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Seeding Date and Performance of Specialty Oilseeds in North Dakota

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Interest in oilseeds and oilseed crop production has recently been heightened by the growing potential for biofuels. Traditional oil seed crops, such as sunflower (*Helianthus annuus* L., Asteraceae), flax (*Linum usitatissimum* L., Linaceae), and more recently canola (*Brassica napus* L., Brassicaceae) have become crops of major importance in the region. The key to their production success is multi-faceted, but an important factor is the development of good agronomic production practices. Borage (*Borago officinalis* L., Boraginaceae) and evening primrose (*Oenothera biennis* L., Onagraceae) oils are two of the primary sources of gamma linolenic acid, C18:3 (GLA) and are in demand for nutritional, medicinal, and cosmetic markets (Simon et al. 1990). Healthy adults will typically produce GLA from dietary linolenic acid within the body, but this synthesis can be negatively affected during illness and with increased age. Pharmacologically, GLA is used for the treatment of atopic eczema and has some anti-viral and anti-cancer properties (Napier and Michaelson 2001).

BORAGE

Borage has had limited production in the United States (US) and peak production occurred in North Dakota, in 1999 (Berti et al. 2002). The main production areas for borage are Canada, Chile, and the United Kingdom (UK) (Nicholls 1996). Borage has a volatile market due to fluctuations in supply, often influenced by early killing frosts that reduce seed yield (Berti et al. 2002). Berti and Schneiter (1993) indicated borage as having "agronomic potential" in North Dakota and Minnesota; yield limitations were associated with reliance on native pollinators and seed shattering. Seed yields across ten environments ranged from 150 to 375 kg ha^{-1} (Berti 1993).

Seed oil content ranges from 290 to 380 g kg^{-1} with a GLA concentration of 17% to 25% (Simon et al. 1990). Johnson et al. (2005) reported greater GLA levels when borage was grown at a northern location compared with two southern locations in North Dakota. Cooler temperatures at the northern location during reproductive development were beneficial to seed GLA content.

EVENING PRIMROSE

Evening primrose is native to North America and has had limited commercial production in New Zealand, the US, and the UK. Many parts of the plant have been used in folk medicine, but current interest is in the seed oil (Berti 1993). Biennial evening primrose was evaluated in North Dakota by Berti (1993) and produced yields between 571 and 1743 kg ha^{-1}. Belisle (1990) reported that a yield of 700 kg ha^{-1} would be sufficient for commercial production in Canada. Evening primrose seed is desirable due to its relatively high GLA content. Seed oil content ranges from 180 to 250 g kg^{-1}, and is approximately 9% GLA (Christie 1999).

CAMELINA

Camelina (*Camelina sativa* L., Brassicaceae) known as "false flax," is a low input annual or winter annual crop. Camelina is adapted to growing under the same general climatic conditions as flax and canola (Putnam et al. 1993). North Dakota, which leads the nation in flax and canola production, should have a high potential for camelina production as well. An evaluation of camelina by Berti and Schneiter (1993) in North Dakota and Minnesota rated it as a crop with "agronomic potential," although there were issues with stand establishment, acceptable yields were obtained (600 kg ha^{-1}). In Rosemount, Minnesota, Putnam et al. (1993) reported camelina yielded between 600 and 1700 kg ha^{-1}. Characteristics such as frost and drought tolerance (Putnam et al. 1993), low fertility requirements, and allelopathic properties (Lovett and Duffield 1981) make camelina an attractive crop.

Camelina has a seed oil content ranging from 290 to 430 g kg^{-1} (Putnam et al. 1993; Vollmann et al. 1996; Zubr 1997), with a typical oil composition of the fatty acids oleic (C18:1), linoleic (C18:2), alpha linolenic (C18:3), and eicosatrienoic (C20:1). The oil has a wide range of application including human consumption in baking, cooking, and frying, and uses for industrial soaps and varnishes, cosmetic oils and creams, and biofuels (Zubr

1997). As a biofuel, camelina methyl-ester had similar properties and expected yields as canola methyl-ester (Frohlich and Rice 2005). The meal by-product from oil extraction has potential for use in animal feed. Feed augmented with camelina meal has been shown to increase omega-3 fatty acid content in meat and eggs (Peiretti et al. 2006; Rokka et al. 2002). Consumption of dietary omega-3 fatty acid, through enriched foods or directly, can lead to positive health effects in humans and animals (Zubr 1997).

CUPHEA

Cuphea (*Cuphea* spp. L., Lythraceae) is a potential new source of medium-chain fatty acids (MCFA). The seeds of this plant are abundant in caprylic (C8:0), capric (C10:0), lauric (C12:0), and myristic (C14:0) fatty acids that are used in the production of lubricants, soaps, detergents, personal-care products, and cosmetics (Gesch et al. 2002). These MCFAs are currently being supplied to US industries by imported coconut (*Cocos nucifera* L., Arecaceae) and palm kernel (*Elaeis guineensis* Jacq., Arecaceae) oils from Southeast Asia (Knapp 1993). In 2004, imports to the US of palm kernel oil alone were 2.5×10^6 tonnes (t) at a cost of $\$161\times10^6$ (UNFAO 2004). With its adaptation to temperate climates, cuphea has the potential to be a domestic and non-tropical source of MCFA (Knapp 1993) and could open a significant new market to producers.

Cuphea genotype PSR23, derived from the cross between *C. lanceolata* and *C. viscosissima,* exhibits reduced seed shattering (Knapp and Crane 2000) and has been the focus of agronomic evaluation and commercialization in the Midwest (Gesch et al. 2002). A study by Forcella et al. (2005), in central Minnesota, showed that cuphea has potential for yields of more then 1000 kg ha^{-1} when planted in early- to mid-May at an established stand of 1 to 2 million plants/ha. However, actual yields of cuphea ranged from 96 to 657 kg ha^{-1} in both the 2002 and 2003 growing seasons (Forcella et al. 2005).

Commercial cuphea production has been limited to the North Central region of the United States. In 2004, the USDA-ARS North Central Soil Conservation Research Laboratory at Morris, Minnesota, in conjunction with Technology Crops International, and with support from Proctor and Gamble Company had approximately 17 ha of harvestable on-farm cuphea production. The on-farm yields ranged from 78 to 744 kg ha^{-1} with an average of 444 kg ha^{-1} (Gesch et al. 2006).

MATERIALS AND METHODS

The seeding date study was conducted in the 2005 growing season at a North Dakota State University research site in the Red River Valley near Prosper, North Dakota (46°96'N, 97°01'W, elevation 275 m). A single seeding date was planted at a site in North Central North Dakota at Minot (48°23'N, 101°30'W, elevation 518 m). The experimental design was a randomized complete block with a split-plot arrangement and four replications. The main plot was seeding date, with two target seeding dates of late May (D1) and mid-June (D2). The subplot consisted of the four new crops: borage, camelina, cuphea, and evening primrose, and two conventional crops: crambe (*Crambe abyssinica* Hochst., Brassicaceae) and soybean [*Glycine max* (L.) Merr., Fabaceae]. Each experimental unit consisted of six rows spaced 30 cm apart and 4.5 m in length. The seeding rates used were 26, 6, 28, 24, and 4.5 kg ha^{-1} for borage, camelina, crambe, cuphea, and evening primrose, respectively, and 450,000 plants ha^{-1} for soybean. The new crops and crambe were planted at a depth of 13 mm while soybean was planted at a depth of 25 to 35 mm. The previous crop at both research sites was hard red spring wheat (*Triticum aestivum* L., Poaceae).

Plots of camelina, crambe, and soybean were harvested with direct combining after reaching physiological and harvest maturity. Cuphea was harvested by direct combining after a killing frost. Borage and evening primrose were hand swathed and threshed 10 to 14 days later with a plot combine. All seed was air dried at 45°C after harvest and cleaned before any further analysis. Seed yield was measure in g/plot and converted to kg/ha. Seed oil content was determined with a Newport 4000 Nuclear Magnetic Resonance (NMR) Analyzer, Oxford Institute Limited. Samples were dried in an oven at 110°C for 3 hr and cooled to room temperature before the analysis to equilibrate seed moisture content.

Fatty acid compositions of the oils were determined with gas chromatography following standard AOCS methods (Ackman 2002). The statistical analysis was performed by ANOVA (SAS 2004) with character means separation determined by using *F*-protected LSD comparison at the $P \leq 0.05$ level of significance.

RESULTS AND DISCUSSION

Climatic Conditions

At Prosper average monthly temperatures were 20°C for June, 21°C for July, 18°C and for August, and 17°C for September. Precipitation was above normal during June at 161 mm, however, only 14 mm of precipitation occurred after 15 June. July was the driest month of the season with only 34 mm of precipitation, while August and September had precipitation amounts of 113 mm and 104 mm respectively.

At Minot average monthly temperatures was 20°C for June, 21°C for July, and 19°C for August. September was cooler in Minot then at Prosper with an average temperature of 15°C. At Minot, precipitation of 124 mm during June was above normal and more uniformly distributed throughout the month than at Prosper. July precipitation at Minot of 62 mm was greater then precipitation at Prosper. August and September precipitation of 32 mm and 7 mm, respectively at Minot was less than amounts received at Prosper.

Date × Crop Interaction

The results of the study indicate a significant interaction between sowing date and crop for seed yield (Table 1). Soybean was significantly higher at D1 compared to D2 while the new crops and crambe produced similar yields at both dates. The seed yields of the new crops at both seeding dates were lower than the conventional crops. Seed yields for borage at D1 (307 kg ha^{-1}) and D2 (241 kg ha^{-1}) were similar to yields found by Berti and Schneiter (1993). The seed yields for cuphea ranged from acceptable to low when compared to other regional cuphea yields and may be related to date of seeding. A planting date of mid-May was recommended by Gesch et al. (2002) for optimum cuphea yields. Evening primrose seed yield (358 kg ha^{-1}) was low compared to Berti and Schneiter's (1993) results and was just above half the recommended yield (700 kg ha^{-1}) for commercial production (Belisle 1990). The seed yield of camelina was considerably higher than borage, cuphea, and evening primrose at both D1 (1284 kg ha^{-1}) and D2 (1459 kg ha^{-1}). Yield of camelina was also higher than reported by Berti and Schneiter (1993) and mid-range in the yields reported by Putnam et al. (1993).

Seeding date had no significant effect on oil content for any of the crops (Table 1). Oil yield showed a significant interaction between seeding date and crop: there was higher oil yield for camelina at D2 (583 kg ha^{-1}) compared to D1 (496 kg ha^{-1}) and higher oil yields for soybean at D1 (674 kg ha^{-1}) compared to D2 (487 kg ha^{-1}). Higher oil yield at D1 for soybean is a reflection of the significantly higher seed yield at D1. For camelina, higher oil yield at D2 compared to D1 is an additive effect of higher seed yield and higher oil content.

The average oil content of the new crops and crambe was higher than soybean (Table 1). Camelina had a seed yield of 1284 kg ha^{-1} which is 36% of the soybean seed yield of 3512 kg ha^{-1}; however, oil yield of camelina is 496 g kg^{-1} which represents 73% of the soybean's oil yield. The high oil content of camelina enables a greater oil yield. An increase in camelina seed yield could have the potential to make camelina a much more economically competitive crop. Crambe, which had the highest oil yields in the study, had seed yields only moderately higher than camelina; however, performance of both crops would be improved by earlier seeding. Johnson et al. (1995) indicated seeding crambe before mid-May to optimize yield potential in North Dakota.

Table 1. Mean seed yield, oil content, and oil yield for oilseed crops sown at two seeding dates and grown at Prosper, North Dakota, during the 2005 growing season.

	Seed yield (kg ha^{-1})		Oil content (g kg^{-1})			Oil yield (kg ha^{-1})	
Crop	1 June	17 June	1 June	17 June	Mean	1 June	17 June
Borage	307	241	268	260	264	82	63
Camelina	1284	1459	387	399	393	496	583
Crambe	1987	1967	375	363	370	746	715
Cuphea	342	197	252	252	252	86	49
Primrose[z]	358	~	205	~	~	73	~
Soybean	3512	2633	192	185	188	674	487
LSD (0.05)	260		NS		10	74	

[z]Evening primrose not included in statistical analysis.

Environment × Crop Interaction:

The environment by crop interaction was not significant for seed or oil yield (Table 2). This indicates the same relative yield ranking of these crops at Prosper and Minot. The conventional crop crambe performed the best in both seed and oil yields followed by the relatively good yields of camelina. The seed and oil yield of borage and cuphea were low at both Prosper and Minot. Cuphea seed yield at Minot fell within the range of yields reported for the region. There was a significant interaction between environment and crop for oil content (Table 2). The interaction was due to greater oil content for cuphea at Minot (283 g kg^{-1}) compared with Prosper (252 g kg^{-1}), and greater oil content for crambe at Prosper (363 g kg^{-1}) compared with Minot (341 g kg^{-1}). At both locations, camelina had the highest oil content, followed by crambe, while borage and cuphea had similarly low oil contents.

Specialty Crop Oil Composition

Analysis indicated a significant seeding date by fatty acid interaction for borage (Table 3). Seeding date influence on fatty acid concentration in borage indicated lower erucic acid at D2 (2.59%) compared with D1 (2.70%). The small difference seems biologically insignificant, however erucic acid is considered to be a possible health risk to humans in larger doses and lower erucic levels would certainly be an advantage in oils for human consumption. The other fatty acids composing borage oil were not influenced by seeding date.

Table 2. Mean seed yield, oil content, and oil yield for oilseed crops sown in mid-June at Prosper and Minot, North Dakota, in the 2005 growing season.

	Seed yield (kg ha^{-1})		Oil content (g kg^{-1})		Oil yield (kg ha^{-1})	
Crop	Prosper	Minot	Prosper	Minot	Prosper	Minot
Borage	241	208	260	277	63	58
Camelina	1459	1335	399	393	583	525
Crambe	1967	2317	363	341	712	792
Cuphea	197	349	252	283	49	99
LSD (0.05)	NS		18		NS	

Table 3. Mean borage, camelina and evening primrose oil fatty acid concentration when grown at different seeding dates at Prosper, North Dakota, in the 2005 growing season.

	Fatty acid concentration (%)						
	Borage			Camelina			E. primrose
Fatty Acid	1 June	17 June	LSD (0.05)	1 June	17 June	LSD (0.05)	1 June
Palmitic (C16:0)	11.32	11.71	NS	6.95	6.52	NS	7.41
Stearic (C18:0)	4.33	3.97	NS	3.28	2.99	0.06	1.94
Oleic (C18:1)	15.99	16.66	NS	15.72	14.12	NS	12.55
Linoleic (C18:2)	36.26	35.31	NS	22.97	19.02	1.1	67.90
γ-Linolenic acid (C18:3)	22.48	22.94	NS	~	~	~	8.73
α-Linolenic acid (C18:3)	~	~	~	28.33	33.37	NS	~
Arachidic (C20:0)	~	~	~	2.07	1.87	0.12	~
Eicosenoic (C20:1)	3.85	3.78	NS	12.89	13.44	NS	~
Eicosadienoic (C20:2)	~	~	~	1.89	2.1	NS	~
Eicosatrienoic (C20:3)	~	~	~	.93	1.33	0.23	~
Erucic (C22:1)	2.70	2.59	0.11	2.82	3.06	NS	~
Nervonic (C24:1)	1.43	1.44	NS	~	~	~	~

Analysis for camelina indicated a significant seeding date by fatty acid interaction (Table 3). Camelina had greater stearic, linoleic, and arachidic acid concentrations at D1 compared to D2. Camelina's eicosatrienoic acid concentration was greater at D2 compared to D1. The differences in stearic, arachidic, and eicosatrienoic acids are most likely of little biological importance, while the difference in linoleic acid may be of commercial importance because linoleic is an essential fatty acid in human nutrition. The other fatty acids of camelina oil were not influenced by seeding date. Alpha-linolenic acid, although not different between dates, is an important omega-3 fatty acid, desirable in camelina oil for both human and animal nutrition.

CONCLUSIONS

Across date and environment, the new crops borage, camelina, cuphea, and evening primrose had lower seed yields and oil yields then the conventional oilseed crops. However, it is important to remember that these new crops have not seen the same investment of research resources as conventional crops. Although the new crops generally exhibit low yields, their unique oil characteristics and applications give them a high value potential in North Dakota and the surrounding region. Seeding date and other changes in management practices would currently seem to play a smaller role in increasing yields than would overall genetic improvement of the crop through plant breeding. Yet, improvements in management practices are important and are currently under investigation. Continued work in both genetics and production management practices are recommended before these new crops are grown at an intensive commercial scale.

REFERENCES

Ackman, R.G. 2002. The gas chromatograph in practical analyses of common and uncommon fatty acids for the 21st century. Analytica Chimica Acta 465(1–2):175–192.

Belisle, D. 1990. Potential of evening primrose in Canada. Bio-Options 1:4–5.

Berti, M.T. 1993. Agronomic evaluation of new crops for North Dakota. M.S. thesis North Dakota State Univ., Fargo.

Berti, M.T. and A.A. Schneiter. 1993. Preliminary agronomic evaluation of new crops for North Dakota. p. 105–109. In: J. Janick and J.E. Simon (eds.), New crops. Wiley, New York.

Berti, M., R. Wilckens, S. Fischer, and R. Araos. 2002. Borage: A new crop for Southern Chile. p. 501–505. In: J. Janick and A. Whipkey (eds.), Trends in new crops and new uses. ASHS Press, Alexandria, Virginia.

Christie, W.W. 1999. The analysis of evening primrose oil. Indust. Crops Prod. 10:73–83.

Forcella, F., R.W. Gesch, and T.A. Isbell. 2005. Seed yield, oil, and fatty acids of cuphea in the Northwestern corn belt. Crop Sci. 45:2195–2202.

Fröhlich, A. and B. Rice. 2005. Evaluation of *Camelina sativa* oil as a feedstock for biodiesel production. Indust. Crops Prod. 21:25–31.

Gesch, R.W., F. Forcella, N.W. Barbour, B. Phillips, and W.V. Voorheees. 2002. Yield and growth response of *Cuphea* to sowing date. Crop Sci. 42:1959–1965.

Gesch, R., F. Forcella, A. Olness, D. Archer, and A. Hebard. 2006. Agricultural management of cuphea and potential for commercial production in the Northern Corn Belt. Indust. Crops Prod. 24(3):300–306.

Johnson B., M. Berti, B.K. Hanson, and R.A. Henson. 2005. Planting and harvest date influence on borage gamma-linolenic acid content. The ASA-CSSA-SSSA International Annual Meetings. Abstr. [CD-ROM] Nov. 6–10, 2005. Salt Lake City, UT

Johnson B., R.K. McKay, A.A. Schneiter, B.K. Hanson, and B.G. Schatz. 1995. Influence of planting date on canola and crambe production. J. Prod. Agr. 8(4):594–499

Knapp, S.J. 1993. Breakthroughs towards the domestication of *Cuphea*. p. 372–379. In: J. Janick, and J. Simon (eds.), New crops. Wiley, New York.

Knapp, S.J. and J. Crane. 2000. Registration of reduced seed shattering *Cuphea* germplasm PSR23. Crop Sci. 40:298–299.

Lovet, J.V. and A.M. Dufffield. 1981. Allelochemicals of *Camelina sativa*. J. Appl. Ecol. 18(1):283–290.

Napier, J.A., and L.V. Michaelson. 2001. Towards the production of pharmaceutical fatty acids in transgenic plants. J. Sci. Food Agr. 81:883–888.

Nicholls, F. 1996. New crops in the U.K.: From concept to bottom line profits. p. 21–26. In: J. Janick (ed.), Progress in new crops. ASHS Press, Alexandria, Viginia.

Peiretti P.G., P.P. Mussa, L. Prola, and G. Meineri. 2007. Use of different levels of false flax (*Camelina sativa* L.) seed in diets for fattening rabbits. Livest. Sci. 107:192–198

Putnam, D.H., J.T. Budin, L.A. Field, and W.M. Breene. 1993. Camelina: A promising low-input oilseed. p. 314–322. In: J. Janick and J.E. Simon (eds.), New crops. Wiley, New York.

Rokka T., K. Alén, J. Valaja, and E.L. Ryhänen. 2002. The effect of *Camelina sativa* enriched diet on the composition and sensory quality of hen eggs. Food Res. Int. 35:253–256.

Simon, J.E., N. Beaubaire, S.C. Weller, and J. Janick. 1990. Borage: A source of gamma linolenic acid. p. 528. In: J. Janick and J.E. Simon (ed.), Advances in new crops. Timber Press, Portland, Oregon.

United Nations Food and Agricultural Organization. 2004. Statistical data bases. www.fao.org. (Accessed 10 Jan 2007).

Vollmann, J., A. Damboeck, A. Eckl, H. Schrems, and P. Ruckenbauer. 1996. Improvement of *Camelina sativa*, an underexploited oilseed. p. 357–362. In: J. Janick (ed.), Progress in new crops. ASHS Press, Alexandria, VA.

Zubr, J. 1997. Oil-seed crop: *Camelina sativa*. Indust. Crops Prod. 6:113–119.