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A meta-analysis of the effects of dietary canola / double low rapeseed meal on growth performance of weanling and growing-finishing pigs

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ABSTRACT

A meta-analysis was conducted to quantify the effect of dietary inclusion rate of canola/rapeseed meal (CRM) on average daily gain (ADG), average daily feed intake (ADFI), and feed conversion in weanling and growing-finishing pigs. The dataset included 37 experiments with 3530 experimental units published from 1987 to 2019. The dietary inclusion rates of CRM ranged from 20 to 400 g/kg for weanling pigs and from 37.5 to 488.4 g/kg for growing-finishing pigs. The impact of feeding CRM was calculated using the Cohen's d (CD) to measure differences among control and experimental means, including the effect of pooled standard deviation of treatments. The overall effect size for ADG and feed conversion in weanling pigs showed no significant impact of CRM inclusion, and linear and quadric weighted regression analyses revealed no significant relationships between CRM inclusion and growth performance in weanling pigs. The ADFI for weanling pigs was significantly reduced by CRM inclusion. In growing-finishing pigs, there was a minor, but significant, reduction in the overall effect size for ADG and feed conversion by CRM feeding, while there was and a tendency towards negative effect on ADFI. There were no significant linear and quadratic relationships between CRM inclusion levels and growth performance in growing-finishing pigs. The data used in the present study suggest that increasing dietary inclusion of low glucosinolate CRM reduced ADFI for weanling, but not for growing-finishing pigs, and had minor or no effect on ADG and feed conversion. It is concluded that CRM can be included as a protein source in nutritionally balanced diets for growing-finishing pigs without adverse effects on growth performance.

1. Introduction

Globally, soybean meal (SBM) is the most common protein source in pig diets. Following the rapid expansion in the canola/

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rapeseed crushing industry, canola/rapeseed meal/expeller (CRM) has become the second largest protein source. In northern Europe, where soybeans are a low yielding crop, the interest has been directed towards protein sources grown in Europe, such as rapeseed, as an alternative to imported SBM from South or North America.

Cruciferous seeds like rapeseed are known to contain glucosinolates, that are goitrogenic and hepatotoxic and may reduce palatability of diets, and growth and health of animals (Tripathi and Mishra, 2007). Canola, a low glucosinolate, low erucic acid rapeseed cultivar was initially developed and licensed in Canada in the 1970s (Tower: Stefansson and Kondra, 1975). The word canola is used to identify rapeseed cultivars with less than 30 μmol glucosinolates per gram in the meal fraction and less than 2% erucic acid in its fatty acid profile, which is an internationally recognized standard. In some countries, particularly those in Europe, it may also be referred to as double-zero or double-low rapeseed (Newkirk, 2009; Canola Council of Canada, 2011; Martineau et al., 2013; Mejicanos et al., 2016). The development of new cultivars has greatly improved the suitability of rapeseed meal for animal feed purposes. Although glucosinolate levels have been greatly reduced in modern cultivars, commercial canola meal still may contain low, but variable, levels of glucosinolates (Adewole et al., 2016, Wang et al., 2017).

Several studies have been carried out on CRM as a protein source with different nutritional characteristics in pig diets using different methodologies and experimental conditions. Adewole et al. (2016) recently showed differences in important quality criteria, such as crude protein, fiber, glucosinolates and lysine, in canola meals collected from Canadian processing facilities over four years (2011–2014). These differences were mainly associated with variable processing conditions. Within a wider geographical area (North America, Europe, Asia), differences in cultivar and growing conditions would be expected to cause differences in rapeseed meal characteristics. However, no difference in digestibility of crude protein and amino acids was detected in canola and double-low rapeseed grown in ether North America or Europe (Maison and Stein, 2014; Maison et al., 2015). Most studies with CRM in diets for growing pigs have applied replacement of SBM as the main protein source in the control diet. Isonitrogenous diets have been used in most studies, but few studies have used digestible essential amino acids in diet formulation. The amino acid digestibility of CRM is lower than that of SBM, partly due to the negative impact of higher fiber content in CRM (Messad et al., 2016). Processing conditions, especially time and temperature in the toaster, have been shown to influence amino acid digestibility of CRM, and may affect growth performance (Hulshof et al., 2016). Increasing toasting time in the processing of CRM to remove organic solvent and to inactivate antinutrients may decrease protein hydrolysis and protein digestibility (Salazar-Villanea et al., 2016). Higher fiber content in CRM than in SBM may affect growth performance unless compensated by adding fat to achieve isoenergetic diets (Pedersen et al., 2016).

Normal industry practice is that all canola or rapeseed are mechanically expelled (pressed) to remove 30–60% of the oil. The industry may remove the remaining oil by use of solvent extraction, resulting in a canola or rapeseed meal containing approximately 2–3% oil. An alternative method, often used by the bio-fuel industry, is another expelling process resulting in canola or rapeseed expeller with a level of 5–12% residual oil (Brand et al., 2001; Seneviratne et al., 2010; Grageola et al., 2013; Woyengo et al., 2016). There is, thus, a large number of factors that may contribute to explaining variable responses to use of CRM in diets for growing pigs. In this study, we investigate effects of different inclusion of meal and expeller CRM on growth performance in pigs by reviewing CRM literature and performing meta-analysis, using a standardized methodology.

To our knowledge, no meta-analysis has been published to evaluate growth performance responses to CRM feeding in growing pigs. The objective of the present study was to evaluate by meta-analysis of published data the average daily feed intake (ADFI), average daily gain (ADG), and feed conversion when low glucosinolate CRM gradually substitute other protein sources in diets for weanling and growing-finishing pigs.

2. Materials and methods

2.1. Search strategy and inclusion criteria

The guidelines in the Cochrane Handbook for Systematic Reviews of Interventions (Higgins and Green, 2008) and the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) Statement (Moher et al., 2009) were used to conduct this meta-analysis.

Study selection was conducted from June of 2018 to January of 2019, searching the following databases: ISI Web of Knowledge (1987–2019), ISI Web of Science (1987–2019), Blackwell (1987–2019), Google Scholar (1987–2019), Science Direct (1987–2019). The following search terms and Boolean operators were used to conduct these searches: Topic (complete document) = (swine OR pig OR piglet OR weanling OR growing-finishing OR grow-finish AND Topic (complete document) = (canola OR rapeseed) AND Topic = (growth). The database search strategy was supplemented by manual searches.

The following pre-specified inclusion criteria were defined to prevent selection bias: 1) random allocation of animals and experimental treatments; 2) use of CRM, not oil; 3) weanling and/or growing-finishing pigs; 4) growth study presenting ADG, ADFI, feed conversion as feed to gain (F:G, growing-finishing pigs) or gain to feed (G:F, weanling pigs) ratio; 5) study results presented in English; 6) presence of a control group that did not include the test ingredient. Duplicate reports were removed. Reviews and conference proceedings were not included in the meta-analysis. Studies on breeding animals (gestating and lactating sows) were omitted, due to limited data. Only studies that included low glucosinolates (< 40 mmol kg^{-1}), low euricic acid varieties of CRM were included in the meta-analysis. Studies were not categorized according to expeller and solvent-extracted CRM.

2.2. Data extraction

Relevant data were extracted from each study using a standardized proforma. Data extracted included: study design, sample size, glucosinolates level, dietary inclusion level of CRM, and life stage. Additional requirements included the use of an appropriate control diet, ADG, ADFI (as fed basis) and feed conversion (G:F or F:G), or sufficient data to calculate ADG, ADFI and feed conversion, and a reported standard deviation (SD) for each parameter or data sufficient to calculate SD. Feed conversion was reported as gain to feed (G:F) for weanling pigs and feed to gain (F:G) for growing-finishing pigs. This was done to maximize data capture. Consequently, the feed conversion data from two out of 11 articles in the weanling group were omitted from the test due to use of F:G (Brand et al., 1999; King et al., 2001), and feed conversion data from nine out of 23 articles in the growing-finishing group were omitted from the test due to use of G:F (Castell and Cliplef, 1993; Shelton et al., 2001; Seneviratne et al., 2010; Woyengo et al., 2014; Zhou et al., 2014; Choi et al., 2015; Little et al., 2015; Hulshof et al., 2016; Velayudhan et al., 2017).

2.3. Statistical analysis

This meta-analysis was conducted using Mix Version 2.0 (Bax, 2010). Cohen's d (CD; Cohen, 1998) was used to measure standardized differences between control and experimental means. The confidence interval (CI) was set at 95% and the alpha level was set at $P < 0.05$. CD was calculated, data were analyzed for normality, and heterogeneity was accessed using *Q*index as described in detail by Collins et al. (2013). A random-effects model was used to calculate summary statistics, which took into account heterogeneity and sampling error (Hedges and Vevea, 1998) and data were pooled and weighted (DerSimonian and Laird, 1986).

Weighted linear and quadratic regression analysis of inclusion rate on CD for ADG, ADFI and feed conversion of weanling and growing-finishing pigs, based on each data point included in this study was performed using JMP software package (JMP Pro 14, SAS Institute, Cary, NC, USA).

3. Results

3.1. Study description

Out of the randomized, controlled experiments that were identified, four experiments were excluded for following reasons: growth results presented by figures (Bourdon and Aumaître, 1990), lack of statistical variance (Mullan et al., 2000), lack of ingredient inclusion rates in the diets (Svetina et al., 2003), uneven start weight for the growing period (Do et al., 2017). Recordings from the total feeding period was used in the present analysis, except if the inclusion level of test ingredient was changed during different phases, then recordings from the first phase was used (Bell and Keith, 1987; Little et al., 2015; Smit et al., 2018), or the actual treatment was omitted from the analysis (Seneviratne et al., 2010).

Thirty-seven experiments, reported between 1987 and 2019, met the inclusion criteria set for this project (Supplementary Tables 1–6). Within these experiments, the sample sizes for each experimental treatment ranged from three to 20 experimental units, thus, a total of 3530 experimental units were included in the final data set for this study. The dietary inclusion rates of CRM in the weanling pig experiments ranged from 20 to 400 g/kg and from 37.5 to 488.4 g/kg in the growing-finishing pig experiments. Table 1 gives an overview over the typical composition of the different CRMs included in this meta-analysis. Forest plots in Figs. 1–6 show the pooled effect of CRM inclusion on ADG, ADFI and feed conversion in weanling and growing-finishing pigs.

3.2. Weanling pigs

Of the data points used for the weanling pig portion of the meta-analysis, 20 showed a decrease in ADG as a result of dietary inclusion of CRM, while 36 showed positive or neutral effects; 35 showed decreased ADFI due to dietary CRM, whereas 21 showed positive or neutral effects; and 11 showed decreased G:F due to dietary CRM, while 34 showed increase or neutral effects.

The ADG data set had 56 data points from 13 studies (Supplementary Table 1; Fig. 1). Ingredient effect size ranged from -3.40 (400 g/kg) to 0.88 (200 g/kg). The overall effect size was -0.01 (95% CI: -0.14 to 0.11; P = 0.82). The ADFI data set had 56 data points from 12 experiments (Supplementary Table 2; Fig. 2). Ingredient effect size ranged from -2.62 (400 g/kg) to 0.98 (20 g/kg). The overall effect size was -0.32 (95% CI: -0.45 to -0.20; P = < 0.0001). The G:F data set had 45 data points from 11 experiments (Supplementary Table 3; Fig. 3). Ingredient effect size ranged from -1.24 (20 g/kg) to 0.64 (200 g/kg). The overall effect size was 0.07 (95% CI: -0.07 to 0.21; P = 0.30).

Weighted linear and quadratic regressions revealed no significant connections between dietary inclusion level of CRM and CD for ADG and G:F in weanling pigs, but a linear decrease in ADFI (Table 2).

3.3. Growing-finishing pigs

Among the data points used for the growing-finishing pig part of the meta-analysis, 52 showed decreased ADG as a result of the dietary inclusion of CRM, while 29 showed positive or neutral effects; 40 showed a decrease in ADFI due to dietary CRM, while 31 showed positive or neutral effects; and 15 showed decreased F:G as a result of dietary CRM, whereas 36 reported an increase or neutral effects.

The ADG data set had 81 data points from 24 experiments (Supplementary Table 4; Fig. 4). Ingredient effect size ranged from -8.08 (196 g/kg) to 2.06 (50 g/kg). The overall effect size was -0.25 (95% CI: -0.35 to -0.14; $P < 0.0001$). The ADFI data set had 71 data points from 23 studies (Supplementary Table 5; Fig. 5). Ingredient effect size ranged from -2.56 (150 g/kg) to 2.81 (226 g/kg). The overall effect size was -0.09 (95% CI: -0.20 to 0.009; P = 0.074). The F:G data set had 51 data points from 18 studies

Table 1
Average chemical composition of canola /rapeseed meal/expeller (CRM) included in this meta-analysis.*

	Type	GE (MJ/kg)	DM (g/kg)	CP (g/kg)	Lipid (g/kg)	Ash (g/kg)	CF (g/kg)	GSL (μmol/g)	ADF (g/kg)	NDF (g/kg)
Weanling	**Meal**									
Do et al. (2017)	Canola meal			328	10	86		38		
King et al. (2001)	Canola meal	17.1	883	372	25		112	4.0		
Landero et al. (2011)	Canola meal		889	340	35	68	93	3.84	172	260
Landero et al. (2013)	Canola meal		892	392	17	73	74	10.8	134	199
Parr et al. (2015)	High-protein canola A	12.1	912	457	35	69		15.5	127	183
Parr et al. (2015)	High-proein canola B	14.0	911	470	33	61		14.2	110	179
Parr et al. (2015)	Conventional canola	10.4	899	351	38	80		8.7	175	250
Pedersen et al. (2016)	Conventional canola	17.6	910	360	30	73		4.4	217	276
Pedersen et al. (2016)	High-protein canola	18.7	875	432	26	59		12.6	188	264
Wang et al. (2017)	Canola meal 1, *B. napus*		912	373	35	67		4.7	193	247
Wang et al. (2017)	Canola meal 2, *B. napus*		912	362	38	69		2.1	195	276
Wang et al. (2017)	Canola meal 3, *B. napus*		918	383	36	73		7.4	187	237
Wang et al. (2017)	Canola meal 4, *B. napus*		906	419	31	69		1.1	158	225
	Average	15.0	902	393	32	69	93	7,4	169	236
	Expeller									
Le et al. (2014)	Extruded *B. juncea* expeller		951	344	169	63	60	10.9	127	195
Lee and Woyengo (2018)	Canola press-cake		923	396	160	65		14.9	143	207
Zhou et al. (2016)	Canola press-cake		910	370	204	65		11.1	201	225
Landero et al. (2012)	Expeller canola		944	363	103	69	69	10.9	160	242
	Average		932	368	159	66	65	12.0	158	217
Growing-finishing	**Meal**									
Baidoo et al. (1987)	Commercial canola meal	19.1		368	27	75	129	10.1		
Baidoo et al. (1987)	Commercial canola meal	19.2		376	28	77	127	9.8		
Bell and Keith (1987)	Triazine-resistent canola	20.2	876	411	27	74	104	8.3	167	207
Bell and Keith (1987)	Westar canola	20.1	900	386	34	72	110	8.4	168	230
Brand et al. (2001)	Solvent extracted Canola			428	33		105			
Choi et al. (2015)	Rapeseed meal			360				34.1		189
Castell and Cliplef (1993)	Canola meal			360				8.9		
Homb and Matre (1989)	Canola no1		897	307	35		92			
Fang et al. (2007)	Canola meal			425		81			309	450
Homb and Matre (1989)	Canola no 2		892	325	37		89			
Hulshof et al. (2016)	Rapeseed meal, *B. napus*		895	383	39	75				
Kim et al. (2015)	Rapeseed meal		875	342		65	85		141	223
Kim et al. (2015)	Canola meal		886	378		63	95		162	251
Little et al. (2015)	Conventional canola meal		889	405	16			20.1	143	189
Little et al. (2015)	High protein canola meal		894	450	21			10.0	92	151
McDonnell et al. (2010)	Rapeseed meal	17.0	887	332		69		4.0		290
Shelton et al. (2001)	No information									
Siljander-Rasi et al. (1996)	Rapeseed meal. *Kulta*		891	314	53	64	109	2.9		
Smit et al. (2018)			904	385	38	64	113	6.1	187	240
Spiegel et al. (1993)	00-RSM. *Liardonna*							13		
Thacker and Newkirk (2005)	Canola meal, toasted		916	382	31	74		1.0		246
Thacker and Newkirk (2005)	Canola meal, non-toasted		924	388	16	70		15.6		211
Thacker (2001)	Canola meal			337						
	Average	19.1	895	373	32	71	107	19.2	151	221
	Expeller									
Brand et al. (2001)	Expeller canola			316	92		154			
Seneviratne et al. (2010)	Expeller canola meal	21.1	956	385	133	69	77	23.2	175	280
Skugor et al. (2019)	Expeller rapeseed meal		892	306	110	57		2.3		
Velayudhan et al. (2017)	Expeller canola	21.1		384				9.3		269
Zhou et al. (2014)	Extruded *B. juncea* expeller		950	344	169	63	60	10.9	127	195
	Average	21	953	357	131	66	97	14.5	151	248
	Full fat CRM									
Brand et al. (1999)	Full fat RSM			260	410					
Woyengo et al. (2014)	Full-fat canola meal	27.5	948	236	409	57	45	10.0	101	209
	Average		948	248	409	57	45	10	101	209

* GE = Gross energy; DM = Dry matter; CP = Crude protein; CF = Crude fibre; GSL = Glucosinolates; ADF = Acid detergent fibre; NDF = Neutral detergent fibre; CMR = Canola / rapeseed meal. Busboom et al. (1991) and Mejicanos et al. (2017) did not provide any nutrient composition.

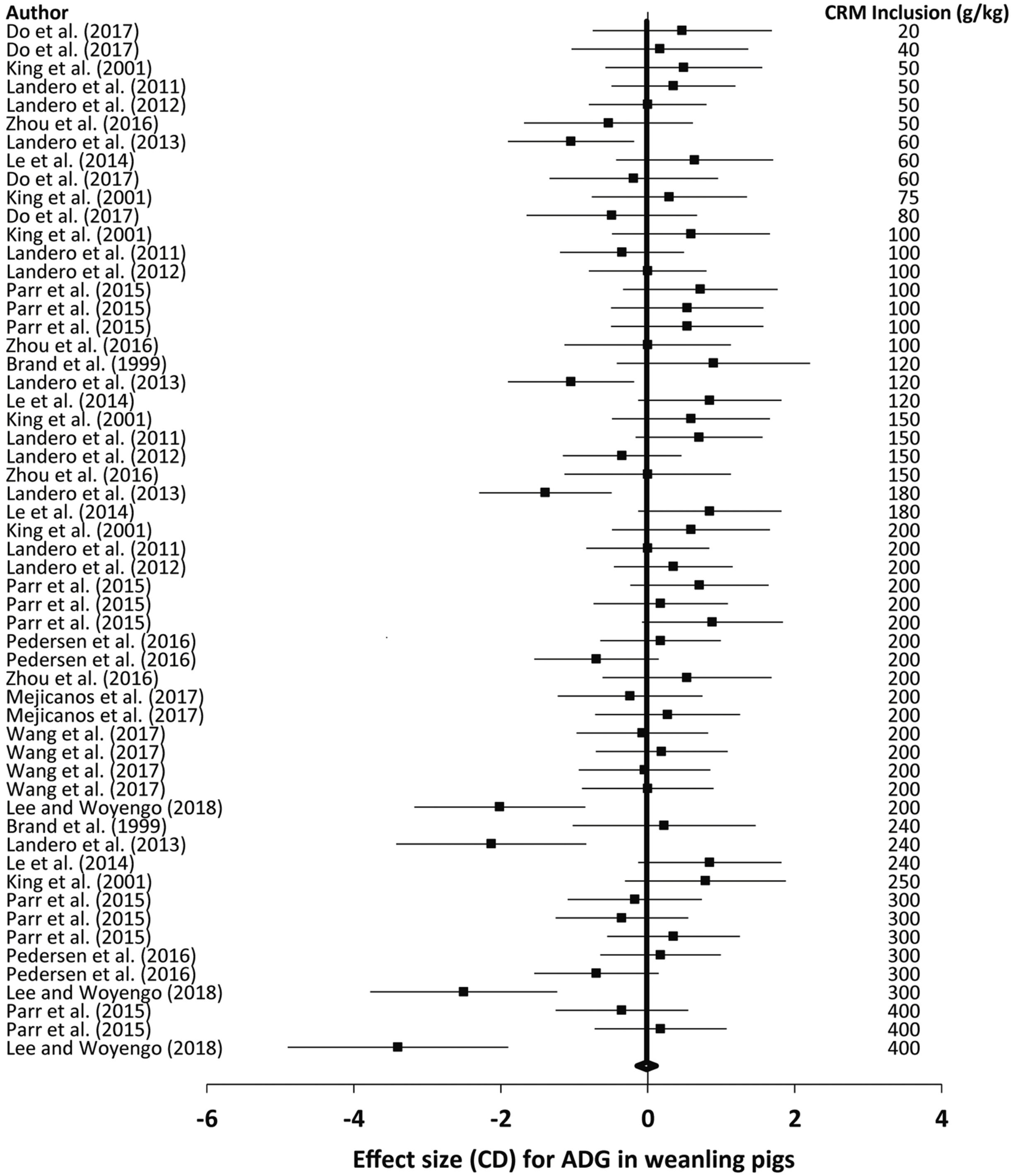

Fig. 1. Forest plot of treatment effect sizes (CD) by canola / double low rapeseed meal/expeller (CRM) dietary concentration on average daily gain (ADG) in weanling pigs.

(Supplementary Table 6; Fig. 6). Ingredient effect size ranged from -1.84 (100 g/kg) to 9.15 (200 g/kg). The overall effect size was 0.34 (95% CI: 0.21 to 0.47; $P < 0.0001$).

There were no significant linear or quadratic relationships identified between the dietary inclusion levels of CRM and the CD of ADG, ADFI or F:G in growing-finishing pigs (Table 2).

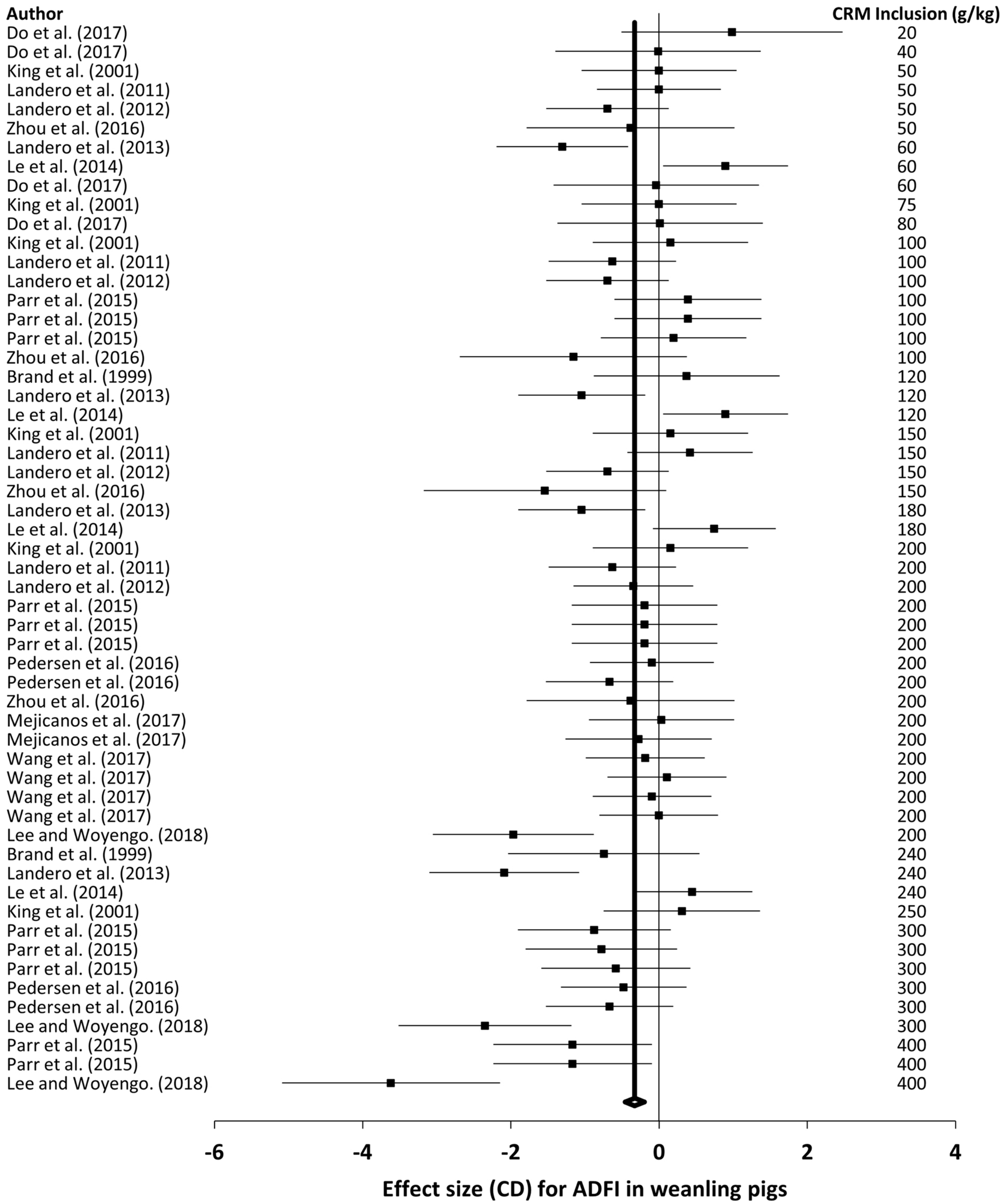

Fig. 2. Forest plot of treatment effect sizes (CD) by canola / double low rapeseed meal/expeller (CRM) dietary concentration on average daily feed intake (ADFI) in weanling pigs.

4. Discussion

Concerns of ecological and economic sustainability, and regional feed security issues, are generating increasing interest in the use of CRM as a protein source in pig diets, especially in the northern countries (van Zanten et al., 2015; Pérez de Nanclares et al., 2017;

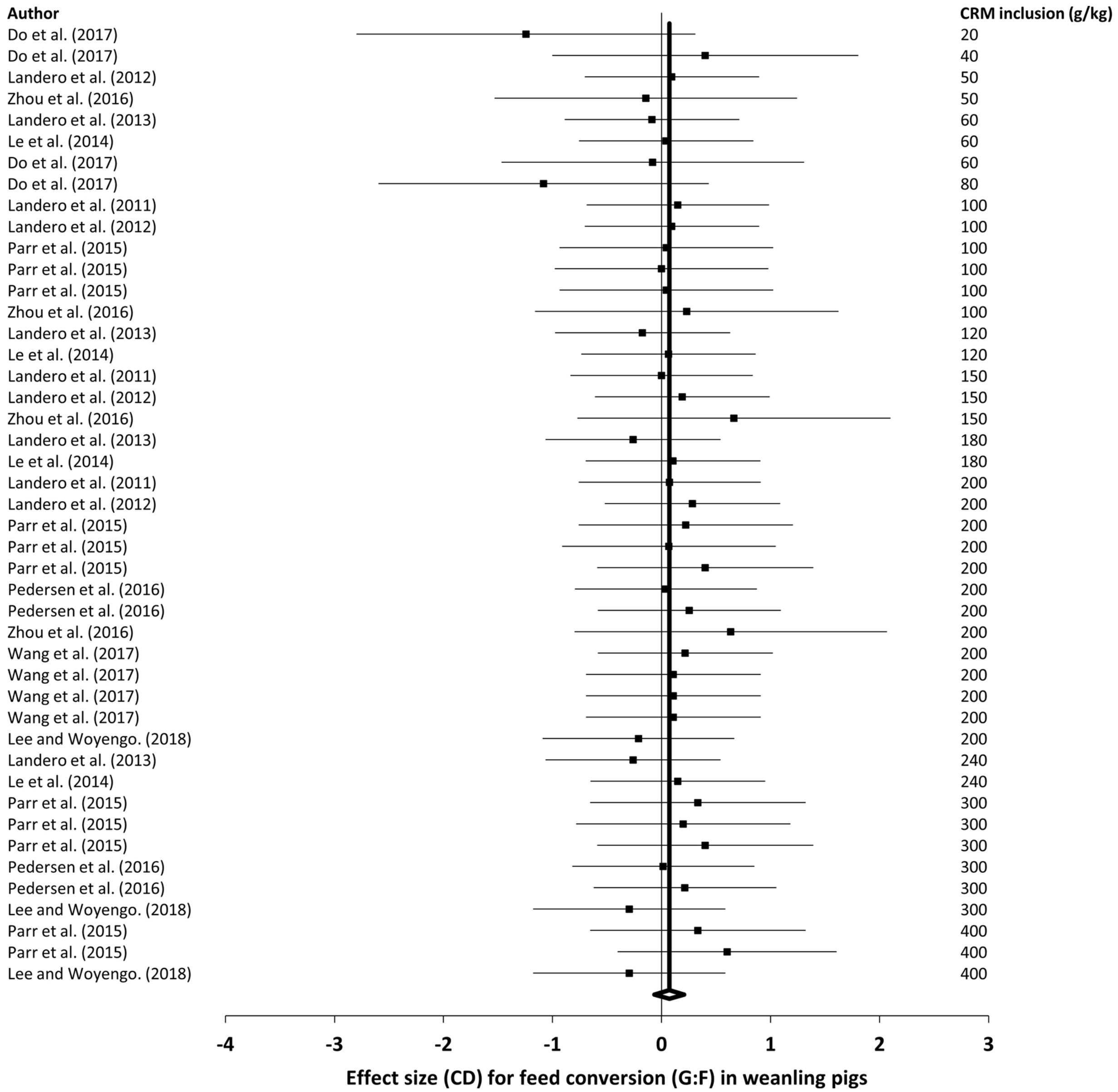

Fig. 3. Forest plot of treatment effect sizes (CD) by canola / double low rapeseed meal/expeller.
(CRM) dietary concentration on feed conversion (Gain:Feed) in weanling pigs.

Kaewtapee et al., 2018). The effect of CRM in pig diets may be dependent on a great diversity of factors, such as botanical variety, chemical characteristics, diet formulation, inclusion level and replacement strategy, amino acid or enzyme supplementation, methods used for CRM and diet processing, and feeding methods applied. Consequently, there is a number of factors potentially causing discrepancy among studies on the use of CRM as a protein source in pig diets. The present study aimed at using meta-analysis to obtain a quantitative synthesis of data from previously published studies using CRM in pig diets. The results obtained by meta-analysis would be more robust than data from single studies included in the meta-analysis. Published data used in the current meta-analysis covered a wide range of CRM products and experimental conditions, and the results provide overall insights into the direction of effects obtained across studies with CRM in diets for weanling and growing-finishing pigs. However, a meta-analysis implies limitations associated with a number of variable factors from study to study, and interpretation of effect sizes obtained in a meta-analysis may be controversial, especially if number of relevant studies are limited.

The current meta-analysis utilized data from studies with meal from canola or double-low rapeseed (00-rapeseed) with low concentrations of glucosinolates and erucic acid, but information on the actual glucosinolate content in CRM or processed feed was limited in many studies. The majority of the included studies has been carried out with meal from the *Brassica napus* species, but some recent studies have included *Brassica juncea* canola meal. Canola meal from *B. juncea* has higher amino acid digestibility and net

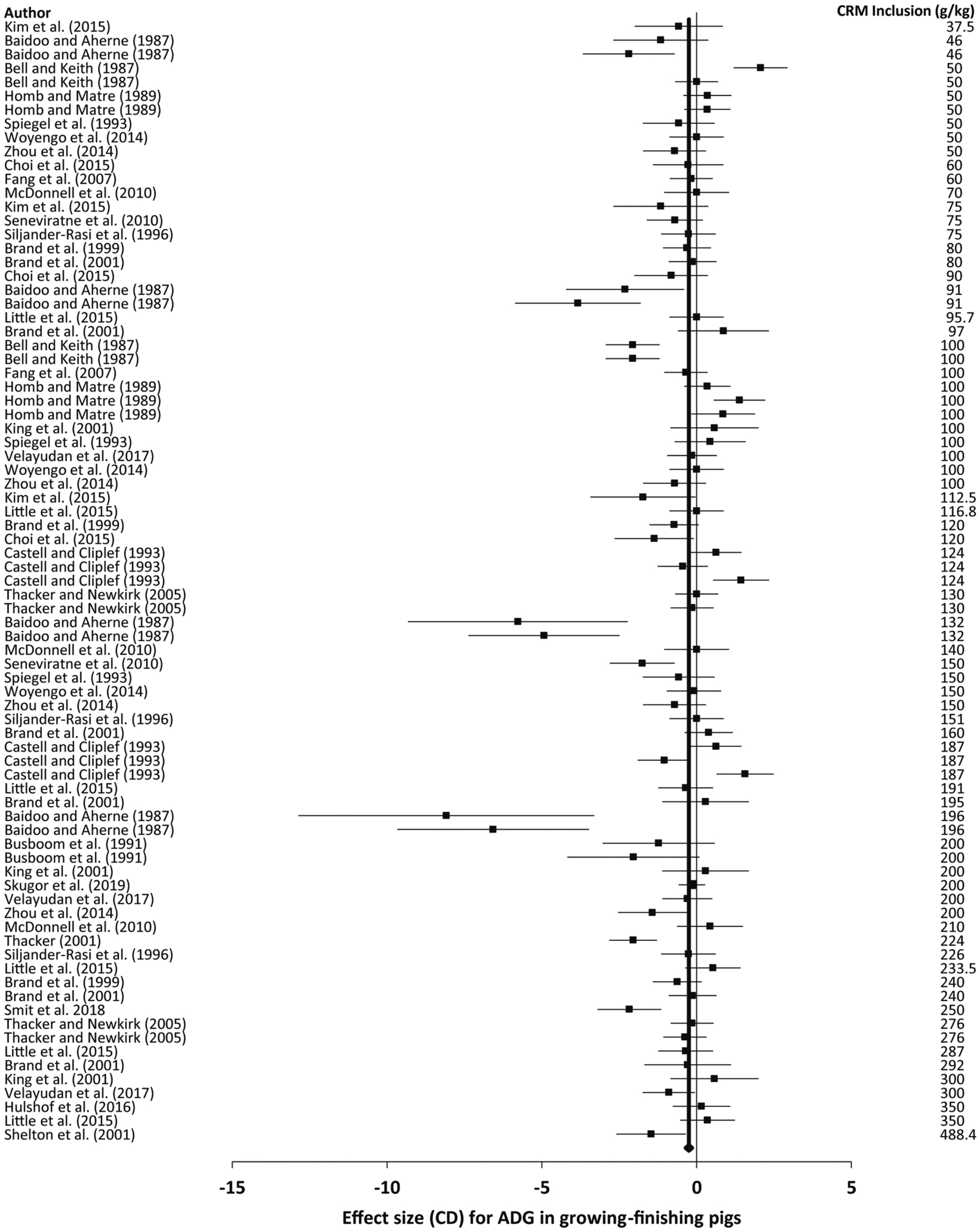

Fig. 4. Forest plot of treatment effect sizes (CD) by canola / double low rapeseed meal/expeller (CRM) dietary concentration on average daily gain (ADG) in growing-finishing pigs.

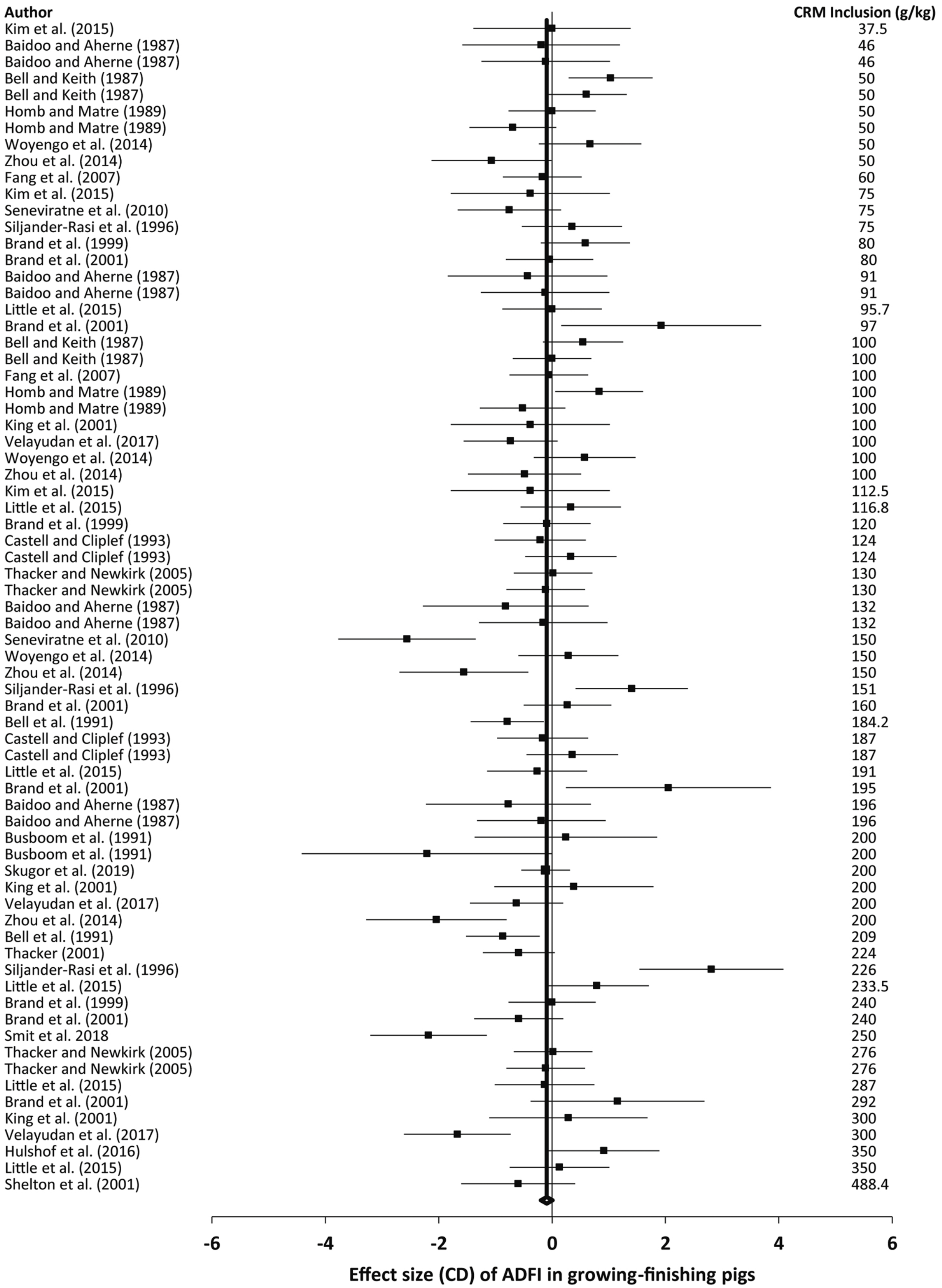

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Fig. 5. Forest plot of treatment effect sizes (CD) by canola / double low rapeseed meal/expeller (CRM) dietary concentration on average daily feed intake (ADFI) in growing-finishing pigs.

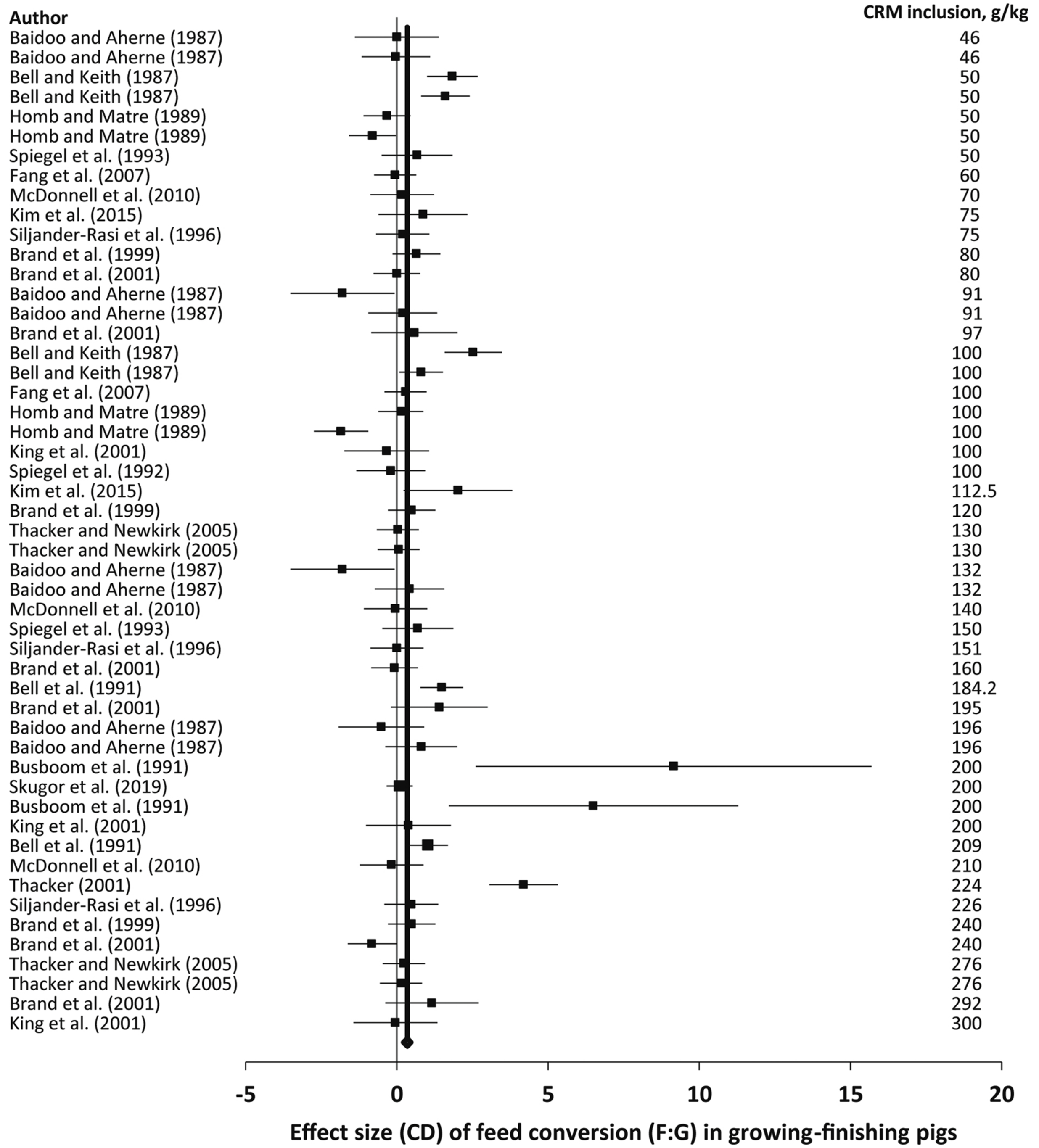

Fig. 6. Forest plot of treatment effect sizes (CD) by canola / double low rapeseed meal/expeller (CRM) dietary concentration on feed conversion (Feed:Gain) in growing-finishing pigs.

energy content than *B. napus* meal (Sanjayan et a., 2014; Woyengo et al., 2017), but pigs may be less tolerant to *B. juncea*-derived glucosinolates than *B. napus* glucosinolates due to higher contents of toxic aliphatic glucosinolates (Woyengo et al., 2017). There are only minor differences in chemical composition between canola and 00-rapeseed, but differences in nutritional characteristics among sources of CRM may occur due to different seed varieties and differences in climatic, agronomic and harvesting conditions (Maison and Stein, 2014; Maison et al., 2015). Moreover, different processing of meals and diets (especially heat treatment) may generate

Table 2
Linear and quadratic weighted regressions of effect size (CD) with *P* and r^2 values for the ADG, ADFI and feed conversion for weanling pigs and growing-finishing pigs fed increasing dietary levels of canola / double low rapeseed meal/expeller (CRM).

Parameter	Regression type	Equation	*P*	r^2
Weanling pigs				
ADG (g/day)				
	Linear	$y = -0.002x + 0.267$	0.14	0.05
	Quadratic	$y = -9.39*10^{-6}x^2 + 0.001x + 0.27$	0.21	0.05
ADFI (g/day)				
	Linear	$y = -0.0034x + 0.26$	0.002	0.16
	Quadratic	$y = -1.72*10^{-5}x^2 - 0.003x + 0.28$	0.002	0.21
Feed conversion				
	Linear	$y = 0.0007x - 0.05$	0.12	0.05
	Quadratic	$y = 3.17*10^{-6}x^2 + -0.0001x - 0.05$	0.21	0.07
Growing-finishing pigs				
ADG (g/day)				
	Linear	$y = -0.001x - 0.06$	0.31	0.01
	Quadratic	$y = 3.28*10^{-7}x^2 + -0.001x - 0.06$	0.60	0.01
ADFI (g/day)				
	Linear	$y = -0.0013x + 0.011$	0.20	0.02
	Quadratic	$y = 5.60*10^{-6}x^2 - 0.002x + 0.13$	0.34	0.03
Feed conversion				
	Linear	$y = 0.0007x + 0.23$	0.67	0.003
	Quadratic	$y = -4.11*10^{-6}x^2 + 0.0009x - 0.24$	0.91	0.004

ADFI = Average daily feed intake.
ADG = Average daily gain.

variation in nutritional value, digestible indispensable amino acids and contents of glucosinolates (Newkirk et al., 2003; Tripathi and Mishra, 2007; Trindade Neto et al., 2012; Almeida et al., 2014; Eklund et al., 2015; Adewole et al., 2016; Salazar-Villanea et al., 2016; Wang et al., 2017). This may partially explain variable responses in pig performance among different studies.

Comparison of effect sizes indicated no negative impact of dietary CRM on the ADG of weanling pigs in the current meta-analysis. From a total of 56 treatments, the ADG effect size was positive or neutral in 36 and negative in 20 as a response to CRM inclusion, and the overall effect size showed no significant effect. However, the overall effect size and results of weighted linear and quadratic regression analyses showed significant effect of CRM on the ADFI of weanling pigs. These results support the general view that rapeseed/canola meal may reduce voluntary feed intake in the early growth phase due to bitter taste (poor palatability), high fiber content, or metabolic effects of glucosinolates (Bell, 1993; Tripathi and Mishra, 2007; Mejicanos et al., 2016; Velayudhan et al., 2017; Woyengo et al., 2017). Differences among diets in energy content may have influenced the ADFI of weanling pigs in some studies with CRM, as pigs may compensate for reduced dietary energy content due to CRM inclusion by increased voluntary feed intake (Pedersen et al., 2016). However, the diets in most recent studies have been formulated to constant net energy (NE) level (Mejicanos et al., 2016). In a recent study, weaned pigs preferred a SBM diet over canola meal diets, but the lower feed preference did not equate to poorer feed intake (Landero et al., 2018).

A high fiber content in CRM may reduce nutrient and energy availability, but in our meta-analysis, the overall effect size showed no significant effect on feed conversion in weanling pigs, and linear and quadratic regressions revealed no significant relationship between increasing CRM inclusion and feed conversion. Studies by Parr et al. (2015) indicate that up to 20% canola meal with low glucosinolate concentration can be used in diets for weanling pigs, and even higher inclusion rates of up to 40% may be possible without reducing growth performance. Noteworthy, dietary energy levels in the latter study were balanced by adding fat to diets containing canola meal to compensate for the reduced energy content compared with the replaced SBM. The weanling pig studies included in our database were conducted in the period from 1999 to 2019, and advances in plant breeding, and optimization of processing may have reduced concentration of glucosinolates in CRM during this period (Adewole et al., 2016). A comparison of the effect sizes did not indicate, however, that publication year influenced ADG, ADFI or feed conversion of weanling pigs in the present meta-analysis.

Growing-finishing pigs are expected to be more tolerant to the inclusion of high CRM levels than weanling pigs in terms of effects on growth performance (Mejicanos et al., 2016). The overall effect sizes of the current meta-analysis showed minor, but significantly negative effects of CRM on ADG and feed conversion, and a tendency towards negative effect on ADFI ($P = 0.07$). The linear and quadratic regression analyses, however, did not show clear trends in growth performance or acceptable threshold levels with increasing CRM inclusion in diets for growing-finishing pigs. Thus, our approach of comparison across studies revealed that CRM may be used at high levels in diets for growing-finishing pigs without detrimental effects on the ADFI, ADG or feed conversion. To our knowledge, this has not been estimated before in meta-analyses of experiments with growing-finishing pigs. Correspondingly, Stein et al. (2016) concluded in a recent review that it appears that if canola meal is included in well balanced diets for growing-finishing pigs that do not contain other high-fiber ingredients, there are few limitations to the inclusion rate. Feeding of CRM in some of the studies included in our meta-analysis caused increased dietary fiber contents, and it may be surprising that there were only minor effects on growth performance. This might be due a number of factors related to different sources of CRM and diet formulation and processing. The meta-analysis revealed considerable variability in effect sizes among different studies, and extrapolation to conditions different from those used in the studies of the applied dataset should be done with caution. A high CRM inclusion rate may thus be acceptable only when diets are formulated on constant levels of NE and standardized ileal digestible amino acids (Landero et al., 2013; Sanjayan et al., 2014).

5. Conclusion

The meta-analyses and weighted regression models showed no differences in ADG, and feed:gain of using CRM in diets for weanling pigs, but ADFI was significantly reduced. Using CRM in diets for growing-finishing pigs resulted in a minor reduction in overall effects size of ADG and gain:feed, while regression analyses revealed no differences in growth performance with increasing levels of CRM in diets. Overall, the results suggest that low glucosinolate CRM can be used as an alternative feed resource without adverse effects on growth performance if used in well-balanced diets for weanling and growing-finishing pigs.

Declaration of Competing Interest

None

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.anifeedsci.2019.114302.

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