Processing effects on the starch and fibre composition of Canadian pulses

Authors: Babatunde, Olufemi O., Cargo-Froom, Cara L., Ai, Yongfeng, Newkirk, Rex W., Marinangeli, Christopher P.F., et al.

Source: Canadian Journal of Animal Science, 103(1) : 92-100

Published By: Canadian Science Publishing

URL: https://doi.org/10.1139/cjas-2022-0108

The BioOne Digital Library (https://bioone.org/) provides worldwide distribution for more than 580 journals and eBooks from BioOne's community of over 150 nonprofit societies, research institutions, and university presses in the biological, ecological, and environmental sciences. The BioOne Digital Library encompasses the flagship aggregation BioOne Complete (https://bioone.org/subscribe), the BioOne Complete Archive (https://bioone.org/archive), and the BioOne eBooks program offerings ESA eBook Collection (https://bioone.org/esa-ebooks) and CSIRO Publishing BioSelect Collection (https://bioone.org/csiro-ebooks).

Your use of this PDF, the BioOne Digital Library, and all posted and associated content indicates your acceptance of BioOne's Terms of Use, available at www.bioone.org/terms-of-use.

Usage of BioOne Digital Library content is strictly limited to personal, educational, and non-commmercial use. Commercial inquiries or rights and permissions requests should be directed to the individual publisher as copyright holder.

BioOne is an innovative nonprofit that sees sustainable scholarly publishing as an inherently collaborative enterprise connecting authors, nonprofit publishers, academic institutions, research libraries, and research funders in the common goal of maximizing access to critical research.

Downloaded From: https://complete.bioone.org/journals/Canadian-Journal-of-Animal-Science on 27 Feb 2025
Terms of Use: https://complete.bioone.org/terms-of-use

Canadian Journal of Animal Science

OPEN ACCESS | Article

Processing effects on the starch and fibre composition of Canadian pulses

Olufemi O. Babatunde[a], **Cara L. Cargo-Froom**[a,b], **Yongfeng Ai**[c], **Rex W. Newkirk**[d], **Christopher P.F. Marinangeli**[e], **Anna K. Shoveller**[b], **and Daniel A. Columbus**[a,c]

[a]Prairie Swine Centre, Inc., Saskatoon, SK S7H 5N9, Canada; [b]Animal Biosciences, University of Guelph, Guelph, ON N1G 2W1, Canada; [c]Department of Food and Bioproduct Sciences, University of Saskatchewan, Saskatoon, SK S7N 5A8, Canada; [d]Department of Animal and Poultry Science, University of Saskatchewan, Saskatoon, SK K S7N 5A8, Canada; [e]Protein Industries Canada, Regina, SK S4P 1Y1, Canada

Corresponding author: **Daniel A. Columbus** (email: dan.columbus@usask.ca)

Abstract

Starch and fibre contribute to the energy components and add functionality to the end-product feed ingredients. An understanding of the impact of processing on carbohydrate content will support accurate formulation of feed. Six ingredients, grown or sourced in Canada, were used in this study. They included five pulses, Amarillo peas, Dun peas, chickpeas, lentils, and faba beans, and soybean meal (SBM) as a comparison. All ingredients were ground into fine or coarse products and then pelleted at one of three different temperatures. Grinding reduced the total starch (TS) content of Amarillo peas and chickpeas ($P < 0.05$), crude fibre (CF) in Dun peas ($P < 0.05$), and total dietary fibre (TDF) and insoluble fibre (IDF) in lentils ($P < 0.05$). Grinding only affected soluble fibre (SDF) in chickpeas. The effect of pelleting was variable for TDF across pulses. Pelleting did not affect the SDF content of pulses ($P > 0.05$). Finely processed SBM had higher ($P < 0.05$) TS, TDF, and IDF content than coarsely processed SBM. Results indicate that grinding and pelleting could affect the starch and fibre composition of some pulses.

Key words: fibre, grinding, pelleting, pulses, starch

Introduction

Pulses are dry, edible, leguminous seeds that are an important source of carbohydrates and protein in animal and human diets (Asif et al. 2013). Pulses are also rich in fibre, vitamins (folate and riboflavin), and minerals (iron and zinc; Tosh and Yada 2010). Commonly available pulses include field peas, beans, lentils, chickpea, cowpeas, and faba beans. Pulses are increasingly used in diets of livestock due to the rising costs of conventional ingredients, such as soybeans and corn, or their relative abundance in a particular region or country. Furthermore, pulses provide both protein and carbohydrate and may reduce the amount of cereals that need to be included in the diet to satisfy energy requirements. The carbohydrate fraction of pulses represents 55%–65% of their dry matter (DM), as primarily starch and dietary fibre, with minor amounts of monosaccharides (Berrios et al. 2010). The starch, fibre, and sugars in pulses contribute toward the energy requirement of animals and, in addition, the dietary fibre fraction can support gastrointestinal health, positive behaviour, and wellbeing of animals (de Lange et al. 2010; Bach Knudsen et al. 2012).

Starch is a portion of carbohydrates that can be digestible in the small intestine through the action of endogenous enzymes and involves the breakdown of glycosidic bonds to release glucose. Generally, starch from pulses is relatively more digestible than potato starch but less digestible than starch from cereals; however, the digestibility can vary between species or within varieties of pulses (Liu et al. 2006). Dietary fibre refers to the portion of carbohydrates that is indigestible in the small intestine and includes complex polysaccharides such as lignin, gum, pectin, cellulose, hemicellulose, and resistant starch (Shiga et al. 2009). Some of the physiochemical properties of fibre considered of importance in animal nutrition include its hydration properties, cation exchange capacity, adsorptive properties, and viscosity (Lindberg 2014). Based on the solubility of its components, total dietary fibre (TDF) is often characterized as insoluble fibre (IDF) or soluble fibre (SDF). The IDF fraction has been reported to increase the rate of passage in the gut by enhancing fecal bulk, while SDF has been reported to increase the viscosity of digesta and water-holding capacity in the gut while decreasing the rate of passage (Lindberg 2014).

Given the presence of anti-nutritional properties such as tannins, saponnins, and protease inhibitors in raw pulse seeds, it is common for whole pulse seeds to undergo some form of processing before use in animal diets (Setia et al. 2019). Common processing methods include milling or grinding of whole seeds, followed by dehulling or decortication methods to separate hulls from cotyledon (Wood and Malcolmson 2011). Other processes such as extrusion, toasting, micronizing, and pelleting make use of heat and moisture to convert pulses into products that are more valuable to animal nutrition with improved digestibility via the deactivation of anti-nutritional factors. However, processes such as grinding and pelleting could affect the protein, starch, fibre, or lipid fractions of pulses due to the action of pressure, moisture, and heat (Cargo-Froom et al. 2022). Furthermore, reducing the particle size of feed ingredients can increase the digestibility of some nutrients and their biological utilization by livestock (Kim et al. 2005). Svihus and Zimonja (2011) also report the impact of heat on starch through gelatinization, as well as on the composition of TDF, IDF, and SDF in feed ingredients.

Previous work (Cargo-Froom et al. 2022) investigated the effects of processing on the protein and amino acid constituents of pulses grown in Canada. However, there is limited information on how common feed mill processes such as grinding and pelleting could influence the starch and fibre components of pulses. Since pulses are becoming a valuable feed alternative to soybean meal (SBM) in animal diets, it is imperative that changes in the nutrient profile of pulses due to feed processing be investigated to ensure that accurate information on the nutrient composition of pulses is included when formulating diets for livestock. The objective of this study was to characterize the effects of grinding and pelleting on the starch and fibre composition of Canadian pulses.

Materials and methods

Ingredients and processing

All selected pulses and SBM were grown or sourced in Canada. SBM (IDFN 5-04-604; Cargill Animal Nutrition, North Battleford, SK, Canada) was included in the study as a standard because its nutrient content and the effects of processing have been well examined in the literature (Karr-Lilienthal et al. 2005; Cromwell 1999). Pulses investigated included Amarillo field pea (IDFN 5-08-481, CDC Amarillo Variety; Oren and Marlene Robinson, Landis, SK, Canada), Dun field pea (CDC Dakota; Faba Canada, Tisdale, SK, Canada), chickpeas (Kabuli variety; AGT Foods, Regina, SK, Canada), faba beans (IDFN 5-09-262, Snowbird variety; Faba Canada, Tisdale, SK, Canada), and lentils (Laird variety; AGT Foods, Regina, SK, Canada). All processing methods, including grinding and pelleting, have been previously described by Cargo-Froom et al. (2022). Briefly, ingredients were sourced and then ground in batches of 500 kg using a hammermill (G.J. Vis. Model: VISHM2014) either through a 3.97 or 0.79 mm screen to create coarse and fine ground product, respectively. The average particle size for fine and coarse ground ingredients, respectively, were as follows: ground Amarillo peas (255 and 662 μm), ground Dun peas (278 and 744 μm), ground chickpeas (216 and 556 μm), ground faba beans (272 and 826 μm), ground lentils (296 and 654 μm), and SBM (370 and 854 μm). Subsequently, coarse and fine ground ingredients were pelleted in smaller batches (~100 kg) at low, medium, and high temperature ranges of 60–65, 70–75, and 80–85 °C, respectively, using a pilot scale pellet mill (Colorado Mill Equipment ECO R30). All grinding and pelleting processes occurred at the Canadian Feed Research Centre (North Battleford, SK, Canada). Sample collection began after the ingredients had been pelleted at a steady temperature for 1 min and were collected for all runs at the beginning (sample 1), middle (sample 2), and end (sample 3) of the pelleting run for each ingredient processing parameter. Samples were allowed to cool prior to storage and further analysis. All pelleted samples were ground through a 0.5 mm screen (Ultra Centrifugal Mill Type ZM 200 Retsch Part #20.823.0003 Serial #1214030238P) and stored at −20 °C until analysis.

Nutrient analysis

Samples were analyzed for moisture with AOAC method 930.15 (AOAC 2012) and crude fibre (CF) with AOAC method Ba 6a-05 (AOAC 2012) at SGS Agri-Foods Laboratories (Guelph, ON, Canada). Total starch (TS) analysis was done using the Megazyme Total Starch Assay Kit in accordance with AACC Method 76-13.01 (AACC 2000). TDF and its fractions (IDF and SDF) were determined using an ANKOM dietary fibre analyzer (model TDF Serial #TDF110150; ANKOM Technology, Macedon, NY, USA) based on AOAC method 991.43 (AOAC 2016). The average nutrient value in all finely and coarsely ground and pelleted feed ingredients samples was determined and referred to as ground and pelleted samples, respectively.

Statistical analysis

Data were analyzed using a fixed model via PROC GLIMMIX in SAS (SAS v 9.4; SAS Institute Inc., Cary, NC, USA). Contrasts were used to compare whole vs. ground, whole vs. pelleted, ground vs. pelleted, fine vs. coarse grind, and fine pelleted vs. coarse pelleted samples. Where appropriate, temperature within grind was treated as a fixed effect and a post hoc Tukey's HSD test was used for mean comparisons between pelleted samples. Differences were deemed significant when $P \leq 0.05$ and a tendency declared at $0.05 > P \leq 0.1$.

Results

Amarillo peas

There was no difference between the DM of whole and ground Amarillo peas; however, pelleted Amarillo peas had a lower DM ($P < 0.05$) than whole and ground Amarillo peas (Table 1). Fine pelleted Amarillo peas had lower ($P < 0.05$) DM than coarse pelleted Amarillo peas. Ground Amarillo peas had a lower ($P < 0.05$) TS content, but tended to have a higher ($P = 0.06$) CF content when compared with whole Amarillo peas. Pelleted Amarillo peas were lower ($P < 0.05$) in both TS and CF contents than whole Amarillo peas. There was no difference in the TS and CF content of fine and coarse ground Amarillo peas but differences ($P < 0.05$) were observed between fine and coarse pelleted Amarillo peas. Ground Amarillo peas had higher ($P < 0.05$) TDF and IDF but similar SDF with whole and pelleted Amarillo pea peas. There were no differences in the dietary fibre components between pelleted and whole Amarillo peas. Coarse ground and pelleted peas had a lower ($P \leq 0.05$) IDF, but similar SDF than their respective, finely ground and pelleted Amarillo peas.

Table 1. Nutrient composition (dry matter basis) of whole, ground, and pelleted Amarillo peas[1].

		Grind size			Pellet					Contrasts				
Item, %	Whole	Ground[2]	Fine grind	Coarse grind	Pellet[2]	Fine pellet	Coarse pellet	SEM	*P* value	Whole vs. ground	Whole vs. pellet	Ground vs. pellet	Fine vs. coarse grind	Fine vs. coarse pellet
Dry matter	86.83	86.56	86.56	86.56	86.16	85.43	86.89	0.19	<0.01	0.29	<0.01	0.02	1.00	<0.001
Total starch	52.30	48.05	48.60	47.50	49.48	48.61	50.36	0.65	<0.01	<0.01	<0.01	0.01	0.26	<0.01
Crude fibre	6.14	6.66	6.68	6.64	5.13	5.31	4.96	0.25	<0.01	0.06	<0.01	<0.01	0.91	0.01
Total dietary fibre	14.51	20.27	20.55	19.98	15.03	15.32	14.73	0.57	<0.01	<0.01	<0.01	<0.01	0.50	0.06
Insoluble fibre	13.64	19.52	20.13	18.91	14.29	14.53	14.06	0.40	<0.01	<0.01	0.14	<0.01	0.05	0.04
Soluble fibre	0.87	0.75	0.41	1.08	0.74	0.8	0.67	0.31	0.19	0.75	0.69	0.97	0.17	0.43

[1] Data are least square means of three replicates.

[2] Ground and pellet values are averages of finely and coarsely ground and pelleted samples, respectively.

Dun peas

Ground Dun peas tended ($P = 0.08$) to have lower DM content than whole peas while pelleted Dun peas had significantly lower ($P < 0.05$) DM than whole Dun peas (Table 2). The TS content of whole Dun peas was higher ($P < 0.05$) when compared with ground and pelleted Dun peas. There were no differences between the TS content of fine and coarsely ground or pelleted Dun peas. CF in Dun peas was affected by processing, as grinding resulted in lower ($P < 0.05$) CF values than whole Dun peas. Pelleting further reduced ($P < 0.05$) CF content when compared with ground Dun peas. TDF and its components were not affected by grinding or pelleting. Pelleting resulted in lower ($P < 0.05$) TDF and IDF values when compared with ground Dun peas. Soluble fibre content in Dun peas was not affected by grinding, grind size, or pelleting.

Chickpeas

Whole and ground chickpea products had a greater ($P < 0.05$) DM content when compared with pelleted chickpeas (Table 3). The TS content was highest ($P < 0.05$) in pelleted chickpeas followed by whole chickpeas and then ground chickpeas. Finely ground chickpeas had a higher ($P < 0.05$) TS content compared with coarsely ground chickpeas, but no difference was observed between fine and coarse pelleted chickpeas. There were no differences between the fibre components of whole and ground chickpea chickpeas except for SDF which was lower ($P < 0.05$) in ground chickpeas. When the fibre components of whole and pelleted chickpeas were compared, the CF was lower ($P < 0.05$) in pelleted chickpeas, but other components were similar. Pelleted chickpeas had lower ($P < 0.05$) CF and IDF values but higher ($P < 0.05$) SDF values than ground chickpeas. Finely ground chickpeas were only significantly higher ($P < 0.05$) in CF than coarsely ground chickpeas when all the fibre components were considered.

Faba beans

Pelleted faba beans had lower ($P < 0.05$) DM content when compared with whole or ground faba beans (Table 4). Coarsely pelleted faba beans also had a lower ($P < 0.05$) DM content when compared with finely pelleted faba beans. Pelleting increased ($P < 0.05$) the TS and CF content of faba beans when compared with whole or ground faba beans. The TDF and IDF of ground and pellet faba beans were higher ($P < 0.05$) than whole faba beans; however, no differences were observed between ground and pelleted faba beans. The CF, TDF, and IDF content in coarsely ground faba beans were reduced ($P < 0.05$) by 42.5, 42.0, and 39.7%, respectively, when compared with finely ground faba beans. Similarly, when coarse and finely pelleted faba beans were compared, a 24.0%, 17.7%, and 15.9% difference ($P < 0.05$) was observed in the CF, TDF, and IDF components, respectively. The SDF component of faba beans was not affected by grinding or pelleting when compared with whole faba beans; however, it was influenced by grind size with lower ($P < 0.05$) values observed with coarsely processed faba beans.

Table 2. Nutrient composition (dry matter basis) of whole, ground, and pelleted Dun peas[1].

	Grind size				Pellet					Contrasts				
Item, %	Whole	Ground[2]	Fine grind	Coarse grind	Pellet[2]	Fine pellet	Coarse pellet	SEM	*P* value	Whole vs. ground	Whole vs. pellet	Ground vs. pellet	Fine vs. coarse grind	Fine vs. coarse pellet
Dry matter	87.44	86.79	86.83	86.75	86.46	86.01	86.92	0.28	<0.01	0.08	<0.01	0.19	0.84	<0.01
Total starch	50.90	47.20	47.30	47.10	46.96	47.33	46.58	1.06	0.08	0.02	<0.01	0.77	0.90	0.25
Crude fibre	6.18	5.63	5.58	5.68	5.15	5.29	5.02	0.19	<0.01	0.01	<0.01	<0.01	0.68	0.02
Total dietary fibre	17.13	18.62	19.99	17.25	15.33	15.13	15.53	1.05	0.03	0.28	0.13	<0.01	0.10	0.49
Insoluble fibre	16.02	17.73	19.16	16.30	14.61	14.43	14.79	0.87	0.02	0.15	0.15	<0.01	0.04	0.45
Soluble fibre	1.11	0.89	0.83	0.96	0.74	0.74	0.74	0.24	0.11	0.49	0.18	0.43	0.72	0.98

[1] Data are least square means of three replicates.
[2] Ground and pellet values are averages of finely and coarsely ground and pelleted samples, respectively.

Table 3. Nutrient composition (dry matter basis) of whole, ground, and pelleted chickpeas[1].

	Grind size				Pellet					Contrasts				
Item, %	Whole	Ground[2]	Fine grind	Coarse grind	Pellet[2]	Fine pellet	Coarse pellet	SEM	*P* value	Whole vs. ground	Whole vs. pellet	Ground vs. pellet	Fine vs. coarse grind	Fine vs. coarse pellet
Dry matter	88.52	88.07	87.98	88.17	87.19	87.19	87.18	0.35	<0.01	0.33	<0.01	<0.01	0.96	0.06
Total starch	41.10	37.85	40.10	35.60	44.43	44.37	44.49	0.71	<0.01	<0.01	<0.01	<0.01	<0.01	0.72
Crude fibre	3.22	3.24	3.51	2.97	2.71	2.71	2.71	0.18	<0.01	0.89	<0.01	<0.01	0.03	0.93
Total dietary fibre	12.36	12.29	12.84	11.75	12.32	11.92	12.71	0.84	0.11	0.95	0.96	0.97	0.38	0.07
Insoluble fibre	10.74	11.94	12.50	11.38	10.96	10.78	11.14	0.57	0.14	0.11	0.72	0.04	0.19	0.21
Soluble fibre	1.62	0.36	0.34	0.38	1.36	1.14	1.58	0.46	0.02	0.04	0.59	0.01	0.96	0.08

[1] Data are least square means of three replicates.
[2] Ground and pellet values are averages of finely and coarsely ground and pelleted samples, respectively.

Table 4. Nutrient composition (dry matter basis) of whole, ground, and pelleted faba beans[1].

	Grind size				Pellet				Contrasts				
Item, %	Whole	Ground[2]	Fine grind	Coarse grind	Pellet[2]	Fine pellet	Coarse pellet	SEM	*P* value	Whole vs. ground	Whole vs. pellet	Ground vs. pellet	Fine vs. coarse grind	Fine vs. coarse pellet
Dry matter	87.96	87.21	87.19	87.24	86.19	86.51	85.87	0.39	<0.01	0.14	<0.01	<0.01	0.92	0.03
Total starch	32.40	36.55	35.10	38.00	42.22	41.35	43.09	2.37	0.02	0.18	<0.01	<0.01	0.41	0.16
Crude fibre	6.21	7.02	8.92	5.13	8.32	9.45	7.18	0.49	<0.01	0.19	<0.01	<0.01	<0.01	<0.01
Total dietary fibre	13.33	18.06	22.86	13.27	16.81	18.44	15.17	0.96	<0.01	<0.01	<0.01	0.11	<0.01	<0.01
Insoluble fibre	12.02	16.74	20.90	12.59	15.73	17.09	14.38	0.92	<0.01	<0.01	<0.01	0.17	<0.01	<0.01
Soluble fibre	1.31	1.32	1.96	0.68	1.07	1.35	0.79	0.33	0.02	0.98	0.49	0.34	0.01	<0.01

[1] Data are least square means of three replicates.
[2] Ground and pellet values are averages of finely and coarsely ground and pelleted samples, respectively.

Lentils

Pelleted lentils were lower ($P < 0.05$) in DM when compared with whole or ground lentils (Table 5). There was a tendency ($P = 0.07$) for pelleted lentils to have a higher TS content when compared with whole lentils; however, grinding and grind size did not affect the TS composition of lentils. All fibre components except SDF were affected by processing, with reductions ($P < 0.05$) observed in the CF, TDF, and IDF components of lentils as further processing occurred (i.e., whole > ground > pelleted lentils). Coarsely ground lentils had higher ($P < 0.05$) CF, TDF, and IDF values when compared with finely ground lentils. No differences were observed between the crude and dietary fibre components of coarse and finely pelleted lentils.

Soybean meal

There were no whole samples for SBM as it had been preprocessed before use in the study. However, there were some differences in the nutrient composition between ground and pelleted SBM (Table 6). Finely pelleted SBM had lower ($P < 0.05$) DM content when compared with coarsely pelleted SBM. The TS component in SBM was affected by grind size with a reduction ($P \leq 0.01$) of 82.6% and 61.8% in coarsely ground and pelleted products when compared with finely ground and pelleted products, respectively. There was no effect of processing on the CF component of SBM. Pelleted SBM had lower ($P < 0.05$) TDF values compared with ground SBM and coarse products had a lower ($P < 0.05$) TDF value compared with their respective fine product. There was no difference between the IDF component of ground and pelleted SBM; however, finely ground products had higher ($P < 0.05$) IDF values than coarse products. Soluble fibre was reduced ($P < 0.05$) by 36.4% in pelleted SBM when compared with ground SBM. In addition, finely ground SBM had increased ($P < 0.05$) SDF values compared with coarsely ground SBM.

Pelleting of pulses and SBM at each grind size occurred at various temperatures (60–80 °C) with differences observed within each nutrient fraction and for each feed ingredient (Supplementary Table S1).

Discussion

Pulses are an important group of crops serving as a feed source to the livestock industry. Pulses have gained interest in monogastric feeds due to the rising cost of contemporary feed ingredients, such as corn and soybean. While pulses have the advantage over cereals and SBM by providing protein and amino acids, digestible carbohydrate, and dietary fibre (Kiarie and Nyachoti 2009; Babatunde et al. 2021), studies have reported varying performance and nutrient utilization responses when pulses were fed to pigs or broiler chickens at different inclusion levels and in combination with other feed ingredients (Algam et al. 2012; White et al. 2015). When formulating diets for livestock, nutrient composition of whole ingredients are utilized in formulation programs and used to prepare diets. However, it is common practice for feed ingredients such as pulses to undergo some form of processing before being fed to livestock. These processes could include

Table 5. Nutrient composition (dry matter basis) of whole, ground, and pelleted lentils[1].

	Grind size				Pellet					Contrasts				
Item, %	Whole	Ground[2]	Fine grind	Coarse grind	Pellet[2]	Fine pellet	Coarse pellet	SEM	*P* value	Whole vs. ground	Whole vs. pellet	Ground vs. pellet	Fine vs. coarse grind	Fine vs. coarse pellet
Dry matter	90.46	88.90	88.38	89.42	86.57	86.84	86.29	0.74	<0.01	0.1	<0.01	<0.01	0.33	0.31
Total starch	43.20	45.35	45.60	45.10	47.63	47.83	47.42	2.16	0.41	0.43	0.07	0.19	0.87	0.70
Crude fibre	5.22	3.50	3.29	3.71	1.36	1.34	1.39	0.08	<0.01	<0.01	<0.01	<0.01	0.02	0.51
Total dietary fibre	16.60	13.63	12.62	14.62	12.33	12.48	12.18	0.53	<0.01	<0.01	<0.01	<0.01	0.02	0.29
Insoluble fibre	15.74	13.05	11.99	14.11	11.42	11.48	11.35	0.40	<0.01	<0.01	<0.01	<0.01	<0.01	0.54
Soluble fibre	0.80	0.58	0.64	0.52	1.00	1.00	1.00	0.52	0.81	0.67	0.62	0.30	0.87	1.00

[1] Data are least square means of three replicates.
[2] Ground and pellet values are averages of finely and coarsely ground and pelleted samples, respectively.

simple procedures, such as grinding and pelleting, or more complicated processing, such as extrusion or steam explosion. Some studies report that feed processing could affect the nutrient composition of ingredients due to the introduction of external factors, such as heat, moisture, pressure, or force (Abdollahi et al. 2013). Currently, there is limited information on how processing influences the nutrient composition of pulses. Results from this study demonstrate that processing parameters under the context of pelleting can affect various nutrient attributes of pulse ingredients, which could have implications for when they are used as an ingredient as a feedstuff.

Pelleting aims to agglomerate smaller feed particles by utilizing pressure, heat, and moisture via the addition of steam (Skoch et al. 1981), resulting in a higher moisture content. Thus, as expected, the DM content of all whole or ground pulses and SBM were higher when compared with their corresponding pelleted forms due to the inclusion of moisture in the pelleting procedure.

The TS content of pulses ranged from 32%–52% with faba beans having the lowest and field peas (Amarillo and Dun) having the highest concentrations. Total starch values in pulses were similar to those observed previously (Simsek et al. 2009; Lu et al. 2018; Punia et al. 2019). SBM had the lowest concentration of TS compared with other pulses due to pre-processing resulting in a high-protein product containing limited amounts of starch and fibre. There were varying effects of processing on the TS content of pulses, with grinding reducing the TS concentrations in Amarillo peas, Dun peas, and chickpeas while pelleting increased or tended to increase the TS concentrations in chickpeas, faba beans, and lentils.

The reduction in starch from grinding may be due to loss of hulls in the peas, which may have contained more of the starch fraction as compared with faba beans or lentils. However, this is contrary to reports from Wang et al. (2009) where increased TS was observed in dehulled peas. Starch is deposited mostly in the cotyledons of leguminous seeds as insoluble, semi-crystalline granules and are made up of two glucose polymers namely amylose and amylopectin (Wang et al. 2011). Amylose is an unbranched glucose complex bound by α-1,4-glycosidic bonds while amylopectin contains glucose chains in a branched structure bound by both α-1,4- and α-1,6-glycosidic bonds. The amylose concentration as well as the length and placement of branches in the amylopectin structure could influence the properties of starch such as water absorption, gelatinization, and susceptibility to enzymatic degradation (Jane 2007). To this end, the introduction of external factors such as heat, pressure, or moisture from processing could influence the structure of starch in the seeds and cause an increase in TS concentrations of some pulses with pelleting. In this regard, the methods for quantifying starch use enzymes to degrade the amylose and amylopectin constituents into glucose (McCleary et al. 2019). The relatively high temperatures used in the pelleting process may have caused a partial gelatinization of the starch, increasing the susceptibility to the enzymes utilized in starch determination resulting in higher starch content for pelleted pulses. Similarly, finely ground and pelleted SBM had higher TS content than when coarse ground SBM was pelleted in this study,

Table 6. Nutrient composition (dry matter basis) of ground and pelleted soybean meal[1].

	Grind size			Pellet					Contrasts		
Item, %	Ground[2]	Fine grind	Coarse grind	Pellet[2]	Fine pellet	Coarse pellet	SEM	*P* value	Ground vs. pellet	Fine vs. coarse grind	Fine vs. coarse pellet
Dry matter	87.63	87.56	87.71	87.03	85.69	88.37	0.58	<0.01	0.21	0.86	<0.01
Total starch	4.05	6.90	1.20	5.77	8.35	3.19	1.31	<0.01	0.11	0.01	<0.01
Crude fibre	3.54	3.59	3.49	3.85	3.86	3.84	0.28	0.60	0.20	0.81	0.92
Total dietary fibre	19.84	21.25	18.44	18.98	19.28	18.67	0.33	<0.01	0.05	<0.01	0.04
Insoluble fibre	17.04	17.42	16.73	17.12	17.42	16.81	0.11	<0.01	0.60	0.04	<0.01
Soluble fibre	2.80	3.90	1.71	1.78	1.70	1.86	0.39	0.01	<0.01	<0.01	0.46

[1] Data are least square means of three replicates.
[2] Ground and pellet values are averages of finely and coarsely ground and pelleted samples, respectively.

which was likely due to increased surface area exposure to enzymatic degradation and digestibility or some level of starch cooked from the heat of grinding (Koch 1996; Abdollahi et al. 2013). Thus, as with starch gelatinization, fine ground samples may have had increased exposure to the enzymes used in starch determination.

CF composition of pulses and SBM was similar to reports from NRC (2012). Processing, especially pelleting, resulted in reduced CF content of all pulses, except faba beans, which had increased CF with pelleting. Generally, whole pulses can be divided into three main fractions, including the seed coat (hulls), cotyledon, and embryo which, depending on seed type, constitute 10%–20%, 80%–90%, and 1%–2% of the whole seed mass, respectively (Karatas et al. 2017). Most of the dietary fibre of pulses is found within the coat. Given that faba beans have larger seeds and thicker seed coats when compared with chickpeas or lentils (Karatas et al. 2017), the higher CF content of whole faba beans was observed in the current study. Thinner hulls of chickpeas and lentils may explain the lower CF following processing compared with faba beans, as the mechanical force from grinding and pelleting could have increased separation and loss, thus decreasing CF concentrations. There was no effect of processing on the CF of SBM, likely because SBM is a pre-processed feed ingredient that already had its hulls separated.

Dietary fibre is the carbohydrate portion of plants that is resistant to enzymatic digestion by monogastric animals. Despite its low digestibility, dietary fibre has been reported to support digestion, maintain gut microbiota, and encourage hindgut fermentation (Kim et al. 2013; Chen et al. 2020). Dietary fibre differs from CF in that it takes into account both the soluble and insoluble fractions of fibre in plant materials (Chen et al. 2020). Insoluble fibre is that portion of TDF that is considered not readily fermentable and includes cellulose, hemicellulose, and lignin. It has been shown to improve gut health through reducing pathogen proliferation (Lindberg 2014; Molist et al. 2014). Soluble fibre, which consists of materials such as β-glucan, inulin, resistant starch, gums, and pectin, is considered susceptible to fermentation by the gut microbiome, producing metabolites that may be beneficial to gut health and function (Pascoal et al. 2015; Mudgil 2017). As both soluble and insoluble dietary fibre can have significant impacts on monogastric nutrition and physiology, it is important that the total, soluble, and insoluble dietary fibre content of feedstuffs be characterized and the impact of processing be determined.

The TDF content of whole pulses ranged from 12% to 17%, which is in agreement with values from literature (Hall et al. 2017). Chickpeas had the lowest amount of dietary fibre while Dun peas had the highest concentration among pulses, with the highest amount of TDF found in SBM. The grinding process increased the TDF and IDF content of Amarillo peas and faba beans, decreased the same components in lentils, but had no effect on the SDF fractions in all three pulses. Since most of the TDF in pulses are insoluble (Wang et al. 2010), it is logical that the effects of grinding on TDF were carried over from the effects on IDF. Dehulling of pulses would usually result in the loss of IDF since most of the cellulose and hemicellulose are located in the seed coat (Hall et al. 2017). Even though grinding may have caused a dehulling of the field peas and faba beans, thicker hulls may not have been all lost during grinding, and thus the higher TDF content. However, if the seed coats are thin, such as with lentils, then most of the hulls may have been lost during grinding.

Pelleting reduced IDF content in Amarillo peas, Dun peas, lentils, and chickpeas but had no effects on SDF content. A similar trend was reported by Berrios et al. (2010) such as reductions in IDF content of extruded peas and lentils. Similar to starch, pelleting conditions may have caused a modification of the fibre components in pulses, thus affecting the content of IDF and TDF levels in pulses.

The SDF fraction of pulses was generally not affected by any processing methods applied. This could be due to their lower proportion in relation to the TDF when compared with the IDF fraction (Hall et al. 2017). However, levels of SDF in faba beans were affected by particle size, with finely processed samples having higher levels than coarse samples. Again, the increase in surface area likely results in finely processed sample being more susceptible to degradation during the fibre determination procedure. Interestingly, we observed that while pelleting reduced the IDF content of chickpeas and lentils as compared with grinding, there was a slight increase in the SDF content of both pulses. This may indicate that feed processing involving heat, moisture, and other factors may influence the structure of the IDF components in feed ingredients, thus making them more soluble.

Pelleting reduced the TDF and SDF content in SBM but had no effect on IDF content. Since the ratio of SDF to TDF in SBM was greater than in other pulses due to pre-processing, with the removal of lipid from soybeans and reduced fibre component overall, the greater soluble fiber fractions in SBM may have been more susceptible to factors associated with the pelleting procedure as compared with other pulses. In addition, the fibre component of SBM was influenced by particle size, with finer samples having greater fibre content compared with coarse samples. The observed differences between the fibre content, particularly IDF content, of coarse and finely processed ingredients in this study may highlight some accuracy challenges that occur as a result of the processing of samples prior to fiber determination in the laboratory (McCleary et al. 2012) and thus may require further investigation. Although the moisture and carbohydrate composition of pulses and SBM were affected by the different temperatures used in pelleting, effects were varied and dependent on the nutrient fraction measured or the ingredient evaluated. However, there was no single temperature that resulted in optimum nutrient values across all feed ingredients.

Conclusions

The starch and fibre components of pulses may be affected by the processing method utilized in preparing the feed. However, the degree to which starch and fibre content are affected is dependent on the pulse type or the processing method carried out and, as such, must be considered when selecting ingredients for diet formulation. Accurate nutrient values should also be utilized when formulating diets with raw or processed pulses to ensure that adequate nutrients are being supplied to animals even as we move towards precision nutrition. Lastly, grind size affected fibre and starch content and, therefore, may play a role in improving the availability of these nutrients. Processing method of pulses and SBM, therefore, should be accounted for when formulating diets.

Acknowledgements

The authors would like to acknowledge the staff at the Prairie Swine Centre, Canadian Feed Research Centre, and the University of Saskatchewan for their assistance with processing and analyzing samples.

Article information

History dates

Received: 20 September 2022
Accepted: 11 December 2022
Accepted manuscript online: 14 December 2022
Version of record online: 6 February 2023

Copyright

Data availability

Data is available upon reasonable request to the corresponding author.

Author information

Author ORCIDs

Daniel A. Columbus https://orcid.org/0000-0002-3335-6973

Author contributions

Conceptualization: CLC-F, YA, RWN, CPFM, AKS, DAC
Data curation: CLC-F
Formal analysis: OOB, CLC-F, YA, RWN, DAC
Funding acquisition: DAC
Methodology: CLC-F, YA, RWN, CPFM, AKS, DAC
Project administration: DAC
Rresources: DAC
Supervision: AKS, DAC
Writing – original draft: OOB, CLC-F, YA, RWN, CPFM, AKS, DAC
Writing – review & editing: OOB, CLC-F, YA, RWN, CPFM, AKS, DAC

Competing interests

The authors declare there are no competing interests.

Funding

This research was supported by Swine Innovation Porc (17103a), Saskatchewan Pulse Growers, and MITACS Accelerate (IT12203).

Supplementary material

Supplementary data are available with the article at https://doi.org/10.1139/CJAS-2022-0108.

References

AACC. 2000. Approved methods of analysis of AACC International. 10th ed. AACC, St. Paul, MN.

Abdollahi, M.R., Ravindran, V., and Svihus, B. 2013. Review: pelleting of broiler diets: an overview with emphasis on pellet quality and nutritional value. Anim. Feed Sci. Technol. **179**(1–4): 1–23. doi:10.1016/j.anIDFeedsci.2012.10.011.

Algam, T.A., Abdel Atti, K.A., Dousa, B.M., Elawad, S.M., and Fadel Elseed, A.M. 2012. Effect of dietary raw chick pea (*Cicer arietinum* L.) seeds on broiler performance and blood constituents. Int. J. Poultry Sci. **11**(4): 294–297. doi:10.3923/ijps.2012.294.297.

AOAC. 2012. Official methods of analysis of AOAC International. 19th ed. AOAC, Gaithersburg, MD.

AOAC. 2016. Official methods of analysis of AOAC International. 20th ed.Edited by W. George Latimier, Jr. AOAC, Gaithersburg, MD.

Asif, M., Rooney, L.W., Ali, R., and Riaz, M.N. 2013. Application and opportunities of pulses in food system: a review. Crit. Rev. Food Sci. Nutr. **53**(11): 1168–1179. doi:10.1080/10408398.2011.574804. PMID: 24007421.

Babatunde, O.O., Park, C.S., and Adeola, O. 2021. Nutritional potentials of atypical feed ingredients for broiler chickens and pigs. Animals, **11**(5): 1196. doi:10.3390/ani11051196.

Bach Knudsen, K.E., Hedemann, M.S., and Laerke, H.N. 2012. The role of carbohydrates in intestinal health of pigs. Anim. Feed Sci. Technol. **173**(1–2): 41–53. doi:10.1016/j.anIDFeedsci.2011.12.020.

Berrios, J., Morales, P., Camara, M., and Sanchez-Mata, M. 2010. Carbohydrate composition of raw and extruded pulse flours. Food Res. Int. **43**(2): 531–536. doi:10.1016/j.foodres.2009.09.035.

Cargo-Froom, C.L., Newkirk, R.W., Marinangeli, C.P.F., Shoveller, A.K., Ai, Y., Kiarie, E.G., and Columbus, D.A. 2022. The effects of grinding and pelleting on nutrient composition of Canadian pulses. Can. J. Anim. Sci. **102**(3): 457–472. doi:10.1139/CJAS-2021-0111.

Chen, T., Chen, D., Tian, G., Zheng, P., Mao, X., Yu, J., et al. 2020. Effects of soluble and insoluble dietary fiber supplementation on growth performance, nutrient digestibility, intestinal microbe and barrier function in weaning piglet. Anim. Feed Sci. Technol. **260**: 114335. doi:10.1016/j.anIDFeedsci.2019.114335.

Cromwell, G.L. 1999. Soybean meal—the "Gold Standard". The farmer's pride. KPPA News, **11**(20).

de Lange, C.F.M., Pluske, J., Gong, J., and Nyachoti, C.M. 2010. Strategic use of feed ingredients and feed additives to stimulate gut health and development in young pigs. Livest. Sci. **134**(1–3): 124–134. doi:10.1016/j.livsci.2010.06.117.

Hall, C., Hillen, C., and Robinson, J.G. 2017. Composition, nutritional value, and health benefits of pulses. Cereal Chem. **94**(1): 11–31. doi:10.1094/CCHEM-03-16-0069-FI.

Jane, J.L. 2007. Structure of starch granules. J. Appl. Glycosci. **54**(1): 31–36. doi:10.5458/jag.54.31.

Karatas, S.C., Gunay, D., and Sayar, S. 2017. In vitro evaluation of whole faba bean and its seed coat as a potential source of functional food components. Food Chem. **230**: 182–188. doi:10.1016/j.foodchem.2017.03.037.

Karr-Lilienthal, L.K., Grieshop, C.M., Spears, J.K., and Fahey, G.C. 2005. Amino acid, carbohydrate, and fat composition of soybean meals prepared at 55 commercial U.S. soybean processing plants. J. Agric. Food Chem. **53**(6): 2146–2150. doi:10.1021/jf048385i. PMID: 15769148.

Kiarie, E., and Nyachoti, C.M. 2009. Alternative feed ingredients in swine diets. In Proceedings of the Saskatchewan Industry Symposium, Saskatoon, SK, Canada. pp. 17–18.

Kim, M.S. Hwang, S.S. Park, E.J. and Bae, J.W. 2013. Strict vegetarian diet improves the risk factors associated with metabolic diseases by modulating gut microbiota and reducing intestinal inflammation. Environ. Microbiol. Rep. **5**(5): 765–775. doi:10.1111/1758-2229.12079.

Kim, J.C., Mullan, B.P., and Pluske, J.R. 2005. A comparison of waxy versus non-waxy wheats in diets for weaner pigs: effects of particle size, enzyme supplementation, and collection day on total tract apparent digestibility and pig performance. Anim. Feed Sci. Technol. **120**(1–2): 51–65. doi:10.1016/j.anifeedsci.2005.01.004.

Koch, K. 1996. Hammer mills and roller mills. In MF-2048 feed manufacturing. Department of Grain Science and Industry, Kansas State University, Manhattan, KS. pp. 1–4.

Lindberg, J.E. 2014. Fibre effects in nutrition and gut health in pigs. J. Anim. Sci. Biotechnol. **5**: 15. doi:10.1186/2049-1891-5-15. PMID: 24580966.

Liu, Q., Donner, E., Yin, Y., Huang, R. L., and Fan, M. Z. 2006. The physicochemical properties and in vitro digestibility of selected cereals, tubers and legumes grown in China. Food Chem. **99**(3): 470–477. doi:10.1016/j.foodchem.2005.08.008.

Lu, Z.H., Donner, E., Tsao, R., Ramdath, D.D., and Liu, Q. 2018. Physicochemical and digestion characteristics of flour and starch from eight Canadian red and green lentils. Int. J. Food Sci. Technol. **53**(3): 735–746. doi:10.1111/ijfs.13649.

McCleary, B.V., Charmier, L.M.J., and McKie, V.A. 2019. Measurement of starch: critical evaluation of current methodology. Starch, **71**(1–2): 1800146. doi:10.1002/star.201800146.

McCleary, B.V., DeVries, J.W., Rader, J.I., Cohen, G., Prosky, L., Mugford, D.C., et al. 2012. Determination of insoluble, soluble, and total dietary fiber (codex definition) by enzymatic-gravimetric method and liquid chromatography: collaborative study. J. AOAC Int. **95**(3): 824–844. doi:10.5740/jaoacint.CS2011_25. PMID: 22816275.

Molist, F., van Oostruma, M., Pérez, J.F., Mateos, G.G., Nyachoti, C.M., and van der Aar, P.J. 2014. Relevance of functional properties of dietary fibre in diets for weanling pigs. Anim. Feed Sci. Technol. **189**: 1–10. doi:10.1016/j.anifeedsci.2013.12.013.

Mudgil, D. 2017. Chapter 3. The interaction between insoluble and soluble fibre. In Dietary fibre for the prevention of cardiovascular disease. Edited by A. Rodney Samaan. Academic Press. pp. 35–59. doi:10.1016/B978-0-12-805130-6.00003-3.

National Research Council. 2012. Nutrient requirements of swine. 11th ed. National Academy Press, Washington, DC.

Pascoal, L.A.F., Thomaz, M.C., Watanabe, P.H., Ruiz, U.S., Amorim, A.B., Daniel, E., and Silva, S.Z. 2015. Purified cellulose, soybean hulls and citrus pulp as a source of fibre for weaned piglets. Sci. Agric. **72**(5): 400–410. doi:10.1590/0103-9016-2014-0210.

Punia, S., Dhull, S.B., Sandhu, K.S., and Kaur, M. 2019. Faba bean (*Vicia faba*) starch: structure, properties, and in vitro digestibility—a review. Legum. Sci. **1**(1): e18. doi:10.1002/leg3.18.

Setia, R., Dai, Z., Nickerson, M.T., Sopiwnyk, E., Malcolmson, L., and Ai, Y. 2019. Impacts of short-term germination on the chemical compositions, technological characteristics and nutritional quality of yellow pea and faba bean flours. Food Res. Int. **122**: 263–272. doi:10.1016/j.foodres.2019.04.021. PMID: 31229080.

Shiga, T.M., Cordenunsi, B.R., and Lajolo, F.M. 2009. Effect of cooking on non-starch polysaccharides of hard-to cook beans. Carbohydr. Polym. **76**(1): 100–109. doi:10.1016/j.carbpol.2008.09.035.

Simsek, S., Tulbek, M.C., Yao, Y., and Schatz, B. 2009. "Starch characteristics of dry peas (*Pisum sativum* L.) grown in the USA. Food Chem. **115**(3): 832–838. doi:10.1016/j.foodchem.2008.12.093.

Skoch, E.R., Behnke, K.C., Deyoe, C.W., and Binder, S.F. 1981. The effect of steam-conditioning rate on the pelleting process. Anim. Feed Sci. Technol. **6**(1): 83–90. doi:10.1016/0377-8401(81)90033-X.

Svihus, B., and Zimonja, O. 2011. Chemical alterations with nutritional consequences due to pelleting animal feeds: a review. Anim. Prod. Sci. **51**(7): 590–596. doi:10.1071/AN11004.

Tosh, S.M., and Yada, S. 2010. Dietary fibres in pulse seeds and fractions: characterization, functional attributes, and applications. Food Res. Int. **43**(2): 450–460. doi:10.1016/j.foodres.2009.09.005.

Wang, N., Hatcher, D.W., Toews, R., and Gawalko, E.J. 2009. Influence of cooking and dehulling on nutritional composition of several varieties of lentils (*Lens culinaris*). LWT- Food Sci. Technol. **42**(4):842–848. doi:10.1016/j.lwt.2008.10.007.

Wang, N., Hatcher, D.W., Tyler, R.T., Toews, R., and Gawalko, E.J. 2010. Effect of cooking on the composition of beans (*Phaseolus vulgaris* L.) and chickpeas (*Cicer arietinum* L.). Food Res. Int. **43**(2): 589–594. doi:10.1016/J.FOODRES.2009.07.012.

Wang, S., Sharp, P., and Copeland, L. 2011. Structural and functional properties of starches from field peas. Food Chem. **126**(4): 1546–1552. doi:10.1016/j.foodchem.2010.11.154. PMID: 25213925.

White, G., Smith, L., Houdijk, J., Homer, D., Kyriazakis, I., and Wiseman, J. 2015. Replacement of soya bean meal with peas and faba beans in growing/finishing pig diets: effect on performance, carcass composition and nutrient excretion. Anim. Feed Sci. Technol. **209**: 202–210. doi:10.1016/j.anifeedsci.2015.08.005.

Wood, J.A., and Malcolmson, L.J. 2011. Pulse milling technologies. Pulse Foods, 193–221. doi:10.1016/B978-0-12-382018-1.00008-3.