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Evaluation of safflower and other oilseed crops grown in the United States Northern Plains Region for biofuels/biobased products

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Abstract
The competition between energy, human food and livestock feed needs is resulting in unprecedented prices for oilseed crops and other agricultural commodities. Using vegetable oil from oilseeds as an alternative energy source in the United States is being challenged from a moral point of view and from an economic perspective.

Oil and meal quality factors associated with the oilseed crops grown in the United States Northern Great Plains, high oleic and high linoleic safflower (C*arthamus tinctorius)*, Canola (*Brassica napus)*, flax (*Linum usitatissimum)*, soybeans (*Glycine max)*, mid oleic and high oleic sunflowers (*Helianthus annuus)* and camelina (*Camelina sativa*) have been evaluated by Montana State University's Eastern Agricultural Research Center, at Sidney, Montana, USA. Many of these quality factors influence the potential of the oilseeds for use as alternate energy sources, food, livestock feed and other uses. Comparative research results related to oil quality, meal quality, biodiesel quality, oilseed crop yield potential, economic return and other factors are presented for each oilseed crop.

Key Words: safflower – biofuels – oilseed meal quality – oil quality – *Carthamus tinctorius*

Introduction

The demand for oilseeds, and the commodities derived from oilseeds have increased in the past several years. This demand has been driven by both an increasing need for food products as well as the potential of vegetable oils to contribute to the supply of renewable fuels that can be used for energy. While economics will determine where oilseeds fit in the overall picture it is important that the agronomic and quality characteristics of the oilseed crops grown in the Northern Great Plains of the United States be determined in a comparative manner so that the uses for these seeds may be optimized accordingly.

Experiments were carried out during the 2006 and 2007 cropping seasons at the Montana State University Eastern Agricultural Research Center (MSU/EARC) at Sidney, Montana, USA to evaluate the yield response and quality factors associated with the oilseed crops oleic safflower, linoleic safflower, mid oleic sunflower, high oleic sunflower, Canola, flax, Camelina, and soybeans when these crops were grown under irrigation and spring sown conditions. The crop oil yield, oil content, oil fatty acid composition, tocopherol content and meal protein content were determined.

Location and Climate

The research center is located in the lower Yellowstone River Valley near Sidney, Montana, USA with an elevation of 594 meters. The soil is a silty clay loam. The growing season averages 127 frost free days, 2237 degree days (base 10^{o}C), and 352 mm precipitation. The conditions of the oilseed crop experiments in 2006 and 2007 are given in tables 1 and 2.

Materials and Methods

The analytical laboratory procedures used in this study for measuring and documenting the oil content, the tocopherol composition and the fatty acid composition of the oil seeds grown in this study were previously described by Flynn and Bergman (1). The protein content of the defatted oilseed meals produced was determined by combustion using a Leco FP-2000 carbon/nitrogen analyzer.

Unrefined vegetable oil from each of the oilseeds grown in this study (Canola, sunflower, safflower, flax, soybean, and Camelina was obtained using a De Smet Rosedowns Mini 40 screw press expeller. The oil obtained from the press expeller was allowed to settle in a cool place for 7-10 days. During this time, fine particulate material associated with these oils settled to the bottom of the holding vessels. The upper layer of oil was decanted off and filtered through a paper type, multi plate filter press, using paper (Grade 938) made by ErtelAlsop, Kingston, NY. The resulting filtered oil was then stored at 4-5°C for biodiesel production.

The free fatty acid content (FFA) of the oils was determined using Method CA 5a -40 (93) from the American Oil Chemists Officials Methods and Recommended Practices Volume 1.

Biodiesel Production

A RD 37-144 Biodiesel System made by SunBio Systems, 400 South Saliman Rd #137, Carson City, Nevada 89701, USA, is shown in the attached photo. This biodiesel production and refining system was used to produce biodiesel from the vegetable oils in quantities from 5 to 30 gallons.

The biodiesel system involved methylating the vegetable oil with methanol and sodium methoxide at approximately 60°C and separating the resulting biodiesel and glycerin produced. The biodiesel was then refined to meet ASTM (American Society of Testing and Measurements) specifications using flash evaporation of the excess methanol under vacuum, followed by resin bed adsorption of traces of methanol, catalyst, water and glycerin. The resin bed was charged with either Amberlite (TM) - BD10 dry resin or PUROLITE PD206. The refining unit utilized a system of air driven pumps, stainless steel tubing, and a set of shut-off valves for easy manipulations and for safety.

Results

The results of the 2006 and 2007 oilseed crops experiments and two-year averages are shown in tables 1-3. The fatty acid and tocopherol compositions of the oilseed crops are shown in tables 4-5. The results of processing the oilseeds through the screw press expeller are shown in table 6.

Table 1. Montana Oilseed Crops Experiment, 2006, Montana State University Eastern Agricultural Research Center, Sidney, Montana, USA

Crop[1/]	Variety	Plant Date	Bloom Date[2/]	Harvest Date	Ht. cm	Test Wt. kg/hl	Oil Content %[3/]	Yield kg/ha Variety	Yield kg/ha Crop	Oil Yield kg/ha Variety	Oil Yield l/ha A[4/] Crop
Sunflower	Mid Oleic	5/13	7/9	9/15	145	26.2	41.4	3143	--	1301	--
Sunflower	High Oleic	5/13	7/11	9/15	168	26.4	43.4	3316	3230	1440	241
Flax	Omega	5/13	6/28	10/13	62	42.0	36.0	1193	--	430	--
Flax	York	5/13	6/28	10/13	61	41.3	35.9	1379	1286	494	81
Crambe	Crambe	5/13	6/29	8/8	77	9.7	23.8	199	199	47	8
Canola	Canola	5/13	6/24	8/8	86	39.9	41.6	472	472	196	34
Camelina	Camelina	5/13	6/28	8/8	71	39.4	32.1	364	364	116	20
Safflower	Montana 71	5/13	7/15	9/8	61	31.0	46.2	3856	--	1780	--
Safflower	MT 2004	5/13	7/13	9/8	62	31.4	39.6	3834	--	1516	--
Safflower	Nutrasaff [5/]	5/13	7/15	9/8	65	30.9	48.6	3372	--	1639	--
Safflower	Mondak	5/13	7/15	9/8	62	32.6	39.8	4558	3905	1814	296
Soybean	Barnes	5/3	--	10/6	80	43.8	19.1	3242	--	619	--
Soybean	Walsh	5/3	--	10/6	88	43.4	20.6	3739	3491	771	123
	Mean				83.6	33.7	36	2513		935.8	
	LSD (0.05)				17.17	3.268	1.583	439.4		196.7	

Previous crop: Sugarbeets
Soil type: Silty clay loam
3 replications, plot size: 7.4 sq m
[1/] 4 row plots, row 6.1 m long, 0.305 m apart except for sunflowers 3 row plots, 6.1 m long and 0.61 m apart
[2/] Date of first flower
[3/] Oil content reported on an oven-dry weight basis
[4/] Oil yield based on 0.936 kg/l
[5/] Variety specific bird damage by Goldfinches observed and noted on Nutrasaff

Irrigation: May 17 (12.7mm), June 28 (31.75mm), July 12 (31.75mm)
Herbicide (preplant): 0.57 l/ha Eptam (EPTC) on 5/12/2006; no herbicide applied on Camelina
Fungicide applied: 110.1 ml/ha Quadris (azoxystrobin) on reps 2 and 3 on 7/17/2006
Fertilizer applied: 56 kg/ha nitrogen (28-0-0) on 10/3/2005
Precipitation for average crop year: 352 mm
Precipitation for 2006 crop year: 433 mm
Crop year is considered October 1 through September 30.
Precipitation for April 1 – August 31, 2006: 236 mm
Average precipitation for this period: 240 mm

Table 2. Montana Oilseed Crops Experiment, 2007, Montana State University Eastern Agricultural Research Center, Sidney, Montana, USA

Crop [1/]	Variety	Plant Date	Bloom Date [2/]	Harvest Date	Ht. cm	Test Wt. kg/hl	Oil Content %[3/]	Yield kg/ha Variety	Yield kg/ha Crop	Oil kg/ha Variety	Oil l/ha[4/] Crop
Sunflower	Mid Oleic	5/9	7/20	10/12	143	27.8	43.0	1836	--	790	--
Sunflower	High Oleic	5/9	7/19	10/12	141	26.1	37.3	1607	1721	599	121
Flax	Omega	5/9	7/16	9/18	51	42.9	36.3	936	--	339	--
Flax	York	5/9	7/16	9/18	52	43.0	36.2	1140	1038	413	66
Crambe[5/]		5/9	--	--	--	--	--	--	--	--	--
Canola[5/]		5/9	--	--	--	--	--	--	--	--	--
Camelina[6/]		5/9	--	--	--	--	--	--	--	--	--
Safflower-Oleic	Montana 71	5/9	7/20	9/17	51	31.4	47.5	2874	--	1365	--
Safflower-Oleic	MT 2004	5/9	7/18	9/17	45	32.3	39.3	2689	--	1057	--
Safflower-Linoleic	Nutrasaff[7/]	5/9	7/20	9/17	59	31.0	50.7	2471	--	1253	--
Safflower-Oleic	MonDak	5/9	7/20	9/17	59	32.0	40.3	3568	2901	1437	236
Soybean	Barnes	5/11	--	10/1	74	45.0	22.2	2615	--	580	--
Soybean	Walsh	5/11	--	10/1	58	44.6	20.3	1944	2280	394	86
	Mean				73	35.6	37.3	2168		823	
	LSD (0.05)				9.5	10.99	3.47	543		241	

3 reps, Plot Size: 7.4 sq m
1/ 4 row plots, row 6.1 m long, 0.305 m apart except for sunflower 3 row plots, row 6.1 m long, 0.61 m apart
2/ Date of first flower
3/ Oil content reported on an oven-dry weight basis
4/ Oil yield based on 0.936 kg/l
5/ In 2007 these crops were lost to hail damage on June 16, 2007, other crops also suffered yield loss
6/ Crop failed to establish due to heavy rain and crusting after planting
7/ Variety specific bird damage by Goldfinches observed and noted on Nutrasaff

Irrigation Dates: July 13 (17.8 mm), and July 19 (18.3 mm)
Previous crop: Sugarbeets; Soil type: Silty clay loam
Herbicide (preplant): 0.57l/ha Sonolan (ethalfluralin) on 5/1/2007; No herbicide applied on Camelina
Fungicide applied: 110.1 ml/ha Quadris (azoxystrobin) on reps 2 and 3 on 7/17/2006
Fertilizer applied: 56 kh/ha nitrogen (28-0-0) on 10/25/2006
Precipitation for average crop year: 352 mm
Precipitation for 2007 crop year: 825.2 mm
Crop year is considered October 1 through September 30.
Precipitation for April 1 – August 31, 2007: 265.2 mm
Average precipitation for this period: 240 mm

Table 3. Montana Oilseed Crops Experiment, Two-Year Average 2006-2007, Montana State University Eastern Agricultural Research Center, Sidney, Montana, USA

Crop	Variety	Height cm	Test Wt. kg/hl	Oil Content %[1/]	Yield kg/ha Variety	Yield kg/ha Crop	Oil Yield kg/ha Variety	Oil Yield l/ha Crop
Sunflower	Mid Oleic	144	27.0	42.2	2489	--	1046	--
Sunflower	High Oleic	155	26.3	40.4	2462	2476	1020	181
Flax	Omega	57	42.5	36.2	1065	--	385	--
Flax	York	57	42.2	36.0	1260	1163	454	74
Crambe*	Crambe	77	9.7	23.8	199	199	47	8
Canola*	Canola	86	39.9	41.6	472	473	196	34
Camelina**	Camelina	71	39.4	32.1	364	364	116	20
Safflower-Oleic	Montana 71	56	31.2	46.9	3366	--	1572	--
Safflower-Oleic	MT 2004	54	31.9	39.5	3261	--	1287	--
Safflower-Linoleic	Nutrasaff	62	30.9	50.0	2922	--	1446	--
Safflower-Oleic	Mondak	61	32.3	40.0	4063	3404	3251	267
Soybean	Barnes	77	44.4	20.7	2929	--	600	--
Soybean	Walsh	73	44.0	20.5	2841	2886	582	104

[1/] Oil content reported on an oven-dry basis
* 2006 data only, 2007 crop lost to hail damage
** 2006 data only, 2007 crop failed to establish due to heavy rain and crusting after planting

Table 4. Fatty Acid Composition of Oil Seed Crops, Two-Year Average 2006-2007, Montana State University Eastern Agricultural Research Center, Sidney, Montana, USA

Crop	Variety	Fatty Acid Composition, % Palmitic C16:0	Stearic C18:0	Oleic C18:1	Linoleic C18:2	Linolenic C18:3	Arachidic C20:0	Eicosenoic C20:1	Behenic C22:0	Erucic C22:1	Lignoceric C24:0	% Total Saturates
Sunflower	Mid Oleic	4.4	5.3	56.9	30.9	--	0.4	0.3	0.6	--	0.3	10.2
	High Oleic	3.4	3.4	88.0	2.6	--	0.7	0.3	0.7	--	0.3	7.7
Oleic Safflower	Montana 71	4.1	1.8	82.1	20.1	--	0.4	0.3	0.3	--	0.2	6.7
	Mondak	4.3	1.2	79.0	13.4	--	0.3	0.3	0.3	--	0.2	6.3
	MT 2004	3.7	1.5	83.3	9.4	--	0.4	0.4	0.3	--	0.2	6.2
Linoleic Safflower	Nutrasaff	6.5	2.1	11.0	78.5	--	0.3	0.2	0.2	--	0.1	9.1
Flax	Omega	4.8	5.0	25.9	15.8	46.8	0.2	0.2	0.2	--	0.2	10.3
	York	4.9	5.2	51.1	15.8	46.2	0.2	0.2	0.3	--	0.3	10.5
Canola*	Canola	4.0	2.3	67.3	16.2	--	0.2	0.7	1.2	--	0.2	7.6
Camelina**	Camelina	5.6	2.3	16.0	19.2	30.2	1.9	14.0	0.5	3.5	0.3	10.5
Crambe*	Crambe	2.1	1.0	17.9	8.5	4.3	2.0	3.7	2.2	50.6	0.8	8.1
Soybean	Barnes	9.1	3.7	26.1	51.6	7.2	0.4	0.3	0.3	--	0.1	13.1
	Walsh	10.2	4.3	24.6	50.5	7.7	0.3	0.3	0.3	--	0.1	14.9

* 2006 data only, 2007 crop lost to hail damage
** 2006 data only, 2007 crop failed to establish due to heavy rain and crusting after planting

Table 5. Tocopherol Composition of Oil Seed Crops, Two-Year Average 2006-2007
Montana State University Eastern Agricultural Research Center, Sidney, Montana, USA

Crop	Variety	Tocopherol Composition, %			
		alpha	beta	gamma	delta
Sunflower	Mid Oleic	94.9	4.3	0.9	--
	High Oleic	96.6	2.8	0.7	--
Oleic Safflower	Montana 71	95.5	2.7	1.1	--
	Mondak	96.5	1.7	0.9	--
	MT 2004	93.2	5.1	0.6	--
Linoleic Safflower	Nutrasaff	95.8	2.5	0.6	0.1
Flax	Omega	2.2	23.7	70.8	2.1
	York	1.4	23.1	71.6	1.7
Canola*	Canola	31.9	0.5	62.7	3.5
Crambe*	Crambe	6.5	1.1	81.9	6.6
Camelina**	Camelina	7.8	1.6	80.2	5.4
Soybean	Barnes	7.3	0.9	54.8	36.5
	Walsh	6.3	0.9	56.3	36.8

* 2006 data only, 2007 crop lost to hail damage
** 2006 data only, 2007 crop failed to establish due to heavy rain and crusting after planting

Table 6. Results of processing oilseeds through Mini 40 Screw Press

Crop	Variety	Oil Content of Seeds, %	Free Fatty Acid, %	Residual Oil % in Meal	Defatted Meal Protein %
Sunflower	High Oleic	45.2	0.26	20.9	36.3
Safflower	Nutrasaff	49.5	0.65	13.7	37.0
Safflower	MT 2004	35.2	0.30	11.7	22.0
Flax	Flax	39.2	0.31	17.0	39.5
Canola	Canola	43.0	0.23	20.2	38.7
Soybean	Soybean	20.6	0.79	10.7	40.2
Camelina	Camelina	34.8	0.34	16.4	39.9

Discussion and Conclusions

The highest irrigated seed oil yields were produced by safflower (3,404 kg/ha and 267 l/ha respectively). Sunflower averaged 2,476 kg/ha seed yield and 181 l/ha oil yield. Soybean produced a high seed yield of 2,886 kg/ha but produced a low seed oil content of 20.6% and a lower oil yield of 104 l/ha when compared to either safflower or sunflower. Flax produced a seed yield of 1,163 kg/ha and an oil yield of 74 l/ha. Seed and oil yields for Camelina, Canola, and Crambe were only reported in 2006 due to adverse weather impacts on these oilseed crops in 2007. In 2006, the seed yields of Canola, Crambe and Camelina were 473, 199 and 364 kg/ha, whereas the oil yields were 34, 8, and 20 l/ha respectively. It should be noted that Canola, a cool season crop, and Camelina, a short growing season crop, would be expected to produce higher yields with an earlier planting date. The oilseed crops each produced different proportions of fatty acids and tocopherols as shown in tables 4 and 5. Canola and Crambe were so severely damaged by a hail storm that occurred on June 16, 2007 that the crops were destroyed. In 2007, Camelina failed to establish due to a heavy rain and crusting after planting and prior to crop emergence.

The oilseeds evaluated differed considerably in productivity (seed yield and oil yield) and in fatty acid and tocopherol composition. High oleic safflower and high oleic sunflower offer the best choice for food and biodiesel markets and economic return potential under the climatic conditions of this investigation. The fatty acid composition (carbon chain length and degree of unsaturation) and tocopherol compositions of the oils will influence biodiesel performance and stability. The biodiesel quality characteristics manufactured by each of the vegetable oils in this study are under assessment.

References

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