DEVELOP NEW STRATEGIES TO EFFICIENTLY UTILIZE OAT GRAINS IN HIGH PRODUCTION DAIRY COWS TO MAXIMUM ECONOMIC RETURN AND BENEFIT TO PRAIRIE OAT GROWERS

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Progress Report # 2

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Other Project Information
Marcela Tosta (Graduate Student) and PDF fellow (**Luciana Prates)**

Project Collaborators and Advisory Committee Members:
Dr. **David Christensen** (Animal, U of S), Dr. **John McKinnon** (Animal, U of S),
Dr. **Aaron Beattie** (Plant Sciences, U of S), Dr. **Rex Newkirk** (CFRC, U of S)

Industry Organization Support/Collaborators:
Shawna Mathieson and Dawn Popescul (POGA) and **SaskMilk** -RDTRF

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1. Executive Summary:

This 2nd progress report provides information on the current status of this collaborative oat feed research program.

The objectives of this feed (oat grain) research program are:

Long-term: To increase economic returns to oat producers and related industries; To advance our current knowledge by increasing and enhancing basic knowledge of the optimal nutrient supply to dairy cattle through variety selection, feed processing, and optimal feed ingredient blending; To advance our molecular structure and nutrition interaction knowledge by increasing and enhancing basic knowledge of the nutritional relevance of biopolymers intrinsic structure and chemistry on a molecular basis.

Short-term: In general: To use a systematic approach to develop new strategies to more efficiently utilize feed type and milling type of oat grain grown in Prairie by integration with or maximum replacing barley or other cereal grains in sustainable dairy production for improving animal production and health; To assist Canadian dairy industry to develop low-cost/alternative feeding strategies by utilizing alternative feed resources (oat grain).

This prairie oat research program (with POGA and SaskMilk) consists of the following sub-projects which are close related to each other. This five-year feed (oat) research program includes following projects and will be completed in different phases:

- Project 1: Systematically compare prairie oat grain varieties/types with common barley in Feed Milk Value (FMV) for dairy cattle in western Canada in order to find the good variety or type of oat grain with highest FMV value for dairy cows;

- Project 2: Improve/increase FMV of oat grain through feed processing applications (steam-flaking vs. rolling vs. pelleting) in comparison with barley for lactating dairy cows. The suitable processing will be determined for Prairie oat grain grown under western Canadian cool climate condition. Feed processing methods/technology will be tested and applied at Canadian Feed Research Centre (CFRC: Feed Processing Centre);

- Project 3: Effect of various feed processing applications on FMV of the Feed-Type and Milling-Type of oat grain in comparison with barley for lactating dairy cows;

- Project 4: Develop new feeding strategies of the milling type or feed-type oat grain to find maximum or optimal replacement level of barley grain with of oat grain in high production lactation dairy cow to maximize benefit and economic return to prairie oat growers and dairy milk producers;

- Project 5: Develop new feeding strategy for both raw and heated feed type or milling type of oat grain based on the performance of the best ratio found in above Projects in high production lactation dairy cows to benefit of prairie oat growers and dairy milk producers.

The projects has been initiated and is on track. The 1st PDF research fellow (Luciana L.

Prates), the first graduate student (Marcela Tosta) at a MSc level, and the 2nd graduate student (Chaoli Lang) at a PhD level have been recruited for the project.

Marcela started her program in the Sept 2017. She is doing part of the program and the results form the basis of the student graduate MSc degree program.

Chaoli started her PhD program in the Jan 2020. She is doing part of the program and the results will form the basis of the student graduate PhD degree program.

The following professors or scientists are involving in this program and they are also Marcela Tosta and Chaoli Lang' advisory committee, which includes:

Dr. David Christensen (Animal Science, U of S)
Dr. John McKinnon (Animal Science, U of S),
Dr. Rex Newkirk (Canada Feed Research Centre (Feed Processing), U of S)
Dr. Gabriel de Oliveira Ribeiro (Beef Industry Chair, Animal Science, U of S),
Dr. Aaron Beattie (Oat/Barley Breeder, Crop Development Centre, Plant Sciences, U of S)
Dr. Ryan Brook (Committee Chair, Animal science, U of S).
Dr. Fiona Buchannan (Committee Chair, Animal science, U of S).

In the 2nd progress report, we provided information on the current status of the ongoing projects, which is undertaken by the PDF and students and SRP Feed Chair Research Team (SRP Research Technician/Assistant as well as other PDF fellow and graduate students) since we initiated this program in 2016/2017. Up to date, Project 1 has been completed. Projects 2 has been completed. The project 3 is ongoing and will be reported in Progress Report 3

In this report, we also reported full details of available results that includes several studies (see next section for details).

In terms of Tech Transfer activities, this SRP Feed Chair program with POGA-NSERC and SaskMilk has caused lots of attention. This Oat-for-Milk program was selected to be presented at the 37TH Western Canadian Dairy Research Seminar (37th WCDS) in Red Deer in 2019 (mainly focus on dairy producers, nutritionists, and livestock specialist in western Canada). Our Oat-for-Milk projects have also been presented in various other industry meetings and scientific meetings: ADSA meeting, Joint ASAS-CSAS meeting, Annual Dairy Information Day (by SaskMilk). We are also writing and have published extension articles on our oat for animals in industry newsletter and magazines. The oat research findings have also been published high impact peer-reviewed scientific journals in our discipline (see the following section for the details in Tech Transfer.)

2. Research Progress:

2.1. Background and Motivation:

Why propose this research? Background: Development of domestic and international market for oat producers and oat related industries is a key to maintain and increase business, maximize profit and provide economic return and benefit to prairie oat producers. To develop competitive market in dairy industry, we need to investigate which oat grain variety or what types of oat grain (milling-type or feed-type) has highest Feed Milk Value (FMV) and highest absorbed nutrient supply and determine how much FMV in oat grain can be further/highly improved/increased by optimal feed processing applications, what is suitable and optimal processing conditions for oat grain, and how much corn, barley or other cereal grains can be replaced by oat grain in high production dairy diets.

The present feeding barley grain to dairy cattle is faced with increasing challenges in terms of price volatility, animal health, nutrient availability, utilization efficiency, and/or environmental pollution. The cost of feed grains has more than doubled in the last several years, seriously threatening the economic competitiveness dairy production in western Canada.

In Canada, the largest single cost of production facing dairy operations is feed (ca. 60-70%). Research to enhance feed efficiency and develop low-cost and alternative feeding strategies to conventional feed sources is most important for feed and dairy industries (Note although feed prices have come down, there remains potential for great volatility). Compared to corn, barley has lower energy value and lower nutrient availability mainly due to two facts: (1) its extremely higher undigested hull content (11-23% of total weight), and (2) its higher extent and rate of rumen degradation of starch and protein (>80%). This often results in three big problems: a) Digestive disorders e.g bloat and acidosis, which have a serious economic impact on feeding program (and cause dairy producers millions of lost dollars each year); b) An imbalance between nutrient breakdown and microbial protein synthesis, resulting in unnecessary nutrient loss from the rumen and inefficient utilization of nutrient components; c) An inefficient utilization of nutrient components can result in environment pollution in some intensive dairy production areas.

There is an urgent need (1) To use a systematic approach to find best variety or best type of oat grain with highest FMV and high nutrient supply for high production lactation dairy cows, (2) To further improve digestive behaviors and FMV in dairy cows through optimal feed processing technology, and (3) To develop new and alternative feeding strategies to efficiently utilize oat grains in high production lactation dairy cows to find a maximum replacement level to common barley or corn with feed-type or milling-type of oat grain in order to maximum economic return and benefit to prairie oat growers and support market development of oat grain nationally and internationally.

It is anticipated that the proposed research program with the systematic approach has tremendous potential that can highly influence and benefit not only prairie oat producers but also dairy and feed industries. Even a small improvement in the nutritive value of the oat grains could be of significant economic consequence. For example, if western Canada produces 15-20 million tones of oats per year. An improvement of only 1% in improved nutrient utilization has the potential to increase extra feed oats by 15,000-20,000 tones for dairy production and highly benefit to oat producers and dairy industry.

Objectives of Overall Project:

Short-term: In general: To use a systematic approach to develop new strategies to more efficiently utilize feed type and milling type of oat grain grown in Prarire by integration with or maximum replacing barley or other cereal grains in sustainable dairy production for improving animal production and health; To assist Canadian dairy industry to develop low-cost/alternative feeding strategies by utilizing alternative feed resources (oat grain).

This prairie oat research program (which was asked by oat grower industry-POGA) consists of the following projects which are close related to each other.

Overall objective of Project 1 is to systematically compare several different prairie oat grain varieties/types with common barley in FMV for dairy cattle in western Canada in order to find best variety or best type of oat grain with highest FMV value for dairy cows;
Overall objective of Project 2 is to highly improve/increase FMV of the feed type or milling type of oat grain through feed processing applications in comparison with barley for lactating dairy cows. The suitable and optimal processing conditions will be determined for Prairie oat grain grown under western Canadian cool climate condition. Several different feed processing methods/technology will be tested and applied at Canadian Feed Research Center (CFRC);
Overall objective of Project 3 is to develop new feeding strategies of the milling type or feed-type oat grain to find maximum or optimal replacement level of barley grain with oat grain in high production lactation dairy cow to maxim benefit and economic return to prairie oat growers and dairy milk producers;
Overall objective of Project 4 is to develop new feeding strategy for both raw and heated feed type or milling type of oat grain based on the performance of the best ration in high production lactation dairy cows to benefit of prairie oat growers and dairy milk producers.

Long-term: To increase economic returns to oat producers and related industries; To advance our current knowledge by increasing and enhancing basic knowledge of the optimal nutrient supply to dairy cattle through variety selection, feed processing, and optimal feed ingredient blending; To advance our molecular structure and nutrition interaction knowledge by increasing and enhancing basic knowledge of the nutritional relevance of biopolymers intrinsic structure and chemistry on a molecular basis.

2.2. The Graduate Student Research Proposals (MSc and PhD (1st and 2nd graduate students) Full Proposals/Protocols)
Based on our objectives, we have developed the 1st MSc proposal and the protocol for each study of her program. We are carrying out studies one by one.
Now we are developing the 2nd PhD proposal in oat grain's internal molecular structure profile in relation to nutrient utilization and availability study in dairy cows.

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3. Progress to Date

3.1. Project 1: Systematically compare prairie oat grain varieties/types with common barley in FMV for dairy cattle in western Canada in order to find best variety or type of oat grain with highest FMV value for dairy cows (Completed)

This project has been completed with different studies in each sub-project. Details of this project have been presented at various industry meetings and the project findings have also been written as extension article and full scientific papers. The oat feed results have been presentation at the 6th Dairy Information Day organized by SaskMilk and the 37th Western Canadian Dairy Seminar in Red Deer , Organized by Dairy Industry and Universities.
Please see the detailed results, finding, tech transfer (extension and scientific publication) in our first progress report (submitted in 2019)

3.2. Project 2: Improve/increase FMV of oat grain through feed processing applications (eg. steam-flaking vs. rolling vs. pelleting) in comparison with barley for lactating dairy cows. The suitable processing will be determined for Prairie oat grain grown under western Canadian cool climate condition. Feed processing methods/technology will be tested and applied at Canadian Feed Research Centre (CFRC: Feed Processing Centre) (Completed)

This project has been completed with different studies. Details of this project have been presented at industry and scientific meetings. The project findings have also been written as extension article and full scientific paper. See the following section for the detailed results.

3.3. Project 3: Effect of various feed processing applications on FMV of the Feed-Type and Milling-Type of oat grain in comparison with barley for lactating dairy cows; (Ongoing)

This project is ongoing. The results will be presented in the Progress Report #3. Some interesting findings will be presented at industry meeting and scientific meeting and two full manuscripts will be written.

3.4. Detailed Results of MSc Graduate Student in Project 2 for Her Thesis.

Project 2: Improve/increase FMV of oat grain through feed processing applications (steam-flaking vs. rolling vs. pelleting) in comparison with barley for lactating dairy cows. The suitable processing will be determined for Prairie oat grain grown under western Canadian cool climate condition. Feed processing methods/technology will be tested and applied at Canadian Feed Research Centre (**completed)**

For the Thesis Chapter 4:

[4. Impact of feed processing methods (steam-flaking vs. rolling vs. pelleting) on the nutritional, physiochemical and molecular structural characterization of oats grain in comparison with barley grain

  4.3.6. Intestinal digestion of nutrients
  4.3.7. Hourly effective degradation ratios between N and OM, and potential N to energy synchronization
  4.3.8. Prediction of nutrient supply using DVE/OEB and NRC 2001 systems
  4.3.9. Fourier transformed infrared (FTIR) spectroscopy analysis
    4.3.9.1. Univariate molecular spectral analysis of protein profile
    4.3.9.2. Multivariate molecular spectral analysis of protein profile
4.4. Results and Discussion
4.5. Chapter conclusions]

Research Studies and Results for the Thesis

Chapter 1: Introduction

Chapter 2: Literature review

Chapter 3: Impact of variety and type on the nutritional, physiochemical and molecular structural characterization of oats grain in comparison with barley grain

Chapter 4. Impact of feed processing methods (steam-flaking vs. rolling vs. pelleting) on the nutritional, physiochemical and molecular structural characterization of oats grain in comparison with barley grain

Table 4.1. Effect of feed processing methods (steam-flaking vs. rolling vs. pelleting) on chemical profile of oats grain in comparison with barley grain.

	Oats (O)						Contrast P-value		
Items	Rolled (R)	Flaked (F)	Pellet (P)	Barley (B)	SEM	P-value	B vs. O	B vs. FP	O vs. FP
Basic chemical profile									
DM (%)	87.73	86.70	88.37	85.78	0.984	0.37	0.63	0.96	0.25
Ash (%DM)	3.56	2.92	3.34	2.68	0.256	0.20	0.40	0.55	0.52
EE (%DM)	3.95^{a}	4.60^{a}	4.31^{a}	1.21^{b}	0.272	<0.01	0.01	<0.01	<0.01
OM (%DM)	96.44	97.08	96.66	97.31	0.256	0.21	0.40	0.55	0.52
Protein profile									
CP (%DM)	13.48	13.64	13.02	11.76	0.401	0.09	0.13	0.10	0.46
SCP (%DM)	5.77^{a}	3.49^{b}	4.29^{ab}	3.98^{ab}	0.312	0.02	0.03	0.02	0.20
SCP (%CP)	42.75^{a}	25.56^{b}	30.03^{ab}	33.87^{ab}	1.876	0.01	<0.01	<0.01	0.08
ADICP (%DM)	004	0.02	0.02	0	0.024	0.73	0.93	0.94	0.98
ADICP (%CP)	0.31	0.18	0.15	0.02	0.189	0.76	0.91	0.93	0.96
NDICP (%DM)	1.02^{b}	1.24^{a}	0.73^{c}	0.78^{c}	0.037	<0.01	<0.01	<0.01	0.02
NDICP (%CP)	7.62^{ab}	9.12^{a}	5.64^{c}	6.62^{bc}	0.341	<0.01	<0.01	<0.01	0.02
Carbohydrate profile									
CHO (%DM)	79.00^{b}	78.83^{b}	79.31^{b}	84.34^{a}	0.677	<0.01	0.06	0.03	0.05
Starch (%DM)	48.91^{b}	52.59^{b}	47.55^{b}	66.58^{a}	1.726	<0.01	0.43	0.07	<0.01
Sugar (%DM)	1.95	1.75	1.96	2.10	0.145	0.48	0.21	0.20	0.72
NFC (%DM)	55.09^{b}	59.99^{b}	58.42^{b}	71.86^{a}	0.951	<0.01	0.18	0.04	0.01
NFC (%CHO)	69.75^{b}	76.10^{b}	73.65^{b}	85.20^{a}	1.491	<0.01	0.96	0.49	0.10
NSC (%DM)	50.87^{b}	54.35^{b}	49.51^{b}	65.68^{a}	1.398	<0.01	0.57	0.08	<0.01

Table 4.1. *Cont'd* Effect of feed processing methods (steam-flaking vs. rolling vs. pelleting) on chemical profile of oats grain in comparison with barley grain.

	Oats (O)						Contrast P-value		
Items	Rolled (R)	Flaked (F)	Pellet (P)	Barley (B)	SEM	P-value	B vs. O	B vs. FP	O vs. FP
Fiber profile									
aNDF (%DM)	23.91^{a}	18.84^{ab}	23.91^{a}	12.48^{b}	1.309	<0.01	0.87	0.71	0.17
ADF (%DM)	10.29^{a}	8.43^{b}	9.93^{ab}	4.36^{c}	0.312	<0.01	0.55	0.04	<0.01
ADF (%NDF)	43.18	45.09	47.54	34.98	3.001	0.14	0.41	0.18	0.08
ADL (%DM)	2.72^{a}	2.04^{ab}	2.11^{ab}	0.75^{b}	0.281	0.03	0.60	0.42	0.34
ADL (%NDF)	11.49	10.92	10.04	6.04	1.883	0.30	0.47	0.40	0.61
uNDF (%DM)	15.36^{a}	13.76^{a}	13.41^{ab}	3.11^{b}	1.772	0.04	0.13	0.07	0.09

SEM: standard error of mean; $^{a\text{-}d}$ Means with the different letters in the same row are significantly different ($P < 0.05$); Multi-treatment comparison using Tukey method; R: rolled oats; F: flaked oats; P: pelleted oats; B: rolled barley; B vs. O: contrast between barley and oats grain; B vs. FP: contrast between barley grain and heat-processed oats; R vs. FP: contrast between rolled oats and heat-processed oats; DM: dry matter; OM: organic matter; EE: ether extract (crude fat); CP: crude protein; SCP: soluble crude protein; ADICP: acid detergent insoluble crude protein; NDICP: neutral detergent insoluble crude protein; CHO: carbohydrates; NFC: non-fiber carbohydrate; NSC: non-soluble carbohydrate; aNDF: neutral detergent fiber analyzed with amylase; ADF: acid detergent fiber; ADL: acid detergent lignin; uNDF: undigestible neutral detergent fiber analyzed after 288h in situ incubation.

Table 4.2. Effect of feed processing methods (steam-flaking vs. rolling vs. pelleting) on truly digestible nutrients, total digestible nutrients and predicted energy values of oats grain in comparison with barley grain.

	Oats (O)						Contrast P-value		
Items	Rolled (R)	Flaked (F)	Pellet (P)	Barley (B)	SEM	P-value	B vs. O	B vs. FP	O vs. FP
Truly digestible nutrients (%DM)									
tdNDF	12.86	10.58	11.55	8.06	0.955	0.08	0.84	0.92	0.40
tdCP	13.46	13.38	13.01	11.76	0.391	0.10	0.23	0.18	0.45
tdNFC	56.14^{b}	61.39^{b}	59.53^{b}	73.24^{a}	1.081	<0.01	0.27	0.07	0.02
tdFA	2.95^{a}	3.60^{a}	3.31^{a}	0.36^{b}	0.204	0.01	<0.01	<0.01	<0.01
Total digestible nutrients (%DM)									
TDN_{1x}	82.12^{b}	86.47^{a}	84.56^{ab}	86.87^{a}	0.670	0.02	0.06	0.07	0.94
Predicted energy values (Mcal/kg)									
DE_{1x}	3.63	3.81	3.73	3.81	0.031	0.04	0.07	0.08	0.85
DE_{p3x}	3.33^{b}	3.50^{a}	3.42^{ab}	3.49^{a}	0.028	0.03	0.06	0.07	0.78
ME_{p3x}	2.92	3.09	3.01	3.08	0.029	0.04	0.07	0.07	0.74
NE_{Lp3x}	1.87^{b}	1.99^{a}	1.93^{ab}	1.98^{ab}	0.021	0.04	0.06	0.06	0.71
ME	2.97	3.12	3.05	3.12	0.027	0.04	0.08	0.08	0.89
NE_{m}	2.01	2.13	2.07	2.13	0.022	0.04	0.07	0.08	0.93
NE_{g}	1.35	1.46	1.41	1.46	0.019	0.04	0.08	0.08	0.92

SEM: standard error of mean; $^{a\text{-}c}$ Means with the different letters in the same row are significantly different ($P < 0.05$); Multi-treatment comparison using Tukey method; R: rolled oats; F: flaked oats; P: pelleted oats; B: rolled barley; B vs. O: contrast between barley and oats grain; B vs. FP: contrast between barley grain and heat-processed oats; R vs. FP: contrast between rolled oats and heat-processed oats; tdNDF: truly digestible neutral detergent fibre; tdCP: truly digestible crude protein; tdNFC: truly digestible non-fibre carbohydrate; tdFA: truly digestible fatty acids; $TDN_{1\times}$: total digestible nutrient at one time maintenance. $DE_{l3\times}$: digestible energy at production level of intake (3×); $ME_{3\times}$: metabolizable energy at production level of intake (3×); $NE_{L3\times}$: net energy for lactation at production level of intake (3×); ME: metabolizable energy; NE_{m}: net energy for maintenance; NE_{g}: net energy for growth.

Table 4.3. Effect of feed processing methods (steam-flaking vs. rolling vs. pelleting) on protein and carbohydrates subfraction according to CNCPS 6.5 of oats grain in comparison with barley grain

	Oats (O)						Contrast P-value		
Items	Rolled (R)	Flaked (F)	Pellet (P)	Barley (B)	SEM	P-value	B vs. O	B vs. FP	O vs. FP
Protein subtractions (%CP)									
PA2	42.75^{a}	25.56^{b}	33.03^{ab}	33.87^{ab}	1.88	0.01	<0.01	<0.01	0.08
PB1	49.63^{b}	63.31^{a}	61.32^{ab}	59.50^{ab}	2.08	0.02	0.02	0.01	0.06
PB2	7.31^{ab}	8.94^{a}	5.49^{b}	6.60^{b}	0.33	<0.01	<0.01	<0.01	0.02
PC	0.31	0.18	0.15	0.02	0.19	0.76	0.92	0.93	0.97
Carbohydrate subfractions (%CHO)									
CA4	2.48	2.23	2.46	2.49	0.18	0.71	0.30	0.31	0.93
CB1	61.89^{b}	66.71^{b}	59.94^{b}	78.93^{a}	1.74	<0.01	0.92	0.16	<0.01
CB2	5.37	7.16	11.25	3.78	2.12	0.21	0.89	0.38	0.06
CB3	21.60	17.25	19.74	12.54	1.73	0.07	0.74	0.94	0.27
CC	8.64^{a}	6.64^{ab}	6.59^{ab}	2.26^{b}	0.86	0.02	0.46	0.32	0.34
Rumen degradable fractions (%DM)									
TRDP	9.77	9.30	9.16	8.37	0.282	0.10	0.56	0.53	0.81
TRDCHO	53.48^{c}	55.88^{b}	55.30^{bc}	64.56^{a}	0.360	<0.01	0.01	<0.01	<0.01
Rumen undegradable fractions (%DM)									
TRUP	3.78^{ab}	4.35^{a}	3.86^{ab}	3.30^{b}	0.109	0.01	<0.01	<0.01	0.07
TRUCHO	25.78^{a}	23.18^{ab}	24.27^{a}	20.06^{b}	0.637	0.01	0.80	0.76	0.16

SEM: standard error of mean. $^{a-c}$ Means with the different letters in the same row are significantly different ($P < 0.05$); Multi-treatment comparison using Tukey method; R: rolled oats; F: flaked oats; P: pelleted oats; B: rolled barley; B vs. O: contrast between barley and oats grain; B vs. FP: contrast between barley grain and heat-processed oats; R vs. FP: contrast between rolled oats and heat-processed oats; PA2: soluble true protein; PB1: insoluble true protein. PB2: fiber-bound protein; PC: indigestible protein; CHO: carbohydrates; CA4: sugars; CB1: starches; CB2: soluble fiber; CB3: digestible fiber; CC: indigestible fiber; TRDP: Total rumen degradable protein; TRDCHO: Total rumen degradable carbohydrate; TRUP = Total ruminally undegraded protein; TRUCHO: Total ruminally undegraded carbohydrate.

Table 4.4. Effect of feed processing methods (steam-flaking vs. rolling vs. pelleting) on in situ rumen degradation kinetics of dry matter (DM) of oats grain in comparison with barley grain.

	Oats (O)						Contrast P-value		
Items	Rolled (R)	Flaked (F)	Pellet (P)	Barley (B)	SEM	P-value	B vs. O	B vs. FP	O vs. FP
In situ rumen degradation									
Kd (%/h)	49.83^{ab}	33.51^{bc}	64.86^{a}	11.88^{a}	7.591	<0.01	<0.01	<0.01	0.01
T0 (h)	0.13	0	0.18	0.25	0.137	0.63	0.37	0.58	0.37
S (%)	17.99^{a}	20.74^{a}	11.13^{ab}	3.98^{b}	3.134	<0.01	<0.01	<0.01	0.09
D (%)	59.06^{b}	52.92^{b}	64.98^{b}	90.61^{a}	3.651	<0.01	<0.01	<0.01	0.06
U (%)	22.94^{a}	26.33^{a}	23.88^{a}	5.41^{b}	1.615	<0.01	<0.01	<0.01	0.17
BDM (g/kg DM)	299.08^{b}	345.23^{ab}	296.34^{b}	377.86^{a}	13.292	<0.01	<0.01	<0.01	0.01
EDDM (g/kg DM)	700.92^{a}	654.78^{ab}	703.66^{a}	622.14^{b}	13.292	<0.01	<0.01	<0.01	0.01

SEM: standard error of mean; $^{a-c}$ Means with the different letters in the same row are significantly different ($P < 0.05$); Multi-treatment comparison using Tukey method; R: rolled oats; F: flaked oats; P: pelleted oats; B: rolled barley; B vs. O: contrast between barley and oats grain; B vs. FP: contrast between barley grain and heat-processed oats; R vs. FP: contrast between rolled oats and heat-processed oats; Kd: the degradation rate of D fraction (%h); T0: lag time; S: soluble fraction in the in-situ incubation; D: degradable fraction; U: rumen undegradable fraction; BDM: rumen bypass or undegraded feed dry matter; EDDM: effective degraded dry matter.

Table 4.5. Effect of feed processing methods (steam-flaking vs. rolling vs. pelleting) on in situ rumen degradation kinetics of organic matter (OM) of oats grain in comparison with barley grain.

	Oats (O)						Contrast P-value		
Items	Rolled (R)	Flaked (F)	Pellet (P)	Barley (B)	SEM	P-value	B vs. O	B vs. FP	O vs. FP
In situ rumen degradation									
Kd (%/h)	51.76^{ab}	34.78^{bc}	67.21^{a}	11.97^{c}	8.250	<0.01	<0.01	<0.01	0.01
T0 (h)	0.14	0.00	0.17	0.25	0.137	0.63	0.36	0.57	0.37
S (%)	17.92^{a}	20.75^{a}	11.04^{ab}	3.99^{b}	3.158	<0.01	<0.01	0.01	0.10
D (%)	59.57^{b}	53.26^{b}	65.47^{b}	91.26^{a}	3.653	<0.01	<0.01	<0.01	0.06
U (%)	22.50^{a}	25.98^{a}	23.48^{a}	4.75^{b}	1.549	<0.01	<0.01	<0.01	0.14
BOM (g/kg DM)	292.99^{b}	339.72^{ab}	291.37^{b}	371.44^{a}	13.486	<0.01	<0.01	<0.01	0.01
EDOM (g/kg DM)	681.92^{a}	641.01^{ab}	684.94^{a}	610.56^{b}	13.500	<0.01	<0.01	<0.01	0.02
%BOM	29.30^{b}	33.97^{ab}	29.14^{b}	37.14^{a}	1.35	<0.01	<0.01	<0.01	0.01
%EDOM	70.70^{a}	66.03^{ab}	70.86^{a}	62.85^{b}	1.348	<0.01	<0.01	<0.01	0.01

SEM: standard error of mean; $^{a-c}$ Means with the different letters in the same row are significantly different ($P < 0.05$); Multi-treatment comparison using Tukey method; R: rolled oats; F: flaked oats; P: pelleted oats; B: rolled barley; B vs. O: contrast between barley and oats grain; B vs. FP: contrast between barley grain and heat-processed oats; R vs. FP: contrast between rolled oats and heat-processed oats; Kd: the degradation rate of D fraction (%h); T0: lag time; S: soluble fraction in the in-situ incubation; D: degradable fraction; U: rumen undegradable fraction; BOM: rumen bypass dry matter; EDOM: effective degradability of dry matter.

Table 4.6. Effect of feed processing methods (steam-flaking vs. rolling vs. pelleting)on in situ rumen degradation kinetics of crude protein (CP) of oats grain in comparison with barley grain.

	Oats (O)						Contrast P-value		
Items	Rolled (R)	Flaked (F)	Pellet (P)	Barley (B)	SEM	P-value	B vs. O	B vs. FP	O vs. FP
In situ rumen degradation									
Kd (%/h)	40.66^{ab}	18.03^{bc}	41.18^{a}	10.06^{c}	6.402	<0.01	<0.01	<0.01	<0.01
T0 (h)	0.00	0.27	0.16	0.53	0.207	0.36	0.13	0.10	0.46
S (%)	31.58^{a}	23.35^{ab}	17.26^{b}	16.37^{b}	3.095	0.01	0.04	0.04	0.76
D (%)	59.17^{b}	61.37^{b}	70.05^{b}	82.02^{a}	3.114	<0.01	<0.01	<0.01	0.33
U (%)	9.24^{b}	15.28^{a}	12.69^{ab}	1.61^{c}	1.306	<0.01	<0.01	<0.01	0.02
%BCP=%RUP	17.06^{b}	31.77^{a}	21.33^{b}	33.20^{a}	1.343	<0.01	<0.01	<0.01	<0.01
BCP (g/kg DM)	23.02^{b}	43.38^{a}	27.90^{b}	39.14^{a}	2.034	<0.01	<0.01	<0.01	<0.01
RUP (g/kg DM)	25.55^{b}	48.15^{a}	30.97^{b}	43.44^{a}	2.257	<0.01	<0.01	<0.01	<0.01
EDCP (g/kg CP)	111.77^{a}	93.09^{c}	102.33^{b}	78.57^{d}	1.541	<0.01	<0.01	<0.01	<0.01
%BCP=%RUP	17.06^{b}	31.77^{a}	21.33^{b}	33.20^{a}	1.343	<0.01	<0.01	<0.01	<0.01
%EDCP	82.94^{a}	68.23^{b}	78.67^{a}	66.80^{b}	1.343	<0.01	<0.01	<0.01	<0.01

SEM: standard error of mean; $^{a-c}$ Means with the different letters in the same row are significantly different ($P < 0.05$); Multi-treatment comparison using Tukey method; R: rolled oats; F: flaked oats; P: pelleted oats; B: rolled barley; B vs. O: contrast between barley and oats grain; B vs. FP: contrast between barley grain and heat-processed oats; R vs. FP: contrast between rolled oats and heat-processed oats; Kd: the degradation rate of D fraction (%h); T0: lag time; S: soluble fraction in the in-situ incubation; D: degradable fraction; U: rumen undegradable fraction; BCP: rumen bypassed crude protein in DVE/OEB system; RUP: rumen undegraded crude protein in the NRC Dairy 2001 model; EDCP: effectively degraded of crude protein.

Table 4.7. Effect of feed processing methods (steam-flaking vs. rolling vs. pelleting)on in situ rumen degradation kinetics of starch (ST) of oats grain in comparison with barley grain.

	Oats (O)						Contrast P-value		
Items	Rolled (R)	Flaked (F)	Pellet (P)	Barley (B)	SEM	P-value	B vs. O	B vs. FP	O vs. FP
In situ rumen degradation									
Kd (%/h)	54.77^{ab}	47.05^{ab}	93.85^{a}	18.09^{b}	15.364	0.03	0.02	0.01	0.17
T0 (h)	0.20^{b}	0.00^{b}	0.11^{b}	0.98^{a}	0.171	<0.01	<0.01	<0.01	0.46
S (%)	24.71	19.98	9.39	19.24	7.111	0.48	0.88	0.80	0.73
D (%)	72.50	71.37	86.09	79.17	7.053	0.45	0.76	0.99	0.38
U (%)	2.79^{b}	8.65^{a}	4.52^{ab}	1.58^{b}	1.029	<0.01	<0.01	0.13	<0.01
BST (g/kg DM)	50.44^{b}	55.75^{b}	34.44^{b}	156.16^{a}	13.148	<0.01	<0.01	<0.01	0.42
EDST (g/kg DM)	438.72^{b}	470.16^{ab}	441.04^{b}	509.65^{a}	13.80	0.01	<0.01	<0.01	0.10
%BST	10.38^{b}	10.63^{b}	7.29^{b}	23.30^{a}	2.021	<0.01	<0.01	<0.01	0.48
%EDST	89.61^{a}	89.36^{a}	92.70^{a}	76.70^{b}	2.021	<0.01	<0.01	<0.01	0.48

SEM: standard error of mean; $^{a-b}$ Means with the different letters in the same row are significantly different ($P < 0.05$); Multi-treatment comparison using Tukey method; R: rolled oats; F: flaked oats; P: pelleted oats; B: rolled barley; B vs. O: contrast between barley and oats grain; B vs. FP: contrast between barley grain and heat-processed oats; R vs. FP: contrast between rolled oats and heat-processed oats; Kd: the degradation rate of D fraction (%h); T0: lag time; S: soluble fraction in the in-situ incubation; D: degradable fraction; U: rumen undegradable fraction; BST: rumen bypass or undegraded feed starch; EDST: effective degraded starch.

Table 4.8. Effect of feed processing methods (steam-flaking vs. rolling vs. pelleting)on intestinal digestion of dry matter (DM) and organic matter (OM) of oats grain in comparison with barley grain.

	Oats (O)						Contrast P-value		
Items	Rolled (R)	Flaked (F)	Pellet (P)	Barley (B)	SEM	P-value	B vs. O	B vs. FP	O vs. FP
DM intestinal digestion									
%dBDM (%BBDM)	25.08^{b}	34.86^{b}	34.27^{b}	63.27^{a}	2.949	<0.01	0.11	0.03	0.02
IDBDM (%BDM)	7.64^{b}	12.05^{b}	10.15^{b}	23.46^{a}	1.384	<0.01	0.28	0.05	<0.01
IDBDM (g/kg DM)	23.34^{b}	41.70^{b}	30.09^{b}	101.62^{a}	9.087	<0.01	0.36	0.09	0.01
TDDM (%DM)	77.73^{b}	77.53^{b}	80.52^{b}	86.31^{a}	0.789	<0.01	0.01	<0.01	0.15
TDDM (g/kg,DM)	681.87^{b}	672.25^{b}	711.53^{a}	734.73^{a}	5.131	<0.01	<0.01	<0.01	0.63
OM intestinal digestion									
dBOM (%BOM)	25.55^{b}	35.33^{b}	34.41^{b}	71.49	4.293	<0.01	0.11	0.03	0.02
IDBOM (%BOM)	7.63^{b}	12.02^{b}	10.02^{b}	23.69^{a}	1.378	<0.01	0.27	0.05	<0.01
IDBOM (g/kg DM)	22.87^{b}	40.95^{b}	29.20^{b}	100.61^{a}	9.125	<0.01	0.36	0.09	0.01
TDOM (%DM)	78.33^{b}	78.05^{b}	80.89^{b}	87.34^{a}	0.828	<0.01	<0.01	<0.01	0.09
TDOM (g/kg DM)	755.39^{b}	757.73^{b}	781.81^{b}	848.39^{a}	7.523	<0.01	<0.01	<0.01	0.06

SEM: standard error of mean; $^{a-b}$ Means with the different letters in the same row are significantly different ($P < 0.05$); Multi-treatment comparison using Tukey method; R: rolled oats; F: flaked oats; P: pelleted oats; B: rolled barley; B vs. O: contrast between barley and oats grain; B vs. FP: contrast between barley grain and heat-processed oats; R vs. FP: contrast between rolled oats and heat-processed oats; dBDM: intestinal digestibility of rumen bypass dry matter; IDBDM: intestinal digested rumen bypass dry matter; TDDM: total digested dry matter; dBOM: intestinal digestibility of rumen bypass organic matter; IDBOM: intestinal digested rumen bypass organic matter; TDOM: total digested organic matter.

Table 4.9. Effect of feed processing methods (steam-flaking vs. rolling vs. pelleting)on intestinal digestion of crude protein (CP) and starch (ST) of oats grain in comparison with barley grain.

	Oats (O)						Contrast P-value		
Items	Rolled (R)	Flaked (F)	Pellet (P)	Barley (B)	SEM	P-value	B vs. O	B vs. FP	O vs. FP
CP intestinal digestion									
dIDP (%RUP)	42.18^{b}	54.17^{ab}	52.99^{ab}	65.28^{a}	3.524	<0.01	0.87	0.92	0.87
IDP (%RUP)	7.14^{c}	17.25^{ab}	11.46^{bc}	21.76^{a}	1.413	<0.01	0.04	0.13	0.11
IDP (g/kg DM)	9.61^{b}	23.55^{a}	15.10^{b}	25.66^{a}	1.980	<0.01	0.01	0.03	0.32
TDP (%CP)	90.08^{a}	85.48^{b}	90.13^{a}	88.56^{a}	0.688	<0.01	<0.01	<0.01	0.35
TDP (g/kg DM)	121.39^{a}	116.65^{a}	117.43^{a}	104.23^{b}	2.253	<0.01	0.39	0.19	0.12
ST intestinal digestion									
dBST (%BST)	78.78^{ab}	70.74^{b}	87.59^{a}	89.33^{a}	3.533	<0.01	<0.01	<0.01	0.28
IDBST (%BCHO)	8.16^{b}	7.56^{b}	6.52^{b}	20.89^{a}	1.989	<0.01	0.06	<0.01	<0.01
IDBST (g/kg DM)	39.66^{b}	39.68^{b}	30.78^{b}	159.65^{a}	8.132	<0.01	<0.01	<0.01	<0.01
TDBST (% ST)	97.77^{ab}	96.9^{b}	99.23^{a}	97.59^{ab}	0.436	0.02	0.03	0.18	0.01
TDBST (g/kg DM)	478.39^{b}	509.85^{b}	471.82^{b}	649.77^{a}	11.027	<0.01	0.09	<0.01	<0.01

SEM: Standard error of mean; $^{a-c}$ Means with the different letters in the same row are significantly different ($P < 0.05$); Multi-treatment comparison using Tukey method; R: rolled oats; F: flaked oats; P: pelleted oats; B: rolled barley; B vs. O: contrast between barley and oats grain; B vs. FP: contrast between barley grain and heat-processed oats; R vs. FP: contrast between rolled oats and heat-processed oats; dIDP: intestinal digestibility of rumen bypass protein on percentage basis; IDP: intestinal digested crude protein; TDP: total digested crude protein; dBST: intestinal digestibility of rumen bypass starch on percentage basis; IDBSTP: intestinal digested bypass starch; TDBST: total digested bypass starch.

Table 4.10. Effect of feed processing methods (steam-flaking vs. rolling vs. pelleting)on hourly effective degradation ratios between N and OM of oats grain in comparison with barley grain.

	Oats (O)						Contrast P-value		
Items	Rolled (R)	Flaked (F)	Pellet (P)	Barley (B)	SEM	P-value	B vs. O	B vs. FP	O vs. FP
Ratio of N to OM	22.37^{a}	22.49^{a}	21.56^{a}	19.47^{b}	0.421	<0.01	0.02	0.01	0.25
Ratio of ED_N/ED_OM	26.24^{a}	23.69^{b}	24.05^{b}	20.47^{c}	0.480	<0.01	0.86	0.59	0.27
Ratio at individual incubation hours (g/kg)									
h0	40.74	26.12	38.93	72.92	18.004	0.43	0.26	0.2	0.45
h2	21.23	16.93	21.06	15.52	1.367	0.04	0.17	0.42	0.15
h4	27.03^{a}	23.14^{a}	31.52^{a}	12.77^{b}	3.015	<0.01	0.82	0.29	<0.01
h8	34.48^{bc}	46.34^{ab}	72.06^{a}	13.52^{c}	7.798	<0.01	0.45	0.03	<0.01
h12	99.66^{ab}	101.19^{ab}	168.74^{a}	14.33^{b}	39.497	0.04	0.85	0.27	0.01
h24	1232.26	1572.16	2420.78	17.19	1003.44	0.24	0.71	0.35	0.09

SEM: Standard error of mean; $^{a-c}$ Means with the different letters in the same row are significantly different ($P < 0.05$); Multi-treatment comparison using Tukey method; R: rolled oats; F: flaked oats; P: pelleted oats; B: rolled barley; B vs. O: contrast between barley and oats grain; B vs. FP: contrast between barley grain and heat-processed oats; R vs. FP: contrast between rolled oats and heat-processed oats; N: nitrogen; OM: organic matter; ED: effective degradability.

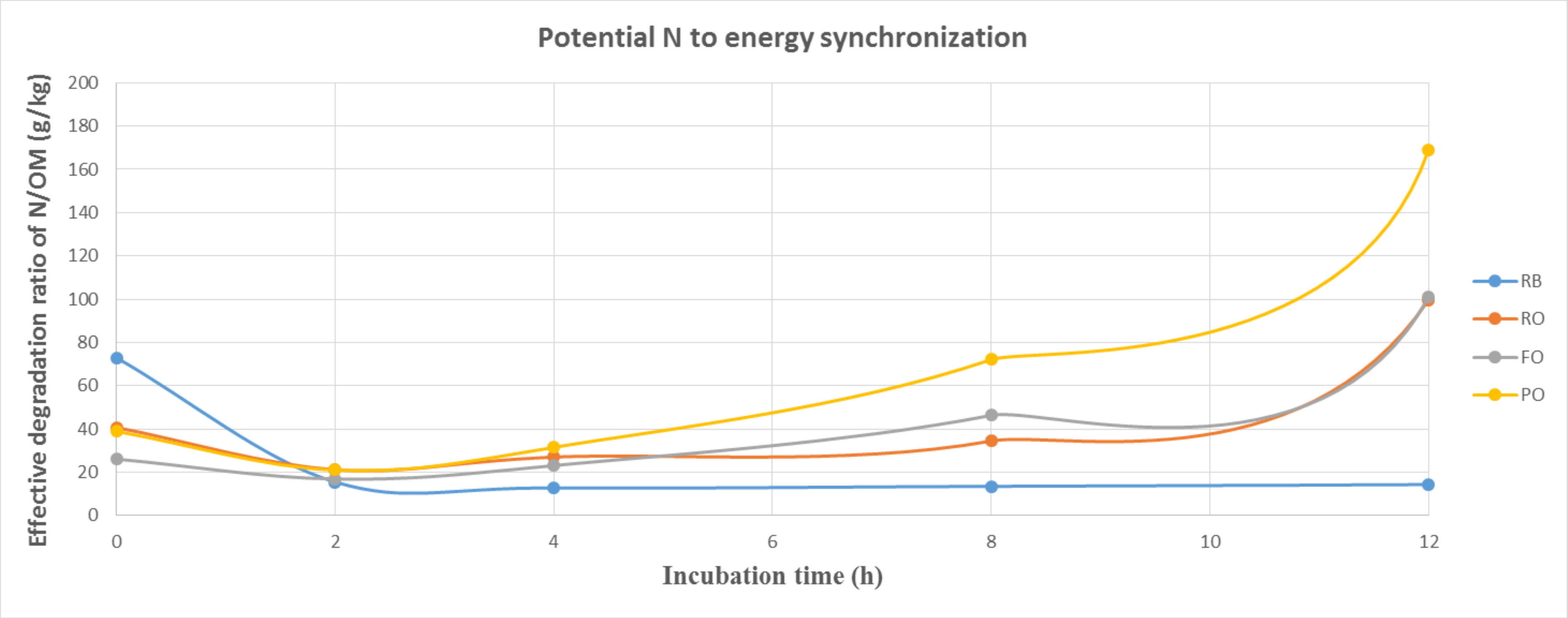

Figure 4.2. Hourly effective degradation ratios between available N and available OM (ED_N/ED_OM) of different varieties of oats grain in comparison to barley grain.

Table 4.10. Effect of feed processing methods (steam-flaking vs. rolling vs. pelleting)on metabolic characteristics and truly absorbable nutrient supply (based on non-TDN system: DVE-OEB) of oats grain in comparison with barley grain

	Oats (O)						Contrast P-value		
Items	Rolled (R)	Flaked (F)	Pellet (P)	Barley (B)	SEM	P-value	B vs. O	B vs. FP	O vs. FP
Truly digestible nutrient supply to dairy cattle (g/kg DM)									
BCP (g/kg DM)	25.55^{b}	48.15^{a}	30.97^{b}	43.44^{a}	2.257	<0.01	<0.01	<0.01	0.22
EDCP (g/kg DM)	111.17^{a}	93.09^{c}	102.33^{b}	78.57^{d}	1.541	<0.01	0.03	0.29	<0.01
MREE (g/kg DM)	95.97	91.17	100.99	98.67	2.858	0.14	0.04	0.10	0.31
MREN (g/kg DM)	109.24^{a}	88.32^{c}	99.26^{b}	74.23^{d}	1.606	<0.01	<0.01	0.11	<0.01
DVME (g/kg DM)	61.18	58.12	64.38	62.90	1.822	0.14	0.04	0.10	0.31
DVBE (g/kg DM)	15.14^{b}	25.57^{a}	13.10^{b}	26.29^{a}	2.148	<0.01	0.01	0.09	0.01
Degraded protein balance (OEB) and Total true protein supply (DVE) to dairy cows (g/kg DM)									
DVE (g/kg DM)	59.71^{b}	66.95^{ab}	62.74^{b}	80.80^{a}	3.542	<0.01	0.85	0.46	0.11
OEB (g/kg DM)	13.26^{a}	-2.86^{b}	-1.73^{b}	-24.44^{c}	2.708	<0.01	0.65	0.43	0.27
Feed milk value (kg milk/kg DM fed)									
FMV	1.21^{b}	1.36^{ab}	1.27^{b}	1.64^{a}	0.071	<0.01	0.85	0.45	0.10

SEM: Standard error of mean; $^{a-c}$ Means with different letters in the same row are significantly different ($P<0.05$); Multi-treatment comparisons using Tukey method; R: rolled oats; F: flaked oats; P: pelleted oats; B: rolled barley; B vs. O: contrast between barley and oats grain; B vs. FP: contrast between barley grain and heat-processed oats; R vs. FP: contrast between rolled oats and heat-processed oats; BCP: bypass crude protein; MREE: microbial protein synthesized in the rumen based on available energy; EDCP: effective degradability of CP; MREN: microbial protein synthesized in the rumen; DVME: rumen synthesized microbial protein digested in the small intestine; DVBE: truly absorbed bypass protein in the small intestine; DVE: truly digested protein in the small intestine; OEB: degraded protein balance; FMV: feed milk value.

Table 4.11. Effect of feed processing methods (steam-flaking vs. rolling vs. pelleting) on metabolic characteristics and truly absorbable nutrient supply (based on TDN system: NRC dairy) of oats grain in comparison with barley grain.

	Oats (O)						Contrast P-value		
Items	Rolled (R)	Flaked (F)	Pellet (P)	Barley (B)	SEM	P-value	B vs. O	B vs. FP	O vs. FP
Truly Digestible Nutrient Supply to Dairy Cattle (g/kg DM)									
RUP	23.02^{b}	43.38^{a}	27.90^{b}	39.14^{a}	2.034	<0.01	<0.01	<0.01	0.23
MCP$_{TDN}$	98.05^{c}	103.24^{a}	100.96^{b}	103.72^{a}	0.464	<0.01	<0.01	<0.01	0.90
MCP$_{RDP}$	95.00^{a}	79.13^{c}	86.98^{b}	66.78^{d}	1.309	<0.01	0.03	0.29	<0.01
AMCP	60.80^{a}	50.64^{c}	55.67^{b}	42.74^{d}	0.837	<0.01	0.03	0.29	<0.01
ARUP	13.64^{b}	23.04^{a}	11.80^{b}	23.68^{a}	1.935	<0.01	0.01	0.09	0.01
ECP	10.41^{ab}	10.29^{ab}	10.49^{a}	10.19^{b}	0.068	0.04	0.38	0.93	0.04
AECP	4.17^{ab}	4.12^{ab}	4.19^{a}	4.07^{b}	0.026	0.03	0.39	0.94	0.04
Total metabolizable protein supply and degraded protein balance to dairy cattle (g/kg DM)									
MP	78.61^{a}	77.80^{a}	71.66^{a}	70.50^{a}	2.081	0.03	0.10	0.23	0.28
DPB	-3.92^{a}	-28.73^{c}	-16.80^{b}	-43.82^{d}	1.200	<0.01	<0.01	<0.01	<0.01
Feed milk value (kg milk/kg DM fed)									
FMV	1.58	1.58	1.47	1.43	0.041	0.06	0.10	0.16	0.57

SEM: Standard error of mean; $^{a-d}$ Means with the different letters in the same row are significantly different ($P < 0.05$); Multi-treatment comparisons using Tukey method; R: rolled oats; F: flaked oats; P: pelleted oats; B: rolled barley; B vs. O: contrast between barley and oats grain; B vs. FP: contrast between barley grain and heat-processed oats; R vs. FP: contrast between rolled oats and heat-processed oats; RUP: rumen undegradable feed crude protein; MCP$_{TDN}$: rumen synthesized microbial protein base on available TDN; MCP$_{RDP}$: microbial protein synthesized in the rumen based on available protein; AMCP: truly absorbed microbial protein in the small intestine; ARUP: truly absorbed rumen undegradable protein in the small intestine; ECP: rumen endogenous protein; AECP: truly absorbed rumen endogenous protein in the small intestine; MP: metabolizable protein; DPB: rumen degraded protein balance; FMV: feed milk value.

Table 4.12. Effect of feed processing methods (steam-flaking vs. rolling vs. pelleting) pm protein molecular structure profile of oats grain in comparison with barley grain.

	Oats (O)						Contrast P-value		
Items	Rolled (R)	Flaked (F)	Pellet (P)	Barley (B)	SEM	P-value	B vs. O	B vs. FP	O vs. FP
Amide heights and spectra ratio									
Amide I	0.04	0.06	0.03	0.04	0.008	0.17	0.80	0.59	0.07
Amide II	0.02	0.02	0.01	0.01	0.003	0.11	0.94	0.35	0.03
Amide I/Amide II	2.57	2.38	2.57	3.47	0.500	0.5	0.71	0.51	0.35
Secondary structure heights and spectra ratio									
α-helix	0.04	0.06	0.03	0.04	0.008	0.18	0.84	0.58	0.07
β-sheet	0.03^{ab}	0.05^{a}	0.02^{b}	0.04^{ab}	0.004	0.03	0.30	0.92	0.02
A-helix/β-sheet	1.46	1.24	1.48	1.16	0.096	0.18	0.21	0.31	0.52
Amide area and spectra ratio									
Amide I	2.45	4.27	1.15	2.95	0.621	0.09	0.66	0.62	0.04
Amide II	0.56	1.16	0.18	0.38	0.218	0.12	0.97	0.35	0.03
Amide I/Amide II	4.41	3.70	9.89	17.28	6.855	0.54	0.5	0.34	0.3

SEM: standard error of mean; $^{a-b}$ Means with different letters in the same row are significantly different ($P<0.05$); R: rolled oats; F: flaked oats; P: pelleted oats; B: rolled barley; B vs. O: contrast between barley and oats grain; B vs. FP: contrast between barley grain and heat-processed oats; R vs. FP: contrast between rolled oats and heat-processed oats.

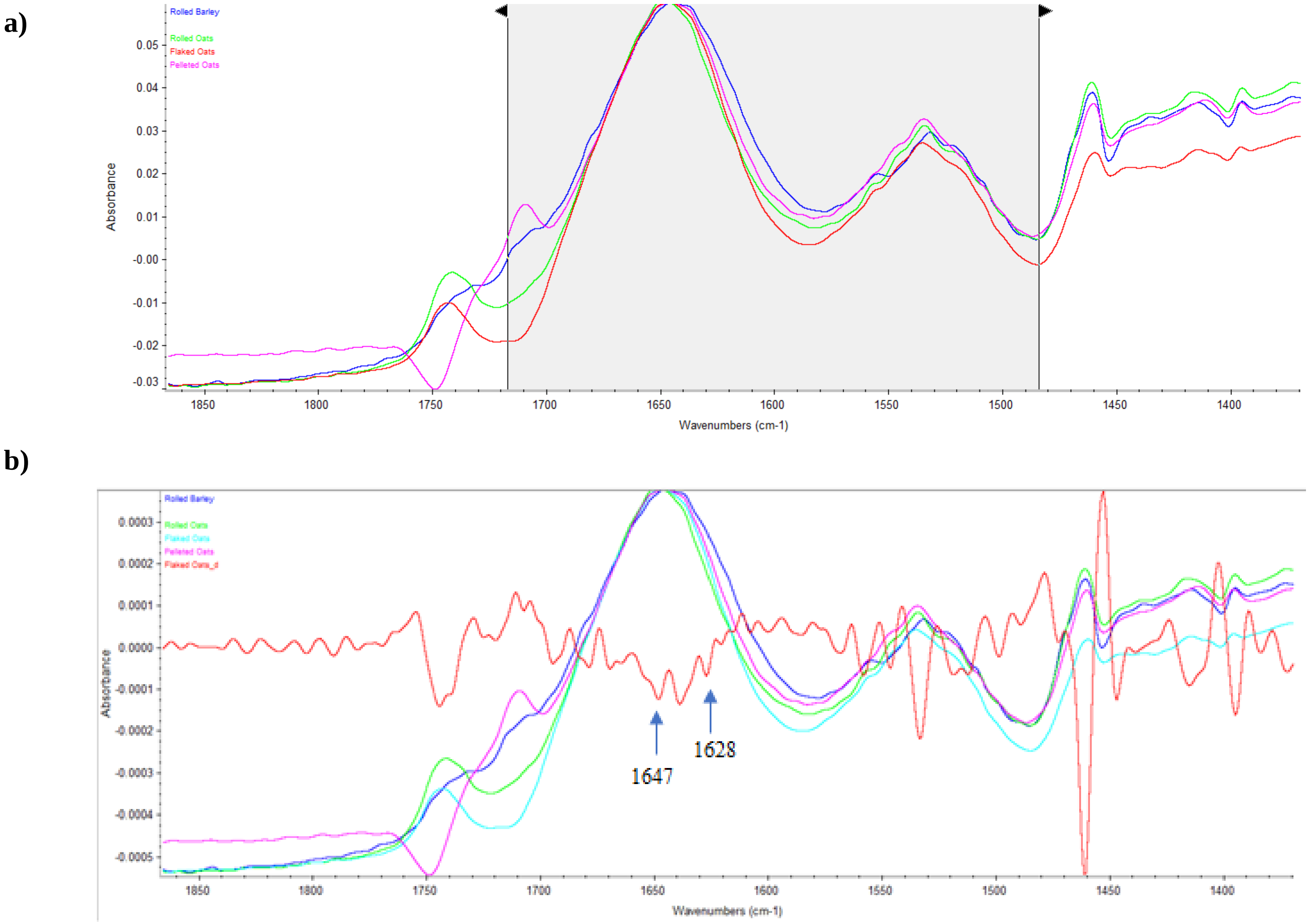

Figure 4.3. (a) Fourier transformed infrared attenuated total reflectance (Ft-IR/ATR) biomolecular spectra of different processed oats grain in comparison with barley grain of the protein molecular structures, amide I and amide II; (b) Protein secondary structures α-helix and β-sheet heights.

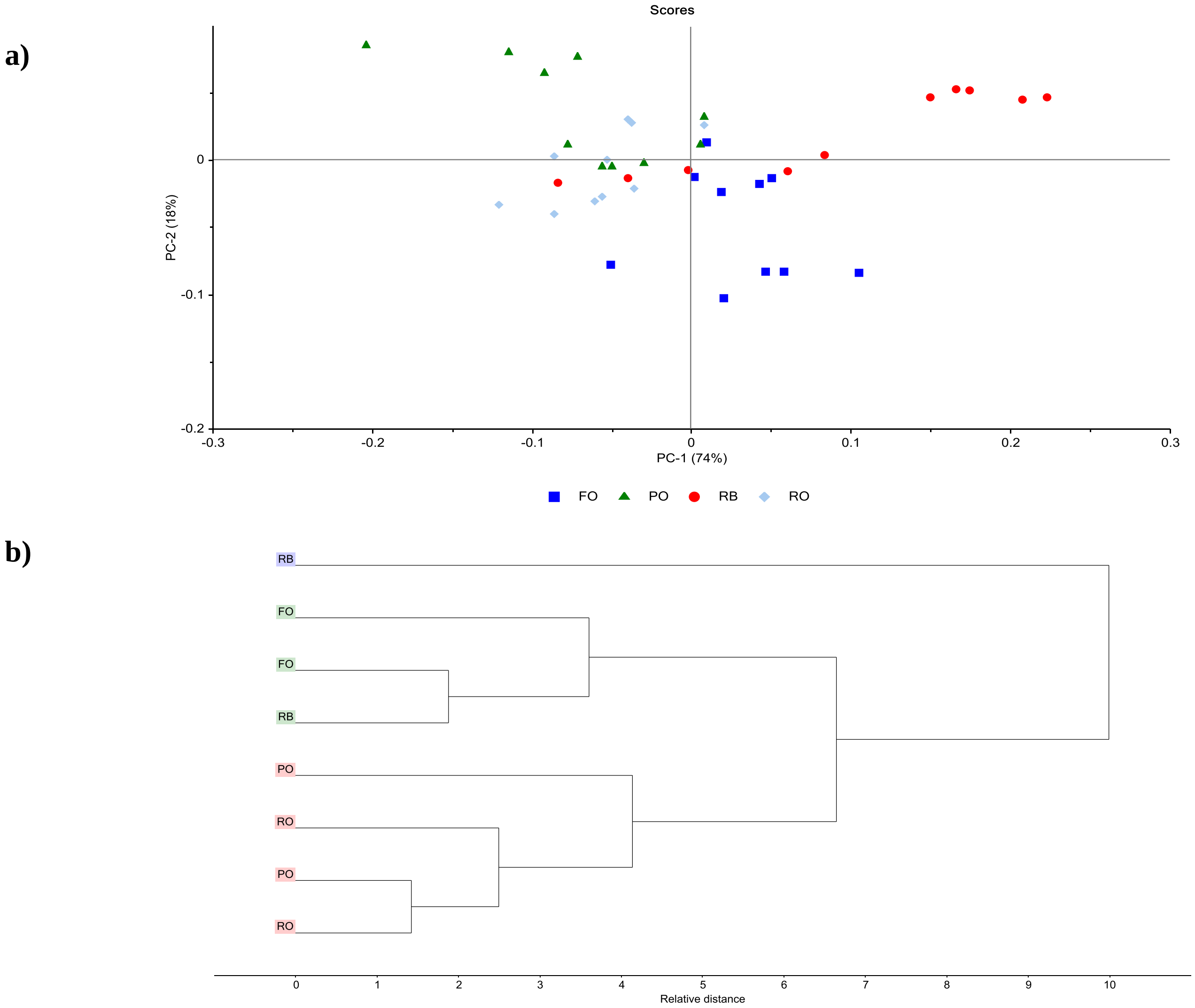

Figure 4.4. Multivariate spectral analyses of different processed oats grain in comparison with barley grain using FTIR vibrational spectroscopy at whole Amide region (ca. 1710-1480 cm^{-1}). (a) PCA (principal component analysis) with a scatter plot of the 1st principal components (PC1) vs. the 2nd principal components (PC2); (b) CLA (cluster analysis): cluster method (Ward's algorithm) and distance method (Squared Euclidean). RB: rolled barley; RO: rolled oats; FO: flaked oats; PO: pelleted oats.

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Effect of Feed Processing Methods (Rolling, Steam-Flaking, Pelleting) on Protein Molecular Structure Profile, Rumen Degradation, Intestinal Digestion, and Feed Milk Value (FMV) of Cool-Climate Adapted Oats Grain in Comparison with Barley Grain in Western Canada

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RUNNING HEAD: Influence of Processing Methods of Cool-Climate Adapted Oat Grain

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Abstract:

Processing cereal grains can lead to an improvement in nutrient digestibility and have an impact on the rate and site of grain nutrients digestion. There are several methods of processing and it is important to understand which processing method is better recommended for dairy cows ration with cool-climate adapted oat grain. The main objective of this study was to determine the impact of processing methods (Rolling, Steam-Flaking, Pelleting) on the nutritional and digestive characteristics and the protein related molecular spectral profiles of cool-climate adapted oats grain in comparison to barley grain. Results showed that heat treating oats (steam-flaking and pelleting) did not alter SCP of cool-climate adapted oats grain. Steam-flaking increased the intermediate degradable protein fraction PB1 (+13.68% CP), while reduced PA2 (-17.19% CP) fraction when compared to rolled oats. Steam-flaking also increased bypass CP (+14.71%BCP) while decreasing the EDCP in the rumen (-14.71%). In the DVE/OEB system, steam-flaked oats and pelleted oats presented lower values of OEB when compared to rolled oats, but they were higher than the value for rolled barley. Univariate analysis of the protein molecular structure features showed only changes in the protein beta-sheet height, with flaked oats presenting the higher value, pelleted oats showing the lowest value and rolled barley and oats showing intermediate values. There was overlap among the treatments when analyzed with PCA, implying similar molecular structure among the treatments.

Keywords: Technological Treatments and Processing, Cool-Climate Adapted Oat Kernel, Degradation Kinetics, Intestinal Digestion, Protein Molecular Structural Characteristics.

Abbreviations:

CP = Crude protein; **SCP** = Soluble crude protein; **ADICP** = Acid detergent insoluble crude protein; **NDICP** = Neutral detergent insoluble crude protein; **TRDP** = Total ruminally degradable protein; **TRUP** = Total ruminally undegraded protein; **RUP** = Rumen undegraded crude protein; **EDCP** = Effectively degraded of crude protein; **BSt** = Rumen bypass starch; **EDSt** = Effective degradability of starch; **dIDP** = Intestinal digestibility of rumen bypass protein on percentage basis; **dBSt** = Intestinal digestibility of rumen bypass starch on percentage basis; **N_OM** = Ratio between nitrogen and organic matter; **ED_N/ED_OM** = Effective degradation rate between nitrogen and organic matter; **FMV**= feed milk value

1. Introduction

Oats (*Avena sativa*) is one of the most important cereal grain produced in Canada. In recent years, with the increase in demand by international market, the oat production has grown significantly, more than 10% in the last two years, which promoted an increase in availability of this grain for Canadian farms (Statistics Canada, 2018). Although oats seem to be a good replacement for other cereal grains for high production dairy cattle, oats grain generally has a high proportion of hull, accounting for up to 25% of the whole oat weight (Crosbie et al., 1985), and this high content of fiber protecting the groats is known to decrease the total-tract digestibility of the grain and increases the loss of whole grains in feces (Beauchemin et al., 1994; Morgan and Campling, 1978).

Processing methods are shown to improve nutrient digestibility and the rate and site of grain digestion (Chrenkova et al., 2018; Prates et al., 2018). Several studies showed the benefits of processing feed for cattle, but grains can be physically processed by the application of several combinations of heat, moisture, time and pressure. It is important then to understand which kind of processing method is more adequate to optimize overall dairy cattle performance and milk production. It is also important to understand how the molecular structure of grains is affected by processing methods and how the changes in protein molecular structure can affect nutrient profile and availability for dairy cattle.

Recently, ATR-FT/IR molecular spectroscopy has been used as a non-invasive and non-destructive technique to rapidly characterize the feed molecular structure and use these data to predict nutrient profile and degradation.

Therefore, the present study was conducted to evaluate three different processing methods for cool-climate adapted oats grain in comparison to barley grain in terms of chemical profile and protein sub-fractions, rumen degradation kinetics, intestinal digestibility, and nitrogen to energy synchronization and protein molecular structure, in order to determine the most efficient processing method to enhance truly absorbable nutrient supply to high production dairy cattle. The hypothesis was that different processing methods could affect nutrient supply differently in ruminant systems.

2. Material and Methods

2.1 Grains Collection and Processing

Representative samples of cool-climate adapted oats and barley grain used in this study were obtained from Canadian Feed Research Centre (CFRC, University of Saskatchewan). Processing of the grains were conducted in the CFRC (North Battleford, Canada). Pelleting was made at 62°C in a pellet mill (UAS-Muyang Model: MUZL350II) with a die inside diameter of 350 mm and hole area of 4 mm die. For steam-flaking, samples were steamed for 25 min at atmospheric pressure and subsequently flakes were made at approximately 100°C (AT Ferrell 18×39 Dual Drive), before being transferred to the flaker cooler (Geelen Model VK 28 × 28 KL).

Dry rolled samples were made using a roller grinder (G.J. Vis Triple Pair 12" x 20"), and grains had a processing index (PI) of 50.9 PI for oats and 73.4 for barley grain.

2.2 Protein Molecular Structures Analysis

Samples were ground through a 0.12 mm screen and subsequently analyzed using a JASCO FTIR-ATR-4200 spectrometer (JASCO Corp., Tokyo, Japan). Right before samples were submitted to spectra collection, the background spectrum was measured with 256 scans to correct the spectra for CO_2 noise. Spectra were collected at the mid-IR region (approximately 4000–700 cm^{-1}) with a spectra resolution of 4 cm^{-1} and using 128 co-added scans (SpectraManager II software, JASCO Corp., Tokyo, Japan). Each sample had five spectra collected as sub-sample replicate.

For univariate analysis the collected spectrum data related to the protein structure were pre-processed using OMINIC 7.3 software (Spectra Tech, Madison, WI, USA). Each spectrum was normalized, and a second derivative was generated and smoothed, prior to the calculation of peak heights and areas. The primary protein structure, amide I region (at ca. 1718-1584 cm^{-1}) and amide II (at ca. 1584-1485 cm^{-1}), as well as the secondary structures, α-helix (at ca. 1647cm^{-1}) and β-sheets (at ca.1628 cm^{-1}) were measured for height and area, and their ratios between Amide I to Amide II and α-helix to β-sheet were determined.

The multivariate spectral analysis was performed to distinguish the inherent differences in the whole protein structure between the grains. The whole protein related structures (Amide I and Amide II) were analyzed using Principal Component Analysis (PCA) and Hierarchical Cluster Analysis (HCLA) using Ward's algorithm method. Multivariate spectra analysis was performed using the Unscrambler X software v. 10.3 (Camo Software, Norway).

2.3 Chemical Analysis

The samples were ground through a 1 mm screen (RetschZM200, Retsch Inc., PA, USA) and subsequently analyzed for DM (AOAC official method 930.15), CP (AOAC official method 984.13). The NDICP and ADICP were analyzed according to the procedures described by Licitra et al. (1996). The SCP was determined according to Roe et al. (1990) by incubating samples in borate-phosphate buffer and filtrating it through Whatman filter paper (#54). Starch was analyzed using a Megazyme Total Starch Kit (Megazyme International Ltd., Wicklow, Ireland).

2.4 Protein Subfraction Profile

The Cornell Net Carbohydrate and Protein System (CNCPS) version 6.5 was used to partition the protein sub-fractions. Fractions were subdivided considering the rate and extent of degradation in the rumen. Protein was fractioned into: PA2= soluble true protein with a Kd ranging from 10 to 40%/h; PB1= insoluble true protein with a Kd of 3-20%/h; PB2= fiber-bound protein with a Kd ranging from 1-18%/h and PC= indigestible protein.

2.5 Rumen Incubation

The University of Saskatchewan Animal Care Committee approved the animal trial under the Animal Use Protocol No. 19910012 and animals were cared for and handled in accordance with the updated Canadian Council of Animal Care (CCAC, 2009) regulations. The in situ experiment was carried out in the Rayner Dairy Teaching and Research Facility, University of Saskatchewan, Canada. For the incubation, four Holstein cows fitted with an 88 mm cannula were used. Cows were housed in individual tie stalls with free access to water and fed a TMR composed of barley silage, alfalfa hay and lactating pellet twice a day.

The incubation procedure followed a ‘gradual addition/all out` schedule according to the Dept in situ protocol. Nylon bags with a 40 µm pore size were used to incubate approximately 7 g per sample per bag for 0, 2, 4, 8, 12, and 24 h with multi-bags (2, 2, 2, 2, 3, 4) for each treatment and incubation time as well as each experiment run. The incubation procedure was performed for two experimental runs using the same four cannulated cows. After incubation was completed, bags were removed and water six times to wash out all the rumen fluid, and subsequently dried at 55°C for 48h in a forced-air oven. Samples taken out of the oven were exposed to room temperature and moisture before being weighted and composite by incubation time point and treatment. Pooled samples were then ground through 1 mm screen and analyzed for chemical composition CP using LECO protein analyzer (Model FP-528, Leco Corp., St. Joseph, MI, USA), DM according to AOAC (2005), and starch was analyzed using a Megazyme total starch kit (Megazyme International Ltd.).

2.6 Rumen Degradation Kinetics

Degradation characteristics of CP and Starch were determined following the first-order kinetics degradation model described by Ørskov and McDonald (1979) and modified by Tamminga et al. (1994). The results of rumen degradation kinetics were analyzed using NLIN procedure of SAS (Statistical Analysis System,) version 9.4 with iterative least-square regression (Gausse Newton method).

$$R(t) = U + D \times e^{-Kd \times (t - T0)},$$

where, R(t) was the residue present after t hours of incubation; U was the undegradable fraction (%); D was the potentially degradable fraction (%); Kd was the degradation rate (h^{-1}); and T0 was the lag time.

The percentage of bypass values of protein (BCP or RUP) and starch (BST) were calculated according to NRC Dairy (2001):

$$\% \text{ BCP (or RUP)} = U + D \times Kp / (Kp+Kd)$$

$$\%BSt = 0.1 \times S + D\, Kp / (Kp + Kd),$$

where, S=soluble fraction (%); Kp=estimated passage rate from the rumen (h^{-1}) and was assumed to be 6%/h for CP and Starch (Tamminga et al., 1994). The rumen undegradable or bypass Starch, in g/kg DM, were calculated as:

$$BSt\ (g/kg\ DM) = ST\ (g/kg\ DM) \times \%\ BSt,$$

while the rumen bypass CP (BCP) or rumen undegraded CP (RUP) were calculated differently according to the DVE or NRC model:

$$BCP\_DVE\ (g/kg\ DM) = 1.11 \times CP\ (g/kg\ DM) \times \%BCP$$

$$RUP\ NRC\ (g/kg\ DM) = CP\ (g/kg\ DM) \times \%RUP$$

The effective degradability (ED), or extent of degradation was predicted according to NRC as:

$$\% \text{ EDCP or EDSt} = S + D \times Kd/(Kp + Kd),$$

$$\text{EDCP or EDSt (g/kg DM)} = \text{CP or St (g/kg DM)} \times \%\text{EDCP (or EDSt)}.$$

2.7 Hourly Effective Rumen Degradation Ratio and Potential N to Energy Synchronization

The effective degradation of available N and available OM were calculated according to Sinclair et al. (1993):

$$\text{Hourly ED (g/kg DM)} = S + [(D \times Kd)/ (Kp + Kd)] \times 1 - e^{-t\times(Kd+Kp)}.$$

The difference in cumulative amounts degraded among successive hours was used to calculate the hourly effective degradation ratio between N and OM (ED_N/ED_OM) following the equation described by Sinclair (1993):

$$\text{Hourly ED N/OM}_t = (\text{HEDN}_t - \text{HEDN}_{t-1})/ (\text{HEDOM}_t - \text{HEDOM}_{t-1}),$$

where, hourly ED_N/ED_OM was the ratio of N to OM at the time t (gN/kgOM); HEDN_t was the hourly ED of N at the time t (g/kg DM); HEDN_{t-1} was the hourly ED of N 1h before the time t (g/kg DM); HEDOM_t was the hourly ED of OM at the time t (g/kg DM); HEDOM_{t-1} was the hourly ED of OM 1 h before the time t (g/kg DM).

2.8 Intestinal Digestion of Rumen Undegradable Protein and Total Track Digestion

The intestinal digestion of CP was determined using the three-steps in vitro protocol by Calsamiglia and Stern (1995). Briefly, residues taken out after 12 hours ruminal incubation and containing approximately 15 mg of N were placed in a 50 ml centrifuge tube with 10 ml of pepsin (Sigma P-7000) solution (0.1 N HCl with pH 1.9) and incubated for 1 h at 38°C. After incubation, 0.5 ml of 1 N NaOH solution and 13.5 ml of pancreatin (Sigma P-7545) were added and the solution was incubated for 24 h at 38°C. After the incubation, 3 ml of TCA was used to stop hydrolysis and then centrifugated at 1000g for 15 min and the supernatant was analyzed for soluble N by the Kjeldahl method. Intestinal digestion of protein was calculated as TCA soluble N divided by N present after ruminal incubation.

2.9 Nutrient Supply and Feed Milk Value

The DVE/OEB system and the NRC model were used to estimate the nutrient supply and feed milk value. In the Dutch system described by Tamminga et al. (1994, 2010), the DVE represents the value of a feed protein and it is calculated as: DVE = DVME + DVBE – ENDP, where, DVME is the microbial true protein synthesized in the rumen and digested in the small intestine, DVBE is the feed crude protein undegraded in the rumen but digested in the small intestine and ENDP is the endogenous protein lost in the digestive process. The OEB value is calculated as: OEB = MREN – MREE, where, OEB is the difference between the potential microbial protein synthesis based on MREN and the potential microbial protein.

In the NRC 2001 model, the total metabolizable protein (MP) is constituted by the rumen undegraded feed crude protein (RUP), ruminally synthesized microbial crude protein (MCP) and the rumen endogenous crude protein (ECP), and so MP is calculated as: MP (g/kg of DM) = ARUP+AMCP+AECP, where ARUP is the truly absorbable rumen undegraded CP, AMCP is the truly absorbable ruminal synthesized microbial CP and AECP is the truly absorbable endogenous CP.

The degraded protein balance (DPB) reflects the difference between the potential microbial protein synthesis based on the rumen degradable protein (RDP) and the potential microbial protein synthesis based on energy (TDN) available for microbial fermentation in the rumen. The DPB is calculated as: DPB (g/kg of DM) = RDP – 1.18 x MCP^{TDN}, where, RDP is the rumen degradable protein and MCP^{TDN} is the microbial protein synthesis (discounted TDN). Feed milk value was calculated based on metabolizable protein (MP).

2.10 Statistical Analysis

Results were analyzed using the Mixed model procedure in SAS 9.4 (SAS Institute Inc., NC, USA). The detailed chemical profile, protein and carbohydrate subfractions, energy values and protein spectral profile were analyzed according to the model:

$$Y_{ij} = \mu + T_i + e_{ij},$$

where, Y_{ij} was the observation of the dependent variable ij, μ was the effect of the population mean, T_i was the fixed effect of treatment and e_{ij} was the random error associated with the observation ij.

The studies of rumen degradation kinetics, hourly effective degradation ratio, nutrient supply and intestinal digestion of rumen undegraded nutrients were conducted and analyzed as randomized complete block design (RCBD) with experimental run used as a random block, and analyzed with the Mixed model in SAS 9.4, using the model:

$$Y_{ijk} = \mu + T_i + S_k + e_{ijk},$$

where, Y_{ijk} was the observation of the dependent variable ijk, μ was the population mean, T_i was the effect of treatment as fixed effect, S_k was the random effect of in situ incubation run and e_{ijk} was the random error associated with the observation ijk.

For all statistical analyses, significance was declared at $P \leq 0.05$ and trends at $0.05 < P < 0.10$. The differences among the treatments were compared using a multiple comparison test following the Tukey method. Contrast statement was used to compare the difference between barley grain and oats grain. The model assumptions were checked using research analysis. The normality test was carried out using Proc Univariate with Normal and Plot option.

3. Results

3.1 Impact of Processing Method on Protein Molecular Spectral Features of Cool-Season Adapted Oats

The different processing methods (Table 1) did not affect the Amide I height (P=0.17), Amide II height (P=0.11) or Amide I/Amide II height ratio (P=0.5) when comparing all treatments. Amide I area tended to be different between treatments (P=0.09). Analysis of the protein secondary structure profile revealed that α-helix did not differ between treatments (P=0.18); β-sheet height also showed no difference between rolled oats and pellet and flaked oat, although flaked oats showed 40% higher than pelleted oat (0.05 and 0.02, respectively). The processing methods did not impact the α-helix to β-sheet ratio among treatments (P=0.18).

The PCA was able to group different processing methods of oats and barley grain by its whole Amide related region, however none of the treatments was clearly separated from the other implying similar molecular structure in terms of protein make up in some degree (Figure 1a). Principal component one (PC1) explained 74% of the variation between spectra data while PC2 explained 18% of the variation. The same overlap could be seen in the hierarchical cluster analysis (HCLA), with pelleted and rolled oats being grouped into one cluster, while rolled barley and flaked oats was cluster into another group (Figure 1b).

3.2 Impact of Processing Method on Protein Profile and Protein Subfractions of Cool-Season Adapted Oat Grain

In this study, ADICP (P=0.73) did not differ among treatments (Table 2), while SCP was lower (P=0.02) for flaked oats when compared to rolled oats (3.49 and 5.77% DM, respectively). NDICP was higher (P<0.01) for flaked oats (1.24% DM). Rolled barley tended to have a lower CP content (P=0.09) when compared to the oat treatments.

Steam-flaking decreased the soluble true protein fraction (PA2) in 59% (Table 2). Rolled oats showed lower values of PB1 (P=0.02) when compared to flaked oats. Total rumen degradable protein did not differ among treatments (P=0.28), but total rumen undegradable protein was higher for flaked oats (P=0.01) when compared to barley (4.35 and 3.30% DM, respectively).

3.3 Impact of Processing Method on Rumen Degradation Kinetics of Cool-Season Adapted Oats

Higher values (P<0.01) of rumen undegradable crude protein (RUP) are seen in flaked oats and rolled barley (48.15 and 43.44, respectively) (Table 3). Rolled oats presented the highest value (P<0.01) of rumen effective degradable crude protein (112 g/kg DM) followed by pelleted oats (102 g/kg DM). When the results are compared on a percentage basis, rolled oats and pelleted oats did not differ, probably because of the lower content of protein in pelleted oats when compared to rolled oats.

The values for bypass starch ranged from 34 g/kg DM (pelleted oats) to 156 g/kg DM (rolled barley), as seen on Table 4. BST was impacted by grain type (P<0.01), but it did not differ between different processing of oats. Effective degradability of starch (EDST) was similar for flaked oats and rolled barley when measured in a g/kg DM basis and they showed higher values when compared to the other oat's treatments. However, rolled barley contained the highest amount of starch (66.58% DM) for the studied treatments, followed by flaked oats (52.59 %DM), which may have impacted the high amount of the ruminal effective degradable starch (510 and 470 g/kg DM, respectively). The values for EDST taken in a percentage basis showed that barley truly had a smaller amount of rumen degradable starch when compared to the oats grain treatments (P<0.01). In the present study, no difference was observed for BST when comparing rolled and pelleted oats.

3.4 Impact of Processing Method on Intestinal Digestion and Total Track Digestion of Cool-Season Adapted Oats

In this study, flaking and pelleting did not significantly increase ($P=0.87$) the intestinal digestion of bypass crude protein (Table 5). The numerically increase in intestinal digestibility of RUP seen in flaked oats could have been caused by the increased PB2 sub-fraction. The intestinal digestion of rumen bypass starch (Table 5) was lower for flaked oats ($P<0.01$, 70.74 %BST) when compared to pelleted oats and rolled barley (87.59 and 89.33 %BST, respectively), but it was not different when compared to rolled oats (78.78 %BST). Despite the intestinal digestibility of starch being higher for pelleted oats on a percentage basis, changing the unit to g/kg of DM showed higher ($P<0.01$) intestinal digestibility and total-tract digestibility for rolled barley (160 and 650 g/kg DM, respectively).

3.5 Impact of Processing Method on Hourly Effective Degradation Ratio between N and OM in Cool-Season Adapted Oats

The analysis of the data showed that overall ED_N/ED_OM (Table 6) were higher ($P<0.01$) for oats products when compared to rolled barley. Rolled oats showed the highest value of ED_N/ED/OM (26.24 g/kg), while rolled barley showed the lowest value. At individual incubation times 4 h, 8 h 12 h and 24 h, pelleted oats showed the highest ratio of degradation between available N and available OM (31.52, 72.06, 168.74 and 2420.78 g/kg, respectively). Therefore, the highest point in the degradation curve for oats grain was reached at 24 h incubation, while rolled barley had its highest point at the beginning of the incubation period (0h). In the present study, pelleted oats, that had the lowest conditioning temperature of the two processing methods showed higher hourly values of degradation in all the time points when compared to flaked oats.

3.6 Impact of Processing Method on Feed Milk Value and Nutrient Supply from Cool-Season Adapted Oats to Dairy Cows

The microbial protein synthesized in the rumen based on available energy (MREE) did not show any difference ($P=0.14$) among treatments (Table 7). On the other hand, the potentially synthesized microbial protein based on available nitrogen (MREN) showed a decline ($P<0.01$) when oats were submitted through heat treatments (steam-flaking and pelleting). The total true protein degradable and absorbed in the small intestine (DVE) was higher ($P<0.01$) for rolled barley (80.80 g/kg DM), followed by flaked oats (66.95 g/kg DM). The degraded protein balance was higher ($P<0.01$) for rolled oats when compared to the other treatments, with flaked oats and pelleted oats showing intermediate levels and rolled barley showing the lowest value. The predicted feed milk value was higher ($P<0.01$) for rolled barley, followed by flaked oats (1.64 and 1.36 kg milk/kg DM fed, respectively).

Data for the metabolic characteristics and true nutrient supply based on the NRC model are shown in Table 8. The microbial protein synthesized based on available TDN (MCP_{TDN}) was higher ($P<0.01$) for rolled barley and flaked oats (103.72 and 103.24 g/kg DM, respectively) and lower for pelleted oats (-2.76 g/kg DM) and rolled oats (-5.67 g/kg DM). Processing treatments (steam-flaking and pelleting) reduced ($P<0.01$) the amount of microbial protein that could be potentially synthesized based on rumen degradable protein (MCP_{RDP}). The degraded protein balance was reduced with processing, steam-flaking and pelleting ($P<0.01$; -24.81 and -12.88 g/kg DM, respectively). The predicted feed milk value was not impacted by treatments ($P=0.06$).

4. Discussion

Feed samples submitted through processing with application of heat (as steam-flaking, pelleting, roasting, etc.) can suffer significant impact on the protein profile and protein digestion (Prates et al., 2018). Sub-fraction PC is bound to lignin, tannins and to protein complexes of Maillard products (Sniffen et al.,1992), but although processing methods can increase the Maillard reactions and consequently increase the PC fraction of feeds, the results showed no influence of processing methods on the PC fraction. Prates et al. (2018) reported that autoclaving increased the indigestible protein content, however dry heating and microwave irradiation did not increase the PC fraction in barley grain, showing similar results to this study. The higher value of CP content that barley grain tended to show were previously reported by other authors (Rahman et al., 2016; Prates et al., 2018). Steam-flaking increased the RUP content of oat grains. Chrenkova et al. (2018) reported similar results for flaked wheat, maize and barley, showing higher RUP (40.1, 67.6 and 49.2 % CP, respectively) and lower rumen degradable protein. The increase of NDICP (slowly degraded in the rumen), major constituent of RUP (Sniffen et al., 1992), for flaked oats may be directly related to the increase in RUP shown by the flaking process.

The molecular analysis of the protein profile provides a more complete understanding of the impacts of the processing methods on the protein profile. The different structure heights and areas can signal differences in the site and extent of degradation of protein in ruminants. Xu et al. (2018) found a strong positive correlation between Amide I and Amide II peak area and rumen degradable protein (RDP), but in the present study, higher values of Amide I and II area were found for flaked oats and are presented together with lower EDCP and a higher RUP, suggesting a lower protein degradation for flaked oat grains. The lack of significant difference between rolled oat and steam-flaked and pelleted oat was similar to findings reported by Huang et al. (2015), but these are in contrast with the molecular changes induced by processing methods described in other studies (Prates et al., 2018; Rodriguez Espinosa, 2018).

Previous studies showed different impacts of processing methods on the site and extent of digestion of starch in ruminants. Processing oat grains did not alter the effective degradability of starch on ruminants, as has been reported by Ljøkjel et al. (2003), that studying untreated and pelleted oats, reported no significant differences when comparing EDST. Goelema et al. (1999) reported a significant reduction of 51% in BST when a feed mixture of broken peas, lupin and faba beans was submitted to pelleting conditions at 80°C. The difference between results could have been raised by the incomplete gelatinization of the starch obtained by pelleting of peas, which had a much higher starch gelatinization temperature when compared to oats grain, 50% in 55°C on average (Hoseney, 1994). In contrast, Prates et al. (2018) showed no impact on BST for barley grain submitted to dry heating, similar to the results found by this study. Similarly, Rahman et al. (2016) found no difference between the percentage of feed incubated in the rumen after 16 hours between raw and dry roasted oat grains.

Processing methods can increase the rumen undegradable content for protein and carbohydrates, however the subsequently intestinal digestion of this portions are highly important for the milk production (Chrenkova et al., 2018). Studying the effects of dry roasting and microwave irradiation on oat grains, Rahman et al. (2016) did not notice a significant difference on the intestinal digestibility of RUP of the grains submitted to dry roasting, but microwave irradiation numerically increased the RUP digestion in the small intestine, which could be related to a shift in protein sub-fractions, but also a lower degradability of CP in the rumen.

According to Tamminga et al. (1994), the optimal value for OEB is zero or slightly above, and in this case, oats submitted to treatments had the closest to optimal value, therefore these treatments have lower loss of N and adequate supply of energy to the rumen for microbial protein growth. Doiron et al. (2009) presented similar increase of DVE and decrease in OEB when flaxseed was autoclaved, despite none of their treatments reaching a negative value.

5. Conclusions

In conclusion, the present study showed that grain processing methods did not significantly altered the protein molecular structure, but it was effective in increasing the intestinal digestibility of starch and crude protein. This increase in nutrient availability in the small intestine, coupled with a closer to optimum degraded protein balance (OEB) can potentially increase the production performance on dairy cows.

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Table 1. Effect of grain processing methods (Rolling, Steam-Flaking, Pelleting) on protein molecular structure profile of cool-climate adapted oats grain in comparison with cool-climate adapted barley grain using vibrational molecular spectroscopy

	Oats					
Items	Rolled	Flaked	Pellet	Barley	SEM	P-value
Amide heights and spectra ratio						
Amide I	0.04	0.06	0.03	0.04	0.008	0.17
Amide II	0.02	0.02	0.01	0.01	0.003	0.11
Amide I/Amide II	2.57	2.38	2.57	3.47	0.500	0.5
Secondary structure heights and spectra ratio						
α-helix	0.04	0.06	0.03	0.04	0.008	0.18
β-sheet	0.03^{ab}	0.05^{a}	0.02^{b}	0.04^{ab}	0.004	0.03
A-helix/β-sheet	1.46	1.24	1.48	1.16	0.096	0.18
Amide area and spectra ratio						
Amide I	2.45	4.27	1.15	2.95	0.621	0.09
Amide II	0.56	1.16	0.18	0.38	0.218	0.12
Amide I/Amide II	4.41	3.70	9.89	17.28	6.855	0.54

SEM: standard error of mean; $^{a-b}$ Means with different letters in the same row are significantly different ($P<0.05$);

Table 2. Effect of grain processing methods (Rolling, Steam-Flaking, Pelleting) on protein chemical profile and CNCPS protein subfractions of cool-climate adapted oats grain in comparison with cool-climate adapted barley grain.

	Oats					
Items	Rolled	Flaked	Pellet	Barley	SEM	P-value
Protein profile						
CP (%DM)	13.48	13.64	13.02	11.76	0.401	0.09
SCP (%DM)	5.77^{a}	3.49^{b}	4.29^{ab}	3.98^{ab}	0.312	0.02
SCP (%CP)	42.75^{a}	25.56^{b}	30.03^{ab}	33.87^{ab}	1.876	0.01
ADICP (%DM)	004	0.02	0.02	0	0.024	0.73
ADICP (%CP)	0.31	0.18	0.15	0.02	0.189	0.76
NDICP (%DM)	1.02^{b}	1.24^{a}	0.73^{c}	0.78^{c}	0.037	<0.01
NDICP (%CP)	7.62^{ab}	9.12^{a}	5.64^{c}	6.62^{bc}	0.341	<0.01
Protein subtractions with CNCPS 6.5 system						
PA2 (%CP)	42.75^{a}	25.56^{b}	33.03^{ab}	33.87^{ab}	1.88	0.01
PB1 (%CP)	49.63^{b}	63.31^{a}	61.32^{ab}	59.50^{ab}	2.08	0.02
PB2 (%CP)	7.31^{ab}	8.94^{a}	5.49^{b}	6.60^{b}	0.33	<0.01
PC (%CP)	0.31	0.18	0.15	0.02	0.19	0.76

SEM: standard error of mean; $^{a-d}$ Means with the different letters in the same row are significantly different ($P < 0.05$); Multi-treatment comparison using Tukey method; CP: crude protein; SCP: soluble crude protein; ADICP: acid detergent insoluble crude protein; NDICP: neutral detergent insoluble crude protein; PA2: soluble true protein; PB1: insoluble true protein. PB2: fiber-bound protein; PC: indigestible protein;

Table 3. Effect of grain processing methods (Rolling, Steam-Flaking, Pelleting) on in situ rumen degradation kinetics of crude protein (CP) of cool-climate adapted oats grain in comparison with cool-climate adapted barley grain.

	Oats					
Items	Rolled	Flaked	Pellet	Barley	SEM	P-value
In situ rumen degradation of crude protein						
T0 (h)	0.00	0.27	0.16	0.53	0.207	0.36
S (%)	31.58^{a}	23.35^{ab}	17.26^{b}	16.37^{b}	3.095	0.01
D (%)	59.17^{b}	61.37^{b}	70.05^{b}	82.02^{a}	3.114	<0.01
U (%)	9.24^{b}	15.28^{a}	12.69^{ab}	1.61^{c}	1.306	<0.01
%BCP=%RUP	17.06^{b}	31.77^{a}	21.33^{b}	33.20^{a}	1.343	<0.01
BCP (g/kg DM)	23.02^{b}	43.38^{a}	27.90^{b}	39.14^{a}	2.034	<0.01
RUP (g/kg DM)	25.55^{b}	48.15^{a}	30.97^{b}	43.44^{a}	2.257	<0.01
EDCP (g/kg CP)	111.77^{a}	93.09^{c}	102.33^{b}	78.57^{d}	1.541	<0.01
%BCP=%RUP	17.06^{b}	31.77^{a}	21.33^{b}	33.20^{a}	1.343	<0.01
%EDCP	82.94^{a}	68.23^{b}	78.67^{a}	66.80^{b}	1.343	<0.01

SEM: standard error of mean; $^{a\text{-}c}$ Means with the different letters in the same row are significantly different ($P < 0.05$); Multi-treatment comparison using Tukey method; Kd: the degradation rate of D fraction (%h); T0: lag time; S: soluble fraction in the in-situ incubation; D: degradable fraction; U: rumen undegradable fraction; BCP: rumen bypassed crude protein in DVE/OEB system; RUP: rumen undegraded crude protein in the NRC Dairy 2001 model; EDCP: effectively degraded of crude protein.

Table 4. Effect of grain processing methods (Rolling, Steam-Flaking, Pelleting) on in situ rumen degradation kinetics of starch (ST) of cool-climate adapted oats grain in comparison with cool-climate adapted barley grain.

	Oats					
Items	Rolled	Flaked	Pellet	Barley	SEM	P-value
In situ rumen degradation of starch						
T0 (h)	0.20^b	0.00^b	0.11^b	0.98^a	0.171	<0.01
S (%)	24.71	19.98	9.39	19.24	7.111	0.48
D (%)	72.50	71.37	86.09	79.17	7.053	0.45
U (%)	2.79^b	8.65^a	4.52^{ab}	1.58^b	1.029	<0.01
BST (g/kg DM)	50.44^b	55.75^b	34.44^b	156.16^a	13.148	<0.01
EDST (g/kg DM)	438.72^b	470.16^{ab}	441.04^b	509.65^a	13.80	0.01
%BST	10.38^b	10.63^b	7.29^b	23.30^a	2.021	<0.01
%EDST	89.61^a	89.36^a	92.70^a	76.70^b	2.021	<0.01

SEM: standard error of mean; $^{a\text{-}b}$ Means with the different letters in the same row are significantly different ($P < 0.05$); Multi-treatment comparison using Tukey method; Kd: the degradation rate of D fraction (%h); T0: lag time; S: soluble fraction in the in-situ incubation; D: degradable fraction; U: rumen undegradable fraction; BST: rumen bypass or undegraded feed starch; EDST: effective degraded starch.

Table 5. Effect of grain processing methods (Rolling, Steam-Flaking, Pelleting) on intestinal and total track digestion of crude protein (CP) and starch (ST) of cool-climate adapted oats grain in comparison with cool-climate adapted barley grain

	Oats					
Items	Rolled	Flaked	Pellet	Barley	SEM	P-value
Intestinal and total track digestion of crude protein						
dIDP (%RUP)	42.18^{b}	54.17^{ab}	52.99^{ab}	65.28^{a}	3.524	<0.01
IDP (%RUP)	7.14^{c}	17.25^{ab}	11.46^{bc}	21.76^{a}	1.413	<0.01
IDP (g/kg DM)	9.61^{b}	23.55^{a}	15.10^{b}	25.66^{a}	1.980	<0.01
TDP (%CP)	90.08^{a}	85.48^{b}	90.13^{a}	88.56^{a}	0.688	<0.01
TDP (g/kg DM)	121.39^{a}	116.65^{a}	117.43^{a}	104.23^{b}	2.253	<0.01
Intestinal and total track digestion of starch						
dBST (%BST)	78.78^{ab}	70.74^{b}	87.59^{a}	89.33^{a}	3.533	<0.01
IDBST (%BCHO)	8.16^{b}	7.56^{b}	6.52^{b}	20.89^{a}	1.989	<0.01
IDBST (g/kg DM)	39.66^{b}	39.68^{b}	30.78^{b}	159.65^{a}	8.132	<0.01
TDBST (% ST)	97.77^{ab}	96.9^{b}	99.23^{a}	97.59^{ab}	0.436	0.02
TDBST (g/kg DM)	478.39^{b}	509.85^{b}	471.82^{b}	649.77^{a}	11.027	<0.01

SEM: Standard error of mean; $^{a\text{-}c}$ Means with the different letters in the same row are significantly different ($P < 0.05$); Multi-treatment comparison using Tukey method; dIDP: intestinal digestibility of rumen bypass protein on percentage basis; IDP: intestinal digested crude protein; TDP: total digested crude protein; dBST: intestinal digestibility of rumen bypass starch on percentage basis; IDBSTP: intestinal digested bypass starch; TDBST: total digested bypass starch.

Table 6. Effect of grain processing methods (Rolling, Steam-Flaking, Pelleting) on hourly effective degradation ratios between N and OM of cool-climate adapted oats grain in comparison with cool-climate adapted barley grain

	Oats					
Items	Rolled	Flaked	Pellet	Barley	SEM	P-value
Ratio of N to OM	22.37^{a}	22.49^{a}	21.56^{a}	19.47^{b}	0.421	<0.01
Ratio of ED_N/ED_OM	26.24^{a}	23.69^{b}	24.05^{b}	20.47^{c}	0.480	<0.01
Ratio at individual incubation hours (g/kg)						
Ratio at h0	40.74	26.12	38.93	72.92	18.004	0.43
Ratio at h2	21.23	16.93	21.06	15.52	1.367	0.04
Ratio at h4	27.03^{a}	23.14^{a}	31.52^{a}	12.77^{b}	3.015	<0.01
Ratio at h8	34.48^{bc}	46.34^{ab}	72.06^{a}	13.52^{c}	7.798	<0.01
Ratio at h12	99.66^{ab}	101.19^{ab}	168.74^{a}	14.33^{b}	39.497	0.04
Ratio at h24	1232.26	1572.16	2420.78	17.19	1003.44	0.24

SEM: Standard error of mean; $^{a\text{-}c}$ Means with the different letters in the same row are significantly different ($P < 0.05$); Multi-treatment comparison using Tukey method; N: nitrogen; OM: organic matter; ED: effective degradability.

Table 7. Effect of grain processing methods (Rolling, Steam-Flaking, Pelleting) on metabolic characteristics and truly absorbable nutrient supply (based on non-TDN system: DVE-OEB) of cool-climate adapted oats grain in comparison with cool-climate adapted barley grain

	Oats					
Items	Rolled	Flaked	Pellet	Barley	SEM	P-value
Truly digestible nutrient supply to dairy cattle (g/kg DM)						
BCP	25.55^{b}	48.15^{a}	30.97^{b}	43.44^{a}	2.257	<0.01
EDCP	111.17^{a}	93.09^{c}	102.33^{b}	78.57^{d}	1.541	<0.01
MREE	95.97	91.17	100.99	98.67	2.858	0.14
MREN	109.24^{a}	88.32^{c}	99.26^{b}	74.23^{d}	1.606	<0.01
DVME	61.18	58.12	64.38	62.90	1.822	0.14
DVBE	15.14^{b}	25.57^{a}	13.10^{b}	26.29^{a}	2.148	<0.01
Degraded protein balance (OEB) and Total true protein supply (DVE) to dairy cows (g/kg DM)						
DVE	59.71^{b}	66.95^{ab}	62.74^{b}	80.80^{a}	3.542	<0.01
OEB	13.26^{a}	-2.86^{b}	-1.73^{b}	-24.44^{c}	2.708	<0.01
Feed milk value (kg milk/kg DM fed)						
FMV	1.21^{b}	1.36^{ab}	1.27^{b}	1.64^{a}	0.071	<0.01

SEM: Standard error of mean; $^{a-c}$ Means with different letters in the same row are significantly different ($P<0.05$); Multi-treatment comparisons using Tukey method; BCP: bypass crude protein; MREE: microbial protein synthesized in the rumen based on available energy; EDCP: effective degradability of CP; MREN: microbial protein synthesized in the rumen; DVME: rumen synthesized microbial protein digested in the small intestine; DVBE: truly absorbed bypass protein in the small intestine; DVE: truly digested protein in the small intestine; OEB: degraded protein balance; FMV: feed milk value.

Table 8. Effect of grain processing methods (Rolling, Steam-Flaking, Pelleting) on metabolic characteristics and truly absorbable nutrient supply (based on TDN system: NRC dairy) of cool-climate adapted oats grain in comparison with cool-climate adapted barley grain.

	Oats					
Items	Rolled	Flaked	Pellet	Barley	SEM	P-value
Truly digestible nutrient supply to dairy cattle (g/kg DM)						
RUP	23.02^{b}	43.38^{a}	27.90^{b}	39.14^{a}	2.034	<0.01
MCP_{TDN}	98.05^{c}	103.24^{a}	100.96^{b}	103.72^{a}	0.464	<0.01
MCP_{RDP}	95.00^{a}	79.13^{c}	86.98^{b}	66.78^{d}	1.309	<0.01
AMCP	60.80^{a}	50.64^{c}	55.67^{b}	42.74^{d}	0.837	<0.01
ARUP	13.64^{b}	23.04^{a}	11.80^{b}	23.68^{a}	1.935	<0.01
ECP	10.41^{ab}	10.29^{ab}	10.49^{a}	10.19^{b}	0.068	0.04
AECP	4.17^{ab}	4.12^{ab}	4.19^{a}	4.07^{b}	0.026	0.03
Total metabolizable protein supply and degraded protein balance to dairy cattle (g/kg DM)						
MP	78.61^{a}	77.80^{a}	71.66^{a}	70.50^{a}	2.081	0.03
DPB	-3.92^{a}	-28.73^{c}	-16.80^{b}	-43.82^{d}	1.200	<0.01
Feed milk value (kg milk/kg DM fed)						
FMV	1.58	1.58	1.47	1.43	0.041	0.06

SEM: Standard error of mean; $^{a-d}$ Means with the different letters in the same row are significantly different ($P < 0.05$); Multi-treatment comparisons using Tukey method; RUP: rumen undegradable feed crude protein; MCP_{TDN}: rumen synthesized microbial protein base on available TDN; MCP_{RDP}: microbial protein synthesized in the rumen based on available protein; AMCP: truly absorbed microbial protein in the small intestine; ARUP: truly absorbed rumen undegradable protein in the small intestine; ECP: rumen endogenous protein; AECP: truly absorbed rumen endogenous protein in the small intestine; MP: metabolizable protein; DPB: rumen degraded protein balance; FMV: feed milk value.

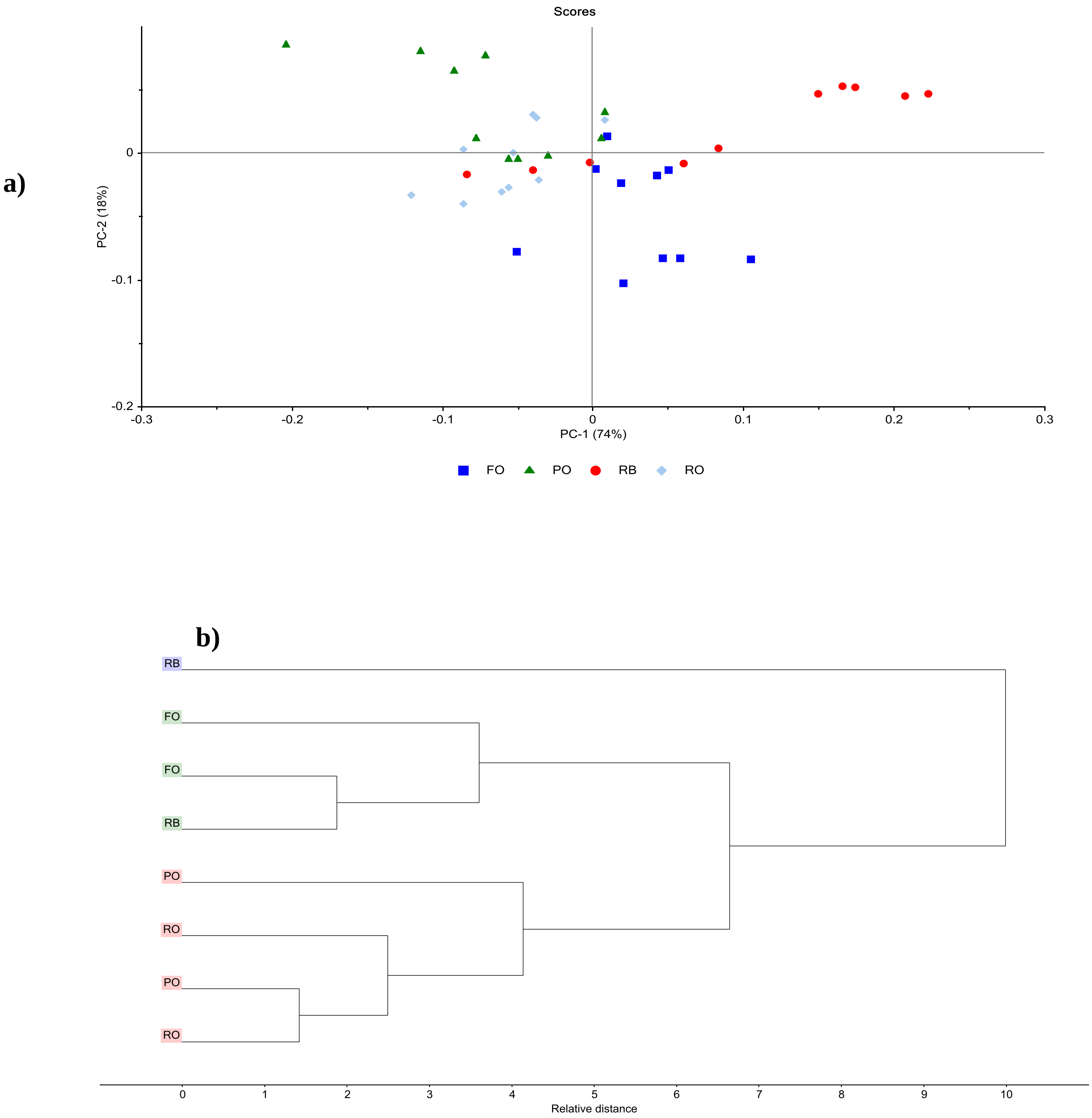

Figure 1. Multivariate spectral analyses of different processed cool-climate adapted oats grain in comparison with cool-climate adapted barley grain using vibrational molecular spectroscopy-FTIR at whole Amide region (ca. 1710-1480 cm^{-1}). (a) PCA (principal component analysis) with a scatter plot of the 1st principal components (PC1) vs. the 2nd principal components (PC2); (b) CLA (cluster analysis): cluster method (Ward's algorithm) and distance method (Squared Euclidean). RB: rolled barley; RO: rolled oats; FO: flaked oats; PO: pelleted oats.

4. Current and Proposed Research

Following projects: the 1st project has been completed and we will continue projects 2 and 3.

Project 1: Systematically compare prairie oat grain varieties/types with common barley in FMV for dairy cattle in western Canada in order to find best variety or type of oat grain with highest FMV value for dairy cows;
This project included several sub-projects. All the studies have been completed. Wrote scientific article and industry tech transfer articles

Project 2: Improve/increase FMV of oat grain through feed processing applications (steam-flaking vs. rolling vs. pelleting) in comparison with barley for lactating dairy cows. The suitable processing will be determined for Prairie oat grain grown under western Canadian cool climate condition. Feed processing methods/technology will be tested and applied at Canadian Feed Research Centre (CFRC: Feed Processing Centre)
This Project 2 has been completed. Wring scientific article and industry tech transfer articles.

Project 3: Effect of various feed processing applications on FMV of the Feed-Type and Milling-Type of oat grain in comparison with barley for lactating dairy cows.
This Project 3 is ongoing and partial results are available. The final report will be provide in next report.

5. *Cont'd*: Highly Qualified Personal Training from This Feed Research Program

- Graduate Student Training: One MSc student, One PhD student, and One PDF are being trained through this POGA, SaskMilk, and NSERC-CRD as well as SRP Chair program.

Graduate Student Thesis:

Marcela Tosta, Physiochemical, Nutritional Characterization, Molecular Structural and Dairy Cow Feeding Value of Oat Grain in Comparison with Barley Grain: Impact of Varieties (Feed-Type vs. Milling-Type) and Processing Methods (Raw vs. Flaking vs. Pelleting). University of Saskatchewan (Ongoing Scientific Paper Writing).

6. *Cont'd:* Technology Transfer, Extension Activities, Research Publications, and Industry Presentations /Seminars

Summary: Presentations in the industry and scientific meetings, such as:

- The Annual Dairy Info Day.
- The Western Canadian Dairy Seminar
- The Western Nutrition Conference.
- ASAS-ADSA-CSAS-WSASAS Joint Annual Meeting
- ADSA Annual Meeting

Industry Presentations: Examples

Presentation for Industry "37th Western Canadian Dairy Seminar" (To Farmers, Nutritionist and Livestock Producers): Marcela Tosta, Luciana Prates, David Christensen, John McKinnon, and Peiqiang Yu*. 2019. Physiochemical, molecular structural and nutritional characterization of Oat grain varieties in comparison to barley grain. The 37th Western Canadian Dairy Seminar, Red Deer, Canada, March 5-8, 2019 (*My role: as supervisor, PI, corresponding author).

Presentation for Industry "7th Annual Dairy Information Day" (To Farmers, Nutritionist and Livestock Producers): Luciana L. Prates, Peiqiang Yu*. 2018. Effect of Oat Type (Feed-Type vs. Milling Type) and Processing Method on True Nutrient Supply to Dairy Cattle. The 7th Annual Dairy Information Day, SaskMilk, January 25, 2018, Brian King Centre, Warman SK, http://www.saskmilk.ca/index.php/publications/dairy-info-day (*My role: as supervisor, PI, corresponding author).

Extension Articles and Abstracts for Various Meetings:

New

Industry Support: Assisted to write industry extension article regarding our project information for Oat organizations: Prairie Oat Growers Association, The Alberta Oat Growers Commission, The Manitoba Oat Growers Association, The Saskatchewan Oat Development Commission (Required in May 2020)

New

Published in Journal of Dairy Science (Annual ADSA Dairy Meeting Proceedings): M. R. Tosta, L. L. Prates, D. A. Christensen, J. J. McKinnon, and P. Yu*. 2019. Milk Production Performance and Ruminal Fermentation in Lactating Dairy Cows Fed Processed Oats Grain in Comparison with Barley Grain. J. Dairy Sci. Vol. 102, Suppl. 2: pp 370 (2019 ADSA Annual Meeting Integrating Dairy Science Globally, June 23–26, Cincinnati, Ohio, pp 370 in the Book of Abstract, June 23-26, 2019 (*My role: as supervisor, PI, corresponding author).

Published Feed Extension Article: In: "The Milk Producer (Magazine)", Title "Peiqiang Yu*. 2018. FOCUS ON FEED: What are Feed Milk Value (FMV) and Available Nutrients of New Feed-Type and Milling-Type of Oats for Dairy Cows in Comparison with Common Barley Grain? The Milk Producer (Magazine), Vol 94 Issue 5 (Accepted in 27Feb2018; Proof on 23Apr2018; Published in May2018).

Published Feed Extension Article: In: "Forage and Livestock eNews": Title "Peiqiang Yu*. 2018. Prairie Oats for Beef and Dairy Cattle: Effect of Oat Type (Feed-Type vs. Milling Type) and Feed Processing Method on Feed Milk Value and True Nutrient Supply. Forage and Livestock eNews, Vol 10 Issue 4 (Accepted on 21Feb2018; published in 17Apr2018) www.saskforage.ca

Published Feed Extension Article: In: "Advances in Dairy Technology": Title "Marcela Tosta, Luciana Prates, David Christensen, John McKinnon, and Peiqiang Yu*. 2019. Effects of Feeding Processed Oats Grain on Ruminal Fermentation and Animal Production Performance in Lactating Dairy Cows" Advances in Dairy Technology, Volume 31, pp 359, Editor: Mike Steele, Editor, Published by the University of Alberta, Edmonton, Alberta, Canada; Article Available Online: http://www.wcds.ca/proceedings.cgi" (*Role: as supervisor, PI, corresponding author).

Published Feed Extension Article: In: "Advances in Dairy Technology": Title "Marcela Tosta, Luciana Prates, David Christensen, John McKinnon, and Peiqiang Yu*. 2019. Physiochemical, Molecular Structural and Nutritional Characterization of Oat Grain Varieties in Comparison to Barley Grain" Advances in Dairy Technology, Volume 31, pp 358, Editor: Mike Steele, Editor, Published by the University of Alberta, Edmonton, Alberta, Canada; Article Available Online: http://www.wcds.ca/proceedings.cgi" (*Role: as supervisor, PI, corresponding author).

Industry Support: Review a short web article regarding our project information for Oat organizations: Prairie Oat Growers Association, The Alberta Oat Growers Commission, The Manitoba Oat Growers Association, The Saskatchewan Oat Development Commission (Required on 15Jun 2017)

Industry Support: Review a short article for Oat organizations: Prairie Oat Growers Association (Required on 25Sept2017)

Research Findings for Scientific Journals: Manuscripts and Publications:

New article:
Marcela Ribeiro Tosta, Luciana Louzada Prates, David A. Christensen, Peiqiang Yu* 2019. Biodegradation Kinetics by Microorganisms, Enzymatic Biodigestion, and Fractionation of Protein in Kernels of Cool-Season Adapted Oats: Comparison among Varities and between Milling-Type and Feed-Type. Journal of Cereal Science. 89: In press (DOI: 10.1016/j.jcs.2019.102814) (Fully Accepted on 15Dec2019; Published online on 18Dec 2019) (*My role: as supervisor, PI and corresponding author).

New article:
Marcela Ribeiro Tosta, Luciana Louzada Prates, David A. Christensen, Peiqiang Yu* 2019. Effect of Processing Methods (Rolling, Steam-Flaking, Pelleting) on Protein Molecular Structure Profile, Rumen Degradation, and Intestinal Digestion of Cool-Climate Adapted Oats Grain in Comparison with Barley Grain in Western Canada. Livestock Science. 232: In press (DOI: 10.1016/j.livsci.2019.103901) (Fully Accepted on 25Jul2019; Published online on 8Aug 2019) (*My role: as supervisor, PI and corresponding author).

Luciana L. Prates, Peiqiang Yu. 2017. Detect Unique Molecular Structure Associated with Physiochemical and Nutrient Properties in CDC Developed Oat Varieties in Comparison with Barley Grain Using Advanced Molecular Spectroscopy as a Non-Destructive Biological Tool. Journal of Cereal Science (England, IF=2.223) 74: 37-45 (DOI: 10.1016/j.jcs.2017.01.006) (Fully Accepted on 16Jan2017; Published online on 29Jan 2017) (*My role: as supervisor, PI and corresponding author).
Journal of Cereal Science (ELSEVIER, England, UK; a SCI journal): Rank: #35 of 128 journals in the Category: CHEMISTRY, MULTIDISCIPLINARY - SCIE in 2016-Journal Citation Reports; Rank: #116 of 286 journals in the Category: FOOD SCIENCE & TECHNOLOGY - SCIE in 2016-Journal Citation Reports; Impact Factor=2.223 in 2016; 5-Year Impact Factor = 2.665.

Luciana Louzada-Prates, Basim Refat, Yaogeng Lei, Mariana Louzada-Prates, Peiqiang Yu*. 2018. Relationship of Carbohydrates and Lignin Molecular Structure Spectral Profiles to Nutrient Profile in Newly Developed Oats Cultivars and Barley Grain. Spectrochimica Acta Part A - Molecular and Biomolecular Spectroscopy (IF=2.880 in 2017). 188: 495-506. (DOI: 10.1016/j.saa.2017.07.042). (Fully Accepted on 20Jul2017; Published online on 24Jul2017) (*My role: as Supervisor, PI and Corresponding Author)

Luciana L. Prates, Peiqiang Yu*. 2017. Recent Research on Molecular Structure, Physiochemical Properties, Metabolic Characteristics of Food & Feed-Type Avena Sativa Oats and Processing-Induced Changes with Molecular MicroSpectroscopic Techniques. Applied Spectroscopy Reviews (USA IF=3.226). 52 (10): 850-867 (DOI: 10.1080/05704928.2017.1331447) (Fully Accepted on 14May2017; Published online on 16May2017) (*My role: as Supervisor, PI and Corresponding Author)
Applied Spectroscopy Reviews (USA, a SCI journal): Rank: #4 of 41 journals in the Category: SPECTROSCOPY - SCIE in 2016-Journal Citation Reports; Rank: #3 of 58 journals in the Category: INSTRUMENTS & INSTRUMENTATION - SCIE in 2016-Journal Citation Reports; Impact Factor=4.254 in 2016; 5-Year Impact Factor = 4.014.

Manuscripts Preparation:

New
Marcela Ribeiro Tosta, Luciana Louzada Prates, Peiqiang Yu*. Research Progress in Structural and Nutritional Characterization and Technologically Processing Impact on Cool-Season Adapted Oat Cereal Kernels with Wet Chemistry and Advanced Vibrational Molecular Spectroscopy (Review Writing)