MBOLD
The GREATER MSP Partnership

MBOLD
Protein Catalyst

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food centre Saskatchewan Food Industry Development Centre Inc.

PROCESSING OPPORTUNITIES FOR MAXIMIZING VALUE IN OAT PROTEIN INGREDIENTS

PHASE 1:
Functionality, Manufacturing Processes, Ingredient Transformation, and Commercial Opportunities

ABOUT MBOLD AND THIS REPORT

The MBOLD Coalition's Protein Catalyst Initiative drives innovation in the protein sector by:

- advancing the market success of plant-based proteins and the environmental sustainability of animal-based proteins
- conducting and sharing industry-oriented research to address key knowledge gaps
- fueling the growth of high-potential start-ups in the protein sector and
- supporting pre-competitive collaboration across protein value chains.

MBOLD commissioned this study as the first phase of our research to evaluate pathways for further development of oat as a protein ingredient. This initial study evaluates potential processing pathways for oat protein and associated sidestreams, provides techno-economic assessments of dry fractionation and hybrid processing technologies, and makes recommendations for next steps.

We are indebted to the team at the Saskatchewan Food Industry Development Centre, Inc., particularly Dr. Mehmet Tulbek, Vishvendra Kumar and Dr. Maria Hounjet, for their skilled analysis and continued partnership. We also thank the Centre, Prairie Oat Growers Association and SunOpta for contributing photos that are featured in this report.

MBOLD welcomes feedback, dialogue and additional collaborators. Please watch for our upcoming research on process mapping, functionality, food applications and commercial / consumer proposition assessments for oat ingredients, as well as similar assessments for navy / pinto beans and chickpea. You can reach us through www.mbold.org/protein and at info@mbold.org.

Finally, we thank Builders Vision and the McKnight Foundation for their support of the MBOLD Protein Catalyst. MBOLD is an initiative of GREATER MSP.

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EXECUTIVE SUMMARY AND STRATEGIC RECOMMENDATIONS

After analysis of multiple oat processing technologies, this report recommends two strategic pathways to further develop oat as a protein ingredient and maximize value in the oat industry by valorizing processing sidestreams:

1. **Dry milling and air classification technologies to produce oat protein and oat starch concentrates through low-cost, sustainable processing.**
   - **Our analysis suggests that dry milling and air classification could generate $1,159,000 in value above raw material cost from 1,000 MT of raw oats.**
2. **Utilization of oat milk okara through alternative processing pathways, including dry fractionation, wet fractionation, and fermentation technologies, to recover protein, fiber, carbohydrates, and biomass streams.**
   - One of the most significant developments has been the rise of oat milk as a major category in the plant-based beverage sector. The expansion of oat milk production has generated large quantities of okara by-product, a fiber- and protein-rich product that has traditionally been underutilized in North America[1-4]. As sustainability and circular economy principles gain importance, recovering and commercializing okara-derived ingredients present a major opportunity for value creation, sustainability benefits, and waste reduction.
   - **Our assessment suggests that these pathways could generate an incremental value of $110,000–$496,000 from 2,000 MT of oat milk okara, relative to a low-value wet oat okara outlet**.
   - The most suitable pathway will depend on how the okara is handled after the oat milk production. Fresh okara could be processed directly through wet fractionation, while stabilization and milling would provide a shelf-stable ingredient when immediate processing is not feasible. Stabilized okara could also be further processed through dry fractionation to produce protein, fiber, and carbohydrate-rich fractions.

We view these two pathways as equally important, while being independent of one another, involving different processing and handling infrastructure, and serving different purposes. Specifically, dry fractionation of oats provides scalable, high-value plant-based food ingredients via resource-efficient processing, whereas oat okara utilization advances the circular economy by valorizing side-streams from oat milk manufacturing.

Our assessment indicates that dry fractionation technologies offer significant advantages in capital requirements, operating costs, scalability, water use, ingredient functionality, and sustainability. In contrast, wet fractionation systems may provide higher ingredient purity but require substantially greater investment (5 to 7 times that of dry fractionation technologies) and greater operational complexity. **Hybrid processing, particularly the use of oat milk okara, may offer intermediate solutions that balance cost and performance.**

As global demand for protein, dietary fiber, functional foods, plant-based nutrition, and precision fermentation ingredients continues to grow, oats are uniquely positioned to support future food innovation. **The integration of dry fractionation, okara utilization, and full-crop valorization strategies will enable the industry to maximize economic returns while improving environmental performance and resource efficiency.**

Strategic Recommendations

Based on the technical, economic, and sustainability assessment conducted in this report, the following opportunities are recommended for advancing oat-based ingredient development to maximize ingredient value, profitability and long-term sustainability of the oat industry and expand options for plant-based protein ingredients.

1. **Prioritize dry fractionation operations as the near-term commercialization pathway** due to their lower capital requirements, minimal water usage, process simplicity, scalability, and the ability to preserve the native ingredient functionality.
2. **Develop oat protein concentrates and starch-rich fractions as the primary value-added ingredients,** targeting their applications in bakery, snacks, beverages, functional foods, pet foods, and nutritional products.
3. **Develop oat milk okara valorization strategies by evaluating three practical processing pathways: direct wet fractionation of fresh okara; stabilization and milling into dried okara flour; and dry fractionation of stabilized okara.** These pathways should be evaluated for their potential to recover or produce value-added protein, fiber, and carbohydrate ingredients, maximize value from oat milk processing side streams, and support a more circular oat industry.
4. **Align oat variety selection through breeding programs that consider ingredient improvement** related to high-protein, high-beta-glucan, low-fat, and high-starch oat varieties customized for specific processing pathways.
5. **Develop full-crop utilization strategies incorporating hulls, okara, and carbohydrate streams** into food, feed, fermentation, and industrial biotechnology applications to boost resource efficiency.
6. **Complete detailed techno-economic and market assessments** for evaluating product specifications, customer requirements, capital investment, operating costs, and commercialization pathways.

STRATEGIC RECOMMENDATIONS

for Advancing Oat-Based Ingredient Development

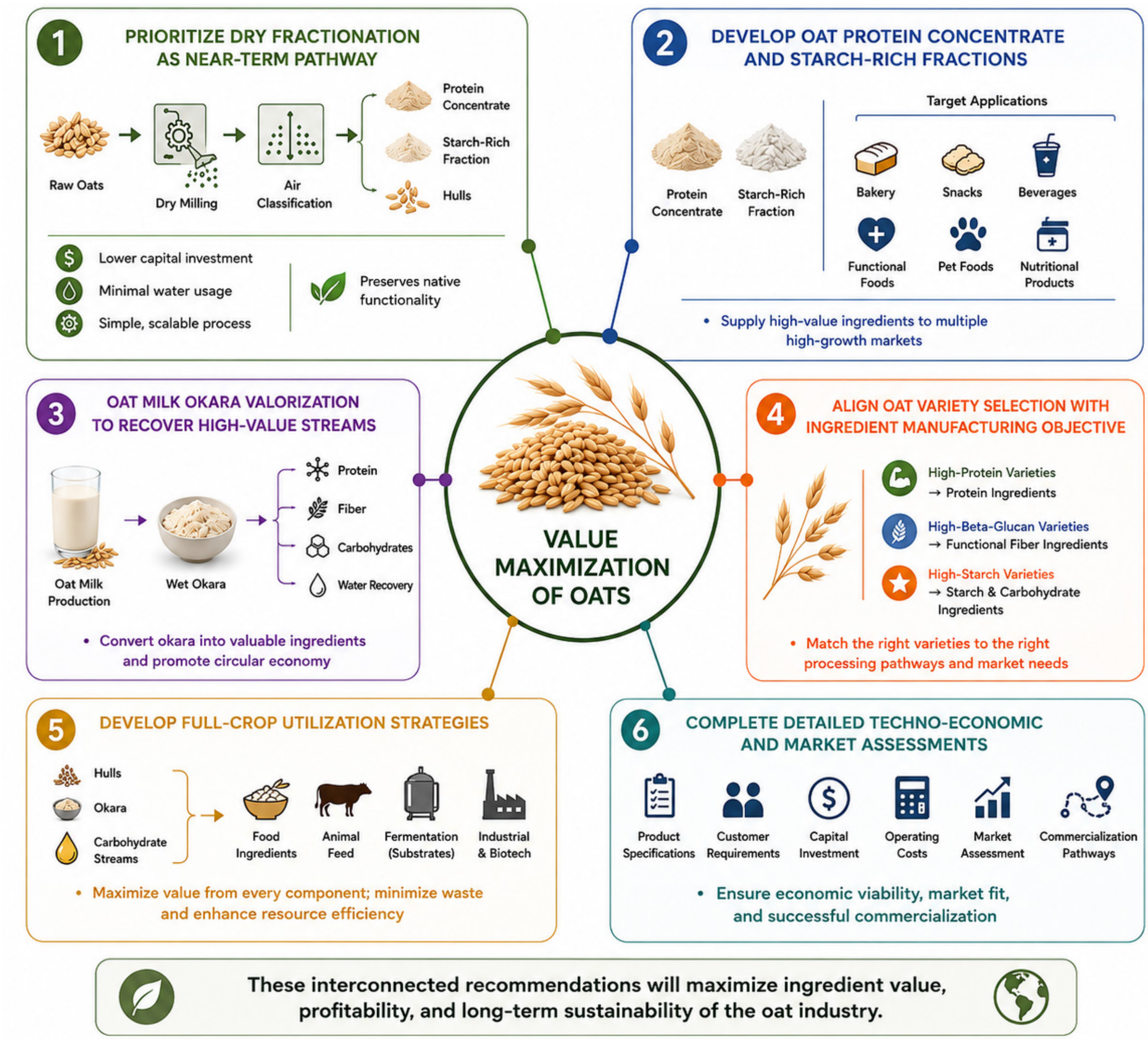


Figure 1. ***Strategic recommendations for advancing oat-based ingredient development***

GLOBAL OAT INDUSTRY OVERVIEW

Oats are recognized as a nutritious cereal grain used in both human food and animal feed. Historically, oat production was concentrated in cooler and temperate regions where climatic conditions favored cultivation. Over time, advances in breeding, agronomy, and processing technologies have improved the quality and utilization potential of oats, enabling their transition from a commodity grain to a source of high-value ingredients.

Global oat production ranges from 19 to 26 million metric tonnes annually[5]. Major producing regions include Canada, Russia, the European Union, Australia, and the United States. Canada consistently ranks among the world's largest exporters and is internationally recognized for high-quality oats for milling[5, 6]. In the European Union, several mid-sized facilities process oats, oat flours, and okara into oat-based ingredients.

The Canadian oat industry plays a key role in domestic food manufacturing and in international markets. Saskatchewan, Manitoba, and Alberta together account for a significant share of Canadian production and serve as strategic supply regions for North American oat processors[7]. Strong quality standards, reliable logistics, and extensive agricultural expertise have contributed to Canada's leadership in food-grade oat processing. Oats can also be grown in the United States; however, the growth of soybean and corn production, along with limited availability of genetics adapted to warmer regions, can challenge efforts to expand oat production[8-10].

Oats (*Avena sativa L.*) exhibited a significant transformation over the past four decades, evolving from a traditional breakfast cereal staple into a strategic platform for value-added applications across food, beverages, nutraceuticals, pet food, and industrial products. Oats possess unique compositional (beta-glucan, soluble dietary fiber, high protein quality) and functional characteristics that position them among the most promising crops for next-generation ingredient manufacturing[11, 12].

Historically, the oat milling industry relied primarily on dry milling technologies to produce food-grade oat products. More recently, advances in dry fractionation, wet extraction, enzymatic hydrolysis, membrane filtration, and separation technologies have enabled food and ingredient manufacturers to selectively concentrate proteins, fibers, starches, and bioactive compounds[13, 14]. These advances have created opportunities to substantially increase the potential value of each tonne of raw oats.

The growth of oat milk, plant-based foods, functional ingredients, and high-protein nutrition has accelerated investment in oat processing technologies and ingredient innovation over the past two decades. Beyond traditional products such as rolled oats, oat bran, and oat flour, the industry now produces oat protein concentrates, beta-glucan concentrates, oat starch concentrates, dietary fiber, and fermentation substrates, primarily in the European Union[15–17]. This transformation reflects growing consumer demand for clean-label, non-GMO, sustainable ingredients that deliver nutritional and functional benefits[17].

One of the most important developments in the oat business in recent decades has been the rise of oat milk. Consumer demand for dairy alternatives has driven rapid growth in plant-based beverages, with oat milk emerging as one of the fastest-growing categories thanks to its flavor, texture, functionality, sustainability credentials, and nutritional profile. All market segments have shown consistent interest in oat milk and oat-based dairy alternatives, including oat and chia puddings and barista applications[18, 19].

The rise of oat milk has had implications beyond beverage production. It has spurred investment in oat processing capacity, ingredient development, and co-product utilization. At the same time, growing interest in protein enrichment, dietary fiber, and clean-label ingredients has expanded opportunities for oat-derived proteins, starches, and specialty ingredients.

The oat processing and end-use industry is now at the intersection of several major trends, including plant-based nutrition, functional foods, sustainability, circular-economy initiatives, and industrial biotechnology. These trends are expected to continue to shape future investment and innovation strategies.

OAT COMPOSITION, FUNCTIONALITY, AND NUTRITIONAL ATTRIBUTES

Oats have a distinctive composition that sets them apart from many other cereal grains. Typical oat kernels contain protein, starch, dietary fiber (rich in beta-glucan), lipids, vitamins, minerals, and bioactive compounds, each contributing to their nutritional value and functionality.

Protein content typically ranges from 12–20%, depending on variety and growing conditions. Compared with other cereals, oats have relatively balanced amino acid profiles and desirable functional properties, including emulsification, foaming, and water-binding[20–22].

Starch is the primary component of oats, typically accounting for 45–60% of the kernel's composition. Oat starch contributes to texture, viscosity, and energy content and may serve as a substrate for fermentation and in industrial applications[23].

Dietary fiber is one of the most significant nutritional benefits of oats. Total fiber content typically ranges from 10–15%, comprising both soluble and insoluble fractions. Beta-glucan, the primary soluble fiber in oats, has attracted extensive scientific attention for its association with cholesterol reduction, glycemic control, digestive health, and satiety[24, 25].

Lipids make up about 5–9% of oat composition and contribute to flavor, mouthfeel, and nutritional quality. Oat lipids contain unsaturated fatty acids and bioactive compounds that enhance nutritional value but require stabilization to prevent oxidation, given their high enzymatic activity[25].

These compositional characteristics enable oats to support diverse applications across food, beverage, pet food, nutraceutical, and industrial markets. The ability to selectively concentrate proteins, fibers, starches, and bioactive compounds has become increasingly important as processors seek to maximize ingredient value.

EVOLUTION OF OAT PROCESSING TECHNOLOGIES

Evolving consumer preferences, advances in food process engineering, and rising demand for value-added ingredients have driven the evolution of oat processing technologies. Historically, oats were processed primarily for breakfast cereals and animal feed using relatively simple mechanical operations such as cleaning, dehulling, kilning, rolling, and milling. While these technologies remain important today, modern oat processing has expanded significantly to include ingredient concentration, separation, modification, and bioprocessing.

Conventional oat processing begins with grain cleaning to remove foreign material, followed by dehulling to separate the fibrous hull from the groat. The groats are then stabilized by kilning or heat treatment to inactivate lipases and prevent rancidity due to oats' relatively high lipid content. Stabilized groats may then be processed into rolled oats, steel-cut oats, oat bran, or oat flour[26, 27].

During the 1980s and 1990s, growing interest in dietary fiber and cholesterol reduction spurred research into oat beta-glucan and functional ingredients[28, 29]. This research led to the development of specialized milling technologies that could concentrate fiber fractions and produce oat bran ingredients with higher beta-glucan levels[29].

The growth of plant proteins and functional foods in the 2000s accelerated investment in dry fractionation and wet extraction technologies. Dry milling and air-classification systems enabled processors to separate protein- and starch-rich fractions while preserving the ingredients' native functionality. These systems offered lower capital requirements and improved sustainability compared with conventional wet processing methods[30].

At the same time, wet fractionation technologies used in the corn, soy, wheat, and pulse industries were adapted for oats. These processes use alkaline extraction, enzymatic hydrolysis, centrifugation, ultrafiltration, nanofiltration, and spray drying to produce high-purity protein isolates, starch isolates, and fiber concentrates[13].

The rapid growth of oat milk manufacturing over the past decade has spurred additional processing innovations. Enzymatic hydrolysis technologies are now widely used to convert oat starch into fermentable sugars and to achieve desirable beverage texture and sweetness profiles. Advanced separation systems recover liquid and solid fractions while enabling formulation flexibility[13].

More recently, fermentation technologies have emerged as promising tools for using oat ingredients. Precision fermentation, biomass fermentation, and fungal cultivation systems can use oat-derived substrates to produce alternative proteins, bioactive compounds, and industrial biotechnology products[31].

The future of oat processing is expected to emphasize automation, digital manufacturing, water conservation, energy efficiency, and circular-economy principles. Integrating multiple processing technologies within a single biorefinery framework may enable processors to maximize the value extracted from every component of the oat crop while minimizing waste.

OAT INGREDIENT MARKET LANDSCAPE AND DEMAND DRIVERS

The global market for oat-based ingredients has grown significantly over the past two decades as consumers increasingly seek nutritious, sustainable, and functional foods. Oats benefit from strong consumer recognition and a positive health image, making them attractive across multiple market segments.

One of the most significant drivers of demand for oat ingredients has been the growing interest in plant-based nutrition. Consumers are increasingly incorporating plant-based foods into their diets for health, environmental, and ethical reasons. This trend has created substantial opportunities for oat proteins, oat beverages, and oat-derived functional ingredients[32].

Protein remains a leading driver of innovation in the food industry. High-protein foods and beverages continue to see strong demand across categories such as sports nutrition, healthy aging, weight management, meal replacements, and functional snacks. While soy and pea proteins currently dominate the plant protein market, oat proteins offer unique advantages, including consumer familiarity, mild flavor, and clean-label positioning.

Dietary fiber is another major growth area. Health authorities continue to emphasize fiber intake for digestive and cardiovascular health, as well as for glycemic control. Oat beta-glucan is particularly attractive because it has approved health claims in multiple jurisdictions and has been extensively studied in clinical research[16, 33].

The oat milk sector has become one of the most dynamic segments of the plant-based beverage industry. Consumers often view oat milk as more sustainable than dairy milk and appreciate its creamy texture and neutral flavor. This growth has spurred investment in oat processing infrastructure and ingredient development.

The pet food industry presents an additional opportunity. Premium pet food formulations increasingly incorporate plant proteins, dietary fibers, and functional ingredients that support digestive health and overall wellness. Oat-derived ingredients can provide functionality while supporting clean-label formulations[34].

Industrial biotechnology markets are emerging as a new growth frontier. Oat starches, fibers, and carbohydrate streams can serve as feedstocks for precision fermentation processes that produce proteins, enzymes, organic acids, and bio-based materials[35].

The combination of these demand drivers indicates that oat-based ingredients will continue to see strong market growth. Processors that can efficiently convert oats into specialized ingredients are likely to capture greater value as the market evolves.

OAT VARIETY SELECTION AND INGREDIENT OPPORTUNITIES

The selection of appropriate oat varieties is a critical factor affecting ingredient yield, functionality, and economic performance. Oat varieties vary considerably in protein content, starch composition, fiber concentration, lipid levels, and processing characteristics[36].

High-protein oat varieties are particularly well-suited to protein concentration technologies. These varieties may contain more than 15% protein, improve yields, and enhance the economics of protein-ingredient production. As demand for plant protein continues to grow, high-protein varieties may become increasingly important[37].

High-beta-glucan varieties offer opportunities for functional foods, dietary supplements, and nutraceutical ingredients. Beta-glucan concentrations exceeding 5–6.5% can significantly improve the economics of fiber-concentration processes and support premium ingredient positioning[37].

Moderate-protein, high-starch varieties are often preferred for oat milk production because they offer favorable carbohydrate profiles and support efficient enzymatic hydrolysis[38]. These varieties may also be suitable as fermentation substrates and for industrial biotechnology applications.

Hull-less oat varieties present another emerging opportunity. Although these oats still develop a hull, the hull is loosely attached and typically separates during harvesting or threshing, reducing the need for conventional dehulling. This can improve processing efficiency, reduce fiber dilution, and increase ingredient yields. However, the remaining hulls, agronomic performance, and supply chain considerations must also be evaluated[39].

Future breeding programs are expected to focus on improving protein content, fiber quality, disease resistance, yield performance, and sustainability. The development of varieties tailored for ingredient manufacturing could significantly enhance value-creation opportunities in the oat sector.

Ultimately, successful commercialization strategies will require alignment among variety selection, processing technologies, and target market applications.

OAT PROCESSING PATHWAYS AND INGREDIENT OPPORTUNITIES

Advances in oat processing technologies have greatly expanded the range of value-added ingredients that can be produced from oats. Beyond conventional milling practices, processors can now access multiple manufacturing pathways that selectively recover proteins, starches, dietary fiber, beta-glucan, and other functional ingredients for food, feed, nutraceutical, and industrial applications. The selection of an appropriate processing route depends on the desired functional characteristics of the ingredient, target markets, available capital investment, and overall commercialization strategy.

One of the most commercially attractive approaches is dry milling and air classification, which produce reduced-particle-size powder, develop an out-flour, and separate into protein-enriched and starch-rich fractions through particle classification. These processing operations require relatively low capital investment, consume minimal water, preserve the native functionality of oat components, and produce ingredients suitable for bakery products, snacks, cereals, pet food, and other food applications.

An alternative approach is wet fractionation, in which the process flow involves aqueous enzymatic extraction, centrifugation, membrane filtration, and other separation technologies to produce higher-purity ingredients such as oat protein isolates, starch concentrates, and beta-glucan concentrates. Although these ingredients generally command higher market values, the process is considerably more capital-intensive and operationally complex than dry fractionation.

The rapid expansion of the oat milk industry has created an additional processing pathway that goes beyond beverage production. During oat milk production, enzymatic hydrolysis and solid-liquid separation yield both the liquid oat beverage and fiber-rich oat okara. Rather than being treated as a low-value by-product, oat okara can serve as a valuable upcycled fraction for the recovery of proteins, dietary fiber, starch, and soluble carbohydrates.

Lastly, oat okara valorization has emerged as an important opportunity to utilize the ingredient better and advance sustainability and the circular economy. Fractionation and recovery of okara components can generate additional ingredient streams for food, pet food, fermentation, and industrial biotechnology applications, while decreasing waste and increasing the overall value of oat processing.

These synergistic processing pathways demonstrate that oats can serve as an adaptable raw material for producing a diverse portfolio of functional ingredients. Figure 2 provides an overview of these processing routes and the range of ingredient opportunities available from oats. The technical characteristics, economic elements, and commercial potential of these pathways are discussed in greater detail in the following sections, including the comparative techno-economic assessment of wet and dry fractionation.

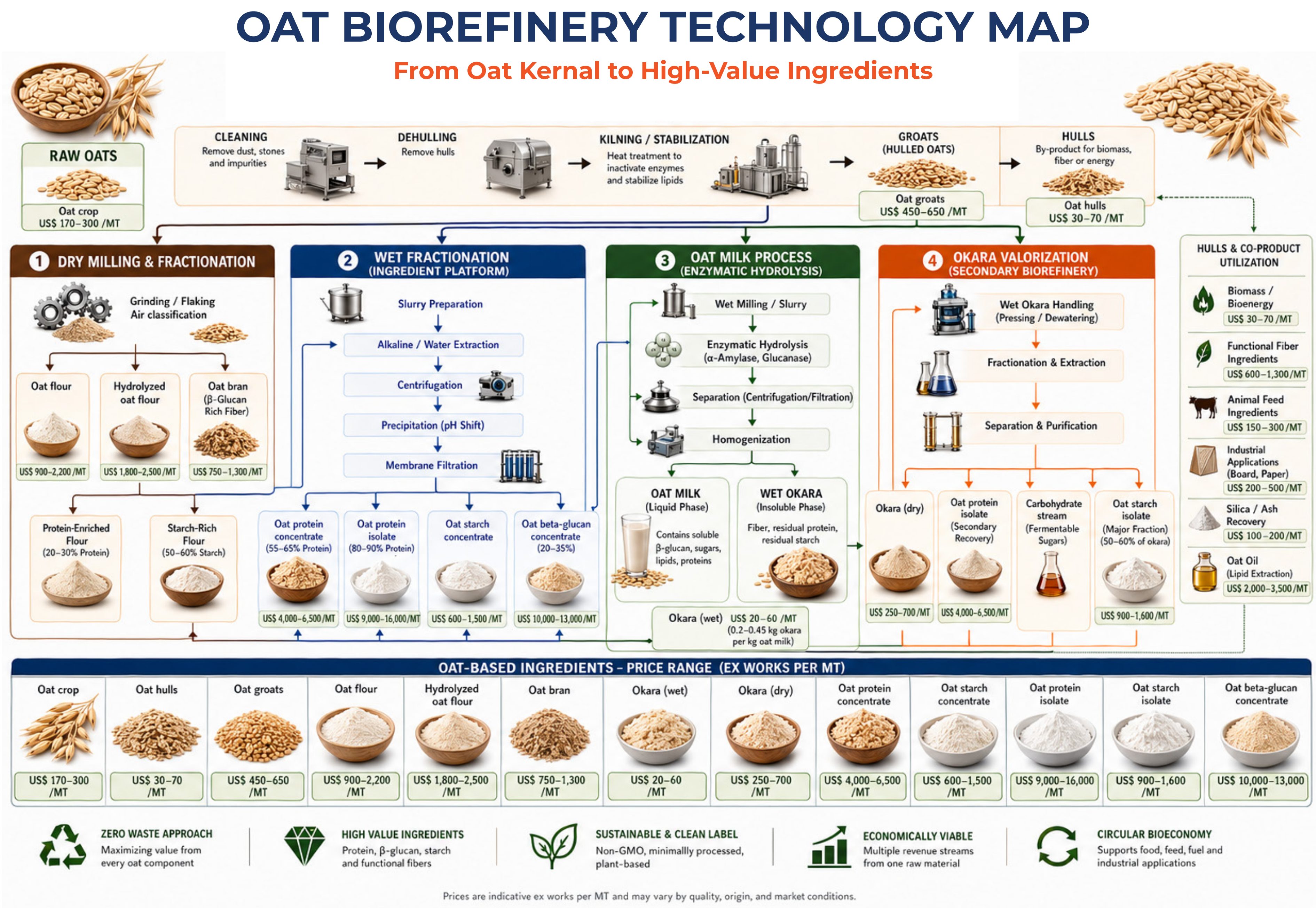


Figure 2. ***Value-Added Processing Pathways for Oat-Based Ingredients***

DRY MILLING AND AIR CLASSIFICATION TECHNOLOGIES

Dry milling and air classification are among the most promising pathways for sustainable oat ingredient production. These technologies enable the concentration of proteins and starches while minimizing water use, energy consumption, and capital investment.

The process typically begins with cleaning and dehulling raw oats. Groats are then milled using hammer, pin, roller, or air-classifying mills to achieve the desired particle-size distribution. The resulting fine-milled flour is then subjected to air classification, which separates particles by size, density, and aerodynamic properties[30, 40].

Protein-rich particles tend to concentrate in the fine fraction, whereas starch-rich particles are recovered in the coarse fraction. Multiple classification stages may be used to achieve higher protein concentrations[40].

The primary advantages of dry fractionation include low capital costs, reduced operational complexity, minimal water use, high scalability, and preservation of native ingredient functionality. Unlike wet extraction technologies, dry fractionation does not require extensive drying operations or wastewater treatment systems[30, 40, 41]. Due to the medium-range fat content (5–9%), oats still require a defatting process before fine milling and air fractionation[40].

Defatting technologies range from conventional hexane extraction to emerging green-solvent and solvent-free systems. Hexane is the most established industrial method due to its high efficiency and low cost; however, it raises concerns related to flammability, safety, volatile emissions, and consumer perception. Alternative methods include ethanol, isopropanol, ethyl acetate, supercritical CO_2, aqueous/enzymatic extraction, and newer bio-based solvents such as 2-methyltetrahydrofuran, terpenes, ethyl lactate, and deep eutectic solvents[42–46]. The solvent selection is typically guided by fat-removal efficiency. However, effects on protein solubility, flavor, residual solvent limits, cost, regulatory acceptance, and compatibility with the clean-label market should be considered[47–49].

A representative dry fractionation mass balance can begin with 1,000 kg of raw oats. After dehulling, approximately 250 kg of hulls are removed as a co-product, and 750 kg of oat groats are recovered for further processing. During milling, approximately 20 kg may be lost as fine dust, handling loss, or process loss, resulting in approximately 730 kg of oat flour entering air classification. Air classification can then separate the flour into approximately 170 kg of protein-rich concentrate and 560 kg of starch-rich fraction. On this basis, the overall mass balance totals approximately 1,000 kg, with the main product streams comprising approximately 17% protein-rich concentrate, 56% starch-rich fraction, 25% hulls, and 2% process loss.

The values shown should be considered representative rather than fixed. Actual yields will depend on oat variety, groat composition, dehulling efficiency, lipid content, milling intensity, particle-size distribution, air-classifier settings, and the target protein concentration. Higher protein enrichment generally requires more selective classification and may reduce the mass yield and total protein recovery.

Protein concentrations can range from 30% to over 60%, depending on classification efficiency and yield targets. Higher protein concentrations typically require additional processing steps and may lead to lower overall yields.

Economically, dry fractionation offers significant advantages over wet fractionation. Capital investment for a greenfield 100,000 MT facility has been estimated at $100 million, compared with roughly $700 million for a comparable wet-extraction facility. Operational costs, maintenance requirements, and utility consumption are also substantially lower.

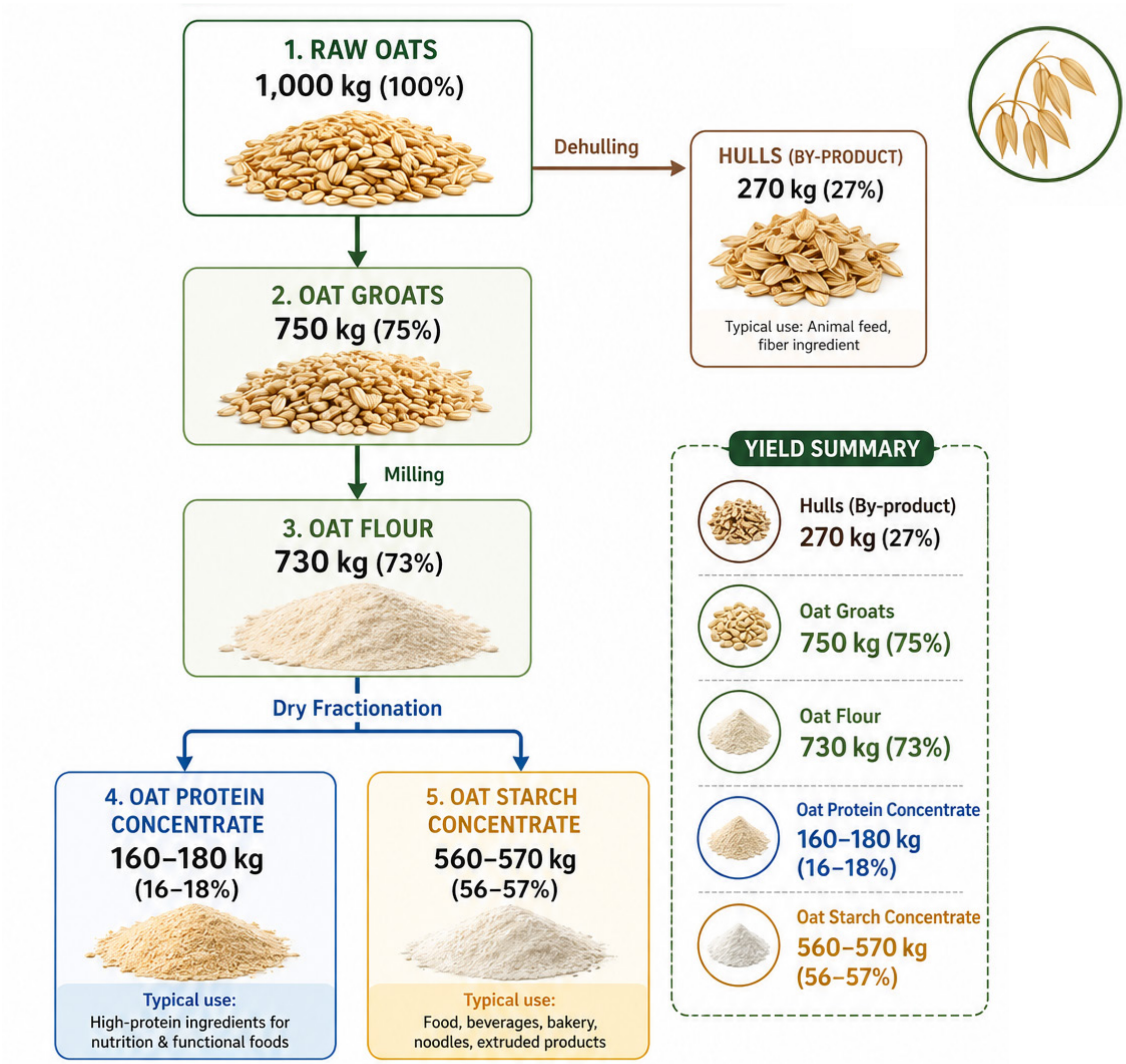
From a sustainability perspective, dry fractionation aligns closely with circular-economy objectives. Water use is minimal, greenhouse-gas emissions are reduced, and ingredient functionality remains largely intact.

In terms of application, the protein-rich fraction may be positioned for protein enrichment in bakery, snacks, cereals, pet food, and selected plant-based applications, while the starch-rich fraction may be suitable for bakery, beverage, fermentation, and other food or industrial uses. Hulls should also be considered within a full-crop utilization strategy, including applications in animal feed, fiber ingredients, fermentation substrates, energy recovery, or industrial materials[50, 51].

As consumer demand for protein-rich foods continues to grow, dry fractionation technologies are likely to become increasingly important in the oat industry.

OAT DRY FRACTIONATION FLOWCHART

Starting from 1 MT (1,000 kg) Raw Oats



MASS BALANCE SUMMARY

STEP	OUTPUT	WEIGHT (kg)	% OF RAW OATS
Raw oats (input)	–	1,000	100%
Hulls (by-product)	Removed during dehulling	270	27%
Oat groats	After dehulling	750	75%
Oat flour	After milling	730	73%
Oat protein concentrate	After dry fractionation	160 – 180	16 – 18%
Oat starch concentrate	After dry fractionation	560 – 570	56 – 57%

Yields are typical values and may vary based on oat variety, processing conditions and equipment.

Figure 3. ***Oat Flour – Dry Milling and Air Classification Conceptual Process Flowchart***

Note: *The figure is intended as a conceptual illustration of the process. For the corrected representative mass balance used in this report, 1,000 kg of raw oats yields approximately 250 kg of hulls, 750 kg of groats, 20 kg of milling/handling loss, 170 kg of protein-rich concentrate, and 560 kg of starch-rich fraction. These values close the overall mass balance and should be used for interpretation.*

OAT MILK PROCESSING AND OKARA VALORIZATION

The growth of oat milk manufacturing has created significant opportunities and challenges for the oat industry. While oat milk production generates substantial value, it also yields large quantities of okara, a protein-rich co-product high in fiber and carbohydrates.

Oat milk production typically begins by milling oats into flour and mixing the flour with water to form a slurry. Then, the slurry undergoes enzymatic hydrolysis, which breaks down starch into smaller carbohydrates, thereby improving sweetness, mouthfeel, and processability[38, 52]. After hydrolysis, solid-liquid separation removes insoluble material, yielding the final beverage base.

A typical process may convert 1,000 kg of oat flour into approximately 5,000 kg of oat milk, generating 2,000–2,100 kg of wet okara. Historically, okara has often been treated as a low-value by-product, despite its significant nutritional and functional value.

Okara utilization presents one of the largest opportunities to maximize value in the oat industry. Protein extraction technologies can recover protein-rich fractions suitable for food, beverage, and pet food applications. Dietary fiber fractions may be used in functional foods, bakery products, and nutritional formulations.

Carbohydrate-rich streams recovered from okara may serve as fermentation substrates for industrial biotechnology applications[53]. Biomass fermentation technologies can convert these streams into fungal proteins, algae-derived ingredients, enzymes, and other value-added products.

Hybrid processing approaches that integrate enzymatic hydrolysis, separation technologies, and fermentation may offer particularly attractive opportunities. Such systems can generate multiple product streams while fully utilizing oat-derived materials.

From a sustainability perspective, the use of okara aligns strongly with circular economy objectives. By converting a low-value co-product into multiple high-value ingredients, processors can improve profitability while reducing waste.

As oat milk production continues to grow globally, effective okara valorization strategies will be increasingly important for maintaining competitiveness and maximizing resource efficiency.

A representative oat milk process can use 1,000 kg of oat flour and add process water to produce approximately 5,000 kg of oat milk base and approximately 2,000 kg of wet oat okara. The wet okara stream is typically high in moisture and contains recoverable protein, fiber, carbohydrates, and water. For mass-balance purposes, the corrected example assumes 2,000 kg of wet okara at approximately 80% moisture, equivalent to about 400 kg of dry solids and 1,600 kg of water.

In the corrected fractionation scenario, 2,000 kg of wet okara can be separated into approximately 80 kg of protein-rich solids, 120 kg of fiber-rich solids, 500 kg of carbohydrate syrup at 40% solids, and 1,300 kg of recovered water. The carbohydrate syrup, therefore, contains approximately 200 kg of dry solids and 300 kg of water. This gives a total of 400 kg of recovered dry solids and 1,600 kg of recovered water, thereby closing the mass balance.

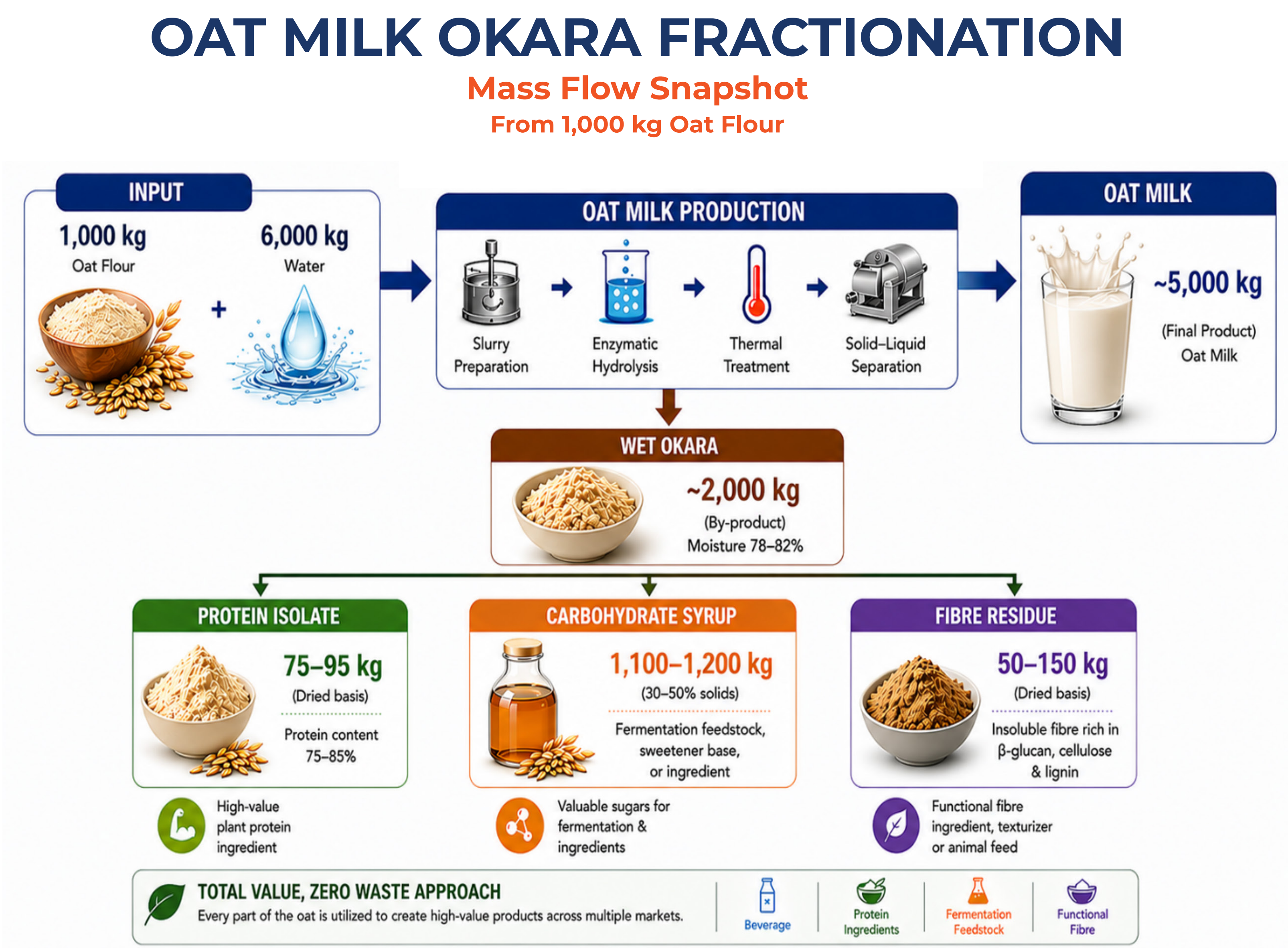


Figure 4. ***Oat Milk Okara – Conceptual Fractionation Process Flowchart***

Note: *The figure is intended as a conceptual process illustration. For the corrected representative okara balance used in this report, 2,000 kg of wet okara at approximately 80% moisture contains about 400 kg of dry solids and 1,600 kg of water. The corrected output streams are approximately 80 kg of protein-rich solids, 120 kg of fiber-rich solids, 500 kg of carbohydrate syrup at 40% solids, and 1,300 kg of recovered water.*

The okara valorization pathway offers an opportunity to convert a high-moisture, low-value co-product into multiple functional streams. Protein-rich solids may be evaluated for food, pet food, bakery, snack, and nutritional applications. Fiber-rich solids may be suitable for bakery, texturizing, dietary fiber enrichment, or animal feed applications. The carbohydrate syrup may be used as a fermentation substrate or as an ingredient stream where soluble carbohydrates are desirable. Because wet okara is highly perishable, commercial implementation should also consider stabilization requirements, microbial control, drying energy requirements, storage conditions, and logistics[2].

Company	Country	Application
Livoo Foods	Sweden	Upcycled oat protein (40% protein and 20% fiber)[54]
Fazer Group	Finland	Confectionery and snack applications[55]
Oatly, Axfoundation, The Green Dairy, Elajo Technology Solutions, and various other organizations	Sweden	Part of a collaboration initiative called Over & Oat, aimed at valorizing oat okara through food ingredient development[56, 57].

Table 1: ***Okara Manufacturers in the European Union***

Livoo commercialized one of the first oat protein products made entirely from oat okara. The ingredient has value propositions for bakery products, cakes, energy bars, meat and dairy alternatives, pet food, and nutraceutical applications[58].

Lantmannen is one of the largest oat-ingredient processors in the EU and has been producing oat protein concentrate (55% protein), oat flour, oat fiber, and beta-glucan ingredients. Lantmannen acquired Tate & Lyle's former oat-ingredient business in Kimstad, Sweden[59].

DRY AND WET FRACTIONATION PATHWAYS

A simplified economic comparison was prepared using representative mass-balance assumptions, indicative ingredient prices, and capital-cost estimates discussed in this report. This example is intended to show the decision logic rather than replace a full techno-economic assessment. The assumptions are based on reported oat composition, oat protein extraction, dry fractionation, and plant-protein processing literature.

For illustration, assume 1,000 MT of raw oats are processed at a representative raw-oat cost of US$250/MT. The total raw material cost would therefore be:

Raw material cost = 1,000 MT × US$250/MT = US$250,000

Dry Fractionation Estimated Product Value

For the dry fractionation pathway, the representative mass balance would generate approximately 250 MT of hulls, 170 MT of oat protein concentrate, 560 MT of starch-rich fraction, and 20 MT of process loss[60]. Using indicative midpoint prices of US$50/MT for hulls, US$5,250/MT for oat protein concentrate, and US$900/MT for the starch-rich fraction, the gross product value would be[61]:

PRODUCT VALUE
Hulls: 250 MT × US$50/MT = US$12,500
Oat protein concentrate: 170 MT × US$5,250/MT = US$892,500
Starch-rich fraction: 560 MT × US$900/MT = US$504,000
Total gross product value: US$1,409,000

After subtracting the raw material cost, the value above the raw material would be:

US$1,409,000 – US$250,000 = US$1,159,000

TECHNO-ECONOMIC ASSESSMENT

Wet Extraction Estimated Product Value

A simplified wet fractionation isolate pathway may generate higher-value ingredients, such as oat protein isolate, starch concentrate, and beta-glucan concentrate. If 1,000 MT of raw oats were to produce 100 MT of oat protein isolate, 300 MT of oat starch concentrate, 20 MT of beta-glucan concentrate, and 250 MT of hulls, and if midpoint prices were applied, the gross product value would be[62]:

PRODUCT VALUE
Oat protein isolate: 100 MT × US$12,500/MT = US$1,250,000
Oat starch concentrate: 300 MT × US$1,050/MT = US$315,000
Beta-glucan concentrate: 20 MT × US$11,500/MT = US$230,000
Hulls: 250 MT × US$50/MT = US$12,500
Total gross product value: US$1,807,500

After subtracting the raw material cost, the value above the raw material would be:

US$1,807,500 – US$250,000 = US$1,557,500

Although the isolate pathway generates approximately US$398,500 more value above raw material on a 1,000 MT raw oat basis, the processor should weigh this advantage against the much higher capital intensity of wet extraction[63]. If the capital requirement was approximately US$100 million for dry fractionation and approximately US$700 million for wet extraction, the incremental capital requirement would be:

US$700 million – US$100 million = US$600 million

If this incremental capital difference were spread over a 100,000 MT/year facility over 15 years, the additional capital burden would be[63]:

US$600,000,000 ÷ (100,000 MT/year × 15 years) = US$400/MT raw oats

On a 1,000 MT raw oat basis, this would be equivalent to:

1,000 MT × US$400/MT = US$400,000

This additional capital cost would be approximately equal to the extra gross value generated by the isolate pathway before accounting for higher water use, chemicals, drying, labor, wastewater treatment, maintenance, and operational complexity. Therefore, while oat protein isolates may command a higher price per unit of protein, oat protein concentrates produced through dry fractionation represent the more practical near-term opportunity because they offer lower capital intensity, simpler operation, lower utility demand, and multiple saleable co-product streams[64, 65].

Items	Dry fractionation/ Protein concentrate pathway	Wet fractionation/ Protein isolate pathway
Raw oats processed	1,000 MT	
Raw oat cost	US$250,000	
Protein product yield	170 MT concentrate	100 MT isolate
Protein product revenue	US$892,500	US$1,250,000
Starch revenue	US$504,000	US$315,000
Beta-glucan revenue	—	US$230,000
Hull revenue	US$12,500	
Total gross product value	US$1,409,000	US$1,807,500
Value above raw material cost	US$1,159,000	US$1,557,500
Estimated facility CAPEX	US$100M	US$700M
Additional capital burden vs. dry fractionation	—	~US$400/MT raw oats
Recommended pathway	Preferred near-term pathway	Longer-term/ selective pathway

Table 2: ***Comparison of estimated product value between dry fractionation (protein concentrate) and wet fractionation (protein isolate)***

Note: *This example is intended to illustrate the estimated costs and revenues between dry and wet extraction. Final economics will depend on actual oat composition, recovery yields, product specifications, utility costs, market prices, and co-product utilization.*

OAT OKARA VALORIZATION PATHWAYS

A simplified economic comparison was also prepared for oat milk okara valorization using the same decision-logic approach applied to the dry fractionation and wet fractionation examples. This analysis is intended to show the potential incremental value that can be generated from oat okara compared with low-value by-product outlets. The assumptions are based on the representative okara mass balance used in this report, indicative ingredient price ranges, and literature describing oat okara composition, perishability, stabilization requirements, and food ingredient applications[53].

For illustration, assume that 1,000 MT of oat flour is used for oat milk production. Based on the representative mass balance, this process can generate approximately 5,000 MT of oat milk base and approximately 2,000 MT of wet oat okara[66]. In this analysis, the oat flour cost is assigned to the primary oat milk process, while the okara analysis focuses on the incremental value of the co-product stream.

For mass-balance purposes, the 2,000 MT wet okara stream is assumed to contain approximately 80% moisture and 20% dry solids[67]. Therefore:

Dry solids in wet okara = 2,000 MT × 20% = 400 MT dry solids

Water in wet okara = 2,000 MT × 80% = 1,600 MT water

This means that any okara valorization pathway must address both ingredient recovery and moisture management. The most appropriate pathway depends on whether the okara can be processed immediately at the oat milk facility or whether it must be stabilized for storage, transportation, or delayed processing[2, 53].

Baseline Low-Value Okara Outlet

In a baseline case, wet okara may be sold or transferred into low-value outlets such as animal feed, biogas, or other non-specialty applications. Using an indicative midpoint value of US$40/MT for wet okara, the gross co-product value would be[68]:

Wet okara: 2,000 MT × US$40/MT = US$80,000

This option has the advantage of simplicity, but it captures limited value because most of the stream is water and because wet okara is costly to transport, unstable during storage, and susceptible to spoilage.

Direct Wet Fractionation of Fresh Okara

When oat okara is generated at an integrated oat milk processing facility, wet fractionation can be performed immediately after solid-liquid separation, while the okara is still wet. In this scenario, full drying or stabilization before extraction is not required, provided that the okara is transferred rapidly under hygienic conditions and processed within a controlled holding time. This pathway may be advantageous because it avoids the energy-intensive step of drying wet okara and then rehydrating it for aqueous extraction.

Using the corrected representative mass balance, 2,000 MT of fresh wet okara can be separated into approximately 80 MT protein-rich solids, 120 MT fibre-rich solids, 500 MT carbohydrate syrup at 40% solids, and 1,300 MT recovered water.

The carbohydrate syrup would contain:

Dry solids in syrup = 500 MT × 40% = 200 MT dry solids

Water in syrup = 500 MT × 60% = 300 MT water

The dry-solids balance would therefore be:

80 MT protein-rich solids + 120 MT fibre-rich solids + 200 MT syrup solids = 400 MT dry solids

The water balance would be:

1,300 MT recovered water + 300 MT water in syrup = 1,600 MT water

Using conservative indicative values of US$4,000/MT for protein-rich solids, US$950/MT for fibre-rich solids, and US$250/MT for carbohydrate syrup, the gross product value would be[69]:

PRODUCT VALUE
Protein-rich solids: 80 MT × US$4,000/MT = US$320,000
Fibre-rich solids: 120 MT × US$950/MT = US$114,000
Carbohydrate syrup: 500 MT × US$250/MT = US$125,000
Recovered water: 1,300 MT × US$0/MT = US$0
Total gross product value: US$559,000

Compared to the wet okara outlet, direct wet fractionation would increase the gross product value by:

US$559,000 – US$80,000 = US$479,000

On a wet-okara basis, the additional value generated by direct wet fractionation compared with the wet okara outlet would be:

US$479,000 ÷ 2,000 MT wet okara = US$239.50/MT wet okara

On a dry-solids basis, the additional value generated by direct wet fractionation compared with the wet okara outlet would be:

US$479,000 ÷ 400 MT dry solids = US$1,197.50/MT dry solids

This indicates that direct wet fractionation of fresh okara can tolerate up to approximately US$240/MT wet okara in combined additional costs before losing its gross-value advantage over the baseline wet okara outlet. These costs would include hygienic transfer, short holding time, temperature control, enzymes, separation, labor, utilities, drying of recovered fractions, quality control, wastewater management, and capital recovery.

Stabilized and Milled Dry Okara Estimated Product Value

If immediate wet fractionation is not available, wet okara may need to be stabilized through dewatering, pasteurization, drying, freezing, fermentation, or another preservation step. A stabilization and milling pathway may convert the 2,000 MT wet okara stream into approximately 400 MT dry-solids equivalent of dried okara flour or dried okara ingredient. If the final dried okara ingredient is produced at approximately 8% moisture, the final as-is product mass would be approximately:

Final dried okara ingredient = 400 MT dry solids ÷ 0.92 = 435 MT at 8% moisture

For simplified comparison, the economic calculation below uses 400 MT dry-solids equivalent. Using an indicative midpoint value of US$475/MT for dried okara flour, the gross product value would be[70]:

Dried okara flour: 400 MT × US$475/MT = US$190,000

Compared with the wet okara outlet, stabilization and milling increase the gross co-product value by:

US$190,000 – US$80,000 = US$110,000

This pathway is useful because it converts a high-moisture, perishable co-product into a more stable ingredient that can be stored, transported, milled, blended, or used in food applications. However, the additional value must be compared with the cost of dewatering, drying, milling, packaging, storage, microbial testing, and quality control.

Dry Fractionation of Stabilized Okara

If stabilized and milled dry okara is used as a secondary feedstock for dry fractionation, the dry okara material would most likely be separated into two main ingredient streams: a protein-rich fine fraction and a fibre-/carbohydrate-rich coarse fraction. This is consistent with the general principle of dry milling and air classification, where smaller protein-rich particles are separated from larger starch- or fibre-rich particles based on particle size, density, and aerodynamic properties[71].

Using the corrected representative okara dry-solids basis:

Total dry matter available from wet okara = 400 MT dry solids

For illustration, the stabilized okara could be separated into:

Protein-rich fraction = 80 MT

Fibre-/carbohydrate-rich fraction = 320 MT

Total recovered dry matter = 80 MT + 320 MT = 400 MT

Using conservative indicative values of US$4,000/MT for the protein-rich okara fraction and US$800/MT for the fibre-/carbohydrate-rich fraction, the gross product value would be[72]:

PRODUCT VALUE
Protein-rich fraction: 80 MT × US$4,000/MT = US$320,000
Fibre-/carbohydrate-rich fraction: 320 MT × US$800/MT = US$256,000
Total gross product value: US$576,000

Compared with the wet okara outlet, dry fractionation of stabilized okara increases gross product value by:

US$576,000 – US$80,000 = US$496,000

Compared with selling whole dried okara flour, dry fractionation of stabilized okara increases gross product value by:

US$576,000 – US$190,000 = US$386,000

On a wet-okara basis, the additional value generated by dry fractionation compared with the wet okara outlet would be:

US$496,000 ÷ 2,000 MT wet okara = US$248/MT wet okara

This pathway may be attractive when okara must first be stabilized for storage or transport, and when the processor wants to generate dry-ingredient fractions without reintroducing large volumes of water. However, the exact split between the protein-rich fraction and the fibre- and carbohydrate-rich fraction must be validated experimentally, as it depends on okara composition, drying method, milling intensity, particle-size distribution, and air-classifier settings.

TECHNO-ECONOMIC ASSESSMENT

Wet Fractionation of Stabilized Dry Okara

Stabilized and milled dry okara may also be used as a feedstock for wet fractionation or enzymatic extraction. However, if the okara has already been dried, this route requires rehydration and introduces additional costs related to water use, energy, enzymes, separation, drying of recovered fractions, wastewater management, and process control. Therefore, wet fractionation of stabilized dry okara should be considered mainly when the target market requires higher-purity protein, soluble carbohydrate streams, fermentation substrates, or specialized functional ingredients.

Interpretation and Recommendation

This analysis indicates that oat okara valorization should be evaluated as a staged decision rather than as a single process route. If fresh wet okara can be processed immediately at an integrated oat milk facility, direct wet fractionation should be evaluated first because the material is already hydrated and suitable for aqueous extraction, enzymatic treatment, separation, and fermentation-substrate recovery. This pathway avoids drying and rehydration costs but requires strong microbial control, hygienic transfer, short holding time, and on-site processing capacity.

If okara cannot be processed immediately, stabilization becomes necessary. In that case, stabilized and milled dry okara can serve as a shelf-stable ingredient platform. It may be sold as whole dried okara flour, used in bakery, snacks, pet food, or fibre-enriched products, or further upgraded through dry fractionation to generate protein-rich, -rich, and carbohydrate-rich fractions.

Wet fractionation of stabilized dry okara remains a longer-term or specialized pathway. It may be justified when higher-purity protein ingredients, soluble carbohydrate streams, or fermentation substrates command enough value to offset the added costs of rehydration, extraction, separation, drying, and wastewater handling.

For MBOLD's upcoming Phase 2 research, the recommended approach is to compare three practical okara pathways:

- Direct wet fractionation of fresh okara
- Stabilization and milling into dried okara flour, and
- Dry fractionation of stabilized okara

Wet fractionation of stabilized dry okara should be considered only when the target application requires higher purity, improved solubility, or specific fermentation performance that justifies the added cost.

Items	Low-value wet okara outlet	Direct wet fractionation of fresh okara	Stabilized/milled dry okara	Dry fractionation of stabilized okara
Oat flour processed	1,000 MT	1,000 MT	1,000 MT	1,000 MT
Wet okara	2,000 MT	2,000 MT	2,000 MT	2,000 MT
Okara dry solids	400 MT	400 MT	400 MT	400 MT
Main product yield	2,000 MT wet okara	80 MT protein-rich solids; 120 MT fibre-rich solids; 500 MT carbohydrate syrup at 40% solids	400 MT dry-solids equivalent dried okara flour	80 MT protein-rich fraction; 320 MT fibre-/carbohydrate-rich fraction
Wet okara revenue	US$80,000	—	—	—
Protein-rich solids revenue	—	US$320,000	—	US$320,000
Fibre-rich solids revenue	—	US$114,000	—	—
Carbohydrate syrup / dry carbohydrate revenue	—	US$125,000	—	—
Fibre-/carbohydrate-rich fraction revenue	—	—	—	US$256,000
Dried okara flour revenue	—	—	US$190,000	—
Recovered water revenue	—	US$0	—	—
Total gross product value	US$80,000	US$559,000	US$190,000	US$576,000
Incremental value vs. wet okara outlet	—	US$479,000	US$110,000	US$496,000
Incremental value per MT wet okara	—	US$239.50/MT	US$55/MT	US$248/MT
Main technical limitation	Low value, perishability, transport cost	Microbial control, short holding time, wet separation cost	Drying energy, microbial control, market acceptance	Fractionation efficiency and product specifications

Table 3: ***Comparison of Estimated Product Value Between Oat Okara Valorization Pathways***

Note: *This example is intended to illustrate the economic logic for oat okara valorization. Final economics will depend on actual okara composition, moisture content, stabilization method, drying cost, milling performance, fractionation efficiency, recovery yields, product specifications, microbial control, customer demand, and validated market prices.*

SUSTAINABILITY, CIRCULAR ECONOMY, AND FULL-CROP UTILIZATION

Sustainability has become a defining factor in decision-making across the food industry. Consumers, regulators, investors, and food manufacturers increasingly assess products based on environmental performance and resource efficiency.

The oat industry has several inherent sustainability advantages. Oats generally require fewer agricultural inputs than some competing crops and can contribute positively to crop rotation systems. Their favorable environmental profile supports consumer interest in sustainable food systems[7].

Full-crop utilization is a key sustainability objective. Historically, some oat components, such as hulls and okara, have had limited economic value. Modern processing technologies offer opportunities to convert these materials into useful products.

Dry fractionation technologies support sustainability by reducing water use, lowering energy requirements, and minimizing waste generation. Similarly, okara valorization enables the recovery of proteins, fibers, and carbohydrates that might otherwise go underutilized.

Circular economy principles encourage processors to maximize value from all material streams while minimizing waste. Future oat biorefineries may integrate food-ingredient production, fermentation technologies, energy-recovery systems, and co-product utilization strategies to achieve near-complete utilization of the crop.

COMMERCIAL OPPORTUNITIES AND FUTURE MARKET APPLICATIONS

The market potential for oat-derived ingredients extends far beyond traditional food products. Protein ingredients, dietary fibers, beta-glucan concentrates, and fermentation substrates can support multiple industries.

Food applications include high-protein beverages, bakery products, snack foods, breakfast cereals, meal-replacement products, and functional foods. Oat proteins and fibers provide nutritional and functional benefits while supporting clean-label positioning.

Pet food applications represent a rapidly growing market. Premium pet foods increasingly include functional ingredients to support digestive health, weight management, and overall wellness.

Industrial biotechnology applications are expected to expand significantly. Oat-derived carbohydrate streams can support precision fermentation, biomass protein production, enzyme manufacturing, and the production of bio-based chemicals.

Health and wellness products also present significant opportunities. Functional foods targeting cardiovascular and digestive health, satiety, and glycemic control align well with oat-derived ingredients.

As these markets continue to expand, oats are likely to become an increasingly important platform for ingredient innovation.

CONCLUSIONS AND RECOMMENDATIONS FOR THE NEXT PHASE OF RESEARCH

The oat industry is entering a period of rapid transformation, driven by shifting consumer preferences, technological innovation, and sustainability goals. While traditional oat products remain important, future growth will increasingly depend on specialized ingredients and value-added processing.

Among the technologies evaluated, dry milling and air classification offer the most attractive near-term opportunity. These manufacturing technologies deliver favorable economics, low environmental impact, scalability, and strong commercialization potential for oat ingredients.

Oat milk okara utilization presents a second strategic opportunity to significantly improve resource efficiency and profitability. Protein recovery, fiber concentration, and fermentation technologies can transform a low-value co-product into multiple high-value ingredients.

Phase 2 research should focus on:

- **Direct wet fractionation of fresh oat milk okara,** where the material can be processed immediately after oat milk production, to recover protein, fiber, carbohydrates, and other valuable streams.
- **Stabilization and milling into dried okara flour,** providing a shelf-stable ingredient that could be used directly in food or feed applications when immediate processing is not feasible.
- **Dry fractionation of stabilized okara** to produce protein- and fiber-rich fractions and evaluate their potential for higher-value applications.

Across these pathways, Phase 2 research should focus on assessing the scalability of the processing technologies, evaluating the potential functional properties of the resulting ingredients and fractions, techno-economic modeling, and commercial planning.

Ongoing development of high-protein and high-beta-glucan oat varieties may further improve ingredient yields and economic performance. Integrating advanced processing technologies with crop improvement programs will strengthen long-term competitiveness.

Overall, oats have the nutritional composition, functionality, consumer acceptance, and sustainability credentials to support future food innovation. Organizations that invest in value-added processing, ingredient diversification, and circular-economy solutions will be well-positioned to lead the next generation of oat-based ingredient manufacturing.

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Prairie Oat Growers Association (POGA): oat field close up (cover); oats in a swath (p. 11); bowl of oatseed (p. 15); harvest (p. 19, 35)

Saskatchewan Food Industry Development Centre: extruded snacks3 (cover); extruded snacks1 (p. 3); oats in machine (p. 5); processing (p. 9); lab fermenation (p. 12); pasta extrusion (p. 14); spinning (p. 17); packaging extruded snacks (p. 30)

SunOpta: oats surrounded oat flour in red bowl (p. 2); oat field landscape (p. 7); tractor oatfield (p. 8); oats + milk & plant (p. 19)



Saskatchewan Food Industry Development Centre Inc.

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