Development of Oilseed Crops for Biodiesel Production under Colorado Limited Irrigation Conditions

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Final Report to the Colorado Water Institute

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Table of Contents

Introduction

Since 2001, Colorado State University's Crops Testing Program, in collaboration with many other university and USDA ARS researchers, extension agents, farmers, private companies, and a non-profit organization, has undertaken oilseed-for-biofuel crop research and extension. The objective of this research is to test and adapt oilseed crop species (and varieties) to dryland, limited irrigation, and fully irrigated cropping systems prevalent in eastern Colorado, eastern Wyoming, western Kansas, and the Nebraska Panhandle. Regionally applied research has focused on agronomy trials, interaction with first-adopter farmers, weed control experiments, insect pest observations, crop water use experiments, and crop response to variable climatic conditions. This research has resulted in strong collegial relationships among researchers, farmers, private company representatives, and extension agents within the Great Plains area.

This research project is an integral contributor and benefactor of our overall efforts to provide cropping alternatives that are economically feasible and environmentally sustainable to eastern Colorado producers, specifically those with limited irrigation.

History of the Diesel Engine

During 1885, Rudolf Diesel set up his first shop-laboratory in Paris and began the 13-year ordeal of creating his distinctive engine. In 1893, he published a paper describing an engine with 'sparkless' combustion within a cylinder, named the internal combustion engine. Baron von Krupp and Machinenfabrik Augsburg Nurnberg Company in Germany supported Rudolf Diesel financially and provided engineers to work with him on the development of an engine designed to burn coal dust, because there were mountains of useless coal dust piled up in the Ruhr Valley. The first experimental engine was built in 1893and used high pressure air to blast the coal dust into the combustion chamber. The engine exploded and further developments of coal dust based fuel failed. However, a compression ignition engine that used oil, putatively peanut oil, as fuel was successful, and a number of manufacturers were licensed to build similar engines. In 1894, Diesel filed for a patent for his new invention, dubbed the diesel engine. Rudolf Diesel was almost killed by his engine when it exploded. However, the engine was the first to prove that fuel could be ignited without a spark. In 1896, Diesel demonstrated another model with the theoretical efficiency of 75 percent, in contrast to the 10 percent efficiency of the steam engine. In 1898, Rudolf Diesel was granted his patent #608,845 for an "internal combustion engine" and in that same year, Busch installed a Rudolf Diesel-type engine in its brewery in St. Louis. That was the first engine of that kind in the United States.

Scope

This two-year project used field, greenhouse, and laboratory facilities to screen oilseed germplasm from around the world and to select oilseed cultivars adapted to Colorado’s limited irrigation conditions and train a new crops specialist.

Objectives

1. To screen advanced lines of promising oilseed crop species (canola, camelina, soybean, sunflower) for adapted cultivars that could be grown by Colorado producers in the near future for biodiesel production and oilseed meal to feed northeast Colorado livestock.
2. To develop a research-based agronomic package of best management practices for oilseed production under limited irrigation conditions especially oriented toward weed control and water management.
3. To import and screen potentially new and underdeveloped oilseed crop species from temperate zones around the world.
4. To train a new crop agronomist/breeder to the PhD level. To train summer students and research associates in new crop research techniques and methodologies.
5. To determine the economic feasibility of oilseed crop production under limited irrigation conditions in light of dynamic interactions of variable yield, fuel costs, and input costs.

Definition and Conceptualization of Limited Irrigation in Colorado

“Limited irrigation occurs when water supplies are restricted in some way to the point that full evapotranspiration demands cannot be met” (Klocke et al., 2004). Full irrigation is the amount of water minus rainfall and stored soil moisture needed to achieve maximum crop yield. However, when irrigation water is insufficient to meet crop demand, limited irrigation management strategies should be considered (Norton et al., 2000).

There are two types of limited irrigation:

1. Supply: The amount of water available is fixed at any given time in the crop season and applied on a delivery schedule, not on crop demand. During high demand, the crop water requirements may not be met. The Fort Collins trials were conducted under this production environment (in addition to high pH and highly sodic soil conditions).
2. Capacity: The global water amount is limited in quantity but not in a fixed schedule, and crops can be irrigated on demand. However, it is important to choose the most critical stage when the water is to be applied. The other trials in the study were established under this water regime.

When addressing the definition of limited irrigation, the following question seems relevant: what is the goal of limited irrigation in the cropping system? Is it to homogenize the precipitation in a cropping system, or is it to decrease the amount of water use in an irrigated cropping system? In our experimentation, both situations are considered (Figure 1).

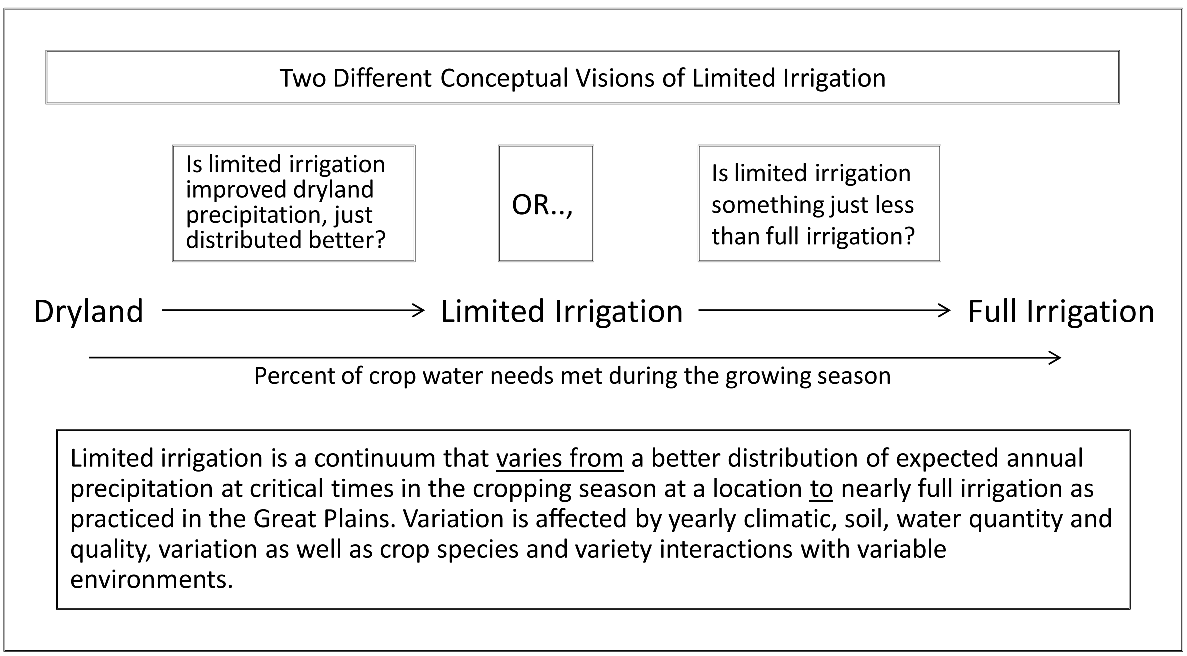

Figure 1: The two different conceptual visions of limited irrigation.

Crop response to limited irrigation can be determined by comparing the ETP with yield for four crop species (Fig 2). Based on data developed in 2006 at Akron, Colorado, camelina shows the highest potential for dryland production. Canola has a better response curve to irrigation and is more suitable for limited and full irrigation than for dryland production. The best agronomic management practices for safflower are not developed enough to make any conclusions.

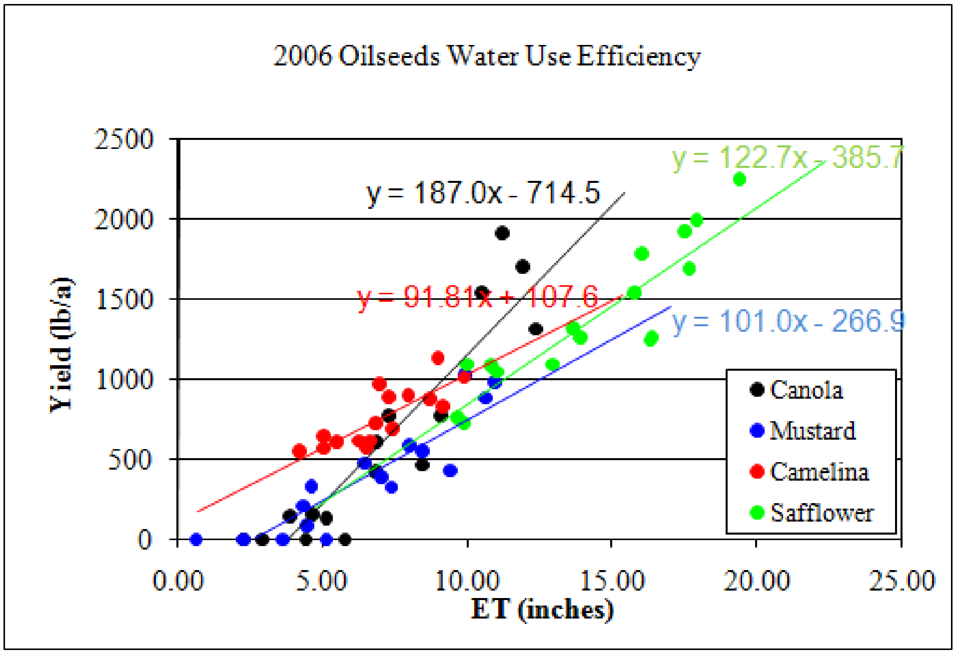

Figure 2: Comparison of oilseed species for water use efficiency (Akron, Colorado).

Project

Target Species Variety Performance Trials Results and Analyses

In 2007 and 2008, five target oilseed crops were studied: soybeans, safflower, sunflower, canola, and camelina. Performance trials were conducted at nine locations within Colorado: Fort Collins, Akron, Walsh, Dailey, Idalia, Yuma, Brandon, Julesburg, Yellow Jacket, and Rocky Ford. Oilseed crops were tested under three environmental conditions: dryland, limited irrigation, and full irrigation. Crop data included yield, percent grain moisture, plant height, and pod shattering. The oil profile was evaluated for canola, camelina, and safflower in 2007.

The five target oilseed crops being studied in three Colorado cropping systems are shown in Table 1. Sunflower, soybean, and safflower are summer annual broadleaf crops. Late fall harvest of sunflower eliminates the possibility of planting winter wheat the same year. Soybean is primarily an irrigated crop. Sunflower is both a dryland and an irrigated crop. Safflower is primarily a dryland crop.

Winter canola and winter camelina can be either integrated into the dryland wheat-based cropping system or into an irrigated cropping system. Canola should be considered primarily as an irrigated crop, whereas camelina is competitive in both dryland and irrigated conditions.

Spring canola and camelina are opportunity crops that can be integrated into the dryland wheat rotations predominant in eastern Colorado, planted in early spring, harvested in July, and followed by wheat planting in September. Spring canola may be limited by high summer temperatures that reduce pollination and pod filling. Camelina is more drought tolerant and less sensitive to high temperature during pollination and pod filling.

Table 1: Cropping Systems for Adaptable Oilseed Crops in Colorado

	Month										
Crops	August	September	October to February	March	April	May	June	July	August	September	October
Soybean						Planting				Harvest	Harvest
Sunflower							Planting				Harvest
Safflower							Planting				Harvest
Winter Canola and Winter camelina		Planting						Harvest	Planted back to wheat		
Spring Camelina and Canola				Planting				Harvest	Planted back to wheat		

Results of 2007 and 2008 Crop Variety Performance Trials

In 2007, six variety performance trials of soybean, nine of sunflower, three of safflower, six of canola, and three of camelina were conducted. In 2008, one variety performance trial of soybean, four of sunflower, ten of canola, and eight of camelina were conducted. A total of 31 oilseed crop variety trials were conducted in nine eastern Colorado locations (Table 2) in 2007, and 23 were conducted in 2008, for a total of 54 oilseed trials over the two years of the project.

Table 2: Number of Trials by Irrigation Level and by Crop in 2007 and 2008

Water regime	Dryland		Limited Irrigation		Full irrigation	
	2007	2008	2007	2008	2007	2008
Soybean	1	0	4	0	1	1
Sunflower	4	2	2		2	2
Safflower	1	0	2	0	0	0
Canola (spring)	1	2	3	2	1	1
Canola (Winter)	1	1	2	2	3	2
Camelina (spring)	1	2	2	4	0	2
Total	9	7	15	8	7	8
Total Trials						54

Soybean

Soybean is a well-established oilseed crop currently grown on limited acreage in eastern Colorado. It has an established market and federal crop insurance. Soybean is a relatively good fit for irrigated cropping systems but is not suited for dryland production. Soybean variety trial maximum yields in eastern Colorado were 99 bu/ac in 2006 and 2007 (Table 3). Soybeans require 24 inches of water to produce maximum yields.

We believe that soybean is an underexploited crop in Colorado due to low input costs and lower water requirements than corn. Major seed companies are investing millions of dollars in soybean research, some of which benefits Colorado producers. Pest management and agronomics are well understood under Colorado conditions. Soybean has excellent emergence and stand establishment is not problematic. Soybean fits into an irrigated winter wheat rotation with wheat benefitting from symbiotically-fixed nitrogen from soybeans. Soybean processing into biofuel is straightforward and simply requires pressing the oil from the seed.

Soybean is the major oil source for current biodiesel production in the United States. The soybean oil profile is in accordance with the U.S. biodiesel standard (ASTM PS 121-99). It has a high level of oleic fatty acid, low level of saturated fatty acid, and medium polyunsaturated fatty acid content (24%), which also makes soybean oil a good source for straight vegetable oil (SVO). Soybean meal has high protein content and is the preferred and most consumed livestock protein feed additive, something of considerable interest to Colorado confined feeding operations. No specialized equipment is needed for soybean planting, cultivation, and harvest.

Limitations to soybean production in Colorado also exist. All soybean production, like most sunflower crops, must be transported out of state (usually to Goodland, Kansas) for crushing and processing. It is felt that the lack of a soybean crushing capacity in northeast Colorado is a major constraint to more widespread cultivation of soybeans in the state. Other constraints include above-average sensitivity to high pH, salty, and sodic soil conditions. Soybean crop residue after harvest is insignificant. Soybeans have low oil content in comparison to other oilseed crops (15-20%). Planting, irrigation, and harvest may overlap with other summer crops, creating a time constraint for some farmers. There is no state 'check-off' program in Colorado to support state crop improvement research. All soybean production in the United States, including Colorado, is potentially threatened by soybean rust.

Table 3: Soybean Trial Performance Summary

Location	Maturity	Water regime	Average	Max	Min	Oil
			lb/ac	lb/ac	lb/ac	gal/ac
Akron	Early	Dryland	684	1092	354	14
Fort Collins	Early	Limited Irrigation	1242	1818	654	25
Fort Collins	Medium	Limited Irrigation	1524	1998	924	30
Rocky Ford	Early	Limited Irrigation	2070	2934	1236	41
Rocky Ford	Medium	Limited Irrigation	2424	2694	2190	48
Yuma 2007	Late	Irrigated	4680	5964	4014	94
Yuma 2008	Late	Irrigated	3540	4320	3120	71

*Soybean oil content is estimated to be 18%.

Sunflower

Sunflower is a crop that has a long history in Colorado, but large acreages have been grown in Colorado only since the early-1990s due to local development and extension efforts by Golden Plains agronomist, Ron Meyer. Sunflower is adapted to both dryland and irrigated production. Crop variety trials conducted since the early 1990s show dryland oil sunflower yields from 1000-2000 lb/ac and irrigated yields in excess of 3000 lb/ac with oil content in seed as high as 47% (Table 4). High yields have been obtained under limited irrigation in northeast Colorado, where available water for irrigation is a serious production constraint for all crops. A well established market for the crop and a federal crop insurance program exist, and there is a premium for high oil content paid to sunflower producers. There is a good understanding of pest problems and management in Colorado conditions, and sunflowers are better able to recover from hail damage than many other crops.

Sunflowers fit well into both conventional and no-till cropping systems. Colorado producers are adopting rotations, including a summer crop like sunflower, corn, or proso millet, while moving away from the traditional wheat-fallow rotation. Many high-yielding and high oil content sunflower hybrid varieties are available for producers who benefit from sunflower improvement conducted by many major crop seed companies and crop variety testing under Colorado conditions. Sunflowers are well suited to direct harvest with planting, tillage, and harvest equipment already owned by Colorado producers. Even prior to the recent release of herbicide-resistant sunflower hybrids, conventional chemical weed control packages existed that—albeit not perfect—were suitable for Colorado production. High protein sunflower meal is valuable to sunflower processing companies. In addition to the National Sunflower Association, which supports research and promotes sunflower products, the Colorado Sunflower Administrative Committee, our state 'check-off' organization created and funded by Colorado producers, supports applied research and promotion of Colorado produced sunflower products. Sunflower oil is the second most produced oilseed for biofuel in Europe.

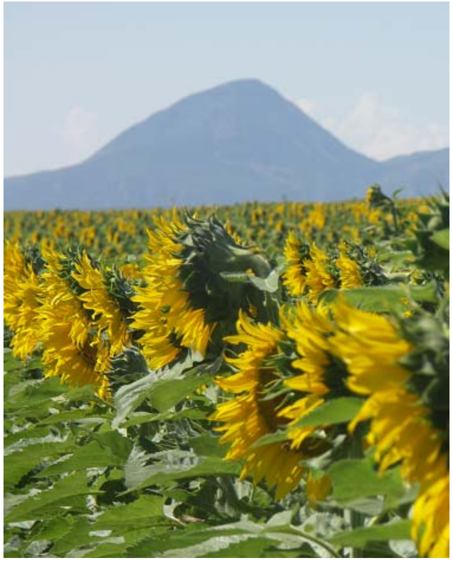

Figure 3: Sunflower field in Yellow Jacket, Colorado.

Some constraints to sunflower production should be mentioned. There have been some instances of yield reduction in the crops subsequent to sunflower due to extensive water and nutrient extraction by a good sunflower crop. Sunflowers have a history of poor emergence under dry planting conditions, resulting in poor stand establishment. Weed management in sunflower can be troublesome when dealing with late emerging weeds. Sunflower residue after harvest is not significant and does not stand up to high winds. Rodents, voles, ground squirrels, and birds can unearth newly planted sunflower seed, causing poor stand establishment in parts of fields. Bird damage can be severe before harvest, especially in areas where sunflowers are widely grown and have become targets of local blackbird populations. When processing sunflower for biofuel, wax content from the oils needs to removed to avoid damage to engines. Although sunflower has good potential as a biofuel crop in Colorado, vegetable oil market prices have historically exceeded the value of the oil for biofuel. The Colorado company crushing sunflowers for oil is in Lamar, and the whole oil is exported out of Colorado for refining and retail sales. The majority of the Colorado sunflower crop produced in northeast Colorado must be transported to Goodland, Kansas, for crushing. A new facility will begin operations in 2009 in Dove Creek, Colorado.

Table 4: 2007 and 2008 Sunflower Trial Performance Summary

Location	Type	Water regime	Yield						Oil		
			Average		Max		Min				
			2007	2008	2007	2008	2007	2008	2007	2008	Average
			lb/ac	lb/ac	lb/ac	lb/ac	lb/ac	lb/ac	%	%	gal/ac
Brandon	Oil	Dryland	2005	1366	2445	1936	1611	953	38.7	40	89.9
Julesburg	Oil	Irrigated	2768		3474		2278		41.15	40	147.6
Idalia		Irrigated		2407		3620		1269		40	128.4

Safflower

Safflower is a potential oilseed crop for Colorado that is well suited to dryland production. There is a limited market established for safflower in the state meaning that producers interested in growing safflower should identify a market before planting the crop. There is no crop insurance available for safflower in Colorado, and there is no 'check-off' or grower organization that would support research and marketing of safflower. Being a relatively short-season crop, it fits well into crop rotations. It is also an aggressive scavenger for water and residual fertility. Safflower seed has relatively high oil content and is easily processed; it requires no special equipment for planting and is directly harvested. Emergence and stand establishment are typically not a problem in production of safflower.

Safflower production and use constraints outnumber the constraints for more widely produced crops like sunflower and soybean. There is not a varietal improvement program in the High Plains, and seed for planting can be hard to find. Weed management in safflower can be problematic due to the lack of herbicides labeled for broadleaf weed control. Hauling the harvested crop is an issue since the market is limited. The research knowledge base for safflower production in Colorado is scarce because there is no producer organization to promote this crop. Safflower's response to irrigation is not established but is being researched. Safflower can present a fire hazard during harvest and leaves little residue. Safflower is another potential biofuel crop but, like sunflower, it competes directly with human consumption.

Safflower has an acceptable oil profile for SVO. Trial results in 2007 show yields up to 467 lbs/ac (Table 5). However, much higher yields have been achieved in different years with better crop management practices. Safflower oil content can approach 50% in some cultivars.

Table 5: Safflower Trial Variety Performance Summary

Location	Water regime	Yield			Oil	
		Average	Max	Min		
		lb/ac	lb/ac	lb/ac	%	gal/ac
Akron	Dryland	430	467	395	40	22.9
Fort Collins*	Limited irrigatior	221	301	182	40	11.8
Walsh	Dryland	208	250	148	40	11.1

*Grown under specific limited irrigation conditions in high pH and highly sodic soils.

Winter and Spring Canola

Canola is another potential irrigated biofuel crop in Colorado that could find a niche in limited irrigation rotations. There are both winter and spring canola varieties that can be planted in Colorado. Winter canola needs to be planted before the end of August to obtain plants that are developed enough to withstand low temperatures during winter. Late planted winter canola, especially north of I-70, has not been able to withstand winter freeze. Weed control is generally not a problem, because winter canola starts re-growth in early spring and competes well with weeds. Varieties from public and private sources have been screened in five different Colorado agro-climatic conditions through a collaborative research program with Kansas State University. Planting and harvest equipment are readily available, although canola is commonly swathed prior to threshing to allow uniform maturity of pods from the top to the bottom of the canopy and to avoid excessive shattering. Fall planted varieties present a grazing opportunity for livestock and can still yield well. Spring canola might be an attractive alternative crop under limited irrigation due to existence of high yielding roundup-ready cultivars from private seed companies. Peak water use for canola is at the end of May and early June, well before the peak water demands of summer crops (corn, alfalfa, and sunflower). Canola leaves relatively sturdy residue after harvest. Oil content in canola is relatively high (40-45%), and the seed is easily processed.

The meal byproduct is high in protein and is a valuable livestock feed, like soybean. Canola produces a high-quality fuel and has good potential for biofuel and meal production for use on the farm.

There are several downsides to canola production. Flea beetles that attack young canola seedlings must be controlled with chemical treatments. There is not a well established market, and there is no Colorado grower organization to promote production and research. Canola is not a good candidate for direct harvest and should be swathed and then picked up much the same as millet. Canola is sensitive to many of the herbicides used in other crops and in fallow periods such as atrazine, Ally, and others. Since there is not a well established market for canola in Colorado, hauling of the harvested product can be an issue.

Canola is small-seeded and needs to be shallow planted to obtain good stands. Deep seeding, or soil crusting, or planting into dry soil conditions can significantly reduce stands. Canola is sensitive to high temperatures during flowering, which may reduce yields. Lack of adequate soil moisture will reduce yields more than with camelina. Canola has a taproot system giving the crop access to deep water and nutrients (Downey et al., 1974). However, when grown in semiarid regions such as the High Plains, the canola roots require adequate subsoil moisture to sustain the crop during flowering and seed filling. Under managed irrigation, winter canola is capable of yielding more than 3,000 lbs/ac. Low crop prices and lack of an established market infrastructure for canola are significant obstacles to more widespread production in Colorado. With limited grower experience and the lack of insurance programs, production of canola has been limited.

Figure 4: 2008 oilseed harvest at Fort Collins, Colorado.

Winter and spring canola varieties are being screened to identify promising cultivars for Colorado's limited irrigation and dryland conditions. Trials conducted in 2007 and 2008 demonstrate yields of 800 lbs/ac under dryland, of 2,400 lbs/ac under limited irrigation, and up to 3724 lbs/ac under full irrigation (Table 6).

Table 6: 2007 and 2008 Canola Variety Trial Performance Summary

				Yield				
Location	Source	Year	Water regime	Average	Max	Min	Oil	
				Lbs/ac	Lbs/ac	Lbs/ac	%	gal/ac
Akron	Commercial	2007	Limited Irrigation	1891	2397	1458	40	101
	Commercial	2007	Full Irrigation	1837	2424	1205	40	98
	Cargill	2007	Limited Irrigation	1645	2900	831	40	88
	Cargill	2007	Dryland	401	807	343	40	21
	Blue Sun	2007	Limited Irrigation	1259	1777	1406	40	67
Fort Collins	Commercial	2007	Limited Irrigation	259	761	79	40	14
Fruita	National trial	2006-2007	Irrigated	2339	3621	872	40	125
Yello Jacket	National trial	2006-2007	Irrigated	651	1236	428	40	35
Rocky Ford	Commercial	2006-2007	irrigated	1750	3171	752	40	93
Rocky Ford	National trial	2007-2008	Irrigated	1816	2703	815	40	97
Fruita	National trial	2007-2008	Irrigated	2760	3724	2124	40	147
Walsh	National trial	2007-2008	dryland	602	1175	102	40	32
Akron winter canola	Blue Sun	2007-2008	Limited Irrigation	1172	1784	731	40	63
Akron winter canola	National trial	2007-2008	Limited Irrigation	1370	2236	828	40	73

Camelina

Camelina is an oilseed crop native to southeast Europe and southwest Asia. The plant has been known for about 4,000 years as a cultivated crop, but there has been relatively little research conducted on it worldwide. Camelina is a promising new oilseed crop that has become the subject of widespread research in the last few years because it is not attacked by flea beetles, is more resistant to drought than other spring oilseed crops, and can be direct harvested. Camelina is a low input crop. It can be grown in both dryland and limited irrigation cropping systems. Water requirements for irrigated camelina are being investigated, but like canola, its peak water demand occurs early in the season when full summer crop water demands are low.

Camelina is an early maturing crop, planted in early April and harvested in mid-July. Although some production issues must be solved, camelina could become an excellent crop for the wheat-based, no-till cropping systems that dominate eastern Colorado. With sufficient spring precipitation, camelina can be planted in the spring following fall harvest of corn, sunflowers, or proso millet and can be harvested in time to allow for accumulation of late July to mid-September precipitation before planting wheat. Instead of harvesting two crops in three years, the current improved cropping system, by producing camelina in the spring it would be possible to harvest three crops in three years. Camelina's seed is extremely small, and seeding rates and seed costs are low. Fertilizer requirements of Camelina are low. Camelina does not respond well to nitrogen fertilizer application. Several private seed companies and universities have camelina improvement projects that are providing varieties for testing in Colorado. Winter camelina is more winter hardy than winter canola and can be planted later in the fall and still survive low winter temperatures. Camelina does not require any special planting equipment and can be direct harvested, which means that equipment is readily available for production. Insect pressure on camelina is almost non-existent. Camelina oil is high in Omega 3 fatty acids, and studies are currently underway to determine if real health benefits result from consumption of camelina oil. Under experimental conditions, camelina meal has been fed to livestock in Montana and Wyoming, and it appears to be wholly satisfactory.

Currently, there are significant production and marketing constraints for camelina. Understandably, the agronomics of camelina production are less well known than those of other crops. Due to small seed size, camelina must be planted shallow and pressed into the soil to have good seed-to-soil contact. Camelina can be planted in early spring; some claim that it can be seeded anytime during the winter or spring. Emergence is slow under cool spring soil temperatures, especially in variable soil moisture conditions. Unlike canola, camelina is not attacked by flea beetles. Camelina's stand establishment and weed control are being investigated in the Great Plains and the Pacific Northwest. There is currently very little acreage of camelina being planted in Colorado, and there is no grower 'check-off' program to support research and production. Federal and state agencies are providing research funds that have helped address some basic water and fertilizer requirement issues and conduct variety trials. For several years, camelina producers were able to sell seed to Blue Sun Biodiesel, but seed prices were low and hauling to crushing facilities was an additional cost. Marketing needs to be fully investigated by producers before planting. Camelina is a small-seeded crop that may require adjustments to equipment to prevent loss during harvest and hauling. Camelina's meal is currently not legal for sale as livestock feed, although high omega 3 content in the oil and meal indicates that it might be more beneficial than other oilseed for human and livestock health.

Figure 5: Charlie Rife, a breeder from Blue Sun Biodiesel, inspects camelina trials.

Camelina's seed oil content ranges from 30% to 45%. Over 50% of its fatty acid, when cold pressed, is polyunsaturated. Alpha linolenic acid (omega 3) represents 30% to 45% of the total oil. Omega 3 fatty acid content has been shown to have beneficial effects on human health.

Trials conducted in 2007 and 2008 achieved dryland yields up to 1,138 lbs/ac under dryland conditions, up to 1,725 lbs/ac under limited irrigation, and up to 2386 lbs/ac under full irrigation (Table 7).

Table 7: Camelina Trial Performance Summary

Location	Source	Water regime	Yield						Oil*
			Average		Max		Min		
			2007 lb/ac	2008 lb/ac	2007 lb/ac	2008 lb/ac	2007 lb/ac	2008 lb/ac	Average gal/ac
Akron	Blue Sun/GPO/ MSU	Limited Irrigation	1243	1053	1725	1332	973	555	53.6
Akron	Blue Sun/GPO/ MSU	Dryland	789	-	1138	-	529	-	36.8
Fort Collins	Blue Sun/GPO/ MSU	Limited Irrigation	547	1159	839	1500	283	794	39.8
Yellow Jacket	Blue Sun/GPO/ MSU	Fully Irrigated	.	2002	.	2386	.	1739	93.4

*Camelina oil content is estimated to be 35%.

Oil Meal Quality

Camelina meal contains 40% to 45% crude protein and 10% fiber, which is similar to that of soybean. The glucosinolate content is close to zero (Korsrud et al., 1978; Lange et al, 1995), and camelina meal has 12% oil remaining after cold pressing with 5% of omega 3. A Montana study shows a higher level of omega-3 content in eggs as camelina meal content in feed increases. Up to 15% can be integrated into a balanced feed ration (Pilgeram et al., 2007). Budin et al. (1995) found that Camelina oil has 30% more antioxidant than other commercial edible oil, which could explain superior storage quality of raw camelina oil. Feed for beef containing camelina meal does not show significant difference for average daily gain nor feed efficiency (Pilgeram et al., 2007).

Fuel properties

The cloud point of camelina biodiesel is 4°C and the pour point is -8°C (Fröhlich et al., 2005), which is similar to other biodiesel feedstocks such as canola (Table 8).

Table 8: Low Temperature Properties of Blends of Camelina and Mineral Diesel Oil

Camelina ester %	Mineral diesel %	Cloud point °C	CFPP °C	Pour point °C
100	0	+3	-3	-4
80	20	+3	-7	-6
60	40	+3	-9	-9
40	60	+3	-11	-12
20	80	+3	-13	<-18
0	100	+3	-15	<-21

(Source: Fröhlich et al., 1998)
CFPP: Cold filter plug point

Camelina oil has a high iodine value: 155 mg I2/g Oil. The limit of the European standard is 120 mg I2/g Oil. This can be an issue for cold climates. A concern with a high iodine value is that unsaturated acids might polymerize in the engine and cause deterioration.

Oil Profile Analysis of the Targeted Crops

Different vegetable oils for fuel can be differentiated by their oxidative and cold flow properties. These two criteria are linked. Some vegetable oils have to be heated to ensure flow but warm temperatures increase the rate of fatty acid oxidation which adversely affects power.

Fatty acids that reduce the cold flow quality of SVO are palmitic (C16:0) and stearic acids (C18:0). The cloud point is correlated to the level of saturated fatty acid. The cloud point of vegetable oil ranges from 8C to -18C, with changes in saturated fat ranging from 23% to 3%. Table 9 provides the percentage of these fatty acids in three main crops of the study.

Table 9: Saturated Fatty Acid Profile Summary

Species	Camelina	Canola	Safflower
Unit	%	%	%
Palmitic (C16:0)	6	5	6
Stearic (C18:0)	2.5	2	2.5
Total saturated	11.5	8.5	10

There are no significance differences among these crops for saturated fatty acid content. These levels of saturated fatty acid are acceptable for SVO.

Polyunsaturated fatty acids improve cold flow properties but are more susceptible to oxidation. Bringe (2004) recommends no more than 24% polyunsaturated fatty acids in vegetable oil for dual use in the food and fuel industry. The level of polyunsaturated fatty acid (PUFA) has another major impact. High levels of PUFA increase the amount of nitrogen oxides released into the atmosphere upon combustion (McCormick et al., 2001). Another important property of oil for fuel is ignition quality, which is measured by the cetane number (CN). High CN is desired to have the best ignition and combustion. The CN number increases with increased content of oleic acid in the oil.

Table 10: Oleic and Polyunsaturated Fatty Acid Profile

Species	Camelina	Canola	Safflower
Unit	%	%	%
Oleic (C18:1)	19	62	37
Linolenic (C18:3)	30	6	0.1
Total polyunsaturated	51	25	52

There are significant differences among crops regarding fatty acid content. Camelina has a very high level of linolenic acid and polyunsaturated fatty acid (Table 10). Crop improvement is needed to increase the oleic acid content of camelina. The ideal fuel oil profile is approximately 65% oleic acid, 22% linoleic fatty acid, 3% linolenic acid, and the lowest possible level of palmitic and stearic fatty acid (2%). The high level of polyunsaturated acid makes camelina one of the best crops known for human vegetable oil consumption.

Canola has an acceptable oil profile for fuel with a high level of oleic acid and medium level of polyunsaturated acids, which is the result of successful breeding programs.

Safflower’s oil profile is similar to camelina’s. However, high variation is noticed between safflower cultivars. Selection has reduced the level of polyunsaturated acid and increased the level of oleic acid. Oleic acid level varies from 14% to 70% and polyunsaturated fatty acids levels range from 18 to 75% (Table 11).

Table 11: Oil Profiles of the Targeted Crops Compared to Desired SVO Profile

Fatty Acid (Carbon saturation)	Palmitic (C16:0)	Stearic (C18:0)	Total saturated	Oleic (C18:1)	Linoleic (18:2)	Linolenic (C18:3)	Total polyunsaturated
unit	%	%	%	%	%	%	%
Ideal SVO Profile	<6	<5	<13	>50	±20	<5	<25
Soybean	5	2	10	65	18	2	22
Sunflower	5	2	8	75	8	2	12
Safflower	6	2.5	10	37	40	0.1	52
Canola	5	2	8.5	62	18	6	25
Camelina	6	2.5	11.5	19	20	30	51

Camelina Agronomy Trial

In 2008, two types of agronomy trials were conducted. The first trial examined the effect of seeding rates, variety, and nitrogen rate on camelina yield at multiple locations in a split plot factorial design (Table 12). The second study evaluated the impacts of different gypsum rates, varieties, and seeding rates on camelina yield in a sodic soil near Fort Collins (Table 13).

First trial:

1. Experimental design: split plot factorial
2. Nitrogen rates: Soil N, 60 lbs, 120 lbs
3. Seeding Rates: 2, 5, 8, 11 and 14 lbs/ac
4. Varieties: Cheyenne (Blue Sun) and Calena (Montana State University)
5. Location: Akron dryland and limited irrrigation, Yellow Jacket, Colorado

Only the Yellow Jacket trial was successful. In Akron, herbicide from previous years damaged the trial and no nitrogen was applied. Only the Yellow Jacket results are reported.

Table 12: 2008 Camelina Agronomy Trial Analysis of Variance

Effect	Num DF	Den DF	F Value	Pr > F
variety (var)	1	58	5.25	0.03
Seeding rate (sr)	4	58	2.41	0.06
var*sr	4	58	1.60	0.19
nitrogen	2	58	0.20	0.82
var*nitrogen	2	58	1.43	0.25
sr*nitrogen	8	58	1.48	0.18
var*sr*nitrogen	8	58	1.25	0.29

- Nitrogen was not was significant for yield (P value = 0.82)
- Seeding rate was weakly significant for yield (P value = 0.08)
- The seeding rate of 2 lbs/ac was significantly lower for yield than the other seeding rates

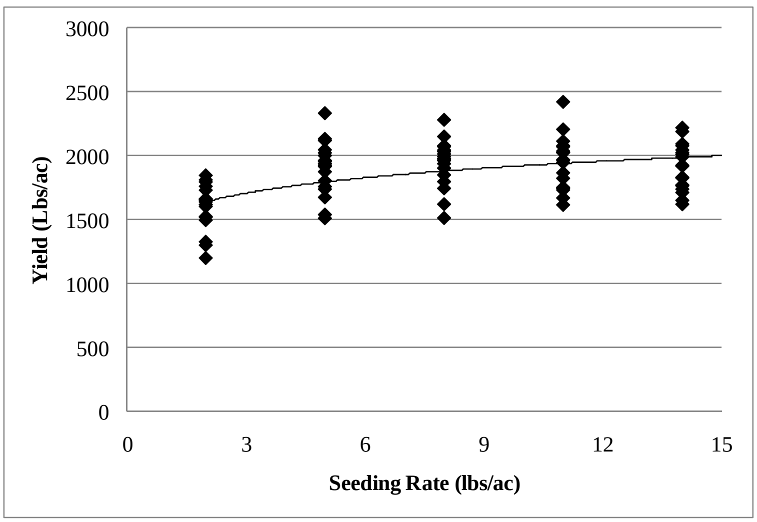

Figure 6: Non-linear regression of seeding rate by yield Averaged over all other factors at Yellow Jacket, Colorado, 2008.

In Fort Collins we are conducting trials in a specific environment with high sodium content. Crusting and high pH are the main issues. Gypsum could be a solution to fix and leach sodium down the soil profile.

<u>Second Trial:</u>

- Experimental design: split plot factorial
- Factors
    - o Gypsum rates: 0, 1 and 2 t/ac
    - o Seeding Rates: 2, 5, 8, 11 and 14 lbs/ac
    - o Varieties: Cheyenne (Blue Sun) and Calena (Montana State University)

- Location: Fort Collins, limited irrrigation (total water: 11 inches) under one sodic soil: Medium high SAR: 7.5.

- No significant interaction between variety, seeding rate, and gypsum occurred.
- A positive yield response occurred with increasing gypsum rate with camelina. Plant height shows an increase with gypsum rate.
- All studied traits except height show a significance among seeding rates. Optimum yield appears to be at 5 lbs/ac. At this density, number of pods and number of branches are higher than at higher seeding rates. Figure 7 shows the high correlation between number of pods and number of branches.

Table 13: Statistical Analysis of Various Growth and Experimental Parameters for Camelina

	Average	Min	Max	P-Value		
Traits				Variety	Seeding-Rate	Gypsum
Primary Branches	1.9	1.2	3.8	0.53	0.0001	0.43
Total number of branches	4.1	1.7	7.6	0.86	>.0001	0.16
Pods Number	48.1	11.6	117.8	0.52	>.0001	0.22
Yield (lbs/ac)	610	282	999	0.11	0.002	0.35
Height (Inches)	21.72	19.33	25.33	0.15	0.08	0.63
Stand (plant/ac)	1419483	398000	2374000	0.75	>.0001	0.63

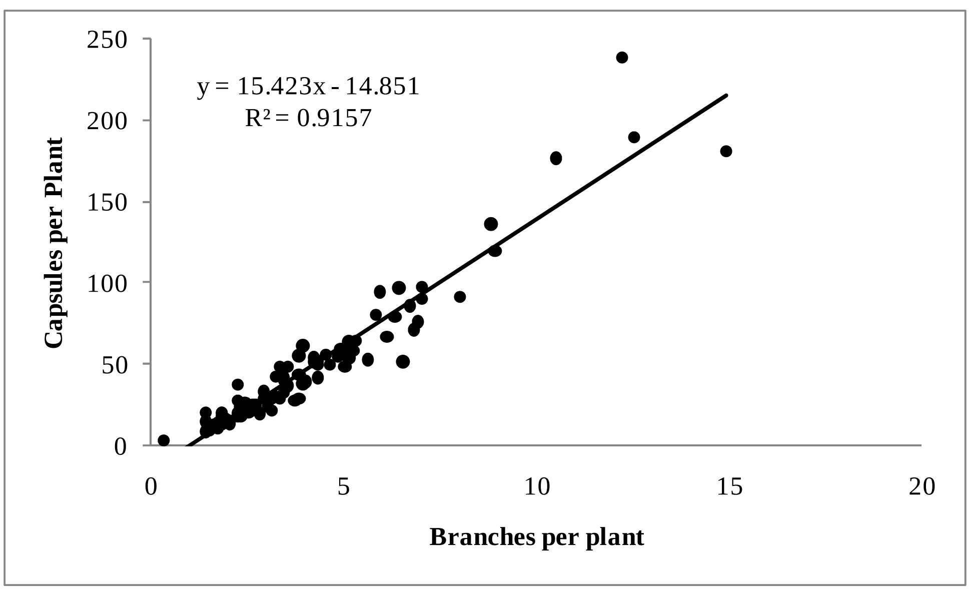

Figure 7: Correlation between branches per plant and capsules per plant in the seeding rate X gypsum rate trial.

Screening New Alternative Crops

The genetic study of camelina's drought resistance is based on a unique set of over 100 accessions from the European collection. Europe is the center of origin for camelina. The approach is simple, and water use efficiency is the main research objective. The collection is planted in the greenhouse and in the field under fully irrigated and dry conditions, and all growth and reproduction characteristics are measured. The first objective, which has already been met, is to determine if there is sufficient variation in drought response to justify further investigation, or if additional genetic material needs to be included in the set of accessions. After the first round of greenhouse/field observations, John McKay and Nicolas Enjalbert have identified accessions that show repeatable variation in response to drought both in the greenhouse and in the field. Correlations with growth and reproduction observations have given them some insight into which characteristics might be responsible for differential response to drought. This research should lead to identification of measurable traits that indicate improved water use efficiency, which can be used by breeders to identify drought resistant lines within their breeding populations. This research presents the base for future investigators to identify regions in the camelina genome responsible for the traits that confer drought resistance, and to provide oilseed physiologists the information necessary to better understand the mechanisms of drought resistance.

Camelina *sativa*

The Camelina *sativa* accessions in the tested collection have 16 countries of origin (Table 14).

Country of origin	# accessions
Czech Republic/Slovakia	1
Former Soviet Union	14
Belgium	2
Bulgaria	6
Germany	38
Italy	1
Kyrgyzstan	1
Poland	5
Romania	1
Russia	1
Spain	1
Sweden	1
Switzerland	1
Ukraine	1
unknown	26
Former Yugoslavia	1
Total	101

Table 14: Country of Origin of Camelina Accessions

Figure 8: Map of Europe showing countries of origin for camelina accessions.

Figure 8: Camelina experiment in the greenhouse.

Brassica *carinata* (Ethiopian mustard)

The Brassica *carinata* accessions in the tested collection have four countries of origin.

Table 15: Country of Origin of Ethiopian Mustard Accessions

Country of origin	# accessions
Ethiopia	33
Thailand	1
unknown	1
Zambia	4
Total	39

Figure 9: Brassica *carinata* experiment in the greenhouse.

Figure 10: A student works on the greenhouse experiment.

The Approach

Greenhouse Study

Two moisture treatments were applied: drought (60% of field capacity) and fully irrigated.

There were four replicates for each treatment.

Phenotypic measurement included height, number of pods, and seed weight.

Field Study

85 accessions of *Camelina sativa* were grown.

39 accessions of Brassica *carinata* were grown.

100 accessions of Brassica *juncea* were grown.

Two treatments: dryland and irrigated (flood irrigated three times).

Two replicates for each treatment.

Previous crop was alfalfa.

Planted by hand in one-meter rows.

Phenotypic measurements included height, date of flowering, number of pod, pods density, pod size, seed weight, number of seed per pods, number of branches, and biomass per plant.

Results and Analysis

Several field conditions affected plant emergence and growth. The seed bed was rough, and there was high clay content in the seed bed soil. Plant growth was suppressed and plant population was reduced by flooding caused by the tornado that struck the research station in June 2008.

Camelina sativa

There were significant differences among accessions for height and pod number in the greenhouse, as well as significant differences among accessions for seed weight in the field (Table 16).

Table 16: Summary of Camelina Performance in the Greenhouse and in the Field

	Greenhouse		Field		
	Height	Pods	Height	Seed wt	plt Biomass
	p-value	p-value	p-value	p-value	p-value
Accessions	0.0002	0.0013	0.0905	0.0018	0.1014
Treatment	<.0001	<.0001	<.0001	<.0001	<.0001
Interaction	0.99	0.27	0.16	0.0044	0.252
CV	16	41	47	79	53

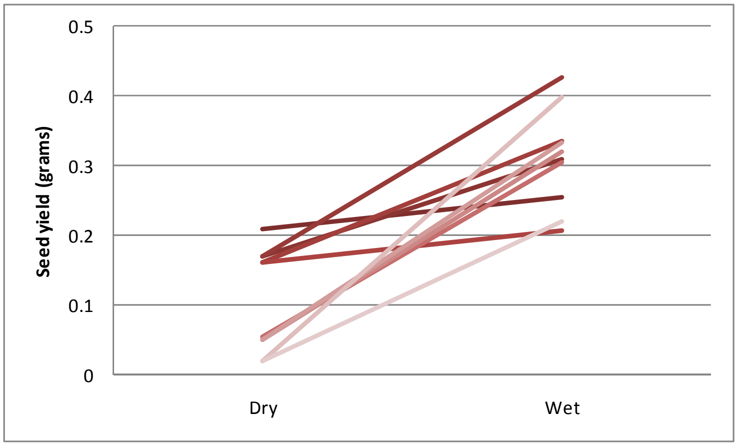

Figure 11: The interaction of accessions under wet and dry conditions for seed weight in the greenhouse.

All traits measured in the greenhouse were also measured in the field. Table 17 is the complete correlation table for these traits. Figure 13 is an example of one correlation showing that seed weight in the greenhouse is negatively correlated under dry conditions to seed weight from all accessions under well watered conditions (r = -0.36; P = 0.0099). This suggests that some accessions are better adapted to dry environments. These accessions are potential sources of genes for drought tolerance.

Table 17: Correlation of Traits in Field and Greenhouse-grown Plants

	heighGHD	Seedghd	podghd	heightghw	seedghw	podghw	heightfd	seedfd	biomassfd	heightfw	seedfw	biomassfw
heighGHD	1 50	0.20351 0.1563 50	0.10886 0.4517 50	0.64286 <.0001 50	0.05818 0.6882 50	0.11399 0.4306 50	-0.03463 0.8133 49	-0.00919 0.9495 50	-0.01611 0.9116 50	-0.08694 0.5483 50	-0.1033 0.4753 50	-0.07584 0.6006 50
Seedghd	0.20351 0.1563 50	1 50	0.45218 0.001 50	-0.04652 0.7484 50	-0.36171 0.0099 50	0.03064 0.8327 50	-0.25584 0.076 49	-0.14253 0.3234 50	-0.21899 0.1265 50	-0.24179 0.0907 50	-0.21377 0.1361 50	-0.25159 0.078 50
podghd	0.10886 0.4517 50	0.45218 0.001 50	1 50	-0.05395 0.7098 50	-0.28749 0.0429 50	0.11883 0.4111 50	-0.07708 0.5986 49	-0.04315 0.7661 50	-0.0905 0.532 50	-0.11927 0.4094 50	-0.10529 0.4668 50	-0.12568 0.3845 50
heightghw	0.64286 <.0001 50	-0.04652 0.7484 50	-0.05395 0.7098 50	1 50	0.22733 0.1124 50	0.33434 0.0176 50	-0.10604 0.4684 49	-0.16734 0.2454 50	-0.1399 0.3325 50	-0.30724 0.03 50	-0.30789 0.0296 50	-0.29148 0.04 50
seedghw	0.05818 0.6882 50	-0.36171 0.0099 50	-0.28749 0.0429 50	0.22733 0.1124 50	1 50	0.27548 0.0528 50	0.0314 0.8304 49	0.02137 0.8829 50	-0.02397 0.8687 50	0.00836 0.954 50	-0.07626 0.5987 50	0.01545 0.9152 50
podghw	0.11399 0.4306 50	0.03064 0.8327 50	0.11883 0.4111 50	0.33434 0.0176 50	0.27548 0.0528 50	1 50	-0.17559 0.2275 49	-0.35056 0.0126 50	-0.24427 0.0873 50	-0.21595 0.132 50	-0.23899 0.0946 50	-0.25534 0.0735 50
heightfd	-0.03463 0.8133 49	-0.25584 0.076 49	-0.07708 0.5986 49	-0.10604 0.4684 49	0.0314 0.8304 49	-0.17559 0.2275 49	1 49	0.58265 <.0001 49	0.95338 <.0001 49	0.12442 0.3943 49	0.15537 0.2864 49	0.12334 0.3985 49
seedfd	-0.00919 0.9495 50	-0.14253 0.3234 50	-0.04315 0.7661 50	-0.16734 0.2454 50	0.02137 0.8829 50	-0.35056 0.0126 50	0.58265 <.0001 49	1 50	0.5809 <.0001 50	0.12565 0.3846 50	0.16767 0.2445 50	0.1223 0.3975 50
biomassfd	-0.01611 0.9116 50	-0.21899 0.1265 50	-0.0905 0.532 50	-0.1399 0.3325 50	-0.02397 0.8687 50	-0.24427 0.0873 50	0.95338 <.0001 49	0.5809 <.0001 50	1 50	0.14308 0.3215 50	0.16778 0.2441 50	0.14732 0.3073 50
heightfw	-0.08694 0.5483 50	-0.24179 0.0907 50	-0.11927 0.4094 50	-0.30724 0.03 50	0.00836 0.954 50	-0.21595 0.132 50	0.12442 0.3943 49	0.12565 0.3846 50	0.14308 0.3215 50	1 50	0.92376 <.0001 50	0.98827 <.0001 50
seedfw	-0.1033 0.4753 50	-0.21377 0.1361 50	-0.10529 0.4668 50	-0.30789 0.0296 50	-0.07626 0.5987 50	-0.23899 0.0946 50	0.15537 0.2864 49	0.16767 0.2445 50	0.16778 0.2441 50	0.92376 <.0001 50	1 50	0.8853 <.0001 50
biomassfw	-0.07584 0.6006 50	-0.25159 0.078 50	-0.12568 0.3845 50	-0.29148 0.04 50	0.01545 0.9152 50	-0.25534 0.0735 50	0.12334 0.3985 49	0.1223 0.3975 50	0.14732 0.3073 50	0.98827 <.0001 50	0.8853 <.0001 50	1 50

f: field; gh: Greenhouse; D: dry; W: wet.

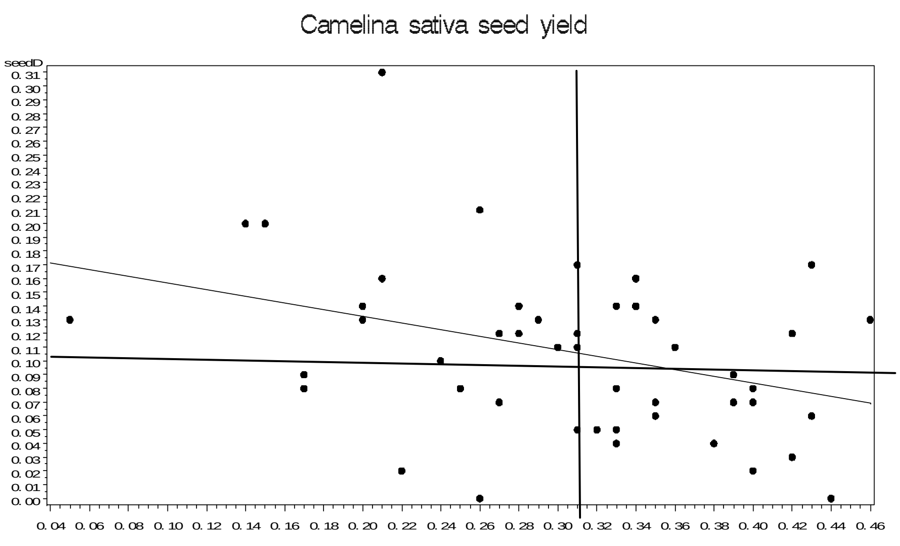

Figure 12: Example of a significant negative correlation in seed weight between wet and dry treatment in the greenhouse.

Depending on the origin of camelina accessions, their differences are significant. The Spanish camelina lines tend to do better under dry treatment in both environments. The origin of different accessions may explain some drought tolerance characteristics. For example, single accessions from Spain and Germany respond differently to wet vs. dry growing conditions. In both the greenhouse and the field, the accessions from Germany had higher seed weight than the accessions from Spain. However, the accession from Spain was equal or superior to accessions from Germany under dry conditions (Figures 14 and 16).

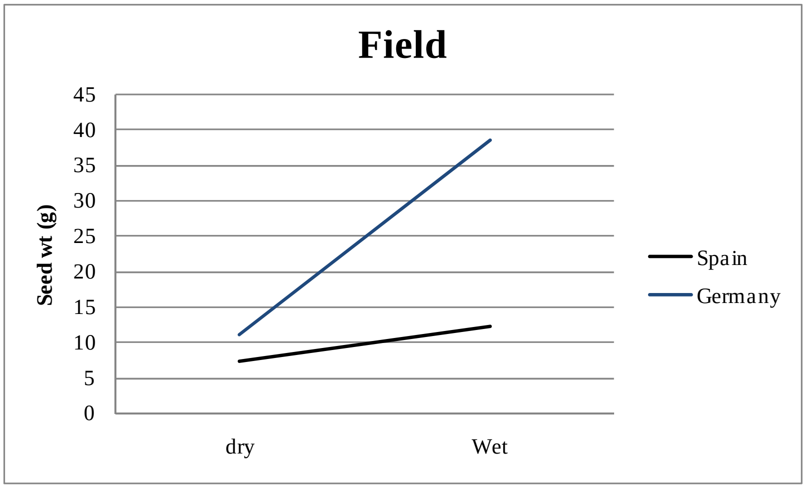

Figure 13: Reaction norm for seed weight per plant in the field between two accessions from different origins.

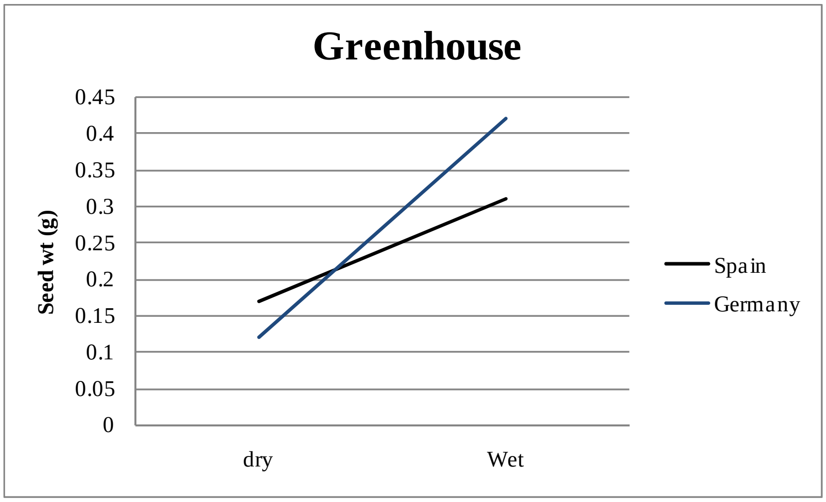

Figure 14: Reaction norm for seed weight per plant in the greenhouse between two accessions from different origins.

Brassica carinata

There were significant differences among accessions for height, seed weight, pod number, and plant biomass in the field (Table 18).

Table 18: Summary of *Brasica carinata* Screening Statistical Analysis

	Height	Seed wt	plt Biomass	Pods
	p-value	p-value	p-value	p-value
Accessions	<.0001	<.0001	0.1400	<.0001
Treatment	<.0001	<.0001	<.0001	<.0001
Interaction	0.0036	0.09	0.47	0.25
CV (%)	12	27	43	19

Flea beetle is one of the most damaging pests to canola. Notes were taken on all accessions. The flea beetle pressure was very high. Some *Brassica carinata* accessions did not have any flea beetles on them, and some were entirely infested. The evaluation was done on a scale from one to three:

- One: no damage
- Two: partially infested
- Three: entirely infested

The results show a strong correlation between dry and wet treatments, suggesting that the flea beetle tolerance is not dependent on water regime. Some accessions appear to be resistant to flea beetles. It could be attributed to the glucosinolate content in the plant, which inhibits insect feeding. Camelina was not affected by flea beetles.

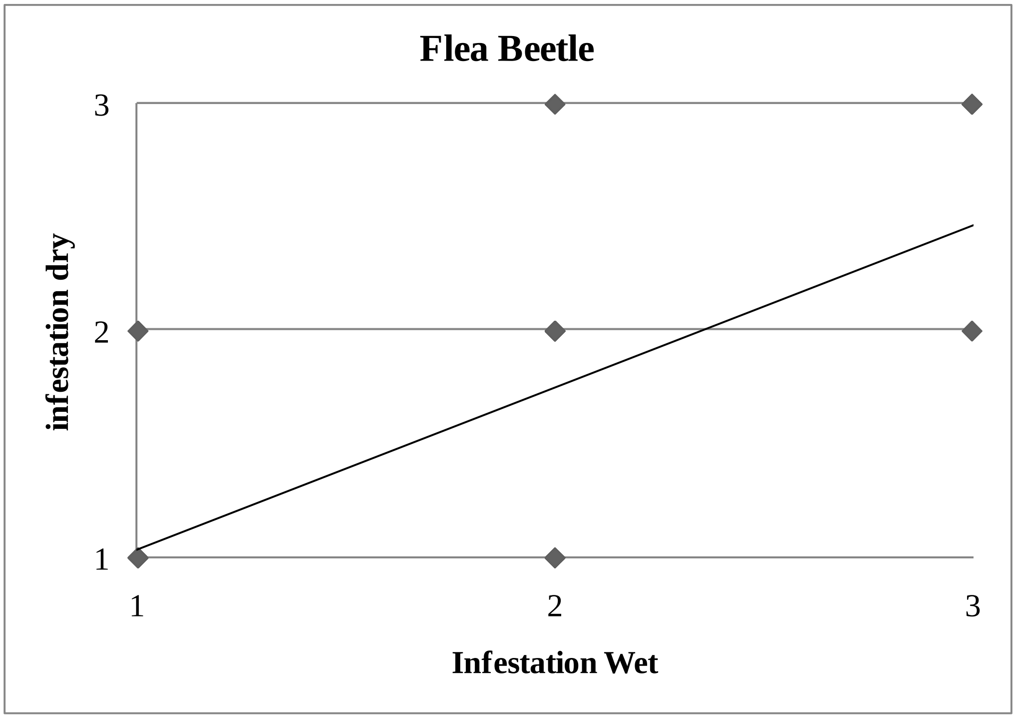

Figure 15: Significant positive correlation (r = 0.853) for flea beetle infestation of accessions between wet and dry treatments. (Infestation scale: one = no infestation; three = totally infested)

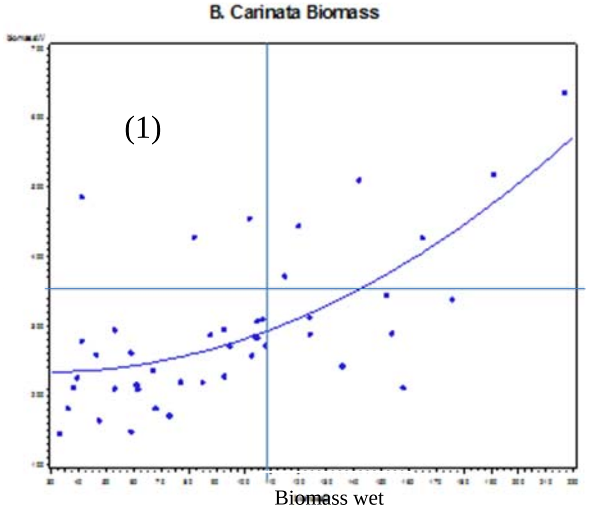

Figure 16: Significant positive correlation (r = 0.628) for biomass of accessions between wet and dry treatments. Presence of outliers (1) shows that some accessions do better under dry environments than other accessions.

Table 19: Correlation of Traits in Field-Grown *Brassica carinata*

	heightD	HeightW	biomasW	biomasD	seedW	seedD	podD	podW
heightD	1	0.23316	0.19738	0.25294	0.16641	0.12536	0.44935	0.22472
		0.1147	0.1937	0.0937	0.2636	0.4119	0.0015	0.1289
	47	47	45	45	47	45	47	47
HeightW	0.23316	1	0.53879	0.36023	0.33341	0.08989	0.3288	0.65001
	0.1147		0.0001	0.0139	0.0206	0.5524	0.0225	<.0001
	47	48	46	46	48	46	48	48
biomasW	0.19738	0.53879	1	0.62829	0.73085	0.11262	0.08611	0.0706
	0.1937	0.0001		<.0001	<.0001	0.4667	0.5694	0.641
	45	46	46	44	46	44	46	46
biomasD	0.25294	0.36023	0.62829	1	0.21302	0.37905	0.17958	-0.00553
	0.0937	0.0139	<.0001		0.1552	0.0094	0.2324	0.9709
	45	46	44	46	46	46	46	46
seedW	0.16641	0.33341	0.73085	0.21302	1	0.18996	0.09873	0.08807
	0.2636	0.0206	<.0001	0.1552		0.2061	0.5044	0.5517
	47	48	46	46	48	46	48	48
seedD	0.12536	0.08989	0.11262	0.37905	0.18996	1	0.10733	0.03764
	0.4119	0.5524	0.4667	0.0094	0.2061		0.4777	0.8039
	45	46	44	46	46	46	46	46
podD	0.44935	0.3288	0.08611	0.17958	0.09873	0.10733	1	0.48003
	0.0015	0.0225	0.5694	0.2324	0.5044	0.4777		0.0006
	47	48	46	46	48	46	48	48
podW	0.22472	0.65001	0.0706	-0.00553	0.08807	0.03764	0.48003	1
	0.1289	<.0001	0.641	0.9709	0.5517	0.8039	0.0006	
	47	48	46	46	48	46	48	48

W: irrigated; D: dryland

Many yield components of accessions show a positive correlation between dry (D) and wet (W) treatments.

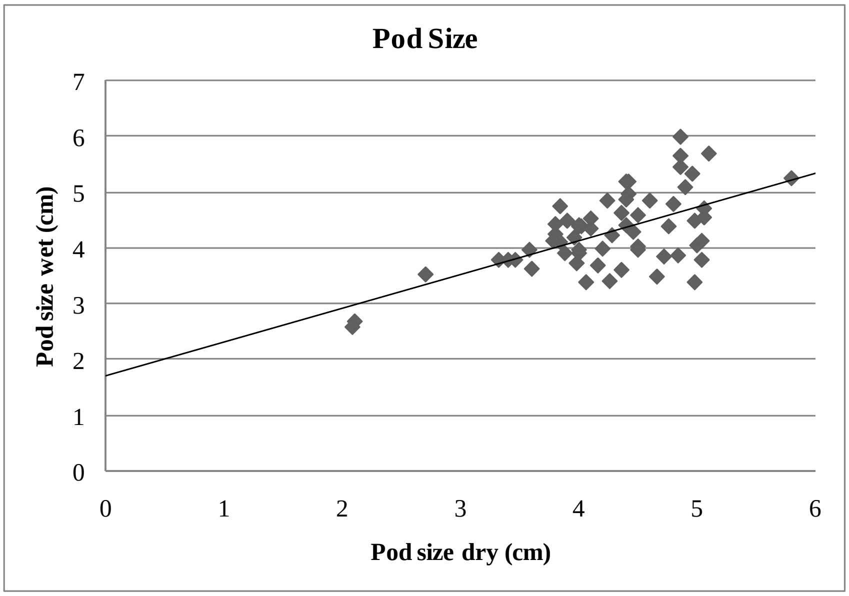

Figure 17: Significant positive correlation (r = 0.601) for pod size of accessions between wet and dry treatment.

We have found substantial variation among Camelina *sativa*, Brassica *carinata,* and Brassica *juncea* accessions in several traits of interest. These traits exhibit significant effects of genotype and treatment, as well as interactions between them, emphasizing the importance of local environment for the evaluation of lines for selection. Additional traits of importance will be evaluated in these accessions (such as oil content and profile, carbon isotope ratio, seed size, and protein content). In future years, a mapping population of camelina will be evaluated to localize genetic regions associated with these traits.

Economic Feasibility

The following economic feasibility study is designed to address three practical economic questions frequently asked about oilseed production for use as SVO on the farm. Oilseed crops in the Brassicacea family, like canola and camelina, are good rotation crops because they could fit into a wheat-based cropping system, and they can break some harmful pest cycles.

1. What is the break-even price per pound and yield that would make it economically feasible to produce oilseed under limited irrigation conditions, dryland and full irrigation?
2. What price per gallon of petroleum diesel vs. oilseed yield is feasible to grow your own fuel?
3. What is the break-even price per pound and diesel that would make it economically feasible to buy and crush oilseed for fuel without growing any crop?

Cropping systems options that include oilseed production for biofuel can be considered, but in the interest of answering these three questions as succinctly and clearly as possible our economic example is based on:

1. A limited irrigation system: three crops in three years and including winter wheat: corn/spring canola /winter wheat
2. A dryland system: three crops in three years and including winter wheat: corn/spring camelina/winter wheat

The rotation with spring canola allows the producer to harvest the oilseed in late July and plant winter wheat in the same year. Our limited irrigation cropping system production costs differ from the costs of full irrigation by lower costs of nitrogen fertilizer and slightly lower irrigation costs. Moreover, the fixed cost per crop is lower in the spring oilseed/winter wheat rotation because there are three crops in three years, as opposed to three crops in four years. The operating costs and direct costs assumed for this example are provided in Table 17. The nitrogen cost is very volatile. The price used is $0.6/lb. Oilseed meal (approximately 2/3 of harvest weight) from crushed oilseed is currently worth approximately $0.15/lb and has been included in the net return calculations, based on the assumption that it could be sold locally or used on the farm.

Limited Irrigation Rotation

Price $/lb	Alternative Yield (lbs/acre)					
	1800	2000	2200	2400	2600	2800
0.1	-167	-147	-127	-107	-87	-67
0.12	-131	-107	-83	-59	-35	-11
0.14	-95	-67	-39	-11	17	45
0.16	-59	-27	5	37	69	101
0.18	-23	13	49	85	121	157
0.2	13	53	93	133	173	213
0.22	49	93	137	181	225	269
0.24	85	133	181	229	277	325
0.26	121	173	225	277	329	381
0.28	157	213	269	325	381	437

1. Limited Irrigated Spring Canola Break-Even Analysis – Per Acre Returns Over Total Direct Cost ($/acre) in Eastern Colorado.

Price $/lb	Alternative Diesel price($/gal)					
	2.5	2.8	3.1	3.4	3.7	4
0.1	246	276	306	336	366	396
0.12	202	232	262	292	322	352
0.14	158	188	218	248	278	308
0.16	114	144	174	204	234	264
0.18	70	100	130	160	190	220
0.2	26	56	86	116	146	176
0.22	-18	12	42	72	102	132
0.24	-62	-32	-2	28	58	88
0.26	-106	-76	-46	-16	14	44
0.28	-150	-120	-90	-60	-30	0

3. Limited Irrigated Spring Canola Break-Even Analysis – Per 2200 lbs Returns Over Total Cost Oilseed ($/lb) and Diesel Price ($/gal) in Eastern Colorado.

1. **Producing canola under limited irrigation is profitable producing a positive net return of 49 $/ac**
2. **Producing seed and crushing is the most interesting option at current diesel price: 127 $/ac**
3. **Buying seed and crushing give a net return of $100 for every 2200 lbs crushed**

Price $/gal	AlternativeYield (lbs/acre)					
	1800	2000	2200	2400	2600	2800
1.9	-33	2	37	71	106	141
2.2	-8	29	67	104	142	180
2.5	16	57	97	137	178	218
2.8	41	84	127	170	213	256
3.1	65	111	157	203	249	295
3.4	90	139	187	236	284	333
3.7	115	166	217	269	320	371
4	139	193	248	302	356	410

2. Limited Irrigated Spring Canola Break-Even Analysis – Per Acre Returns Over Total Direct Cost ($/acre) as a function of diesel price, in Eastern Colorado

Figure 18: Canola economic study under limited irrigation.

At average yield of 2,200 lbs/ac under limited irrigation (2007 average trial yield), the net return at the current market price ($0.18/lb) is estimated at $127/ac, if the seed is crushed on farm. At yields of 2,200 and 2,400 lbs/ac, the break-even points are estimated at $0.15 and $0.14, respectively. After several years of experimentation and experience in farmer's fields, we believe that average and sustainable limited irrigation canola yields of 2000-2400 lb/ac are realistically attainable. Even when the price of petroleum diesel is at $2.50/gallon and hypothetical yields of 1800 lb/ac, positive returns per acre would be expected for SVO production on the farm with canola, but not with camelina. At average yields of 2200 lb/ac and petroleum diesel at $2.50/gallon, net returns are expected to be $96/ac.

Dryland Rotation

Price $/lb	AlternativeYield (lbs/acre)					
	400	600	800	1000	1200	1400
0.1	-75	-55	-35	-15	5	25
0.12	-67	-43	-19	5	29	53
0.14	-59	-31	-3	25	53	81
0.16	-51	-19	13	45	77	109
0.18	-43	-7	29	65	101	137
0.2	-35	5	45	85	125	165
0.22	-27	17	61	105	149	193
0.24	-19	29	77	125	173	221
0.26	-11	41	93	145	197	249
0.28	-3	53	109	165	221	277

1. Dryland Spring Camelina Break-Even Analysis – Per Acre Returns Over Total Direct Cost ($/acre) in Eastern Colorado.

Price $/lb	Alternative Diesel price($/gal)					
	2.5	2.8	3.1	3.4	3.7	4
0.1	112.0	125.6	139.1	152.7	166.3	179.8
0.12	92.0	105.6	119.1	132.7	146.3	159.8
0.14	72.0	85.6	99.1	112.7	126.3	139.8
0.16	52.0	65.6	79.1	92.7	106.3	119.8
0.18	32.0	45.6	59.1	72.7	86.3	99.8
0.2	12.0	25.6	39.1	52.7	66.3	79.8
0.22	-8.0	5.6	19.1	32.7	46.3	59.8
0.24	-28.0	-14.4	-0.9	12.7	26.3	39.8
0.26	-48.0	-34.4	-20.9	-7.3	6.3	19.8
0.28	-68.0	-54.4	-40.9	-27.3	-13.7	-0.2

3. Dryland Spring Camelina Break-Even Analysis – Per 1000 lbs Returns Over Total Cost Oilseed ($/lb) and Diesel Price ($/gal) in Eastern Colorado.

1. Producing camelina under dryland is profitable. At 0.18 $/lbs and 1000 lbs/ac, the net return is 46 $/ac.
2. Producing seed and on farm crushing bring the biggest net return: 81.5 $/ac
3. Buying seed and crushing has an equivalent net return that to only producing seed, but safer.

Price $/gal	AlternativeYield (lbs/acre)					
	400	600	800	1000	1200	1400
1.9	-45	-10	24	59	94	129
2.2	-40	-2	35	73	111	148
2.5	-34	6	46	87	127	167
2.8	-29	14	57	100	144	187
3.1	-23	22	68	114	160	206
3.4	-18	31	79	128	176	225
3.7	-12	39	90	142	193	244
4	-7	47	101	155	209	263

2. Dryland Spring Camelina Break-Even Analysis – Per Acre Returns Over Total Direct Cost ($/acre) as a function of diesel price, in Eastern Colorado

Figure 19: Camelina economic study under dryland production.

At average yield of 1,000 lbs/ac under dryland (2007 average trial yield), the net return at the current market price ($0.18/lb) would be $81.5/ac if seed is crushed on farm. After several years of experimentation and experience in farmers' fields, we believe that average and sustainable dryland camelina yields of 800-1000 lb/ac are realistically attainable. Perhaps equally important is that on-farm production of biofuel (independence from foreign energy) would make Colorado's food and feed supply more secure without being affected by world affairs beyond local control. In addition, the carbon footprint of Colorado agriculture would be smaller.

Table 20: 2008 Estimated Production Costs and Returns – Limited Irrigation Spring Canola, Colorado

2008 Estimated Production Costs and Returns - Irrigated Spring Canola, Colorado

	Unit	Cost/unit	Quantity	**Cost/value per ac**	Cost per unit of production
Production	lbs.	0.11	3000	330	
Total Receipts				330	0.11
Direct Cost:					
Operating Preharvest					
Disc	Acre			2.66	0.006
Nitrogen	lbs.	0.60	120	72.00	0.164
Phosphate	lbs.	0.33	20	6.60	0.015
Potassium	lbs.	0.14	24	3.36	0.008
Sulfur	lbs.	0.21	10	2.10	0.005
Custom Fertilizer Appl	Acre			1.16	0.003
Seed	lbs.	7.00	5	35.00	0.080
Herbicide (Sonalan/treflan)	oz	0.40	24	9.60	0.022
Custom Herbicide Appl	Acre			1.55	0.004
Irrigation Energy	Acre			40.00	0.091
Irrigation Labor	hr.	10.00	1	10.00	0.023
Interest on Op.Cap	DOLS.				0.000
Total Preharvest:	DOLS.			184.03	0.419
Operating Harvest:					
Machinery Operating Cost/haul	bu.	0.24	50	12.00	0.004
Total Harvest				12.00	0.064
Total Operating Cost:				196.03	0.483
Property and Ownership Costs:					
Machinery replacement & Machinery Taxes & Insura	DOLS.			9.7	
General Farm Overhead	DOLS.			15	
Real Estate taxes	DOLS.			16	
Total Property and ownership costs:	DOLS.			40.7	
Total Direct Costs:				236.73	
Factor payment:				111.05	
Net Receipts - Factor Payments:				347.78	0.12
Net Return				-17.78	
Break-even to cover:	lbs			3,162	0.12

Table 21: 2008 Estimated Production Costs and Returns – Dryland Spring Camelina, Colorado

2008 Dryland Spring Camelina in Northeastern Colorado						
		Unit	Cost/unit	Quantity	**Cost/value per ac**	Cost per unit of production
Production		lbs.	0.15	1000	150	
Total Receipts					150	0.15
Direct Cost:						
Operating Preharvest						
	Nitrogen	lbs.	0.6	40	24	0.0547
	Phosphate	lbs.	0.33	0	0	0.0000
	Potassium	lbs.	0.14	0	0	0.0000
	Sulfur	lbs.	0.21	0	0	0.0000
	Custom Fertilizer Appl	Acre			1.16	0.0026
	Seed	lbs.	2	2.5	5	0.0114
	Herbicide (Sonalan/treflan)	oz	0.4	24	9.6	0.0219
	Custom Herbicide Appl	Acre			1.55	0.0035
	Machinery Op. Costs	DOLS.			19.85	0.0452
Total Preharvest:		DOLS.			61.16	0.0942
Operating Harvest:						
	Machinery Operating Cost	DOLS.			15.2	0.0152
	Hauling	DOLS.			4	0.0040
Total Harvest					19.2	0.0641
Total Operating Cost:					80.36	0.1583
Net return					69.64	
Property and Ownership Costs*:						
	Machinery replacement & Machinery Taxes & Insurance	DOLS.			18.0	
	General Farm Overhead	DOLS.			6.6	
	Real Estate taxes	DOLS.			1.2	
Total Property and ownership costs*:		DOLS.			35.0	
Total Direct Costs:					115.4	
Factor payment*: land at 4.00%					19.0	
Net Receipts - Factor Payments:					134.4	0.13
Net Return with fixe cost					15.6	
Break-even to cover:		lbs			1,222	0.13
*Fix costs established in a three years rotation with three crops.						

Benefits of SVO for Colorado

SVO has many benefits when compared to petro-diesel and other biofuels. It requires no refining, and it is not harmful to living organisms. As a renewable resource it provides a reliable income opportunity for many farming generations. The German Federal Water Act on the Classification of Substances Hazardous to Waters denotes SVO as NWG (non hazardous to water)[1]. Biodiesel, on the other hand, is slightly hazardous to water, while diesel and gasoline are rated as highest toxicity. A North American study of the toxicity of vegetable oil in freshwater has found no harmful SVO effects[2].

Figure 20: iCAST Engineering Project manager Micah Allen presents "How to Make Your Own Fuel" to a group of farmers.

As a fuel, SVO emits 40 to 60% less soot[3,4] than petro-diesel. It does not contain sulphur, and therefore does not cause acid rain[5]. In addition, carbon monoxide and particulate emissions are slightly lower. CO_2 emissions are also reduced by 80 to 96%[6,7] compared to petro-diesel when

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[1] (*WGK (Wassergefährdungsklassen):The German Water hazard classes.* Available at http://www.folkecenter.dk/plant-oil/WGK_ENG.htm; http://www.folkecenter.dk/plant-oil/publications/vwvws.pdf)
[2] (http://www.epa.gov/oilspill/pdfs/Li-Lee-Cobanli-Wrenn-Venosa-Doe_FSS06.pdf)
[3] (http://home.clara.net/heureka/gaia/veggie-oil.htm).
[4] (http://www.biomatnet.org/secure/Fair/F484.htm)
[5] www.folkecenter.dk/plant-oil/publications/PPO-emissions.htm
[6] (http://www.folkecenter.dk/plant-oil/publications/energy_co2_balance.pdf)

locally produced and used for fuel. Finally, Polycyclic Aromatic Hydrocarbons (PAH) emissions are distinctly lower for all vegetable fuels, reducing risks of cancer[8] (Figure 22). SVO can contribute to an energy-independent Colorado agricultural system and can increase food and feed sector security. Gasoline has a 0.873[9] energy ratio (energy yield/energy input). If we include distribution and the value of canola meal, the energy ratio number for canola-based SVO is 5.45[10], while for sunflower-based SVO, it is 6.33[11] (Table 22).

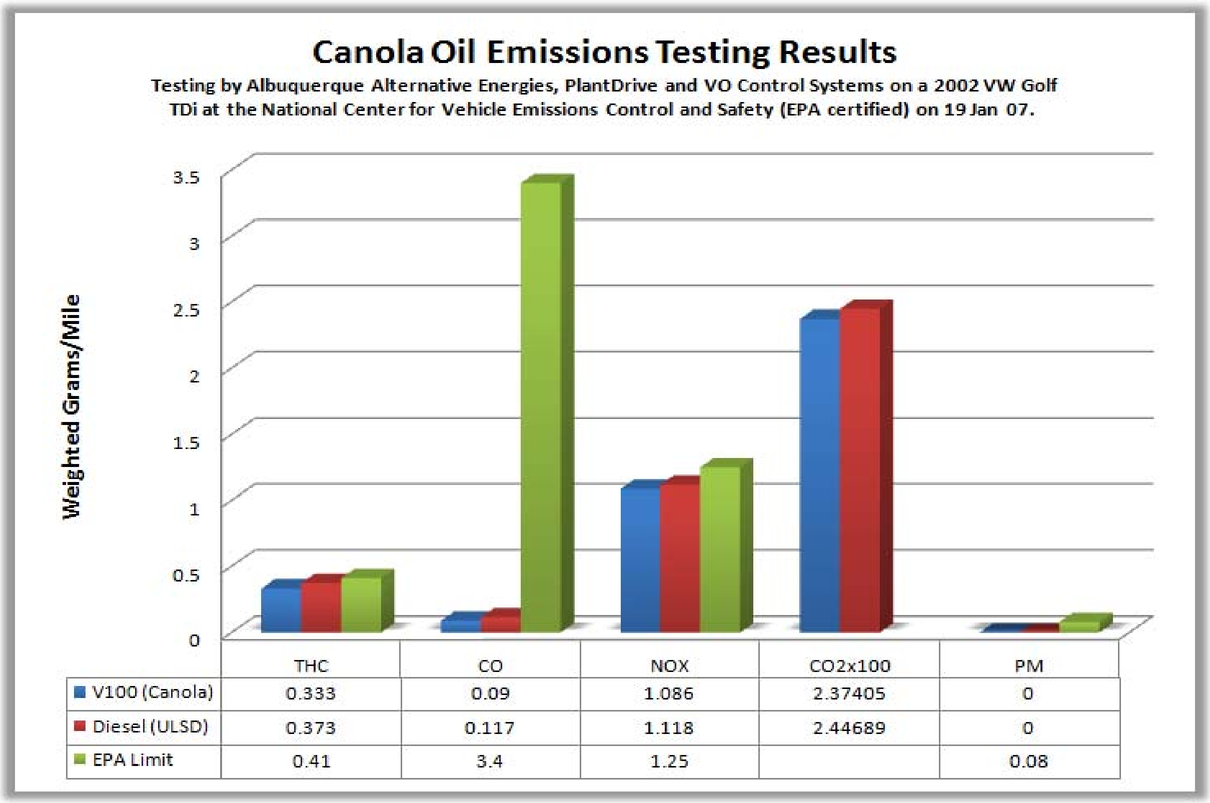

Figure 21: Canola oil emissions testing results.

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7 Institut Français des Huiles Végétales Pure, ADEME 21/11/06

8 http://www.biomatnet.org/secure/Fair/F484.htm

9 Institut Français des Huiles Végétales Pure, ADEME 21/11/06

10 http://www.valbiom.be/, Biomass certification

11 ADVA 31

Table 22: Energy Ratio of Different Fuels Including SVO

	Regular Unleaded	Diesel	Biodiesel Canola	Biodiesel Sunflower	SVO Canola	SVO Sunflower
Ration energy produced / Non renewable energy used	0.873	0.917	2.99	3.16	**5.45**	**6.33**
Green house gas emissions (q eq. CO2 / kg)	3650	3390	888	745	**660**	**498**

Training

Figure 22: Shusong Zeng, a CSU post-doctoral researcher from China.

Figure 23 : CSU undergraduate student Tom Fitzgerald with Shusong Zeng.

Figure 24: Gaelle Berges, master's student from Ecole d'Ingenieur de Purpan in France.

Figure 25 : David Johnson and Blake Robinson, high school students Fort Collins.

Figure 26: CSU graduate student Jean-Nicolas Enjalbert.

Figure 27: A biodiesel adventure journalist from Japan.

Figure 28: A group of farmers at the Oilseed Field Day at Yellow Jacket, Colorado, summer 2008.

Figures and Tables

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