Scotland's Rural College

Investigations of the nutritive value of meals of double-low rapeseed and its influence on growth performance of broiler chickens

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

Published in:
Poultry Science

DOI:
10.3382/ps/pex157

First published: 11/07/2017

Document Version
Peer reviewed version

Link to publication

Citation for pulished version (APA):
Olukosi, OA., Kasprzak, MM., Kightley, S., Carre, P., Wiseman, J., & Houdijk, JGM. (2017). Investigations of the nutritive value of meals of double-low rapeseed and its influence on growth performance of broiler chickens. *Poultry Science*, *96*(9), 3338 - 3350. Advance online publication. https://doi.org/10.3382/ps/pex157

Investigations of the nutritive value of meals of double-low rapeseed and its influence on growth performance of broiler chickens

O. A. Olukosi*[1], M. M. Kasprzak[†], S. Kightley[‡], P. Carre[§], J. Wiseman[†], and J. G. M. Houdijk[*].

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

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

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

[§] CREOL, Pessac, 33600, France

[1]Full address of corresponding author:

Oluyinka A. Olukosi
Monogastric Science Research Centre
Scotland's Rural College, Edinburgh
EH9 3JG, UK
Tel: 1292 525103
Fax: 1292 525098
Email: oluyinka.olukosi@sruc.ac.uk

Section: Metabolism and Nutrition

Investigations of the nutritive value of meals of double-low rapeseed and its influence on growth performance of broiler chickens

ABSTRACT

Four experiments were carried out to study the possible differences in ME of meals (**RSM**) or expeller meals (**RSE**) from double-low rapeseed (Expt. 1), the influence of processing on ME (Expt. 2) and on relative P bioavailability (Expt. 3) in RSM, and effect of RSM inclusion on growth performance of broilers (Expt. 4). For Expt. 1, diets with 300 g/kg RSM from 11 RSM and 4 RSE varieties were fed to broilers from d 14 to 21, with excreta collection on d 19 to 21. Each treatment had eight replicates and three birds per replicate. Energy metabolizability of RSM of a specialized high glucosinolates variety (V275OL) was greater ($P < 0.05$) than all the other varieties. In Expt. 2, two RSM varieties were processed with mild or conventional processing condition. There were no variety effects on ME, but ME and MEn were greater ($P < 0.01$) for RSM processed by mild processing condition. In Expt. 3, P bioavailability of RSM was determined, relative to MSP, using growth performance and tibia ash as responses. Phosphorus relative bioavailability values were greater ($P < 0.05$) in RSM of DK Cabernet variety processed using the mild processing condition. In Expt. 4, two RSM varieties were added to wheat-soybean meal-based diet at the rates of 50, 100, 150 or 200 g/kg and fed to broilers from d 0 to 42. Inclusion of 150 and 200 g/kg of RSM resulted in reduced weight gain and increased FCR compared ($P < 0.01$) with the lower inclusion levels during the starter phase. For the entire trial (day 0 to 42), weight gain was greater ($P < 0.01$) for birds receiving diets with RSM from PR46W21 variety. It was concluded from the experiments that apart from the residual ether extract content, variety differences had no impact on ME of RSM, conventional processing reduced ME and relative bio-availability of P; and that the maximum level of RSM inclusion depends on maximum growth performance level desired.

Key words: broilers, growth, metabolizable energy, phosphorus bioavailability, rapeseed meal,

INTRODUCTION

The varieties of rapeseed, *Brassica napus*, that have been bred for low levels of glucosinolates and erucic acid are known as double-low (or double-zero) oil-seed rape (**OSR**) varieties in Europe, or canola in United States and Canada (Khajali and Slominski, 2012). Because of their relatively high crude protein content and amino acid digestibility, their hexane-defatted co-products rapeseed meals (**RSM**) or expeller-defatted meals (**RSE**) are used as protein feedstuffs, especially in non-ruminant animals (Lee et al., 1995; Woyengo et al., 2010; Kasprzak et al., 2016a,b). Residual oil content is generally low in RSM but the feedstuff, when used at high levels in the diet, can contribute to the ME and P contents of the diet although its ME and digestible P are reported to be relatively modest (Woyengo et al., 2011; Olukosi et al., 2015).

Rapeseed meal is not routinely used in non-ruminant animal diets in the United Kingdom because of the potential for negative effects of its antinutritive factors. For young birds, maximum inclusion level was recommended to be 20 g/kg, or 50 g/kg for older birds (Henkel and Mosenthin, 1989). However the modern varieties are very low in their content of glucosinolates and, accordingly, are likely to be better tolerated by poultry as suggested in recent studies (Woyengo et al., 2011; Aljuobori et al., 2016). Because the primary product of OSR is its oil, processing conditions are understandably geared to maximize oil extraction from the seed and minimize mechanical pressure on the press. This processing requires an extra cooking step during seed preparation and it is likely that the application of the extra heat may reduce the value of the resulting RSM as a source of ME and bioavailable P for poultry as has been demonstrated for other feedstuffs for poultry (Chompreeda and Fields, 1984; Carlson and Poulsen, 2003). Zeb et al. (2002) showed that dry heating reduced the nutritive value of RSM in their study. On the other hand, because of low levels of potential anti-nutrients in the modern varieties of OSR, there is possibility that it will be feasible to incorporate raw seeds directly in the diet where this is available. This option needs to be investigated.

There is need for a better understanding of the nutritive value of the modern varieties of RSM in order to explore possibility for greater inclusion of RSM in the diet. Consequently four experiments were designed to study: (1) the influence of OSR varieties on ME, (2) interactive effects of variety types and processing intensity on ME, and (3) the relative bioavailability of P, and (4) the influence of graded level of RSM dietary inclusion on growth performance of male broiler chickens.

MATERIALS AND METHODS

All the animal experiment procedures used in this study were approved by Scotland's Rural College's Animal Experiment Committee. A total of four experiments were conducted to determine the ME content of RSM and RSE in broiler chickens (Expt. 1), ME of RSM processed using mild or conventional conditions (Expt. 2), relative bioavailability of P in RSM processed as described previously (Expt. 3), and the effect of the RSM on growth performance and characteristics of the digestive organs in broiler chickens (Expt. 4)

Rapeseed, rapeseed meals and rapeseed expeller meals

The OSR, RSM and RSE used in the current study were all grown in England between 2013 and 2014. The location of where the OSR were grown and the chemical composition of the RSM and RSE have been described previously (Olukosi et al., 2015; Kasprzak et al., 2016b).

Rapeseed processing conditions

All the seeds processing was carried out at a pilot plant (CREOL / OLEAD, Pessac, France). The processing conditions for RSM used in Experiments 2, 3 and 4 are described below.

Conventional processing. The "conventional" processing was carried out with 3,500 kg of each batch of seeds (DK Cabernet and PR46W21). The seeds were flaked using a Bühler flaking mill with smooth rolls (400 mm in diameter × 600 mm in length) separated by a 0.2 mm gap. Resulting flakes were continuously conditioned in a two-stage horizontal conditioner (OLEXA, France). DK Cabernet and PR46W21 were cooked with, respectively, 325 kg/h and 319 kg/h with residence time of 43 min and 45 min and a final temperature of 90.1 and 89.6°C. Prepressing was done with the same press as the cold pressing. For DK Cabernet and PR46W21, the conditions were, respectively: temperature 80.3°C and 77.1°C, oil throughput 38.8% and 37.2% of flakes input, and intensity by the press 15.1A and 15.9A.

Extraction and desolventization occurred in the same units as the cake from "mild" processing. The extractor was fed at a constant 220 kg/h rate. In desolventizer, the indirect steam pressure was set at 3.5 barg, residence time 90 min and direct steam at 25 kg/h. DK Cabernet and PR46W21 final temperatures were, respectively, 115.9°C and 110.5°C. The difference in processing for the two varieties is explained by a longer effective residence time for DK Cabernet.

Mild processing. For the “mild” processing, 500 kg of each seed batch were dried to reduce the water content below 7% and cold pressed using a MBU 75 press (OLEXA, France) at a constant throughput of 250 kg/h. Cold pressed cakes were directed into a continuous flow extractor (belt diffuser by DeSmet Ballestra, Belgium) at 180 kg/h where a counter-flow of hexane extracted the oil. The resulting residue was continuously forwarded to the desolventization unit using a six-tray continuous desolventiser (Desmet Ballestra, Belgium). The residence time was 80 min and the indirect steam pressure heating the trays was set at 1 barg whereas direct steam was 25 kg/h. The residence time was 80 minutes and the final temperature for DK Cabernet and PR46W21 were, respectively, 105.9°C and 105.3°C.

Experiment 1

A total of 408 Ross 308 male broilers were used for the study to determine the ME and MEn of RSM from 11 varieties of OSR and of RSE from 4 varieties of OSR (Table 1).

The birds were raised together from d 0 to 14 of age and they all received corn-soybean meal-based diet that met the energy and nutrient requirements of Ross 308 broiler chickens (Aviagen, 2014). On d 14, the birds were allocated to 17 treatments in a randomized complete block design ensuring that the average body weight was the same for all the treatments. Each of the treatments had 8 replicate cages with 3 birds per replicate cage. The birds received the experimental diets, containing 5 g/kg of titanium dioxide as digestibility marker, from d 14 to 21 and excreta were collected on d 19 to 21.

Diet 1 was a corn-soybean meal-based reference diet which was formulated to meet the energy and nutrient requirements of the birds (Aviagen, 2014). The subsequent 12 diets had 12 RSM from 11 varieties of OSR (Table 1) proportionally replacing all the energy yielding components of the reference diet (corn, SBM, soy oil) at 300 g RSM per kg diet. Diets 14 to 17 had RSE from four varieties of OSR proportionally replacing the energy yielding components of the reference diet at 300 g/kg. The proportional replacement of the energy-yielding components is essential to enable calculation of the ME of RSM and RSE by the difference method as previously described (Olukosi and Adeola, 2009). The processing for the RSM used in the experiment is as previously described (Kasprzak et al., 2016b). The ingredient composition of the experimental diets is shown in Table 2.

Experiment 2

Two OSR varieties (DK Cabernet and PR46W21) used for this experiment were selected from the 13 varieties tested in Expt. 1 on the basis of their market availability, standardized ileal amino acid digestibility (**SIAAD**) and glucosinolates content (Kasprzak et al., 2016b, Table 3). The OSR samples were subjected to two oil removal conditions denoted as mild or conventional. The mild processing condition avoids a cooking step during the preparation of the seed for oil extraction. The details of the two processing conditions are described above.

A total of 120 Ross 308 male broilers were used for this experiment. As previously explained for Expt. 1, the birds were allocated to dietary treatments on d 14 of age in a randomized complete block design on the basis of initial body weight. The treatments were a corn-soybean meal-based reference diet and four additional diets in which RSM from DK Cabernet and PR46W21 varieties processed using the conventional or mild condition were added at 300 g/kg to proportionally replace the energy yielding components of the reference diet (Table 2). All the diets had titanium dioxide added at 5 g/kg to serve as digestibility marker to enable calculation of digestibility by the index method.

Each of the five treatments had eight replicate cages with three birds per replicate cage. Excreta were collected on d 19 to 21. The ME and MEn of the RSM were calculated using the difference method as previously described (Olukosi and Adeola, 2009).

Experiment 3

The aim of this experiment was to determine the relative bioavailability of P in RSM from two varieties of OSR. The four RSM used for this experiment were as described above for Expt. 2. Phosphorus bioavailability was determined relative to monosodium phosphate (**MSP**).

A total of 330 Ross 308 male broiler chickens at 11 d of age were allocated to 11 treatments in a randomized complete block design. The birds were previously raised from d 0 to 11 on wheat-soybean meal-based diet formulated to meet all the nutrients requirements (Aviagen, 2014). On d 11, the birds were allocated to 11 treatments, each treatment had six replicate pens and each pen had five birds. Birds and feed were weighed on d 11 and 21. On d 21, the birds were euthanized by cervical dislocation and the left tibia bones were collected from 2 randomly selected birds per pen and the bones were later defatted and ashed.

The 11 treatments included a basal diet (diet 1) that was formulated to be adequate in all nutrients and energy and deficient in non-phytate P. Soybean meal was the only source of P in the basal diet and provided 2.9 g/kg total P. Diets 2 and 3 were similar to the basal diet except that MSP, was added at the rates of 4.8 or 9.3 g/kg to increase dietary total P levels to 4.0 or 5.0 g/kg for diets 2 and 3, respectively. The remaining 8 diets had two levels each of RSM from DK Cabernet and PR46W21 varieties processed under conventional or mild conditions. The meals were denoted DKC and DKM for meals from DK Cabernet processed using conventional and mild conditions, respectively or PRC and PRM for meals from PR46W21 processed using conventional and mild conditions, respectively The RSM were added at the rates of 110 or 220 g/kg to the basal diet to provide dietary total P levels of 3.9 or 4.9 g/kg, respectively. The ingredients and chemical composition of the experimental diets are shown in Table 4.

Experiment 4

On the basis of ME content of RSM determined in Experiment 2 and SIAAD content of the RSM determined earlier (Kasprzak et al., 2016b), the RSM were included in practical broiler diets (Table 5). The objective was to ascertain the effect of inclusion levels of RSM on growth performance and characteristics of the digestive organs of the broiler chickens in response to step-wise dietary inclusion of RSM.

A total of 1,500 Ross 308 male broilers at 1 d of age were allocated to 10 dietary treatments in a randomized complete block design ensuring the treatments had the same body weight on d 0. Each of the treatments had 10 replicate pens with 15 birds per replicate pen. The treatments included a wheat-soybean meal-based basal diet, which was formulated to meet the nutrient recommendation for the birds. Diets 2 to 5 had RSM from DK Cabernet, added at the rates of 50, 100, 150 or 200 g/kg for diets 2, 3, 4, and 5, respectively to partly replace wheat and soybean meal in the basal diets. Diets 6 to 9 had RSM from PR46W21 variety added at the rates indicated above. Diet 10 had DK Cabernet unprocessed, ground seeds added at the rate of 80 g/kg to partly replace wheat and SBM in the basal diet. The ingredients and chemical composition of the diets are shown in Table 4.

The diets were fed as pellets for the duration of the experiment (crumbed pellets on d 0 to 7). The diets were fed in two phases with the starter (d 0 to 21) and the finisher phases (d 21 to 42). Feed and birds were weighed on d 0, 21, and 42 to determine the growth performance. On d 42, one bird from each of the pens, with body weight closest to the pen median body weight, were euthanized by intravenous injection of pentobarbitone. An incision was made below the sternum to expose the abdominal cavity as previously described (Olukosi and Dono, 2014). The entire small intestine was removed and the weight and length of the duodenum, jejunum, and ileum were taken. The weights of the gizzard (emptied), pancreas, and liver were also taken. The duodenum was defined as the section of the small intestine from the pyloric junction to the end of the duodenal loop. The jejunum was defined as the section from the caudal end of the duodenal loop to the Meckel’s diverticulum. The ileum was defined as the section of the small intestine from the Meckel’s diverticulum to the ileo-ceacal junction.

Chemical analysis

Diets, ileal digesta and excreta were analyzed for dry matter, N, gross energy, and ether extractable fat. Titanium was analyzed using the method of Short et al. (1996). In addition, RSM and RSE were analyzed for phytic acid, glucosinolates, sinapine, tannins, Ca, P and neutral detergent fiber. Tibia bones obtained in Experiment 3 were defatted and ashed in a muffle furnace at 600°C for 12 h.

DM was determined by drying the samples in a drying oven (Uniterm, Russel-Lindsey Engineering Ltd., Birmingham, England, UK) at 105°C for 24 h (AOAC Method 934.01; AOAC, 2006). Total N content was determined (Leco FP analyzer Model, Leco Corp., St. Joseph, MI, USA) by the combustion method (Method 968.06; AOAC, 2006). Crude protein was calculated as N × 6.25. Gross energy was determined in an isoperibol bomb calorimeter (Model 6200, Parr Instruments, Moline, IL, USA) using benzoic acid as an internal standard. Mineral contents was determined using Inductively Coupled Plasma – Optical Emission Spectroscopy (AOAC Method 990.08; AOAC, 2006) following digestion, in turn, in concentrated HNO_3 and HCl. Free fat (as ether extract) was determined using extraction by petroleum ether in a Soxhlet apparatus for six hours (AOAC, 2006). Neutral detergent fiber (**NDF**) was analyzed using the Ankom nylon bag technique (ANKOM, 2006). Glucosinolates were analyzed using ISO method 9167-1 (ISO, 1992). Tannins were analyzed using the vanillin HCl assay (Butler et al., 1982; Hagerman, 2011). Sinapine levels were quantified through an in-house method combining extraction and HPLC as described previously (Cai and Arntfield, 2001; Li and Rassi, 2002). Phytic acid was measured as phosphorus released by phytase and alkaline phosphatase, using commercially available kits (Megazyme assay procedure; K-PHYT kit).

Statistical analysis

The data for each experiment, except Expt. 3, were analyzed by the MIXED procedure of SAS as appropriate for a randomized complete block design. In all experiments, the dietary treatments were the fixed effects and the blocks were the random effect. For Expt. 1, the between-varieties means for RSM and RSE data were compared separately using Tukey but data for RSE versus RSM were compared using the contrast statement. For Expt. 2, data on ME and MEn of the RSM processed using the two conditions were analyzed as 2×2 factorial arrangement using variety (DK Cabernet and PR46W21) and processing conditions (Conventional or Mild) as factors. The data for Expt. 3 were analyzed using common-intercept slope ratio assay using the GLM procedure of SAS. The three assumptions for validity of slope ratio assay (Littell et al., 1997) were tested on the data and fulfilled prior to employing the assay. Linear and quadratic effects of supplementing MSP or RSM to the basal diets were examined using orthogonal polynomial contrasts. The data for Expt. 4 were analyzed as factorial (two type of RSM and four levels of each RSM) showing the main and simple effects as appropriate. Linear and quadratic effects of step-wise increase in dietary RSM inclusion were investigated using orthogonal polynomial contrasts. The effect of dietary inclusion of the seed in the diet was investigated using an additional contrast. Statistical significance was set at $P \leq 0.05$.

RESULTS

Chemical composition of test ingredients

Table 1 shows that the RSM were similar in composition and that large variability only exists in the contents of phytic acid and total glucosinolates with CV of 31% and 63%, respectively. There was a large variability in glucosinolates content of RSE as well with CV of 35%. For both RSM and RSE though, within-rapeseed meal type variability was relatively low for GE, CP and ether extract.

The chemical composition of the two selected OSR varieties (DK Cabernet and PR46W21) processed using conventional or mild processing conditions are shown in Table 3. The main influence of processing, within each of the varieties, was evident in composition of ether extract and glucosinolates. Generally OSR processed using the mild condition had greater quantity of ether extract and glucosinolates than when processed using the conventional condition. Analyzed total P in the diet for Expt. 3 shows that the expected dietary P were met and the relative differences between diets in total P were maintained (Table 4). In addition, analysis of the diets used for growth performance (Table 6) shows that the intended isocaloric and iso-nitrogenous profiles of the diets were maintained.

Metabolizable energy of RSM and RSE (Expt. 1)

Energy metabolizability (**EM**), ME, and MEn of RSM and RSE are shown in Table 7. Rapeseed expeller meals had greater ($P < 0.01$) EM, ME and MEn than RSM but the numerical difference in ME and MEn between RSM and RSE was larger than the numerical difference in EM. Variety affected EM, which was greater ($P < 0.05$) for V275OL than all the other varieties, which all had statistically similar EM. In addition, both ME and MEn were greater ($P < 0.05$) for Ability than all the other varieties.

Within the RSE samples, Compass had greater ($P < 0.05$) EM, ME and MEn than the other varieties, whereas ME and MEn were lower ($P < 0.05$) for Sesame compared with the other varieties. DK Cabernet and NK Grandia both had similar amount of ME and MEn.

Correlation of ME content of RSM with their chemical composition produced significant ($P \leq 0.05$) positive correlation coefficients of 0.57, 0.88 and 0.62 for crude protein, ether extract and ochratoxin, respectively. The correlation coefficients of ME with NDF, total glucosinolates, tannins, sinapine, and phytic acid were not significant.

Influence of variety and processing condition on ME of RSM (Expt. 2)

There was no significant main effect of variety or a variety × processing interaction effect on any of the responses (Table 8). However, there were effects ($P < 0.01$) of processing condition on ME, MEn and EM, which were all greater ($P < 0.01$) for RSM processed by mild processing condition compared with the conventional method.

Influence of variety and processing conditions on relative P bioavailability of RSM (Expt. 3)

Table 9 shows the data on growth performance and tibia ash responses to the low-P basal diets supplemented either with MSP or RSM from DK Cabernet or PR46W21 processed using conventional (**DKC** or **PRC**, respectively) or mild (**DKM** or **PRM**, respectively) conditions. There was a ($P < 0.05$) linear response of weight gain and feed intake to supplemental MSP and RSM, except for PRM for which there was a trend for linear growth response. There was also a ($P < 0.05$) linear bone ash response to supplemental MSP. There were no quadratic treatment effects, except for feed intake response ($P < 0.05$), to increasing level of DKC. Feed conversion ratio also had quadratic response ($P < 0.01$) to increasing level of DKM and PRM.

Multiple regression analyses were done on the intake of supplemental P coming from MSP or the RSM using weight gain as response criteria. The regression based on MSP, DKC, and DKM yielded the equation: : $Y = 487 + 87.5 \pm 1.10 MSP + 11.9 \pm 1.30 DKC + 28.2 \pm 1.25 DKM$, ($r^2 = 0.72$). The regression based on MSP, PRC and PRM yielded the equation $Y = 486 + 88.3 \pm 1.25 MSP + 19.7 \pm 1.44 PRC + 27.0 \pm 1.49 PRM$, ($r^2 = 0.70$).

Regression analyses were also done on the intake of supplemental P coming from MSP or the RSM samples using tibia ash as response criteria (Table 9). For the regression based on MSP, DKC, and DKM, the equation was $Y = 13.9 + 3.82 \pm 0.09 MSP + 1.78 \pm 0.11 DKC + 0.81 \pm 0.11 DKM$, ($r^2 = 0.60$). The regression based on MSP, PRH, and PRM yielded the equation $Y = 14.1 + 3.82 \pm 0.08 MSP + 1.38 \pm 0.10 PRC + 1.29 \pm 0.10 PRM$, ($r^2 = 0.66$).

On the basis of the regression equations, percentage relative bioavailability of P in the RSM varieties, based on weight gain or tibia ash are presented in Table 10. Relative P bioavailability value, using weight gain was greater ($P < 0.05$) for DKM compared with DKC but the opposite was the case when tibia ash was used as response criterion. Processing condition had no significant effect on relative P bioavailability for PRC and PRM. Relative P bioavailability for RSM processed using the mild condition was generally greater (on the average 32.2 vs. 24.0 % for mild versus conventionally processed RSM, respectively). This excluded data for DK Cabernet where tibia ash was used as the response criterion, for which relative bioavailability was greater for RSM processed by conventional processing.

Growth performance responses of broilers to dietary inclusion of RSM or OSR

The growth performance responses of broilers to dietary inclusion of graded levels of RSM to wheat-soybean meal diets are presented in Table 11. Dietary inclusion of RSM from DK Cabernet and PR46W21 resulted in linear reduction of weight gain, feed intake and increase in FCR ($P < 0.01$) in all ages. There was no effect of RSM inclusion on feed intake during the finisher phase. There was no quadratic response to RSM inclusion in weight gain or FCR. There was no variety or variety × level interaction during the starter phase (d 0 to 21). There was variety × level interaction ($P < 0.05$) for weight gain during the finisher phase which was explained by steeper reduction in weight gain in response to increasing dietary level of RSM of PR46W21 compared with DK Cabernet. There was significant ($P < 0.01$) RSM level effect on FCR during the finisher phase with broiler chickens receiving 150 and 200 g/kg RSM in the diet having greater FCR compared with the other treatments irrespective of variety. For the overall phase (d 0 to 42), weight gain was greater ($P < 0.01$) for birds receiving diets with RSM from PR46W21 whereas increasing RSM inclusion linearly decreased weight gain and increased FCR ($P < 0.01$). Feeding of 80 g/kg of unprocessed OSR resulted in a decrease ($P < 0.05$) in weight gain, feed intake and increase in FCR in all the phases of the study.

There were no variety or variety × level interaction effects on any of the digestive organs measured (data not presented). There was no RSM level effect except for liver weight, which decreased ($P < 0.05$) between 50 and 100 g/kg RSM inclusions and then increased ($P < 0.05$) with higher RSM inclusion level.

DISCUSSION

The objective of the current study was to determine, for broiler chickens, the nutritive value of double-low RSM produced in the UK. The RSM are characterized by their low contents of glucosinolates and erucic acid and are the same as canola meal in the North America (Adewole et al., 2016). The study took a step-wise approach in which RSM from 11 varieties of double-low were first evaluated for ME and SIAAD (Kasprzak et al., 2016b). Subsequently two of the varieties were chosen on the basis of market availability, differences in SIAAD and glucosinolates contents. These two varieties were further assayed for ME and relative bioavailability of P. The energy content determined and SIAAD values (Kasprzak et al., 2016b) were then used in diet formulation to determine broiler chickens response to inclusion of RSM from the two varieties in practical broiler diets.

Chemical composition of RSM and effect of processing

The chemical composition of the RSM varieties tested is within the range that is generally reported in the literature (Woyengo et al., 2010; Parr et al., 2015; Adewole et al., 2016). The glucosinolates and sinapine contents of the varieties are within the range for meals from modern varieties of rapeseed. There was generally narrow variability in the chemical composition of the RSM from the different varieties. This similarity may be a reflection of the fact that the varieties were all processed in one plant (Pessac, France).

Glucosinolates in RSM and RSE conferred the greatest variability among the varieties. The especially high CV in glucosinolates content was likely due to the presence of a specialized variety V275OL which is a high-oleic, low-linoleic acid variety. In spite of these differences in glucosinolates content, the data from the current study indicates that there is a generally low variability in nutrient content of RSM when processing conditions are standardized.

The effect of processing conditions on nutrient composition of the meals is shown in differences in chemical composition of RSM obtained from the conventional and mild processing conditions. The RSM obtained from conventional processing condition had lower GE, CP, ether extract, Ca and total P (except for NDF in DK Cabernet). The decrease in composition of some of the chemical components may reflect an increase in composition of some other components not analyzed in the current study. Ether extract and glucosinolates contents were the most dramatically reduced components in conventionally processed RSM in the current study. The reduction in ether extract level is expected because the additional heat application in the conventional processing is to enable greater ether extract extraction. It has been shown that hydrolysis of glucosinolates may occur during processing of the seed (Bell, 1984; Khajali and Slominski, 2012) and this may be responsible for the reduction in its level as reported in the current experiment. The reduction in glucosinolates, as observed in the current study, may be advantageous but the degree to which this is beneficial may be marginal given that the varieties were already low in glucosinolates. On the other hand, the lower ether extract content negatively influenced energy content of RSM for poultry as further described below.

Varietal differences in ME content of RSM and the impact of seed processing for oil extraction

The average ME and MEn of the RSM assayed in the current study were 2,096 and 1,905 kcal/kg, respectively. This ME represents approximately 45% of the gross energy in the meal. The ME of RSM determined in the current study is similar to values reported earlier (Bell, 1993; Mandal et al., 2005; Woyengo et al., 2010; Radfar et al., 2017). The greater ME content of RSE was largely due to its much higher ether extract content, which was generally more than twice the ether extract content of RSM whereas the EM of RSM and RSE are much closer in values. Availability of energy in feedstuffs is dependent on the balance of the energy yielding constituents in the feedstuff and factors that impede their utilization. The low energy availability in RSM and RSE could be due to the presence of such factors as pectic oligosaccharides and insoluble fibers (Khajali and Slominski, 2012), which may have negative effects on energy digestibility. De-hulling and consequent reduction in fiber content have been reported to increase ME of RSM but exogenous enzymes have not consistently improved ME of RSM in various studies (Slominski et al., 1994; Zobac et al., 1998; Mandal et al., 2005) even though such enzymes have been reported to decrease concentration of non-starch polysaccharides in the small intestine (Kocher et al., 2000).

There was similarity in EM, ME, and MEn contents in the RSM varieties assayed in the current study. Although the varieties had high variability, especially in their contents of phytic acid and glucosinolates, correlation analysis showed that these components were not associated with variability in ME content. The main drivers of energy availability in RSM were their ether extract and gross energy contents, which have correlation coefficient of > 0.88. Consequently it appears that the variation in the commonly considered antinutritional factors (such as tannins, phytic acid, glucosinolates, and sinapine) in modern varieties of RSM is unlikely to be constraining its nutritionally available energy value. Kasprzak et al. (2016a,b) came to similar conclusions with regards to protein nutritional value. Therefore, energy availability will largely depend on content and ease of hydrolysis of the energy yielding fractions of the RSM as also observed by Lee et al. (1995).

The data from Expt. 2 show that ME and MEn were not different between varieties but were influenced by differences in processing. The conventional processing condition is similar to the conventional condition except that a step requiring cooking at 90℃ is avoided in the preparatory stage of the processing. This difference in processing produced lower EM, and consequently ME and MEn. Although Aljuobori et al. (2014) showed that extruded canola meal had greater ileal digestible energy compared with non-extruded meal, the difference in the study appeared to emanate from differences in gross energy and fiber contents rather than the effect of processing per se.

Chemical analysis showed that the difference in processing influenced the ether extract content of the meal. Generally the meals that underwent the conventional processing had at least 20% less ether extract than the counterpart from milder processing. The application of heat (cooking) during preparation of the seeds for ether extract extraction reduces the mechanical energy required by the press but also enhances ability to more completely extract oil from the seed and the latter reduces the value of the meal as an energy source. Nevertheless, although ether extract is the major contributor to GE content of the meal, there is also negative effect of additional heat treatment on EM. Consequently, it is the combination of the effects of the processing on ether extract content and EM that ultimately influenced the ME content of the meals.

Relative bioavailability of phosphorus

There is a considerable amount of P in RSM and it can contribute a sizeable amount of P to diets. However, as with other plant feedstuffs, one-half or more of the total P is in the form of phytate P (Bell, 1993; Olukosi et al., 2015). Phosphorus is a critical mineral for growth; therefore the provision of extra available P by inclusion of incremental levels of RSM resulted in enhanced growth performance and tibia ash, relative to the control treatment.

The relative bioavailable P content was generally greater for RSM processed by the mild condition and the difference was wider for DK Cabernet. Olukosi et al. (2015) reported that the true digestibility of P was 42.5 % for conventionally processed RSM of DK Cabernet variety. The digestible P content was therefore calculated to be 4.39 g/kg. In the current study, the bioavailable P content for DK Cabernet processed using the mild processing condition was 3.88 g/kg. In addition, the values of bioavailable P (3.88 g/kg) for DK Cabernet reported in the current study, as well as the value of ileal digestibility of DK Cabernet (4.39 g/kg) reported in Olukosi et al. (2015) gave an efficiency value of 88.4%. This is comparable to the value of 87.4% reported by Adeola and Walk (2013).

Processing can impact P bioavailability. In a study with barley and wheat, Carlson and Poulsen (2003) observed that heat treatment inactivated the plant phytase and this negatively affect P availability. It is acknowledged though that plant phytase in rapeseed is generally low. On the other hand, heat treatment has been shown to improve P bioavailability in corn-Distillers Dried Grains with Solubles (Amezcua et al. 2004; Amezcua and Parsons, 2007). Heat treatment generally decreased phytate P (Khan et al. 1991) but heat application can also reduce P extractability as demonstrated in autoclaved soybean meal (Chompreeda and Fields, 1984). The reduced extractability was suggested to be due to possible complex formation with P leading to reduced P availability. It has also been shown that heat treatment decreased phytate P digestibility in other animals (Park et al., 2000). It can be expected that the effect of heat treatment on P availability is feedstuff-dependent but negative effect of additional heat application during processing was evident in P bioavailability of RSM used in the current study.

Dietary inclusion of RSM and its effect on growth performance

Weight gain and FCR decreased in a linear fashion with addition of RSM in wheat-SBM-based diets. There was 2.25 g or 1.79 g loss in body weight gain with every 1 g/kg inclusion of RSM from DK Cabernet or PR46W21, respectively. Similar depression in broiler growth performance following inclusion of RSM in broiler diets has been observed by others (Zeb et al., 2002; Woyengo et al., 2011; Aljuobori et al., 2014).

Woyengo et al. (2011) observed deterioration of growth performance and FCR with increased supplementation of expeller extracted canola meal in their study. There were minimal effects on the organs they studied except an increase in liver weight and plasma T4 concentration. Others have suggested that factors such as high glucosinolates content of RSM may contribute to reduced growth performance (McNeill et al., 2004). However in view of the fact that the glucosinolates content is much less in modern varieties, the impact of this compound alone is likely to be very small if at all (Khajali and Slominski, 2012).

The decrease in growth performance was more severe at dietary inclusion of 150 and 200 g/kg RSM inclusion levels. Zeb et al. (2000) observed depressed performance at RSM inclusion of 200 g/kg in their study. Levels at which negative effect is observed will depend on many factors including the processing of RSM and overall nutrient profile of the diet. In the current study, all the diets were formulated on the basis of standardized digestible amino acids and were isocaloric. Part of the reduction in growth performance may have been due to the decrease in feed intake which may influence intake of nutrient and thus depress growth performance especially during the early growing phase.

The treatment with unprocessed OSR was added in the current study to investigate the possibility of using the feedstuff where it may be available in quantity not justifying the cost of processing of the seed. Although there was a depression in growth performance, relative to the control diet, at the inclusion level used in the current study the level of performance observed was within the level observed with RSM inclusion. This suggests therefore that the raw seed is tolerated by the broilers to the same extent that RSM was tolerated. We are not aware of any study in which unprocessed OSR was used in broiler diets. A study with full fat soybean showed that feeding of irradiated soybean led to increased weight gain and total protein efficiency in broilers (El-Din and Farag, 1998). This was attributed to destruction of anti-nutritive factors in the bean by radiation treatment. It is possible that the observation of similar response of broilers to feeding of OSR and RSM in the current study is an indication of the low level of anti-nutrients in both feedstuffs.

In view of the above it may be concluded that difference in ME of RSM from different varieties of rapeseed is primarily driven by residual ether extract content of the meal and that conventional processing condition negatively affects ME and P bioavailability. In addition, because all the birds performed above breed target, even at 200 g/kg RSM inclusion, but all levels of RSM reduced growth performance relative to the control, dietary level of RSM above 100 g/kg may be acceptable depending on rate of growth desired in the production system. .

ACKNOWLEDGEMENTS

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

REFERENCES

Adeola, O., and C. L. Walk. 2013. Linking ileal digestible phosphorus and bone mineralization in broiler chickens fed diets supplemented with phytase and highly soluble calcium. Poult. Sci. 92:2109–2117.

Adewole, D. I., A. Rogiewicz, B. Dyck, and B.A. Slominski. 2016. Chemical and nutritive characteristics of canola meal from Canadian processing facilities. Anim. Feed Sci. Technol. 222:17-30.

Aljuobori, A., I. Zulkifli, A. F. Soleimani, N. Abdullah, and J. B. Liang. 2014. Extrusion enhances metabolizable energy and ileal amino acids digestibility of canola meal for broiler chickens. Ital. J. Anim. Sci. 13:44–47.

Aljuobori, A., I. Zulkifli, A. F. Soleimani, N. Abdullah, J. B. Liang, and A. Mujahid. 2016. Higher inclusion rate of canola meal under high ambient temperature for broiler chickens. Poult. Sci. 95: 1326-1331.

Amezcua, C. M., and C. M. Parsons. 2007. Effect of heat processing and particle size on phosphorus bioavailability in corn distillers dried grains with solubles. Poult. Sci. 86:331 - 337.

Amezcua, C. M., C. M. Parsons, and S. L. Noll. 2004. Content and relative bioavailablity of phosphorus in distillers dried grains with solubles in chicks. Poult. Sci. 83:971 – 976.

ANKOM. 2006. ANKOM Technology Method 13. Neutral detergent fiber in feeds. Filter bag technique. Accessed Apr. 2017. https://www.ankom.com/sites/default/files/document-files/Method_13_NDF_A2000.pdf.

AOAC. 2006. Official methods of analysis. 18th ed. AOAC Int., Arlington, VA.

Aviagen, 2014. Ross 308 broiler: Nutrition specifications. Accessed Oct. 2014. http://en.aviagen.com/assets/Tech_Center/Ross_Broiler/Ross308BroilerNutritionSpecs2014-EN.pdf

Bell, J. M. 1984. Nutrients and toxicants in rapeseed meal: A review. J. Anim. Sci. 58:996-1010.

Bell, J. M. 1993. Factors affecting the nutritional value of canola meal: A review. Can. J. Anim. Sci. 73:679 -697.

Butler, L. G., M. L. Price, and J. E. Brotherton. 1982. Vanillin assay for proanthocyanidins (condensed tannins) - Modification of the solvent for estimation of the degree of polymerization. J Agri Food Chem. 30:1087-1089.

Cai R., and S. D. Arntfield. 2001. A rapid high-performance liquid chromatographic method for the determination of sinapine and sinapic acid in canola seed and meal. J. Am, Oil Chem. Soc. 78:903-910.

Carlson, D., and H. D. Poulsen. 2003. Phytate degradation in soaked and fermented liquid feed – effect of diet, time of soaking, heat treatment, phytase activity, pH and temperature. Anim. Feed Sci.Technol.103:141–154.

Chompreeda, P. T., and M. L. Fields. 1984. Effect of heat and fermentation on the extractability of minerals from soybean meal and corn meal blends. J. Food Sci. 49:566-568.

El-Din, M. D., and H. Farag. 1998. The nutritive value of chicks of full-fat soybeans irradiated at up to 60 kGy. Anim. Feed Sci.Technol.73:319-328.

Hagerman, A. E. 2011. The Tannins Handbook. Accessed Apr. 2017. http://www.users.miamioh.edu/hagermae/

Henkel, H., and R. Mosenthin. 1989. Rapssaat und Rapsprodukte in der Tierernährung. Ubersichten zur Tierernahrung. 17:139-190.

ISO. 1992. Rapeseed – determination of glucosinolates content – Part 1: Method using high-performance liquid chromatography. ISO 9167-1. Pages.1–9 in Official ISO Standards, 1st ed. International Organization for Standardization.

Kasprzak, M. M., J. G. M. Houdijk, S. Liddle, K. Davis, O. A. Olukosi, S. Kightley, G. A. White, and J. Wiseman. 2016a. Rapeseed napin and cruciferin are readily digested by poultry. J. Anim. Physiol. Anim. Nutr. Accessed Nov. 2016. doi:10.1111/jpn.12576 http://onlinelibrary.wiley.com/doi/10.1111/jpn.12576/full

Kasprzak, M. M., J. G. M. Houdijk, S. Kightley, O. A. Olukosi, G. A. White, P. Carre, and J. Wiseman. 2016b. 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. Anim. Feed Sci. Technol. 213:90-98.

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

Khan, N., R. Zaman, and M. Elahi. 1991. Effect of heat treatments on the phytic acid content of maize products. J. Sci. Food Agric. 54:153-156.

Kocher, A., M. Choct, M. D, Proter, and J. Broz. 2000. The effects of enzyme addition to broiler diets containing high concentrations of canola or sunflower meal. Poult.Sci. 79:1767-1774.

Lee, K., G. Qi, and J. S. Sim. 1995. Metabolizable energy and amino acid availability of full fat seeds, meals and oils of flax and canola. Poult. Sci. 74:1341-1348.

Li, J., and Z. El Rassi. 2002. High performance liquid chromatography of phenolic choline ester fragments derived by chemical and enzymatic fragmentation processes: Analysis of sinapine in rape seed. J. Agr. Food Chem. 50:1368-1373.

Littell, R. C., P. R. Henry, A. J. Lewis, and C. B. Ammerman. 1997. Estimation of relative bioavailability of nutrients using SAS procedures. J. Anim. Sci. 75:2672-2683.

Mandal, A. B., A. V. Elangovan, P. K. Tyagi, P. K. Tyagi, A. K. Johri, and S. Kaur. 2005. Effect of enzyme supplementation on the metabolizable energy content of solvent-extracted rapeseed and sunflower seed meals for chicken, guinea fowl and quail. Br. Poult. Sci. 46: 75-79.

McNeill, L., K. Bernard, and M. G. MacLeod. 2004. Food intake, growth rate, food conversion and food choice in broilers fed on diets high in rapeseed meal and pea meal with observations of the resulting poultry meat. Br. Poult. Sci. 45:519–523.

Olukosi, O. A., and O. Adeola. 2009. Estimation of the metabolizable energy value of meat and bone meal for swine. J. Anim. Sci. 87:2590-2599.

Olukosi, O. A., and N. D. Dono. 2014. Modification of digesta pH and intestinal morphology with the use of benzoic acid or phytobiotics and the effects on broiler growth performance and nutrient utilization. J. Anim. Sci. 92:3945-3953.

Olukosi, O. A., C. Combemorel, S. Kightley, J. Wiseman, and J. G. M. Houdijk. 2015. True digestibility of phosphorus determined by regression method for double zero rapeseed meal. Livest. Sci. 182:8-10.

Park, W. Y., T. Matsui, F. Yano, and H. Yano. 2000. Heat treatment of rapeseed meal increases phytate flow into the duodenum of sheep. Anim. Feed Sci. Technol. 88:31-37.

Parr, C. K., Y. Liu, C. M. Parsons, and H. H. Stein. 2015. Effects of high-protein or conventional canola meal on growth performance, organ weights, bone ash, and blood characteristics of weanling pigs. J. Anim. Sci. 93:2165-2173.

Radfar, M., A. Rogiewicz, and B.A. Slominski. 2017. Chemical composition and nutritive value of canola-quality *Brassica juncea* meal for poultry and the effect of enzyme supplementation. Anim. Feed Sci. Technol. 225:97-108.

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

Slominski, B. A., L. D. Campbell, and W. Guenter. 1994. Oligosaccharides in canola meal and their effect on nonstarch polysaccharide digestibility and true metabolizable energy in poultry. Poult. Sci. 73:156-162.

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

Woyengo, T. A., E. Kiarie, and C. M. Nyachoti. 2011. Growth performance, organ weights, and blood parameters of broilers fed diets containing expeller-extracted canola meal. Poult. Sci. 90:2520–2527.

Zeb, A., A. Sattar, A. B. Shah, B. Bibi, and U. ter Meulen. 2002. Effects of feeding increased levels of heat processed rapeseed meal on performance of broiler chicks. Arch. Geflügelk. 66:158-163.

Zobac, P., I. Kumprecht, V. Prokop, and J, Cmolik. 1998. Use of rapeseed meal and lecithin slops in diets for broiler chicks. Czech J. Anim. Sci. 43:511-519.

Table 1. Chemical composition (g/kg dry matter basis) of rapeseed meals and rapeseed expeller meals (Expt. 1).

Variety	Dry matter	Gross energy, kcal/kg	Crude protein	Ether extract	Phytic acid	Total glucosinolates, µmol/g	Sinapine	Tannins[1], mg/g
Rapeseed meals								
Ability	981	4,637	439	43.3	11.0	12.6	51.1	19.3
Avatar	981	4,493	393	34.8	13.1	9.94	70.5	19.1
Compass	970	4,445	388	27.5	25.9	6.61	58.6	18.8
DK Cabernet[2]	979	4,469	367	28.0	16.2	12.6	56.1	19.1
DK Cabernet[2]	984	4,493	371	28.4	17.1	11.2	47.3	20.1
Excalibur	976	4,469	398	27.3	24.0	19.1	50.1	21.2
Incentive	977	4,445	418	31.5	36.7	12.3	52.2	20.7
Palmedor	979	4,493	436	25.6	25.6	13.4	47.8	19.6
PR46W21	983	4,541	409	31.9	23.4	22.8	51.0	21.9
Quartz	959	4,398	389	29.1	23.8	8.93	41.3	21.4
Trinity	959	4,398	369	30.6	23.2	7.59	49.7	11.9
V2750L	966	4,493	414	40.4	17.3	42.4	46.3	11.6
Average	974	4,469	399	31.5	21.4	14.9	51.8	18.7
CV	0.873	1.36	5.89	16.5	31.1	62.6	13.6	17.5
Rapeseed expeller meals								
Compass	913	5,330	329	76.3	22.7	11.9	82.3	18.8
DK Cabernet	894	4,995	351	61.3	24.9	28.1	67.0	11.7
NK Grandia	919	5,114	341	53.7	10.5	38.2	63.4	15.9
Sesame	898	4,947	348	79.1	8.7	35.0	65.9	13.5
Average	919	4,230	342	72.5	16.7	33.3	73.3	15.0
CV	1.32	2.90	2.47	15.5	42.9	35.9	10.7	17.8

[1] Tannins are expressed in cathecin equivalent.

[2] DK Cabernet variety was grown in two different fields.

Table 2. Ingredient and chemical compositions (g/kg) of experimental diets (Expt. 1 and 2) for determination of metabolizable energy of RSM and RSE.

Ingredients	Reference diet	Test diet
Corn	535.2	366.0
Soybean meal	367.0	251.0
Soybean oil	47.0	32.2
Dicalcium phosphate	17.5	17.5
Limestone	14.0	14.0
Titanium dioxide	5.0	5.0
Test feedstuff	-	300
Vitamin-mineral premix[1]	5.0	5.0
DL-Methionine	1.9	1.9
L-Lysine·HCl	3.6	3.6
L-Threonine	0.7	0.7
Salt	3.1	3.1
Total	1,000	1,000
Calculated nutrients and energy		
ME, kcal/kg	3,006	3,079
Protein, g/kg	219.8	267.3
Ca, g/kg	9.9	11.6
P, g/kg	7.0	8.5
Available P, g/kg	4.5	5
Na	1.4	1.4
Cl	2.1	2.1
Calculated total amino acids, g/kg		
Arg	14.8	13.2
His	5.9	5.3
Ile	9.3	8.3
Leu	19.1	17.1
Lys	15.1	13.8
Met	5.3	5.0
Cys	3.6	3.2
Phe	10.6	9.5
Tyr	8.8	7.8
Thr	9.1	8.2
Trp	3.0	2.7

[1] Supplied the following per kilogram of diet: vitamin A, 5,484 IU; vitamin D_3, 2,643 ICU; vitamin E, 11 IU; menadione sodium bisulfite, 4.38 mg; riboflavin, 5.49 mg; d-pantothenic acid, 11 mg; niacin, 44.1 mg; choline chloride, 771 mg; vitamin B12, 13.2 µg; biotin, 55.2 µg; thiamine mononitrate,2.2 mg; folic acid, 990 µg; pyridoxine hydrochloride, 3.3 mg; I, 1.11 mg; Mn, 66.06 mg; Cu, 4.44 mg; Fe, 44.1 mg; Zn, 44.1 mg; Se, 250 µg.

Table 3. Chemical composition (g/kg dry matter basis) of meals of double-low rapeseed varieties subjected to conventional or mild processing conditions.

Variety	Processing	Dry matter	Gross energy, kcal/kg	Crude protein	Ether extract	Phytic acid	Total glucosinolates, μmol/g	Sinapine	Tannins[1], mg/g	NDF	Ca	P
DK Cabernet	Conventional	924	4,646	392	50.0	18.0	2.70	31.0	2.20	433	10.1	11.4
DK Cabernet	Mild	922	4,732	406	78.0	14.2	6.30	36.0	2.30	330	11.1	12.1
PR46W21	Conventional	932	4,643	426	46.0	25.4	4.60	39.0	2.50	321	10.1	9.31
PR46W21	Mild	899	4,708	456	58.0	26.7	7.30	39.0	2.50	325	10.7	9.43

[1] Tannins are expressed in cathecin equivalent.

Table 4. Ingredients and chemical composition (g/kg) of experimental (Expt. 3) diets to determine the relative bioavailability of phosphorus in RSM.

Items	Basal diet	MSP		RSM	
Corn starch	308	304	302	236	163
Dextrose	151	150	149	113	76
Monosodium phosphate (MSP)	-	4.8	9.3	-	-
Rapeseed meal (RSM)	-	-	-	110	220
Soybean meal	474	474	474	474	474
Soybean oil	35	35	35	35	35
Limestone	12	12	12	12	12
Titanium dioxide	5	5	5	5	5
Salt	4	4	2.9	4	4
Vitamin-mineral premix[1]	5	5	5	5	5
DL-Methionine	2.5	2.5	2.5	2.5	2.5
L-Threonine	1.3	1.3	1.3	1.3	1.3
L-Lysine·HCl	2	2	2	2	2
Total	1,000	1,000	1,000	1,000	1,000
Calculated nutrients (g/kg) and energy					
Protein	225.2	225.2	225.2	268.1	311
ME, kcal/kg	3,146	3,127	3,114	3,091	3,036
Ca	5.8	5.8	5.8	6.6	7.3
P[2]	2.9 (3.0)	4.0 (4.0)	5.0 (5.0)	3.9 (4.4)	4.9 (5.5)
P from MSP or RSM	-	1.0	2.0	1.0	2.0
Na	1.6	2.3	2.6	1.6	1.6
Cl	2.4	2.4	1.7	2.4	2.4
Calculated total amino acids, g/kg					
Arg	16.5	16.5	16.5	18.8	21.1
His	6.1	6.1	6.1	7.1	8.1
Ile	10	10	10	11.6	13.1
Leu	17.7	17.7	17.7	20.4	23.2
Lys	15.6	15.6	15.6	17.7	19.9
Met	5.7	5.7	5.7	6.5	7.2

[1] Supplied the following per kilogram of diet: vitamin A, 5,484 IU; vitamin D_3, 2,643 IU; vitamin E, 11 IU; menadione sodium bisulfite, 4.38 mg; riboflavin, 5.49 mg; d-pantothenic acid, 11 mg; niacin, 44.1 mg; choline chloride, 771 mg; vitamin B12, 13.2 µg; biotin, 55.2 µg; thiamine mononitrate,2.2 mg; folic acid, 990 µg; pyridoxine hydrochloride, 3.3 mg; I, 1.11 mg; Mn, 66.06 mg; Cu, 4.44 mg; Fe, 44.1 mg; Zn, 44.1 mg; Se, 250 µg.

[2] Analyzed P content shown in parenthesis.

Table 5. Ingredient and chemical composition (g/kg) of the experimental (Expt. 4) starter and finisher broiler diets.

	Starter phase				Finisher phase			
Items	Control	RSM50	RSM200	OSR80	Control	RSM50	RSM200	OSR80
Wheat	370.0	430.1	399.0	402.2	378.0	435.0	404.3	417.0
Corn	190.0	130.0	130.0	130.0	190.0	130.0	130.0	130.0
Soybean meal	345.0	298.0	175.0	310.0	345.0	298.0	175.0	300.0
Soybean oil	45.0	43.0	50.0	28.0	42.0	43.0	50.0	29.0
Monocalcium phosphate	15.0	14.4	13.0	15.8	13.0	12.5	10.5	12.8
Limestone	16.0	15.5	14.0	15.0	13.0	12.5	11.2	12.2
RSM/OSR[1]	0.0	50.0	200.0	80.0	0.0	50.0	200.0	80.0
Vitamin-mineral premix[2]	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
DL-Methionine	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
L-Lysine·HCl	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Sodium bicarbonate	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Salt	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Total	1,000	1,000	1,000	1000	1,000	1,000	1,000	1,000
Calculated nutrients, energy and digestible amino acids[3]								
Protein	227.4	226.9	225.7	224.3	228.3	227.4	226.3	222.8
ME, kcal/kg	2,998	2,944	2,886	2,921	2,995	2,959	2,902	2,942
Ca	10.0	10.0	10.1	10.2	8.5	8.5	8.5	8.5
Available P	4.5	4.5	4.5	4.8	4.0	4.0	4.0	4.0
Arg	13.1	12.8	12.1	11.6	13.1	12.8	12.1	11.7
His	5.1	5.0	5.1	4.5	5.1	5.1	5.1	4.5
Ile	8.2	8.0	7.6	7.2	8.2	8.0	7.6	7.3
Leu	15.0	14.6	14.0	13.2	15.1	14.6	14.0	13.3
Lys	14.3	13.9	13.2	13.0	14.3	14.0	13.2	13.1
Met	6.9	6.9	7.2	6.6	6.9	6.9	7.2	6.6
Phe	10.2	9.7	8.5	9.0	10.2	9.7	8.5	2.9
Thr	7.1	7.0	6.9	6.2	7.1	7.0	6.9	6.3
Trp	3.3	3.1	2.7	2.9	3.3	3.1	2.7	3.0
Val	8.9	8.8	8.7	7.9	8.9	8.8	8.7	8.0
TSAA	10.0	10.6	12.2	9.4	10.1	10.6	12.2	9.5
Phe+Tyr	16.8	16.8	16.6	15.0	16.9	16.8	16.6	15.2

[1] RSM from DK Cabernet or PR46W21 varieties were incorporated to the control diet at the rate of 50, 100, 150 or 200 g/kg. Unprocessed OSR of DK Cabernet variety was added to the diet at the rate of 80 g/kg.

[2] Supplied the following per kilogram of diet: vitamin A, 5,484 IU; vitamin D_3, 2,643 ICU; vitamin E, 11 IU; menadione sodium bisulfite, 4.38 mg; riboflavin, 5.49 mg; d-pantothenic acid, 11 mg;

niacin, 44.1 mg; choline chloride, 771 mg; vitamin B12, 13.2 µg; biotin, 55.2 µg; thiamine mononitrate,2.2 mg; folic acid, 990 µg; pyridoxine hydrochloride, 3.3 mg; I, 1.11 mg; Mn, 66.06 mg; Cu, 4.44 mg; Fe, 44.1 mg; Zn, 44.1 mg; Se, 250 µg.

[3] Standardized digestible amino acids content were derived from total amino acids content and their standardized digestibility values reported by Kasprzak et al. (2016b).

Table 6. Analyzed chemical composition (g/kg, as fed basis) of the experimental starter and finisher broiler diets (Expt. 4).

Phase	RSM Variety	Diet RSM level, g/kg	Dry matter	Gross energy, kcal/kg	Crude protein	Ether extract	NDF[1]
Starter	Basal diet	0	894	4,045	217	62.5	63.0
	DK Cabernet	50	890	4,063	217	64.6	83.0
	DK Cabernet	100	892	4,052	214	67.3	91.0
	DK Cabernet	150	888	4,056	215	65.9	111.0
	DK Cabernet	200	894	4,128	214	77.0	120.0
	PR46W21	50	887	4,031	219	57.8	77.0
	PR46W21	100	894	4,063	214	65.1	84.0
	PR46W21	150	890	4,064	213	59.9	98.0
	PR46W21	200	897	4,150	208	71.4	106.0
	DK Cabernet OSR[2]	80	899	4,016	214	85.2	77.0
Finisher	Basal diet	0	885	4,002	229	58.8	64.0
	DK Cabernet	50	883	4,015	208	61.8	91.0
	DK Cabernet	100	888	4,079	201	65.4	91.0
	DK Cabernet	150	886	4,059	204	67.1	102.0
	DK Cabernet	200	887	4,135	203	74.1	112.0
	PR46W21	50	886	4,052	217	62.1	76.8
	PR46W21	100	884	4,059	218	34.8	98.0
	PR46W21	150	888	4,063	219	65.2	92.0
	PR46W21	200	894	4,137	210	73.3	117.0
	DK Cabernet OSR[2]	80	882	4,221	203	98.2	80.0

[1] NDF = neutral detergent fiber.

OSR = unprocessed double-low rapeseed.

Table 7. Metabolizable (and nitrogen corrected) metabolizable energy (DM basis) of RSM and RSE for broilers (Expt. 1).

Varieties	EM[1], %	ME, kcal/kg	MEn, kcal/kg
RSM			
Ability	45.6^{bc}	2,158^{a}	1,943^{a}
Avatar	45.5^{bc}	2,088^{cd}	1,900^{cd}
Compass	45.5^{bc}	2,096^{c}	1,912^{d}
DK Cabernet	45.5^{bc}	2,084^{de}	1,902^{de}
DK Cabernet	45.6^{bc}	2,072^{e}	1,890^{de}
Excalibur	45.5^{bc}	2,072^{e}	1,878^{e}
Incentive	45.7^{bc}	2,081^{de}	1,871^{de}
Palmedor	45.6^{bc}	2,086^{cd}	1,869^{cd}
PR46W21	45.4^{c}	2,086^{cd}	1,895^{cd}
Quartz	45.5^{bc}	2,096^{c}	1,910^{c}
Trinity	45.5^{bc}	2,086^{cd}	1,921^{cd}
V275OL	45.9^{a}	2,144^{b}	1,950^{b}
Pooled SEM	0.084	4.30	5.74
P-values	0.003	< 0.001	< 0.001
RSE			
Compass	47.0^{a}	2,749^{a}	2,596^{a}
DK Cabernet	46.3^{b}	2,581^{b}	2,419^{b}
NK Grandia	46.3^{b}	2,581^{b}	2,412^{b}
Sesame	46.3^{b}	2,533^{c}	2,369^{c}
Pooled SEM	0.130	7.89	9.32
P-values	0.003	< 0.001	< 0.001

$^{a-e}$ Means in the same column, within a group, but with different superscripts are different ($P < 0.05$).

[1] EM = energy metabolizability.

n = 8 replicate cages with 3 birds per replicate cage.

Table 8. ME and MEn of RSM subjected to conventional or mild processing conditions (Expt. 2).

Variety	Processing condition	ME, kcal/kg	MEn, kcal/kg	EM, %
		Means for simple effects		
DK Cabernet	Conventional	1,623	1,448	35.7
PR46W21	Conventional	1,814	1,620	39.7
DK Cabernet	Mild	2,072	1,892	44.2
PR46W21	Mild	1,998	1,804	43.5
Pooled SEM		70.7	72.2	1.50
Variety × Processing		0.082	0.097	0.151
Means for main effect of RSM variety				
PR46W21		1,906	1,712	42.0
DK Cabernet		1,848	1,670	40.0
Pooled SEM		47.8	49.0	1.01
Variety effect		0.408	0.563	0.275
Means for main effect of RSM processing conditions				
	Conventional	1,719	1,534	38.0
	Mild	2,035	1,848	44.0
Pooled SEM		47.8	49.0	1.01
Processing effect		< 0.001	< 0.001	< 0.001

EM = energy metabolizability.

n = 8 replicate cages with 3 birds per replicate cage for simple effects means.

n = 16 replicate cages with 3 birds per cage for main effects means.

Table 9. Growth performance, bone mineralization and ileal P digestibility of broilers receiving graded levels of dietary phosphorus supplied by monosodium phosphate or RSM produced by two processing conditions (Expt. 3).

Treatment	Diet P, g/kg	Weight gain[1], g	ADFI, g	FCR[2]	Tibia ash[3], %
Basal (B)	3.4	471.7	439.8	0.935	15.08
B + MSP[4]	4.5	607.0	539.1	0.889	19.07
B + MSP	5.5	646.3	557.4	0.863	18.55
B + DKC[5]	4.6	504.7	447.0	0.886	16.67
B + DKC	5.7	544.2	493.9	0.909	16.73
B + DKM[5]	4.4	522.0	447.6	0.858	14.30
B + DKM	5.3	540.6	519.8	0.961	16.10
B + PRC[6]	4.9	510.1	459.9	0.902	15.53
B + PRC	6.1	523.1	501.9	0.962	16.32
B + PRM[6]	4.2	492.4	433.6	0.88	16.60
B + PRM	5.4	514.7	488.4	0.949	16.33
Pooled SEM		13.2	12.5	0.021	0.791
P-values for linear and quadratic contrasts					
Linear – MSP		< 0.001	< 0.001	0.021	0.029
Quadratic – MSP		0.072	0.060	0.686	0.084
Linear – DKC		0.001	< 0.001	0.393	0.235
Quadratic – DKC		0.824	0.039	0.174	0.518
Linear – DKM		0.002	0.001	0.393	0.433
Quadratic – DKM		0.310	0.064	0.006	0.258
Linear – PRC		0.015	0.024	0.500	0.318
Quadratic – PRC		0.423	0.602	0.206	0.873
Linear – PRM		0.053	0.033	0.602	0.235
Quadratic – PRM		0.967	0.104	0.024	0.323

[1] Multiple regression based on weight gain (Y, g) on supplemental P intake (g) from MSP or DKC and DKM yielded the equation: Y = 487 + 87.5±1.10MSP + 11.9±1.30DKC + 28.2±1.25DKM, ($r^2 = 0.72$); whereas the equation for PRC or PRM yielded the equation: Y = 486 + 88.3±1.25MSP + 19.7±1.44PRC + 27.0±1.49PRM, ($r^2 = 0.70$).

[2] Mortality-corrected FCR.

[3] Multiple regression based on tibia ash (Y, %) on supplemental P intake (g) from MSP, DKC and DKM yielded the equation: $Y = 13.9 + 3.82 \pm 0.09MSP + 1.78 \pm 0.11DKC + 0.81 \pm 0.11DKM$, ($r^2 = 0.60$); whereas the equation for PRC or PRM yielded the equation: $Y = 14.1 + 3.82 \pm 0.08MSP + 1.38 \pm 0.10PRC + 1.29 \pm 0.10PRM$, ($r^2 = 0.66$).

[4] MSP = monosodium phosphate.

[5] DKC and DKM = DK Cabernet RSM derived from conventional or mild processing conditions, respectively.

[6] PRC and PRM = PR46W21 RSM derived from conventional or mild processing conditions, respectively.

n = 6 replicate cages with 5 birds per replicate cage.

Table 10. Relative P bioavailability, total P and bioavailable P content of RSM (Expt. 3).

Variety	Processing	Relative Bioavailability, %[1]	Total P, g/kg	Bioavailable P content, g/kg[2]
			Weight gain	
DK Cabernet	Conventional	13.6	11.4	1.56
DK Cabernet	Mild	32.2	12.1	3.88
SEM		6.35		
P-value		0.001		
PR46W21	Conventional	22.3	9.31	2.08
PR46W21	Mild	30.5	9.42	2.88
SEM		5.35		
P-value		0.154	-	-
			Tibia ash	
DK Cabernet	Conventional	46.6	11.4	5.33
DK Cabernet	Mild	21.2	12.1	2.56
SEM		4.05		
P-value		0.037		
PR46W21	Conventional	36.1	9.31	3.36
PR46W21	Mild	33.8	9.42	3.18
SEM		3.62		
P-value		0.634	-	-

---

[1] Bioavailability of the P in RSM relative to MSP. Calculated by the common intercept slope ratio using the multiple regression equations in the footnote of Table 9.

[2] Bioavailable P content was derived as the product of bioavailability coefficient and the total P in the oilseed rape meals.

n = 6 replicate cages with 5 birds per replicate cage.

Table 11. Growth performance response of broilers to the experimental diets (Expt. 4).

Diets	Variety	Level, g/kg	Starter (d 0 to 21)			Finisher (d 21 to 42)			Overall (d 0 to 42)		
			Weight gain, g	Feed intake, g	FCR	Weight gain, g	Feed intake, g	FCR	Weight gain, g	Feed intake, g	FCR
1	Basal diet	0	1,015	1,259	1.241	2,593	4,028	1.554	3,608	5,287	1.466
2	DK Cabernet	50	958	1,222	1.275	2,453	3,976	1.624	3,411	5,198	1.525
3	DK Cabernet	100	956	1,281	1.288	2,496	4,011	1.608	3,451	5,241	1.520
4	DK Cabernet	150	894	1,169	1.309	2,375	3,929	1.655	3,269	5,098	1.560
5	DK Cabernet	200	893	1,203	1.348	2,265	3,892	1.718	3,158	5,095	1.613
6	PR46W21	50	981	1,253	1.278	2,490	3,975	1.597	3,471	5,228	1.506
7	PR46W21	100	971	1,228	1.265	2,427	3,870	1.595	3,398	5,098	1.500
8	PR46W21	150	894	1,177	1.316	2,414	4,052	1.679	3,308	5,227	1.581
9	PR46W21	200	899	1,193	1.327	2,353	3,871	1.646	3,252	5,064	1.558
10	DK Cabernet seed	80	963	1,212	1.259	2,351	3,817	1.624	3,314	5,029	1.518
	Pooled SEM		9.57	13.5	0.014	31.6	57.9	0.022	33.8	61.0	0.017
P-values for main effects and interaction											
Variety			0.375	0.155	0.346	0.408	0.782	0.072	0.001	0.757	0.497
Level			< 0.001	< 0.001	< 0.001	< 0.001	0.829	0.005	< 0.001	0.158	<0.001
Variety × Level			0.755	0.779	0.491	0.024	0.075	0.140	0.054	0.069	0.170
P-values for contrasts											
Linear: DK Cabernet (1 to 5)			< 0.001	0.003	< 0.001	< 0.001	0.089	< 0.001	< 0.001	0.022	< 0.001

Quadratic: DK Cabernet (1 to 5)	0.173	0.289	0.796	0.442	0.690	0.558	0.741	0.953	0.169
Linear: PR46W21 (1 and 6 to 9)	< 0.001	< 0.001	< 0.001	< 0.001	0.228	0.001	< 0.001	0.031	< 0.001
Quadratic:PR46W21 (1 and 6 to 9)	0.726	0.696	0.822	0.288	0.807	0.428	0.255	0.834	0.612
Basal vs. DK Cabernet seed	0.001	0.015	< 0.001	< 0.001	0.012	< 0.001	< 0.001	0.004	< 0.001

n = 10 replicate pens with 15 birds per replicate pen.