although both may be used for weaving, line fibre is prized for its superior quality while tow fibre may be considered to be second-grade. Hackling is done in a two-step process (rough hackling, and fine hackling) and further removes shive material from the fibres. After fine hackling, fibre is ready to be spun and processed into linen material.

Effect of planting density

Recommended planting density varies depending on factors such as seed quality, variety, climate, and whether flax is grown for seed or fibre production. The Manitoba Flax Growers

Association (n.d.) recommends an application rate between 45 and 56 kg/ha to obtain a stand of approximately 323 plants per square metre for seed production.

Previous research has found that higher planting densities positively correlate with stem length, leading to increased quantity of fibre (Arslanoglu et al. 2022). This research found the optimal planting density for fibre production was 2000 seeds/m^2 (Arslanoglu et al. 2022). Other research found that 2500 seeds/m^2 produced the highest fibre yields (Eldaiem 2015).

This study aims to provide guidance to optimize seed and fibre production of flax through strategic planting densities and varietal selection within the unique growing conditions of the Fraser Valley.

METHODS

Field Site

The experiment took place at the farm of Kwantlen Polytechnic University, located in Richmond, British Columbia on the Garden City Lands.

Experimental design

The experiment utilized a completely randomized design with one replicate. Four varieties of flax (Avian, Emeraude, Linore x Agatha, and Marilyn) were each planted at four densities (1000, 1500, 2000, and 2500 seeds per m^2), resulting in 16 different plots (Fig. 1). Planting densities of 1000, 1500, 2000, and 2500 seeds per m^2 were equivalent to seeding rates of approximately 47, 68, 89, and 109 kg per hectare, respectively.

FIG. 1. Plot map of the completely randomized design used for this experiment.

Avian is a fibre flax variety, bred in the Netherlands by Wiersum Plantbreeding. Emeraude is an older fibre variety, grown in France since the 1960s. This variety has had previous success when grown in Richmond, BC. Linore x Agatha is a hybrid variety, adapted to coastal climates. Linore is recognized as a winter hardy mixed-use variety bred by Oregon State University in 1962 while Agatha is a traditional fibre variety from the Netherlands. Marilyn is a fibre variety, also from the Netherlands, recognized to be a less hardy variety. All seed was provided by Dr. Kathy Dunster. Varieties were selected based on availability.

The research area was cultivated and flame weeded prior to sowing. Seeds were hand-sown inside 1 m^2 plots and raked in to roughly cover with soil. Plots were irrigated as needed for the first four weeks of growth. Mild weather with regular precipitation was relied upon after this time to irrigate plots (Fig. 2). Weeding was done by hand regularly throughout the growth period.

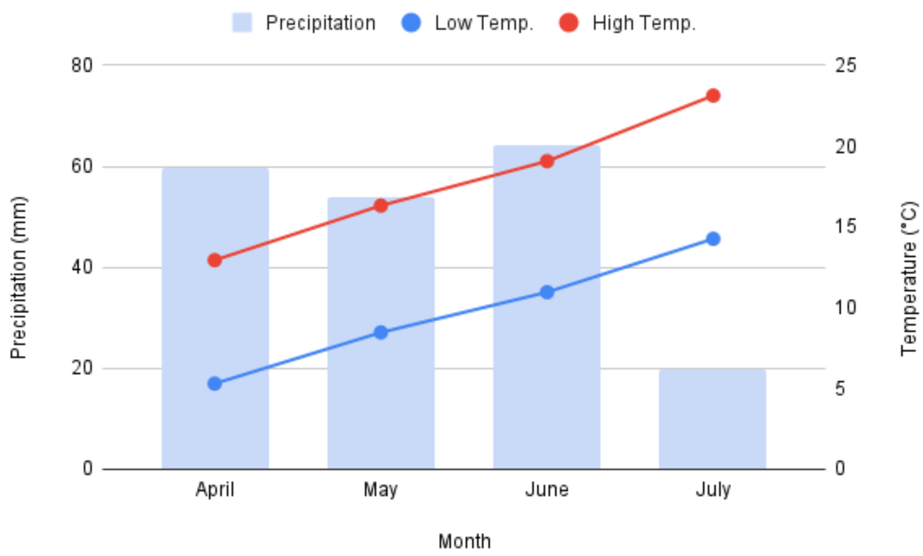

FIG. 2. Average monthly high and low temperatures and total monthly precipitation during growing period. Weather data obtained from the Vancouver International Airport weather station via the Environment and Climate Change Canada Historical Climate Data website.

Flax was grown for approximately 100 days between April 2 and July 18, 2024. Plots were harvested by hand-pulling at an equal phenological stage when seed bolls began to dry and seeds inside were audibly loose.

Data collection

An inner 40 by 40 cm plot was utilized as the experimental plot, excluding a 30 cm perimeter to account for edge effects. Flax stems were dried outdoors in a covered space, kept in paper yard waste bags. Seeds were removed from stems using a rolling pin on a hard surface. Using a Holland Laboratory seed air separator, seeds were separated from residual plant material and weighed using a digital analytical laboratory scale, accurate to 0.001 grams. Equipment used to clean and weigh seed was sourced from the Seed Lab, located at Kwantlen Polytechnic University's Richmond campus.

Stem counts for each experimental plot were recorded as well as stem weight by plot, using a Taylor brand kitchen scale, purchased from Costco, accurate to 1 gram. A random sample of 20 stems from each plot was measured to obtain average length.

Bundles of flax stems were retted mid-October, submerged in water for up to 18 days. This time varied due to contrasting stem thicknesses between varieties; thicker stems required more retting time. Bundles were removed from the retting pond by variety; Avian had the finest stems and was removed after 10 days; Marilyn after 12 days; Emeraude after 16 days; and Linore x Agatha after 18 days.

After air drying indoors with the use of a dehumidifier, stems were processed using a flax break for approximately four minutes per bundle. Stems were scutched for approximately five minutes, using a metal kitchen bench scraper against a wood surface. A homemade rough hackle was constructed, consisting of five alternating rows, spaced at one inch of four-inch long galvanized spiral framing nails on a wooden plank. Scutched fibres were combed through the rough hackle until nearly all of the outer plant material had been removed. Fibre weight was recorded using a digital kitchen scale purchased from Amazon, accurate to 0.1 grams.

Statistical analysis

Data was analyzed with a linear regression using the *car* and *emmeans* package of the jamovi interface for R (Fox and Weisberg 2020; Lenth 2020; R Core Team 2021; The jamovi project 2022). Data was normally distributed and did not require transformation, however an outlier was recorded for the plot Linore x Agatha planted at a density of 2500 seeds per m^2. The data from this plot was excluded from all analysis to enhance significance.

RESULTS

Seed yield

An increase in planting density positively correlated ($p = 0.027$) with an increase in seed yield across all varieties (Table 1). Variety had a moderate effect on seed yield ($p = 0.045$). There was no significant difference in total seed yield (Fig. 3) between varieties Avian (73.4 grams), Emeraude (74.9 grams), and Marilyn (73.3 grams), however Linore x Agatha produced a notably higher total seed yield (111.1 grams).

Table 1. *P* values for effect of planting density and variety on seed yield.

Model Coefficients - Seed yield (g)

Predictor	Estimate	SE	t	p
Intercept [a]	18.75513	6.18699	3.03	0.013
Variety:				
Avian – Linore x Agatha	-14.99047	5.15113	-2.91	0.016
Emeraude – Linore x Agatha	-14.61352	5.15113	-2.84	0.018
Marilyn – Linore x Agatha	-15.01804	5.15113	-2.92	0.015
Planting density (seeds/m2)	0.00833	0.00323	2.58	0.027

[a] Represents reference level

Note. Linore xAgatha was used as the reference level to compare against other varieties as it produced the highest seed yield.

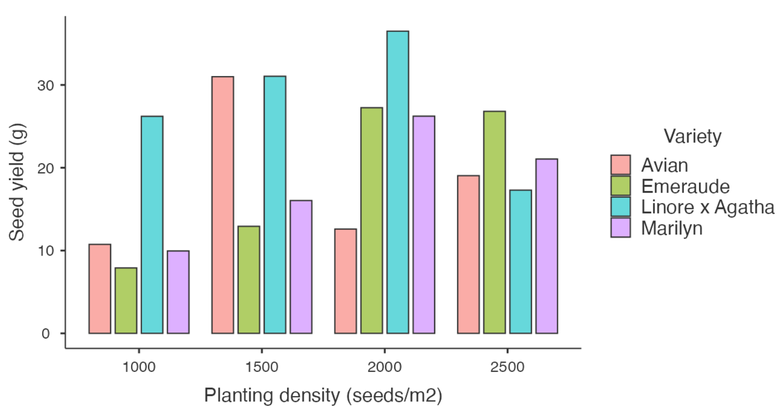

FIG. 3. Seed yield for 40 by 40 cm experimental plots separated by planting density and variety.

Stem length

Planting density and stem length were positively associated (p = 0.029; Table 2). Variety also had a strong effect on stem length (p = 0.005). Emeraude produced the longest stems across all varieties with an average of 77.5 cm while Avian produced the shortest with an average 52.7 cm (Fig. 4).

Table 2. *P* values for effect of planting density and variety on average stem length.

Model Coefficients - Stem length (cm)

Predictor	Estimate	SE	t	p
Intercept [a]	37.11029	7.31416	5.07	<.001
Variety:				
Emeraude – Avian	24.71250	5.24967	4.71	<.001
Linore x Agatha – Avian	18.03186	5.74132	3.14	0.010
Marilyn – Avian	18.86250	5.24967	3.59	0.005
Planting density (seeds/m2)	0.00919	0.00360	2.55	0.029

[a] Represents reference level

Note. Avian was used as the reference level to compare against other varieties as it produced the shortest stems.

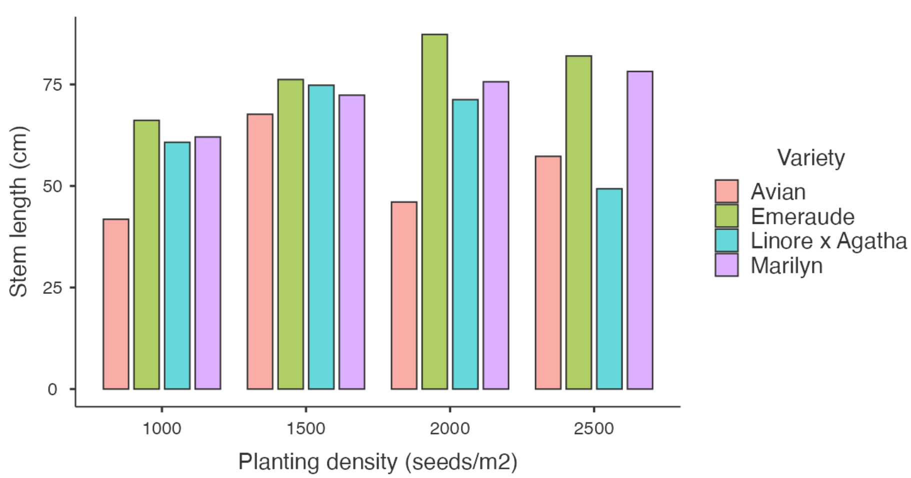

FIG. 4. Average length of 20 stems, separated by planting density and variety.

Fibre production

A strong positive correlation was observed between planting density and fibre yield (p = 0.003; Table 3). Variety also had a strong effect on fibre yield (p = 0.005). Marilyn outperformed all other varieties in fibre production (Fig. 5), producing an average of 28.2 grams across all plots while Linore x Agatha had limited fibre production with an average of 7.4 grams across all plots.

Table 3. *P* values for effect of planting density and variety on fibre yield.

Model Coefficients - Fibre yield (g)

Predictor	Estimate	SE	t	p
Intercept [a]	9.1279	5.73219	1.59	0.142
Variety:				
Avian – Marilyn	-13.0500	4.11423	-3.17	0.010
Emeraude – Marilyn	-13.8250	4.11423	-3.36	0.007
Linore x Agatha – Marilyn	-20.8564	4.49954	-4.64	<.001
Planting density (seeds/m2)	0.0112	0.00282	3.98	0.003

[a] Represents reference level

Note. Marilyn was used as the reference level to compare against other varieties as it yielded the most fibre.

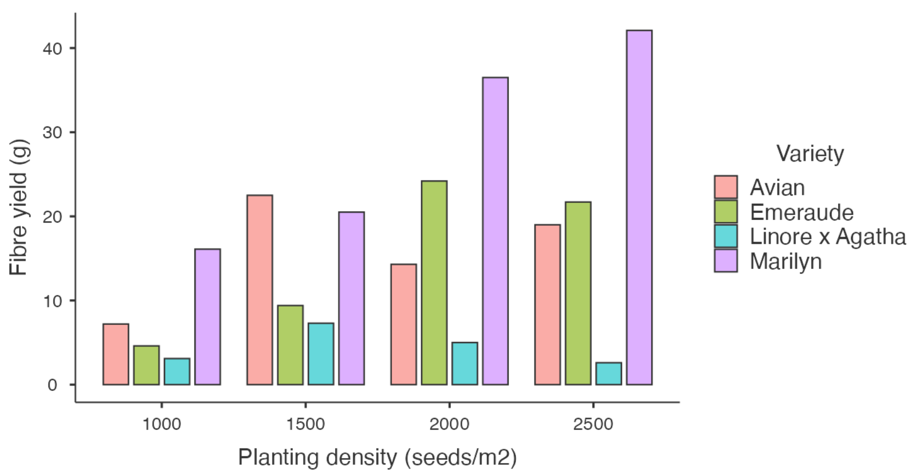

FIG. 5. Fibre yield measured in grams, separated by planting density and variety.

DISCUSSION

It was anticipated that lower planting densities would correlate with an increase in seed yield while higher planting densities would lead to higher fibre yield and stem lengths. This was not the case across all plots. While an increase in planting density was generally associated with an increase in both seed and fibre yield, there was an outlier identified for the plot Linore x Agatha grown at 2500 seeds/m^2. This plot produced very limited seed and fibre, as well as having reduced stem lengths. The data from this plot was excluded from all analysis to increase statistical significance.

There was a presumption of reduced accuracy in actual planting density due to hand-sowing seeds, however the variety Linore x Agatha had an unexpectedly low actual density across all plots (Table 4). Despite a very low planting density, Linore x Agatha produced the highest amount of seed. Other research has found that lower planting densities encourage branching of stems (Arslanoglu et al. 2022) and Linore x Agatha was the only variety that displayed branching (Fig. 6). At 1000 and 1500 seeds/m^2 approximately 41% of stems were

FIG. 6. Linore x Agatha branched stem.

branched. This decreased to 22% at 2000 seeds/m^2 and no branching was observed at 2500 seeds/m^2. This result supports previous research stating lower planting densities encourage seed production.

Table 4. Percentage yield of plots as a function of counted number of stems divided by the expected number of stems.

Plot	Counted Stems	Expected # of Stems	Percent Yield
Avian1000	248	160	155%
Avian1500	503	240	210%
Avian2000	401	320	125%
Avian2500	529	400	132%
Emer1000	136	160	85%
Emer1500	146	240	61%
Emer2000	391	320	122%
Emer2500	392	400	98%
LxA1000	40	160	25%
LxA1500	40	240	17%
LxA2000	79	320	25%
LxA2500	90	400	23%
Marilyn1000	187	160	117%
Marilyn1500	292	240	122%
Marilyn2000	402	320	126%
Marilyn2500	442	400	111%

Note. Expected number of stems was calculated by multiplying each planting density by 0.16, representing the experimental plot area as a portion of the total seeded area.

The cause of reduced germination for the variety Linore x Agatha is likely due to the age of the seed. Flax seed is known to have a half-life of two to four years (Ranson 2019). The exact age of the seed used in this experiment for all varieties was unknown. A germination test was not conducted prior to sowing to determine seed viability.

Approximately half of the plots produced a seed yield that would be considered within commercial ranges between 1300 and 2000 kg of seed/hectare (Table 5). One previous study looking into the effect of planting density on seed yield found that commercial ranges were only reached at a planting density of 2000 seeds/m^2 (Arslanoglu et al. 2022).

There is no research available exploring reasonable flax fibre yields for Fraser Valley or Canadian growing conditions. Research in Turkey found that planting densities between 1250 and 2000 seeds per m^2 will yield 1754 to 1986 kg of fibre per hectare (Arslanoglu et al. 2022). This experiment observed a strong varietal effect for fibre production and similar yields as Arslanoglu et al. were obtained only by the variety Marilyn (Table 5).

Table 5. Fibre and seed yield of plots converted into kilograms per hectare.

Plot	Seed Yield (kg/ha)	Fibre Yield (kg/ha)
Avian1000	671.4	450.0
Avian1500	1937.5*	1406.3
Avian2000	787.2	893.8
Avian2500	1190.2	1187.5
Emer1000	493.6	287.5
Emer1500	807.9	587.5
Emer2000	1703.2*	1512.5
Emer2500	1675.8*	1356.3
LxA1000	1638.3*	193.8
LxA1500	1940.6*	456.3
LxA2000	2281.0*	312.5
LxA2500	1080.9	162.5
Marilyn1000	621.7	1006.3
Marilyn1500	1002.6	1281.3
Marilyn2000	1639.4*	2281.3
Marilyn2500	1315.8*	2631.3

Note. *denotes seed yield values that are within commercial ranges.

Flax has a considerable root system, much of which remains in the soil after harvest (Fig. 7). Future research might explore the applications of flax in remediation efforts as flax is able to be grown in low-nutrient, disturbed environments with little irrigation after initial establishment (Ranson 2019). On farms, this could not only enhance diversity of crops, the incorporation of flax may also provide alternative streams of income from flaxseed, straw, and provided there is a local market, fibre.

FIG. 7. Flax root systems after harvesting by pulling (left) and after digging approximately 30 cm deep (right). Roots on the right have been washed.

CONCLUSION

This experiment demonstrated a positive correlation between planting density and seed yield, stem length, and fibre yield. Increased planting density resulted in higher seed yield across all varieties, indicating a potential for increased crop production through optimized planting strategies. While variety had a moderate effect on seed yield, Linore x Agatha exhibited significantly higher total seed yield compared to other varieties.

The experiment also revealed a strong positive correlation between planting density and stem length, with Emeraude displaying the longest stems. This suggests that denser planting may influence plant morphology, potentially impacting resource competition and overall plant development.

Variety significantly impacted fibre yield, with Marilyn demonstrating superior performance in fibre production compared to other varieties, particularly when compared to Linore x Agatha. These findings highlight the importance of selecting appropriate varieties and planting densities for specific yield goals, considering both seed and fibre production.

LITERATURE CITED

Allaby, R. G., G. W. Peterson, D. A. Merriwether, and Y.-B. Fu. 2005. Evidence of the Domestication History of Flax (*Linum usitatissimum L.*) from Genetic Diversity of the sad2 Locus. Theoretical and Applied Genetics 112:58–65.

Arslanoglu, Ş. F., S. Sert, H. Alp Şahin, S. Aytaç, and A. El Sabagh. 2022. Yield and Yield Criteria of Flax Fiber (*Linum usititassimum L.*) as Influenced by Different Plant Densities. Sustainability 14.

Beckman, C. 2024. Canada: Outlook for Principal Field Crops, 2024-10-21. Pages 7–8 Agriculture and Agri-Food Canada. Government of Canada.

Canadian Food Inspection Agency. 2012, March. The Biology of *Linum usitatissimum L.* (Flax). Government of Canada. https://inspection.canada.ca/en/plant-varieties/plants-novel-traits/applicants/directive-94-08/biology-documents/linum-usitatissimum-flax.

Deckers, J., S. Manshoven, and L. F. Mortensen. 2023. The Role of Bio-based Textile Fibres in a Circular and Sustainable Textiles System. Research Gate. European Environment Information and Observation Network.

Eldaiem, A. 2015. Response of Some Flax Genotypes under Different Plant Densities. Journal of Plant Production 6:1247–1261.

Fox, J., & Weisberg, S. 2020. *car: Companion to Applied Regression*. [R package]. Retrieved from https://cran.r-project.org/package=car.

Jhala, A. J., and L. M. Hall. 2010. Flax (*Linum usitatissimum L.*): Current Uses and Future Applications. Australian Journal of Basic and Applied Sciences 4:4304–4312.

Jones, J., T. Higham, R. Oldfield, T. O'Connor, and S. Buckley. 2014. Evidence for Prehistoric Origins of Egyptian Mummification in Late Neolithic Burials. PLoS ONE 9:e103608.

Kalmakoff, J. 2023. The Flax Mill at Petrofka. Doukhobor Heritage. https://doukhobor.org/author/jkalmakoff/page/2/

Kenaschuk, E. O., and G. G. Rowland. 1995. Flax. Pages 173–180 Harvest of Gold: The History of Field Crop Breeding in Canada. University Extension Press, Univ. of Saskatchewan, Saskatoon, Sask.

Kennedy, R. 1996. Producing Fiber Flax Using Modern Machinery and Field Retting. Master's Dissertation, Oregon State University.

Lenth, R. 2020. emmeans: Estimated Marginal Means, aka Least-Squares Means. [R package]. Retrieved from https://cran.r-project.org/package=emmeans.

Manitoba Flax Growers Association. (n.d.). Growing Flax Profitably - Quick Tips Guide. Flax Council of Canada. https://mbcropalliance.ca/wp-content/uploads/2023/03/MFGA-Quick-Tips-Guide.pdf

Millam, S., B. Obert, and A. Pretova. 2005. Plant Cell and Biotechnology Studies in *Linum Usitatissimum* – A Review. Journal of Plant Biotechnology 82:93–103.

Ranson, R. 2019. Homegrown Linen: Transforming Flaxseed into Fibre. Crowning Hen Books, Victoria, British Columbia.

Reda, A., T. Dargent, L. Thomas, S. Grec, L. Buchaillot, and S. Arscott. 2024. The Influence of Dew Retting on the Mechanical Properties of Single Flax Fibers Measured Using Micromechanical and Nanomechanical Approaches. Fibers 12.

R Core Team. 2021. R: A Language and Environment for Statistical Computing. (Version 4.1) [Computer software]. Retrieved from https://cran.r-project.org. (R packages retrieved from MRAN snapshot 2022-01-01).

Rowland, G. G. 2013. Flax. The Canadian Encyclopedia. https://www.thecanadianencyclopedia.ca/en/article/flax.

Saskatchewan Flax Development Commission. (n.d.). Industry Overview. https://www.saskflax.com/industry/index.php.

Tancock, K. 2024. From Field to Frock, Clothing Made from Canadian Flax and Linen is Full of Promise. https://www.theglobeandmail.com/life/style/article-flax-linen-clothing-natural-fibres-canada/.

The jamovi project. 2022. jamovi. (Version 2.3) [Computer Software]. Retrieved from https://www.jamovi.org.