Product Development from Gluten Free Oat Fractions

Final Report

Sponsor:
Prairie Oat Growers Association
Alberta Crop Industry Development Fund

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PROJECT OVERVIEW

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Project title: Product Development from Gluten Free Oat Fractions

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SUMMARY

The objective of the project was to extract and isolate protein and starch fractions from oat grains, and then develop food prototypes from each fraction. With the support of the Prairie Oat Growers Association (POGA) and the Alberta Crop Industry Development Fund (ACIDF), the University of Alberta in collaboration with the Northern Alberta Institute of Technology (NAIT) were successful in developing four food prototypes using oat protein and/or oat starch including meat analogue, pasta, doughnut and ice cream. These good prototypes represent good models to test protein or starch functionalities such as foaming/emulsifying (ice cream, doughnut) and gelling (pasta, meat analogue) capacity. Also they reflect industry's interest to replace egg and dairy proteins in food formulations. All these food products developed fit into the niche category of being gluten-free and vegan. In some formulations, new foods with a high protein inclusion were developed that are qualify for high protein claims. The key attributes of each food prototype with different oat ingredient inclusion levels were evaluated such as protein content, moisture retention, texture and nutritive value. As a stand-alone ingredient, the oat proteins are good foam and emulsion stabiliser as well as moisture binder in doughnut and provide a creamy mouthfeel to the ice cream style product. Oat starch had gelling properties and provided texture to the meat analogue with gums. In combination, the starch and protein fractions mimicked the sheer strength of gluten in the pasta product and created a structural matrix to capture carbon dioxide during the fermentation process in the yeast-risen vegan doughnuts. The present research affords a new way to deliver the healthful benefits of oat grains. Finding food applications for oat fractions will help attract interest from industry players to build facility in western Canada for oat fractionation and their food application development. This will potentially create diversified commercial opportunities for oat crops, and foster growth in the Canadian oat sector and food industry.

BACKGROUND

Canada is a major world supplier of oats with an annual production of 3.8 million tons (statistics Canada, 2017). Recently the human food market for oat has been gaining momentum mainly due to the growing public awareness of the health benefits of beta-glucan for reducing blood cholesterol and regulating blood glucose levels. Several techniques have been developed to isolate β-glucan from oat grain as health ingredients in food and cosmetic products. The remaining components such as protein, starch and oil are awaiting research to develop their full value. For example, oats have the highest protein level (12-24%) among cereals with nutritive value nearly equivalent to soy and pea protein. Oat proteins are gaining in popularity among food manufacturers due to its high nutritive value and neutral flavor and taste.

This project is being driven by an emerging industry interest in using fractionated gluten free oat ingredients (protein, starch, fiber) as a source of product innovation. Within the last couple of years the program has engaged in discussions with 10+ companies who are interested in trying various fractionated oat ingredients in their product development applications. Target applications range from proteins for bakery applications to fiber for nutrition, and starches for food and non-food applications.

The program is developing a fractionation process for oats that will produce quality ingredient fractions from oats. The combination of this developing fractionation capability and the emerging interest in gluten free oat fractions is creating a product development opportunity, which could gradually increase the utilization of oat ingredients within specific market segments. One of the project's primary goals is to demonstrate how the unique functionalities of oats can be used to improve existing products or develop innovative products that can be commercialized.

One of the limitations of oats that industry has identified is the economics associated with fractionated ingredients. The majority of the current fractionation methods are focused on extracting one main ingredient, typically the beta glucan. Focusing the extraction of a single fraction can negatively impact the quality and value of the other fractions as they become considered by-product or waste streams. This work wants to demonstrate that the value and market potential of oats can be significantly increased through the utilization of each ingredient fraction. Local processing of oats and regional product development will enable producers, processors, governments, and other agencies to gradually recapture the value from ingredient processing that has been lost through crop exportation.

OBJECTIVES

This is a collaborative research between University of Alberta and NAIT's culinary arts program with the aim to demonstrate food application potentials of oat ingredients

The specific objectives are to:

1. Develop food prototypes from each fraction (protein, starch)
    a. Demonstrate the unique functionalities and properties of each fraction
    b. Provide comparative data to other major ingredient crops

2. Analyze the food quality to support the commercialization of the most promising prototypes

3. Work with industry partners to develop a sustainable supply chain of fractionated oat ingredients within western Canada and to promote commercialization of the oat ingredients

RESULTS AND DISCUSSIONS

1. Fractionation to prepare oat ingredients

Gluten-free oats were provided by Avena Foods (Regina, SK). The whole oat flours contain 16.1% protein as determined by the elemental analysis using a conversion factor of 5.83 on a Leco nitrogen analyzer. Starch and β-glucan content were 3.4% and 50.7% as determined by the enzymatic kits.

A wet processing was developed to separate protein and starch from oat grains. This was based on the good solubility of protein at mild alkaline solution, thus can be separated from insoluble component (e.g. starch and insoluble dietary fiber). The extraction processing conditions such as particle size, flour-to-solvent ratio and pH determine protein and starch content in the extracts, thus these parameters were optimized as follows. The whole oat seeds were milled using 0.5 mm sieve to produce whole grain flour. Oat flour was mixed with water at 1:6 ratio (w/v), the pH was adjusted to 9.2 using 1 mol/L NaOH, and solution was stirred at 500 rpm for 1 hour at room temperature. The alkali extract was centrifuged at 7500×g for 15 min at 23 °C and the precipitated starch was separated from the supernatant. Supernatant was then collected and adjusted to neutral pH using 1mol/L HCl and stored in the refrigerator. This optimized processing in lab (3 L) led to protein concentrate (86% protein) with a yield of 58.6%. This processing was then scaled up (1000 L) in the Food Processing Development Centre at Leduc, Alberta Agriculture and Forestry. The pilot protein sample contain 70.2% protein with a yield of 40.7%, and the other components include 2.9% β-glucan and 0.8% starch. The insoluble components in alkaline solution was collected after centrifuge as precipitates and then further purified to generate an oat starch fraction containing 71.1% starch, 15.5% protein and 1.8% β-glucan. These two pilot samples were used to develop oat based food prototypes in the next step.

Bean Preparation:

1. Soak beans in water overnight (minimum 8 hours) at room temperature.
2. Drain soaked beans, add fresh water to cover the beans by at least 2.5 cm.
3. Bring beans to a boil and then turn heat down to medium-low.
4. Simmer for about 1 hour or until the beans are soft.
5. Drain cooked beans and rinse with cold water.
6. Chill beans until they can be comfortably handled prior to pureeing

Infused Oil:

1. Slowly and gently heat the oil, no higher than 150 °C—any more, and it will start to cook, changing the oil's flavor profile and potentially becoming rancid.
2. Add the ingredients after the oil has been removed from the heat, and let it steep in a covered container.
3. Allow the infused oil to come to room temperature (about 4 hours), and store it in the cooler.

Oat Milk:

1. Add 1 cup of oats and 4 cups of water to the blender.
2. Blend for 1 minute or until the mixture is well combined.
3. Strain through a micro bag.
4. Transfer to a sealed container and refrigerate.

2. Develop food prototypes from oat protein and oat starch ingredients

Ingredients:

- Oat protein: 70.2% protein, 0.8% starch, 2.9% β-glucan
- Oat starch: 15.5% protein, 71.1% starch, 1.8% β-glucan

Products developed:

- Kidney bean meat analogue
- Gluten-free, vegan doughnut
- Pasta
- All oat ice cream.

Four food prototypes were developed using oat protein and/or oat starch ingredients including meat analogue, pasta, doughnut and ice cream. These represent good models to test protein or starch functionalities such as foaming/emulsifying (ice cream, doughnut) and gelling (pasta, meat analogue) capacity. Also they reflect industry's interest to replace egg and dairy proteins in food formulations. All products developed fit into the niche category of being gluten-free and vegan. In some formulations, oat proteins were mixed with pulse proteins to create new foods with a high protein status that qualify for protein label claims. Cereal and pulse proteins are complementary in essential amino acids and their combinations represent close to optimum essential amino acid profile.

The key attributes of each food prototype with different oat ingredient inclusion levels were evaluated such as protein content, moisture retention and texture using established methods. The food nutritive value was also evaluated with some nutrition fact tables presented.

Product 1: Kidney bean meat analogue

Recipe

Ingredient	Amount
Puréed kidney beans *	250 g
Mushrooms (any kind available)	150 g
Pea protein (15 g protein)	20 g
Buckwheat flour	20 g
Activa (transglutaminase)	2.5 g
Infused Oil *	25 g
White Pepper	25 g
Black Pepper	25g
Pink Pepper	10 g
Coriander	10g
Canola Oil	500 mL
Brown Sugar	5 g
Salt	5 g
Nutritional Yeast	5 g
Oat Starch	**24 g**
Paprika	5 g
Tomato Puree	10 g
Liquid Smoke	to taste
Xanthan Gum	1.2 g
1.5% Konjac Gel	70 g

* See Appendix A

1. Purée the prepared kidney beans three times with the blade devise in the Pacojet on setting 10; (Pacojet AG, Pacojet, Zug Switzerland).

2. Finely chop mushrooms with blade device in Pacojet on setting 6.

3. Add all other ingredients and mix well by hand.

4. Roll into a torchon (log shape) with food wrap and vacuum package.

5. Cook in Rational combi-oven or thermocirculator at 90 °C or 200 °F for one hour.

6. When cooked, let rest for 8 hours. The first hour at room temperature and then place in the cooler for the remaining 7 hours or longer until the core temperature reaches 4 °C or less.

Product development and quality analysis

Consumers are becoming more health conscious of the foods they consume, and demand foods that provide high in proteins but low in fat contents and calories. In addition, the rise in number of consumers adopting veganism across the globe has led to an increased preference for plant based meat alternatives. Achieving meat-like chewy texture and taste is important for success of the meat analogue products. Oat starch has a gelling capacity which contributed to the product texture by increasing the hardness, cohesiveness, and chewiness, while complementing the other ingredients. The oat starch alone did not give the meat analogue the desired meat-like texture, however, and acceptable meat-like texture was achieved with the addition of konjac and xanthan gum. Various amounts of oat starch were tried in the formulation (0%, 5%, 10%, 15%).

The cross-section the meat analogue products was observed using a stereo microscope. The moisture content was measured using a Mettler-Toledo Moisture analyzer MJ33. The protein content was determined by the Leco nitrogen analyzer. The Texture Profile Analysis (TPA) was applied to study the meat analogue texture using an Instron 5967 universal testing machine. TPA is designed as a two cycle compression performed to simulate successive "chews" for determining the textural properties of foods. The samples were compressed at a crosshead speed of 1 mm/min until a deformation of 50% of the initial height. Hardness, springiness, cohesiveness, and chewiness were calculated using the force-time curve. Hardness indicates the food firmness as the force required to attain a given deformation. Cohesiveness indicates the amount of deformation for a food product before rupture when compressed with molars. Springiness indicates how well a product physically springs back after the first compression. Chewiness indicates the energy required to chew a product until is ready to be swallowed.

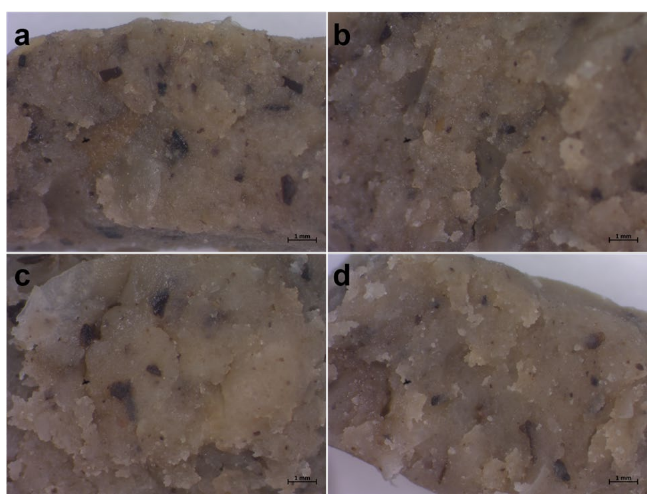

Figure 1. Images of meat analogue with different percent of oat starch obtained by stereo microscope: (a) 0%, (b) 5%, (c) 10%, and (d) 15%.

The morphology of the meat analogue samples are shown in Figure 1. Their protein and moisture content, and texture are described in Table 1 and 2.

Table 1. Physical and chemical properties of the meat analogue

	Sample-0%	Sample-5%	Sample-10%	Sample-15%
Moisture content%	60.84	62.66	56.98	55.81
Protein content%	45.36 ± 3.93	28.09 ± 0.81	26.60 ± 4.71	33.89 ± 2.09

Table 2. Texture analysis of the meat analogue

Texture analysis	0%	5%	10%	15%
Hardness (N)	6.05 ± 0.57	12.27 ± 0.67	11.38 + 2.12	17.40 ± 3.80
Cohesiveness	0.21 ± 0.01	0.22 ± 0.02	0.19 ± 0.01	0.16 ± 0.01
Springiness	0.28 ± 0.02	0.31 ± 0.01	0.24 ± 0.02	0.17 ± 0.02
Chewiness (N)	0.37 ± 0.09	0.82 ± 0.08	0.53 ± 0.16	0.46 ± 0.01

From photos in Figure 1, the meat analogue samples with different oat starch contents show similar morphology with compact structure. They also show similar moisture content (Table 1). The bean based meat analogue is high in protein (45.36%). The protein content decreased after addition of oat starch, but the protein contents are still maintained at 26.6-33.89% which is qualified to be claimed as high protein food products (defined to contain 20-35% protein).

As shown in Table 3, meat analogue texture was significantly improved in the presence of oat starch. The product firmness (hardness value) was doubled (from 6.05N to 12.27N) with 5-10% oat starch inclusion, and tripled with 15% oat starch inclusion. The chewiness was also substantially increased from 0.37 N to 0.82 N by adding oat starch in the formulation. This result confirms good gelling capacity of oat starch for potential meat analogue applications. Compared to meat analogue products in the market, the samples with oat starch demonstrated good hardness and chewiness, but their springiness and cohesiveness still need to be improved.

Nutrition Facts	
servings per container	
Serving size	**(100g)**
Amount per serving	
Calories	**150**
	% Daily Value*
Total Fat 6g	**8%**
Saturated Fat 0g	**0%**
Trans Fat 0g	
Cholesterol 0mg	**0%**
Sodium 420mg	**18%**
Total Carbohydrate 17g	**6%**
Dietary Fiber 5g	**18%**
Total Sugars 2g	
Includes 1g Added Sugars	**2%**
Protein 10g	
Vitamin D 0mcg	0%
Calcium 26mg	2%
Iron 3mg	15%
Potassium 369mg	8%

*The % Daily Value tells you how much a nutrient in a serving of food contributes to a daily diet. 2,000 calories a day is used for general nutrition advice.

Table 3 Nutrition facts of bean based meat analogue using oat starch as binding ingredient

The nutrition facts table shows the meat analogue samples are significantly lower in fat content (~50% reduction) compared to beef patty based on the same calory. In addition, the meat analogue product is high in dietary fiber from beans that bring additional health benefits. Foods containing fiber can help to maintain a healthy weight and lower the risk of diabetes and heart disease.

Summary: Oat starch demonstrates good gelling capacity and potential to be used as food binder to make meat analogues when combined with gums. The formulations can be further improved to provide desired meat-like texture by increasing the product springiness and cohesiveness.

Product 2: Gluten-free, vegan doughnut

Recipe

Ingredient	Amount
Gluten-free flour (Kinnicknnick)	350 g
Salt	2.5 mL
Baking powder	1.25 mL
Sugar	100 g
Dry instant yeast	15 mL
Oat protein	**20 g**
Lentil protein	30 g
Oat milk *	70 mL
Margarine	60 g
Oat milk *	85 mL
Vanilla	4 g

1. Add the yeast to 85 mL warmed oat milk (110 °F) with 30 g of the sugar and let sit until foamy on top (about 10 minutes).

2. Cream margarine, remaining 70 g of sugar, and vanilla in a commercial mixer on medium speed.
3. Combine gluten-free flour, salt, and baking powder together and sift into a separate container.
4. In a separate container, combine lentil protein, oat protein and 70 g of oat milk together and mix until creamy. Add mixture to the creamed ingredients.
5. Add the dry ingredients to the creamed ingredients and mix on medium speed, scraping down the sides, until the ingredients are well combined.
6. Add the liquid ingredients to the dry ingredients and mix on medium speed until blended, scraping down the sides a few times.
7. Dust the counter with rice flour and roll out to a thickness of ½" and cut the doughnuts.
8. Proof in a proofing chamber for about 1 hour. The doughnut is ready to fry when a fingerprint indentation remains after touching the side of the doughnut lightly.
9. Fry at 350 °F until light brown in a commercial fryer, filled with canola oil, for 3 to 5 minutes.

Product development and quality analysis

The confectionery product industry represents a major segment of the North American food processing industry. Among the numerous snacks offered in the market, doughnuts represent the single most popular type of pastry consumed, accounting for 22% of total pastry sales, and ranks 11th among the foods consumed out of home or from restaurants in Canada. Since doughnuts are often perceived as a high-glycemic, high-caloric and unhealthy snack, manufacturers have responded by offering smaller portion options such as mini doughnuts or creating products with more plant based ingredients to align with the demands of health conscious consumers. Oat protein can be a good choice to replace egg in doughnut products due to its good nutritive value containing high quantities of essential amino acids lysine and threonine. In addition, oat proteins have exhibited good emulsifying and oil holding capacities.

In this work, oat protein was used as an egg-replacer in this recipe due to its emulsifying and foaming characteristics. Various amounts of oat protein ingredients were tried in the formulation (2.5%, 5%, 7.5%). The control sample was made of egg as emulsifying and foaming ingredient. The key attributes of the doughnuts were evaluated including morphology of the inner structures, protein and moisture content, texture and storage stability by the same method as described above.

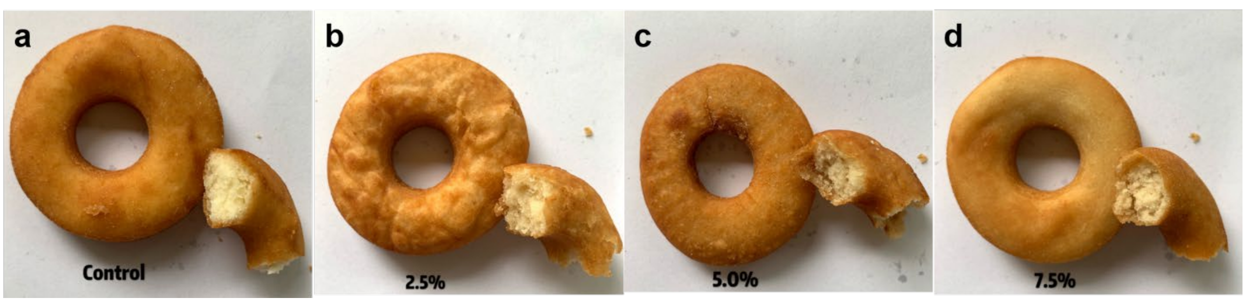

Figure 2. Photographs of doughnut with different percent of oat protein: (a) control, (b) 2.5%, (c) 5.0%, and (d) 7.5%.

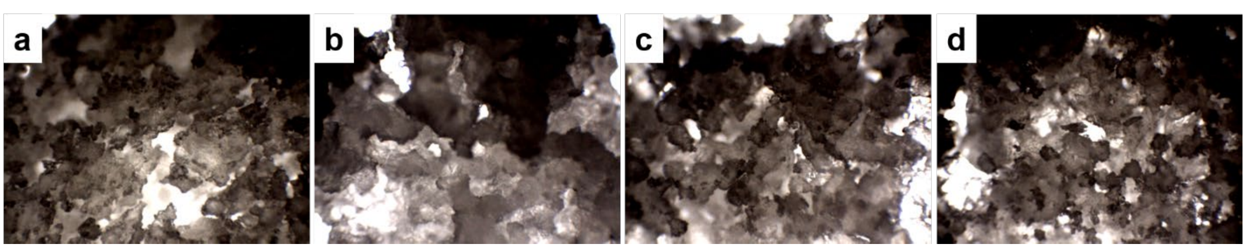

Figure 3. Microscopic images (4 ×) of doughnut with different percent of oat protein: (a) control, (b) 2.5%, (c) 5.0%, and (d) 7.5%.

Table 4. Physical and chemical properties of doughnuts

	Control	Sample-2.5%	Sample-5.0%	Sample-7.5%
Diameter (mm)	60.8 ± 1.8	65.0 ± 2.3	63.8 ± 4.2	62.0 ± 1.9
pH	6.04	5.92	5.92	5.85
Moisture	18.3%	12.1 %	10.9%	18.6%
Protein content	3.53%	5.12%	6.37%	6.85%

Table 5 Texture analysis of the doughnut samples

Texture analysis	Control	2.5%	5.0%	7.5%
Hardness (N)	36.72 ± 5.76	12.97 ± 3.18	12.95 ± 3.22	20.06 ± 2.72
Cohesiveness	0.29 ± 0.12	0.09 ± 0.03	0.16 ± 0.04	0.14 ± 0.01
Springiness	0.71 ± 0.07	0.46 ± 0.07	0.64 ± 0.17	0.74 ± 0.62
Chewiness (N)	7.10 ± 1.94	0.54 ± 0.28	1.34 ± 0.45	1.86 ± 1.25

Table 6 Texture analysis of the doughnut samples frozen for seven days

Texture analysis	Control	2.5%	5.0%	7.5%
Hardness (N)	46.08 ± 0.73	7.97 ± 1.08	14.75 ± 0.79	18.61 ± 1.13
Cohesiveness	0.35 ± 0.03	0.17 ± 0.08	0.18 ± 0.03	0.20 ± 0
Springiness	0.50 ± 0.24	0.34 ± 0.11	0.49 ± 0.02	0.51 ± 0.13
Chewiness (N)	7.79 ± 3.29	0.51 ± 0.41	1.29 ± 0.20	1.40 ± 0.40

As shown in Figure 2, 3 and Table 4, the replacement of egg by oat protein did not significantly change the appearance, inner structure and pH of the cooked doughnuts compared to the control sample with egg.

The ability of doughnuts to bind moisture prevents dehydration and inhibits the Maillard browning reaction. The moisture binding capacity is also an important property to obtain products containing less oil since there is a strong relation between oil uptake and moisture loss during frying. As shown in Table 4, the moisture content was significantly reduced from 18.3% for egg based doughnuts to 10.9-12.1% with addition of 2.5 and 5% oat protein compared to the control doughnut, which can influence product quality. While when the oat protein content increased to 7.5%, the moisture content increased to the same level (18.6%) as the control sample with egg, and the doughnuts showed lighter brown color due to reduced Maillard browning reaction with increased moisture content. The surface colour of products, such as doughnuts or cookies, is an important parameter for the initial acceptance of the product by consumers. This result demonstrate good moisture binding capacity of oat protein in bakery product formulations to prevent dehydration and reduce oil uptake.

Moreover, the protein content was doubled, increasing from 3.53% for the control with egg to 6.85% for the doughnut sample with 7.5% oat protein. The observed protein content (6.37-6.85%) was satisfactory and greater than that (2-4%) in regular wheat flour doughnuts available in retail stores. Developed doughnuts can possibly qualify for a high protein content claim, according to the Canadian Food Inspection Agency (CFIA) (2015), as they contain 25% more protein than regular products present in the market.

Regarding the texture, the doughnuts with oat protein were softer than the control sample with egg as reflected by the significantly decreased hardness values from 36.72 N to 7.97-14.75 N for samples with 2.5 and 5% oat protein (Table 6), as well as the significantly decreased chewiness value. Addition of 7.5% oat protein increase the sample hardness value to 20.06 N. These attributes are directly influenced by the doughnut network developed by the constituents present in the formulations. Above results indicate that egg is still better than oat protein as a binding ingredient in bakery formulation. But increasing oat protein level can improve the texture of the doughnut products due to their good gelling capacity. The springiness value of the oat protein based doughnuts (5 and 7.5%) are similar to that of the control sample with egg, suggesting that oat protein can form a viscoelastic gel structure by heating during the baking processing.

The storage stability of the doughnuts was evaluated by monitoring the changes in the texture profile after 7 days of freezing in -20 ºC in order to study product staling. Frozen samples were thawed prior to analyses and their crumb texture were evaluated as described previously. There was a significant increase in hardness value for the control sample with egg before and after 7 days of freezing from 36.72 N to 46.08 N (Table 6). This enhanced hardness profiles are likely due to the texture staling, a phenomenon related to the change in both chemical and physical attributes of doughnuts post preparation, giving products a drier and harder texture, with reduced elasticity. It is interesting to notice that hardness of the doughnut samples with 5-7.5% oat protein only changed slightly after the freezing-thaw cycle and the cohesiveness value even improved after storage. This might be related to strengthened oat protein network by heating treatment followed by freezing. Our previous work demonstrated that heat-induced gels from oat were further reinforced during cooling step due to formation of more crosslinking structures.

Summary: This research demonstrated the feasibility of using oat protein as an egg-replacer to make gluten-free and vegan doughnuts that are suitable for protein claims. Oat proteins are efficient foam and emulsion stabiliser as well as moisture binders in doughnut formulations, comparable to egg. The final products have good sensory quality by professional evaluation (Certified Chef de Cuisine program in NAIT) although they showed a softer texture compared to the control sample with egg. But egg is superior as a binding ingredient to provide product texture and cohesiveness. The use of oat protein slowed down doughnut hardening during storage at freezing temperature due to formation of strong oat protein gel network at low temperature that also better hold moisture during the freezing-thawing process. Considering the consumers' demand of convenient snack foods that are high in protein and suitable for vegan, the oat protein based doughnuts may have potential for commercialization with some improvements in texture.

Product 3: Gluten-free Pasta

Recipe

Ingredient	Amount
Yellow Pea Flour	50 g
Chick Pea Flour	50 g
Oat Starch	**96 g**
Oat Protein	**20 g**
Egg	160 g
Activa (transglutaminase)	4 g
Xanthan Gum	3 g
Guar Gum	1.5 g

1. Mix dry ingredients together with a whisk and pour into commercial mixer. Mix on medium speed until the ingredients were blended, approximately 60 seconds.

2. Add eggs and mix on medium speed until all ingredients are incorporated, approximately 2 minutes.

3. Roll the dough into a ball, place it in a vacuum bag and vacuum pack to hydrate the dough thoroughly. No rest time is necessary, the dough can be rolled out immediate after packaging or can be stored before use.

4. Roll out to desired shapes. A Kitchen-Aid pasta attachment can be used or a standard pasta roller to make the noodles.

Product development quality analysis

The consumption of pasta is increasing worldwide due to its convenience, palatability, and nutritional properties such as low fat, low sodium and can be enriched with fibres, minerals and antioxidants. Interest from food industry has focused on the possibility of making gluten free pasta products that is high in plant proteins for the growing number of celiacs, as well as for consumers who wish to exclude gluten-based products from their diet for health reasons. As celiac disease can occur at any age, the production of good quality gluten free products for people with a tradition consuming of wheat-based products is necessary as an alternative.

A high protein content and a “strong” gluten are required to process semolina into a suitable final pasta product with an optimal cooking performance. Therefore, there are a number of challenges to the food industry in terms of the cooking quality of gluten-free pasta and their textural characteristics such as cooking loss and firmness. In this work, the combination of oat protein and oat starch forms a protein matrix, provides gelling capacity, and acts as a binder in gluten free formulations. It also improved the flavour, making it more neutral and less “pulsey”. The pasta had good colour, hydration and sheer strength; however, the formulation was deemed unsuccessful due to the bitterness flavour.

Thus yellow pea flour and chick pea flour were included in the formulation, which masked bitterness while showcasing the functionality of the oat protein and oat starch. The pulse flour inclusion darkened the pasta colour and the combination of the oat fractions and pulse flours were complementary ingredients as they served to mask the undesirable flavours from each ingredient. The oat fractions masked the beany flavours from the pulse flours while the pulse flours masked the bitterness from the oat fractions. In addition, addition of pea and chick pea flours helps to improve protein content in the final products.

Various amounts of oat protein ingredients were tried in the formulation (15%, 25%, 35%). The control pasta sample was made of wheat flour. The pasta samples were cooked by adding 10-g portions to beaker containing 300 ml boiling distilled water. The optimum cooking time (min) was determined using AACC Approved Method 66-50 (AACC 2005). The samples were removed from cooking water at 30-sec intervals and squeezed between two pieces of clear plastic. When center core just disappeared, stop timer and record cooking time. When "cooking time" was reached, the sample was rapidly drained into a Büchner funnel, retaining cooking water. Then the sample was rinsed with stream of distilled water for 30 sec held at consistent temperature. The cooking and rinse water were combined and evaporating to the constant weight in an air oven at 105◦C. The residue was weighed, and the cooking loss and water absorption capacity were evaluated. Swelling index was also calculated and expressed as following: weight of [cooked pasta (g) – weight of the pasta after drying (g)]/weight of the pasta after drying (g). The moisture content and texture were studied using the Moisture analyzer and the Instron 5967 Universal testing instrument. For the pasta texture, the tensile strength (MPa), elongation (%) and Young's modulus (MPa) were calculated. Tensile strength indicates force that a material can support without fracture when being stretched. Elongation is expressed as the length at breaking expressed as a percentage of its original length. Young's modulus indicates the stiffness of the pasta.

Table 7 Optimal cooking time

Pasta	Control (BF)	15%	25%	35%
Optimal cooking time (min)	4.5	4.5	6	6

Figure 4 Appearance of the uncooked and cooked pasts products

Table 8 Cooking loss, water absorption capacity, swelling index, moisture content

Pasta	Cooking loss (%)	Swelling index (%)	Moisture content (%)
Control	0.000 ± 0.000d	1.167 ± 0.108b	30.61 ± 7.764d
15%	2.851 ± 0.352c	3.917 ± 0.075a	50.77 ± 0.615c
25%	6.800 ± 0.000a	3.902 ± 0.000a	56.71 ± 1.916a
35%	5.101 ± 0.722b	3.893 ± 0.027a	53.77 ± 0.800b

[a-d] *P* <0.05 compared with pasta type

Table 9 Protein content of the pasta samples

Pasta	Original (%)	Cooked (%)
Control	17.36 ± 0.291cB	19.50 ± 0.358dA
15%	22.35 ± 0.221aB	25.40 ± 0.551aA
25%	18.09 ± 0.082cB	22.71 ± 0.333bA
35%	20.74 ± 0.071bB	20.22 ± 0.050cA

[a-d] *P* <0.05 compared with pasta type

[A-B] *P* <0.05 compared between original and cooked pasta

Table 10 Texture characteristics of the pasta samples

Pasta	Tensile strength (MPa)	Elongation (%)	Young's modules (MPa)
Control	0.551 ± 0.048a	18.94 ± 3.412a	1.280 ± 0.016c
15%	0.533 ± 0.043b	10.80 ± 1.030b	1.730 ± 0.489b
25%	0.261 ± 0.018c	3.062 ± 0.141d	2.678 ± 0.084a
35%	0.222 ± 0.027d	5.237 ± 1.361c	1.289 ± 0.070c

[a-d] *P* <0.05 compared with pasta type

The results obtained for cooking properties of pasta and for chemical composition of the cooked product are summarized in the Table 7-9. The oat and pulse based gluten-free pasta samples were darker in colour due to the inclusion of pulse flours. The optimum cooking time slightly increased from 4.5 to 6 min when oat protein and oat starch were used to form gel network, replacing gluten in the formulation. The cooking lost was higher for the pasta samples made of oat protein and starch than that of the control sample made of wheat flours, but the values were generally low (0-5.1%). In previous work by Edwards et al. and Brennan et al., the pasta or those enriched with fibers showed cooking loss values of ~5-11%. Above results suggest that oat protein together with oat starch have potential to replace gluten to form a good gel network by cooking to bind different components together in the pasta products.

As shown in Table 8, the swelling index of pasta was significantly increased from 1.2% to 3.9% when gluten was replaced by the oat protein and oat starch, as well as the moisture content of the cooked pasta (increased from 30.6 to 56.7%). This was due to the gelatinization of starch and hydration of protein, and then formation of a mixture gel network that can hold larger amount of water. Texture can be reduced due to the higher swelling index and water absorption in pasta. Cooked samples contain 19.5 to 25.4% protein, thus, the developed pasta based on oat and pulse proteins are suitable for a high protein content claim, as they contain 25% more protein than regular products (9-16% protein) present in the market.

The main criteria generally accepted to assess the overall quality of cooked pasta are based on the textural evaluation. Instrumental methods have been proved to successfully estimate the textural characteristics of pasta such as tensile strength and firmness. As shown in Table 10, the pasta tensile strength (decreased from 0.55 MPa to 0.22-0.26MPa) and elongation (decreased from 18.9% to 3-5%) were significantly reduced when gluten was replaced by the oat protein and starch gel network. These results suggest that cooked pasta samples made of oat and pulse ingredients were softer and less elastic than those prepared from wheat flours. These results suggest that the oat protein and starch gels are less strong then gluten network. The high swelling index of the developed sample also led to decreased pasta texture. Improving texture of gluten-free pasta is a challenge facing food industry. The product quality can be further improved by adding fibers such as oat beta-glucan that were efficient to increase the texture of pasta products in previous works.

Summary: In this work, the combination of oat protein and oat starch provides gelling capacity, and acts as an efficient binder in gluten free pasta formulations. The addition of oat and pulse protein ingredients makes the pasta products suitable for high protein claim. Texture analysis suggests that improvements in the product strength and elasticity may be needed in order to increase the overall acceptance. This may be achieved by add fibers in the formulation such as oat beta-glucan. The sensory evaluation indicated the bitterness flavor of the pasta products with high oat ingredients. This might be related to oat lipid oxidation during product preparation and storage. The oat oil is rich in unsaturated lipids and lipolytic enzymes such as lipases and lipoxygenases, accounting for the greater tendency of oats to undergo oxidative spoilage. Thus the prevention of lipid oxidation needs to be considered when developing oat fractionation and ingredient processing.

Product 4 – All oat ice cream

Recipe

Ingredient	Amount
oat protein	**12 g**
oat milk *	500 g
sugar	126 g
powdered invert sugar	14 g
glycerol monostearate	2.5 g
guar gum	1.5 g
canafen	0.5 g
vanilla	5 mL

* See Appendix A

1. Combine all ingredients by hand.

2. Heat in a pot on medium heat, stirring constantly, until it is lightly bubbling.

3. Cool the custard in the cooler overnight for a minimum of 8 hours.

4. Churn the next day in an ice cream maker or in a Pacojet.

5. If using the Pacojet, place the custard in a Pacojet beaker and freeze it. Blend on setting 7 before serving.

Note: this formulation is for a hard, French-style, ice cream.

Figure 5 Appearance of all oat ice cream

Product development and quality analysis

Typically, ice cream contains 10 to 16% fat. In recent years, both ice cream manufacturers and consumers are interested in new ice cream products with reduced fat and replacing those fat solids with carbohydrates or proteins. Imitation ice creams have also attracted interest, both for the purpose of eliminating dairy components that cause allergic or intolerance reactions, and to eliminate dairy fat and cholesterol. The ice cream and frozen novelty products market are in a state of continuous expansion, as demonstrated by the enormous variety of new products launched every year.

During the freezing of ice cream, the whipping action and ice crystallization destabilizes the fat emulsion in the mix. The destabilized fat acts as a cementing agent and provides support to the air bubbles primarily lined by proteins. The combination of milk proteins and partially coalesced fat provides strength and structure to the ice cream. Thus, creating and stabilizing the desired structure in low-fat and non-dairy frozen dessert products presents a big challenge.

Oat protein is being used in this work as an egg and dairy replacer due to its good emulsifying properties. Various amounts of oat protein ingredients (2%, 3%, 4%) were added in the formulation based on oat milk. Canafen was added to further improve the emulsion stability and provide a strengthened structure and texture. The control sample was made of egg as emulsifier. As shown in Figure 5, the developed all oat frozen-nondairy dessert have the creamy texture, mouth feel and appearance of an ice cream product.

The key attributes of the ice cream were evaluated including total solid content, formula mixture viscosity and melting point. Frozen ice cream samples (5 g) were quantitatively weighed and then dried to constant weight in air oven at 95°C for total solid content measurement. Frozen ice cream samples were thawed at room temperature and the thawed ice cream solution was measured using a Rheometer, with a plate-and-plate geometry. A shear experiment was conducted with shear rates at 10 s^{-1}. All analyses were conducted at a controlled temperature of 25 C. First dripping and complete melting times of ice cream samples were determined in seconds. For this analysis, the hardened ice cream samples (25 g) were left to melt on a 0.2 cm wire mesh screen above a beaker at room temperature and first dripping and complete melting times of samples were determined as seconds.

Table 11 pH, total solids and viscosity

Samples	pH	Total solids (g /100 g)	Viscosity (Pa•s)
Control	6.38	29.91 ± 0.694a	0.055 ± 0.001c
2%	6.05	29.99 ± 0.201a	0.639 ± 0.004a
3%	5.97	30.63 ± 0.395a	0.419 ± 0.001b
4%	6.01	29.88 ± 0.407a	0.403 ± 0.017b

$^{a\text{-}d}$ Significant difference

Table 12 Meting point

Samples	A: First dripping time (min)	B: Complete melting time (min)
Control	44.1 ± 6.9a	73.5 ± 0.7a
2%	32.9 ± 2.7b	62.5 ± 2.1b
3%	26.7 ± 4.7d	60.5 ± 3.5b
4%	39.1 ± 1.5c	58 ± 1.4b

$^{a\text{-}d}$ Significant difference

It was reported that the total solids could impact the rate of meltdown of ice cream products. Formulations with high total milk solids melted faster than those with lower total solids, and related it to the effect of dissolved solids on the freezing point depression. As shown in Table 10, the pHs and total solid contents of the all oat ice cream products were not significantly different from the control sample with egg as emulsifier. But the viscosity of the ice cream mixes was much higher. The increase in the viscosity of oat protein based mixture compared to the egg based one suggests a more entangled structure in the ice cream formulation containing oat protein. Appropriate mix viscosity is important to improve the aeration, to restrict ice crystal growth during storage and to control the rate of melt-down. This result suggests that in addition to act as an emulsifier, oat protein may also form a network in ice cream formulation that can be modulated to provide improved ice cream aeration, structure and texture, which deserves further investigation.

The all oat ice cream melted faster than the control sample with egg as reflected by decreased dripping time (from 44.1 min to 39.1%) and complete melting time (from 73.5 to 58 min), but are generally acceptable by consumers. Sakurai et al. (1996) reported that about 85% meltdown in an ice cream at 75th min. Li et al. (1997) determined that ice cream with a high percentage of solids (39%) reached 100% melting at around 60 min.

Nutrition Facts	
servings per container	
Serving size	**(100g)**
Amount per serving	
Calories	**120**
	% Daily Value*
Total Fat 1.5g	**2%**
Saturated Fat 0g	**0%**
Trans Fat 0g	
Cholesterol 0mg	**0%**
Sodium 30mg	**1%**
Total Carbohydrate 27g	**10%**
Dietary Fiber 0g	**0%**
Total Sugars 24g	
Includes 21g Added Sugars	**42%**
Protein 2g	
Vitamin D 1mcg	6%
Calcium 111mg	8%
Iron 0mg	0%
Potassium 124mg	2%

*The % Daily Value tells you how much a nutrient in a serving of food contributes to a daily diet. 2,000 calories a day is used for general nutrition advice.

The nutrition facts table shows the all oat ice cream products are much lower in calories (~60% reduction) and fat content (~90% reduction) compared to the typical dairy ice cream in the market.

Summary: This research demonstrated the feasibility of using oat milk and oat protein as an egg-replacer to make vegan, low fat and lactose-free imitation ice cream products. Oat protein served as emulsifier in the formulation, but also formed an entangled network when combined with gum to improve aeration, provide texture and restrict ice crystal growth. The developed all oat frozen-nondairy ice cream have the creamy texture, mouth feel and appearance of an ice cream product. Considering the consumers' demand of vegan and low fat frozen snacks foods, the all oat ice cream may have potential for commercialization with further improvements in texture and sensory quality.

CONCLUSION

Overall, the results obtained from Product Development from Gluten Free Oat Fractions project are extremely valuable in showcasing the applications of oat fractions in popular consumer food products and promoting an increase of oat fractions for human consumption. Protein from gluten-free oats offers a sustainable source of plant based protein which is convenient and low allergenic, while the fibre fraction offers significant amount of dietary fibre, especially beta-glucan, and the starch fraction contain over 70% starch. These fractions are increasingly valued by consumers globally. Using the results obtained from this oat fractionation research will help to provide value-added opportunities of oat crops and support the sustainability of the Western Canadian enterprises along oat value-added chains.

RESEARCH RESULT DISSEMINATION

Scientific publication:

Yang, C., Wang, Y., Lu, L., Unsworth, L., Guan, L.L., Chen, L. (2018). Oat protein-shellac beads: Superior protection and delivery carriers for sensitive bioactive compounds, Food Hydrocolloids, 77, 754-763, doi:10.1016/j.foodhyd.2017.11.017.

Yang, C., Wang, Y., Xie, Y., Liu, G., Lu, Y., Wu, W., Chen, L (2019) Oat protein-shellac nanoparticles as a delivery vehicle for resveratrol to improve bioavailability in vitro and in vivo, Nanomedicine, DOI: 10.2217/nnm-2019-0244.

Note: These two papers are not related to oat fraction food development, but they are developed based on oat protein gelling properties. We then develop oat protein gels into delivery systems of bioactive compounds. Financial supports from POGA have been acknowledged.

Other publications:

Alary, B. (2019, February 26). Against the grain: How researchers are transforming Alberta oats into tasty, innovative products. *Techlife Today.* Retrieved from https://techlifetoday.ca/articles/2019/research-explores-new-ways-to-transform-oats#

NOTE: The above article got picked up by several news outlets:
https://poga.ca/news/415-open-wide-for-fermented-oat-cheese
https://vegnews.com/2019/3/chef-cretes-vegan-danish-blue-cheese-from-fermented-oats
https://fitworldsport.com/food/2019/03/02/chef-creates-vegan-danish-blue-cheese-from-fermented-oats-vegnews/
https://www.ecosia.org/news?c=en&q=site%3Avegnews.com

Macpherson, A. (2019, June 3). Cutting Edge Kitchen. *Avenue Magazine.* Retrieved from https://www.avenueedmonton.com/city-life/longform/cutting-edge-kitchen/

Alibert, Nafi. (2019, August 2). L'avoine: bien plus qu'un flocon. *ICI Alberta.* Retrieved from https://ici.radio-canada.ca/nouvelle/1246185/gruau-vegan-recette-fromage-alberta-nait (Note: This one did not specifically mention the POGA project, more so it talked about how oats are being used in new product development)

International scientific conference:

Chen, L. (2019) Road Map for Plant Proteins: the Oat Example, The Plant Protein Summit, May 29-30, Saskatoon, SK, Canada (invited oral presentation, targeting global protein industries

Kolskog, M. (June 3-5, 2019). Conference Speaker. Co-Product Innovation: Challenges & Opportunities for Plant-Based Foods. *Bridge2Food 13th Plant Based Food Summit*, Calgary, Alberta, Canada.

Kolskog, M. (January 28-30, 2020) Keynote Speaker. The Future of Plant-Based Foods: A Chef's Perspective. *International Production and Processing Expo.* Atlanta, Georgia, USA.

Industry workshops:

Chen, L. (2018) Oat protein value-added processing and applications, Prairie Oat Grower Association Annul General Meeting, January 29, Westin, Edmonton

Chen, L. (2018) Challenges and opportunities in oat protein processing and applications, invited by Roquette, June 4, 2018

Chen, L. (2018) Structure function properties of plant proteins and their value added applications, Nov. 19-22, Protein Mission to Japan and China, invited by Protein Industries Canada.

Chen, L. (2019) Plant protein structure function properties, Invited by Beyond Meat, August 30, Los Angeles, CA, US.

Media articles:

Koskog, M. (2019, February 5). Personal Interview with Adrienne Pan, Rod Kurtz and the *Radio Active* team from the Canadian Broadcasting Corporation (CBC).

Lingyun Chen (January 31, 2019) Consumer Demands Driving Value-Added Oat Research, Grainews, https://www.grainews.ca/features/consumer-demands-driving-oat-research/

Potential benefits to oat industry

The majority of oat fractionation that is currently being undertaken in the market is focused on extracting one fraction, typically the fibre or the oil. This emphasis on the extraction of a single ingredient caused the remaining fractions to be produced at lower qualities or concentrations, which can significantly reduce the value added potential. Dr. Chen's program is developing a fractionation process for oats that will produce quality ingredients from major oat components including protein, starch and fibers. The ability to produce quality ingredient fractions from oats will be a step towards full crop utilization.

This current project has demonstrated the unique functionalities of oat protein and starch in food models. Specifically, oat starch showed good gelling capacity to be used as food binder to make meat analogues when combined with gums. Oat proteins were efficient emulsion and foam stabilizers with good potential to replace egg and dairy proteins in doughnuts and ice cream formulations. The combination of oat protein and oat starch formed a protein matrix, and acted as a binder in gluten free pasta formulations. Based on these unique properties, 4 different food prototypes were developed including meat analogue, pasta, doughnut and ice cream. All these food products were vegan, gluten-free and suitable for high protein claims. The research outcomes have laid a foundation to identify new market and product opportunities for oat protein and starch, and the high value utilizations of the major oat components will significantly increase the value that can be obtained from the fractionation process to ensure viability of the oat fractionation industry. This will improve the entire value chain profitability and support the sustainability of the Western Canadian enterprises along oat value-added chains.

This project has also generated a number of benefits in other areas. In terms of production this research has demonstrate how value can be generated through the utilization of each of the primary oat fractions. This will provide some initial levels of market analysis, and provide a model for expanding the utilization of fractionated oat ingredients into other market segments, such as personal care and nutraceutical industries as they are also demanding natural emulsion and foam stabilizers and plant protein of high nutritive value. This research also demonstrated that the supply chain for the production of quality, and concentrated fractionated oat ingredients can be conducted in Alberta to at least pre-commercial levels with the assistance of the Leduc Food Processing and Development Centre.

This project has also allowed the research team to engage industry, and research facilities from across western Canada. The generated new knowledge will benefit current and potential oat processing industry and end users to enhance their competitive strength in the global market by affording new ways to deliver the healthful benefits of oat grains. Such connections will help development of a domestic market for the developed products and Alberta produced ingredients.

Technology transfer plan

This project team will engage potential oat processing companies (e.g. Richardson Milling, Pleasant Valley Oil Mills) to seek their interest in building a facility in western Canada for oat fractionation to generate value components including protein, dietary fiber and starch. Scientists from U of A will be available to help industry set up and optimise their processing facility.

On the other hand, the project will engage ingredient suppliers and food manufacturing industry to promote commercialization of oat fractions. The target market for the products developed will be food companies looking to increase the level of protein and fibre in their existing products, as well as the companies seeking gluten free, vegan, non-GMO, non-allergen, dairy-free options.

The team will also seek additional funding from provincial and federal government to support pilot food product development in collaboration with industry partners that are interested in this work, and conduct sensory evaluations of the pilot samples. These studies will provide the scientific and consumer support to convince industry players to invest in oat fraction and oat food product development.

Moreover, POGA will help knowledge dissemination of project results through various communication tools including industry meetings and newsletters, and help build oat value-added chains through established networks with oat producers, processers, buyers and end users.

Financial Report:

Total Revenues
Alberta Crop Industry Development Fund & Prairie Oat Growers Association: $112,000
Total revenues: $112,000

Expenditure:
Salaries and benefits: $ 97,437.52
Materials and supplies: $13,510.58
Travel: $1,051.90
Total expenditures: 112,000

Balance: $0