J. Agronomy & Crop Science **188**, 350—356 (2002)
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ISSN 0931-2250

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Comparison of European Fibre Flax (*Linum usitatissimum*) Cultivars under Eastern Canadian Growing Conditions

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Received December 21, 2001; accepted February 5, 2002

Abstract

Renewed interest in natural fibres, decreasing subsidies to European producers, and high production costs have led the move to reintroduce fibre flax (*Linum usitatissimum* L.) production into eastern Canada. Research was conducted at the Macdonald Campus of McGill University, Québec, Canada in 1998 and 1999 and at Winchester and Kemptville, Ontario, Canada in 1998, to assess the performance of seven European fibre flax cultivars. Parameters evaluated included plant density, branching ratio, stem diameter, fresh and dry biomass, and mean harvest height. Data from all sites and years were subjected to a pooled ANOVA where appropriate. The cultivar main effect was detected for all parameters measured, with the exception of mean fresh weight and mean height at harvest. There was also a site main effect for all parameters except for branching ratio. A cultivar–site interaction was found for all parameters except for mean stem diameter and mean dry weight. Results indicate a strong potential for producing fibre flax in eastern Canada using currently available European cultivars.

Key words: cultivar — fibre — flax — *Linum usitatissimum*

Introduction

Fibre flax (*Linum usitatissimum* L.) is an ancient crop that is currently enjoying a resurgence of interest in various parts of the world (Kozlowski and Manys 1994, Smeder and Liljedahl 1996). Fibre flax was an economically important crop in eastern Canada and parts of the United States until the end of World War II (Stephens 1997a, Robert 1998). During the postwar years, loss of government subsidies, competition from newly developed synthetic fibres, and technological advancements promoting the adoption of other natural fibres helped to reduce and eventually end fibre flax production in North America (Roseberg 1996, Stephens 1997a). Not surprisingly, little basic or applied research on this crop was carried out in North America between the 1950s and the late 1980s. During those years, however, fibre flax has maintained a degree of popularity in Western Europe, where breeding programmes and technological improvements have led to highly efficient production systems (Roseberg 1996).

Linen derived from fibre flax enjoys some degree of niche market status. Increased interest is being observed from a variety of manufacturing and industrial sectors in the fibres derived from flax (Smeder and Liljedahl 1996). Although the reasons behind the increased demand for flax fibres are clear, there has been some uncertainty as to where the necessary increase in production will occur. Although fibre flax is currently being produced in regions other than Western Europe, notably in Eastern Europe, China, and Brazil, local production methods are generally obsolete with abundant and inexpensive human labour only partially compensating for outdated local technologies (Roseberg 1996). Thus, North American fibre flax producers may be well positioned to reassume an important role in the future production of this commodity. North America retains considerable land for agricultural production and more technologically advanced production systems compared with other parts of the world. A number of important fibre flax production concerns need to be addressed prior to the large-scale reintroduction of this crop into the eastern Canadian provinces of Québec and Ontario. One critical area that requires immediate attention and is thus the objective of this research is a comparison of the growth potential and suitability of widely grown European cultivars under eastern Canadian conditions.

Materials and Methods

The research was carried out during 1998 and 1999 at the Macdonald Campus of McGill University in Ste. Anne-de-Bellevue, Québec, Canada and in 1998 at Kemptville and Winchester, in eastern Ontario, Canada. The soil type at the Macdonald site in 1998 (Mac98) was a St. Bernard loam (well drained, Melanic Brunisol; pH 6.1), and was sown to barley (*Hordeum vulgare* L.) in 1997. The Kemptville site in 1998 was located on a Grenville sandy loam soil (well drained, Melanic Brunisol; pH 6.9) at the Kemptville College Agronomy Research Station in Kemptville, Ontario, which had been sown to wheat (*Triticum aestivum* L.) in 1997. The Winchester site was located on a North Gower clay loam soil (slightly imperfectly drained, Gray Brown Podzolic; pH 6.4) at the Kemptville College Agronomy Research Station located in Winchester, Ontario, and was in corn (*Zea mays* L.) the previous year. The 1999 field trial at Macdonald (Mac99) was located on a St. Amable loamy sand soil (well drained, Gleyified Humo Ferric Podzol; pH 5.8), which was fallow in 1998.

Seven fibre flax cultivars, Argos, Ariane, Belinka, Diane, Escalina, Hermes and Viking, were compared in a series of four experiments during 1998 and 1999, for a total of four site-years. Plots were arranged in a randomized complete block design with four replications, except for the Winchester trial where three replications were used. Experimental plots measured 7.5 m^2, except for the Kemptville trial where they measured 12 m^2. Land preparation at all sites in both years included autumn moldboard ploughing, spring discing and harrowing prior to seeding. At all sites, 200 kg ha^{-1} of fertilizer (N-P_2O_5-K_2O) was broadcast and incorporated prior to seeding.

Differential seeding rates were used based on seed size and preliminary germination tests, to provide population densities of 2000 plants m^{-2}. In 1998 at the Macdonald site, a custom forage seeder (Fabro Industries, Ste-Marthe, QC) having an 18-cm row spacing was used for seeding on 30 April. At the Winchester site, a Carter forage plot seeder (Carter MFG Co. Inc., Brookston, IN) with a row spacing of 16 cm was used, and plots were seeded on 1 May. At the Kemptville site, a turf plot seeder (broadcast) was used for seeding on 5 May, while a Carter plot seeder with 18-cm row spacing was used to seed plots on 6 May in the Mac99 trial.

In 1998 at the Macdonald site, quackgrass [*Elytrigia repens* (L.) Nevski] control was achieved by spraying plots 21 days after seeding (DAS) with fluazifop-p-butyl + mineral oil surfactant at a rate of 0.7 kg a.i. ha^{-1} + 0.5 % (v/v). Bentazon (BASF Canada Inc., London, ON) was applied at a rate of 1.08 kg a.i. ha^{-1} for the control of emerged broadleaf weed species 1 week later. The Winchester site was heavily infested with wild mustard [*Brassica kaber* (DC.) L.C. Wheeler] and was hand-weeded 28 and 36 DAS. The Kemptville site did not require herbicide treatment. In 1999, the Macdonald site was sprayed with bromoxynil/MCPA MCPA (4-chloro-2-methylphenoxy acetic acid) (+ sethoxydim (BASF Canada Inc.) + mineral oil surfactant at a rate of 560 g a.i. ha^{-1} + 276 g a.i. - ha^{-1} + 0.5 % v/v for the control of broadleaf and grass weeds 32 DAS. Herbicide rates were based on Ontario recommendations for oilseed flax (Anonymous 1997).

At all sites, stem diameters were measured prior to harvest on a random subsample of 50 plants per plot using an electronic digital caliper (Marathon Electronics, Belleville, ON), approximately 2 cm above soil level. The mean stem diameter for each plot was used in statistical analyses. Plant densities in each plot were assessed twice within two 0.5-m^2 quadrats at 42 DAS. Within each of these quadrats, the number of plants with branches on the lower 50 cm of stem was also noted. Branch ratio was calculated as the number of plants with branches divided by the total number of plants in the sample or plot. Plant density data and branching ratio values were square-root and square-root + 1-transformed, respectively, in order to satisfy the normality requirement of ANOVA (Gomez and Gomez 1984). Data collected also included average plant height at time of harvest (i.e. measured from soil level to the uppermost point of each plant and by holding approximately 8–12 plants together against a meter-stick and estimating their average height). The plot average was the mean of two observations.

Fresh biomass was determined by manually uprooting plants when they had shed two-thirds of their leaves during the yellow stage, within a randomly placed 0.5-m^2 quadrat in each experimental plot. This procedure was carried out at approximately 79–84 DAS. Dry biomass was obtained by oven-drying a 200-g subsample of fresh tissue to a constant weight at 65 °C. There was no decapsulation process prior to the determinations of fresh and dry biomass.

To determine main effects and interactions attributable to cultivar and/or site-year on the parameters described above, data were subjected to ANOVA using the GLM procedure in SAS (SAS Institute 1985). Bartlett's test for homogeneity of variance was applied to all site-years. Those site-years that did not meet the homogeneity of variance requirement were not included in the pooled analyses. Significant results ($P < 0.05$) were then subjected to a Tukey's HSD means comparison procedure (Motulsky 1995) to identify specific differences among cultivars or site-years.

Results and Discussion

Fresh biomass yield

Fresh biomass yield was evaluated at all four site-years; however, tests for homogeneity of variance indicated the variability at the Kemptville location to be too large and thus these data were omitted from the pooled analysis. There were no significant ($P > 0.05$) differences amongst cultivars in harvest

Table 1: Comparison of cultivar means across cultivars and sites

	Mean plant density (m^{-2})	Mean branching ratio	Mean stem diameter (mm)	Mean fresh weight (t ha^{-1})	Mean dry weight (t ha^{-1})	Mean plant harvest height (cm)
Cultivar						
Argos	1542 a	1.01 b	1.64 ab	18.3	3.8 ab	79.49
Ariane	1603 a	1.01 b	1.59 b	18.9	3.7 b	77.65
Belinka	984 b	1.04 a	1.80 a	15.7	4.1 ab	79.35
Diane	1579 a	1.01 b	1.69 ab	20.6	3.7 b	81.93
Escalina	1550 a	1.01 b	1.65 ab	18.1	3.8 ab	77.03
Hermes	1649 a	1.01 b	1.64 ab	16.0	4.0 ab	78.76
Viking	1864 a	1.01 b	1.53 b	15.6	4.3 a	73.67
m.s.d.	558	0.03	0.2	–	0.6	–
Site						
Winchester	1168 b	–	1.61 bc	19.8 a	4.4 a	86.58 a
Kemptville	1461 ab	1.01	1.68 ab	–	–	–
Mac98	1706 a	1.02	1.80 a	19.4 a	4.3 a	80.40 a
Mac99	1820 a	1.00	1.51 c	13.7 b	3.0 b	67.81 b
m.s.d.	438	–	0.13	5.6	1.3	12.59
Significance						
Cultivar	**	**	*	ns	*	ns
Site	**	ns	***	**	***	***
Site × cultivar	**	*	ns	***	ns	***

Values within a column followed by the same letter(s) do not differ according to Tukey's HSD test, $P < 0.05$.
m.s.d., minimum significant difference.

Mean plant density and stem diameter include all four sites. Mean branching ratio includes both Macdonald sites and the Kemptville site. Mean fresh and dry weights include both Macdonald sites and the Winchester site. Mean plant harvest height includes both Macdonald sites and the Winchester site. Mean branching ratio includes both Macdonald sites and the Kemptville site.

*, **, ***Significant at $P < 0.05$, $P < 0.01$ and $P < 0.001$ levels of probability, respectively.
ns, not significant.

fresh weight at the three sites (Table 1). Fresh weights ranged from 20.6 to 15.6 t ha^{-1} for the cultivars Diane and Viking, respectively (Table 1). Stephens (1996, 1997b) reported a mean retted straw yield of 7 t ha^{-1} from trials at the Connecticut Agricultural Experiment Station, Storrs, CT, from 1992 to 1995. Our yields were also considerably greater than yields reported by Rowland (1980) in fibre flax trials in Saskatchewan, Canada. Assuming a 33 % fresh weight loss following retting (Sultana 1983, Stephens 1997a), and potentially 25 % of the fresh weight converted to fibre (Roseberg 1996), the cultivar Diane yielded 6.67 t ha^{-1} of retted straw and 5 t ha^{-1} of fibre, levels considerably greater than the Western European average of 1.5–2 t ha^{-1} (Roseberg 1996). Using the above assumptions, the popular French cultivar, Ariane, yielded 6 t ha^{-1} of retted straw and 4.6 t ha^{-1} of fibre. These calculated values are only estimates, and preliminary on-farm data collected by Fibrex Québec Inc. personnel during 1999 suggest yields to correspond more closely to Western European levels (T. Niedermann, Fibrex Québec Inc., Salaberry-de-Valleyfield, Québec, Canada, personal communication).

A highly significant ($P < 0.01$) effect of site-year on fresh biomass yield was also observed (Table 1). Fresh biomass yield at the Mac99 site was 13.7 t ha^{-1} compared with 19.4 t ha^{-1} at the Mac98 site, 19.8 t ha^{-1} at the Winchester site, and 19.4 t ha^{-1} at the Kemptville site (Table 1). These differences in yield were probably attributable to the unusually low rainfall received in the spring of 1999, which accelerated flax development and maturation (Sultana 1983).

A highly significant ($P < 0.001$) cultivar by site-year interaction, where some flax cultivars yielded greater fresh biomass at one site-year than another, was also found (Table 1). For instance, the cultivar Escalina yielded 21.4 t ha^{-1} at the Mac98 site, and ~ 17.6 t ha^{-1} at both the Kemptville and Winchester sites, whereas the cultivar Argos yielded ~ 21.5 t ha^{-1} at the Mac98 site and Kemptville sites, and 17.2 t ha^{-1} at the Winchester site

(Table 1). These effects may have been a result of variability in soil types amongst the sites. Berger 1969) suggested that medium-heavy loams or clay-loams are optimal for fibre flax production, while Robinson and Cook (1931) concluded that fibre flax yields on heavier soils were consistently greater than on lighter soils. Research findings in Québec suggest that lighter soils can allow a more rapid growth of fibre flax (Robert 1998).

Dry biomass yield

Dry biomass yield was evaluated at all four site-years, although data for Kemptville are not included because of high variability. Dry weight varied significantly ($P < 0.05$) among cultivars, with Viking yielding 4.3 t ha^{-1}, and Ariane and Diane yielding only 3.7 t ha^{-1} (Table 1). Sultana (1983) reported that fibre flax dry biomass yield was on average 38 % of the fresh biomass yield. Although highly variable, our findings indicate that the dry biomass yield was approximately 25 % of the fresh weight. Robert (1998) also reported greater dry biomass yields in Québec compared with yields obtained in Western Europe.

Site-year had a highly significant ($P < 0.001$) effect on dry biomass yield (Table 1). The Mac99 site yielded less dry biomass (3.0 t ha^{-1}) than the Mac98 and Winchester sites (4.3 and 4.4 t ha^{-1}, respectively) (Table 1). As with fresh biomass production, lack of moisture in the spring of 1999 may have accelerated physiological maturity, thus limiting overall growth (Sultana 1983, Hassan and Leitch 2001). Hassan and Leitch (2001) observed the opposite effect on linseed flax, noting that moist, cool conditions probably prolonged the vegetative growth of the plants. There was no cultivar by site-year interaction effect on dry biomass yield (Table 1). This finding was unexpected since these two factors produced a highly significant interaction for fresh biomass yield. Differences amongst cultivars in their ability to partition carbon into dry biomass during periods of low moisture availability may explain the observed variation.

Plant density

There was a highly significant ($P < 0.01$) cultivar effect on plant density, with Belinka having the lowest (984 plants m^{-2}) population density (Table 1). Plant densities did not vary significantly ($P > 0.05$) among the other cultivars, and ranged from 1542 to 1864 plants m^{-2} (Table 1). Removing Belinka from the analysis resulted in no significant differences in plant density amongst cultivars. The establishment of Belinka in the field may have been hampered by its relatively small seed size and poor germination compared with the other cultivars used (Couture 1999). Seeding rates were adjusted for Belinka only, because of exceptionally low seed weights [4.9 g (1000 seeds)$^{-1}$ vs. a mean of 6.04 g for all other cultivars] and reduced germination potential (69 % vs. 97.9 %) (Couture 1999). Despite this procedure, Belinka populations were still very low at all sites. Plant population densities in our study were generally lower than the optimal level of 1800 plants m^{-2} suggested by Lockhart and Wiseman (1988). The low population densities observed for Belinka may have also contributed to the significantly higher branching ratio values found at two of the three sites (see below).

There was a site-year effect on plant density, with the Winchester site (1168 plants m^{-2}) having significantly ($P < 0.01$) lower plant densities than both Mac sites ($\sim$ 1760 plants m^{-2}) (Table 1). The Kemptville site had intermediate population densities averaging 1461 plants m^{-2}. These differences in population densities amongst the sites may have been caused by managerial rather than environmental or edaphic factors. Population densities at the Winchester site were probably lower as a result of severe infestation by wild mustard followed by hand-weeding. Plant populations were often lower at the Kemptville site than at the Mac sites, probably an effect of differences in seeding methods (i.e. broadcast vs. narrow rows). These findings indicate that, for broadcast establishment, increased seeding rates are required.

There was also a highly significant ($P < 0.01$) interaction effect of cultivar by site-year on plant density (Table 1). The cultivar Argos, for example, averaged over 2000 plants m^{-2} at the Mac99 site and 1100 plants m^{-2} at the Winchester site (Table 1). It is possible that some cultivars did not respond equally to the two seeding regimes (i.e. broadcast vs. rows) and/or to hand-weeding. Populations of Argos were lowest in the hand-weeded plots at Winchester in 1998 compared with the Mac98 and Kemptville plots, while Diane populations were greater at the Winchester site in 1998 than at the Mac98 and Kemptville sites. Belinka populations were greatest in the broadcast-seeded plots at Kemptville. Optimal plant population densities are essential for the production of highly valuable longer fibres (Hocking et al. 1987, Easson and Long 1992, Lafond 1993). The intense intraspecific competition between plants at high densities is known to stimulate plants to grow tall with little or limited branching.

Branching ratio

Branching ratio values differed significantly ($P < 0.01$) amongst cultivars, with plants of the cultivar Belinka having 4 times greater branching than all other cultivars. The branching ratio in the other six cultivars did not differ significantly ($P > 0.05$) (Table 1). Stephens (1997a) suggested that flax fibres can extend from the below-ground portion of the plant up to the first branch, and that the longer the fibres, the higher quality they may be considered (Smeder and Liljedahl 1996). Hence, to produce large quantities of long fibres in each plant, branching must be minimized. The sowing of fibre flax at high densities is one practical method of limiting branching in this crop.

Cultivars were consistent in their branching patterns both within sites and across site-years (Table 1). This is not surprising given that plant breeding programmes have focused on minimizing this feature for many years. Moreover, the limited branching of fibre flax cultivars is one of the main characteristics distinguishing them from oilseed flax cultivars (Lockhart and Wiseman 1988). There was an interaction effect observed between cultivar and site-year on branching ratio (Table 1). The cultivar Belinka had a very high branching ratio at the Mac98 site, almost twice the ratio found at the Kemptville site, while an even lower branching ratio was obtained at the Mac99 site (Table 1). This variability in branching ratio is difficult to explain, especially as plants in all trials were subjected to the same fertilizer regime and cultural practices. Branching patterns in flax may also be affected by weather patterns and moisture availability. Hassan and Leitch (2001) noted that moisture stress led to a decrease in branching in their oilseed flax trials in Wales.

Stem diameter

Mean stem diameters differed significantly ($P < 0.05$) amongst cultivars at all locations, with plants of Belinka having the largest stem diameters (1.8 mm) and plants of Viking having the smallest diameters (1.53 mm) (Table 1). Stem diameter has been linked to fibre quality (Hocking et al. 1987). Although thinner stems may contain slightly less fibre, the fibres tend to be less coarse and therefore easier to ret. The retting of less coarse fibres limits losses in quality that are commonly observed with the over-retting of coarse straw (Stephens 1996). Moreover, lodging, which is a serious problem in this crop, has often been associated with thicker stems and poor fertility management (i.e. excess nitrogen) (Berger 1969, Easson and Long 1992). In contrast, thicker stems may contain more fibre cells, leading to a higher overall fibre content (Hocking et al. 1987).

In this study, there was a highly significant ($P < 0.001$) effect of site on stem diameter (Table 1). Plants at the Mac98 site had the greatest mean stem diameter (1.8 mm), while plants at the Mac99 site had the lowest stem diameters (1.51 mm). Surprisingly, Easson and Long (1992) found that higher flax planting densities and increased nitrogen availability had only a limited effect on overall fibre quality. Sankari (2000) reported that stem diameter in oilseed flax may have a significant effect on stem yield. In that study, cv. Gold Merchant had the lowest stand densities yet yielded the greatest quantities of stem material. In the present work, Belinka had significantly lower stand densities than all other cultivars and significantly higher stem diameters. However, there were no significant ($P > 0.05$) differences in fresh or dry biomass. The likely conclusion is that the lower densities in the Belinka plots resulted in greater stem diameters leading to greater biomass production.

Plant height

Variability in plant height was high at the Kemptville site, and therefore these data were excluded from the pooled analysis. Mean plant height at harvest did not differ significantly ($P > 0.05$) amongst cultivars at the Winchester, Mac98 and Mac99 sites (Table 1). Heights ranged from 73.7 cm (Viking) to 81.9 cm (Diane) (Table 1). Soil fertility can have a large impact on plant height in oilseed flax (Lafond 1993) and increased row spacing in flax results in greater plant heights (Easson and Long 1992, Lafond 1993). As row spacing increases, plant density within rows also increases, and is consistent with the view that higher density increases plant height and restricts branching. Taller plants are desirable as the highest quality fibres extend almost the entire length of the plant, and can reach over 70 cm in length. There was a highly significant (P < 0.001) effect of site-year on mean height at harvest (Table 1). Mean height at the Mac99 site was 67.8 cm, compared with 80.4 cm at the Mac98 site and 86.6 cm at the Winchester site. Although not included in the pooled analyses, mean plant height at the Kemptville site was in excess of 97 cm (Table 1). This result contradicts earlier findings that greater flax population densities lead to taller plants. It is likely that the lack of moisture and high temperatures in 1998 accelerated the maturation process in these plants (Sultana 1983). Differences in soil structure and fertility amongst sites may also have influenced plant height.

A highly significant (P < 0.001) interaction between cultivar and site was also apparent (Table 1). The cultivar Escalina was shorter than the cultivar Ariane at the Winchester site, taller at the Mac98 site, and shorter at the Mac99 site (Table 1). Escalina plants were substantially taller than Viking plants at the Mac98 and Winchester sites, but Viking plants were taller at the Mac99 site. These variable results are difficult to explain and suggest that these cultivars differ in their response to different environments (Couture 1999).

Conclusion

Findings from this research indicate that fibre flax can be grown successfully in eastern Canada, but, like any other crop, several abiotic (e.g. climate and soil properties) and managerial (e.g. seeding rate, row spacing and cultivar selection) factors can influence growth and productivity. Scheer-Triebel et al. (2000) recently reported that it may be possible to cultivate flax for the dual purposes of seed and fibre, as harvesting flax at capsule maturity did not affect fibre quality. Fresh and dry biomass yields obtained in our field plot trials were exceptionally high and suggested a substantial biomass production potential for fibre flax in eastern Canada relative to production levels obtained in Western Europe. Although biomass production may be positively correlated to flax fibre production, it may not necessarily be indicative of fibre quality. When the Belinka cultivar was excluded from the analyses, the only significant effect of cultivar on the parameters measured was detected for dry biomass. However, dry biomass production may not be an accurate enough indicator of fibre quality to permit firm cultivar recommendations for eastern Canada. The relationship between fibre quantity and quality requires further study, especially under eastern Canadian growing conditions.

Zusammenfassung

Vergleich zwischen Europaischen Flachssorten (*Linum usitatissimum*) unter Ostkanadischen Anbaubedingungen

Erneutes Interesse an natürlichen Fasern sowie die sinkenden Subventionen der europäischen Erzeuger bei hohen Produktionskosten haben dazu geführt, den Faserflachsanbau (*Linum usitatissimum* L.) im östlichem Kanada wieder einzuführen. Eine Untersuchung wurde auf dem Macdonald Campus von der McGill Universität Québec in 1998 und 1999 und in Winchester sowie Kemptville, Ontario in 1998 durchgeführt, um die Leistung von sieben europäischen Faserflachs Sorten zu beurteilen.

Parameter beurteilten eingeschlossene Pflanzendichte, verzweigendes Verhältnis, Stammdurchmesser, frische und trockene Biomasse und gemeine Erntehöhe. Daten von allen Standorten und Jahren wurden einem zusammengelegten ANOVA unterzogen wo aneignen sich. Die Cultivar Hauptwirkung wurde für alle mit Ausnahme gemeiner frischen Gewichts und gemeiner Höhe an Ernte gemessenen Parameter wahrgenommen. Es gab auch eine Standorthauptleitungswirkung für alle Parameter außer verzweigendem Verhältnis. Eine Cultivar × Standortinteraktion wurde für alle Parameter gefunden, außer gemeine Stammdurchmesser und Mittel Gewicht trocknen. Ergebnisse zeigen ein starkes Potential an, Faserflachs in östlichem Kanada mit Hilfe von gegenwärtig verfügbarem europäischem Cultivars zu produzieren.

Acknowledgements

This work was supported by a research grant from the Conseil des Recherches en Pêche et en Agroalimentaire du Québec (CORPAQ) dans le cadre du Programme de Recherche de l'Entente auxiliare Canada-Québec sur le développement agroalimentaire.

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