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# The effects of grinding and pelleting on nutrient composition of Canadian pulses

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## Abstract

Understanding the effects of processing pulses is required for their effective incorporation into livestock feed. To determine the impact of processing, Canadian peas, lentils, chickpeas, and faba beans, plus soybean meal (SBM; as a comparison), were ground into fine and coarse products and pelleted at three different temperatures (60–65, 70–75, and 80–85 °C). Grinding increased crude protein content in all the pulses ( $P < 0.05$ ), but did not affect most amino acids (AA) ( $P > 0.05$ ). Pelleting increased crude protein content in Amarillo peas, Dun peas, and lentils ( $P < 0.05$ ), but decreased in SBM ( $P < 0.05$ ). Pelleting increased cysteine, lysine (Lys), and methionine, and decreased histidine and tyrosine (Tyr) in most pulses ( $P < 0.05$ ). Comparatively, pelleting significantly increased Lys and decreased Tyr content in SBM ( $P < 0.05$ ). These results suggest that processing can positively affect protein and AA content of pulses. However, specific effects on nutritional composition differed across ingredient type.

**Key words:** pulses, processing, nutrient composition

## Résumé

Comprendre les effets de la transformation des légumineuses à grain est nécessaire pour leur incorporation efficace dans les aliments du bétail. Afin de déterminer les impacts de la transformation, des pois, lentilles, pois chiches, et féveroles d'origine canadienne, ainsi que le tourteau de soja (comme comparaison), ont été broyés de façon fine et brute, puis soumis à la granulation à 3 températures différentes (60 à 65, 70 à 75, et 80 à 85 °C). Le broyage a augmenté la teneur en protéines brutes pour toutes les légumineuses à grain ( $P < 0,05$ ), mais n'a pas eu d'effet sur la plupart des acides aminés dans les légumineuses à grain et le tourteau de soja ( $P > 0,05$ ). La granulation a augmenté la teneur en protéines brutes dans les pois Amarillo, pois Dun, et lentilles ( $P < 0,05$ ), mais l'a diminuée dans le tourteau de soja ( $P < 0,05$ ). La granulation a augmenté la cystéine, la lysine, et la méthionine, et a diminué l'histidine et la tyrosine dans la plupart des légumineuses à grain ( $P < 0,05$ ). Comparativement, la granulation a augmenté la teneur en lysine et a diminué la teneur en tyrosine de façon significative ( $P < 0,05$ ) dans le tourteau de soja. Ces résultats suggèrent que la transformation peut avoir un effet positif sur la teneur en protéines et en acides aminés chez les légumineuses à grain. Par contre, les effets particuliers sur la composition nutritionnelle différaient selon le type d'ingrédient. [Traduit par la Rédaction]

**Mots-clés :** légumineuses à grain, transformation/traitement, composition des éléments nutritifs

## Introduction

Pulses are “crops harvested solely for dry seed, excluding crops harvested green for food, oil extraction, or crops grown and harvested exclusively for sowing purposes” (FAO (Food and Agriculture Organization of the United Nations) 1994). Given their nutrient density, with high levels of protein, fibre, and micronutrients, pulses provide an alluring value proposition in human diets and animal feeds. Also,

due to continuous global population growth and potential food production imbalances due to climate change, there is a risk for future food shortages and increased competition between human and animal nutrition sectors for quality protein ingredients. Consequently, the agri-food industry needs to investigate alternative ingredients, with a focus on alternative protein sources, including plant-based proteins (Aiking 2011). Information on the nutrient content and the impact of

common processing techniques will be critical to increase the use of pulses as a source of protein in animal feed (Sherasia et al. 2017).

It is primarily the contribution of energy and protein that make pulses an attractive ingredient in animal feeding (Sherasia et al. 2017). For example, when compared with cereal grains, pulses have nearly twice the amount of protein (Singh 2017). However, plant proteins, including pulses, tend to have lower levels of one or more indispensable amino acids (AA), including sulphur AA (SAA; methionine; Met, and cysteine; Cys) and tryptophan (Trp), but tend to be rich in lysine (Young and Pellett 1994; Singh 2017). While pulses are a nutrient-rich seed, their use in livestock animal feed is minimal compared with common feed ingredients such as soybean meal (SBM). Soybean meal is a protein-rich sub-product of soybean processing and primarily used in animal feeds (FAO 2004). A variety of processing methods are used to produce animal feeds that may alter nutrient content and bioavailability. Prior to their incorporation into a feed formulation, pulses are typically milled prior to processing. While whole pulses can be milled into a coarse or fine product, some pulses, such as peas, can be separated into various components. This involves the removal of the seed coat/hull known as dehulling/dehulling and splitting of the cotyledon (inner seed portion). Each component can be subsequently milled or ground into a flour, with varying nutritional and functional attributes (Wood and Malcolmson 2011). Impact mills, such as hammermills, are commonly used to produce pulse flours from whole and dehulled seeds (Wood and Malcolmson 2011). The fibre, protein, and lipid fractions of pulses as well as other factors, such as variety, size/shape, moisture content, and storage duration, can affect milling performance (Wood and Malcolmson 2011; Thakur et al. 2019). Pulse fibres are tough, and are well recognized as a primary milling obstacle (Ribéreau et al. 2018; Thakur et al. 2019). To obtain a uniform particle size, ground ingredients are passed through screens, with mill configuration and screen size dictating final particle size (Wood and Malcolmson 2011). Particle size is of interest in the animal agriculture industry as it can influence nutrient availability and gut health and ultimately animal performance. For example, diets with mean particle size of 485–600  $\mu\text{m}$  had positive effects on energy digestibility and growth in pigs consuming these diets (Wondra et al. 1995; Rojas and Stein 2015).

Soybean meal is a preprocessed ingredient, with processes including cracking, dehulling, flaking, extraction/desolventizing, and toasting for solvent-extracted SBM and heat treatment followed by extrusion, toasting, micronizing, or jet sploding to produce full-fat SBM (Willis 2003). Pelleting is a common method used to produce animal feeds. The process uses a combination of grinding, mixing, heat, and moisture. On its own, milling and grinding performance can be affected by the protein, fibre, and lipid composition of raw ingredients. Studies have also reported varying effects of milling on starch damage. In addition to grinding, dry ingredients used for pelleting are conditioned with steam then forced through holes in a die, causing friction (Svihus and Zimonja 2011). While the temperatures during pelleting are lower than that of other methods of

processing (e.g., boiling and extrusion), it can still cause alterations to various components including denaturation of proteins and formation of Maillard reaction and cross-linked AA products (loss of AA), gelatinization of starch, changes in insoluble and soluble dietary fibre, and destruction of some vitamins (Svihus and Zimonja 2011). Pelleting has also been reported to increase ileal digestibility of starch and AA in pigs, which could enhance the protein quality of the final product (Vande Ginste and de Schrijver 1998; Stein and Bohlke 2007; Lahaye et al. 2008).

As pulses are increasing as valued nutritious and sustainable feed ingredients, data regarding the effects of pelleting on nutrient composition are required for the effective integration into animal feed products. Thus, the purpose of this study was to systematically evaluate the effects of grinding and temperature on the nutrient composition of pelleted Canadian peas, chickpeas, faba beans, and lentils.

## Materials and methods

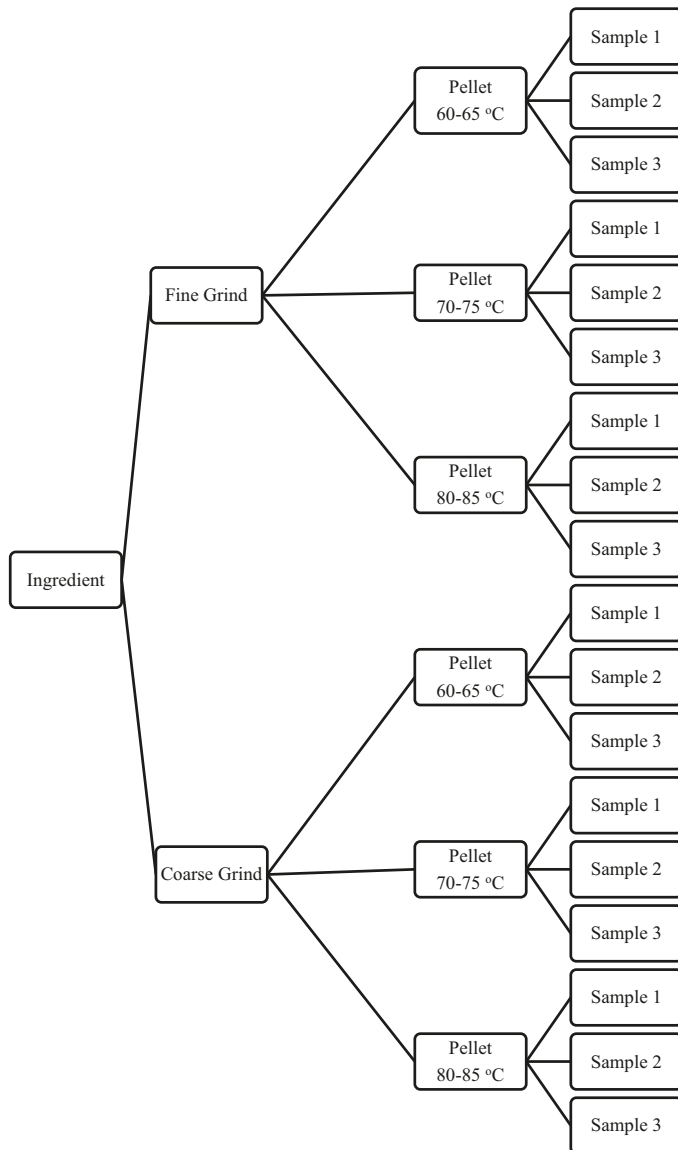
### Ingredients

Five Canada-grown pulses and SBM were selected as the ingredients of interest. Soybean meal was also included as its nutrient content and the effects of processing have been well-characterized, making it ideal for comparison. Selected pulses included Amarillo and Dun field pea varieties (IFN 5-08-481; CDC Amarillo Variety; Oren and Marlene Robinson, Landis, SK, Canada and CDC Dakota; Faba Canada, Tisdale SK, Canada), chickpeas (Kabuli variety; AGT Foods, Regina, SK, Canada), faba beans (IFN 5-09-262; Snowbird variety; Faba Canada, Tisdale SK, Canada), lentils (Laird variety; AGT Foods, Regina, SK, Canada), and SBM (IFN 5-04-604; Cargill Animal Nutrition; North Battleford, SK, Canada).

### Processing

Grinding and pelleting occurred at the Canadian Feed Research Centre (North Battleford, SK, Canada; Fig. 1), with processing replicating commercial processing as closely as possible. Ingredients were first sourced, then ground in 500 kg batches for both fine and coarse ground ingredients. Ingredients were then pelleted in smaller batches (~100 kg) at three distinct temperatures. Ingredients were ground 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. Average particle size for fine and coarse ground ingredients, respectively, were as follows: ground Amarillo peas (255 and 662  $\mu\text{m}$ ), ground chickpeas (216 and 556  $\mu\text{m}$ ), ground Dun peas (278 and 744  $\mu\text{m}$ ), ground faba beans (272 and 826  $\mu\text{m}$ ), ground lentils (296 and 654  $\mu\text{m}$ ), and SBM (370 and 854  $\mu\text{m}$ ). Coarse and fine ground ingredients were pelleted at low-, medium-, and high-temperature ranges of 60–65, 70–75, and 80–85 °C, respectively (average pelleting temperatures: 62, 72, 82 °C), using a pilot scale pellet mill (Colorado milling equipment ECO R30). Approximately 100 kg of ground pulse per grind size and processing temperature (Fig. 1) were pelleted. Sample collection began only after the ingredients had been pelleted at a steady temperature for 1 min (initial pellets discarded). Prior to processing, a test

**Fig. 1.** Overview of processing procedures for ingredients of interest.



run was conducted to determine the length of time it took to pellet ~100 kg of sample. Samples 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 samples were ground through a 0.5 mm screen (Ultra Centrifugal Mill Type ZM 200 Retsch Part No. 20.823.0003 Serial No. 1214030238P) and stored at  $-20^{\circ}\text{C}$  until analysis.

## Analytical procedures

### Proximate analysis

Samples were analyzed for moisture (930.15; [AOAC International 2012](#)), crude protein (990.03; [AOAC International 2012](#)), crude fat (AM 5-04; [American Oil Chemists' Society 1989](#)), ash (942.05; [AOAC International 2012](#)), and crude fi-

bre (Ba 6a-05; [American Oil Chemists' Society 1989](#)) at SGS Agri-Foods Laboratories (Guelph, ON, Canada).

### Amino acids analysis

Amino acid content was determined in ingredients via hydrolysis and ultraperformance liquid chromatography (UPLC; Waters Corporation, Milford, MA, United States) analysis. Amino acid content, except Cys, Met, and Trp, were determined using acid hydrolysis adapted from AOAC method 994.12 ([2012](#)). In brief, ~0.1 g of sample and 5 mL of 6 N hydrochloric acid (HCl)-phenol solution were added to glass digestion tubes. The tubes were flushed with nitrogen gas, sealed, and digested at  $110^{\circ}\text{C}$  for 24 h, after which samples were removed from the digestion block and cooled to room temperature. Samples were mixed with 1 mL of internal norvaline standard (5 mmol/L) after which 1 mL aliquots of each sample were transferred to microcentrifuge tubes and stored at  $-20^{\circ}\text{C}$  until analysis. Prior to UPLC analysis, samples were thawed and neutralized by mixing 120  $\mu\text{L}$  of sample with 100  $\mu\text{L}$  of NaOH (6 N) and 400  $\mu\text{L}$  of deionized water.

Sulphur AA (Cys and Met) and lysinoalanine (LAL) content of samples were determined using oxidative hydrolysis adapted from AOAC method 994.12 ([2012](#)). In brief ~0.1 g of sample and 2.5 mL of ice-cold oxidation solution (9:1 ratio of phenolic formic acid (88%) and 30% hydrogen peroxide, respectively) were added to glass digestion tubes, capped loosely, placed in an ice-cold water bath, and stored for 18–20 h in a fridge. Samples were removed from the fridge and 0.4 mg of sodium metabisulphite (Sigma, Oakville, ON, Canada) was added to each sample. Samples were rested for 2 h with occasional mixing to decompose excess performic acid. After 2 h, 2.5 mL of concentrated HCl (12 N) was added to each sample, tubes were flushed with  $\text{N}_2$  gas, sealed, and digested at  $110^{\circ}\text{C}$  for 24 h, after which samples were treated as previously stated. Prior to UPLC analysis, samples were thawed and neutralized by mixing 100  $\mu\text{L}$  of sample with 160  $\mu\text{L}$  of NaOH (6 N) and 400  $\mu\text{L}$  of deionized water.

Tryptophan content of samples was determined using alkaline hydrolysis adapted from AOAC method 988.15 ([2012](#)). In brief, ~0.1 g of sample and 2.5 mL of 6 N NaOH were added to glass digestion tubes. Tubes were flushed with  $\text{N}_2$  gas, sealed, and digested for 20 h at  $110^{\circ}\text{C}$ , after which samples were removed from digestion block and cooled to room temperature. In an ice-cold water bath 7.5 mL of 1% phenolic-HCl (2 N) and 1 mL of internal norvaline standard (5 mmol/L) were added to each sample and gently mixed. After mixing, 500  $\mu\text{L}$  of sample was mixed with 500  $\mu\text{L}$  of deionized water in a microcentrifuge tube and stored at  $-20^{\circ}\text{C}$  until further analysis.

Amino acid standards and samples were derivatized using an AccQ-Tag Ultra derivatization kit (Waters Corporation, Milford, MA, United States). Derivatized AA (1  $\mu\text{L}$  injection volume) was separated in a column (2.1  $\times$  200 mm, 1.7  $\mu\text{L}$ ) maintained at  $55^{\circ}\text{C}$  using UPLC with ultraviolet detection at a wavelength of 260 nm. Amino acid peak areas were analyzed using Waters Empower 2 Software (Waters Corporation, Milford, MA, United States).



## Statistical analysis

Data were analyzed using a fixed-model approach via PROC GLIMMIX in SAS (SAS v 9.4, SAS Institute Inc., Cary, NC, United States) where temperature within grind was treated as a fixed effect and a post hoc Tukey's HSD test was used for means comparisons between pelleted samples. 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. Differences were deemed significant when  $P \leq 0.05$ .

## Results

### Amarillo peas

#### Proximate analysis

Nutrient composition of whole, ground, and pelleted Amarillo peas are reported in [Table 1](#). There were no differences between whole and ground samples in dry matter (DM) content ( $P > 0.05$ ). Generally, pelleting decreased DM content compared with whole and ground pulses ( $P < 0.05$ ). Grinding and pelleting increased crude protein (CP) content compared with whole samples ( $P < 0.05$ ). Coarse ground (10/64) samples had higher CP content compared with fine ground samples (2/64) ( $P < 0.01$ ). There were no differences between whole and ground samples and whole and pelleted samples in crude fat and ash content ( $P > 0.05$ ). Crude fibre content decreased in all pelleted samples compared with whole and ground samples ( $P < 0.05$ ). Fine pelleted samples had higher crude fibre content compared with coarse pelleted ( $P < 0.05$ ).

#### Indispensable amino acids

With the exception of threonine (Thr), there were no differences between whole and ground samples for all indispensable AA ( $P > 0.05$ ; [Table 1](#)). There were no differences between fine ground and coarse ground samples for all indispensable AA ( $P > 0.05$ ). Pelleting decreased histidine (His) content compared with whole and ground samples ( $P < 0.01$ ). Pelleting increased content of isoleucine (Ile), Lys, Met, phenylalanine (Phe), and valine (Val) content compared with whole and ground samples ( $P < 0.05$ ). Grinding increased Thr content compared with whole samples ( $P < 0.05$ ), and decreased Thr content in fine-ground pelleted samples ( $P < 0.05$ ). Pelleting decreased His content compared with whole and ground samples ( $P < 0.01$ ). Fine pelleted samples had higher His and Phe content compared with coarse pelleted samples ( $P < 0.05$ ).

#### Dispensable amino acids

Dispensable AA content is reported in [Table S1](#). With the exception of Cys and serine (Ser), there were no differences between whole and ground samples for all dispensable AA ( $P > 0.05$ ). Cysteine content increased and Ser content decreased in ground samples compared with whole ( $P < 0.05$ ). There were no differences between fine and coarse ground samples for all dispensable AA ( $P > 0.05$ ). Pellet-

ing increased arginine (Arg) and Cys content compared with whole and ground samples ( $P < 0.05$ ). Pelleting did not increase Ser content of samples compared with whole samples ( $P > 0.05$ ), but increased Ser content of pelleted samples compared with ground samples ( $P < 0.05$ ). Pelleting decreased tyrosine (Tyr) content compared with whole and ground samples ( $P < 0.05$ ). There were no differences between fine and coarse pelleted samples for all indispensable AA ( $P > 0.05$ ).

#### Lysinoalanine

There were no differences between whole and ground samples, and whole and pelleted samples in LAL content ( $P > 0.05$ ). There were no differences between fine and coarse ground samples and fine and coarse pelleted samples ( $P > 0.05$ ).

### Chickpeas

#### Proximate analysis

Nutrient composition of whole, ground, and pelleted chickpeas and are reported in [Table 2](#). There were no differences between whole and ground samples in DM content ( $P > 0.05$ ). Pelleting decreased DM content compared with whole and ground pulses ( $P < 0.05$ ). Grinding increased crude protein content compared with whole and pelleted samples ( $P < 0.05$ ), however, there were no differences between whole and pelleted samples ( $P > 0.05$ ). There were no differences in CP content between fine and coarse ground samples, and fine and coarse pelleted samples ( $P > 0.05$ ). There were no differences between whole and ground samples, and fine and coarse ground samples in crude fat and ash content ( $P > 0.05$ ). There were no differences between whole and ground samples compared with pelleted samples in crude fat content, but coarse pelleted samples had higher crude fat content compared with fine pelleted ( $P < 0.01$ ). Fine ground samples had higher crude fibre content compared with coarse ground samples ( $P < 0.05$ ). Pelleting decreased ash and crude fibre content compared with whole samples ( $P < 0.05$ ).

#### Indispensable amino acids

With the exception of Ile, there were no differences between whole and ground samples for all indispensable AA ( $P > 0.05$ ; [Table 2](#)). Isoleucine content increased in ground samples compared with whole ( $P < 0.05$ ). There were no differences in indispensable AA content of fine ground samples compared with coarse ground ( $P > 0.05$ ). Pelleting decreased His content compared with whole and ground samples ( $P < 0.01$ ). Pelleting increased Lys and Met content compared with whole and ground samples ( $P < 0.05$ ). Pelleting increased leucine (Leu) content only when compared with fine ground samples ( $P < 0.05$ ), but was not different from whole samples or coarse ground ( $P < 0.05$ ). Pelleting increased Val content compared with whole and coarse ground samples ( $P < 0.05$ ). There were no differences between fine and coarse pelleted samples ( $P > 0.5$ ), with the exception of His where

**Table 1.** Analyzed nutrient composition (dry matter basis) of whole, ground, and pelleted Amarillo peas.

										SEM	P value	Contrasts				
	Grind size			Pelleted fine			Pelleted coarse					Whole vs. ground	Whole vs. pellet	Ground vs. pellet	Fine vs. coarse grind	Fine vs. coarse pellet
	Whole	Fine	Coarse	60 °C	70 °C	80 °C	60 °C	70 °C	80 °C							
Dry matter	86.83	86.56	86.56	85.05 <sup>c</sup>	85.16 <sup>c</sup>	86.08 <sup>b</sup>	86.74 <sup>ab</sup>	86.97 <sup>a</sup>	86.95 <sup>a</sup>	0.19	<0.01	0.29	<0.01	0.02	1.00	<0.001
<b>Proximate analysis, %</b>																
Crude protein	21.27	21.66	22.31	22.54	22.57	22.49	22.72	22.62	22.74	0.15	<0.01	<0.01	<0.01	<0.01	<0.01	0.13
Crude fat	1.62	1.86	1.74	1.49	1.40	1.33	1.44	1.58	1.45	0.13	0.12	0.28	0.25	<0.01	0.55	0.37
Ash	2.53	2.67	2.40	2.68	2.59	2.52	2.65	2.79	2.53	0.12	0.44	0.97	0.48	0.38	0.15	0.49
Crude fibre	6.14	6.68	6.64	5.47	5.14	5.31	4.86	4.99	5.04	0.25	<0.01	0.06	<0.01	<0.01	0.91	0.01
<b>Indispensable AA, %</b>																
Histidine	0.47	0.49	0.47	0.29 <sup>b</sup>	0.43 <sup>a</sup>	0.30 <sup>b</sup>	0.31 <sup>b</sup>	0.31 <sup>b</sup>	0.28 <sup>b</sup>	0.01	<0.01	0.53	<0.01	<0.01	0.49	<0.01
Isoleucine	0.67	0.69	0.66	0.86	0.82	0.91	0.90	0.84	0.80	0.05	<0.01	0.98	<0.01	<0.01	0.73	0.60
Leucine	1.39	1.41	1.45	1.53 <sup>ab</sup>	1.45 <sup>b</sup>	1.60 <sup>a</sup>	1.60 <sup>a</sup>	1.54 <sup>ab</sup>	1.49 <sup>ab</sup>	0.04	<0.01	0.35	<0.01	<0.01	0.40	0.45
Lysine	1.25	1.31	1.26	1.75	1.72	1.74	1.85	1.77	1.71	0.08	<0.01	0.71	<0.01	<0.01	0.66	0.48
Methionine	0.20	0.20	0.18	0.23 <sup>ab</sup>	0.24 <sup>a</sup>	0.23 <sup>ab</sup>	0.23 <sup>ab</sup>	0.23 <sup>ab</sup>	0.21 <sup>b</sup>	0.006	<0.01	0.69	<0.01	<0.01	0.05	0.08
Phenylalanine	0.97	0.98	0.95	1.07	1.13	1.12	1.10	1.05	1.01	0.03	<0.01	0.73	<0.01	<0.01	0.52	0.02
Threonine	0.74	0.78	0.76	0.75 <sup>abc</sup>	0.74 <sup>cd</sup>	0.77 <sup>abc</sup>	0.78 <sup>ab</sup>	0.79 <sup>a</sup>	0.72 <sup>d</sup>	0.009	<0.01	0.02	0.16	0.06	0.20	0.14
Tryptophan	0.14	0.16	0.13	0.16	0.17	0.18	0.20	0.17	0.14	0.02	0.32	0.79	0.18	0.16	0.27	0.85
Valine	0.78	0.79	0.76	0.95	0.89	1.00	0.97	0.92	0.89	0.04	<0.01	0.97	<0.01	<0.01	0.60	0.38
<b>Cross-linked AA, %</b>																
Lysinoalanine	0.02	0.01	0.02	0.02	0.02	0.02	0.01	0.02	0.02	0.004	0.28	0.44	0.81	0.13	0.29	0.09

<sup>a-d</sup>Means comparison of pelleted samples. Means within the same row with differing superscripts are different from one another ( $P < 0.05$ ).

**Table 2.** Analyzed nutrient composition (dry matter basis) of whole, ground, and pelleted chickpeas.

										SEM	P value	Contrasts				
	Grind size			Pelleted fine			Pelleted coarse					Whole vs. ground	Whole vs. pellet	Ground vs. pellet	Fine vs. coarse grind	Fine vs. coarse pellet
	Whole	Fine	Coarse	60 °C	70 °C	80 °C	60 °C	70 °C	80 °C							
Dry matter	88.52	87.98	88.17	85.83 <sup>c</sup>	88.82 <sup>a</sup>	86.92 <sup>c</sup>	87.13 <sup>bc</sup>	87.17 <sup>bc</sup>	87.24 <sup>bc</sup>	0.35	<0.01	0.33	<0.01	<0.01	0.96	0.06
<b>Proximate analysis, %</b>																
Crude protein	22.85	23.18	23.34	22.92 <sup>a</sup>	22.73 <sup>ab</sup>	22.64 <sup>ab</sup>	22.73 <sup>ab</sup>	22.74 <sup>ab</sup>	22.49 <sup>b</sup>	0.07	<0.01	<0.01	0.22	<0.01	0.14	0.05
Crude fat	6.04	6.16	6.39	5.62 <sup>c</sup>	6.18 <sup>abc</sup>	5.98 <sup>bc</sup>	6.57 <sup>a</sup>	6.46 <sup>ab</sup>	6.23 <sup>ab</sup>	0.12	<0.01	0.15	0.33	0.33	0.21	<0.01
Ash	2.69	2.48	2.59	2.28	2.34	2.17	2.23	2.25	2.51	0.12	0.06	0.32	<0.01	0.02	0.55	0.44
Crude fibre	3.22	3.51	2.97	2.57	2.72	2.85	2.91	2.57	2.64	0.18	<0.01	0.89	<0.01	<0.01	0.03	0.93
<b>Indispensable AA, %</b>																
Histidine	0.52	0.49	0.53	0.45 <sup>a</sup>	0.30 <sup>b</sup>	0.29 <sup>b</sup>	0.29 <sup>b</sup>	0.30 <sup>b</sup>	0.32 <sup>b</sup>	0.01	<0.01	0.45	<0.01	<0.01	0.26	<0.01
Isoleucine	0.72	0.79	0.86	0.76 <sup>b</sup>	0.87 <sup>a</sup>	0.83 <sup>ab</sup>	0.79 <sup>ab</sup>	0.85 <sup>ab</sup>	0.87 <sup>a</sup>	0.03	<0.01	<0.01	<0.01	0.92	0.19	0.32
Leucine	1.49	1.46	1.52	1.49	1.62	1.57	1.50	1.60	1.58	0.03	0.02	0.95	0.10	0.02	0.22	0.94
Lysine	1.10	1.21	1.26	1.56	1.67	1.64	1.54	1.62	1.63	0.06	<0.01	0.13	<0.01	<0.01	0.60	0.56
Methionine	0.25	0.25	0.26	0.32	0.38	0.31	0.35	0.33	0.33	0.01	<0.01	0.61	<0.01	<0.01	0.73	0.95
Phenylalanine	1.23	1.14	1.21	1.18	1.25	1.24	1.21	1.31	1.27	0.04	0.13	0.28	0.80	0.06	0.20	0.20
Threonine	0.71	0.70	0.73	0.70	0.72	0.72	0.68	0.71	0.71	0.01	0.05	0.50	0.82	0.19	0.06	0.08
Tryptophan	0.17	0.15	0.14	0.17	0.17	0.17	0.21	0.18	0.17	0.03	0.80	0.52	0.75	0.16	0.83	0.33
Valine	0.75	0.82	0.79	0.78	0.88	0.86	0.81	0.88	0.89	0.03	0.01	0.18	<0.01	0.11	0.51	0.39
<b>Cross-linked AA, %</b>																
Lysinoalanine	0.02	0.01	0.01	0.02	0.01	0.02	0.03	0.02	0.02	0.01	0.40	0.35	0.81	0.23	0.86	0.12

<sup>a-c</sup>Means comparison of pelleted samples. Means within the same row with differing superscripts are different from one another ( $P < 0.05$ )

fine pelleted samples (average) had higher His content compared with coarse pelleted ( $P < 0.01$ ).

### Dispensable amino acids

Dispensable AA content is reported in Table S2. With the exception of glycine (Gly) and Ser, there were no differences between whole and ground samples for all dispensable AA ( $P > 0.05$ ). Glycine content decreased and Ser content increased in ground samples compared with whole ( $P < 0.05$ ). With the exception of Arg and Cys, there were no differences in dispensable AA content between fine and coarse ground samples ( $P > 0.05$ ). Arginine and Cys content were higher in coarse ground samples compared with fine ground ( $P < 0.05$ ). Pelleting increased Cys content compared with whole and ground samples ( $P < 0.01$ ). Pelleting decreased alanine (Ala), Gly, and Tyr content compared with whole and ground samples ( $P < 0.05$ ). There was no difference in Ser content between pelleted and whole samples, but pelleting decreased Ser content of coarse ground samples ( $P < 0.05$ ). There were no differences in dispensable AA content between fine and coarse pelleted samples ( $P > 0.05$ ).

### Lysinoalanine

There were no differences among whole, ground, and pelleted samples in LAL content ( $P > 0.05$ ).

### Dun peas

#### Proximate analysis

Nutrient composition of whole, ground, and pelleted Dun peas are reported in Table 3. There were no differences between whole and ground samples in DM content ( $P > 0.05$ ). Generally, pelleting decreased DM content compared with whole and ground pulses ( $P < 0.05$ ). Grinding and pelleting increased CP content compared with whole samples ( $P < 0.05$ ). There were no differences between CP content of fine and coarse ground samples ( $P > 0.05$ ). There were no differences between whole and ground samples and between fine and coarse ground samples in crude fat and ash content ( $P > 0.05$ ). Grinding decreased crude fibre content compared with whole samples ( $P < 0.05$ ), but there were no differences in crude fibre content between fine and coarse ground samples ( $P > 0.05$ ). Pelleting decreased crude fibre content compared with whole and ground samples ( $P < 0.05$ ). There were no differences in crude fibre content between fine and coarse pelleted samples ( $P > 0.05$ ).

### Indispensable amino acids

There were no differences between whole and ground samples for all indispensable AA ( $P > 0.05$ ; Table 3). With the exception of Trp, there were no differences in indispensable AA content between fine and coarse ground samples ( $P > 0.05$ ). Pelleting decreased His content compared with whole and ground samples ( $P < 0.05$ ). Pelleting increased Leu, Lys, Phe, and Trp content compared with whole and ground pulses.

Pelleting increased Met content compared with whole samples ( $P < 0.05$ ). With the exception of Ile and Val, there were no differences in indispensable AA content between fine and coarse pelleted samples ( $P > 0.05$ ). Isoleucine and Val content were higher in fine pelleted samples compared with coarse pelleted ( $P < 0.05$ ).

### Dispensable amino acids

Dispensable AA content is reported in Table 3. With the exception of Gly and Ser, there were no differences between whole and ground samples for all dispensable AA ( $P > 0.05$ ). Glycine and Ser content decreased in ground samples compared with whole ( $P < 0.05$ ). With the exception of Cys, there were no differences between fine and coarse ground samples ( $P > 0.05$ ). Cysteine content was higher in coarse ground samples compared with fine ground ( $P < 0.01$ ). Pelleting increased Cys content compared with whole and ground samples ( $P < 0.05$ ). Pelleting decreased Gly and Tyr compared with whole and ground pulses. Pelleting decreased Ser content compared with whole pulses ( $P < 0.05$ ) but not ground ( $P > 0.05$ ). With the exception of Arg, there were no differences between fine and coarse pelleted samples ( $P > 0.05$ ). Arginine content was higher in fine pelleted samples compared with coarse ( $P < 0.01$ ).

### Lysinoalanine

There were no differences among whole, ground, and pelleted samples in LAL content ( $P > 0.05$ ).

### Faba beans

#### Proximate analysis

Nutrient composition of whole, ground, and pelleted faba beans are reported in Table 4. There were no differences between whole and ground samples in DM content ( $P > 0.05$ ). Generally, pelleting decreased DM content compared with whole and ground pulses ( $P < 0.05$ ). Grinding increased CP content compared with whole samples ( $P < 0.05$ ). Pelleting decreased crude protein content of coarse pelleted samples compared with coarse ground samples ( $P < 0.05$ ), but there were no differences between CP content of pelleted and whole samples ( $P < 0.05$ ). Crude protein content was higher in coarse ground samples compared with fine ground ( $P < 0.05$ ). There were no differences between whole and ground and between fine and coarse ground samples in crude fat and ash content ( $P > 0.05$ ). There were no differences in crude fat and ash content of pelleted samples compared whole and ground samples ( $P > 0.05$ ). Ash content of coarse pelleted samples was higher compared with fine pelleted ( $P < 0.05$ ). Pelleting increased crude fibre content compared with whole and coarse ground samples ( $P < 0.05$ ).

### Indispensable amino acids

There were no differences between whole and ground samples for all indispensable AA ( $P > 0.05$ ). There were no



**Table 3.** Analyzed nutrient composition (dry matter basis) of whole, ground, and pelleted Dun peas.

										SEM	P value	Contrasts				
	Grind size			Pelleted fine			Pelleted coarse					Whole vs. ground	Whole vs. pellet	Ground vs. pellet	Fine vs. coarse grind	Fine vs. coarse pellet
	Whole	Fine	Coarse	60 °C	70 °C	80 °C	60 °C	70 °C	80 °C							
Dry matter	87.44	86.83	86.75	85.32 <sup>bc</sup>	85.05 <sup>c</sup>	87.65 <sup>a</sup>	85.89 <sup>bc</sup>	87.36 <sup>a</sup>	87.52 <sup>a</sup>	0.28	<0.01	0.08	<0.01	0.19	0.84	<0.01
<b>Proximate analysis, %</b>																
Crude protein	22.82	24.29	24.64	24.07	23.59	23.89	24.12	23.92	23.96	0.24	0.01	<0.01	<0.01	0.01	0.33	0.42
Crude fat	1.39	1.35	1.36	0.90	0.89	1.22	1.05	1.18	1.27	0.13	0.14	0.84	0.06	0.03	0.97	0.13
Ash	2.50	2.63	2.40	2.62	2.25	2.46	2.27	2.53	2.46	0.1	0.31	0.96	0.54	0.46	0.25	0.77
Crude fibre	6.18	5.58	5.68	5.27	5.36	5.23	5.00	4.99	5.06	0.19	<0.01	0.01	<0.01	<0.01	0.68	0.02
<b>Indispensable AA, %</b>																
Histidine	0.52	0.54	0.52	0.32	0.33	0.46	0.39	0.30	0.33	0.04	<0.01	0.83	<0.01	<0.01	0.82	0.37
Isoleucine	0.85	0.84	0.84	0.87 <sup>ab</sup>	0.89 <sup>ab</sup>	0.92 <sup>a</sup>	0.80 <sup>b</sup>	0.68 <sup>c</sup>	0.82 <sup>b</sup>	0.03	<0.01	0.95	0.66	0.61	0.96	<0.01
Leucine	1.51	1.51	1.50	1.60	1.63	1.62	1.61	1.48	1.62	0.03	0.05	0.99	0.06	0.02	0.87	0.14
Lysine	1.43	1.47	1.43	1.90	1.90	1.96	1.86	1.71	1.91	0.09	<0.01	0.84	<0.01	<0.01	0.75	0.21
Methionine	0.22	0.23	0.24	0.23	0.24	0.23	0.23	0.27	0.24	0.008	0.04	0.35	0.07	0.29	0.66	0.06
Phenylalanine	1.02	1.03	1.03	1.12	1.16	1.13	1.11	1.03	1.17	0.04	0.06	0.84	0.04	0.01	0.97	0.32
Threonine	0.80	0.81	0.80	0.80	0.81	0.83	0.82	0.74	0.82	0.02	0.25	0.74	0.73	0.96	0.63	0.36
Tryptophan	0.15	0.13	0.19	0.24	0.21	0.21	0.19	0.22	0.20	0.01	<0.01	0.55	<0.01	<0.01	<0.01	0.17
Valine	0.87	0.86	0.85	0.97 <sup>ab</sup>	1.00 <sup>a</sup>	1.00 <sup>a</sup>	0.91 <sup>ab</sup>	0.78 <sup>b</sup>	0.97 <sup>ab</sup>	0.04	<0.01	0.81	0.13	0.02	0.87	<0.01
<b>Cross-linked AA, %</b>																
Lysinoalanine	0.03	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.07	0.70	0.59	0.20	0.36	0.18	0.99

<sup>a-c</sup>Means comparison of pelleted samples. Means within the same row with differing superscripts are different from one another ( $P < 0.05$ ).

**Table 4.** Analyzed nutrient composition (dry matter basis) of whole, ground, and pelleted faba beans.

	Grind size									SEM	P value	Contrasts				
	Grind size			Pelleted fine			Pelleted coarse					Whole vs. ground	Whole vs. pellet	Ground vs. pellet	Fine vs. coarse grind	Fine vs. coarse pellet
	Whole	Fine	Coarse	60 °C	70 °C	80 °C	60 °C	70 °C	80 °C							
Dry matter	87.96	87.19	87.24	85.35 <sup>c</sup>	86.46 <sup>abc</sup>	87.71 <sup>ab</sup>	85.87 <sup>c</sup>	85.60 <sup>c</sup>	86.12 <sup>bc</sup>	0.39	<0.01	0.14	<0.01	<0.01	0.92	0.03
<b>Proximate analysis, %</b>																
Crude protein	27.31	27.76	29.35	27.39 <sup>b</sup>	27.34 <sup>b</sup>	27.31 <sup>b</sup>	28.42 <sup>a</sup>	28.45 <sup>a</sup>	28.08 <sup>a</sup>	0.17	<0.01	<0.01	0.06	<0.01	<0.01	<0.01
Crude fat	1.53	1.41	1.50	1.52	1.83	1.70	1.98	1.69	1.55	0.15	0.18	0.70	0.29	0.06	0.70	0.63
Ash	3.31	3.19	3.43	3.20	3.23	3.20	3.62	3.49	3.50	0.16	0.43	0.98	0.72	0.67	0.33	0.02
Crude fibre	6.21	8.92	5.13	9.80 <sup>a</sup>	9.31 <sup>a</sup>	9.23 <sup>a</sup>	6.93 <sup>bc</sup>	6.59 <sup>c</sup>	8.02 <sup>ab</sup>	0.49	<0.01	0.19	<0.01	<0.01	<0.01	<0.01
<b>Indispensable AA, %</b>																
Histidine	0.61	0.57	0.64	0.48	0.36	0.35	0.46	0.33	0.40	0.05	<0.01	0.42	<0.01	<0.01	0.56	0.95
Isoleucine	0.85	0.83	0.86	0.92	0.86	0.88	0.87	1.00	1.07	0.05	0.07	0.95	0.19	0.07	0.77	0.04
Leucine	1.81	1.69	1.79	1.81	1.81	1.77	1.86	1.90	1.92	0.04	0.10	0.27	0.58	0.03	0.18	0.03
Lysine	1.47	1.37	1.43	1.87	1.89	1.77	1.91	1.94	1.93	0.07	<0.01	0.48	<0.01	<0.01	0.56	0.16
Methionine	0.19	0.16	0.17	0.21 <sup>b</sup>	0.21 <sup>b</sup>	0.21 <sup>b</sup>	0.29 <sup>a</sup>	0.24 <sup>ab</sup>	0.21 <sup>b</sup>	0.01	<0.01	0.21	0.08	<0.01	0.44	<0.01
Phenylalanine	1.10	1.01	1.08	1.40	1.05	1.09	1.15	0.95	1.18	0.13	0.48	0.74	0.82	0.41	0.74	0.37
Threonine	0.92	0.81	0.88	0.85	0.85	0.83	0.91	0.89	0.88	0.03	0.23	0.07	0.13	0.43	0.14	0.06
Tryptophan	0.18	0.21	0.20	0.14	0.20	0.18	0.18	0.19	0.20	0.03	0.96	0.64	0.95	0.43	0.95	0.50
Valine	0.95	0.92	0.96	0.90 <sup>b</sup>	0.95 <sup>b</sup>	0.96 <sup>b</sup>	0.97 <sup>ab</sup>	1.07 <sup>ab</sup>	1.14 <sup>a</sup>	0.03	<0.01	0.84	0.23	0.07	0.47	<0.01
<b>Cross-linked AA, %</b>																
Lysinoalanine	0.04	0.02	0.02	0.01	0.02	0.02	0.01	0.02	0.02	0.005	0.03	0.01	<0.01	0.26	0.87	0.50

<sup>a-c</sup>Means comparison of pelleted samples. Means within the same row with differing superscripts are different from one another ( $P < 0.05$ ).

differences between fine and coarse ground samples for all indispensable AA ( $P > 0.05$ ). Pelleting decreased His content compared with whole and ground samples ( $P < 0.05$ ). Pelleting increased Leu content compared with ground samples ( $P < 0.05$ ) but not whole samples ( $P > 0.05$ ). Pelleting increased Lys content compared with whole and ground samples ( $P < 0.05$ ). Pelleting increased Met content compared with ground samples ( $P < 0.05$ ) but not whole samples ( $P > 0.05$ ). There were no differences between fine and coarse pelleted samples for most indispensable AA ( $P < 0.05$ ). Isoleucine, Leu, Met, and Val content were higher in coarse pelleted samples compared with fine pelleted ( $P < 0.05$ ).

### Dispensable amino acids

Dispensable AA content is reported in Table S4. There were no differences between whole and ground samples for all dispensable AA ( $P > 0.05$ ). There were no differences between fine and coarse ground samples for all dispensable AA ( $P > 0.05$ ). Pelleting increased Cys content compared with whole and ground samples ( $P < 0.05$ ). Pelleting decreased Tyr content compared with whole and ground samples ( $P < 0.05$ ). There were no differences in fine pelleted and coarse pelleted samples for all dispensable AA ( $P > 0.05$ ).

### Lysinoalanine

Whole samples had higher LAL content when compared with ground and pelleted samples ( $P < 0.05$ ). There was no difference in LAL content between fine and coarse ground samples and fine and coarse pelleted samples ( $P > 0.05$ ).

### Lentils

#### Proximate analysis

Nutrient composition of whole, ground, and pelleted lentils are reported in Table 5. There were no differences between whole and ground samples in DM content ( $P > 0.05$ ). Generally, pelleting decreased DM content compared with whole and ground pulses ( $P < 0.05$ ). Grinding increased CP content compared with whole samples ( $P < 0.05$ ). There were no differences in CP content between fine and coarse ground samples ( $P > 0.05$ ). Pelleting increased CP content compared with whole samples and ground samples ( $P < 0.05$ ), but there were no differences between fine and coarse ground samples ( $P > 0.05$ ). There were no differences in crude fat and ash content between whole and ground samples and between fine and coarse ground samples ( $P > 0.05$ ). Pelleting increased crude fat and ash content compared with whole and ground samples ( $P < 0.05$ ), but there were no differences between fine and coarse pelleted samples ( $P > 0.05$ ). Grinding and pelleting decreased crude fibre content compared with whole samples ( $P < 0.05$ ). Coarse ground samples had higher crude fibre content compared with fine ground ( $P < 0.05$ ). There were no differences in crude fibre content between fine and coarse pelleted samples ( $P > 0.05$ ).

### Indispensable amino acids

With the exception of Leu, there were no differences between whole and ground samples for all indispensable AA ( $P > 0.05$ ; Table 5). Leucine content increased in ground samples compared with whole ( $P < 0.05$ ). There were no differences between fine and coarse ground samples for all indispensable AA ( $P > 0.05$ ). Pelleting increased Ile, Leu, Lys, and Met content compared with whole and ground samples ( $P < 0.05$ ). Pelleting increased Val content compared with whole and coarse ground samples ( $P < 0.05$ ). With the exception of Leu, there were no differences between fine and coarse pelleted samples for all indispensable AA ( $P > 0.05$ ). Leucine content of coarse pelleted samples was higher compared with fine pelleted ( $P < 0.01$ ).

### Dispensable amino acids

Dispensable AA content is reported in Table S5. With the exception of Gly and Tyr, there were no differences between whole and ground samples for all dispensable AA ( $P > 0.05$ ). Glycine decreased and Tyr increased in ground samples compared with whole ( $P < 0.05$ ). There were no differences between fine and coarse ground samples for all dispensable AA ( $P > 0.05$ ). Pelleting increased Cys content compared with whole and ground samples ( $P < 0.05$ ). Pelleting decreased Gly and Tyr content compared with whole and ground samples ( $P < 0.05$ ). There were no differences between fine and coarse pelleted samples for all indispensable AA ( $P > 0.05$ ).

### Lysinoalanine

There were no differences among whole, ground, and pelleted samples in LAL content ( $P < 0.05$ ).

### Soybean meal

#### Proximate analysis

Nutrient composition of whole, ground, and pelleted SBM are reported in Table 6. Due to the fact that SBM was processed prior to this study there are no whole samples to compare to but rather only changes from ground samples. There were no differences in DM content between ground and pelleted samples and between fine and coarse ground samples ( $P > 0.05$ ). Coarse pelleted samples had higher DM content compared with fine pelleted ( $P < 0.05$ ). There were no differences in CP content of fine and coarse ground samples ( $P > 0.05$ ). Pelleting decreased CP compared with ground samples ( $P < 0.01$ ). Coarse pelleted samples had higher CP content compared with fine pelleted samples ( $P < 0.01$ ). There were no differences between ground and pelleted samples and between fine and coarse ground samples in crude fat and crude fibre content ( $P > 0.05$ ). Coarse pelleted samples had higher crude fat content compared with fine pelleted ( $P < 0.05$ ). Coarse ground samples had higher ash content compared with fine ground ( $P < 0.01$ ). Pelleting decreased ash content compared with ground samples ( $P < 0.05$ ). Coarse

**Table 5.** Analyzed nutrient composition (dry matter basis) of whole, ground, and pelleted lentils.

	Grind size									SEM	P value	Contrasts				
	Grind size			Pelleted fine			Pelleted coarse					Whole vs. ground	Whole vs. pellet	Ground vs. pellet	Fine vs. coarse grind	Fine vs. coarse pellet
	Whole	Fine	Coarse	60 °C	70 °C	80 °C	60 °C	70 °C	80 °C							
Dry matter	90.46	88.38	89.42	85.39 <sup>a</sup>	87.31 <sup>a</sup>	87.82 <sup>a</sup>	87.59 <sup>a</sup>	85.46 <sup>a</sup>	85.83 <sup>a</sup>	0.74	<0.01	0.1	<0.01	<0.01	0.33	0.31
<b>Proximate analysis, %</b>																
Crude protein	23.72	26.63	26.91	27.87	27.29	26.95	27.35	27.86	27.61	0.42	<0.01	<0.01	<0.01	0.04	0.64	0.43
Crude fat	0.99	1.00	0.88	2.58	2.57	2.90	2.73	2.69	2.99	0.18	<0.01	0.82	<0.01	<0.01	0.65	0.37
Ash	2.49	2.60	2.47	3.79 <sup>a</sup>	3.75 <sup>ab</sup>	3.70 <sup>ab</sup>	3.24 <sup>b</sup>	3.78 <sup>a</sup>	3.86 <sup>a</sup>	0.11	<0.01	0.75	<0.01	<0.01	0.44	0.16
Crude fibre	5.22	3.29	3.71	0.97 <sup>c</sup>	0.75 <sup>c</sup>	2.31 <sup>a</sup>	1.76 <sup>b</sup>	1.21 <sup>c</sup>	1.19 <sup>c</sup>	0.08	<0.01	<0.01	<0.01	<0.01	0.02	0.51
<b>Indispensable AA, %</b>																
Histidine	0.58	0.57	0.53	0.34	0.32	0.40	0.44	0.41	0.45	0.06	0.04	0.52	0.05	<0.01	0.97	0.07
Isoleucine	0.67	0.80	0.75	0.81	0.86	0.87	0.94	0.84	0.88	0.05	0.03	0.11	<0.01	0.02	0.52	0.24
Leucine	1.49	1.68	1.63	1.66 <sup>b</sup>	1.67 <sup>ab</sup>	1.74 <sup>ab</sup>	1.80 <sup>a</sup>	1.76 <sup>ab</sup>	1.73 <sup>ab</sup>	0.03	<0.01	<0.01	<0.01	0.01	0.31	<0.01
Lysine	1.20	1.37	1.36	1.70	1.68	1.82	1.94	1.79	1.74	0.11	<0.01	0.26	<0.01	<0.01	0.94	0.29
Methionine	0.16	0.15	0.15	0.24	0.24	0.23	0.24	0.24	0.28	0.01	<0.01	0.50	<0.01	<0.01	0.97	0.18
Phenylalanine	1.03	1.14	1.19	1.14	1.18	1.23	1.22	1.19	1.19	0.03	0.03	<0.01	<0.01	0.35	0.35	0.52
Threonine	0.76	0.84	0.82	0.80	0.80	0.85	0.88	0.79	0.85	0.03	0.1	0.09	0.05	0.95	0.70	0.27
Tryptophan	0.14	0.19	0.17	0.15	0.12	0.17	0.12	0.15	0.21	0.05	0.85	0.53	0.77	0.55	0.73	0.69
Valine	0.80	0.92	0.86	0.92	0.97	0.97	1.06	0.92	0.99	0.04	0.03	0.12	<0.01	0.05	0.38	0.31
<b>Cross-linked AA, %</b>																
Lysinoalanine	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.02	0.01 <sup>a</sup>	0.006	0.57	0.67	0.91	0.59	0.81	0.17

<sup>a-c</sup>Means comparison of pelleted samples. Means within the same row with differing superscripts are different from one another ( $P < 0.05$ ).

**Table 6.** Analyzed nutrient composition (dry matter basis) of ground and pelleted soybean meal.

	Grind size		Pelleted fine			Pelleted coarse			SEM	P value	Contrasts		
	Fine	Coarse	60 °C	70 °C	80 °C	60 °C	70 °C	80 °C			Ground vs. pellet	Fine vs. coarse grind	Fine vs. coarse pellet
Dry matter	87.56	87.71	86.28	87.64 <sup>ab</sup>	83.14 <sup>c</sup>	87.08 <sup>ab</sup>	88.43 <sup>ab</sup>	89.60 <sup>c</sup>	0.58	<0.01	0.21	0.86	<0.01
<b>Proximate analysis, %</b>													
Crude protein	51.66	51.96	48.36 <sup>b</sup>	48.42 <sup>b</sup>	51.25 <sup>a</sup>	51.29 <sup>a</sup>	51.11 <sup>a</sup>	48.97 <sup>b</sup>	0.29	<0.01	<0.01	0.56	<0.01
Crude fat	1.20	1.11	0.91	1.21	0.82	1.00	1.55	1.65	0.21	0.08	0.84	0.77	0.02
Ash	6.24	6.69	5.66 <sup>b</sup>	5.87 <sup>ab</sup>	6.18 <sup>a</sup>	6.29 <sup>a</sup>	6.26 <sup>a</sup>	6.00 <sup>ab</sup>	0.10	<0.01	<0.01	<0.01	<0.01
Crude fibre	3.59	3.49	3.81	3.60	4.16	4.00	3.67	3.84	0.28	0.60	0.20	0.81	0.92
<b>Indispensable AA, %</b>													
Histidine	1.02	1.21	1.05 <sup>ab</sup>	1.07 <sup>ab</sup>	1.13 <sup>ab</sup>	1.08 <sup>ab</sup>	1.21 <sup>a</sup>	1.04 <sup>b</sup>	0.03	<0.01	0.53	<0.01	0.26
Isoleucine	1.70	1.75	1.98	2.08	2.13	2.19	2.18	2.06	0.05	<0.01	<0.01	0.59	0.07
Leucine	3.39	3.56	3.51	3.61	3.78	3.79	3.77	3.58	0.07	0.01	<0.01	0.14	0.19
Lysine	2.61	2.80	3.19 <sup>ab</sup>	3.30 <sup>a</sup>	2.99 <sup>b</sup>	3.43 <sup>a</sup>	3.33 <sup>a</sup>	3.43 <sup>a</sup>	0.06	<0.01	<0.01	0.07	<0.01
Methionine	0.65	0.66	0.62	0.84	0.81	0.84	0.71	0.72	0.05	0.07	0.06	0.92	0.92
Phenylalanine	2.30	2.38	2.38	2.46	2.56	2.63	2.67	2.43	0.06	0.01	<0.01	0.39	0.04
Threonine	1.67	1.67	1.64 <sup>b</sup>	1.70 <sup>ab</sup>	1.76 <sup>ab</sup>	1.79 <sup>a</sup>	1.77 <sup>ab</sup>	1.75 <sup>ab</sup>	0.03	<0.01	0.02	0.95	<0.01
Tryptophan	0.46	0.62	0.53	0.45	0.64	0.59	0.65	0.61	0.08	0.42	0.55	0.18	0.25
Valine	1.73	1.61	1.97 <sup>b</sup>	2.07 <sup>ab</sup>	2.11 <sup>ab</sup>	2.16 <sup>a</sup>	2.17 <sup>ab</sup>	2.05 <sup>ab</sup>	0.05	<0.01	<0.01	0.12	0.02
<b>Cross-linked AA, %</b>													
Lysinoalanine	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.03	0.004	0.13	0.96	0.80	0.27

<sup>a-c</sup>Means comparison of pelleted samples. Means within the same row with differing superscripts are different from one another ( $P < 0.05$ ).



pelleted samples had higher ash content compared with fine pelleted ( $P < 0.01$ ).

### Indispensable amino acids

With the exception of His, there were no differences between fine and coarse ground samples for all indispensable AA ( $P > 0.05$ ; Table 6). Histidine content of coarse ground samples was higher compared with fine ground ( $P < 0.01$ ). Pelleting increased Ile, Lys, Phe, Thr, and Val content compared to ground samples ( $P < 0.05$ ). There were no differences between fine and coarse pelleted samples for most indispensable AA ( $P > 0.05$ ). Lysine, Phe, and Val content were higher in coarse pelleted samples compared with fine pelleted ( $P < 0.05$ ).

### Dispensable amino acids

Dispensable AA content is reported in Table S6. There were no differences between fine and coarse ground samples for all dispensable AA ( $P > 0.05$ ). Pelleting increased Arg content compared with ground samples ( $P < 0.05$ ). Pelleting increased Ser content in compared with ground samples ( $P < 0.05$ ). Pelleting decreased Tyr content compared with ground samples ( $P < 0.05$ ). Alanine, aspartate (Asp), glutamate (Glu), Ser, and Tyr content were higher in coarse pelleted samples compared with fine pelleted ( $P < 0.05$ ).

### Lysinoalanine

There were no differences between ground and pelleted samples in LAL content ( $P > 0.05$ ).

## Discussion

While pulses are regarded as nutrient dense and sustainable ingredients foods for livestock, limited data exist regarding the effects of processing on AA profile when common feed processing technologies, such as grinding and pelleting are applied. While the majority of existing research focuses on the effects of pelleting of pulses on nutrient digestibility, growth, and production parameters in agricultural animals, there are limited data reported on the effects of steam pelleting on nutrient changes in pulses. This study systematically demonstrated that various milling and subsequent pelleting conditions can differentially affect the macronutrient and AA profile of varieties of Canadian peas, lentils, chickpeas, and faba beans. To the authors' knowledge, this study is the first to focus on changes in nutrient composition of pulses due to grinding and pelleting.

Dry matter content of whole pulses and SBM ranged from 86 to 90%, with Amarillo peas and faba beans having the lowest and highest DM content, respectively. Dry matter content of whole pulses was slightly lower (1–5%) or of similar content compared with values reported in other studies (de Almeida Costa et al. 2006; Rathod and Annapure 2016; Nosworthy et al. 2017, 2018b, 2020). There were no differences in DM content between whole and ground pulses and SBM, thus signif-

icant changes in DM of pelleted samples are most likely due to the addition of moisture during steam pelleting.

Crude fat content of whole pulses ranged from 1 to 6%, with lentils and chickpeas having the lowest and highest crude fat content of pulses, respectively, while crude fat content of SBM was ~1%. Crude fat content was generally not different in pelleted samples compared with whole samples, with the exception of lentils. However, this increase in crude fat in lentils is most likely due to a shift in overall nutrient percentage as lentils had the overall greatest changes in nutrient composition in a variety of nutrients for pelleted samples compared with whole and ground samples, and may be due to partial dehulling during grinding. In red lentil flour, dehulled samples had significantly higher fat content and significantly lower crude fibre content compared with hulled samples (Ma et al. 2011).

Ash content of whole pulses ranged from 2 to 3%, with lentils and faba beans having the lowest and highest ash content of pulses, respectively. In lentils, ash content increased due to pelleting. This was likely due to the overall change in nutrients due to a significant decrease in crude fibre, as previously mentioned. Interestingly, ash content was significantly lower in pelleted chickpeas and SBM compared with whole and ground samples. Dehulling of chickpeas has been reported to decrease zinc, iron, and calcium content of seeds (Olika et al. 2019). The decrease in ash content in pelleted chickpea samples of this study could be associated with a loss of hull during grinding; however, it would be expected that mineral content would decrease in the ground samples as well. This also does not account for changes observed with SBM samples, suggesting there could be some analytical inaccuracies.

Crude fibre content of whole pulses and SBM ranged from 3 to 6%, with chickpeas and faba beans having the lowest and highest crude fibre content, respectively. Grinding significantly decreased crude fibre content of Dun peas and lentils which could have been attributed to the potential loss of hulls during grinding. Contrary to pulses, there were no changes in crude fibre content of SBM, however, this was expected due to the prior processing of SBM. This could highlight a potential commercial processing concern. If pulse hulls are being separated unintentionally during processing, then utilizing raw ingredients for formulation may not accurately capture the nutrient content of processed ingredients which are being included in feed.

Crude protein content of whole pulses ranged from 21 to 27%, with Amarillo peas and faba beans having the lowest and highest CP content, respectively. These results are consistent with reported CP content of pulses in other studies (Alonso et al. 1998; Alonso et al. 2000; Abd El-Hady and Habiba 2003; Wang et al. 2008; Nosworthy et al. 2017, 2018b, 2020; Mayer Labba et al. 2021). Crude protein content of SBM was ~51%, and similar to data reported for various SBM products (Lagos and Stein 2017). Since there are little data to suggest grinding directly alters CP content, the increase in levels CP in all pulses due to grinding could be attributed to a loss of hulls during the grinding process; this would also account for the significant difference between fine and coarse ground faba bean samples. Given that the pea hulls are >85% fibre, crude

protein increases up to 10.4%, in dehulled peas compared with whole peas (Alonso et al. 1998; Wang et al. 2008). Additionally, there were no differences in CP content between the two grinds, further supporting the loss of hulls hypothesis. Increases in CP due to pelleting appear to be pulse specific. In this study, CP in Amarillo peas, Dun peas, and lentils increased by ~1%, ~1%, and ~3–4%, compared with whole pulses, respectively. In contrast, there were no differences in CP between whole and pelleted samples for chickpeas and faba beans, yet there was a decrease in CP content when compared with ground samples. Additionally, there may have been analytical inaccuracies with CP measurement, which could account for the differences detected. It is important to consider that, while CP content of some pulses increased and others decreased, these changes were relatively small, with lentils having the largest increase. This indicates that grinding and pelleting temperature did not dramatically alter the protein content of these samples.

Indispensable and dispensable AA content of whole pulses were similar to those reported in literature (Nosworthy et al. 2017, 2018a, 2018b, 2020; Mayer Labba et al. 2021). In general, grinding did not affect most indispensable and dispensable AA content between whole and ground pulses and between fine and coarse ground samples (including SBM). As expected, Met, Cys, and Trp were the AA in lowest concentration. Methionine content ranged from 0.16 to 0.25%, with lentils and chickpeas having the lowest and highest Met content of whole pulses, respectively. Cysteine content ranged from 0.21 to 0.37%, with lentils and chickpeas having the lowest and highest Cys content of whole pulses, respectively. Tryptophan content ranged from 0.14 to 0.18%, with Amarillo peas and faba beans having the highest Trp content of whole pulses, respectively. Soybean meal had two- to three-times the amount of Met, Cys, and Trp content, which was expected due to higher CP content, at 0.66, 0.78, and 0.62%, respectively. Sulphur AA content increased in pelleted pulses whereas in pelleted SBM there was no change. Differences between whole and pelleted pulse samples could be due to inaccurate measurement of SAA during analysis. Performic acid oxidation and subsequent hydrolysis of whole pulse samples may not be sufficient in releasing all SAA during digestion. In contrast, exposing pulse samples to steam and pressure through pelleting may have caused more SAA to become available in the sample, which were captured in the AA digestion and analysis process. This could suggest that thermal treatment (pressure and steam) of pulses increases the available amounts of SAA in pulse ingredients. Additionally, this may highlight an error with how SAA is analyzed in raw ingredients not exposed to thermal processing if total SAA is not being released during the digestion process. The increase in Lys observed in all ingredients suggests that there is little to no Lys loss due to potential chemical reactions such as Maillard reaction; of the all the AA, Lys is the most reactive AA due to the presence of its free  $\epsilon$ -amino group (Björck and Asp 1983). This is supported by the lack of differences, with the exception of faba bean, between whole and pelleted samples in LAL content. While there were significant differences between whole LAL content and pelleted LAL content of faba bean, the significance was a decrease in LAL in pel-

leted samples compared with whole samples. Perhaps there was some LAL formation during preparation (grinding) and analysis of the whole faba bean sample, which could account for the higher LAL content; this occurrence was also hypothesized by Jeunink and Cheftel (1979) as a possibility of reported LAL content in the raw protein concentrate of faba beans due to grinding. Additionally, Jeunink and Cheftel (1979) reported no significant changes in LAL in extruded protein concentrates of faba bean compared with raw concentrate. Alternatively, there may have been some analytical inaccuracies, such as the sample remaining under head too long or the temperature of the sample increasing above the digestion temperature, which could account for the higher LAL content of the raw faba bean samples. While extrusion temperatures are much higher than those of pelleting, these results suggest overall that thermal processing, regardless of temperature, results in little to no cross-linking of lysine. Histidine content of pulses and some SBM samples decreased when ingredients were pelleted. This decrease in His has been previously reported, with His content decreasing from 2.21% in raw peas to 1.96% in extruded peas (Alonso et al. 2000). This decrease in His could be attributed to Maillard reaction reducing His availability. While lysine is the most reactive protein-bound AA Arg, Cys, His, and Trp can also be affected (Björck and Asp 1983). There were some changes in other indispensable AA such as Ile, Leu, and Phe, Thr, and Val compared with whole pulses, but these appear to be pulse specific. Additionally, while the majority of AA were not different when comparing fine and coarse pelleted samples, those that were, appeared to be pulse and grind specific. For example, Ile and Val content were significantly higher in fine pelleted Dun peas whereas in faba beans, Ile, Leu, Met, and Val content were higher in coarse pelleted samples. Although there does not appear to be an optimal pelleting temperature, there may be an optimal grind size depending on the pulse. While studies by Nosworthy et al. (Nosworthy et al. 2017, 2018a, 2018b, 2020) did not statistically compare changes in AA content of raw and processed pulses, many AA were reported to numerically increase due to processing, including the indispensable AA such as, Ile, Leu, and Phe. However, these increases appeared to be pulse specific, as some pulses, such as green pea flour, had reported decreases in AA such as His and Lys.

Although there were changes in some dispensable AA, many of these changes do not directly impact protein quality measures of pulses, with the exception of Cys and Tyr which are incorporated in protein quality calculations for sulphur AA and aromatic AA, respectively. In all pulses, an increase in Cys content and a decrease in Tyr content in pelleted samples was observed. A decrease in Tyr was also observed in pelleted SBM, but there was no change in Cys content. An increase in Cys in pulses could improve the delivery of these SAA. While Tyr decreased due to pelleting, Phe increased or did not change. Thus, there may be a shift in protein quality due to the decreases in Tyr, however, since sulphur AA and Trp tend to be the limiting AA, this is unlikely. While not used directly to assess protein quality, the presence of dispensable AA may spare the utilization of nitrogen from indispensable AA for their synthesis, thus increasing the amount of indispensable AA available for

protein synthesis. Additionally, all ingredients studied were rich in Glu and Asp in the whole, ground, and pelleted samples. These AA are used in a variety of important metabolic processes (e.g., transamination) and are extensively oxidized by the small intestine for energy (Wu 2009).

## Conclusion

Overall, there was no ideal processing parameter for all the ingredients. Differences between pelleted samples were not consistent, and nutrient changes appear to be ingredient dependent. There may be an ideal grind size to maximize AA content, however, this appears to be pulse specific, and does not apply to all AA within a pulse. Pulse type also influences changes in nutrient composition due to grinding/pelleting, as such, pulse type should be considered when selecting ingredients as a part of the diet. Additionally, potential loss of hulls/transformation of raw ingredients during processing may cause inaccuracies when utilizing nutrient values from raw, whole pulses when formulating animal feed. Further research is warranted to determine whether there are optimal grind sizes and processing temperatures, and to develop a deeper set of data to truly understand effects of pelleting.

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Daniel Columbus and Elijah Kiarie served as Associate Editors at the time of manuscript review and acceptance; peer review and editorial decisions regarding this manuscript were handled by Chengbo Yang and Gregory Penner.

## Author contributions

CLC-F was the primary researcher responsible for running the study and analysis. CLC-F developed the study, conducted the processing of ingredients, laboratory analyses and statistical analysis, and wrote the original manuscript draft. RWN developed the study and statistical model, interpreted the data, and reviewed the manuscript. CPFM, AKS, and EGK interpreted the data and assisted with manuscript preparation. YA developed the study and reviewed the manuscript. DAC developed the study, interpreted the data interpretation, assisted with manuscript preparation, and is the corresponding author/grant holder.

## Competing interests

The authors have declared that no competing interests exist.

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## Supplementary material

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