Winter Camelina Supply Chain Development & Regional Opportunities for Oilseed Processing

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Table of Contents

Introduction

Winter Camelina (*Camelina sativa* L.) is an oilseed cover crop of the Brassicaceae family which is planted in late summer and harvested in mid to late June. Numerous studies have shown winter camelina to offer an abundance of ecosystem services, such as the prevention of nitrogen leaching into wetlands due to soil erosion, carbon sequestration, and early flowering that provides a plentiful pollen source for honey bees and other beneficial pollinators in the upper Midwest.

Photo: Dylan VanBoxtel

In recent years, winter camelina has also attracted attention for its potential to bring economic benefit to growers as a cash cover crop, as it can be harvested early enough to allow for the planting of a second crop, which increases overall land productivity [1]. Increasing land productivity could in turn increase overall profitability of farm enterprises in the upper Midwest. The seed typically contains 30-40% oil by weight, with 38% of its total oil composed of omega-3 (alpha linolenic acid) fatty acid [3]. It also contains higher levels of vitamin E compared to flax, giving it a longer shelf life, and contains lower levels of anti-nutritional glucosinolate and erucic acid than other mustard seeds [2]. This favorable nutritional profile gives winter camelina strong market potential for use in a variety of commercial products such as cooking oil, prepared foods, plant-based protein food ingredients, animal feed, and feedstock for biofuels and biopolymer production.

Yet despite its known ecosystem benefits and strong potential to benefit growers economically, acreage of winter camelina still remains largely within research plots, with approximately 40 acres of commercial acreage currently planted within the United States.

This report presents research funded by a North Central Sustainable Agriculture and Education (NCR-SARE) Crop Production grant, with the purpose to establish supply chain connections and identify commercialization opportunities and potential barriers to supply chain development as winter camelina enters early-stage commercialization. Research was completed in partnership with the Agriculture Utilization Research Institute (AURI) for oilseed processing, product analyses, and the establishment of supply chain connections.

Stakeholder Engagement & Outreach

Over the 36-month period of this NCR-SARE project, University of Minnesota supply chain and market development researchers worked in partnership with AURI to engage current and potential supply chain stakeholders in various in-person and on-line events to disseminate information about ongoing winter camelina research and communicate winter camelina's environmental benefits and economic potential to farmers, processors, and the public.

Stakeholder engagement included three field day events aimed at launching winter camelina into Minnesota's agricultural landscape by highlighting its potential for food, fuel, and feed markets. Field day events incorporated demonstrations of oil pressing, samplings of food and baked goods made with camelina oil, and researcher presentations.

Additional stakeholder engagement included presentations and attendance at regional agriculture and food science conferences, sharing of information with key industry contacts in formal and informal meetings and dissemination of information about winter camelina through the utilization of several online platforms, including webinars and conferences hosted by the Forever Green Partnership and AURI. Oilseed processors in the upper Midwest were also engaged directly through extended in-person conversations, onsite interviews, and phone calls to better understand processor business practices, identify risks and concerns in processing a novel crop, and gauge the level of stakeholder interest. For more detailed information on winter camelina field days and AURI's involvement in events, outreach, and stakeholder engagement, (see Appendix A).

Winter Camelina Supply Chain & Market Development

Camelina is an annual (spring camelina) or winter annual (winter camelina) oilseed crop. Spring camelina is an ancient crop that originated in Northern Europe but is now also distributed across the United States, Canada, and other countries internationally. In recent years, the oilseed has attracted significant attention for its suitability for a variety of food, feed, and industrial uses and for its use as a biodiesel feedstock. In early 2010, Health Canada approved camelina oil as a novel food for inclusion in human food products, and in 2015, the Canadian Food Inspection Agency approved camelina meal for use as animal feed. As a result, market interest and camelina acreage in Canada has grown rapidly in the last few years. While the number of acres is still small relative to other oilseed commodities such as canola, the fast growth from ~5,000 acres to ~20,000 acres in just a couple years highlights camelina's emerging potential.

Smart Earth Equine Camelina Supplement, Sold in Canada

Winter camelina varieties are grown as winter annuals as part of a continuous living cover system, largely developed by the Forever Green Partnership to maximize agroecological and economic benefits to growers. Winter camelina is a new crop appearing on the landscape. While it is still grown primarily on research plots, some pilot-scale commercial acreage (~40 acres) was planted in fall of 2020 in Minnesota and neighboring states in a coordinated effort between the Forever Green Partnership commercialization team, early-adopter growers, and private partners. Similar to spring camelina, the potential for rapid growth of winter camelina is likely as new uses for camelina oil and meal are developed and supply chains for newly emerging companies mature.

Camelina Seed Meal. Photo: Camelina Solutions

In 2009, the United States Food and Drug Administration (US-FDA) allowed for limited inclusion rates of camelina meal as a feed ingredient in rations for broiler chickens, laying hens, cattle, swine, and goats. However, camelina oil has not yet received FDA GRAS (Generally Recognized as Safe) status for commercial inclusion in multi-ingredient foods. In addition, camelina meal and oil are not yet certified as approved ingredients by the Association of American Feed Controls Officials (AAFCO) for inclusion in pet foods. These regulatory constraints have severely limited camelina's market growth within the United States.

Winter camelina has the potential to bring economic benefits to growers if it proves viable as a companion crop in relay-cropping systems, as a cash cover like winter camelina would provide an additional crop revenue stream to grower enterprises. The primary objective of this NCR-SARE research was to investigate the agronomic viability of winter camelina grown within a sugar beet rotation and the conduct economic analyses (cost-benefits, transportation and processing costs, market price determination) and a supply chain assessment of infrastructure needs for economic viability. However, agronomic research conducted in years 1 and 2 showed winter camelina inclusion in a sugar beet rotation to be unsuccessful, and thus conducting subsequent economic and supply chain analysis of this system would have little value in advancing supply chain development for winter camelina.

Additionally, given that markets and supply chains are not yet developed, generalized cost analyses of transportation and processing expenditures would not prove useful, as these costs are variable depending on factors such as distance from farm gate to processor, size of contract and volume of a given production run. Market prices cannot be determined if no market exists; contract prices cannot be quoted unless there is an actual buyer. Thus, supply chain development research efforts pivoted to investigate regions of opportunity in a crop rotation known to be successful and a deeper investigation of the oilseed processing landscape in the upper Midwest, as it is certain that once acres of winter camelina are planted, they will most assuredly require processing.

A crop rotation that has shown particular promise is winter camelina following spring wheat and preceding soy. The identification of counties for which wheat is grown in MN, ND, and SD were identified using USDA-NASS Census Data, (see Figure 2) and spatial resolution of wheat areas within MN were pinpointed using USDA CropScape and Cropland Data Layer, (see Figure 1). Counties and specific pinpointed areas with higher wheat acreages are likely to be areas of opportunity for future engagement with oilseed growers and processing partners.

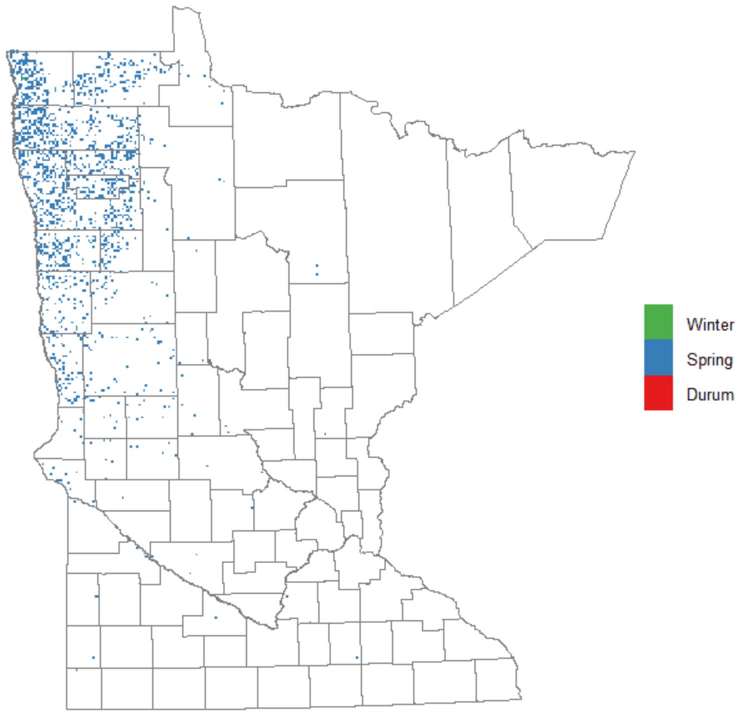


Figure 1: Wheat areas in Minnesota, 2019

Data source: land cover data from USDA CropScape and Cropland Data Layer

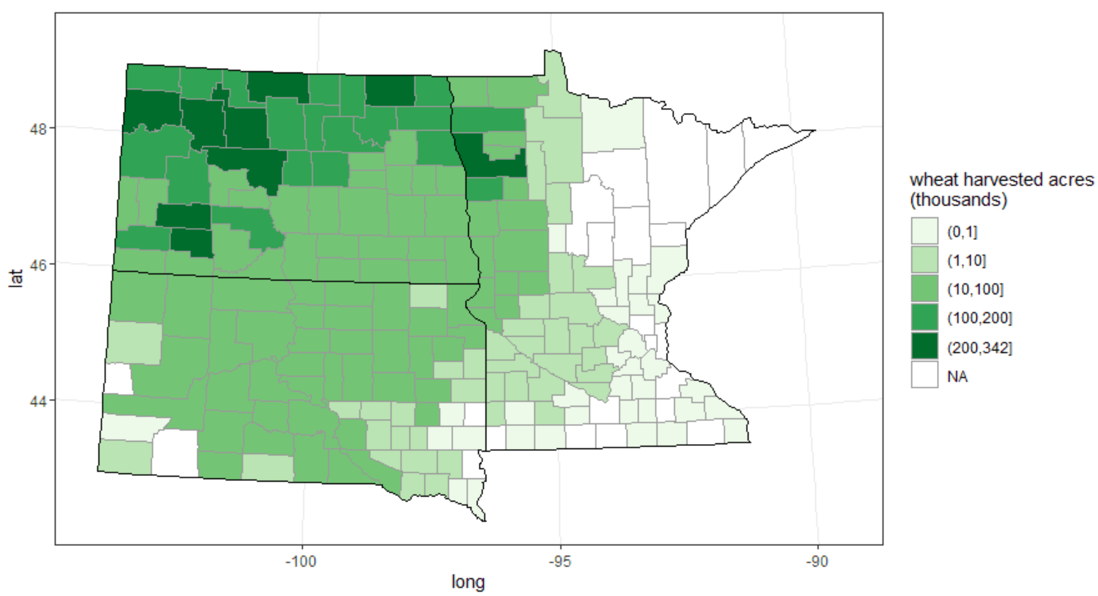


Figure 2: County-level wheat harvested acres in MN, ND, and SD, 2017

Data source: USDA-NASS Census 2017

Oilseed Processing

Processing Overview

Oilseed processing includes all value-added processes carried out from post-harvest to market sale. Oilseed extraction is the process required for the separation of oilseeds into oil and meal. Processes are designed to ensure high yields for oil extraction while attaining oil and meal products that are of high quality with minimal inclusion of undesirable components.

There are several methods for extracting oil. The two most common processes are chemical solvent extraction through use of hexane and mechanical extraction through use of a screw press. In addition to oil extraction, a variety of other processing steps are employed to ensure proper preparation of materials prior to extraction and to further refine products after pressing. All oilseeds must be properly dried, stored, and cleaned prior to pressing.

Additional processing steps for oil and meal are determined based on the necessary specifications for end-use applications in various market channels. The degree of processing which is undergone depends largely on the intended end-use application. Edible oils are typically refined, bleached, and deodorized to create an oil that is odorless and consistent in taste, color, and stability. Depending on the extraction method and end use, meal can be further processed for protein extraction or added to livestock rations.

Drying, Storing, and Cleaning

For successful extraction, oilseeds must be properly dried, stored, and cleaned prior to pressing. Properly stored seed will not become rancid and can be pressed when oil is needed. While smaller quantities of seed can be dried in preparation for storage with ambient air by placing seed in a thin layer outside, larger quantities require drying by blowing air in a grain bin or through a grain aerator attached to a storage tote or bin. Many variables are considered for optimal bin drying, which include seed size, optimal seed moisture content, bin size, and depth of seed stored in the bin [4].

Camelina seed prior to cleaning   *Photo: Colin Cureton*

Optimal moisture content for storage and pressing of winter camelina is 7-9%. If moisture levels are too high, heating of the seed pile or bin are susceptible to fungus, mold, or bacterial growth which can deteriorate seed quality. If moisture content of seed is too low, lower yields of pressed oil and higher press temperatures in processing can result. Press temperatures exceeding the 49°C (120°F) limit for designation of cold-pressed oil is often undesirable, as high temperatures can degrade the nutritional properties of oil intended for sale in high-value food market channels. High temperatures also increase oil phosphorus content which can be harmful to diesel engines if oil is refined for biodiesel.

Seed cleaning to remove unwanted foreign material such as weed seeds, chaff, and other debris is essential. Foreign material can lead to heating and mold growth during storage and can interfere with proper oil extraction during pressing. While it is optimal to perform seed cleaning prior to storage, seed cleaning is more often completed just prior to pressing. This is because harvest and seed drying equipment can generally process higher volumes than seed cleaning equipment. This highlights the importance of investing time in setting the combine properly to ensure harvested material is as clean as possible. Some research indicates that camelina may require a second seed cleaning step to ensure proper removal of other harvested materials prior to pressing [5].

Oil Extraction Methods

Mechanical Oil Extraction

The use of screw (expeller) presses is the most common extraction method used by small and midscale processors due to the relative low capital cost of equipment and the ability to extract oil continuously, which allows large quantities of oilseeds to be processed with minimal labor [7]. Management of solvents can also pose safety and environmental challenges for smaller processors, and mechanical press technologies can effectively extract oil without the use of solvents. Solvent-free processes are also more desirable for products entering high-value food markets as consumer awareness and demand continues to grow for oil products labeled with attributes such as cold-pressed, high-oleic, and non-GMO [6].

A mechanical screw press consists of a vertical feeder and a rotating horizontal screw that exerts pressure on the oilseed as it travels through the press. A barrel with slats surrounding the screw first allows for the release of internal air pressure. Oil is then drained through the barrel and collected in a trough placed beneath the screw. Oilseed meal is simultaneously extruded from the screw end. Some presses produce a pelleted cake, while others produce a flaked cake.

Täby Pressen 70, 1500 lbs/24hrs.
Photo: Oilpress.com

Extraction efficiency is the percentage of oil which can be extracted from the seed. Extraction efficiency is dependent on several factors, such as seed type and cleanliness, pressing temperature, pressure level exerted by the press and press speed. For screw presses, settings such as tip size[1] can be changed to accommodate different seeds and optimize extraction efficiency. Tips are available in varying diameters, typically from 5 mm to 15 mm, and some research has found a 7 mm tip diameter to be successful for camelina crushing.

Screw presses vary in size and the rate for which oilseeds are pressed varies greatly between equipment brands and models. There are several press manufacturers, which include: AgOil Press, Kern Kraft, Komet, and Täbypressen. The capacity, or flow rate, for small-scale presses is often measured in pounds

[1] Diameter of hole through which meal is expelled

of seed in 24 hours (lbs seed/24 hrs), while capacity of larger scale presses is measured in tons per day. While there is no clear delineation between small scale and midscale presses, for the sake of this research, all press machines with capacities of 2-ton per day and less were considered small scale.


Riley Gordon of AURI demonstrates camelina pressing

As part of this NCR-SARE research, AURI's Waseca site performed crushing of winter camelina seed. Initial analysis found 36% oil in the seed. After crushing, the meal still contained ~17% oil, indicating oil removal of 19%, or 52% efficiency for camelina extraction. After optimizing press settings and conditions for winter camelina, an extraction efficiency of 60% was achieved. Thus, 100 pounds of seed would yield approximately 23 pounds of raw oil.

Solvent Extraction

Solvent extraction is the dissolution of oil by contacting oilseeds with a liquid solvent. Chemical solvent extraction is the most efficient oilseed extraction process and is utilized in all large-scale crush facilities. A greater percentage of oil can be extracted from oilseeds through the use of solvents, such as hexane, than is extracted by use of mechanical press technology. The efficiency of extraction depends on extraction temperature, equipment design and other factors.

Solvent extraction is capital intensive, highly complex, poses risks of fire due to the flammability of solvents utilized, and is thus poorly suited for small and midscale processing. With plant capacities ranging from 100 to 9000 metric tonnes per day [9], solvent extraction processing is largely out of scope for this SARE research, which was focused on near and midterm oilseed processing opportunities for winter camelina.

Supercritical (CO_2) Extraction

Supercritical CO_2 extraction is a method by which carbon dioxide gas is used as the solvent to extract fat-based constituents from seeds or other plant materials. CO_2 is released through a series of tube chambers under critical temperatures and pressures, and in this process the CO_2 gas converts to a supercritical state and adopts liquid-like characteristics. The supercritical fluid then washes over plant materials to strip away plant oils and resins. Once processing is complete, the CO_2 is returned to a gaseous state and does not leave solvent residues characteristic of chemical solvent technologies. Thus, CO_2 extraction is marketed as an environmentally-friendly extraction alternative to chemical solvent processes.

Supercritical extraction is a relatively time-intensive batch process. While batch size varies widely based on the size of the extraction equipment, batches are generally small relative to the continuous throughput capacity of mechanical presses and large chemical solvent batches. This extraction method is used primarily in high-value specialty market applications such as premium herbal supplements. Supercritical extraction has become increasingly popular in recent years for extracting CBD and other medicinal constituents from industrial hemp.

Supercritical Extraction System. Photo: Buffalo Extraction Systems

Due to its high Omega-3 content and favorable antioxidant profile, winter camelina oil could be an attractive plant-based alternative to fish oil supplements, and supercritical extraction could be a feasible method for obtaining a premium-quality supplement oil. Nutritional supplements are high-margin products, and if contracted equitably, this market channel could potentially bring a premium price to camelina growers. True omega™, a supplement oil that blends camelina oil and Norwegian cod oil, is currently marketed and sold in the United Kingdom.

Edible Oil Refinement, Bleaching, Deodorizing

Edible oils are salad and cooking oils used for pan cooking, baking, frying, and for inclusion in a variety of products such as sauces, marinades and retail bottled oil. Once oil is extracted from the seed through mechanical pressing or solvent extraction, raw oil must be further refined for suitability as an edible oil. Filtration removes impurities in the oil which can prevent oxidation, improve oil quality, and extend shelf life. Degumming, the process of removing phospholipids from the oil, is the first process in vegetable oil refinement. AURI's pressing and filtration research used diatomaceous earth, bleaching clay and activated charcoal to filter raw winter camelina oil.

Photo: RSDP

While oil is suitable for consumption after filtration, most commercial edible oil processing facilities conduct further processing to create consumer-desirable products that are odorless and consistent in taste and color. Bleaching involves the mixing of clays to absorb colors and contaminants, while deodorizing is a distillation process involving low pressure and high temperatures. Some research suggests temperatures of 195 - 210°C for optimal removal of camelina's undesirable flavors and odors.

Seed Meal Processing and Market Channels for Food and Feed

Seed meal is a valuable co-product of pressed oilseeds. After oil is mechanically extracted through cold pressing, winter camelina meal remains relatively high in nutrient-rich oil, protein and fiber. Oilseed meal is often utilized directly in feed rations for production animals. Camelina meal has FDA approval for: poultry layer and broiler feed rations up to 10%, beef cattle rations up to 10%, and swine feed rations up to 2%. There is also growing interest and research in camelina's use as a substitute for fish oil and fish meal in aquaculture feeds [11]. Because camelina meal is an excellent source of Omega-3, it is thought that inclusion of camelina in feed rations could improve animal health, increase body mass, and reduce animal stress [12]. While camelina meal has FDA approval for inclusion in feeding rations, camelina meal does not yet have certification by the Association of American Feed Control Officials (AAFCO) for inclusion in pet food.

As part of this USDA SARE research, AURI evaluated camelina feed for its market value relative to #2 shell corn price and 44% soybean meal price, both of which are energy and protein ingredients for livestock and poultry diets, (see Appendix A).

In large scale systems, oilseed meal often undergoes additional processing to remove excess oil or undesirable antinutrients. Oilseed meals of the brassica family contain glucosinolates, which are sulfur-containing organic compounds that give brassicas like camelina their bitter taste and can reduce palatability of the feed. Glucosinolates also have anti-nutritional qualities that can block absorption of some nutrients, which can be detrimental to animal health. Camelina and canola have much lower levels of glucosinolates in comparison to mustard meal, which makes them more suitable for feeding.

While feed is a reliable market channel for oilseed meal, higher market prices can be obtained through the sale of meal as a human food ingredient. Global demand and interest in protein as a food ingredient, particularly plant proteins, has greatly increased in recent years. Seed meal can be dried and milled into a protein powder through simple processing methods, and one such product, sold by Ulli's Oil Mill, has recently entered the market. However, the creation of a functional protein and market-viable ingredient for large-scale food applications is more complex, and more efficient means of protein extraction need to be established. This research is currently underway at the University of Minnesota's Plant Protein Innovation Center.

Processing Landscape in the Upper Midwest

Small Scale Processors

The oilseed processing landscape in the upper Midwest is dotted with hundreds—if not thousands—of small scale, on-farm processors. These operators are primarily farmers that have expanded their on-farm capabilities to include some processing functions such as seed cleaning and mechanical oil pressing. Small scale processors are predominantly processing for their own crop or for a few neighboring farms in their local trade area, and production runs are generally non-continuous with periods of equipment downtime.

Oilseed growers that conduct on-farm processing do so for many reasons, which include on-farm revenue diversification, lack of access to or proximity to a processor, quality control, and capture of higher profit margins by vertically integrating[2] processing and taking ownership of value-added

[2] Vertical integration is the combination in one company of two or more stages of production.

functions prior to sale. Some small scale processors may also press oilseeds and further refine oil into biofuel to reduce on-farm fuel costs.

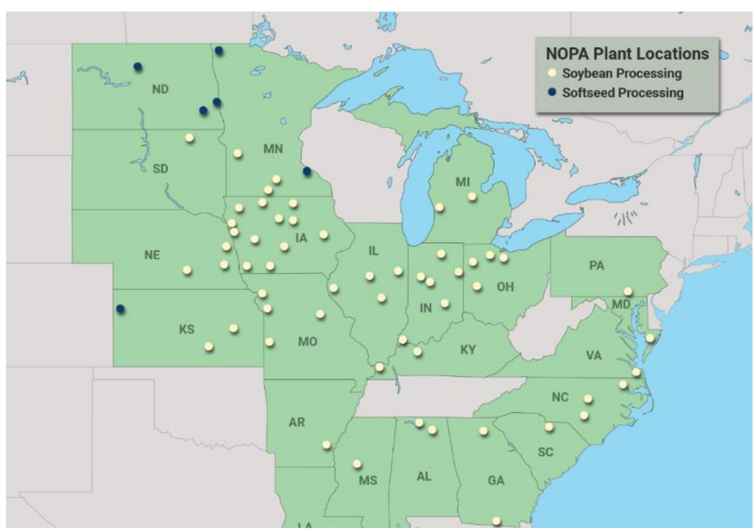
Midscale Processors

In contrast to the many small scale processors, only a handful of midscale oilseed processors operate within the upper Midwest. While these businesses are generally privately-owned and may have started as on-farm operations, processing has become their primary source of revenue through continued investment and expansion of their processing capacity and capabilities. Investments to increase capacity include the purchase of larger oil presses, adding additional presses to a production line, and increasing the number of individual production lines. Investments to increase capabilities include the addition of equipment and infrastructure to provide customers with a greater diversity of process offerings, such as seed cleaning, dehulling, desolventizing, deodorizing, milling, and packaging.

Midscale processors in the upper Midwest serve the oilseed processing demand for a larger number (25+) of regional customers located within a broader trade area (100+ miles) than small scale processors. These facilities are generally food grade and operate mechanical screw presses. While most midscale processors press for more than one oilseed crop and diversify their operations, others may specialize in one crop or press for one crop exclusively. Production runs at midscale crush facilities are longer and equipment utilization is higher in comparison to smaller operations. Production on some lines are continuous, with the exception of mandatory downtime for equipment cleaning and inspection, while other lines may have production downtime for changeovers[3] or production demand fluctuations.

Large Scale Processors

There are around a dozen large scale oilseed processing facilities operating throughout the Midwest. Unlike small and midscale processors, large scale crush facilities are highly capital-intensive, utilize solvent extraction, and crushing at each facility is for a single commodity, such as soy and canola. While solvent extraction was once a batch process,[4] production at large scale is now continuous. While midscale processors often diversify their product mix and their processing functions, large scale processors generally conduct less processing functions per production site. After oil extraction is complete, oil and meal are transported to other facilities for further processing and refinement.



Large Crush Facility Locations. National Oilseed Processors Association

[3] Changeover is the process of converting a line or machine from running one product to another.
[4] Processing of material in batches of limited quantity, non-continuous.

While product mix and processing functions are less diversified at large scale, ownership models are more diverse. Major players include Cargill (privately owned), CHS (cooperatively owned), AGP Grain, Ltd (cooperatively owned), Archer-Daniels-Midland (publicly traded), and Bunge Limited (publicly traded). Bunge LLT Canola Facility image above shows the locations of large scale oilseed processing facilities in the Midwest and Eastern United States.

Oilseed Processing Profitability

Processing is a capital-intensive industry which requires large upfront investments in pressing and other machinery, and oilseed processors of all scales operate with thin profit margins. Profit is maximized through economies of scale, which refers to the cost advantage a company experiences when it increases its scale of production. Economies of scale provide processors with increased market share, as lower costs of production can allow them to reduce prices and thus be more competitive relative to smaller press operations. Economies of scale for oilseed processors are achieved through increasing capacity by increasing the number of production lines, increasing throughput[5] of each production line, contracting for longer production runs, and the minimization of operational downtime due to production line changeovers or the absence of production contracts.

Profit for processors is also maximized through contracted sales of both oil and oilseed meal, which minimizes the loss of profits due to production by-products[6] that have negative market value. In contrast to by-products, oilseed processing co-products are valuable materials generated during a production run together with other valuable materials. If winter camelina is pressed for the sole purpose of obtaining oil, and the meal is not processed into food products or sold as animal feed, camelina seed meal is a by-product of the pressing process. If both the oil and meal are processed and sold through distinct market channels, the seed meal is a processing co-product with market value.

The capture of maximum value is only achievable for an oilseed processor when they have market channels established for sale of both oil and meal for a given production run. Thus, when considering the attractiveness of processing a new oilseed such as winter camelina, the processor heavily considers the feasibility, legality, and ease of product sale through various market channels. Ideally, the processor has options for sale of oilseed products through a diversity of food, feed and industrial markets. At this time, sales opportunities for winter camelina are severely constricted by a lack of GRAS status for sale of oil into high-value food markets and a lack of AAFCO certification for both oil and meal sale into pet food markets.

Oilseed Processor Risk

Oilseed processors operate under some degree of risk. Due to the capital-intensive nature of their business, processors cannot pivot their operations quickly in response to competition. This creates competitive risk for the processor. While processors are safer from competition overall due to high cost barriers to new entry, if there is competition, it can be strong. Direct competition can lead to losses in

[5] Throughput is the rate of production, or flow rate.
[6] A by-product is an incidental or secondary product created by a production process.

market share and the setting of lower profit margins in order to compete, which can be detrimental to business viability. Thus, specific information on the equipment utilized, production line configurations, and production practices is highly guarded by processors and not generally made public.

In addition, risks associated with commodity market price fluctuations can impact processing volume demand. If processing demand for an invested commodity is low, underutilization of process equipment or processing downtime can occur. However, this can also present a unique opportunity for new oilseed market entrants, such as winter camelina, to fill in production gaps.

To minimize risks associated with processing demand fluctuations, some processors choose to diversify their product mix. If demand for pressing one oilseed declines, they can increase contracts on another commodity. However, this may come at a cost from declines in production efficiency, and some equipment and production lines might not be optimized or designed for pressing a wide variety of seeds, or equipment modification and new parts could be required.

Another risk-minimizing strategy is for a processor to only accept large, multi-year contracts. While this also presents a degree of risk if the contract is not upheld, processor costs related to time and labor spent on customer service and other non-revenue generating services and risks associated with production downtimes are reduced.

Small Scale Processor Interviews

Methodology

Information and data gathered from small scale processors was obtained through researcher participation at industry events such as conferences, field days, and meetings for which a diversity of oilseed industry stakeholders were in attendance. Interviews were informal and semi-structured, with questions selectively pulled from the full set of questions asked in onsite interviews conducted at larger, midscale facilities, (see Appendix B). Follow-up phone calls were made to obtain additional information and clarification. A total of 14 short format interviews were completed, each lasting between 10 and 20 minutes in length. Interviews were conducted from November of 2019 until June of 2020.

Not all small scale processors interviewed had oilseed pressing capabilities; eight had oilseed presses of various types and sizes, four had seed cleaning capabilities exclusively, and two processors were utilizing small-batch CO_2 supercritical extraction machines for botanical oil (CBD) extraction.

Key Findings of Small Scale Processor Interviews

Small scale processors are primarily growers

Almost all small scale processors that were interviewed, with only one exception, were on-farm pressing operations in which the owners occupation and main income source was farming. For most, on-site processing was done for their own crop exclusively. Two processors communicated that oilseed pressing was primarily a way to capture additional profit by selling value-added products. For one processor, pressing was a means to reduce their own on-farm fuel costs. While several mentioned that they contracted with neighboring farms, the income they generated from processing contracts was a side revenue stream, and none were interested in transitioning their business operations toward oilseed processing full time. Reasons they cited for this were high startup costs and a lack of necessary capital, lack of specialized knowledge or expertise in oil pressing, high risks associated with processing at scale, and greater career interest and satisfaction in farming.

Because the small scale processors interviewed were primarily growers, their interest and inquiries about winter camelina were predominantly from the perspective of a producer and not an oilseed processor. Questions interviewees asked centered on crop agronomics, soil health benefits, viability in their rotations, yield potential, seed availability and seed cost, and market pricing. While some of these questions could be answered, many could not be answered with the degree of certainty necessary for them to invest in a novel crop. Most communicated that the risks they would be incurring investing in growing new crop were too great. Of particular concern was the wide range of yield data provided and a lack of data specific to their local area. Several mentioned having very little or no prior experience growing cover crops, and while they had some degree of interest in growing cover crops in the future, only two incorporated small grains, such as spring wheat, in their current rotations.

While it was communicated that seed was available for sale at Albert Lea Seed, several small processors voiced concern about the lack of consistency in seed availability and seed quality for a novel crop. Two interviewees also mentioned that it may be more difficult or impossible for them to obtain crop insurance if they were to incorporate a new cover crop into their rotations.

Small scale processors have limited knowledge of winter camelina

Of the 14 small scale processors interviewed, only two had heard of winter camelina prior to the interview, and only six were familiar with spring camelina. None of the small scale farmer-processors had prior experience growing or processing camelina, and none knew of any camelina growers in their local area. All 14 were unfamiliar with products made from camelina or winter camelina and were unaware of growing camelina markets in Canada and elsewhere worldwide.

All small scale processors interviewed communicated they would not be interested in processing winter camelina until markets for both oil and meal were further developed or there was a known buyer contracting in their region.

Small scale processors have limited processing capabilities, capacity, and quality controls

Because small scale processors are primarily processing for their own specific crops, most small processors lack the equipment or equipment modifications necessary to process for a diversity of oilseeds, or the diversity of equipment necessary to process a single crop for sale in multiple end-use markets. Additionally, small scale processors may lack suitable oilseed storage containers, storage capacity, and the controls necessary for ensuring quality. Pressing for a new crop such as winter camelina would likely require additional capital investments, and these investments are likely to be significant relative to the percentage of revenue their enterprises receive from processing.

Of the oilseed processors interviewed, four had mechanical press equipment that would be suitable for pressing winter camelina with relatively minor and inexpensive modifications. However, of those four, only two had the drying and milling equipment necessary for processing meal into value-added products such as protein powder, and only one had additional capabilities for oil purification and refinement.

Two of the processors interviewed were using small-batch supercritical CO_2 equipment for oil extraction of hemp cannabinoids, but only one was interested in experimenting with other crop materials, and only if it were for sales through Certified Organic supplement market channels which would require both Organic and GRAS certification. Both supercritical processors also voiced that their current capacity was too limited to meet customer demand for hemp, and investments made in larger capacity equipment would likely be for processing hemp exclusively.

Several processors noted that drying and storing winter camelina seed could be a challenge and that they may not have the correct dryer size and that they would likely need to invest in a new bin or bin floor to prevent seed from falling through the floor of their bin. Most had limited drying capacity for seed and expressed concerns that winter camelina's small seed size would increase the risk of microbial growth prior to pressing, which would in turn lower economic value of the oil. Storage of meal with high oil content also poses a risk for bacteria and mold growth, and most small scale processors interviewed were not interested in storing meal due to risk of meal value decrease while in storage or a lack of storage capacity overall.

Processors with seed cleaning capabilities suggested that they would likely need to purchase a new gravity separation screen to properly clean such a small seed. One processor with seed cleaning capabilities expressed interest in making a future investment in purchasing a mechanical press, however they would be more likely to make investments for pressing more established crops such as sunflower, canola, or flax, or other emerging crops such as hemp, before considering pressing for winter camelina.

Only one of the 14 small processors interviewed operated a food grade facility, and that processor was processing hemp exclusively in small, 50 pound batch sizes. Most did not have climate-controlled storage for finished product, and the three that did had limited storage capacity. Most did not conduct their own seed quality testing or utilize third party testing companies consistently for seed material harvested on their farm or for oilseed crops they process for neighboring farms. A few used third-party testing for oil impurities after pressing, but only if it was required for a sale.

Small scale processors expressed little interest in pressing for winter camelina

Overall, small scale grower-processors expressed little interest in growing and pressing winter camelina, at least in the short term. While several acknowledged that an additional cover crop in their rotation could be a long-term economic opportunity for their farm enterprise, most were not looking to take on the agronomic risk of introducing a new cover crop into their rotations without economic incentives by means of government payments or subsidies, more certainty on market prices or a direct relationship with a contracting buyer, or regionally-specific agronomic data. Most did not grow cover crops, and the few that did questioned the degree for which camelina benefited the soil in comparison with other covers, like winter rye. Another concern was that if viability of winter camelina depended on an agronomic rotation with spring wheat and soy that would limit grower adoption in their local area.

Risks associated with capital investment purchases for processing equipment were too high to warrant expenditures until supply chains and market channels were more developed. While most were not interested in expanding processing operation, the few small scale processors that were looking to expand their oil extraction capabilities and capacity were more interested in expansion opportunities for other emerging oilseeds such hemp, or to meet growing market demand for other specialty seeds such as sunflower and flax.

Mid-scale Processor Interviews

Methodology

Onsite oilseed processor interviews at midscale facilities were conducted from November of 2019 until February of 2020. Four long format interviews were conducted in total, each lasting approximately two hours in length. Interviews included a full site tour followed by a structured set of questions in categories pertaining to general company information, introductory knowledge and interest in camelina, processing capabilities and capacity, quality, storage, and the number and strength of downstream partnerships established for transportation logistics and processor access to downstream markets. Questions were similar in nature to supplier assessments made within industry prior to contractual agreements being made between parties. To view the full list of questions asked, (see Appendix B).

Due to the COVID-19 pandemic and subsequent safety policies which restricted researcher travel, additional onsite interviews remained uninitiated or were cancelled. However, it is worthy to note that while a sample size of four may initially seem small, very few additional midscale oilseed processing facilities operate within Minnesota and neighboring states. Thus, this sample size is statistically significant and the data obtained is of strong value for determining near-term opportunities for winter camelina processing in the region. The small number of midscale processors in operation also highlights potential challenges and geographic constraints to supply chain development for winter camelina and other emerging oilseeds as they enter the marketplace.

Because the goal of this research was to identify current and near-term opportunities for winter camelina processing partnerships, with a particular focus on supply chains entering high-value food market channels, the target scope for full interviews was narrowed to midscale facilities in the upper Midwest operating in compliance with the FDA's Food Safety Modernization Act (FSMA).

Due to the small number of midscale processors mechanically pressing in the region, specific data and information obtained through onsite tours and interviews remains selectively omitted in this report or data will be offered in ranges to protect against the disclosure of proprietary or identifiable information that could compromise the confidentiality of testimony offered by the processors interviewed. A Confidentiality Consent Form, (see: Appendix C) was presented and signed at the time of interviews.

Key Findings in Midscale Processor Interviews

One of the midscale processors interviewed wasn't actually a processor

Although their company website made claims of processing capabilities for cold oil pressing, dehulling, roasting, and milling; it was learned after the non-disclosure agreement was signed onsite that this business does not have processing capabilities. This business entity is acting as a supply chain intermediary, providing a diversity of services to a wide network of growers that include: brokering, logistics, and access to processors across the United States and Canada. This supply chain intermediary is also an established grower selling their own brand label and white labeled products through a variety of market channels, including an established partnership with a midscale food company with expressed interest in supporting winter camelina product development. For these reasons, data obtained from this interview is included in this report when referencing midscale processor access to logistics providers and downstream market channels, but will not be included in discussions of processing capabilities and capacity.

Midscale processors mechanically press a variety of oilseeds for customers in their region

Midscale processors that were interviewed operate privately-owned, food-grade facilities. They operate one or more mechanical presses and are processing a variety of oilseeds, such as sunflower, flax, hemp, borage, pumpkin, and specialty soy. All midscale processors interviewed started as growers, and three of the four still manage farmland, but oilseed crushing and other value-added oilseed processing activities are now their primary source of business revenue. The number of years for which midscale operations have been in business varied form 2 – 18 years, with two of the three operating mechanical presses for 10 years or more.

Unlike small processors interviewed, which primarily press for their own oilseed crops and perhaps a few neighbors, midscale processors interviewed have a larger number of customers, ranging from 25 to 60, and their customers are located throughout a broader geographic region. The majority of their customers were located within a 100-mile radius of their facility, with some producers bringing oilseeds from as far as 150 miles.

> As processor size increases, the diversity of oilseeds they press decreases.

One of the processors interviewed is a relatively new start-up operation, meeting the growing demand for only one emerging oilseed crop. The other two processors are processing for several oilseed crops, and thus have more diversified operations. It is important to note that the larger the midscale facility was in terms of volume of production, the less customers they were serving, while contract size and production runs increased. Additionally, as processor size increased, the diversification of oilseeds for which they were processing decreased. While the sample size of onsite interviews for this research remains small, this pattern is reflective of the overall trend toward economies of scale in the oilseed processing industry, as large crush facilities throughout the United States generally process for only one crop commodity, such as canola or soy.

Midscale processors have diverse and developed market channel partnerships

All midscale processors, including the non-processing supply chain intermediary, had well-developed downstream partnerships for selling a range of oil and meal products in a variety of market channels for food, feed, cosmetics, pharmaceutical, and industrial applications. For two of the midscale processors, downstream market channels are primarily within the United States; the other two processors have more extensive connections throughout the U.S. and worldwide and offer intermodal import/export services.

> All midscale processors utilized trucks as the sole mode of transportation to and from their facilities

To manage the movement of unprocessed agricultural products goods to their facility and the delivery of finished products to downstream partners, two of the four midscale processors owned their own truck(s) and managed a small percentage of their logistics needs internally. However, the majority of freight logistics at midscale are managed through contracting with one or more third party logistics providers. Only one of the processors had access to rail, but that access was indirect through contract with an intermodal shipping company. Thus, all inbound and outbound product deliveries at midscale processing facilities in this study utilized trucks as the sole mode of transportation. While this may initially be seen as a limitation to growth in a processing partnership because many large scale agricultural commodities such as corn and soy are transported via rail infrastructure, it is important to note that truck transportation still remains the primary mode of transportation utilized for the carry of agricultural freight across all commodity groups [13].

Midscale processors operate food grade facilities with controls for quality

All midscale processors interviewed operated food grade facilities for the production of oil and meal products sold in high-value food markets, and quality control and quality assurance testing are particularly important in food supply chains. Operation of food grade facilities requires the following of regulations and guidelines for food safety as outlined by the United States Food and Drug Administration's Food Safety Modernization Act (FSMA). For FSMA compliance, these processors establish necessary preventive controls in order to reduce food contamination risks in all aspects of their operations, maintain routine records of monitoring, and create mitigation plans for facility response to contamination. This includes compliance to guidelines for facility sanitation, product storage, packaging, and transportation. Food facilities are also regularly inspected by accredited third-party certification bodies.

In addition to FSMA compliance, all midscale processing facilities interviewed have set requirements for the cleanliness and condition of seed prior to pressing. Seed materials are routinely tested for levels of contaminates such as bacteria, mold and yeast. While there is no official standard set for evaluating edible oil quality [14], free fatty acids (FFA), peroxide value (PV) and p-anisidine (PA) values were all evaluated by midscale processors through the use of third-party testing companies for providing quality assurance to their customers.

Two of the three processors interviewed maintain climate controlled storage for finished products onsite, and one of these processors often contracted for additional storage offsite. While one processor did not have temperature controlled storage at the time of the interview and site tour, it was included in their near-term expansion plan.

Midscale processors have diverse capabilities

Midscale processors have diverse capabilities. Two of the three processors interviewed have capabilities to press a variety of seeds of different types and sizes, and all of the oilseed business owners conveyed a sense of confidence in their craft. Technical specifications for pressing and other equipment was shared without referencing documentation, and they communicated information about the equipment settings and modifications that would be necessary for pressing winter camelina, but all communicated with confidence that winter camelina would not be particularly challenging for them to press.

All midscale processors offered seed cleaning services for their customers, and one of them owned and operated a mobile seed cleaning unit. One processor expressed the importance of seed cleanliness for smaller seeds and mentioned high standards for cleaning prior to pressing.

All three midscale processors have capabilities for oil purification, but the degree for which they have invested in oil refinement varied. Each midscale processor also has milling capabilities, although the size of the onsite mill varied greatly. One openly admitted that protein powder wasn't an in-house specialization, but the mill was kept as an offering for a few of their smaller customers. Another processor has invested more heavily in protein milling and other equipment for protein isolation and/or refinement. Two offered packaging and labeling.

Midscale processors have capacity for growth and are interested in expansion

Processing facility size ranged greatly for midscale processors, from 3,000 sq/ft to 36,000 sq/ft, which also speaks to the variation in operation size and perhaps the number of production lines each facility operates or the space dedicated for other processing activities. Total capacity for oilseed pressing was a subject that one processor was not interested in fulling disclosing, but the smallest individual production line was pressing 1 ton/day with several lines operating at multiples of that capacity. Another processor could press 3 ton/day.

Minimum production runs ranged from 10,000 lbs to 50,000 lbs/full truck, although all midscale processors stressed that minimum production runs were not ideal. One processor accepted shorter production runs only because they had secured a one-year contract for monthly processing of a smaller quantity, specialty product for which this processor did not specialize in, however their profit margin on that contract was higher than their normal production runs to account for costs associated with changeover. One processor charge a flat rate fee of $400 for changeovers, the other two incorporated this cost into their quote and did not specify a charge.

All midscale processors interviewed expressed interest in expansion.

Two of the three processors operated their presses continuously without operational downtime except for required equipment cleaning, maintenance or inspection. That said, all three midscale processors expressed interest in expansion, either onsite or opening a second facility, if the right opportunity presented. For two of the three processors, expansion would involve additional risk and expenditure and would require a larger or longer-term contract. Contract length for interest in pressing for winter camelina (assuming a hypothetical scale up to 500,000 acres over 3 years) ranged between 3-5 years.

"My current demand is up over 10% from last year."

The biggest obstacle to expansion for pressing for winter camelina voiced by one midscale processor was the increased demand for other cold-pressed specialty crops. "My current demand is up over 10% from last year."

Storage capacities varied greatly amongst processors, yet all voiced that they "didn't have much" space for storage. Temporary storage of oil wasn't an issue for midscale processors, however none of them had interest in meal storage because storage was too costly for meal and its value degraded over time. If there wasn't a known buyer, the meal could turn to feed-grade within six months.

Midscale processors were familiar with camelina and winter camelina

Midscale processors were familiar with camelina—including winter camelina—and three were familiar with growing market demand for camelina in Canada and elsewhere in the world. That said, all midscale processors thought that scale-up estimates offered by agronomists (500,000 acres in 3 years) were not realistic and thought it would take longer to build significant acreage in the upper Midwest, unless a large buyer entered the market.

Two had prior experience pressing camelina, and thought that winter camelina could be a long-term opportunity for their operations. That said, they did not hear interest coming from producers in their area. When asked if producers in their area view camelina as an economic opportunity, responses were "no," "maybe a few," and "99% no, 1% maybe."

Lack of supply chain and market development were the greatest obstacles to processing

The greatest concern that midscale processors expressed about winter camelina during onsite interviews was that in order to press for an oilseed, they need to be able to sell it, and preferably through a high-value market channel. "If camelina oil doesn't have FDA GRAS status, and the meal doesn't have AAFCO certification, that is really limiting its opportunity in the marketplace," voiced one processor. Another processor commented that without markets like other commodity oils, there would need to be a large buyer contracting directly with growers in order to see sizable regional increases in acreage. Midscale processors also needed more technical information that would be important to prospective buyers, such as stability testing data and other specific data relevant to different end-use applications.

> *"What [winter camelina] needs to get up and going is a big fat buyer."*

All midscale processors suggested that body care would the best-fit option for high-value sale in the short-term, which would include uses in higher-end cosmetics, lotions, and facial oils. Brands such as Aveda, Target private-labels were offered as avenues of exploration. Yet, while all had established connections within the body care industry, only one seemed favorable to opening up a direct dialogue about winter camelina until more acreage was established regionally. One processor also commented that while body care applications could be a good market opportunity, more work would need to be done to fully refine and deodorize the oil, and that product-specific stability testing would be important as body care products tend to be held up for a longer time in distribution, could have slow movement on retail shelves and be consumed slowly by the customer after purchase.

Opportunities and Challenges for Winter Camelina Processing Partnerships

The development of oilseed processing partnerships is an important piece for future supply chain growth of winter camelina. As acreage on the landscape increases, oilseeds will need to be properly processed before entering the marketplace. Processor scale and the types of processing functions necessary will depend largely on the specifications necessary for different end-use applications. Interviews with small and midscale processors identified key opportunities and potential challenges in forming future processing partnerships.

While small processors may present unique opportunities for partnerships if supply chain intermediary support is available for making direct linkages with growers and buyers, most small scale processors lack the necessary mix of capabilities and capacity for partnership without making investments in storage, cleaning, and other processing equipment. These costs may be too high for capturing processor interest. Additionally, most small scale processors are not able to process products entering high-value food markets, as they lack the necessary facilities and controls required for ensuring quality and food safety. This limits the marketing channels for which camelina products can enter into when growers partner with smaller processors.

Opportunities with midscale processors in the upper Midwest are more likely, as these processors have expressed interest in pressing for winter camelina. They also have the capacities and capabilities necessary to process for new oilseeds with only minor investments in new equipment and production infrastructure. However, midscale processors may require multi-year contracts with a reputable buyer in order to recoup their fixed-cost investments. In the short-term, there might not be enough harvested oilseed acreage to meet minimum production runs, or changeover costs could lead to higher costs for finished products. The leap from small scale processing to midscale is significant, and investments may be necessary to bridge the gaps in processing production scale.

Additionally, strong and continued market demand for other specialty oilseeds may also present a high opportunity cost to midscale processors that are focused on building market share and efficiencies of scale through specialization and reducing the number of crops for which they process.

Recommendations for Future Supply Chain and Market Development

Commercial release of any new crop involves the coordinated effort of supply chain stakeholders, stakeholder investment and the proper allocation of resources to address supply chain development bottlenecks. Winter camelina is no exception. Insights gathered over the course of this 36-month research, many of which have been previously identified and discussed in this report, lead to the following recommendations for the future research and supply chain development efforts:

1. Secure GRAS designation for winter camelina to increase market demand. A current plan for this is established, but securing funds necessary for GRAS dossier development is essential and was identified as a market barrier in ALL primary interviews conducted under this NCR-SARE.

2. Increase engagement with potential midscale and large-scale buyers to communicate winter camelina's potential to meet sustainability targets, offer information, determine level of interest in winter camelina, and identify any barriers interested buyers may have to engage or invest. Support buyer engagement in research and development with necessary materials. While MBOLD is a key partner in this effort, increased efforts to engage small and midscale buyers could lead to entrepreneurial innovations that could launch winter camelina supply chains quickly and bring increased media attention to continuous living covers. Make available product samples that meet buyer specifications for product development or novel end-uses.

3. Increased allocation of resources for fixed asset investments—or partnership investment—in scale-appropriate processing and other supply chain infrastructure. Efforts are underway through support

from AURI to increase research and pilot-scale press capacity. The identification of additional resources necessary for successful scale-up and securing funding for those resources will prevent unnecessary bottlenecks of commercial scale-up for winter camelina and other emerging crops.

4. Continued agronomic research on winter camelina in a rotation with spring wheat and soy, including targeting areas of agronomic opportunity for winter camelina that intersect with agroecological objectives/goals. Development of a coordinated and unified system to effectively disseminate and share agronomic data and research with growers is important as Forever Green continues to grow, as growth with lack of personnel capacity can lead to information silos. While some agronomic data is readily available to growers, the pace of new data is outstripping the pace of information dissemination to growers. Additionally, growers engaged over the course of this research continually expressed the need for more certainty on agronomics specific to their local area.

5. Continued research to quantify ecosystem benefits and collaboration with interest-aligned policy partners to lobby for federal, state, and local funds to be allocated to farmers in the form of subsidies and other incentives to de-risk grower adoption of a novel and higher-risk cover crop.

6. Increase personnel capacity for Forever Green supply chain development and market development. Building new supply chains and new markets involves end-to-end coordination, and for Forever Green that means from germplasm research all the way to the end consumer. Current FTE allocation stretches personnel resources thin, as staff are functioning in multiple capacities to engage with industry partners and university researchers, communicate vital information to growers and supply chain partners, manage multiple projects, conduct marketing and outreach, and grant write.

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Appendix A: AURI Final Technical/Progress Report

Project: Winter Camelina: New Cash Crop Opportunities for Sustainable Sugar Beet Production (NCR SARE)
Subaward No: H006873701
Subrecipient: Agricultural Utilization Research Institute (AURI)
AURI PI(s): Dr. Goutham Vemuri/Dr. Michael Stutelberg
Subaward Period of Performance: Oct. 15, 2017 to Oct. 31, 2020

To: Dr. M. Scott Wells, University of Minnesota Department of Agronomy and Plant Genetics
Submitted by: AURI- Dr. Michael Stutelberg (PI)

The Agricultural Utilization Research Institute formally submits this final technical/progress report in accordance with the terms and conditions of Attachment 4 (Reporting and Prior Approval Terms) of the subaward agreement for subaward H006873701, which requires a "final technical progress report" to be submitted to "the PTE's Principal Investigator."

Project- Scope and Activities

Over the 36-month project period, AURI pursued multiple activities focused on analyzing Winter Camelina, assessing its potential uses and processing methods, establishing supply chain connections, and disseminating information about the crop. AURI carried out the project activities in coordination and collaboration with the University of Minnesota and its Forever Green Initiative.

Technical Work- Processing and Product Analysis

Crushing Camelina

AURI's Waseca site performed the crushing of camelina seed. Initial analysis found 36 % oil in the seed. After crushing, the meal still contained ~17% oil indicating a removal of 19%, or a 52% efficiency for camelina extraction. There are a number of variables that can affect the yield of extracted oil and its purity with filtration, including pressure and temperature. After optimizing conditions for camelina, an extraction efficiency of 60% was obtainable. From 50 lbs. of seed that would translate to approximately 11.5 lbs. of raw oil.

To begin filtration, researchers weighed the oil for ideal quantities of diatomaceous earth, bleaching clay and activated charcoal. It is ideal if charcoal can be in the oil for 12-24 hours prior to filtering. The addition of raw oil to the filter, and pressurization to 20-25 PSI, lead to the oil filtering slowly through the plates before collection into a separate container. The filter plates are easy to clean for next batch of oil filtration to remove impurities, prevent oxidation, improve quality, and extend shelf-life of the oil.

Meal Analysis- Nutritional Value for Animal Feed

Camelina meal generated by cold pressing the seed (rather than hexane extraction) caused the residual oil content to be greater within the meal samples analyzed for this project. These elevated levels led to a greater energy value for the camelina meal.

The basis for calculation of nutrient analysis in camelina comes from the nutrition analysis of camelina meal (Table 1). These values were then placed into a Feed Value Calculator tool utilized for the comparison. The feed calculator model focuses on dry matter content, crude protein, total digestible nutrients, net energy for maintenance, and net energy for gain. These values were then compared to #2 shell corn price and 44% soybean meal price (See Appendix).

Foundation for Wider Efforts

As part of a continued partnership with the University of Minnesota, Forever Green, Central Lakes College, and other key stakeholders, AURI is collaborating on another grant-funded project to help commercialize and build supply chains for camelina. This work, funded by the State of Minnesota's Environment and Natural Resources Trust Fund (ENRTF), will continue into 2022. AURI's SARE-funded activities have provided a strong foundation for this work, and the knowledge and networks built during this project will continue to guide commercialization efforts moving forward.

Some notable contribution to the wider efforts conducted as part of the SARE project included crushing a small-scale supply of seed and providing meal for a swine feeding trial. Additional discussions with industry representatives and other researchers have progressed on a need for additional feeding trials to obtain winter camelina AAFCO certification. Furthermore, to help examine issues with generally regarded as safe (GRAS) for winter camelina oil for food applications, the procurement of camelina oil included using distributors in Canada and Europe identifying properties to support camelina GRAS status. AURI's food science team is working with key partners including the Forever Green Initiative to address these regulatory issues as part of the organization's continued winter camelina commercialization efforts.

Events, Outreach, and Stakeholder Engagement

Field Days

Over the course of the project period, AURI worked with project partners to stage three annual field days. These events aimed at sharing information about Winter Camelina and its potential with farmers and other key supply chain stakeholders. The 2020 Field Day was a virtual, online event due to restrictions on in-person events caused by the COVID-19 pandemic. The Field Days aimed at launching Winter Camelina into Minnesota's agricultural landscape by highlighting the crops potential for the food, fuel, and feed markets.

During these Camelina Field Days, AURI showcased crushing and oil filtration of camelina, including presentations on best practices and what to avoid. The 2018 Field Day included a demonstration of AURI's oil press and presentation on oil and meal extraction.

At the 2019 Field Day, AURI food scientists were able to demonstrate the use of camelina oil in cookies and cooking bacon and porkchops to great regard. This early test usage identifies straightforward food applications for camelina oil. A small demonstration in oil lamps compared B20 diesel, soy biodiesel and camelina biodiesel. Biodiesel from camelina oil was synthesized using a standard catalyst with methanol for the transesterification. Demonstrators cleaned this product utilizing washing and gravity separation. What was apparent was the smoke released from B20 and not from either soy or camelina biodiesel indicating a cleaner burn and minimal ash.

At the virtual 2020 Field Day, a step-by-step walkthrough of pressing and oil filtration of camelina was recorded and shared with online participants identifying critical steps and highlighting the importance of purifying the oil through filtration.

Renewable Energy Roundtable

In addition to taking part in field days, AURI featured camelina-related content as part of its *AURI Connects: Renewable Energy Roundtable* initiative. The March 2018 event held at the University Enterprise Laboratories in St. Paul, included presentations from AURI and University of Minnesota researchers highlighting oilseed cover crops including Winter Camelina and their potential utility as a feedstock for bioenergy and renewable chemical development.

Dissemination

Over the course of the project, AURI has engaged its communications team to disseminate information and build awareness about Winter Camelina and its potential through multiple channels. AURI discussed the crop in several articles in AURI's "Ag Innovation News" and posts on the organization's website during the project period. This included discussion about camelina in features and articles on cold pressing technologies, commercialization of new and emerging crops in Minnesota, plant-based proteins, and development of new cover crops and perennials. AURI also used its online platforms to promote Winter Camelina field days hosted by project partners, and shared information about camelina in the organization's annual reports.

Camelina Protein

auri
Agricultural Utilization Research Institute

Minnesota Overview

Camelina, a Crucifer seed and a member of the Brassicaceae family is a short-season oilseed cover crop high in both oil/fat (30-38%) and protein (25-30%) Thus, it can be used for the production of both oil and protein ingredients.

Rainfall and soil nitrogen both influence camelina, with poor yield resulting from limited rainfall. Although higher soil nitrogen levels positively impact camelina yields, very little fertilizer is actually needed for production. This, along with camelina's natural pathogen-resistance, insect-resistance, and potential for farming with equipment for canola and mustard, minimizes production costs.

Nutritional quality

The amino acid composition and hence the nutritional quality of camelina protein is similar to that of canola protein, which in turn is comparable to that of soy protein. Specifically, it meets the World Health Organization's essential amino acids requirements for those over the age of one. Heat treatment, can reduce or eliminate antinutritive factors and improve camelina's nutritional value. New winter varieties of camelina possess particularly low concentrations of glucosinolates, below those of canola (Murphy 2016).

Protein components

Camelina proteins constitute mainly albumins (10.5%, water-soluble fraction), globulins (17.7%, salt soluble), and glutelins (64.6%, alkaline soluble). Legumin-type globulins, cruciferin (11S), and napin-type albumins, napin (2S), are the major storage proteins (~80-85% of total seed proteins) of Brassicaceae seeds, including the Crucifer seed, camelina.

Currently available protein ingredient forms

As of yet, there is no commercial production of camelina protein. Camelina meal, a by-product from oil production, is rich in protein (40-45%). Thus it is necessary to explore extraction techniques to produce a functional protein ingredient for food applications. A recent study demonstrated that camelina protein isolated following salt extraction resulted in higher protein yields compared to isolates from alkaline extraction. The camelina protein concentrate (70-80% protein) produced following salt extraction had better overall functionality.

In 2018, as part of the organization's wider efforts to examine emerging market opportunities, AURI released a report about the use of Minnesota plant-based proteins. This report, prepared in partnership with the University of Minnesota's Department of Food and Nutrition, included two-page section focusing on camelina and its potential feasibility as a source of plant-based protein.[7] The final report, which looked at several different crops, was shared and promoted through AURI's online platforms, helping drive wider awareness of winter camelina and its potential uses.

AURI also shared the information developed over the course of this project industry contacts to help build knowledge and awareness of Winter Camelina and its characteristics. AURI plans to continue to make use of the knowledge developed during this SARE-funded project as it continues work on projects and builds partnerships to commercialize Winter Camelina and expand awareness of cover crops and their economic and environmental benefits.

[7] https://www.auri.org/wp-content/uploads/2018/06/AURI-18-Camelina-Protein-One-Pager.pdf

Table 1. Nutrient analysis of camelina seed and meal compared to soybean.

		Winter Camelina Seed[1]	Soybean Seed[2]	Winter Camelina Meal	44% Soybean Meal
Moisture	%	9.4	7.6	10.8	10.0
Dry matter	%	90.6	92.4	89.2	90.0
Crude Protein	% DM	26.0	40.6	38.2	49.9
Fat	% DM	36.4	21.8	17.6	1.5
Fiber	% DM	16.1	32.2	12.0	7.0
Ash	% DM	3.4	5.3	5.8	7.3
Calcium	% DM	0.3	0.3	0.4	0.3
Phosphorus	% DM	0.8	0.6	1.1	0.7
Potassium	% DM	1.0	1.8	1.3	2.0
Sulfur	% DM	0.6	0.3	0.9	0.4
Magnesium	% DM	0.3	0.3	0.5	0.3
Sodium	%DM	ND	0.0	ND	0.3
Iron	ppm (DM)	116.0	86.6	159.0	175.0
Manganese	ppm (DM)	25.9	32.5	39.6	35.0
Copper	ppm (DM)	7.3	17.3	8.3	24.0
Zinc	ppm (DM)	64.4	42.2	91.8	66.0
Net Energy (Lactation)	Mcal/lbs.	1.3	1.4	1.0	0.9
Metabolizable Energy	Mcal/lbs.	2.1	1.9	1.7	1.8
Digestible Energy	Mcal/lbs.	2.4	2.1	1.9	1.7

1)Winter Camelina data- AURI research, 2019-2020. Funding for AURI Winter Camelina research was provided by USDA SARE and the Minnesota Environment and Natural Resources Trust Fund as recommended by the Legislative-Citizen Commission on Minnesota Resources (LCCMR).

2)Source for Soybean seed and meal data- Format Solutions, Feed Ration Balancer; Feed Management Systems, Inc. 2008

Cold-Pressed Camelina Meal Estimated Feed Value

Appendix: Cold-Pressed Camelina Meal Estimated Feed Value

auri Agricultural Utilization Research Institute

SARE – Camelina
November 2, 2020

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Purpose

To evaluate the potential feed value of cold-press Camelina meal also referred to as cake. All estimates are based on an 'as-is' basis with a current moisture content of 10%.

Evaluation

South Dakota State University Beef Extension Service provided a Feed Value Calculator tool utilized for the comparison. The feed calculator utilized focuses primarily on a commodities dry matter content, crude protein, total digestible nutrients, net energy for maintenance and net energy for gain. These values are then based on #2 shell corn price and 44% soybean meal price, both primary energy and protein ingredients for most livestock and poultry diets.

The project utilized Dairyland Labs in Arcadia, Wisconsin to compare the analyses. The AURI Coproduct Pilot Lab in Waseca, Minnesota generated the meal used in the analyses.

Note: Camelina meal generated by cold-pressing the seed rather than hexane oil extraction will contain much greater levels on oil within the sample. The elevated oil in the sample will result in elevated energy value for the meal. It is important to remember that various forms of processing Camelina seed will result in different nutrient data for the meal.

Potential feed value results at various commodity cost and dry matter content:

	$3.50/bu. corn & $380/ton SBM	$4.20/bu. corn & $440/ton SBM
Product	Value per ton based on protein / value per ton based on energy	Value per ton based on protein / value per ton based on energy
Camelina Meal @ 10% moisture	$192 / $154 per ton	$222 / $185 per ton

Comments

- Camelina meal provides a more significant source of energy when focusing on ingredient value.
- Camelina meal evaluated had a crude protein content of 24%, fat content of 33.4% and Total Digestible Nutrient value of 106% based on an 'as-is' basis. Additional extraction of oil from the meal would significantly increase the ingredient value when based on protein content.

Disclaimer: All AURI technical results generated are for development use only. Work was partially completed with NCR SARE Research and Education Grant. Funding for AURI Winter Camelina research has also been provided by the Minnesota Environment and Natural Resources Trust Fund as recommended by the Legislative-Citizen Commission on Minnesota Resources (LCCMR).

Appendix B: Camelina Processor Questions

General Information

1. Company Profile
    a. Where is your processing facility located?
    b. What is your business ownership model (cooperative, private, nonprofit, public, hybrid)?
    c. What percentage of your business revenue is generated through oilseed processing?
    d. What are your other revenue streams (farming, other processing activity, etc.)?
2. Company History
    a. How many years has your company been in operation?
    b. How many years have you been processing oilseed?
3. Supplier partnerships
    a. How many producer partnerships do you have currently?
    b. What is the size range of your farmer/supplier partnerships (ie. small to mid-sized)?
    c. What is the average distance radius of producers to your processing facility?
4. Product ownership
    a. Do you take ownership of seed prior to processing?
    b. Do producers maintain ownership during processing?
5. Industry affiliations
    a. Do you have any industry affiliations or association memberships relevant to oilseed processing?
6. Regulatory Compliance (USDA, EPA, etc)
    a. Are you a food-grade production facility?
        i. Would you consider becoming one if not currently?
    b. What federal good manufacturing practices do you follow or are you required to follow?
        i. Plant and grounds
        ii. Sanitary operations
        iii. Equipment
        iv. Storage and protection of raw and finished material from damage and contamination from microbes, pests, etc.

Introductory knowledge and interest level in Camelina

1. Are you familiar with Camelina?
2. Do you have prior experience in growing, storing, and/or processing Camelina?
    a. If so, how much experience?
    b. If not, what experience do you have processing other oilseeds?
3. Do you personally know of Camelina growers in your trade area?
4. Do you view Camelina as a potential opportunity, either environmentally or economically, for farmers in your region?
5. In your opinion, do producers in your area view Camelina as an economic opportunity?
6. Do you have interest in expanding and/or diversifying your oilseed processing to include Camelina? Could you rate that interest on a scale of 1-10?

7. What would you see as the greatest challenge in expanding your operation to include Camelina?

Processing Capabilities

1. Current Scale
    a. What is the size of your processing facility (ft^2)?
    b. Besides oilseed pressing, do you have other processing capability (seed cleaning, grinding, milling, drying, etc.)?
    c. What % of your operation (ft^2 and time) is dedicated to oilseed processing?
    d. Minimum/maximum processing runs for oilseeds?
2. Equipment
    a. What type(s) of equipment do you utilize for oilseed pressing (ie. cylinder, cage press, twin barrel)?
        i. Brand name of equipment, if relevant (KernKraft, Keller, Täby, etc.)
        ii. Is your equipment cold press or are seeds pre-heated?
        iii. What is the flow rate (tons/day)?
    b. Equipment tolerances for variation (seed dryness %, etc.)
    c. Equipment setup and switchover time/costs?
    d. Do you know of equipment modifications that may be necessary for Camelina?
    e. Do you have additional oil refinement capability onsite?
3. Capacity
    a. How many operational months/days per year do you have for oilseed processing?
    b. Do you have operational downtime?
    c. Do you currently have excess equipment capacity?
    d. Are there months when equipment utilization is higher or lower?
    e. Does your capacity and/or excess capacity vary year to year?
4. Future Scale & Capacity
    a. Do you have the possibility to expand the size of your processing facility?
    b. Under what conditions would you consider increasing capacity?

Quality

1. Seed Quality
    a. Do you have requirements for cleanliness and condition of seed?
    b. Do you have seed cleaning capability or interest?
    c. Do you test for seed quality and moisture content on site?
2. Oil Quality
    a. Do you test oil quality on site?
    b. Do you test phosphorus levels in oil?
3. Quality Assurance
    a. Do you offer quality assurance for oil and seed cake?
    b. Do you utilize third party quality testing or assurance?

Storage

1. Seed storage
    a. How much seed storage capacity do you have prior to pressing?
    b. Conditions maintained and monitored to minimize seed sweating and sprouting?
        i. Do you use aeration fans/airflow rate or heated drying?
        ii. Do you monitor temperature and humidity?
        iii. Do you conduct rodent monitoring? What rodent control is used?
        iv. Do you monitor for insects and mites? What controls are used for insects?
    c. Do you have procedures in place for maintaining identity preserved seed?
2. Oil storage
    a. What is your oil cooling process?
    b. How is oil stored?
    c. How much space for oil storage?
    d. Where is oil stored?
    e. Is oil storage temperature controlled?
    f. For how long is oil typically stored at your facility?
3. Cake and co-products storage
    a. Do you store oilseed byproducts such as cake and flake?
    b. Are controls in place to prevent cake molding in storage?
    c. How long can co-products be stored at your facility?
    d. How much space for cake storage?
4. Do you have access to or utilize additional storage capacity through third-party contracting?

Waste

1. Do you have a waste removal process?
2. If so, please describe waste removal at your facility.
3. Are waste removal charges additional? Incorporated into proces

Transportation & logistics

1. Do you provide transportation services?
2. Do you have existing logistics partnerships?
3. What transportation modes does your facility utilize for inbound and outbound delivery (rail, truck, post office, air shipment)?

Other services

1. Do you have labeling and packaging capabilities onsite?
2. Downstream market access and partnerships – coproducts partners, finished goods customers

APPENDIX C: CONSENT FORM
Winter Camelina: New cash crop opportunities for sustainable sugar beet production

You are invited to participate in a research study of Camelina supply chain and market development in Minnesota. You were selected as a possible participant because of your role as a mid-scale oilseed processor operating within Minnesota. We ask that you read this form and ask any questions you may have before agreeing to be in the study.

This study is being conducted by Sarah Swan Ray, Supply Chain Development Specialist for the University of Minnesota's Regional Sustainable Development Partnerships (RSDP). It is supported through a NCR SARE grant, and this research is a collaboration between M. Scott Wells and AURI.

Background Information

This research and education project will demonstrate the agronomic viability of integrating winter camelina as a winter-annual oilseed crop in conventional sugar beet cropping systems, and will quantify associated economic and environmental implications. Outreach and education will produce networking opportunities for farmers, researchers, and industry professionals to learn about winter camelina and establish working relationships to build a functioning supply chain.

Procedures:

If you agree to be in this study, we would ask you to participate in an interview lasting up to 90 minutes about your experiences with and perceptions of camelina and other oilseeds grown in Minnesota. Notes will be taken during the interview. With your consent, interviews will also be audio recorded.

Risks and Benefits of being in the Study

A risk of participating in this study may arise if some find your opinions at variance with their own. This risk is minimal, responses are confidential and names will not be linked to any information in any publications. There is also a risk that you may find some of the questions to be uncomfortable or personal. If you are uncomfortable with any questions, you may choose not to answer them; there is no penalty for choosing not to answer a question.

Benefits of participation include increased awareness of Minnesota's winter camelina crop. If you are interested in learning more about hazelnut production and cultivation in Minnesota, we may be able to connect you with grower organizations or others who could address your questions.

Compensation:

There is no compensation for participation in this study.

Confidentiality:

The records of this study will be kept private. In any sort of report we might publish, we will not include any information that will make it possible to identify a subject. Research records and audio recordings will be stored securely and only researchers will have access to the records. Study data will be encrypted according to current University policy for protection of confidentiality. Audio recordings will be stored securely for three years and will then be destroyed.

Voluntary Nature of the Study:

Participation in this study is voluntary. Your decision whether or not to participate will not affect your current or future relations with the University of Minnesota. If you decide to participate, you are free to not answer any question or withdraw at any time without affecting those relationships.

Contacts and Questions:

The researcher conducting this study is: Sarah Swan Ray. Supervisors are M. Scott Wells, Agronomy Department, UMN and Constance Carlson, Regional Sustainable Development Partnerships. You may ask any questions you have now. If you have questions later, **you are encouraged** to contact Swan at 612-978-6224 or swanx078@umn.edu. You may also contact research supervisors, Scotty at 919-741-9876 or Connie at 612-709-6790, carl5114@umn.edu with any concerns.

If you have any questions or concerns regarding this study and would like to talk to someone other than the researcher(s), **you are encouraged** to contact the Research Subjects' Advocate Line, D528 Mayo, 420 Delaware St. Southeast, Minneapolis, Minnesota 55455; (612) 625-1650.

You will be given a copy of this information to keep for your records.

Statement of Consent:

____ I agree to have my responses audio recorded.

____ I do not agree to have my responses audio recorded.

I have read the above information. I have asked questions and have received answers. I consent to participate in the study.

Signature:____ Date: ________________

Signature of parent or guardian:________________________________ Date:
____
(If minors are involved)

Signature of Investigator:_____________________________________ Date:
____