Effects of rapeseed variety and oil extraction method on the content and ileal digestibility of crude protein and amino acids in rapeseed cake and softly processed rapeseed meal fed to broiler chickens

Kasprzak, MM; Houdijk, JGM; Kightley, S; Olukosi, OA; White, GA; Carre, P; Wiseman, J

Published in:
Animal Feed Science and Technology

DOI:
10.1016/j.anifeedsci.2016.01.002

First published: 06/01/2016

Document Version
Peer reviewed version

Title: Effects of rapeseed variety and oil extraction method on the content and ileal digestibility of crude protein and amino acids in rapeseed cake and softly processed rapeseed meal fed to broiler chickens

Author: M.M. Kasprzak J.G.M. Houdijk S. Kightley O.A. Olukosi G.A. White P. Carre J. Wiseman

PII: S0377-8401(16)30002-5
DOI: http://dx.doi.org/doi:10.1016/j.anifeedsci.2016.01.002
Reference: ANIFEE 13447

To appear in: *Animal Feed Science and Technology*

Received date: 2-6-2015
Revised date: 3-1-2016
Accepted date: 4-1-2016

Effects of rapeseed variety and oil extraction method on the content and ileal digestibility of crude protein and amino acids in rapeseed cake and softly processed rapeseed meal fed to broiler chickens

M. M. Kasprzak[a,*], J.G.M. Houdijk[b], S. Kightley[c], O.A. Olukosi[b], G. A. White[a], P. Carre[d] and J. Wiseman[a]

[a] School of Biosciences, University of Nottingham, Sutton Bonington, Loughborough LE12 5RD, United Kingdom

[b] Monogastric Science Research Centre, Scotland's Rural College, EH9 3JG, United Kingdom

[c] National Institute of Agricultural Botany, Cambridge CB3 0LE, United Kingdom

[d] CREOL, Pessac, 33600, France.

*Corresponding author: Miroslaw Kasprzak Tel. (+44)1159516301

EM: miroslaw.kasprzak@nottingham.ac.uk

Highlights

- Thirteen varieties of rapeseed were de-oiled by hexane extraction and cold-pressing.
- Twelve soft rapeseed meal (SRSM) and four rapeseed cakes (RSC) were fed to chickens.
- Content of crude protein (CP) and amino acids (AA) varied depending on RSC and SRSM.
- Digestibility of CP and AA depended on a rapeseed variety and processing method.

Abstract

We examined the effects of rapeseed variety and oil extraction method on crude protein (CP) and amino acid (AA) content in rapeseed co-products, and determined their coefficient of apparent (AID) and standardised ileal digestibility (SID) in broiler chickens. Sixteen rapeseed samples were de-oiled; four were cold-pressed producing rapeseed cake (RSC) and twelve were mild processed and hexane-extracted producing soft rapeseed meal (SRSM). One batch of the variety Compass, grown on the same farm, was processed using both methods obtaining Compass RSC and Compass SRSM. DK Cabernet rapeseed variety, grown on three different farms, was used to produce two SRSM batches and one RSC batch. All rapeseed co-products were ground through a 4 mm screen and mixed into semi-synthetic diets at a level of 500 g/kg. Day-old Ross 308 male broilers were fed a commercial diet for 14 days. A total of 96 pairs of birds were then allotted to 1 of 16 dietary treatments (n=6) and fed a test diet for 8 days. Birds were then culled allowing removal of ileal digesta from Meckel's diverticulum to the ileal-caecal junction. Digestibility of CP and AA was determined using titanium dioxide as an inert marker. The SRSM samples had an increased content of CP (419 to 560 g/kg DM) compared to RSC samples (293 to 340 g/kg DM). Both AID and SID of lysine, and SID of arginine, histidine and threonine were greater in Compass RSC compared to its SRSM counterpart ($P<0.05$). However, AID and SID of AA did not differ in both DK Cabernet SRSM, cultivated in two different farms ($P>0.05$). The SID of lysine was on average 0.03 units greater ($P<0.001$) in RSC than in SRSM. The SRSM produced from variety PR46W21 showed similar or greater AID and SID of individual AA than the RSC from four other rapeseed varieties. It is concluded that selection of rapeseed varieties and extraction method have a potential to deliver high protein dietary ingredients with a good digestibility value.

Keywords: digestibility, broiler, rapeseed cake, rapeseed meal, amino acid.

Abbreviations: AA, amino acid; AID, coefficient of apparent ileal digestibility; Arg, arginine; *B. napus, Brassica napus*; CP, crude protein; DM, dry matter; DMI, dry matter intake; FI, feed intake; GLS, glucosinolates; His, histidine; ; $IAAL_B$, basal ileal endogenous amino acid losses; Ile, isoleucine; Leu, leucine; Lys, lysine; Lys:CP ratio; M+C, methionine and cysteine; NDF, neutral detergent fibre; Phe, phenylalanine; RSC, rapeseed cake; RSE, rapeseed expeller; RSM, rapeseed meal; SBM, soybean meal; SEM; standard error of the difference mean; SID, coefficient of standardised ileal digestibility; SRSM, soft rapeseed meal; TAA, total amino acids; Val, valine.

1. Introduction

The strong dependence of the British livestock sector on imported protein-rich feeds such as soybean meal (SBM), is prompting investigations into the nutritional value of home-grown protein alternatives for animal production. As the European Union is the greatest producer of *Brassica napus* (*B. napus*) rapeseed worldwide (USDA, 2015), rapeseed co-products are of considerable interest as a protein source in animal diets. Compared to SBM, rapeseed meal (RSM) contains considerably less lysine but more sulphur-containing amino acids (AA) (Khajali and Slominski, 2012). The indices for the quality of rapeseed protein may be as high as those of animal protein (e.g. eggs) and far higher than those of other legume or cereal sources (e.g. peas and wheat, respectively) with a high content of indispensable AA (Thompson et al., 1982; Friedman, 1996).

Rapeseed traditionally contains high contents of erucic acid, glucosinolates and fibre, but plant breeding improvement has delivered varieties of *B. napus* with low levels of erucic acid (<20 g/kg) and glucosinolates (<30 µmol/g) in defatted co-products in recent decades (Maison and Stein, 2014). These varieties are called “double-low” or “double zero” rapeseed in Europe, and “canola” in Australia and North America (Newkirk, 2009).

Rapeseed co-products are currently used as a protein ingredient in animal diets; however the nutritional value, measured by protein digestibility, varies and is often reported as being lower than that of SBM (Adedokun et al., 2008). The low digestibility of protein in rapeseed has been associated with components such as enzyme inhibitors, phenolic compounds, glucosinolates and dietary fibre (Rayner and Fox, 1976; Bell, 1993). Moreover, the nutritional value of rapeseed protein is influenced by many different factors that are closely related to the concentration of components and the processing technology employed. The concentration of components in rapeseed co-products (e.g. protein, fibre and oil) might differ considerably depending on the seed cultivars, growing conditions, harvesting time, seed storage conditions, seed drying temperature and further processing such as de-hulling, heat treatment, oil removal method and pelleting (Bell, 1993; Newkirk et al., 2003a, Liu et al. 2014).

Rapeseed co-products are commercially produced using two main de-oiling methods: hexane extraction producing RSM and cold-pressing producing rapeseed cake (RSC). Hexane extraction involves processing at a high temperature (up to 130 ^{o}C) that supports greater extraction of the oil and results in a RSM with less than 50 g residual oil/kg (Woyengo et al. 2010; personal communication, Patrick Carre). Cold-pressing involves crushing of rapeseeds without additional heat supply, delivering a virgin oil and co-products with a high residual oil content (>170 g/kg) (Leming and Lember, 2005). The majority of the crop is crushed, heat treated and then hexane extracted in large industrial complexes, whereas a small proportion of the crop is processed by cold-pressing, mainly on farms by growers or small to medium enterprises.

Mixed varieties of rapeseed are often collected and processed by hexane extraction, which produces rapeseed co-products with potentially differing AA and crude protein (CP) digestibility. Thus, commercially available rapeseed co-products vary in digestibility of AA and CP due to the variation depending on rapeseed co-product origin including cultivar and processing, but also on the level of substitution of RSM/RSC into a diet as well as animal species tested (Zhou et al., 2013; Qaisrani et al., 2014). Therefore, a lack of consistency in selection of rapeseed varieties leads to difficulties in estimation of nutritional value of rapeseed co-products in animal diets.

A recent investigation at a rapeseed pilot plant (CREOL, Pessac, France) showed that decreasing the residence time (RT) in the desolventiser/toaster during the hexane extraction led to production of RSM with a greater content and digestibility of lysine, measured in pigs (Eklund et al. 2015). The reduction of heat treatment in rapeseed processing has the potential to improve digestibility of AA in the final co-products. The aim of the present study was to compare the effects of soft processing by hexane extraction or cold pressing of Western rapeseed varieties on content and digestibility of CP and AA in rapeseed co-products fed to broiler chickens.

2. Material and methods

2.1. Rapeseed co-products and diet formulation

Thirteen varieties of oilseed rape were grown in four South Eastern counties of the United Kingdom (UK) and harvested in 2013. Seven rapeseed varieties were grown in Cambridgeshire (Ability, Avatar, DK Cabernet, NK Grandia, PR46W21, Quartz and Sesame), three in Lincolnshire (Excalibur, Trinity, V2750L), two in Norfolk (Compass and

Incentive) and one in Suffolk (Palmedor). Eleven varieties were characterised as double low varieties, of which ten were winter, and one was spring (Ability). Further diversity was derived by the inclusion of a single-low, high erucic acid oil variety (Palmedor) and a relatively new variety with high oleic and low linolenic oil composition with a high glucosinolate content (V2750L). Twelve rapeseed batches were de-fatted by mild hexane extraction producing a soft rapeseed meal (SRSM), and four batches were cold-pressed producing a RSC.

The hexane extraction was performed at a pilot plant (CREOL, Pessac, France). Each of the rapeseed batches was subjected to conditioning. The seeds were dried to a moisture content of approximately 70 g/kg in a static dryer with movable containers of 1.6 x 1.2 m surface connected to a warm air generator using air at 70 °C. Unlike standard industrial processing, the seeds were softly processed by excluding the cooking step before the pressing and heat supply during the seed crushing. After conditioning, the seeds were cold-pressed at a rate of 250 kg/h using a MBU 75 press (La Mécanique Moderne, France) with a gap between pressing each batch 20 min, in order to avoid mixing the varieties. The expeller meal was then pelletized in 6 mm pellets to prevent possible differences in percolation during the extraction. Pellets were transferred immediately into the extractor. Continuous extraction was undertaken in a belt diffuser (Desmet Ballestra, Belgium). The expeller was leached by a counterflow of hexane in 6 stages. The flow of hexane at 50-55 °C was 230 L/h, resulting in the meal extraction at the rate 140 kg/h (standard deviation, SD: 12 kg/h). Subsequently, by a semi-continuous mode, the meal was forwarded to the desolventisation unit using a 6 tray continuous desolventiser (Desmet Ballestra, Belgium). The RT was 80 min for the following rapeseed varieties: Avatar, Compass, Incentive, Palmedor, PR46W21, Quartz, and DK Cabernet2. The variety of Ability, DK Cabernet1, V2750L, and Excalibur had a RT of 65, 86, 90, and 110 min, respectively. Direct steam was injected at 25 kg/h by the bottom tray with the temperature 102.5 °C (SD: 4.5 °C) to the mass of the de-oiled meal.

The cold-pressing was performed at a local plant in Norfolk (UK). The seeds were crushed at rate of 50 kg/h by a Kern Kraft KK40 press (Egon Keller Gmbh, Remscheid, Germany). The rate of pressing led to an increased temperature of exiting RSC to 55 °C. The cake was expelled through a 10 mm sieve plate, as pellets.

Compass variety grown on one farm was further processed using both methods, providing the possibility to compare the oil extraction methods without confounding effects of variety. Furthermore, DK Cabernet had been grown in three different farms in Cambridgeshire; seeds from two farms were de-fatted by hexane extraction (DK Cabernet SRSM1 and DK Cabernet SRSM2), whilst DK Cabernet seeds from a third farm were processed through cold-pressing.

The resulting twelve SRSM and four RSC samples were ground using a Pulverisette 15 cutting mill (Fritsch GmbH, Idar-Oberstein, Germany) fitted with a 4 mm screen. Then, they were added at one inclusion rate (500 g/kg) into a semi-synthetic diet consisting of wheat starch, glucose, vitamin and minerals, rapeseed oil and titanium dioxide (Table 1).The diets were mixed in a commercial planetary dough mixer.

2.2. Animal study

A total of 192 day-old male Ross 308 broilers were obtained from a British designated breeder (PD Hook Hatcheries Ltd., Thirsk, UK) and housed in the Animal Facility at the School of Biosciences, University of Nottingham. Birds were housed in pairs, in cages of 37 cm wide, 42 cm tall and 30 cm deep, containing a roost. The animal experiment was conducted according to protocols approved by Ethical Review Committee and followed official guidelines for the care and management of birds.

Prior to the trial period, chicks were fed a commercial diet based on wheat and de-hulled SBM (190 g CP/kg as-fed; Chick Starter Crumb, Dodson and Horrell Ltd., Northamptonshire, UK) for 14 days. Subsequently, birds were allocated to the sixteen dietary treatments in a randomized complete block design with each treatment replicated six times. Each experimental diet was allocated to six cages, i.e. 12 birds in total, for eight days. At the end of the trial, the feed intake (FI) of experimental diets was measured and then all birds were culled by asphyxiation with carbon dioxide followed by cervical dislocation to confirm death. The ileal region of the gut was dissected out from the Meckel's diverticulum to the ileo-caecal junction and the ileal contents of the two birds per cage were pooled and collected into a plastic screw-top container and immediately frozen at -20 °C until subsequent analysis.

2.3. Analysis

Dry matter (DM) for RSC, SRSM and diets was determined in duplicate with samples weighing 60 to 65 g that were dried at 100 ^{o}C in a forced air convection oven. Ileal digesta was frozen and then freeze-dried when determining DM. Dried samples were ground through a 0.5 mm sieve using a centrifugal mill (ZM200, Retsch GmbH, Germany). The content of titanium dioxide (TiO_2) was determined using the method of Short et al. (1996). The total amino acid (TAA) content in RSC, SRSM and ileal digesta was determined by hydrolysis of protein, oxidisation with performic acid and further neutralisation with sodium metabisulphite (Llames and Fontaine, 1994). The contents of AA were quantified with the internal standard method by measuring the absorption of reaction products with ninhydrin. Total nitrogen (N) was analysed as follows: 5 to 6 mg of RSC, SRSM and ileal digesta were weighed in aluminium crucibles and burned in furnaces at 900 °C/1060 °C, using CHNS-O Analyser (CE Instruments Ltd, UK) (AOAC, 2000). Sulphanilamide (cert. no.: 183407, CE Instruments Ltd, UK) was used as an internal standard. The content of CP was calculated by multiplying N by 6.25. Neutral detergent fibre (NDF) was assayed with a heat stable amylase and expressed inclusive of residual ash (EN ISO, 2006). Content of total glucosinolates was determined using high pressure liquid chromatography using sinigrin as an internal standard (EN ISO, 1994).

2.4 Calculations

The lysine:crude protein ratio (Lys:CP) for each batch was calculated by expressing the concentration of lysine in the sample as a percentage of the CP in the samples (Gonzalez-Vega et al., 2011).

Coefficient of apparent ileal digestibility (AID) of CP and AA in the assay diets was calculated according to the following equation:

$$\text{AID} = 1 - \left[\frac{I_D \times A_I}{A_D \times I_I}\right]$$

Where I_D = marker content in the assay diet (g/kg of DM), A_I = AA or CP content in ileal digesta (g/kg of DM), A_D = AA or CP content in the assay diet (g/kg of DM), I_I= marker concentration in ileal digesta (g/kg of DM).

Coefficient of standardised ileal digestibility (SID) in the assay diets was calculated according to the following equation:

$$\text{SID} = \text{AID} + \left[\frac{\text{IAAL}_B}{\text{AA}_I} \times 100\%\right]$$

Where IAAL_B = basal ileal endogenous AA losses (g/kg DMI), AA_I = AA concentration in the assay diet (g/kg DM). The following IAAL_B were used; arginine 0.216, histidine 0.209, isoleucine 0.390, leucine 0.381, lysine 0.255, methionine + cysteine 0.257, phenylalanine 0.237, threonine 0.571 and valine 0.440 g/kg dry matter intake (DMI) (Lemme et al. 2004, Masey O'Neill et al. 2014).

2.5. Statistical analysis

In the randomized design experiment, the digestibility values were tested using one-way ANOVA with a rapeseed variety set as the treatment, and a digestibility coefficient as Yvariable. An additional set of three contrasts was used to assess differences between 1) Compass RSC and Compass SRSM, 2) DK Cabernet SRSM1 and DK Cabernet SRSM2, and 3) RSC and SRSM across all varieties. The relationships between the content of NDF, glucosinolates and FI and digestibility of CP and AA were analysed by a linear regression analysis. All statistical analysis was performed using GenStat (15 Edition, VSN International, Hemel Hempstead, UK). Data were expressed as least squares means with differences considered statistically significant at $P<0.05$.

3. Results

3.1. Rapeseed co-products

The chemical composition of RSC and SRSM is shown in Table 2. DK Cabernet SRSM1 and DK Cabernet SRSM2 had similar amounts of CP and a sum of TAA without tryptophan. Compass SRSM had greater CP and TAA values (468 and 386 g/kg DM) than its RSC counterpart (293 and 256 g/kg DM). The content of TAA in rapeseed co-products varied substantially depending on rapeseed varieties; ranging from 256 to 305 g/kg in RSC, and from 396 to 457 g/kg DM in SRSM, while the content of CP varied from 293 to 340 g/kg in RSC and from 419 to 560 g/kg DM in SRSM. The average ratio of Lys:CP was lower across SRSM (5.1%) compared to RSC (5.6%). Similarly, the content of lysine appeared to be slightly decreased in SRSM, with 4.9% in Compass SRSM compared to 5.2% in Compass RSC. The soft hexane extraction lowered the content of glucosinolates (7.4 µmol/g DM) in Compass SRSM compared to cold-pressed Compass RSC (11.1 µmol/g DM). All rapeseed co-products had the content of glucosinolates below 30 µmol/g DM, with the exception of V2750L SRSM with 47.4 µmol/g DM. The contents of NDF ranged from 226 to 283 and 239 to 251 g/kg DM for SRSM and RSC, respectively.

The FI of rapeseed diets varied depending on a rapeseed variety origin. Across the RSC varieties, the FI was 108, 109, 127 and 131 g as-fed/day for Sesame, NK Grandia, DK Cabernet and Compass RSC, respectively. Among the SRSM, the FI was 136, 139, 141, 145, 149, 150, 152, 154, 155, 155, 161, 161 g as-fed/day for Excalibur, Incentive, Quartz, V2750L, Trinity, DK Cabernet SRSM2, DK Cabernet SRSM1, Palmedor, PR46W21, Compass, Ability and Avatar, respectively.

3.2. Apparent ileal digestibility

Apparent ileal digestibility coefficients for CP and AA are shown in Table 3. The AID of all CP and AA was almost identical between DK Cabernet SRSM1 and DK Cabernet SRSM2. The AID of lysine was greater by 0.04 units in Compass RSC compared to its SRSM counterpart ($P=0.002$). Within RSC, the AID of CP and AA did not differ markedly between the varieties used (with the exception of AID of isoleucine). However, AID of CP and AA in SRSM significantly varied among the varieties, being the greatest for PR46W21 and lowest for Quartz within the SRSM group. Average AID of lysine was greater ($P<0.001$) and AID of valine was smaller ($P<0.001$) for the four sources of RSC compared to twelve sources of SRSM.

3.3. Standardised ileal digestibility

Similarly to AID, SID of AA did not differ substantially between DK Cabernet SRSM1 and DK Cabernet SRSM2 within SRSM group (Table 4). The SID of arginine, histidine, lysine and threonine was greater by 0.03, 0.04, 0.05 and 0.04 units for Compass RSC compared to Compass SRSM ($P<0.05$). Standardised ileal digestibility coefficients of all AA were significantly different among the twelve SRSM varieties, whereas none of SID of AA changed markedly among the four RSC varieties. Standardised ileal digestibility coefficient of AA was the greatest in PR46W21 and lowest in Quartz among SRSM varieties ($P<0.05$).

The average SID of arginine, histidine, lysine and phenylalanine was greater in RSC compared to SRSM (P<0.05).

3.4. Relationships between the chemical composition, feed intake and digestibility of rapeseed co-products

There was no significant correlation between the content of NDF and digestibility of CP or AA. Similarly, the content of glucosinolates in the rapeseed co-products did not show any relationship with AID of CP and AA or SID of AA (P>0.05). However, the content of NDF showed a positive relationship with feed intake (coefficient of determination, r^2=0.32, P=0.022)

4. Discussion

Rapeseed co-products contain glucosinolates and NDF, which are anti-nutritional factors that may reduce FI (Seneviratne et al. 2010, Eklund et al., 2015). Although a high inclusion of rapeseed co-products was used in diets, we did not observe any negative effect of glucosinolates or NDF on FI.

4.1. Chemical composition

The content of CP and AA (with the exception of methionine and cysteine) was greater in SRSM and lower in RSC compared to standard processed RSM and rapeseed expellers (RSE), reported by other researchers. A recent study of Liu et al. (2014) tested low-temperature processed canola meal (CM-LT), conventional canola meal (CM-CV) and high temperature processed canola meal (CM-HT) from the conventional prepress solvent extraction process with desolventiser/toaster temperature for production of CM-LT and CM-CV of 91-95 °C and for CM-HT of 99-105 °C. The chemical content of CM-HT, CM-LT and

CM-CV resulted in a similar characteristics; thus CP was 386-409 g/kg, arginine 21.1-23.6 g/kg, histidine 9.7-10.9 g/kg, leucine 25.8-28.1 g/kg, lysine 20.3-23.3 g/kg or phenylalanine 14.7-15.9 g/kg DM. Similarly, a study of Maison and Stein (2014) that characterised the AA content of seven canola meals, ten 00-RSM and five 00-RSE indicating no substantial difference in the composition of indispensable AA among all types of rapeseed co-products (such as arginine 21.5-23.8 g/kg or lysine 20.7-22.1 g/kg DM).

Differences in rapeseed cultivation conditions, oilseed crushing and extraction procedures influence the content of oil and protein and digestibility of components in the meals (Bell, 1993; Newkirk et al., 2003a). All rapeseed varieties used in the current study were grown in similar climatic condition and harvested in the South East of Great Britain. Thus, DK Cabernet SRSM1 and DK Cabernet SRSM2 resulted in a very similar content of AA and CP. The influence of variety and environment on the biochemical analysis of rapeseed co-products in UK were described elsewhere (Kightley et al., 2015).

The effect of processing and variety caused substantial changes in the content of CP and TAA. Both CP and TAA content almost doubled in the Compass SRSM compared to Compass RSC, as well as mean SRSM vs RSC. Also, the content of NDF increased in Compass SRSM compared to Compass RSC. These changes were due to a greater removal of oil during the hexane extraction processing compared to the cold-pressing (Seneviratne et al. 2011a; 2011b).

Besides the increased content of CP and AA, the high temperature of de-oiling process might reduce the AA content in RSM (Gonzalez-Vega et al., 2011). The heating may lead to occurrence of the Maillard reaction, which causes binding of the protein-bound lysine and reducing sugars, and forms deoxyketosyl-lysine derivatives (Hurrell, 1990). Thus, the RT and temperature of desolventisation might be important factors for the content of AA in the final co-product.

Newkirk et al. (2003b) showed that desolventisation/toasting of canola processed at 110 °C with 150 g moisture/kg caused a significant loss of lysine, averaging 7% and, in the extreme case, 11.2% in the desolventised/toasted meal compared to non-toasted meal. Eklund et al. (2015) investigated the increasing residence times of 48, 64, 76, and 93 min in the desolventiser/toaster with combined application of indirect heat (850 kPa and 140 °C) and direct unsaturated steam (15 kg/h) injection; it was observed that the content of lysine linearly decreased from 19.5 to 17.2 g/kg DM as the residence time increased from 48 to 93 min.

A more sensitive indicator for the degree of heat damage is the Lys:CP ratio in feed ingredients (Gonzalez-Vega et al., 2011, Kim et al. 2012). In the current study, we used a relatively mild processing condition (105 °C) in order to minimise the possibility of overriding the variety variation across the SRSM. However, the content of lysine appeared to be slightly decreased in SRSM, indicating a smaller ratio of 4.9% in Compass SRSM compared to 5.2% in Compass RSC. Similarly, the average ratio of Lys:CP was greater across RSC (5.6%) compared to SRSM varieties (5.1%). The ratio varied from 4.5 to 5.5% across all SRSM, indicating that rapeseed variety substantially influences the content of lysine in the rapeseed co-product.

In the present study, the content of glucosinolates varied in rapeseed co-products depending on the rapeseed variety. It is important to notice that the SRSM variety V2750L had a high level of glucosinolates (47.4 µmol/g DM), therefore the use of this variety should be limited in poultry diets.

The content of glucosinolates was also affected by the processing method. Thermal treatment is efficient in deactivating glucosinolates (Jensen et al. 1995). Eklund et al. (2015) reported that the extension of RT in a toaster leads to glucosinolate reduction up to 6 µmol/g DM in final RSM. However, along with application of heat treatment in de-oiling, there are also negative effects on measures of protein quality such as the Lys:CP or digestibility of CP and AA in the rapeseed co-products.

4.2. Digestibility

Digestibility of CP and AA in RSC and SRSM was in broad agreement with previously published values in canola meal fed to broiler chickens (Lemme et al., 2004; Woyengo et al., 2010).

Heat treatment during rapeseed processing, along with the glycoproteins associated with the cell wall structure, might be responsible for a small decrease in AID and SID of CP and individual AA (such as lysine) in rapeseed co-product-rich diets when fed to broiler chickens (Khajali and Slominski, 2012). A study of Newkirk et al. (2003a) compared AID of CP and AA in rapeseed samples collected after various stages of prepress-solvent extraction, and included canola meal at 400 g/kg DM in broiler diets. The results showed a significant reduction in AID of CP, lysine and valine by 0.07 units in desolventised/toasted meal compared to the expeller form. In the current study, SRSM and RSC were added at 500 g/kg into diets, but such large changes in AID of CP and AA between Compass RSC and SRSM were not observed. This implies that both type of processing and rapeseed variety influence the digestibility of individual AA in the rapeseed co-products.

Within the hexane extraction method, the digestibility of CP and AA in rapeseed co-products might also be affected by the RT during the desolventisation process. The oil plants are obliged to produce the RSM with hexane losses lower than 500 ppm in the final product that is below of explosivity limit of hexane (Laisney, 1984). In the current study, the RT was of 80-90 min across most rapeseed varieties. The variations in the RT appeared to be due to physical differences in seed characteristics including content of oil or hull thickness, which overall contribute to adequate requirement of RT for each variety in order to remove sufficiently the hexane from the meal (Evrard and Guillaumin, 1983; Cardarelli and Crapiste, 1996). Interestingly, although the RT of Excalibur was almost twice as high as the RT of Ability, the digestibility of CP and AA for both SRSM was in a good agreement with SRSM of other varieties.

There were significant variations in AID and SID of individual AA due to the effect of rapeseed variety within SRSM group. As such, PR46W21 SRSM showed the greatest AID of CP and AA among SRSM group which was as high as, or greater, than digestibility of RSC from four rapeseed varieties. Thus, the PR46W21 rapeseed variety processed by mild hexane extraction shows potential for greater rapeseed co-product substitution for SBM in animal diets.

The content of dietary fibre and anti-nutritional factors in rapeseed co-products might be responsible for the differences in digestibility of AA and CP (Khajali and Slominski, 2012). The cell wall constituents of rapeseed hull such as pectin, cellulose and hemicellulose may bind AA released during protein hydrolysis and thereby decreases the AA absorption in the small intestine (Howard et al 1986, Bjergegaard et al 1991). Grala et al. (1999) reported a decrease in AID of CP and AA due to the association of protein to the fibre matrix in the rapeseed hulls diet fed to pigs. Similarly, Eklund et al. (2015) showed a close linear relationship between SID of CP and AA and the contents of NDF and glucosinolates in RSM fed to pigs. In contrast to previous studies, we did not observe any negative effect of NDF or glucosinolates on digestibility of CP and AA in rapeseed co-products fed to broiler chickens.

A recent increase in small and medium oil plants focusing on production of high quality virgin oil (Ghazani et al. 2014), is giving new perspectives to deliver rapeseed co-products with high quality rapeseed protein – derived from a single rapeseed variety. The present study showed that the choice of rapeseed variety and processing is important to increase the content of protein in the co-products as well as deliver a product with a consistent nutritional value.

5. Conclusion

The content of AA and CP was substantially changed in rapeseed co-products depending on the rapeseed variety and processing method used. Although there were some significant differences in AID and SID of AA between the cold-pressed and soft hexane extracted co-products, the current study showed that use of mild conditions in hexane extraction along with selection of the appropriate rapeseed variety (such as PR46W21) might result in as high as or greater digestibility of AA and CP in SRSM compared to cold-pressed cake. Thus, selection of rapeseed variety along with soft hexane extraction method may be beneficial to the feed and livestock industry, as it might create products with greater nutritional values in terms of CP and AA. Additionally, high digestibility values of AA and CP in RSC and SRSM suggests there is scope to increase the inclusion of rapeseed co-products in poultry commercial diets.

Conflict of interest statement for manuscript entitled “Effects of rapeseed variety and oil extraction method on the content and ileal digestibility of crude protein and amino acids in rapeseed cake and softly processed rapeseed meal fed to broiler chickens”

On behalf of all authors of this article, I would like to declare that none of the authors has a personal, financial or other relationship with other people or organisations that could inappropriately affect or bias the content of the paper.

Dr Miroslaw Kasprzak
Division of Animal Sciences
School of Biosciences
University of Nottingham
UK

5th January 2016

Acknowledgements

This work is funded by AHDB/HGCA (RD-2012-3812). SRUC receives support from Scottish Government (RESAS).

References

Adedokun, S.A., Adeola, O., Parsons, C.M., Lilburn, M.S., Applegate, T.J., 2008. Standardized Ileal Amino Acid Digestibility of Plant Feedstuffs in Broiler Chickens and Turkey Poults Using a Nitrogen-Free or Casein Diet. Poult. Sci. 87, 2535-2548.

AOAC, 2000. Official Methods of Analysis, 17th ed. Assoc. Off. Anal. Chem. Gaithersburg, MD.

Association Française de Zootechnie, Ajinomoto Eurolysine, Aventis Animal Nutrition, INRA, and Institut Technique des Cereales et des Fourrages., 2000. Amipig: Ileal standardised digestibility of amino acids in feedstuffs for pigs. Association Française de Zootechnie, Paris, France.

Bell, J.M., 1993. Factors Affecting the Nutritional-Value of Canola-Meal - a Review. Can. J. Anim. Sci. 73, 679-697.

Bjergegaard, C., Eggum, B.O., Jensen, S.K., Sørensen, H., 1991. Dietary fibres in oilseed rape: Physiological and antinutritional effects in rats of isolated IDF and SDF added to a standard diet. J. Anim. Physiol. Nutr. 66, 69-79.

Cardarelli, D.A., Crapiste, G.H., 1996. Hexane sorption in oilseed meals. JAOCS. 73, 1657-1661.

Eklund, M., Sauer, N., Schone, F., Messerschmidt, U., Rosenfelder, P., Htoo, J.K., Mosenthin, R., 2015. Effect of processing of rapeseed under defined conditions in a pilot plant on chemical composition and standardised ileal dgestibility in rapeseed meal for pigs. J. Anim. Sci. 93, 2813-2825.

EN ISO, 1994. Rapeseed. Determination of glucosinolates content. Part 2: Method using X-ray fluorescence spectrometry (ISO 9167-2:1994).

EN ISO, 2006. Animal feeding stuffs. Determination of amylase-treated neutral detergent fibre content (aNDF) (ISO 16472:2006).

Evrard, J., Guillaumin, R., 1983. La désolvantation des tourteaux de colza. Etudes et Recherches. 2, 445-452.

Friedman, M., 1996. Nutritional value of proteins from different food sources. A review. J. Agr. Food Chem. 44, 6-29.

Ghazani, S.M., Garcia-Llatas, G., Marangoni, A.G., 2014. Micronutrient content of cold-pressed, hot-pressed, solvent extracted and RBD canola oil: Implications for nutrition and quality. Eur. J. Lipid Sci. Tech. 116, 380-387.

Gonzalez-Vega, J.C., Kim, B.G., Htoo, J.K., Lemme, A., Stein, H.H., 2011. Amino acid digestibility in heated soybean meal fed to growing pigs. J. Anim. Sci. 89, 3617-3625.

Gopinger, E., Xavier, E.G., Elias, M.C., Catalan, A.A., Castro, M.L., Nunes, A.P., Roll, V.F., 2014. The effect of different dietary levels of canola meal on growth performance, nutrient digestibility, and gut morphology of broiler chickens. Poultry Sci. 93, 1130-1136.

Grala, W., Verstegen, M.W.A., Jansman, A.J.M., Huisman, J., van Leeuwen, P., 1999. Apparent protein digestibility and recovery of endogenous nitrogen at the terminal ileum of pigs fed diets containing various soyabean products, peas or rapeseed hulls. Anim. Feed Sci. Tech. 80, 231-245.

Howard, P., Mahoney, R.R., Wilder, T., 1986. Binding of amino acids by dietary fibres and wheat bran. Nutr. Rep. Int. 34, 135-140.

Hurrell, R.F., 1990. Influence of the Maillard Reaction on the Nutritional-Value of Foods. Adv. Lif. Sci. 245-258.

Jensen, S.K., Liu, Y.G., Eggum, B.O., 1995. The effect of heat tratment on glucosinolates and nutritional value of rapeseed meal in rats. Anim. Feed Sci. Technol. 53, 17-28.

Khajali, F., Slominski, B.A., 2012. Factors that affect the nutritive value of canola meal for poultry. Poult. Sci. 91, 2564-2575.

Kightley, S., Appleyard, H., Wiseman, J., Olukosi, O., Houdijk, J., 2015. The influence of variety and environment on the biochemical analysis of oilseed rape meal. 14th International Rapeseed Congress, Saskatoon, Canada. Book of abstracts. 412.

Kim, B.G., Kil, D.Y., Zhang, Y., Stein, H.H., 2012. Concentrations of analyzed or reactive lysine, but not crude protein, may predict the concentration of digestible lysine in distillers dried grains with solubles fed to pigs. J. Anim. Sci. 90, 3798-3808.

Laisney, J., 1984. L'huilerie moderne: art et techniques. Compagnie Française pour le Developpment des fibres textiles. Paris, 180-181.

Leming, R., Lember, A., 2005. Chemical composition of expeller-extracted and cold-pressed rapeseed cake. Agraarteadus, 103-109.

Lemme, A., Ravindran, V., Bryden, W.L., 2004. Ileal digestibility of amino acids in feed ingredients for broilers. World Poultry Sci. J. 423-438.

Llames, C. R., Fontaine, J. Determination of Amino-Acids in Feeds - Collaborative Study. J. AOAC Int. 1994, 77, 1362-1402.

Liu, Y., Song, M., Maison, T., Stein, H.H., 2014. Effects of protein concentration and heat treatment on concentration of digestible and metabolizable energy and on amino acid digestibility in four sources of canola meal fed to growing pigs. J. Anim. Sci. 92, 4466-4477.

Maison, T., Stein, H.H., 2014. Digestibility by growing pigs of amino acids in canola meal from North America and 00-rapeseed meal and 00-rapeseed expellers from Europe. J. Anim. Sci. 92, 3502-3514.

Masey O'Neill, H.V., White, G.A., Bedford, M.R., Htoo, J., Wiseman, J., 2014. Influence of the in vivo method and basal dietary ingredients employed in the determination of the amino acid digestibility of wheat-DDGS with broilers. Poultry Sc. 93, 1178-1185.

Newkirk, R., 2009. Canola Meal. Feed Industry Guide 4th Edition. Canola council.

Newkirk, R.W., Classen, H.L., Edney, M.J., 2003a. Effects of prepress-solvent extraction on the nutritional value of canola meal for broiler chickens. Anim. Feed Sci. Tech. 104, 111-119.

Newkirk, R.W., Classen, H.L., Scott, T.A., Edney, M.J., 2003b. The digestibility and content of amino acids in toasted and non-toasted canola meals. Can. J. Anim. Sci. 83, 131-139.

Qaisrani, S.N., Moquet, P.C.A., van Krimpen, M.M., Kwakkel, R.P., Verstegen, M.W.A., Hendriks, W.H., 2014. Protein source and dietary structure influence growth performance, gut morphology, and hindgut fermentation characteristics in broilers. Poult. Sci. 93, 3053-3064.

Rayner, C.J., Fox, M., 1976. Amino acid digestibility studies of autoclaved rapeseed meals using an in vitro enzymatic procedure. J. Sci. Fd. Agric. 27, 643-648.

Seneviratne, R.W., Beltranena, E., Goonewardene, L.A., Zijlstra, R.T., 2011a. Effect of crude glycerol combined with solvent-extracted or expeller-pressed canola meal on growth performance and diet nutrient digestibility of weaned pigs. Anim. Feed. Sci. Tech. 170, 105-110.

Seneviratne, R.W., Beltranena, E., Newkirk, R.W., Goonewardene, L.A., Zijlstra, R.T., 2011b. Processing conditions affect nutrient digestibility of cold-pressed canola cake for grower pigs. J. Anim. Sci. 89, 2452-2461.

Seneviratne, R.W., Young, M.G., Beltranena, E., Goonewardene, L.A., Newkirk, R.W., Zijlstra, R.T., 2010. The nutritional value of expeller-pressed canola meal for grower-finisher pigs. J. Anim. Sci. 88, 2073-2083.

Short, F.J., Gorton, P., Wiseman, J., Boorman, K.N., 1996. Determination of titanium dioxide added as an inert marker in chicken digestibility studies. Anim. Feed Sci. Tech. 59, 215-221.

Thompson, L.U., Boland, K., Chapkin, R., Jones, J.D., 1982. Nutritional-Evaluation of Residual Meal from Rapeseed Protein-Concentration Process in Rats. Nutr. Rep. Int. 25, 621-628.

USDA, Foreign Agricultural Service. Production, Supply and Distribution Online Database, query for Commodity:"Oilseed, rapeseed"; Data Type:"Production"; Country:"All countries"; Year: "2014","2015". Accessed 12 January 2015. http://apps.fas.usda.gov/psdonline/psdQuery.aspx.

Woyengo, T.A., Kiarie, E., Nyachoti, C.M., 2010. Metabolizable energy and standardized ileal digestible amino acid contents of expeller-extracted canola meal fed to broiler chicks. Poultr. Sci. 89, 1182-1189.

Zhou, X., Oryschak, M.A., Zijlstra, R.T., Beltranena, E., 2013. Effects of feeding high- and low-fibre fractions of air-classified, solvent-extracted canola meal on diet nutrient digestibility and growth performance of weaned pigs. Anim. Feed Sci. Tech. 179, 112-120.

Table 1. Dietary formulation

Ingredient	g/kg diet
RSC/SRSM	500
Wheat Starch	200
Glucose (Dextrose)	195
Vitamins and Minerals Premix*	50
Rapeseed Oil	50
Titanium dioxide	5

RSC, rapeseed cake; SRSM, soft rapeseed meal.
*Target Feeds, Whitchurch, Shropshire, UK. Content per kg of complete diet: 5 g phosphorous, 0.09 g magnesium, 7.5 g calcium, 1.5 g sodium, 0.6 mg copper (as copper sulphate), 160 µg selenium (as selenium BCP), 7500 IU vitamin A, 1500 IU vitamin D3, 10 IU vitamin E (as α-tocopherol acetate), 5 mg vitamin B_1, 4 mg vitamin B_2, 4 mg vitamin B_6, 10 µg vitamin B_{12}, 9 mg pantothenic acid, 1.5 mg folic acid, 150 µg biotin, 1500 mg choline.

Table 2. Contents of crude protein, amino acids, neutral detergent fibre and glucosinolates in rapeseed cake and soft rapeseed meal (g/kg DM as not stated otherwise)

Variety	DM	NDF	GLS*	CP	TAA	Arg	His	Ile	Leu	Lys	M+C	Phe	Thr	Val	Lys:CP**
Rapeseed cake															
Compass	899	239	11.1	293	256	16.3	7.2	10.9	19.7	15.3	16.2	11.4	12.6	14.5	5.2

Sesame	890	249	20.5	332	293	18.4	8.6	12.4	22.1	18.3	20.6	12.7	13.9	17.1	5.5
NK Grandia	892	240	23.6	335	303	19.6	8.6	13.0	22.3	18.0	21.1	12.9	13.9	16.8	5.4
DK Cabernet	881	251	14.8	340	305	19.2	9.5	13.6	23.1	18.9	23.3	12.8	13.8	18.0	5.6
Average	890	245	17.5	325	289	18.4	8.5	12.5	21.8	17.6	20.3	12.5	13.5	16.6	5.6
SEM	3.6	3.2	2.81	10.7	11.4	0.73	0.47	0.57	0.74	0.81	1.50	0.35	0.31	0.75	0.83
Soft rapeseed meal															
DK Cabernet SRSM1	866	279	14.4	419	396	24.9	12.0	18.7	31.8	22.9	27.8	17.6	18.2	25.0	5.5
DK Cabernet SRSM2	864	281	12.7	457	411	25.9	12.2	17.7	32.1	24.0	28.3	17.5	19.5	23.1	5.2
Quartz	866	266	10.0	430	400	25.5	11.9	17.9	31.6	23.6	27.9	17.6	19.1	23.5	5.5
Trinity	868	271	8.3	443	399	25.8	11.7	18.3	31.2	23.7	28.7	17.4	18.5	23.9	5.3
Compass	848	283	7.4	468	386	25.0	11.9	16.8	31.3	23.0	24.5	18.6	19.4	23.2	4.9
Incentive	853	226	13.9	469	440	29.5	12.7	20.8	35.6	24.5	28.0	19.2	20.6	27.0	5.2
Excalibur	833	260	21.6	495	430	27.7	12.7	19.4	33.7	25.0	30.6	18.9	20.2	25.6	5.1
Avatar	856	255	11.3	495	410	26.1	12.9	18.7	32.9	24.3	28.2	19.3	19.7	25.4	4.9
PR46W21	822	252	25.8	507	453	30.0	13.7	19.8	35.2	27.4	33.6	19.5	21.0	25.8	5.4
Palmedor	859	269	15.3	517	451	29.9	14.5	20.9	36.4	26.6	30.8	19.9	21.1	27.8	5.1
V2750L	838	271	47.4	521	444	29.2	13.9	20.9	35.9	26.3	30.5	20.3	20.2	27.9	5.1
Ability	821	266	14.2	560	457	30.7	14.0	20.4	37.1	25.1	30.7	20.7	21.1	26.9	4.5
Average	849	265	16.9	482	423	27.5	12.8	19.2	33.7	24.7	29.1	18.9	19.9	25.4	5.1
SEM	5.0	4.5	3.16	12.0	7.3	0.64	0.28	0.40	0.63	0.42	0.66	0.33	0.28	0.50	0.84

Arg, arginine; CP, crude protein; DM, dry matter; His, histidine; Ile, isoleucine; Leu, leucine; Lys, lysine; M+C, methionine and cysteine; NDF, neutral detergent fibre; Phe, phenylalanine; SEM, standard error of the difference mean; TAA, total amino acids; Val, valine; *GLS, glucosinolates expressed as µmol/g DM; **Lys:CP ratio expressed as %.

Table 3. AID of crude protein and amino acids in rapeseed co-products for broiler chickens

Rapeseed variety	CP	Arg	His	Ile	Leu	Lys	M+C	Phe	Thr	Val	TAA
Rapeseed cake											
Compass	0.79	0.89	0.87	0.78^{ab}	0.82	0.82	0.76	0.84	0.73	0.75	0.81
Sesame	0.77	0.89	0.87	0.77^{b}	0.81	0.80	0.76	0.83	0.68	0.72	0.80
NK Grandia	0.80	0.90	0.88	0.82^{a}	0.85	0.84	0.80	0.86	0.74	0.77	0.84

DK Cabernet	0.80	0.89	0.88	0.80^{ab}	0.83	0.82	0.81	0.84	0.71	0.77	0.82
Average	0.79	0.89	0.87	0.79	0.83	0.82	0.78	0.84	0.72	0.75	0.82
SEM	0.018	0.011	0.011	0.020	0.016	0.016	0.030	0.016	0.024	0.023	0.016
p value	0.426	0.387	0.137	0.045	0.150	0.262	0.245	0.307	0.107	0.101	0.154
Soft rapeseed meal											
DK Cabernet SRSM1	0.77^{def}	0.87^{bcd}	0.85^{cd}	0.81^{bc}	0.84^{abcd}	0.77^{cd}	0.77^{bc}	0.84^{abc}	0.72^{bc}	0.79^{abcd}	0.80^{bcd}
DK Cabernet SRSM2	0.78^{cde}	0.88^{bc}	0.86^{bc}	0.81^{bc}	0.84^{abcd}	0.79^{bc}	0.76^{bc}	0.83^{bc}	0.74^{b}	0.78^{bcd}	0.81^{bc}
Quartz	0.74^{f}	0.85^{d}	0.83^{d}	0.77^{d}	0.81^{d}	0.75^{d}	0.73^{c}	0.81^{c}	0.69^{c}	0.74^{e}	0.77^{d}
Trinity	0.79^{bcde}	0.89^{ab}	0.87^{abc}	0.83^{ab}	0.85^{abc}	0.80^{bc}	0.80^{ab}	0.85^{ab}	0.73^{bc}	0.79^{abcd}	0.82^{ab}
Compass	0.79^{bcde}	0.88^{bc}	0.86^{bc}	0.79^{cd}	0.83^{bcd}	0.78^{bcd}	0.76^{bc}	0.84^{abc}	0.72^{bc}	0.76^{de}	0.80^{bcd}
Incentive	0.76^{ef}	0.88^{bc}	0.85^{cd}	0.81^{bc}	0.84^{abcd}	0.78^{bcd}	0.75^{bc}	0.83^{bc}	0.73^{bc}	0.78^{bcd}	0.80^{bcd}
Excalibur	0.80^{bcd}	0.89^{ab}	0.86^{bc}	0.81^{bc}	0.84^{abcd}	0.80^{bc}	0.77^{bc}	0.84^{abc}	0.75^{ab}	0.79^{abcd}	0.81^{bc}
Avatar	0.79^{bcde}	0.86^{cd}	0.85^{cd}	0.79^{cd}	0.82^{cd}	0.77^{cd}	0.75^{bc}	0.82^{bc}	0.71^{bc}	0.77^{cde}	0.78^{cd}
PR46W21	0.84^{a}	0.91^{a}	0.89^{a}	0.85^{a}	0.87^{a}	0.85^{a}	0.83^{a}	0.87^{a}	0.79^{a}	0.82^{a}	0.85^{a}
Palmedor	0.81^{abc}	0.89^{ab}	0.88^{ab}	0.83^{ab}	0.86^{ab}	0.81^{b}	0.80^{ab}	0.85^{ab}	0.75^{ab}	0.81^{ab}	0.83^{ab}
V2750L	0.81^{abc}	0.89^{ab}	0.87^{abc}	0.83^{ab}	0.85^{abc}	0.81^{b}	0.77^{bc}	0.84^{abc}	0.73^{bc}	0.80^{abc}	0.82^{ab}
Ability	0.82^{ab}	0.89^{ab}	0.87^{abc}	0.82^{abc}	0.85^{abc}	0.80^{bc}	0.79^{ab}	0.85^{ab}	0.74^{b}	0.79^{abcd}	0.82^{ab}
Average	0.79	0.88	0.86	0.81	0.84	0.79	0.77	0.84	0.73	0.79	0.81
SEM	0.017	0.012	0.012	0.016	0.014	0.017	0.026	0.014	0.020	0.016	0.015
p value	<0.001	<0.001	<0.001	0.001	0.008	<0.001	0.023	0.014	0.003	<0.001	<0.001

Table 3. AID of crude protein and amino acids in rapeseed co-products for broiler chickens (continued)

Rapeseed variety	CP	Arg	His	Ile	Leu	Lys	M+C	Phe	Thr	Val	TAA
Contrast of Compass RSC with Compass SRSM											
p value	0.738	0.064	0.342	0.230	0.315	0.002	0.862	0.765	0.664	0.114	0.392
SEM	0.014	0.008	0.007	0.010	0.011	0.010	0.040	0.011	0.016	0.010	0.014
Contrast of DK Cabernet SRSM1 with DK Cabernet SRSM2											

p value	0.578	0.620	0.482	0.877	0.846	0.225	0.883	0.933	0.274	0.532	0.454
SEM	0.015	0.011	0.011	0.018	0.014	0.017	0.020	0.014	0.018	0.017	0.014
Contrast of average AID between RSC and SRSM											
p value	0.767	0.003	0.012	0.007	0.022	<0.001	0.339	0.696	0.051	<0.001	0.339
SEM	0.017	0.011	0.012	0.018	0.015	0.017	0.027	0.015	0.021	0.018	0.016

AID, coefficient of apparent ileal digestibility; Arg, arginine; CP, crude protein; DM, dry matter; His, histidine; Ile, isoleucine; Leu, leucine; Lys, lysine; M+C, methionine and cysteine; NDF, neutral detergent fibre; Phe, phenylalanine; RSC, rapeseed cake; SEM, standard error of the difference mean; SRSM, soft rapeseed meal; TAA, total amino acids; Val, valine. Values in the same column followed by different letters are significantly different ($p < 0.05$).

Table 4. SID of amino acids in rapeseed co-products for broiler chickens

Rapeseed variety	Arg	His	Ile	Leu	Lys	M+C	Phe	Thr	Val
Rapeseed cake									
Compass	0.92	0.93	0.85	0.86	0.85	0.79	0.88	0.82	0.81
Sesame	0.91	0.91	0.83	0.84	0.83	0.79	0.87	0.76	0.77
NK Grandia	0.93	0.93	0.88	0.88	0.87	0.83	0.90	0.82	0.83
DK Cabernet	0.92	0.92	0.86	0.87	0.85	0.83	0.87	0.80	0.82
Average	0.92	0.92	0.86	0.86	0.85	0.81	0.88	0.80	0.81
SEM	0.011	0.010	0.020	0.016	0.016	0.030	0.016	0.024	0.023
p value	0.451	0.166	0.084	0.174	0.256	0.339	0.319	0.079	0.112
Soft rapeseed meal									
DK Cabernet SRSM1	0.89^{bc}	0.89^{bc}	0.85^{bcd}	0.86^{ab}	0.79^{cd}	0.78^{bc}	0.86^{abc}	0.78^{bc}	0.82^{bc}
DK Cabernet SRSM2	0.89^{bc}	0.90^{abc}	0.85^{bcd}	0.87^{ab}	0.81^{bc}	0.78^{bc}	0.86^{abc}	0.80^{ab}	0.81^{bcd}
Quartz	0.86^{d}	0.86^{d}	0.82^{d}	0.84^{b}	0.77^{d}	0.75^{c}	0.83^{c}	0.75^{c}	0.78^{d}
Trinity	0.91^{ab}	0.90^{abc}	0.87^{ab}	0.88^{a}	0.82^{bc}	0.81^{ab}	0.88^{ab}	0.79^{bc}	0.83^{abc}
Compass	0.89^{bc}	0.89^{bc}	0.84^{bcd}	0.86^{ab}	0.80^{bcd}	0.78^{bc}	0.87^{ab}	0.78^{bc}	0.80^{cd}
Incentive	0.90^{ab}	0.88^{cd}	0.85^{bcd}	0.86^{ab}	0.80^{bcd}	0.77^{bc}	0.86^{abc}	0.78^{bc}	0.82^{bc}
Excalibur	0.90^{ab}	0.90^{abc}	0.85^{bcd}	0.87^{ab}	0.82^{bc}	0.79^{bc}	0.87^{ab}	0.80^{ab}	0.83^{abc}
Avatar	0.87^{cd}	0.88^{cd}	0.83^{cd}	0.84^{b}	0.79^{cd}	0.77^{bc}	0.85^{bc}	0.77^{bc}	0.80^{cd}
PR46W21	0.92^{a}	0.92^{a}	0.89^{a}	0.89^{a}	0.87^{a}	0.85^{a}	0.89^{a}	0.84^{a}	0.86^{a}
Palmedor	0.91^{ab}	0.91^{ab}	0.87^{ab}	0.88^{a}	0.83^{b}	0.82^{ab}	0.87^{ab}	0.80^{ab}	0.84^{ab}

V2750L	0.90^{ab}	0.90^{abc}	0.86^{abc}	0.87^{ab}	0.83^{b}	0.79^{bc}	0.87^{ab}	0.79^{bc}	0.84^{ab}
Ability	0.90^{ab}	0.90^{abc}	0.85^{bcd}	0.87^{ab}	0.82^{bc}	0.80^{abc}	0.87^{ab}	0.80^{ab}	0.82^{bc}
Average	0.90	0.90	0.85	0.87	0.82	0.80	0.87	0.80	0.82
SEM	0.012	0.012	0.017	0.014	0.017	0.026	0.014	0.020	0.016
p value	<0.001	0.001	0.005	0.014	<0.001	0.034	0.021	0.008	0.003

Table 4. SID of amino acids in rapeseed co-products for broiler chickens (continued)

Rapeseed variety	Arg	His	Ile	Leu	Lys	M+C	Phe	Thr	Val
Contrast of Compass RSC with Compass SRSM									
p value	0.010	0.002	0.289	0.778	<0.001	0.665	0.274	0.030	0.612
SEM	0.008	0.007	0.010	0.011	0.010	0.040	0.011	0.016	0.010
Contrast of DK Cabernet SRSM1 with DK Cabernet SRSM2									
p value	0.655	0.503	0.972	0.851	0.242	0.873	0.945	0.360	0.644
SEM	0.011	0.011	0.018	0.014	0.017	0.020	0.014	0.018	0.017
Contrast of average SID between RSC and SRSM									
p value	<0.001	<0.001	0.758	0.790	<0.001	0.096	0.013	0.236	0.060
SEM	0.011	0.012	0.018	0.015	0.017	0.027	0.015	0.021	0.018

Arg, arginine; CP, crude protein; DM, dry matter; His, histidine; Ile, isoleucine; Leu, leucine; Lys, lysine; M+C, methionine and cysteine; NDF, neutral detergent fibre; Phe, phenylalanine; RSC, rapeseed cake; SEM, standard error of the difference mean; SID, coefficient of standardised ileal digestibility; SRSM, soft rapeseed meal; TAA, total amino acids; Val, valine. Values in the same column followed by different letters are significantly different ($p < 0.05$).