POULTRY CRC LTD

FINAL REPORT

Sub-Project No: 2.1.8

PROJECT LEADER: R. A. Swick

Replacing supplemental oil with full fat canola seed in broiler diets

DATE OF COMPLETION: November 2013

ISBN 1 921010 69 X

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Published in August 2014

Executive Summary

A study was conducted with broilers to examine the feeding value of canola seed. The industry uses canola seed intact as a feed ingredient to supply fat and digestible amino acids to commercial diets. The fat in seeds is contained in oil bodies that are surrounded by a peptide coating that may limit digestibility of the oil. Furthermore, canola contains the enzyme myrosinase that catalyses the breakdown of glucosinolate to other metabolites including isothiocyanate. Isothiocyanate is a bitter compound and its production from canola can be minimised by applying heat to denature the myrosinase enzyme. Such heat is applied in expeller and solvent extraction operations. In the present study, whole canola seed was compared to solvent extracted canola meal plus refined canola oil at levels to supply the same levels of amino acids and oil. Further, the whole canola seed was either incorporated in whole form into the diets or hammer milled in an attempt to break the seed coat and perhaps release the oil from oil bodies. All feeds were then either cold pelleted (65 °C) or steam pelleted to 85 °C.

Performance of birds was examined in floor pens with wood shaving litter to 35 days. In addition to AME, amino acid profile of the seeds was tested, as was amino acid, fat, dry matter and N digestibility of the diets. Selected relative organ weights were determined. Overall results showed that birds fed canola meal plus oil consumed more feed and were heavier than those fed canola seed. However FCR was better in birds fed canola seed than birds fed canola meal plus oil. Overall economic evaluation in terms of feed cost per kg live weight, FCR corrected to a common 2.7 kg body weight, and calculation of European broiler efficiency index (EBEI) all favoured canola seed over canola meal plus oil. Pelleting conditions (cold or steam) impacted bird growth and efficiency differently depending on canola source. Fat digestibility was lower with higher pellet temperature and also in birds fed canola seed compared to meal plus oil. The AMEn of canola seed was measured to be 4702 kcal/kg DM basis. The results suggest that canola seeds are less palatable than meal plus oil, but overall efficiency favours feeding of canola seed over solvent extracted meal plus oil.

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Introduction

The price of fat and oil for use in broiler feed is increasing due to increased demand from the biofuel industry and the food sector. Broiler diets have subsequently increased in cost. Some Australian broiler producers are including full fat canola seed (CS) in broiler diets. Canola seed can contribute substantially more to the metabolisable energy content of the diet than oil-extracted solvent or expeller canola meal. Canola seed contains approximately 40% oil and 21-23% protein (Fenwick and Curtis, 1980) making it an attractive feed ingredient for poultry diets. The level of inclusion is typically below the amount for complete removal of supplemental oil due to concerns about glucosinolate and isothiocyanate content. Early research conducted by Summers et al. (1982) showed a reduction in weight gain and feed intake of broilers fed diets containing 17.5% or higher CS. However, these authors found that the quality of the diet was not a strong indicator of the poor performance of birds as the experimental diets were not similar in the fat content. In another study conducted by Meng et al. (2006), inclusion of 15% canola seed in mash diet from d 5 to 18 resulted in lower fat and protein digestibility and negatively affected apparent metabolisable energy corrected for nitrogen (AMEn) of the diet. Because of these literature reports suggesting uncertainty in nutrient utilisation, complete substitution of supplemental oil with CS is not practiced.

There are reports indicating that grinding and heat treatment of CS are beneficial in enhancing the nutrient utilisation (Muztar et al., 1978; Salmon et al., 1988). It is believed that disruption of the cell structure resulting in degradation of oil containing bodies within the cell may improve oil digestibility. In comparison to a mash diet, steam-pelleting was shown to enhance the nutritive value of whole CS in maize and soybean meal diets (Shen et al., 1983). However, the effect of pelleting conditions and pre-pellet hammer mill grinding on CS utilisation has not been studied in wheat-based broiler diets. Thus, the present study was designed to examine performance and nutrient digestibility of broilers fed diets containing CS as the major supplemental fat source. The effects of grinding and pelleting conditions on nutrient utilisation were also examined in the experimental diets.

Materials and methods

Experimental design and diets

A 2×3 factorial arrangement of treatments was employed to investigate CS inclusion under various pelleting conditions. Factors were: pelleting conditions: cold pelleting (65 °C) or steam pelleting (85 °C); and diet: canola meal + oil (control), whole canola seed (WCS) or hammer-milled canola seed (HCS). Birds were fed a common diet to day 10 and then randomly allocated to experimental diets containing 11.45% CS or equivalent, as solvent canola meal plus canola oil, from d 10 to 24 and 13% (or meal plus oil) from d 24 to 35. All diets were formulated to meet the requirements of Ross 308 broiler chickens (Aviagen, 2007). Diets were formulated in such a way that CS replaced only canola meal and canola oil in the control diet so that no oil was supplemented to the diets containing canola seed.

To evaluate the effect of hammer milling, canola seed was first hammer milled with wheat in the same proportion as formulated prior to adding to the mixer. Each of the diets was mixed and divided into two batches and then either steam-pelleted (85 °C) at the University of Sydney, Camden or cold-pelleted (no steam at maximum 65 °C) at the University of New England, Armidale. The composition of the canola seed and canola meal is given in Table 1. The ingredient composition, calculated nutrient composition and gross chemical analysis of experimental diets is given in Table 2. Protein and energy contents of the experimental diets were maintained at the same level. The canola seed sample was analysed prior to feed formulation. The ME values of 37.26 (8900 kcal), 10.04 (2400 kcal), and 8.37 (2000 kcal/kg) MJ/kg were used for canola oil, SBM, and canola meal respectively. The value of 21.77 MJ/kg (5200 kcal/kg as fed) was used for energy content of CS which was adjusted according to the oil (44%) and fatty acid composition (Wiseman et al., 2009).

Housing and general management

A total of 672 male day-old Ross 308 broiler chickens, vaccinated for Marek's disease and infectious bronchitis, were obtained from the Baiada commercial hatchery in Tamworth, NSW. Forty-eight floor-based experimental cages (42 × 75 × 25 cm) were used with soft wood-shavings as litter to house the birds in a climate-controlled system. The cages were randomly assigned to each of six treatments, each replicated eight times, with 14 birds per replicate. Temperature was set at 33-34 ºC on the first day of the experiment and then gradually decreased by 1 ºC every second day until a stable temperature of 24 ºC was reached by d 21. A lighting program of 18 h light and 6 h darkness was maintained throughout the trial except for the first week when the birds had 23 hours of light. Birds had access to feed and water ad libitum. Birds were fed a common starter diet for the first 10 d. The grower experimental diets were assigned to the birds from d 10-24 followed by finisher diets fed until d 35. Feed consumption and body weight (BW) were recorded on a cage basis at the beginning and the end of each phase of feeding. Feed conversion ratio, corrected for mortality, was then calculated.

Sample collection and processing, nutrient digestibility

Two samplings (d 24 and d 35) were conducted in which three birds per replicate were randomly selected, weighed and subsequently euthanized by cervical dislocation. From one bird in each sampling, the gastrointestinal tract was excised; the small intestine was divided into three segments; the duodenum (from the gizzard outlet to the end of the pancreatic loop), the jejunum (from the end of pancreatic loop to Meckel's diverticulum), and the ileum (from the Meckel's diverticulum to 3 cm above the ileo-caecal junction). The empty weight of each region of the small intestine along with the proventriculus and gizzard, were measured. The ileal contents of the three sampled birds were collected by gently squeezing the ileum into ice-cold plastic containers, and pooled by replicate cage. Ileal samples were stored at -20 °C and then freeze-dried before conducting further analyses.

Dry matter (DM) and fat content of samples was determined using methods of AOAC (2005). The CP content (Kjeldahl N × 6.25) of the diets and digesta samples was performed using a LECO FP-2000 automatic analyser. Amino acid determination was conducted by Evonic Ltd by hydrolysing the samples with 6M HCl (containing phenol) for 24 h at 110 ± 2 °C in glass tubes sealed under vacuum. Titanium contents of ileal and diet samples were measured using a UV spectrophotometer following the method described by Short et al. (1996). Subsequent digestibility coefficients for different nutrients were calculated using the following formula:

Apparent ileal digestibility coefficient:

$$= \frac{(NT/Ti)_d - (NT/Ti)_i}{(NT/Ti)_d}$$

where,

$(NT/Ti)_d$ was the ratio of nutrient (NT) and titanium (Ti) in diet

$(NT/Ti)_i$ was the ratio of nutrient (NT) and titanium (Ti) in ileal digesta

The Animal Ethics Committee of the University of New England approved all the experimental procedures.

Apparent metabolisable energy of whole canola seed

Two experimental diets were formulated as shown in Table 3. The reference treatment consisted of a common corn-soybean meal diet without enzyme supplementation, formulated to meet or exceed the nutrient requirements of broiler chicks as described in the Ross 308 manual (2007). Canola seed test diets contained 15% of the seed substituting the energy yielding ingredients of the reference. Both diets were fed in a pelleted form and fresh water and feed were available to all chicks for *ad libitum* intake throughout the experiment. A total of 72 male broiler chicks were used in the AME measurement randomly assigned to 2 treatments, each replicated 6 times. From day 1 to 10 and 10 to 18, chicks were fed on conventional starter and grower diets. On d 18 birds were fed the 2 experimental diets (basal diet and canola seed test diet) for 5 d (adaptation period) followed by a 72-h energy balance assay from 22 to 25 d of age. During the 72-h collection period, feed consumption was recorded and the entire excreta was collected to calculate energy and nitrogen intake and excretion.

AMEn of the basal and test diets (DM basis) is determined using the following equations:

$$AMEn = \{(GEI - GEE) - [8.73 \times (NI - NE)]\}/FI$$

Test diets AMEn = basal AMEn – [(basal AMEn – test diet AMEn)/percentage of inclusion rate]

where GEI is the gross energy intake and GEE is the gross energy output of excreta (kcal/kg); 8.73 is nitrogen correction factor; NI is nitrogen intake from the diet and NE is the nitrogen output from the excreta (kg); FI is the feed intake (kg).

Statistical analysis

The 6 treatments of three diets (control, whole CS and hammer-milled CS) and pelleting condition (steam or cold pellet) were arranged in a 3×2 factorial design. Experimental units were randomly allocated to pens within the room. Data were subjected to statistical analysis using 2-way ANOVA of GLM procedure of SAS (2003) to assess the main effects and 2-way interaction. Data were checked for normal distribution. All statements of significance are considered on a *P*-value less than 0.05 unless otherwise specified.

Table 1. Chemical analysis of canola meal and full fat whole canola seed[1]

	Canola meal	Full fat canola seed
Taurine	0.03	0.03
Hydroxyproline	0.31	0.19
Aspartic Acid	2.47	1.43
Threonine	1.52	0.86
Serine	1.26	0.75
Glutamic Acid	6.06	3.32
Proline	2.19	1.18
Lanthionine	0.00	0.00
Glycine	1.86	1.05
Alanine	1.60	0.88
Cysteine	0.85	0.49
Valine	1.88	1.09
Methionine	0.73	0.41
Isoleucine	1.46	0.85
Leucine	2.59	1.45
Tyrosine	1.02	0.61
Phenylalanine	1.49	0.87
Hydroxylysine	0.08	0.04
Ornithine	0.01	0.01
Lysine	2.14	1.27
Histidine	0.99	0.55
Arginine	2.15	1.23
Tryptophan	0.47	0.26
Total amino acids	33.16	18.82
Reactive lysine	2.00	1.25
Reactive lysine:total lysine	0.935	0.984
Moisture (U Missouri)	10.3	5.0
Moisture (UNE)	11.7	6.9
Crude protein (U Missouri)	37.2	20.4
Crude protein (UNE)	36.2	19.9
ADF	17.9	11.0
NDF	28.9	17.9
Ether extract (U Missouri)	3.9	44.3
Crude fat – hexane (UNE)	3.6	44.0
Gross energy (UNE) (kcal/kg)	5055	7012
Crude fibre	13.4	8.4
Ash	7.01	3.85
Glucosinolate µmol/g	6.46	6.42

[1]As is basis

Table 2. Composition of experimental diets (%)

Ingredients	Starter (d 1-10)	Grower (d 10-24)		Finisher (d 24-35)	
		Control	Canola seed	Control	Canola seed
Wheat	60.24	63.182	62.655	63.323	62.776
Soybean meal	30.91	22.050	22.054	20.820	20.829
Canola meal	0.000	6.122	0.000	6.975	0.000
Canola seed	0.000	0.000	11.415	0.000	13.000
Canola oil	4.068	4.815	0.000	5.486	0.000
Limestone	1.471	1.101	1.101	1.052	1.052
Di calcium phosphate	1.345	0.773	0.773	0.666	0.666
Salt	0.304	0.238	0.238	0.234	0.234
L- lysine HCl	0.337	0.246	0.246	0.063	0.063
DL- methionine	0.361	0.243	0.243	0.141	0.141
Sodium bicarbonate	0.231	0.200	0.200	0.200	0.200
Choline chloride	0.189	0.192	0.192	0.192	0.192
L-threonine	0.195	0.116	0.116	0.125	0.125
Mineral premix[1]	0.075	0.075	0.075	0.075	0.075
Vitamin premix[2]	0.050	0.050	0.050	0.050	0.050
Salinomycin	0.050	0.050	0.050	0.050	0.050
Zn bacitracin	0.033	0.033	0.033	0.033	0.033
Phytase	0.010	0.010	0.010	0.010	0.010
Xylanase	0.005	0.005	0.005	0.005	0.005
TiO2	0.000	0.500	0.500	0.500	0.500
Calculated or measured nutrients (% unless otherwise specified)					
ME MJ/kg (kcal/kg)	12.65 (3021)	12.96 (3095)	12.97 (3097)	13.16 (3143)	13.18 (3147)
Protein	21.9	20.2	20.2	19.7	19.7
Protein (measured DM)	-	20.5	20.0	20.3	20.0
Crude fat	6.82	6.65	6.65	7.31	7.31
Crude fat (measured, DM)	-	8.89	9.10	10.9	10.5
Calcium	1.05	0.80	0.80	0.77	0.76
Total phosphorus	0.67	0.58	0.57	0.56	0.54
Available phosphorus	0.50	0.40	0.40	0.38	0.38
Sodium	0.23	0.19	0.20	0.19	0.18
Chloride	0.35	0.27	0.29	0.32	0.32
Digestible Arg	1.35	1.14	1.14	1.12	1.12
Digestible Lys	1.27	1.10	1.10	0.94	0.94
Digestible Met	0.65	0.52	0.52	0.42	0.42
Digestible Met+Cys	0.94	0.83	0.84	0.73	0.74
Digestible Trp	0.30	0.22	0.22	0.22	0.22
Digestible Ile	0.86	0.79	0.78	0.77	0.77
Digestible Thr	0.83	0.72	0.73	0.72	0.73
Digestible Val	0.95	0.85	0.85	0.84	0.84
Measured amino acids					
Met		0.52	0.51		
Cys		0.36	0.36		
Met + Cys		0.88	0.87		
Lys		1.15	1.12		
Thr		0.81	0.81		
Arg		1.22	1.21		

Ile	0.77	0.77
Leu	1.43	1.42
Val	0.91	0.91
His	0.53	0.51
Phe	0.94	0.92
Gly	0.85	0.84
Ser	0.96	0.94
Pro	1.32	1.33
Ala	0.81	0.80
Asp	1.71	1.68

[1] Formulated to supply 12,000 IU vitamin A, 5,000 IU vitamin D3, 75 IU vitamin E, 3 mg vitamin K, 3 mg, thiamine, 8 mg riboflavin, 55 mg nicotinic acid, 13 mg pantothenic acid, 5 mg pyridoxine,0.2 mg biotin, 2.0 mg folic acid, 0.016 mg vitamin B12 per kg of diet.

[2] Formulated to supply 16 mg copper, 1.25 mg iodine, 40 mg iron, 120 mg manganese, 0.30 mg selenium and 100 mg mg zinc per kg of diet.

Table 3. Experimental diets for AME determination of canola seed

Ingredients %	Reference diet	Canola seed diet
Maize	60.00	52.81
Soybean meal	31.37	27.61
Canola seed	0.00	15.00
Canola oil	4.05	0.00
Limestone	1.54	1.54
Dicalcium Phosphate	1.497	1.497
Salt	0.20	0.20
Sodium bicarbonate	0.139	0.139
TiO_2	0.30	0.30
Vitamin premix	0.05	0.05
Mineral premix	0.075	0.075
Choline Chloride 70%	0.057	0.057
L-lysine HCL 78.4	0.250	0.250
DL-methionine	0.326	0.326
L-threonine	0.146	0.146
Calculated composition		
Dry matter %	88.78	89.12
Crude protein %	19.57	20.27
AMEn MJ/kg (kcal/kg)	13.06 (3120)	13.44 (3211)
Calcium	1.00	1.03
Available phosphorus	0.40	0.41
Digestible Met + Cys	0.84	0.90
Digestible Met	0.60	0.62
Digestible Lys	1.10	1.10
Digestible Thr	0.73	0.76

[1] Formulated to supply 12,000 IU vitamin A, 5,000 IU vitamin D3, 75 IU vitamin E, 3 mg vitamin K, 3 mg, thiamine, 8 mg riboflavin, 55 mg nicotinic acid, 13 mg pantothenic acid, 5 mg pyridoxine,0.2 mg biotin, 2.0 mg folic acid, 0.016 mg vitamin B12 per kg of diet.

[2] Formulated to supply 16 mg copper, 1.25 mg iodine, 40 mg iron, 120 mg manganese, 0.30 mg selenium and 100 mg mg zinc per kg of diet.

Results

Metabolisable energy and growth performance

The proximate analysis (UNE) conducted on CS showed that the seed contained 19.9%, (as is basis) crude protein and 44.0% (as is basis) crude fat and the gross energy was 29.35 MJ/kg DM (7012 kcal/kg DM). The AME and AMEn values of CS were found to be 21.08 and 19.68 MJ/ kg DM (5036 and 4702 kcal/kg DM), respectively. For formulation purposes, the AMEn of canola seed was calculated from the AME of canola oil and AME of canola meal. Based on the prediction equations of Wiseman et al. (1991), taking into account bird age, ratio of saturated and unsaturated fatty acids and estimated free fatty acid content of oil in seed (35g/kg) the AME of canola oil for birds older than 21 d should be 9266 kcal/kg or 38.8 MJ/kg. Canola meal was assumed to have an AMEn of 2070 kcal/kg or 8.66 MJ/kg on an 11.6% DM basis based on literature values. Assuming a ratio of 56:44 (canola meal:canola oil = canola seed) based on laboratory analysis of crude fat and crude protein and using the AMEn values for meal and AME values for canola oil, the calculated AMEn of canola seed was 5200 kcal/kg or 21.76 MJ/kg (as is basis). This was used to formulate the diets in this experiment. Actual *in vivo* determination of AME and AMEn values of CS were found to be 5036 and 4702 kcal/kg DM or 21.07 or 19.67 MJ/kg DM, respectively. On an as is basis (5% moisture) the *in vivo* AMEn value is 4466 kcal/kg or 18.69 MJ/kg, 14% lower than expected based on calculation of meal plus oil. As shown in Table 4, inclusion of CS decreased ($P < 0.01$) feed intake of the birds when compared to canola meal plus oil at each time assessed across the study. There was no difference in feed consumption between the birds that received either WCS or HCS. A diet by pellet condition interaction was detected for feed intake on d 24 ($P < 0.05$). Birds fed the unmilled CS had higher feed intake when the diet was steam pelleted whereas birds fed the hammer milled CS and meal plus oil diets had lower feed intake as a result of steam pelleting.

Body weight gain (BWG) was highest in birds fed canola meal plus oil as compared to the CS treatments between d 10 to d 35 ($P < 0.01$). Inclusion of CS improved FCR ($P < 0.05$) of the birds when assessed across the whole period of study. Interaction between processing and diet was detected for FCR and feed intake. FCR was improved from d 10 to d 24 by steam pelleting in birds fed meal plus oil but not either CS ($P < 0.05$). From d 10 to d 35 FCR of steam pelleted WCS fed birds was poorer relative to canola meal plus oil or HCS fed birds ($P < 0.05$).

Intestinal and organ weights

There was no interaction between pelleting condition and diet for the relative weight of proventriculus, gizzard, liver or any of the intestinal regions in this experiment (Table 5). However, gizzard weight was higher ($P < 0.01$) in the birds fed steam-pelleted diets than cold-pelleted at d 24 and 35. At the end of the experiment (d 35), feeding WCS resulted in a heavier ($P < 0.05$) gizzard compared to the other group of birds. The relative weights of the duodenum, jejunum and ileum were higher in birds fed HCS when compared with birds fed the control diet or the diet containing WCS ($P < 0.05$)

Nutrient digestibility

As shown in Table 6, a significant interaction was found for the ileal N digestibility at d 35 where steam pelleting led to a decrease in N digestibility in the birds fed CS, regardless of being hammer-milled or whole pelleted, when compared to meal plus oil ($P < 0.05$). Interactions between diet and pelleting condition were also detected for ileal fat digestibility at d 24 and d 35. At d 24, steam pelleting at 85°C reduced fat digestibility in birds fed WCS while there was no effect on birds fed HSC or canola meal and canola oil (control). There was also a significant interaction of diet and pelleting condition at d 35 for fat digestibility showing lower digestibility observed in WCS diets when steam pelleted but not cold pelleted ($P < 0.05$).

Ileal DM digestibility was not affected at d 24 or 35. However, when assessed at d 35, DM digestibility tended to decrease ($P = 0.06$) in birds fed HSC while there was no significant difference between birds fed control or WCS for DM digestibility. As shown in Tables 7 and 8, there was no significant effect of CS inclusion on amino acid digestibility values at d 24. However, a diet x pelleting condition interaction was detected for ileal Met digestibility revealing the highest values in the birds fed steam pelleted diets containing HCS relative to WCS or meal plus oil ($P < 0.05$). Regardless of diet composition effect, digestibility values for Methionine, Isoleucine, Leusine, Valine, Histidine, Phentlalanine, Serine, Proline, Alanine, Aspartic Acid and Glutamic Acid were higher ($P < 0.05$) in birds fed steam-pelleted diets. It can be said that the heat labile amino acids Lysine and Cysteine were not affected by steam pelleting when compared to cold pelleting.

Economics of Production

Calculation results on economics of production are given in Table 9. No statistical analysis was performed on this data as economics are secondary to the actual performance data. As the study used a common diet to day 10, Ross 308 performance data were used for this period and added to the experimental data from day 10 to 35 to calculate corrected FCR to a common 2.70 kg body weight. Each 100 grams of 35 d body weight was assumed to be equivalent to 0.02 FCR i.e. 2 points. Results indicate benefit for CS over canola meal plus oil. Interestingly, steam pelleting seemed to benefit HCS over WCS.

For the calculation of feed cost per kg live weight, common diet costs were used for the meal plus oil and CS diets within a phase. At the time of writing, feed oil costs are higher than those used in the calculations ($1100/mt at present vs. $885 in the calculation). This would make the diets containing CS more economical than those containing meal plus oil. Feed cost per kg live weight favoured CS over canola meal plus oil. Averaged across pellet conditions, the meal plus oil had a feed cost/kg BW of 0.6577 as compared to the HCS with a cost of 0.6406. This $0.017/ kg is worth $0.0459 per 2.7 kg bird. For a typical farm of 200,000 birds x 5 grow outs this would be worth $22,950.

The European broiler production efficiency index (EBEI) calculation showed overall fantastic performance in this study. Results favoured the HCS over WCS. EBEI was negatively impacted by steam pelleting in birds fed the WCS diet. This was surprising in that it was assumed that steam pelleting would improve digestibility of WCS by breaking the seed coat and releasing oil from oil bodies. Fat digestibility was also impacted by steam pelleting in both the WCS and HCS diets.

Table 4. Effect of canola seed inclusion and feed processing on performance of broiler chickens from d 10 to 35 [1,2]

		Feed intake (g/bird)			Body weight gain (g/bird)			FCR		
Diet	Pellet	d10-24	d24-35	d10-35	d10-24	d24-35	d10-35	d10-24	d24-35	d10-35
Canola meal + oil	Cold	1548.8^{a}	2125.0	3673.8	1101.7	1320.9	2422.7	1.415^{a}	1.609	1.518
	Steam	1502.9^{ab}	2097.6	3600.6	1100.3	1288.7	2389.0	1.366^{ab}	1.628	1.507
WCS	Cold	1457.0^{bc}	1989.4	3446.4	1092.5	1262.9	2355.4	1.334^{b}	1.577	1.463
	Steam	1501.0^{abc}	2014.1	3515.0	1055.9	1273.0	2328.9	1.423^{a}	1.584	1.510
HCS	Cold	1490.5^{bc}	1965.4	3455.9	1093.7	1236.0	2329.8	1.363^{ab}	1.592	1.484
	Steam	1452.9^{c}	1986.1	3439.0	1068.2	1292.8	2361.0	1.361^{ab}	1.537	1.457
	SEM	6.99	12.84	15.48	6.99	8.73	9.18	0.010	0.008	0.006
Main effects										
Canola meal		1525.9^{a}	2111.3^{a}	3637.2^{a}	1101.0	1304.8	2405.8^{a}	1.390	1.619^{a}	1.513^{a}
WCS		1479.0^{b}	2001.8^{b}	3480.7^{b}	1074.2	1268.0	2342.2^{b}	1.378	1.581^{ab}	1.486^{ab}
HCS		1471.7^{b}	1975.8^{b}	3447.4^{b}	1081.0	1264.4	2345.4^{b}	1.362	1.564^{b}	1.470^{b}

Cold pelleted	1498.8	2026.6	3525.4	1096.0	1273.3	2369.3	1.371	1.592	1.488
Steam pelleted	1485.6	2032.6	3518.2	1074.8	1284.8	2359.6	1.383	1.583	1.491
Source of variation									
Diet	0.005	<0.001	<0.001	0.276	0.124	0.011	0.511	0.024	0.032
Pellet condition	0.352	0.817	0.818	0.137	0.512	0.602	0.549	0.565	0.822
Diet × pellet condition	0.021	0.657	0.182	0.581	0.128	0.296	0.021	0.141	0.058

[1]Each value for each treatment represents the mean of 8 replicates
[2]Means within a column not sharing a superscript differ significantly at the *P*<0.05 level for the treatment effects and at the *P* level shown for the main effects.

Table 5. Effect of canola seed inclusion and feed processing on relative weight of organs and different intestinal segments of broiler chickens at d 24 to 35 [1,2]

Treatment		Proventriculus		Gizzard		Liver		Duodenum		Jejunum		Ileum	
		d 24	d 35	d 24	d 35	d 24	d 35	d 24	d 35	d 24	d 35	d 24	d 35
Diet	Pellet	g/100g body weight											
Canola meal + oil	Cold	0.47	0.29	1.21	0.75	2.87	2.48	0.86	0.54	1.49	1.10	1.15	0.81
	Steam	0.44	0.33	1.38	0.93	3.01	2.59	0.87	0.54	1.52	1.02	1.02	0.82
WCS	Cold	0.47	0.28	1.19	0.85	3.10	2.48	0.93	0.52	1.43	0.97	1.09	0.81
	Steam	0.42	0.32	1.40	0.95	2.67	2.42	0.96	0.51	1.47	0.98	1.07	0.71
HCS	Cold	0.38	0.32	1.17	0.89	2.91	2.56	0.98	0.61	1.44	1.18	1.09	0.90
	Steam	0.46	0.32	1.33	1.05	3.08	2.50	0.97	0.58	1.48	1.19	1.12	0.84
Main effects													
Canola meal + oil		0.45	0.31	1.29	0.84[b]	2.94	2.53	0.87	0.54[ab]	1.50	1.05[ab]	1.08	0.81[ab]
WCS		0.44	0.30	1.29	0.90[ab]	2.99	2.52	0.95	0.51[b]	1.45	0.97[b]	1.08	0.76[b]
HCS		0.41	0.32	1.25	0.97[a]	2.88	2.45	0.97	0.59[a]	1.46	1.18[a]	1.10	0.87[a]
Cold pelleted		0.44	0.30	1.19[b]	0.83[b]	2.96	2.51	0.92	0.58	1.45	1.08	1.11	0.84
Steam pelleted		0.44	0.32	1.37[a]	0.98[a]	2.92	2.50	0.93	0.54	1.49	1.06	1.07	0.79
Main effects and interaction (P values)													
Diet		0.676	0.763	0.731	0.040	0.705	0.690	0.171	0.036	0.792	0.007	0.937	0.079
Pellet condition		0.964	0.253	0.002	0.001	0.711	0.950	0.826	0.579	0.558	0.725	0.456	0.166
Diet × pellet condition		0.336	0.577	0.923	0.721	0.056	0.688	0.949	0.899	0.997	0.709	0.440	0.539

[1]Each value for each treatment represents the mean of 8 replicates
[2]Means within a column not sharing a superscript differ significantly at the P<0.05 level for the treatment effects and at the P level shown for the main effects.

Table 6. Effect of canola seed inclusion, intact or hammer-milled, and pelleting condition on nutrient digestibility coefficient [1,2]

		DM		N		fat	
Diet	Pellet	d 24	d 35	d 24	d 35	d 24	d 35
Canola meal + oil	Cold	0.623	0.676	0.790	0.795[bc]	0.753[ab]	0.893[a]
	Steam	0.665	0.660	0.812	0.795[bc]	0.768[ab]	0.883[a]
WCS	Cold	0.662	0.668	0.810	0.796[bc]	0.799[a]	0.876[a]
	Steam	0.645	0.638	0.799	0.825[a]	0.677[c]	0.770[b]
HCS	Cold	0.653	0.648	0.802	0.800[ab]	0.718[bc]	0.887[a]
	Steam	0.669	0.623	0.818	0.772[c]	0.750[ab]	0.784[b]
	SEM	0.0062	0.0055	0.0038	0.0040	0.0097	0.0041
Main effects							
Canola meal		0.644	0.667[a]	0.801	0.795[a]	0.760	0.888[a]
WCS		0.653	0.653[ab]	0.804	0.810[ab]	0.738	0.823[b]
HCS		0.661	0.635[b]	0.809	0.786[b]	0.734	0.835[b]
Cold pelleted		0.646	0.664[a]	0.800	0.796	0.756	0.885[a]
Steam pelleted		0.659	0.639[b]	0.809	0.797	0.731	0.812[b]
Source of variation							
Diet		0.532	0.066	0.622	0.049	0.488	<.0001
Pellet condition		0.293	0.033	0.242	0.967	0.203	<.0001
Diet × pellet condition		0.164	0.868	0.179	0.019	0.004	<.0001

[1]Each value for each treatment represents the mean of 8 replicates

[2]Means within a column not sharing a superscript differ significantly at the $P<0.05$ level for the treatment effects and at the *P* level shown for the main effects.

Table 7. Effect of canola seed inclusion and feed processing on ileal amino acid digestibility coefficients of grower diets at d 24 [1,2]

		Met	Cys	Lys	Thr	Arg	Ile	Leu	Val
Diet	Pellet								
Canola meal + oil	Cold	0.899[c]	0.697	0.843	0.747	0.832	0.772	0.790	0.762
	Steam	0.918[a]	0.728	0.861	0.774	0.858	0.817	0.832	0.803
WCS	Cold	0.917[ab]	0.737	0.859	0.769	0.852	0.802	0.817	0.793
	Steam	0.911[abc]	0.718	0.852	0.767	0.843	0.810	0.824	0.794
HCS	Cold	0.903[bc]	0.724	0.848	0.768	0.840	0.785	0.801	0.778
	Steam	0.919[a]	0.735	0.866	0.780	0.858	0.819	0.834	0.804
	SEM	0.0021	0.0058	0.0029	0.0044	0.0030	0.0039	0.0036	0.0040
Main effects									
Canola meal + oil		0.908	0.712	0.852	0.760	0.844	0.794	0.811	0.782
WCS		0.914	0.727	0.855	0.768	0.847	0.806	0.820	0.793
HCS		0.911	0.729	0.856	0.773	0.849	0.802	0.817	0.791
Cold pelleted		0.906[b]	0.719	0.850	0.761	0.841	0.786[b]	0.802[b]	0.777[b]
Steam pelleted		0.916[a]	0.722	0.859	0.773	0.852	0.814[a]	0.829[a]	0.800[a]
Main effects and interaction									
Diet		0.558	0.427	0.772	0.463	0.866	0.465	0.548	0.517
Pellet condition		0.022	0.503	0.110	0.165	0.060	0.001	0.001	0.007
Diet × pellet condition		0.044	0.225	0.159	0.416	0.051	0.142	0.117	0.134

[1]Each value for each treatment represents the mean of 6 replicates
[2]Means within a column not sharing a superscript differ significantly at the *P*<0.05 level for the treatment effects and at the *P* level shown for the main effects.

Table 8. Effect of canola seed inclusion and feed processing on ileal amino acid digestibility coefficients of grower diets at d 24 [1,2]

		His	Phe	Gly	Ser	Pro	Ala	Asp	Glu
Diet	Pellet								
Canola meal + oil	Cold	0.821	0.754	0.736	0.764	0.818	0.758	0.736	0.861
	Steam	0.848	0.790	0.770	0.797	0.847	0.797	0.783	0.888
WCS	Cold	0.843	0.770	0.766	0.784	0.844	0.787	0.764	0.883
	Steam	0.841	0.779	0.759	0.783	0.847	0.784	0.769	0.889
HCS	Cold	0.824	0.771	0.760	0.777	0.834	0.775	0.754	0.870
	Steam	0.841	0.788	0.773	0.800	0.857	0.796	0.788	0.894
	SEM	0.0031	0.0050	0.0044	0.0040	0.0031	0.0043	0.0045	0.0027
Main effects									
Canola meal + oil		0.834	0.772	0.752	0.780	0.832	0.777	0.760	0.874
WCS		0.842	0.774	0.762	0.783	0.845	0.786	0.766	0.885
HCS		0.832	0.779	0.767	0.788	0.845	0.785	0.770	0.882
Cold pelleted		0.829^{b}	0.768^{b}	0.754	0.775^{b}	0.832^{b}	0.773^{b}	0.751^{b}	0.871^{b}
Steam pelleted		0.843^{a}	0.786^{a}	0.767	0.793^{a}	0.850^{a}	0.792^{a}	0.780^{a}	0.890^{a}
Main effects and interaction									
Diet		0.413	0.816	0.416	0.703	0.145	0.662	0.606	0.244
Pellet condition		0.029	0.042	0.139	0.026	0.005	0.034	0.003	0.001
Diet × pellet condition		0.161	0.510	0.164	0.206	0.225	0.150	0.163	0.239

[1]Each value for each treatment represents the mean of 8 replicates

[2]Means within a column not sharing a superscript differ significantly at the *P*<0.05 level for the treatment effects and at the *P* level shown for the main effects.

Table 9. Economics of production at 35 d

Treatment means	Pellet	[1]FCR 0-35 d Corr to 2.70 kg	[2]Feed cost/ kg live at 35 d	[3]EBEI
Canola meal + oil	Cold	1.459	0.6597	509
	Steam	1.457	0.6557	506
WCS	Cold	1.424	0.6378	514
	Steam	1.470	0.6561	494
HCS	Cold	1.447	0.6458	502
	Steam	1.417	0.6353	517
Main effects				
Canola meal		1.458	0.6577	507
WCS		1.447	0.6470	504
HCS		1.417	0.6406	510
Cold pelleted		1.443	0.6478	508
Steam pelleted		1.448	0.6490	506

[1] Ross 308 performance table data were used for the common 0 to 10 day starter period; for the entire 35 day growout, the correction was 2 points of FCR per 100 grams of BW.
[2] AUD per mt: Starter $483.41; Grower $453.05; Finisher $445.45; Wheat $300; SBM $650; canola oil $885; canola meal $400; canola seed $600. No additional cost for steam pelleting of feeds or hammer milling of canola seed were considered. The prices used for canola meal, seed and oil resulted in the same feed costs within a phase.
[3] European broiler efficiency index = ((ADG (35 d) X % liveability)/FCR) X 10

Discussion

The ME content of canola seed for broilers reported in the literature is variable (Sibbald, 1977; Muztar et al., 1978; Muztar et al., 1981; Assadi et al., 2011) ranging from 4400 to 5269 kcal/kg. This may be attributed to several factors including grinding and texture of the seed, agronomic differences, nutrient and antinutritional factors levels and differing response of individual birds to the palatability and seed texture. The oil content of the CS samples used in the current experiment may provide evidence for relatively high AME value of the seed. However, these values of AME and AME_n are close to a more recent report by Assadi et al. (2011).

It is evident from the results of the current experiment that the growth response of birds fed WCS and HCS with no supplemental oil was comparable to the control birds in the grower phase with 11.4% CS in the diets. This is in agreement with previous studies (Salmon et al., 1988; Ajuyah et al., 1991) and is also in line with the nutrient digestibility values for DM, nitrogen and fat at the end of the growing phase when no negative impact was observed attributed to the inclusion of WCS.

In the finisher phase of feeding with 13.0% WCS and HCS in the diets, fat and N digestibility coefficients were lower than in the grower phase. In addition there was an interaction between pelleting method and diet. These differences for the digestibility values of grower and finisher diets may be attributed to the higher inclusion of WCS and HCS in finisher diets and may have magnified the impact on nutrient utilisation. Meng et al. (2006) showed that feeding WCS in mash diets had a negative impact on ileal fat, protein and AME_n content of the diet compared with canola meal plus oil. It is noteworthy that the assessment of the entire period of study showed BWG in the birds fed WCS and HCS was approximately 60 g lower than the control group. However, the improved feed conversion associated with a lower feed consumption in the birds fed WCS and HCS relative to meal plus oil would be expected to economically offset the lower BWG.

In the current experiment all diets were pelleted, which may, at least in part, explain the discrepancy between these observations made by Meng et al. (2006). Some portion of oil in WCS may be encapsulated in the peptide shell oil body structures impeding maximum fat utilisation (Slominski et al., 2006). Supplementation of diets containing WCS with phytase and carbohydrases has been shown to be effective in minimizing fat encapsulation and therefore maximize nutrient utilisation (Jozefiak et al., 2010). It is therefore possible that enzyme supplementation with protease, carbohydrases and phytase might contribute to enhanced bird performance in diets containing WCS at even higher levels than tested in the current experiment.

Utilisation of protein and amino acids were not affected by the different diets. These observations confirm similar availability of amino acids between the canola seed and canola meal as well as proving potential benefits of incorporation of canola in poultry diets (Barbour and Sim, 1991).

Nevertheless, the marginal adverse effect of WCS or HCS inclusion on feed intake could possibly be a result of higher residual isothiocyante levels in diets containing seed vs. meal, although not directly measured in the current trial. Isothiocyanates are formed from glucosinolates through the action of the enzyme myrosinase (Tripahy and Mishra, 2007). The degree of adverse effect of dietary glucosinolate depends on the level and compositions of glucosinolates and their breakdown products. The breakdown products isothiocyanate and 5-ethenyl-1,3-oxazolidine-2-thione (goitrin) are known to be extremely bitter compounds (Tripahy and Mishra, 2007). Solvent extracted canola meal undergoes heat treatment during processing thereby reducing myrosinase activity whereas the only heat treatment in diets containing WCS or HCS in the current study was from pelleting the diets. Summers et al., (1982) concluded that in broilers fed WCS, lower feed intake may be a problem and is likely attributed to diet palatability. This was indeed observed in the finisher period of the current study and was reflected in the overall 35 day performance. Unheated CS would be expected to have higher levels of myrosinase enzyme as compared to solvent extracted canola meal. Hydrolysis of glucosinolates by myrosinase yields varying amount of nitriles, iso-thiocyanates, oxazolidinethiones and thiocyanate ion, depending on conditions, notably pH and the chemical nature of the parent glucosinolate (Mawson et al., 1994). While all of these breakdown products may contribute to glucosinolate-induced hyperthyroidism, little work has been conducted comparing differences in palatability of diets containing intact glucosinolate or their intact enzyme hydrolyzed end products. It is hypothesized that the dietary CS reduced palatability, feed intake and subsequent growth rate relative to canola meal plus oil in the current study due to higher levels of active myrosinase and subsequent higher levels of hydrolyzed end products in seed relative to solvent extracted meal. Further investigation is needed to elucidate any effect arising from myrosinase activity. Pellet quality of such diets and level of glucosinolate and erucic acids (Olomu et al., 1975) may also be regarded as determinants of the growth performance and warrant more investigation as high levels of CS are likely to have adverse effects on pellet durability index.

In general, grinding may be used to disrupt the cell wall structure of feed ingredients and oil body structure within oil seeds thus increasing the exposure of nutrients to the digestive enzymes which is believed to positively impact bird performance (Assadi et al., 2011). It is already well demonstrated that grinding WCS in mash diets favors bird performance and ME content of the seed (Muztar et al., 1978; Shen et al., 1983). In the current study, however, grinding WCS with a hammer miller resulted in no additional improvement to the growth performance or nutrient digestibility when broilers were fed pelleted diets, suggesting that the pelleting process *per se* may have possibly provided sufficient breakage to the seed, therefore diminishing the influence of pre-pelleting grinding of CS. This would pose an interest for the commercial use of WCS as the grinding process of canola seed would be cumbersome due to high oil content and small seed size. In addition, the grinding prior to diet preparation may accelerate lipid oxidation and may reduce shelf life of the diet (Jia et al., 2008). Thus, it may be advantageous to feed the CS without grinding when the diet is pelleted. It has been demonstrated that grinding of WCS is necessary when used in mash diets as seed rupture is necessary to optimize the nutrient utilisation (Shen et al., 1983). Nevertheless, further research is needed to compare WCS inclusion in mash and pelleted diets in order to elucidate the effect of pelleting and grinding on nutrient utilisation.

If pelleting does indeed sufficiently pulverize WCS and reduce myrosinase activity, higher levels of canola seed than those tested might be possible in the diet of broilers without compromising the growth response (Shen et al., 1983). In the current study, the growth response of birds fed steam or cold pelleted diets did not differ regardless of diet composition. However, the interaction between the diet and pelleting condition indicated that steam pelleting may reduce dry matter and fat digestibility in diets containing whole or hammered seeds although steam pelleting improved amino acid digestibility. Abdollahi et al. (2011) showed that applying 75 °C and 90 °C for the steam conditioning had a negative effect on nutrient utilisation and performance of wheat based broiler diets compared to 60 °C. However, in that experiment the fat digestibility was not examined. In the present study, the lower fat digestibility was observed in the WCS diets subjected to steam pelleting and high conditioning temperature. Regarding fat digestibility, it may be possible that the phytase and xylanase used in the study were somehow partially deactivated by the high temperature of steam pelleting. Therefore, in comparison with cold pelleting, the nutrient utilisation may have been affected. A negative effect of carbohydrate solubilisation may also play a role in fat utilisation, however little contribution of soluble carbohydrate is expected from CS, particularly at a low level of inclusion. The effect of steam conditioning and pellet temperature on digestibility of fat in CS to our best knowledge has not been studied.

It can be deduced from the current study that supplemental oil may be replaced by WCS and HCS in grower diets. However, the inclusion of WCS and HCS at higher levels in finisher diets may result in a marginal depression in feed intake and BWG but improved FCR. Examination of FCR corrected to a common body weight indicated that feeding of CS was economically advantageous when compared to solvent canola meal plus canola oil. Lack of performance differences in birds fed pelleted diets containing WCS or HCS suggests that CS may be included in broiler diets without pre-grinding. Steam pelleting with a high temperature of conditioning adversely influenced feed efficiency and fat utilisation of broilers fed CS. Therefore pelleting conditions are important to consider when using high levels of CS in broiler diets.

Recommendations and research gaps

1. Further research is needed to determine the optimum steam pelleting conditions to maximise fat utilisation when using CS in broiler diets.
2. Determine the reason(s) for a difference in the calculated value of canola seed based on combined meal plus oil values compared to lower *in vivo* determined values of AMEn.
3. Investigate the potential reasons for lower feed intake in broilers fed CS. Determine the effect of myrosinase activity on palatability.
4. Determine the pelleting conditions and/or whether enzyme treatment of diets might deactivate myrosinase.
5. Determination of isothiocyante levels and myrosinase activities in CS and thereby diets containing CS might provide explanations for differences observed in feed consumption.
6. Examine phytate levels in CS and whether phytase at normal or high doses improves feed intake in diets supplemented with high CS.
7. Examine digestibility of unprocessed CS in broiler and layer (mash) diets.

Acknowledgment

This study was funded by Poultry Cooperative Research Center, University of New England, Armidale, Australia (project number: 2.1.8).

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Plain English Compendium Summary

Sub-Project Title:	**Replacing supplemental oil with full fat canola seed in broiler diets**
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Sub-Project Overview	
Background	
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Implications	
Publications	