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Standardised ileal amino acid digestibility of grain legumes is comparable to soybean meal for broiler chickens

O. Hamungalu [a], M.R. Abdollahi [a], P.C.H. Morel [a], S. Liu [b], T.J. Wester [a,*]

[a] School of Agriculture and Environment, Massey University, Palmerston North 4442, New Zealand
[b] Poultry Research Foundation, The University of Sydney, Camden NSW 2570, Australia

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ABSTRACT

The aim of the present study was to determine standardised ileal digestibility (SID) of nitrogen (N) and amino acids (AA) of faba bean, lupin, lentil, chickpea, field pea and soybean meal (SBM) for growing male broilers. Grain legumes were incorporated into experimental diets either raw or after being steam-conditioned at 80°C for 30 s. The assay diets were formulated to contain 150 g/kg crude protein with the test ingredient as the only source of protein. Meanwhile, basal endogenous AA loss was measured by using a N-free diet to estimate SID. From 21–24 days post-hatch, each diet was randomly allocated to four replicate cages (eight birds per cage) with a total of 384 Ross 308 male broiler chickens. On day 24, all birds were euthanised and ileal contents collected to determine SID. No effect ($P>0.05$) was observed for heat treatment on SID of AA for lentil, lupin and field pea, but variable effects were observed in chickpea and faba bean ($P<0.05$). The SID of N and all AA in SBM were not different (P>0.05) to that of raw lentil, but were greater (P<0.05) than that of raw field pea. No differences (P>0.05) were observed for SID of N and AA between raw lupin and SBM, apart from arginine, cysteine, glutamic acid and glycine which were greater (P<0.05) in lupin. In raw chickpea, only SID of isoleucine, leucine, methionine, alanine and tyrosine were lower (P<0.05) than that of SBM. This study suggested that the AA digestibility coefficients of raw lupin, lentil and chickpea were not different from SBM and may be used as a replacement. However, due to their lower AA content, an additional protein source or non-bound amino acids may be needed to form a balanced diet.

1. Introduction

Soybean meal (SBM) is a major protein source in broiler diets. However, wide fluctuations in price of imported SBM create uncertainty for broiler producers and impacts sustainability (Nalle et al., 2012). Grain legumes, potential alternatives to SBM, are not only a good source of protein and energy (Diaz et al., 2006; Kaczmarek et al., 2014; Nalle et al., 2011a, 2012), but they help fix N into soil too (Adamidou et al., 2011; Kaczmarek et al., 2014) and reduce the quantity of N fertilizer added to the soil for crop growth. Grain legumes are generally produced in many parts of the world with faba bean, chickpea, lentil, field pea and lupin being more adaptive to temperate regions (Castell et al., 1996; Hamblin, 1987; Sipas et al., 1997). In 2023, world production of chickpea, lentil and lupin was

Abbreviations: AA, amino acids; SID, standardised ileal digestibility; AID, apparent ileal digestibility; N, nitrogen; CP, crude protein; SMB, soybean meal; EAA, endogenous amino acids; DM, dry matter; TIA, trypsin inhibitor activity; HT, heat treated; Ti, titanium.

* Corresponding author.
E-mail address: t.j.wester@massey.ac.nz (T.J. Wester).

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estimated at 16.5, 7.1 and 1.9 million tonnes, respectively, with Australia ranking first in lupin production (1.3 million tonne) (FAOSTAT, 2025).

Nutritional characteristics of feed ingredients largely define the quality of the complete diet. Accurate determination of ingredient quality allows for close matching of dietary nutrient supply with bird requirements. This ensures feed is utilised efficiently, and translates to improved growth performance, increased profitability and reduced excretion of nutrients, like N, into the environment (Masey O'Neill et al., 2012; Osho et al., 2019). The use of digestible amino acid (AA) values in diet formulation is common practice in the poultry industry because it estimates nutrient availability better than crude protein (CP) or AA composition (Osho et al., 2019).

An *in vivo* digestibility assay is the most used method to assess AA digestibility (Lemme et al., 2004; Moughan et al., 2014; Ravindran and Bryden, 1999). Ileal digestibility is considered superior to total tract determination because it avoids modification of AA by hindgut microbes and eliminates interference by urine (Kong and Adeola, 2014; Moughan, 2003). For the ileal procedure, digesta are collected from the lower part of ileum (Lemme et al., 2004; Stein and Bohlke, 2007) and depending on correction for endogenous AA (EAA) loss, ileal digestibility can be determined as apparent, standardized or true digestibility (Moughan et al., 2014; Stein and Bohlke, 2007). Apparent ileal digestibility (AID) is the difference between ingested AA and those present in the digesta and is not corrected for EAA (Moughan et al., 2014). Standardized digestibility corrects apparent digestibility for basal EAA losses, while true digestibility corrects for total EAA (basal and specific) (Lemme et al., 2004; Ravindran and Bryden, 1999). Endogenous losses are derived mostly from mucin, desquamated cells and digestive enzymes (Lemme et al., 2004). Basal EAA losses are dry matter (DM) dependent while specific EAA are associated with composition of diet or feed ingredient (Kong and Adeola, 2014).

True digestibility is not generally used in diet formulation because limited data are available on specific EAA losses (Stein and Bohlke, 2007). On the other hand, SID has many advantages over AID. Firstly, AID is less additive in complete diets mainly due to underestimation of digestibility values (Hong et al., 2001; Osho et al., 2019). Secondly, AID is influenced by AA intake, with low intake associated with increased EAA losses, which increases underestimation and makes digestible values less reliable (Lemme et al., 2004; Pérez et al., 1993). Underestimation of AID is more pronounced in feed materials that are low or moderate in CP and AA content (Lemme et al., 2004). For example, Pérez et al. (1993) observed a greater difference between AID and SID of AA means in field pea (14.5 %) than in SBM (9.7 %) for growing male broilers.

Published data on AA digestibility of grain legumes is inconsistent and mostly based on AID values (Kaczmarek et al., 2014; Nalle et al., 2010, 2011a; Ravindran et al., 2002), with a few studies on SID of AA for field pea and faba bean (Adekoya and Adeola, 2023a; Bandegan et al., 2011; Masey O'Neill et al., 2012; Olukosi et al., 2019; Pérez et al., 1993; Szczurek, 2009, 2020; Witten et al., 2018). The SID values of CP and AA for lentil, lupin and chickpea for broilers are not available. Further, continual improvement in grain legume breeding (Cargo-Froom et al., 2023) necessitates provision of updated nutritional values to improve diet formulation for better performance of birds. The aim of the present study was to determine SID of AA for lupin, chickpea, field pea, lentil and faba bean grown in Australia compared to SBM for growing broiler chickens. The influence of steam conditioning of grain legumes on AA digestibility was also examined.

2. Materials and methods

The experiment was conducted according to the New Zealand Code of Ethical Conduct for the use of live animals for research, testing and teaching and approved by the Massey University Animal Ethics Committee (MUAC 22/82).

2.1. Ingredients

Grain legumes (faba bean, chickpea, field pea, lentil and lupin) were sourced from commercial suppliers in Australia and ground

Table 1
Composition of assay diets and N-free diet (%, as fed basis) used in standardised ileal amino acid digestibility assay.

	NFD	SBM	Field pea	Chickpea	Lupin	Lentil	Faba bean
Test ingredient	-	37.0	86.0	73.0	57.0	59.0	61.0
Dextrose	84.2	56.0	7.00	20.0	36.0	34.0	32.0
Soybean oil	5.00	3.00	3.00	3.00	3.00	3.00	3.00
Dicalcium phosphate	1.90	1.90	1.90	1.90	1.90	1.90	1.90
Limestone	1.30	1.00	1.00	1.00	1.00	1.00	1.00
Sodium bicarbonate	0.20	0.20	0.20	0.20	0.20	0.20	0.20
NaCl	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Trace mineral premix[a]	0.30	0.10	0.10	0.10	0.10	0.10	0.10
Vitamin premix[a]	0.20	0.10	0.10	0.10	0.10	0.10	0.10
Titanium dioxide	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Solkafloc (Cellulose)	5.00	-	-	-	-	-	-
Dipotassium phosphate	1.20	-	-	-	-	-	-

NFD, N-free diet; SBM, Soybean meal; NaCl, sodium chloride.

[a] Supplied per kilogram of diet: antioxidant (ethoxyquin), 100 mg; biotin, 0.2 mg; calcium pantothenate, 12.8 mg; cholecalciferol, 0.06 mg; cyanocobalamin, 0.017 mg; folic acid, 5.2 mg; menadione, 4 mg; niacin, 35 mg; pyridoxine, 10 mg; trans-retinol, 3.33 mg; riboflavin, 12 mg; thiamine, 3.0 mg; dl-α-tocopheryl acetate, 60 mg; choline chloride, 638 mg; Co, 0.3 mg; Cu, 3.0 mg; Fe, 25 mg; I, 1 mg; Mn, 125 mg; Mo, 0.5 mg; Se, 0.2 mg; Zn, 60 mg.

through a 2.0 mm sieve. Solvent extracted SBM and maize were sourced from the commercial suppliers. A portion of each legume was steam conditioned in the pelleting chamber (Model Orbit 15; Richard Sizer Ltd., Kingston-upon-Hull, UK) at 80℃ for 30 s and then air dried for five days.

2.2. Diets

Eleven assay diets (SBM; and each raw and heat-treated grain legume) were formulated to contain 150 g/kg CP (Table 1; Nalle et al., 2021; Ravindran et al., 2005) with the test ingredient as the only source of CP (Nalle and Ravindran, 2021). The N-free diet was formulated to measure endogenous AA losses which were used to determine SID of AA for test ingredients (Barua et al., 2020). All diets included titanium dioxide at 5 g/kg (TiO_2, Merck KGaA, Darmstadt, Germany) as an indigestible marker. Diets were offered to birds *ad libitum* in mash form from 21 day to 24 days post-hatch.

2.3. Birds and housing

Day-old male broilers (Ross 308) obtained from a commercial hatchery were raised in floor pens (length 1.6 m x width 0.8 m) and moved to cages (length 0.6 m x width 0.6 m) on d-14. On d-14, 384 birds were randomly allocated to 48 cages, with 8 birds per cage and 4 replicated cages per dietary treatment. Before the introduction of test diets on d-21, birds were fed a standard starter diet (230 g/kg CP and 12.56 MJ/kg). Floor pens and cages were housed in an environmentally controlled room supplying 20 h of fluorescent illumination per day. During the trial, temperature was maintained at 23℃, and feed and water was supplied *ad libitum*.

2.4. Determination of the coefficient of standardised ileal digestibility

On d-24, birds were euthanised by intravenous injection (1 mL per 2 kg live weight) of sodium pentobarbitone (Provet NZ Pty Ltd., Auckland, New Zealand), and ileal digesta were collected from the lower half of the ileum in accordance with the procedure described by Ravindran et al. (2005). The ileum was defined as that portion of the small intestine extending from Meckel's diverticulum to a point 40 mm proximal to the ileo-caecal junction. Digesta from the lower ileum of each bird were gently flushed into a plastic container with distilled water and pooled by cage, frozen, and freeze dried (Model 0610, Cuddon Engineering, Blenheim, New Zealand). Diets and freeze dried digesta were ground to pass through a 0.5 mm sieve and stored in airtight containers at 4°C pending laboratory analysis. Ileal digesta samples and test diets were analysed for DM, titanium, N, and AA. The N-free diet was analysed only for DM and titanium (Ti).

2.5. Chemical analysis

The DM of ingredients, diets and ileal samples was determined using standard procedures (Methods 930.15 and 925.10; AOAC, 2016). Nitrogen was determined by combustion (Method 968.06; AOAC, 2016) using a carbon nanosphere-200 carbon, N and sulphur autoanalyser (LECO Corporation, St. Joseph, MI), with CP content calculated as N × 6.25.

Amino acids were measured by standard procedures (Method 994.12; AOAC, 2011). Representative samples were hydrolysed with 6 N HCl containing phenol for 24 h at 110 ± 2ºC in glass tubes in an oven. The AA were determined using an AA analyser (ion exchange) with ninhydrin post column derivatisation. Chromatograms detected at 570 nm and 440 nm were integrated using dedicated software (Agilent Open Lab software, Waldbronn, Baden-Württemberg, Germany). Methionine and cysteine were analysed as methionine sulphone and cysteic acid by oxidation with performic acid-phenol for 16 h at 0ºC prior to hydrolysis, respectively.

Phytic acid was determined using a phytic acid assay kit (Megazyme International Ireland Ltd., Wicklow, Ireland) based on acid extraction of inositol phosphates and treatment with a phytase that is specific for phytic acid (IP6) and the lower myo-inositol phosphate forms (i.e., IP2, IP3, IP4, IP5), then total phosphate measured using a modified colourimetric method (Fiske and Subbarow, 1925). Phytic phosphorus was divided by 0.282 (based on 28.2 % phytic acid P) to determine phytic acid (Adekoya and Adeola, 2023b). The method for determination of trypsin inhibitor activity was as described by Van Eys et al. (2004).

2.6. Calculations

All data were expressed on a DM basis for calculations. The AID coefficient (AIDC) of AA and N was calculated with the following formulae.

$$\text{AIDC of nutrient} = \left[(\text{Nutrient/Ti})_d - (\text{nutrient/Ti})_i\right] / (\text{nutrient/Ti})_d$$

$$\text{Where, } (\text{nutrient/Ti})_d = \text{ratio of nutrient to Ti in the diet, and} (\text{nutrient/Ti})_i = \text{ratio of nutrient to Ti in the ileal digesta.}$$

The basal ileal EAA flow of the birds fed the N-free diet was calculated as grams AA lost per kilogram of DM intake (DMI) using the following formula (Moughan et al., 1992).

$$\text{Basal EAA flow(g/kg DMI)} = \text{AA concentration in ileal digesta(g/kg)} \times [\text{Diet Ti(g/kg)} / \text{ileal digesta Ti(g/kg)}]$$

Apparent digestibility data for N and AA were then converted to SIDC using endogenous N and AA values determined from birds fed the N-free diet (Ravindran et al., 2014).

$$\text{SIDC} = \text{AIDC} + \quad [\text{Basal EAA}(\text{g/kg DMI})/\text{Ingredient AA}(\text{g/kg DM})]$$

Where, SIDC = standardised ileal digestibility coefficient of the AA,
AIDC = apparent ileal digestibility coefficient of the AA,
Basal EAA = basal endogenous AA loss, and
Ing.AA = concentration of the AA in the ingredient.

2.7. Statistical analysis

The data were analysed using the General Linear Models procedure of SAS (version 9.4; 2015. SAS Institute Inc., Cary, NC). One-way ANOVA and orthogonal contrasts (raw vs heat-treated grain legume; SBM vs raw grain legume; SBM vs heat-treated grain legume) were performed. Cage served as the experimental unit. Differences were considered significant at $P < 0.05$.

3. Results

In raw grain legumes, trypsin inhibitor activity (TIA) was greatest in chickpea, followed by field pea and lowest in lentil (Table 2). After heat-treatment of legumes, chickpea was still greatest in TIA and faba bean lowest. The TIA in solvent extracted SBM (0.66 mg/g) was greater than that of raw and heat-treated lentil, faba bean and lupin, but lower than that of chickpea and field pea.

Phytic acid in SBM (Table 2) was greater than that of raw and heat-treated grain legumes. Among grain legumes, phytic acid was greatest in faba bean and lowest in lentil in both raw and heat-treated samples.

Among raw grain legumes, CP content was lowest in field pea and highest in lupin (190 and 285 g/kg DM, respectively). The CP content in SBM was higher than that of grain legumes (Table 3).

Concentration of AA in SBM was higher than that in grain legumes (Table 3). For indispensable AA, grain legumes and SBM were lowest in methionine. For raw grain legumes, lysine ranged from 14.6 g/kg (lupin) to 19.0 g/kg (faba bean), while methionine was lowest (2.50 g/kg) in lupin and field pea and highest (4.00 g/kg) in chickpea. Among dispensable AA, cysteine was lowest and glutamic acid highest, followed by aspartic acid in both SBM and grain legumes.

Heat treatment had no effect ($P>0.05$) on SID of N and AA for lentil, lupin and field pea, but reduced digestibility of N in chickpea and faba bean ($P < 0.05$; Table 4). Heating also reduced ($P < 0.05$) SID of arginine, leucine, methionine and phenylalanine in faba bean, while only aspartic acid, glutamic acid and tyrosine were reduced among dispensable AA. In chickpea, heating reduced ($P < 0.05$) digestibility of all AA except for lysine, cysteine, glycine and serine that remained unchanged.

For SID of grain legumes and SBM, arginine was the most digestible indispensable AA, while among dispensable AA, cysteine had the lowest digestibility and glutamic acid the greatest (Table 5). Digestibility of lysine in legumes was not different to that of SBM, except in field pea which had lower lysine digestibility ($P < 0.05$). The SID of N and all AA in SBM were not different ($P>0.05$) to that of lentil, but were greater ($P < 0.05$) than that of field pea. No differences ($P>0.05$) were observed for SID of N and AA between lupin and SBM, apart from arginine, cysteine, glutamic acid and glycine which were greater ($P < 0.05$) in lupin. In chickpea, only SID of isoleucine, leucine, methionine, alanine and tyrosine were lower ($P < 0.05$) than that of SBM. With exception of lysine, alanine, aspartic acid and glutamic acid, SID of AA in faba bean were lower than that of SBM ($P < 0.05$).

No ($P>0.05$) difference was observed on SID of N and AA between lentil and SBM (Table 6). The SID values of AA in lupin were not different or greater than (arginine and glutamic acid) those of SBM. The SID of N and AA for SBM were greater than ($P < 0.05$) those in field pea, faba bean and chickpea, except for cysteine in field pea which was not different ($P>0.05$).

Among the raw legumes, digestible CP content was greatest in lupin (244.9 g/kg) and lowest in field pea (143.1 g/kg; Table 7). Compared to raw legumes, digestible CP contents of heat-treated lentil and lupin increased (3.3 and 12.7 %, respectively) while that of chickpea decreased (4.4 %), and those for field pea and faba bean were not different. Heating increased digestible content of all AA in lupin. Apart from threonine, alanine, cysteine, proline and tyrosine, which were not affected, digestible contents of AA in lentil increased with heat-treatment (P>0.05). Variable effects of heating were observed with digestible AA contents in chickpea and field

Table 2
Anti-nutritional factors of grain legumes and soybean meal.

Ingredient	TIA (mg/g)		Phytic P (%)		Phytic acid[a] (%)	
	Raw	HT	Raw	HT	Raw	HT
Chickpea	3.19	3.48	0.16	0.15	0.57	0.54
Lentil	0.28	0.18	0.06	0.06	0.20	0.21
Field pea	1.15	0.89	0.14	0.14	0.50	0.49
Faba bean	0.63	0.16	0.20	0.20	0.71	0.71
Lupin	0.44	0.42	0.11	0.13	0.39	0.45
SBM	—— 0.66 ——		——0.49 ——		——1.76 ——	

[a] Phytic acid was calculated by dividing phytic phosphorus by a factor of 0.282. TIA, trypsin inhibitor activity; SBM, soybean meal; HT, heat treated grain legumes were steam conditioned for 30 s at 80°C.

Table 3
Crude protein and amino acid composition of grain legumes (raw and heat-treated) and solvent-extracted soybean meal (g/kg, DM).

	Chickpea		Faba bean		Lentil		Lupin		Field pea		SBM
Item	Raw	HT	Raw	HT	Raw	HT	Raw	HT	Raw	HT	
CP	223	221	267	270	280	291	285	319	190	193	461
Indispensable AA											
Arg	21.3	20.8	24.7	25.5	24.5	25.7	29.7	35.4	15.4	14.8	36.5
His	5.60	5.00	6.90	7.00	9.40	10.6	7.00	8.90	4.50	4.50	12.2
Iso	9.00	9.20	10.2	10.5	9.50	10.8	10.0	13.8	7.20	8.10	20.7
Leu	16.2	16.1	19.2	18.9	18.3	19.7	18.0	24.0	13.0	13.6	37.5
Lys	16.0	15.7	19.0	14.9	18.5	14.8	14.6	18.5	15.4	14.6	33.0
Met	4.00	4.30	2.70	2.80	3.20	3.60	2.50	3.00	2.50	3.00	8.90
Phe	12.9	13.2	11.5	11.8	12.6	13.7	10.6	14.2	9.30	10.1	24.9
Thr	7.80	8.00	9.60	9.60	10.2	10.3	10.0	12.9	7.80	7.90	20.2
Val	10.3	10.4	12.4	12.6	12.5	13.3	11.0	15.0	8.80	9.50	23.3
Dispensable AA											
Ala	9.50	9.80	11.2	10.7	10.8	11.1	9.80	12.8	8.70	8.50	22.0
Asp	27.0	27.2	30.3	30.5	29.5	32.2	27.3	38.3	23.0	22.8	59.3
Cys	3.10	3.20	3.50	3.30	2.70	2.70	3.30	3.90	3.10	3.20	7.20
Glu	37.6	38.4	44.6	43.4	48.8	45.6	58.4	70.4	52.2	30.0	114
Gly	9.50	9.20	12.4	10.3	12.4	10.1	13.9	16.2	9.90	9.40	22.2
Pro	9.40	9.60	11.2	11.2	10.6	10.9	11.5	15.3	8.20	8.60	26.8
Ser	11.1	8.30	13.1	10.2	13.0	12.0	13.7	18.0	9.40	10.4	25.9
Tyr	6.90	6.50	9.60	9.50	9.00	8.90	10.8	13.6	7.30	7.30	20.2
TAA	217	215	252	243	256	256	262	334	206	186	515

CP, crude protein (N x 6.25); AA, amino acids; SBM, soybean meal; HT, heat treated grain legumes were steam conditioned for 30 s at 80°C; TAA, total AA.

pea, but the majority of AA were not affected.

In both raw and heat-treated legumes (Tables 8 and 9), digestible CP and AA contents were lower than that of SBM ($P<0.05$). Grain legumes and SBM were lowest in digestible methionine and cysteine contents.

4. Discussion

The CP and AA contents of grain legumes and SBM were generally comparable to those reported in existing literature. The CP in raw chickpea was within the range reported by Thacker et al. (2002), but greater than values (215 – 217 g/kg) indicated by Rincón et al. (1998), and lower than the findings of Ciurescu et al. (2021) and Viveros et al. (2001). The CP content in faba bean fell within values (229 – 306 g/kg) reported by Nalle et al. (2010), but lower than values reported in other studies (Adamidou et al., 2011; Lacassagne et al., 1988; Woyengo and Nyachoti, 2012). Further, the CP content in field pea was similar to that reported by Alonso et al., (2000b), but lower than values observed by Nalle et al. (2011b), 193 g/kg and 219 – 253 g/kg, respectively. Also, the observed CP values in lupin and lentil were within the range indicated by Nalle et al. (2011a) and Ciurescu et al. (2017), respectively. The AA profiles of grain legumes and SBM were generally comparable to published literature (Barua et al., 2020; Christodoulou et al., 2006; Ciurescu et al., 2017; Diaz et al., 2006; Nalle et al., 2010, 2011a, 2011b; Ravindran et al., 2005, 2014; Thacker et al., 2002; Woyengo and Nyachoti, 2012). In general, chemical composition of grain legumes are known to vary largely due to cultivar effect (Kaczmarek et al., 2014; Nalle et al., 2010; Wang and Daun, 2006) and growing conditions (Wang and Daun, 2006).

Arginine, cysteine, glutamic acid and glycine were more digestible in raw lupin than in SBM, while digestibility of N and other AA were not different. To the best of our knowledge, no study has reported SID of AA for lupin in broiler feeding, however, this observation agreed with findings by Kozłowski et al. (2011) involving three-week-old male turkeys. They reported greater SID values of arginine, cysteine and glycine in lupin than in SBM. For SBM, SID of AA ranged from 82.1 % (cysteine) to 94.8 % (arginine) and were comparable to those reported by Adedokun et al. (2014) and greater than that of Olukosi et al. (2023). Furthermore, digestibility of N and AA in lentil was not different to that of SBM. Published data on AA digestibility for raw lentil in broiler feeding are scare. However, the digestibility pattern of AA for raw lentil in the present study agreed to that observed for pigs (Cargo-Froom et al., 2023), which was characterized by low SID of threonine, cysteine and glycine.

Differences in SID of AA for raw field pea which were lower than SBM in the present study were contrary to findings of Pérez et al. (1993), who observed no difference among SID of AA for field pea and SBM. Also, SID of AA for field pea in the present study agreed to those indicated by Masey O'Neill et al. (2012), but were lower than that of Pérez et al. (1993) and Bandegan et al. (2011). Wiseman et al. (2003) reported greater digestibility of AA for a pea variety with low TIA (1.45 TIU/mg) than a variety high in TIA (8.73 TIU/mg). Although TIA was not measured by Pérez et al. (1993) and Bandegan et al. (2011), the study by Wiseman et al. (2003) suggested that TIA concentration can influence AA digestibility in field pea. Trypsin inhibitors are generally known to exert a negative influence by binding to and inactivating trypsin, subsequently reducing CP digestion in the digestive tract (Al-Bakir et al., 1982). In the present study, however, TIA and phytic acid in field pea were lower than those in chickpea that had greater SID of AA. This indicates that other factors also influence AA digestibility for field pea. One factor, cell wall rigidity of cotyledons was reported to limit accessibility of nutrients to digestive enzymes (Carre et al., 1991).

Table 4
Standardised ileal digestibility (%) of N and amino acids of raw and heat-treated grain legumes fed to growing broilers.[a].

Item	Chickpea		Faba bean		Lentil		Lupin		Field pea		SEM	P value[b]	P value[c]				
													Raw vs. HT				
	Raw	HT	Raw	HT	Raw	HT	Raw	HT	Raw	HT			Chickpea	Faba bean	Lentil	Lupin	Field pea
N	88.7	85.8	87.2	83.6	91.3	91.1	92.1	91.7	82.2	84.0	1.019	0.001	0.047	0.018	0.904	0.770	0.220
Indispensable AA																	
Arg	95.0	93.0	92.4	90.2	95.4	95.2	97.1	97.1	89.6	89.0	0.540	0.001	0.011	0.007	0.745	1.000	0.401
His	90.5	85.6	85.4	82.6	90.7	90.6	92.3	91.8	84.6	82.2	1.020	0.001	0.002	0.063	0.918	0.731	0.106
Iso	85.5	81.1	85.5	82.7	90.5	90.5	91.3	90.5	81.0	80.4	1.201	0.001	0.013	0.109	0.965	0.662	0.704
Leu	86.6	82.4	87.4	84.3	91.2	91.0	92.7	92.0	82.1	81.5	1.063	0.001	0.008	0.044	0.895	0.644	0.717
Lys	88.5	86.1	90.1	87.0	92.2	91.9	88.9	87.4	85.1	86.3	1.155	0.001	0.160	0.071	0.867	0.350	0.477
Met	88.5	82.3	82.8	77.8	88.6	89.0	91.0	88.8	81.2	78.7	1.426	0.001	0.004	0.017	0.854	0.273	0.233
Phe	89.9	86.4	86.9	82.5	92.4	91.9	91.7	91.1	83.2	81.8	1.055	0.001	0.025	0.006	0.727	0.690	0.338
Thr	84.4	78.9	82.9	81.9	88.0	88.3	89.6	87.0	81.1	81.5	1.447	0.001	0.012	0.646	0.894	0.217	0.837
Val	86.4	81.7	85.2	82.6	90.0	90.2	90.4	89.0	80.8	80.6	1.242	0.001	0.012	0.152	0.910	0.439	0.921
Dispensable AA																	
Ala	85.6	81.2	86.5	85.0	89.6	90.5	90.2	89.2	81.3	82.9	1.296	0.001	0.024	0.443	0.627	0.598	0.397
Asp	90.1	86.2	89.3	86.2	92.0	92.6	92.3	91.6	85.0	85.6	1.033	0.001	0.012	0.046	0.684	0.647	0.722
Cys	78.8	73.7	71.3	69.4	79.4	82.3	89.7	86.9	75.7	77.6	1.884	0.001	0.063	0.481	0.272	0.301	0.464
Glu	93.1	90.7	92.5	90.6	94.8	95.0	95.9	96.1	89.8	90.2	0.623	0.001	0.011	0.036	0.822	0.822	0.613
Gly	83.2	80.3	79.4	78.8	84.9	85.9	90.9	89.4	77.0	79.2	1.569	0.001	0.193	0.763	0.663	0.518	0.340
Pro	87.1	83.5	84.4	81.7	89.4	89.7	91.2	89.9	79.5	80.2	1.186	0.001	0.041	0.124	0.836	0.444	0.690
Ser	84.4	80.3	79.7	81.6	88.1	87.7	89.8	87.2	78.3	76.2	1.710	0.001	0.103	0.432	0.854	0.281	0.386
Tyr	85.8	81.7	84.4	81.0	89.3	89.6	92.8	92.2	83.5	83.1	1.095	0.001	0.013	0.039	0.835	0.689	0.785

AA, amino acids; N, nitrogen; SEM, standard error of the mean; HT, steam conditioned for 30 s at 80°C.

[a] Apparent digestibility values were standardised using the following basal ileal endogenous flow values (g/kg DM intake), determined by feeding a N-free diet: N, 3.60; Arg, 0.153; His, 0.064; Ile, 0.140; Leu, 0.21; Lys, 0.147; Met, 0.065; Phe, 0.186; Thr, 0.283; Val, 0.205; Ala, 0.151; Asp, 0.355; Cys, 0.137; Glu, 0.313; Gly, 0.178; Pro, 0.230; Ser, 0.240; Tyr, 0.142.

[b] P value for ANOVA is significantly different at $P < 0.05$.

[c] P value for orthogonal contrast indicates significance ($P < 0.05$) of raw vs heat-treated grain legumes.

Table 5
Standardised ileal digestibility (%) of N and amino acids of raw grain legumes compared to soybean meal fed broilers. [a].

Item	Chickpea	Faba bean	Lentil	Lupin	Field pea	SBM	SEM	P value[b]	P value[c]				
									Legume vs. SBM				
									Chickpea	Faba bean	Lentil	Lupin	Field pea
N	88.7	87.2	91.3	92.1	82.2	90.7	1.019	0.001	0.180	0.019	0.692	0.347	0.001
Indispensable AA													
Arg	95.0	92.4	95.4	97.1	89.6	94.8	0.540	0.001	0.795	0.003	0.438	0.006	0.001
His	90.5	85.4	90.7	92.3	84.6	91.8	1.020	0.001	0.374	0.001	0.472	0.718	0.001
Iso	85.5	85.5	90.5	91.3	81.0	90.7	1.201	0.001	0.005	0.004	0.884	0.737	0.001
Leu	86.6	87.4	91.2	92.7	82.1	90.7	1.063	0.001	0.010	0.034	0.741	0.192	0.001
Lys	88.5	90.1	92.2	88.9	85.1	90.5	1.155	0.001	0.218	0.785	0.313	0.335	0.002
Met	88.5	82.8	88.6	91.0	81.2	92.7	1.426	0.001	0.043	0.001	0.052	0.412	0.001
Phe	89.9	86.9	92.4	91.7	83.2	91.5	1.055	0.001	0.306	0.004	0.529	0.907	0.001
Thr	84.4	82.9	88.0	89.6	81.1	87.5	1.447	0.001	0.133	0.031	0.809	0.318	0.003
Val	86.4	85.2	90.0	90.4	80.8	89.8	1.242	0.001	0.063	0.014	0.899	0.735	0.001
Dispensable AA													
Ala	85.6	86.5	89.6	90.2	81.3	89.7	1.296	0.001	0.031	0.088	0.946	0.776	0.001
Asp	90.1	89.3	92.0	92.3	85.0	90.4	1.033	0.001	0.839	0.457	0.281	0.197	0.001
Cys	78.8	71.3	79.4	89.7	75.7	82.1	1.884	0.001	0.228	0.001	0.314	0.007	0.022
Glu	93.1	92.5	94.8	95.9	89.8	93.5	0.623	0.001	0.694	0.301	0.128	0.009	0.001
Gly	83.2	79.4	84.9	90.9	77.0	86.1	1.569	0.001	0.204	0.005	0.592	0.039	0.001
Pro	87.1	84.4	89.4	91.2	79.5	89.8	1.186	0.001	0.108	0.003	0.790	0.435	0.001
Ser	84.4	79.7	88.1	89.8	78.3	88.5	1.710	0.001	0.097	0.001	0.878	0.594	0.001
Tyr	85.8	84.4	89.3	92.8	83.5	91.5	1.095	0.001	0.001	0.001	0.160	0.416	0.001

AA, amino acids; N, nitrogen; SEM, standard error of the mean; SBM, soybean meal.

[a] Apparent digestibility values were standardised using the following basal ileal endogenous flow values (g/kg DM intake), determined by feeding a N-free diet: N, 3.60; Arg, 0.153; His, 0.064; Ile, 0.140; Leu, 0.21; Lys, 0.147; Met, 0.065; Phe, 0.186; Thr, 0.283; Val, 0.205; Ala, 0.151; Asp, 0.355; Cys, 0.137; Glu, 0.313; Gly, 0.178; Pro, 0.230; Ser, 0.240; Tyr, 0.142.

[b] P value for ANOVA is significantly different at $P < 0.05$.

[c] P value for orthogonal contrast indicates significance ($P < 0.05$) of raw grain legumes vs SBM.

Table 6
Standardised ileal digestibility (%) of N and amino acids of heat-treated grain legumes compared to soybean meal fed to broilers.[a].

Item	Chickpea	Faba bean	Lentil	Lupin	Field pea	SBM	SEM	P value[b]	P value[c]				
									Legume vs. SBM				
									Chickpea	Faba bean	Lentil	Lupin	Field pea
N	85.8	83.6	91.1	91.7	84.0	90.7	1.019	0.001	0.002	0.001	0.783	0.514	0.001
Indispensable AA													
Arg	93.0	90.2	95.2	97.1	89.0	94.8	0.540	0.001	0.021	0.001	0.650	0.006	0.001
His	85.6	82.6	90.6	91.8	82.2	91.8	1.020	0.001	0.001	0.001	0.412	0.986	0.001
Iso	81.1	82.7	90.5	90.5	80.4	90.7	1.201	0.001	0.001	0.001	0.919	0.919	0.001
Leu	82.4	84.3	91.0	92.0	81.5	90.7	1.063	0.001	0.001	0.001	0.843	0.393	0.001
Lys	86.1	87.0	91.9	87.4	86.3	90.5	1.155	0.001	0.011	0.040	0.398	0.062	0.014
Met	82.3	77.8	89.0	88.8	78.7	92.7	1.426	0.001	0.001	0.001	0.076	0.060	0.001
Phe	86.4	82.5	91.9	91.1	81.8	91.5	1.055	0.001	0.002	0.001	0.777	0.777	0.001
Thr	78.9	81.9	88.3	87.0	81.5	87.5	1.447	0.001	0.001	0.010	0.707	0.809	0.006
Val	81.7	82.6	90.2	89.0	80.6	89.8	1.242	0.001	0.001	0.001	0.810	0.662	0.001
Dispensable AA													
Ala	81.2	85.0	90.5	89.2	82.9	89.7	1.296	0.001	0.001	0.016	0.675	0.808	0.001
Asp	86.2	86.2	92.6	91.6	85.6	90.4	1.033	0.001	0.007	0.008	0.142	0.398	0.002
Cys	73.7	69.4	82.3	86.9	77.6	82.1	1.884	0.001	0.003	0.001	0.926	0.079	0.104
Glu	90.7	90.6	95.0	96.1	90.2	93.5	0.623	0.001	0.004	0.003	0.083	0.005	0.001
Gly	80.3	78.8	85.9	89.4	79.2	86.1	1.569	0.001	0.013	0.002	0.920	0.144	0.004
Pro	83.5	81.7	89.7	89.9	80.2	89.8	1.186	0.001	0.001	0.001	0.953	0.988	0.001
Ser	80.3	81.6	87.7	87.2	76.2	88.5	1.710	0.001	0.002	0.008	0.735	0.580	0.001
Tyr	81.7	81.0	89.6	92.2	83.1	91.5	1.095	0.001	0.001	0.001	0.229	0.677	0.001

AA, amino acids; N, nitrogen; SEM, standard error of the mean; SBM, soybean meal.

[a] Apparent digestibility values were standardised using the following basal ileal endogenous flow values (g/kg DM intake), determined by feeding a N-free diet: N, 3.60; Arg, 0.153; His, 0.064; Ile, 0.140; Leu, 0.21; Lys, 0.147; Met, 0.065; Phe, 0.186; Thr, 0.283; Val, 0.205; Ala, 0.151; Asp, 0.355; Cys, 0.137; Glu, 0.313; Gly, 0.178; Pro, 0.230; Ser, 0.240; Tyr, 0.142.

[b] P value for ANOVA is significantly different at $P < 0.05$.

[c] P value for orthogonal contrast indicates significance ($P < 0.05$) of heat-treated grain legumes vs SBM.

Table 7
Standardised digestible crude protein (CP) and amino acid contents (g/kg, as-received basis) of raw and heat-treated grain legumes fed to growing broilers.

Item	Chickpea		Faba bean		Lentil		Lupin		Field pea		SEM	P value[a]	P value[b]				
													Raw vs. HT				
	Raw	HT	Raw	HT	Raw	HT	Raw	HT	Raw	HT			Chickpea	Faba bean	Lentil	Lupin	Field pea
CP	182.8	174.8	213.5	206.8	233.7	241.5	244.9	276.1	143.1	147.5	2.570	0.001	0.033	0.074	0.040	0.001	0.227
Indispensable AA																	
Arg	18.70	17.80	20.98	21.05	21.35	22.23	26.90	32.48	12.65	12.03	0.128	0.001	0.001	0.682	0.001	0.001	0.002
His	4.70	3.93	5.35	5.33	7.83	8.73	6.00	7.70	3.48	3.38	0.070	0.001	0.001	0.803	0.001	0.001	0.323
Iso	7.10	6.83	8.05	7.98	7.85	8.90	8.48	11.83	5.35	5.93	0.121	0.001	0.118	0.664	0.001	0.001	0.002
Leu	13.03	12.20	15.38	14.60	15.23	16.28	15.58	20.93	9.78	10.13	0.184	0.001	0.003	0.005	0.001	0.001	0.187
Lys	13.08	12.48	15.78	11.88	15.58	12.40	12.10	15.28	12.00	11.48	0.176	0.001	0.0217	0.001	0.001	0.001	0.0427
Met	3.28	3.25	2.05	2.03	2.58	2.95	2.13	2.50	1.88	2.13	0.043	0.001	0.683	0.683	0.001	0.001	0.000
Phe	10.70	10.53	9.20	8.90	10.63	11.45	9.08	12.25	7.08	7.50	0.112	0.001	0.278	0.067	0.001	0.001	0.011
Thr	6.08	5.78	7.30	7.23	8.18	8.25	8.33	10.58	5.75	5.85	0.145	0.001	0.154	0.717	0.717	0.001	0.630
Val	8.20	7.83	9.70	9.58	10.23	10.93	9.33	12.60	6.55	6.98	0.140	0.001	0.068	0.533	0.001	0.001	0.040
Dispensable AA																	
Ala	7.55	7.33	8.90	8.30	8.90	9.18	8.20	10.85	6.50	6.43	0.129	0.001	0.228	0.003	0.142	0.001	0.685
Asp	22.50	21.55	24.83	24.10	24.83	27.10	23.53	33.13	17.93	17.73	0.298	0.001	0.031	0.095	0.001	0.001	0.638
Cys	2.30	2.20	2.28	2.10	2.00	1.98	2.78	3.23	2.13	2.28	0.061	0.001	0.255	0.051	0.774	0.001	0.092
Glu	32.40	32.08	37.93	36.03	42.30	39.40	52.28	63.98	42.95	24.68	0.313	0.001	0.468	0.001	0.001	0.001	0.001
Gly	7.33	6.80	9.05	7.43	9.60	7.88	11.83	13.65	7.03	6.75	0.185	0.001	0.053	0.001	0.001	0.001	0.301
Pro	7.60	7.35	8.70	8.33	8.65	8.88	9.75	13.03	5.98	6.25	0.124	0.001	0.164	0.040	0.209	0.001	0.127
Ser	8.70	6.15	9.55	7.65	10.50	9.55	11.48	14.83	6.73	7.25	0.211	0.001	0.001	0.001	0.003	0.001	0.088
Tyr	5.50	4.93	7.43	7.03	7.30	7.25	9.38	11.80	5.60	5.55	0.103	0.001	0.001	0.010	0.733	0.001	0.733

AA, amino acids; SEM, standard error of the mean; HT, steam conditioned for 30 s at 80°C. Crude protein (CP) = N x 6.25.

[a] P value for ANOVA is significantly different at $P < 0.05$.

[b] P value for orthogonal contrast indicates significance ($P < 0.05$) of raw vs heat-treated grain legumes.

Table 8
Standardised digestible crude protein (CP) and amino acid contents (g/kg, as-received basis) of raw grain legumes compared to soybean meal fed broilers.

Item	Chickpea	Faba bean	Lentil	Lupin	Field pea	SBM	SEM	P value[a]	P value[b] Legume vs. SBM				
									Chickpea	Faba bean	Lentil	Lupin	Field pea
CP	182.8	213.5	233.7	244.9	143.1	372.8	2.570	0.001	0.001	0.001	0.001	0.001	0.001
Indispensable AA													
Arg	18.70	20.98	21.35	26.90	12.65	30.8	0.128	0.001	0.001	0.001	0.001	0.001	0.001
His	4.70	5.35	7.83	6.00	3.48	10.0	0.070	0.001	0.001	0.001	0.001	0.001	0.001
Iso	7.10	8.05	7.85	8.48	5.35	16.7	0.121	0.001	0.001	0.001	0.001	0.001	0.001
Leu	13.03	15.38	15.23	15.58	9.78	30.3	0.184	0.001	0.001	0.001	0.001	0.001	0.001
Lys	13.08	15.78	15.58	12.10	12.00	26.6	0.176	0.001	0.001	0.001	0.001	0.001	0.001
Met	3.28	2.05	2.58	2.13	1.88	7.3	0.043	0.001	0.001	0.001	0.001	0.001	0.001
Phe	10.70	9.20	10.63	9.08	7.08	20.3	0.112	0.001	0.001	0.001	0.001	0.001	0.001
Thr	6.08	7.30	8.18	8.33	5.75	15.8	0.145	0.001	0.001	0.001	0.001	0.001	0.001
Val	8.20	9.70	10.23	9.33	6.55	18.7	0.140	0.001	0.001	0.001	0.001	0.001	0.001
Dispensable AA													
Ala	7.55	8.90	8.90	8.20	6.50	17.6	0.129	0.001	0.001	0.001	0.001	0.001	0.001
Asp	22.50	24.83	24.83	23.53	17.93	47.7	0.298	0.001	0.001	0.001	0.001	0.001	0.001
Cys	2.30	2.28	2.00	2.78	2.13	5.3	0.061	0.001	0.001	0.001	0.001	0.001	0.001
Glu	32.40	37.93	42.30	52.28	42.95	94.8	0.313	0.001	0.001	0.001	0.001	0.001	0.001
Gly	7.33	9.05	9.60	11.83	7.03	17.1	0.185	0.001	0.001	0.001	0.001	0.001	0.001
Pro	7.60	8.70	8.65	9.75	5.98	21.5	0.124	0.001	0.001	0.001	0.001	0.001	0.001
Ser	8.70	9.55	10.50	11.48	6.73	20.4	0.211	0.001	0.001	0.001	0.001	0.001	0.001
Tyr	5.50	7.43	7.30	9.38	5.60	16.5	0.103	0.001	0.001	0.001	0.001	0.001	0.001

AA, amino acids; SEM, standard error of the mean; SBM, soybean meal. Crude protein (CP) = N x 6.25.
[a] P value for ANOVA is significantly different at $P < 0.05$.
[b] P value for orthogonal contrast indicates significance ($P < 0.05$) of raw grain legumes vs SBM.

Table 9
Standardised digestible crude protein (CP) and amino acid contents (g/kg, as-received basis) of heat-treated grain legumes compared to soybean meal fed to broilers.

Item	Chickpea	Faba bean	Lentil	Lupin	Field pea	SBM	SEM	P value[a]	P value[b] Legume vs. SBM				
									Chickpea	Faba bean	Lentil	Lupin	Field pea
CP	174.8	206.8	241.5	276.1	147.5	372.8	2.570	0.001	0.001	0.001	0.001	0.001	0.001
Indispensable AA													
Arg	17.80	21.05	22.23	32.48	12.03	30.8	0.128	0.001	0.001	0.001	0.001	0.001	0.001
His	3.93	5.33	8.73	7.70	3.38	10.0	0.070	0.001	0.001	0.001	0.001	0.001	0.001
Iso	6.83	7.98	8.90	11.83	5.93	16.7	0.121	0.001	0.001	0.001	0.001	0.001	0.001
Leu	12.20	14.60	16.28	20.93	10.13	30.3	0.184	0.001	0.001	0.001	0.001	0.001	0.001
Lys	12.48	11.88	12.40	15.28	11.48	26.6	0.176	0.001	0.001	0.001	0.001	0.001	0.001
Met	3.25	2.03	2.95	2.50	2.13	7.3	0.043	0.001	0.001	0.001	0.001	0.001	0.001
Phe	10.53	8.90	11.45	12.25	7.50	20.3	0.112	0.001	0.001	0.001	0.001	0.001	0.001
Thr	5.78	7.23	8.25	10.58	5.85	15.8	0.145	0.001	0.001	0.001	0.001	0.001	0.001
Val	7.83	9.58	10.93	12.60	6.98	18.7	0.140	0.001	0.001	0.001	0.001	0.001	0.001
Dispensable AA													
Ala	7.33	8.30	9.18	10.85	6.43	17.6	0.129	0.001	0.001	0.001	0.001	0.001	0.001
Asp	21.55	24.10	27.10	33.13	17.73	47.7	0.298	0.001	0.001	0.001	0.001	0.001	0.001
Cys	2.20	2.10	1.98	3.23	2.28	5.3	0.061	0.001	0.001	0.001	0.001	0.001	0.001
Glu	32.08	36.03	39.40	63.98	24.68	94.8	0.313	0.001	0.001	0.001	0.001	0.001	0.001
Gly	6.80	7.43	7.88	13.65	6.75	17.1	0.185	0.001	0.001	0.001	0.001	0.001	0.001
Pro	7.35	8.33	8.88	13.03	6.25	21.5	0.124	0.001	0.001	0.001	0.001	0.001	0.001
Ser	6.15	7.65	9.55	14.83	7.25	20.4	0.211	0.001	0.001	0.001	0.001	0.001	0.001
Tyr	4.93	7.03	7.25	11.80	5.55	16.5	0.103	0.001	0.001	0.001	0.001	0.001	0.001

AA, amino acids; SEM, standard error of the mean; SBM, soybean meal. Crude protein (CP) = N x 6.25.
[a] P value for ANOVA is significantly different at $P < 0.05$.
[b] P value for orthogonal contrast indicates significance ($P < 0.05$) of heat-treated grain legumes vs SBM.

Compared to SBM, TIA concentration in chickpea (3.19 mg/g) was greater, but digestibility of N and most AA were not different. Ravindran et al. (2005) attributed poor digestibility of CP and all AA for chickpea compared to SBM fed to 42-day-old male broilers to TIA and haemagglutinins. Likewise, Thacker et al. (2002) reported low CP digestibility for chickpea (Desi and kabuli varieties) compared to SBM in pigs.

The SID of AA for raw faba bean were greater than reported by Smit et al. (2021), Masey O'Neill et al. (2012) and Olukosi et al. (2019), but lower than that reported by Adekoya and Adeola (2023a). In the present study, lysine digestibility for faba bean and SBM was not different, but sulphur-containing AA were poorly digested in faba bean. This pattern agreed with findings of Olukosi et al. (2019) and Koivunen et al. (2016). Several factors such as trypsin inhibitor and condensed tannin negatively influence AA digestibility of faba bean (Gatel, 1994; Koivunen et al., 2016). In the present study, TIA in raw faba bean (0.63 mg/g) was lower than that of SBM (0.66 mg/g). However, tannin was not measured. Tannins reduce digestibility by complexing with both feed CP to reduce availability to enzymes (Castell et al., 1996), and proteases to inhibit enzymatic activity (Woyengo and Nyachoti, 2012).

Steam conditioning of lentil, lupin and field pea had little influence on AA digestibility, however, it reduced digestibility of most AA in faba bean. Heating also reduced digestibility of N and AA in chickpea, except for lysine, cysteine, glycine and serine that remained unchanged. Liu et al. (2013) reported no effect on AA digestibility for 28-day broilers fed a steam pelleted (95℃) sorghum-SBM-based diet (reground mash). However, this is contrary to findings in pigs (Hugman et al., 2021), where steam pelleting of lentil (mash fed) at 80–85℃ improved CP and AA digestibility, but had no effect on TIA. Authors attributed the improvement to protein denaturation that enhanced accessibility of protein to protease. Likewise, Carre (1991) reported improved apparent CP digestibility for young broilers fed field pea pelleted at 75–81℃. The effect of heating on feed largely depends on temperature and duration (Christodoulou et al., 2006; Hejdysz et al., 2016). Pelleting, as performed by Hugman et al. (2021), results in additional heating from mechanical shear stress as feed is forced through the pellet die (Skoch et al., 1981). Grain legumes in the present study were not pelleted but only steam-conditioned, therefore, heating may not have been sufficient to influence AA digestibility of lentil, lupin and field pea. The effect of heating is also influenced by physical and chemical properties of the seed (Carre et al., 1991), as such, feed materials respond differently to heating (Gonzalez-Vega et al., 2011). The variable effect of heating on AA (lysine unchanged) in chickpea and faba bean in the present study agreed with findings of Lichovnikova et al. (2004). Frikha et al. (2013) reported that autoclaving (108℃) of pea protein concentrates from two cultivars (PPC-1 and PPC-2) gave varying AA digestibility for 21-day broilers. They observed an improvement of SID of all AA in PPC-1, while in PPC-2 digestibility of lysine, methionine, threonine and aspartic acid were not changed.

5. Conclusion

This study demonstrated that digestibility of CP and most AA in raw lupin, lentil and chickpea are not different from SBM. However, due to their lower AA content, an additional CP source or synthetic AA may be needed to form a balanced diet. Also, the variable effect of heating on AA digestibility of grain legumes suggest that thermal processing techniques might have different effects on feed material.

Declaration of Generative AI and AI-assisted technologies in the writing process

Authors did not use generative AI or AI-assisted technologies at any stage in the planning, execution, and analysis of experimental work or in preparation of this manuscript.

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Timothy J Wester, M. Reza Abdollahi, and Obright Hamungalu report financial support was provided by AgriFutures Australia. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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