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EFFECTS OF RAPESEED OIL AND GROUND FLAXSEED SUPPLEMENTATION ON PRODUCTIVE PERFORMANCE AND MEAT QUALITY IN GROWING-FINISHING PIGS

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Abstract

The study aimed to evaluate the effects of dietary supplementation with rapeseed oil (RO) and ground flaxseed (GF) on the productive performance and meat quality of growing-finishing pigs (Landrace × Large White hybrid). A total of 90 pigs with an initial average body weight of 27.40 kg were randomly assigned to four dietary treatments: LC (control, without supplementation), L1 (1% RO + 1% GF), L2 (1% RO + 1.5% GF), and L3 (2% RO + 2% GF), each with three replicate pens of 7–8 animals. The experiment was conducted over two consecutive phases: Phase I – growing (25–60 kg) and Phase II – finishing (60–110 kg), with a total duration of 84 days. Productive parameters (initial and final body weight per phase, average daily gain, average daily feed intake and feed conversion ratio) and meat quality indicators (dressing percentage, backfat thickness, lean meat percentage, pH_{45} and pH_{24}, meat colour L, a*, b*, and water holding capacity) were recorded and analysed by one-way ANOVA ($p < 0.05$). The results indicated that L3 supplementation substantially improved the dietary n-6/n-3 ratio (2.2:1 vs. 22.1:1 in LC), while productive performances remained comparable across all groups ($p > 0.05$). Backfat thickness was significantly reduced in L2 and L3 ($p < 0.05$), and lean meat percentage increased linearly with supplementation level, reaching 59.80% in L3 vs. 56.80% in LC. The findings suggest that combined RO and GF supplementation represents a viable nutritional strategy for improving the dietary n-6/n-3 ratio and carcass quality of pigs without compromising growth performance.*

Key words*: ground flaxseed, growing-finishing pigs, meat quality, n-3 fatty acids, productive performance, rapeseed oil.*

INTRODUCTION

The optimization of pig diets through the inclusion of unconventional lipid sources has become a subject of growing interest in both research and commercial swine production (Zahiu et al., 2010). The current global context is characterized by significant volatility in the prices of conventional feed ingredients, particularly soybean meal and vegetable oils, which account for a substantial proportion of total production costs in intensive pig farming (Cavalcanti et al., 2026). Against this backdrop, finding sustainable, locally available, and cost-effective alternatives has become a strategic priority for the European swine sector (European Commission, 2023).

Rapeseed (*Brassica napus* L.) and flaxseed (*Linum usitatissimum* L.) represent two of the most promising oilseed crops cultivated in Romania and across Central and Eastern Europe. Rapeseed oil is characterized by a favourable fatty acid composition, with a relatively low content of saturated fatty acids, high oleic acid (C18:1, approximately 60%), and a significant proportion of linoleic acid (C18:2 n-6, ~21%) and alpha-linolenic acid (ALA, C18:3 n-3, ~9.5%). Ground flaxseed is the richest plant source of ALA among conventional feed ingredients, with ALA representing approximately 57% of total fatty acids, providing an exceptional opportunity to improve the n-6/n-3 ratio in pork (Habeanu et al., 2014).

The dietary n-6/n-3 ratio is of paramount importance not only for animal health and metabolism, but also for the nutritional value of pork for human consumption. Current dietary guidelines recommend a maximum n-6/n-3 ratio of 4:1, whereas conventional corn-

soybean meal-based diets typically deliver ratios exceeding 15:1 or even 20:1. Modifying this ratio through dietary manipulation represents one of the most effective and economically feasible strategies to produce functional pork products enriched in n-3 polyunsaturated fatty acids (PUFA) (Smet et al., 2004).

While several studies have investigated the individual effects of rapeseed oil (Daza et al., 2005; Mitchaothai et al., 2007) or flaxseed (Habeanu et al., 2014) in swine diets, data on their combined supplementation across two distinct production phases – growing and finishing – with simultaneous assessment of productive performance and carcass quality remain limited, particularly for the Landrace × Large White hybrid widely used in Romanian commercial production systems.

The novel aspect of the present study consists of the simultaneous inclusion of both ingredients at three combined dosage levels, evaluated separately for each production phase, using the genotype predominant in intensive Romanian farming.

The study tested the hypothesis that combined dietary supplementation with RO and GF improves the dietary n-6/n-3 ratio and carcass composition without negatively affecting growth performance in growing-finishing pigs. The present study aimed to evaluate the effects of three combined supplementation levels of RO and GF on average daily gain, feed intake, and feed conversion ratio during both growing and finishing phases; to assess the impact on carcass quality parameters, including backfat thickness and lean meat percentage; and to quantify the modification of the dietary n-6/n-3 ratio as a function of supplementation level.

MATERIALS AND METHODS

Animals, Housing, and Experimental Design

The experiment was conducted over a total period of 84 days, covering two consecutive production phases. A total of 90 pigs of the Landrace × Large White hybrid, weaned at 28 days and pre-selected at an average body weight of 27.40 ± 0.82 kg (Phase I entry weight), were used. Animals were in good health and were acclimatized for 10 days prior to the start of the trial.

Pigs were randomly allocated to four dietary treatment groups, each consisting of three replicate pens with 7-8 animals per pen (n = 22-23 per treatment group). The four groups were as follows: LC – control group, without lipid supplementation; L1 – 1% rapeseed oil (RO) + 1% ground flaxseed (GF); L2 – 1% RO + 1.5% GF; L3 – 2% RO + 2% GF.

The experimental design was a completely randomised block design with dietary treatment as the main factor. The pen was considered the experimental unit for productive performance traits, as feed intake was recorded at pen level.

Animals were housed in groups in climate-controlled pens (18-22°C, relative humidity 60-70%, 16 h light/8 h dark cycle). Each pen was equipped with a nipple drinker and a two-sided feeder, allowing ad libitum access to feed and water throughout the experiment. All procedures were conducted in accordance with Directive 2010/63/EU on the protection of animals used for scientific purposes and Romanian Law no. 43/2014.

Dietary Treatments and Feed Formulation

Two complete compound feed formulas were developed for each treatment group, corresponding to the two production phases: Phase I – growing (25-60 kg body weight) and Phase II – finishing (60-110 kg body weight). All diets were formulated to be approximately isoenergetic and iso-nitrogenous within each phase (ME differences between groups did not exceed 0.59 MJ/kg in Phase I and 0.59 MJ/kg in Phase II; see Table 3), meeting or exceeding the NRC (2012) nutritional requirements for growing-finishing pigs. The main ingredients were corn grain, wheat grain, barley grain, soybean meal (44% CP), wheat bran, rapeseed oil, and ground flaxseed, complemented by a standard vitamin-mineral premix (1% inclusion level for all groups).

Flaxseed was freshly ground to a particle size below 2 mm immediately before diet preparation to minimize oxidation of ALA. Rapeseed oil was added by spraying over the dry ingredient blend at a maximum mixing temperature of 40°C. The vitamin E level in the premix was adjusted to 150 mg/kg complete feed for L1 and L2, and to 220 mg/kg for L3, to provide adequate antioxidant protection for the elevated PUFA content. As a synthetic

antioxidant, butylhydroxytoluene (BHT, E321, 150 ppm) was incorporated into the premix of all groups in compliance with Regulation (EC) No 1831/2003 and Commission Regulation (EU) No 574/2011, which authorise BHT as a feed additive (functional group: antioxidants) for all animal species.

Table 1. Composition of experimental diets – Phase I: Growing (25-60 kg), % as-fed

Ingredients	LC (%)	L1 (%)	L2 (%)	L3 (%)
Corn grain	63.05	62.85	62.95	62.55
Wheat grain	8.00	7.00	7.00	6.50
Barley grain	6.50	5.50	5.00	4.50
Soybean meal (44% CP)	17.00	17.20	17.30	17.50
Wheat bran	1.00	1.00	0.80	0.50
Rapeseed oil	-	**1.00**	**1.00**	**2.00**
Ground flaxseed	-	**1.00**	**1.50**	**2.00**
Dicalcium phosphate	1.30	1.30	1.30	1.30
Calcium carbonate	1.40	1.40	1.40	1.40
Iodised salt (NaCl)	0.40	0.40	0.40	0.40
L-Lysine HCl (78%)	0.25	0.25	0.25	0.25
DL-Methionine (99%)	0.05	0.05	0.05	0.05
L-Threonine (98%)	0.05	0.05	0.05	0.05
Vitamin-mineral premix 1%	1.00	1.00	1.00	1.00
TOTAL	**100.00**	**100.00**	**100.00**	**100.00**

Table 2. Composition of experimental diets – Phase II: Finishing (60-110 kg), % as-fed

Ingredients	LC (%)	L1 (%)	L2 (%)	L3 (%)
Corn grain	67.45	66.45	66.55	66.15
Wheat grain	7.00	6.50	6.50	6.00
Barley grain	6.00	5.50	5.00	4.50
Soybean meal (44% CP)	13.00	13.30	13.40	13.50
Wheat bran	2.50	2.20	2.00	1.80
Rapeseed oil	-	**1.00**	**1.00**	**2.00**
Ground flaxseed	-	**1.00**	**1.50**	**2.00**
Dicalcium phosphate	1.10	1.10	1.10	1.10
Calcium carbonate	1.30	1.30	1.30	1.30
Iodised salt (NaCl)	0.40	0.40	0.40	0.40
L-Lysine HCl (78%)	0.20	0.20	0.20	0.20
DL-Methionine (99%)	0.03	0.03	0.03	0.03
L-Threonine (98%)	0.02	0.02	0.02	0.02
Vitamin-mineral premix 1%	1.00	1.00	1.00	1.00
TOTAL	**100.00**	**100.00**	**100.00**	**100.00**

Table 3. Nutritional value of experimental diets by phase and experimental groups

Nutritional parameter	Phase	LC	L1	L2	L3
ME (MJ/kg feed)	I	13.38	13.66	13.70	13.97
ME (MJ/kg feed)	II	13.53	13.81	13.85	14.12
Crude protein (%)	I	17.8	17.9	17.9	18.0
Crude protein (%)	II	15.6	15.7	15.8	15.9
Crude fat (%)	I	3.45	5.05	5.60	7.35
Crude fat (%)	II	3.38	5.00	5.55	7.28
Lysine (%)	I	0.97	0.97	0.97	0.98
Lysine (%)	II	0.76	0.76	0.77	0.77
Total Ca (%)	I	0.72	0.72	0.72	0.72
Total Ca (%)	II	0.63	0.63	0.63	0.63
Total P (%)	I	0.56	0.56	0.56	0.55
Total P (%)	II	0.50	0.50	0.50	0.49
LA C18:2n-6 (%)	I	1.62	2.05	2.12	2.60
LA C18:2n-6 (%)	II	1.55	1.98	2.06	2.55
ALA C18:3n-3 (%)	I	0.08	0.41	0.68	1.20
ALA C18:3n-3 (%)	II	0.07	0.38	0.65	1.17
n-6/n-3 ratio	I	20.3:1	5.0:1	3.1:1	2.2:1
n-6/n-3 ratio	II	22.1:1	5.2:1	3.2:1	2.2:1

ME = metabolisable energy; LA = linoleic acid; ALA = alpha-linolenic acid.

Measurements and analytical methods

Body weight was recorded individually at the beginning of the experiment (day 0), at the transition between phases (day 42 – end of Phase I / start of Phase II), and at the end of the experiment (day 84 – end of Phase II), using a calibrated electronic scale (± 0.1 kg accuracy). Average daily gain (ADG) was calculated separately for each phase and for the overall experimental period.

Feed intake was monitored daily at pen level by weighing the amount of feed offered and the refusals. Average daily feed intake (ADFI) was calculated per animal by dividing the total feed consumed by the number of animal-days. The feed conversion ratio (FCR, kg feed/kg body weight gain) was calculated separately for each phase.

At the end of the experiment (day 84), all 90 pigs were slaughtered at a commercial abattoir under standard conditions. The following carcass and meat quality parameters were recorded: hot carcass weight (kg); dressing percentage (%), calculated as carcass weight divided by live weight at slaughter × 100; backfat thickness (mm), measured at three anatomical points (shoulder, mid-back, and last rib) using a calliper, and averaged; lean meat percentage (%), estimated using the two-point FOM (Fat-O-Meter) method according to Commission Regulation (EC) No 1249/2008; pH at 45 minutes post-mortem (pH_{45}) and at 24 hours post-mortem (pH_{24}), measured in the *Longissimus dorsi* muscle using a portable pH meter (Testo 205); meat colour (L*, a*, b*) at 24 hours post-mortem, measured with a Minolta CR-400 colorimeter in the *Longissimus dorsi* cross-section, according to the CIE L*a*b* system; water holding capacity (WHC), assessed by the filter paper press method (Grau & Hamm, 1953, cited in Honikel, 1998).

Statistical analysis was performed using SPSS v.26 software (IBM Corp., Armonk, NY). Data were analysed by one-way ANOVA with dietary treatment as the fixed effect. Means were compared using Tukey's HSD post-hoc test. The significance level was set at $p < 0.05$. Results are presented as means ± standard error of the mean (SEM). Normality of residuals was verified using the Shapiro-Wilk test.

RESULTS AND DISCUSSIONS

Body weight dynamics and growth performance by phase

The dynamics of body weight across the two experimental phases are presented in Table 4. At the beginning of the experiment, no significant differences were recorded between treatment groups for initial body weight ($p = 0.892$), confirming successful randomisation. All animals were within the target weight range of 25–30 kg at Phase I entry.

Table 4. Body weight dynamics and productive performance by experimental phase (means ± SEM)

Parameter	Phase	LC	L1	L2	L3
Initial BW (kg)		27.42±0.85	27.38±0.91	27.44±0.78	27.36±0.88
BW end Phase I (kg)	I	60.85±1.42	60.12±1.56	59.88±1.38	59.45±1.61
BW end Phase II (kg)	II	108.60±2.15	107.85±2.32	107.40±2.08	106.90±2.44
Total weight gain (kg)		81.18±1.95	80.47±2.18	79.96±2.02	79.54±2.25
ADG Phase I (g/day)	I	802±18	802±21	792±19	780±22
ADG Phase II (g/day)	II	1132±24	1137±26	1131±22	1142±28
ADG overall (g/day)		967±16	959±18	952±17	945±19
ADFI Phase I (kg/day)	I	2.05±0.06	2.07±0.07	2.09±0.06	2.12±0.08
ADFI Phase II (kg/day)	II	2.82±0.08	2.80±0.09	2.78±0.08	2.75±0.09
FCR Phase I (kg feed/kg gain)	I	2.56±0.07	2.58±0.08	2.64±0.07	2.72±0.09
FCR Phase II (kg feed/kg gain)	II	2.49±0.06	2.46±0.07	2.46±0.06	2.41±0.08
FCR overall (kg feed/kg gain)		2.52±0.05	2.51±0.06	2.54±0.06	2.56±0.07

BW = body weight; ADG = average daily gain; ADFI = average daily feed intake; FCR = feed conversion ratio. Means within a row with no superscript letters do not differ significantly ($p > 0.05$, Tukey HSD).

During Phase I (growing, 25–60 kg), all groups showed comparable growth performance. The ADG ranged from 780 g/day (L3) to 802 g/day (LC and L1), with no statistically significant differences between groups ($p = 0.124$). The slight numerical reduction in ADG observed in

L3 during Phase I may be attributable to the adaptation period required for the higher lipid inclusion level (4% total added fat), which can temporarily reduce voluntary feed intake in pigs not previously exposed to high-fat diets. However, ADFI differences were minor and non-significant ($p = 0.510$).

During Phase II (finishing, 60–110 kg), ADG was likewise similar across all groups, ranging from 1131 g/day (L2) to 1142 g/day (L3), with no statistically significant differences ($F(3,8) = 0.26$, $p = 0.876$). FCR values in Phase II (2.41–2.49 kg feed/kg gain) did not differ significantly between groups ($F(3,8) = 1.38$, $p = 0.315$). The higher energetic density of the L3 diet compared to LC (14.12 vs. 13.53 MJ ME/kg) should be acknowledged as a potential confounding factor when interpreting Phase II performance data; however, the absence of significant differences in any productive parameter across all groups indicates that this energy difference did not produce a biologically meaningful effect under the present experimental conditions.

These findings are consistent with published data demonstrating that supplementation of pig diets with polyunsaturated fatty acid-rich oils at levels up to 4% does not impair productive performance (Habeanu et al., 2014; Dugan et al., 2004). The overall FCR values are within the expected range for the Duroc × Pietrain genotype under intensive conditions (Gomes et al., 2025).

Carcass quality and meat quality indicators

The results of carcass and meat quality evaluation are presented in Table 5. Dressing percentage was comparable across all groups (75.8–76.4%), with no significant differences ($p = 0.725$), indicating that the dietary treatments did not affect the overall efficiency of converting live weight into carcass weight.

Table 5. Carcass and meat quality indicators (means ± SEM)

Parameter	LC	L1	L2	L3
Live weight at slaughter (kg)	108.60±2.15	107.85±2.32	107.40±2.08	106.90±2.44
Hot carcass weight (kg)	82.45±1.85	82.00±1.95	81.60±1.78	81.10±2.02
Dressing percentage (%)	75.92±0.62	76.02±0.68	75.98±0.60	75.86±0.71
Backfat thickness – shoulder (mm)	22.40±0.85	21.85±0.92	20.60±0.78	19.20±0.95
Backfat thickness – mid-back (mm)	18.60±0.72	18.10±0.80	17.10±0.69	15.80±0.85
Backfat thickness – last rib (mm)	16.80±0.68	16.30±0.75	15.40±0.62	14.20±0.78
Mean backfat thickness (mm)	19.27±0.72[a]	18.75±0.80[a]	17.70±0.68[b]	16.40±0.85[c]
Lean meat %	56.80±0.85[a]	57.45±0.92[a]	58.60±0.80[b]	59.80±0.95[c]
pH_{45} Longissimus dorsi	6.42±0.08	6.45±0.09	6.48±0.08	6.50±0.10
pH_{24} Longissimus dorsi	5.62±0.05	5.65±0.06	5.68±0.05	5.72±0.06
Meat colour L* (lightness)	50.25±1.12	50.48±1.25	50.82±1.08	51.15±1.30
Meat colour a* (redness)	8.45±0.42	8.62±0.48	8.78±0.40	8.92±0.50
Meat colour b* (yellowness)	4.12±0.28	4.35±0.32	4.52±0.28	4.85±0.35
Water holding capacity (%)	71.25±1.05	71.80±1.15	72.40±1.02	72.95±1.20

Highlighted rows: parameters with statistically significant differences between groups. Different superscript letters (a, b, c) within a row indicate significant differences ($p < 0.05$, Tukey HSD). pH_{45} and pH_{24} measured in *Longissimus dorsi* muscle.

A statistically significant effect of dietary treatment was found for mean backfat thickness ($p = 0.008$). The L3 group showed the lowest mean backfat thickness (16.40 mm), significantly lower than LC (19.27 mm, $p < 0.001$) and L1 (18.75 mm, $p = 0.012$). The L2 group (17.70 mm) was also significantly lower than LC ($p = 0.031$). This reduction in subcutaneous fat deposition with increasing n-3 PUFA supplementation is supported by the known inhibitory effect of ALA and its long-chain derivatives on lipogenesis and adipocyte differentiation (Wood et al., 2008; Habeanu et al., 2014). The elevated content of ALA in L2 and L3 diets (0.65-1.17% in Phase II) likely contributed to the redistribution of energy from fat deposition to muscle protein accretion.

Lean meat percentage showed a significant linear increase with supplementation level ($p = 0.004$), ranging from 56.80% in LC to 59.80% in L3. Pairwise comparisons revealed significant differences between LC and both L2 ($p = 0.022$) and L3 ($p < 0.001$), whereas the difference between LC and L1 did not reach significance ($p = 0.412$). These results indicate that a minimum combined supplementation of 1% RO + 1.5% GF (L2) is required to produce a biologically and commercially meaningful improvement in carcass lean meat content for the Landrace × Large White genotype.

Regarding meat pH, all groups showed values within the normal range for pork (pH_{45} 6.40-6.55; pH_{24} 5.60-5.75), with no significant differences between treatments ($p > 0.05$). These values exclude the occurrence of PSE (pale, soft, exudative) or DFD (dark, firm, dry) meat defects in any of the experimental groups, confirming that the dietary supplementation did not induce metabolic stress during the perimortem period.

Meat colour parameters (L*, a*, b*) showed consistent numerical trends with increasing supplementation levels, with slight increases in redness (a*) and yellowness (b*) in L2 and L3. The increase in b* (yellowness) in L3 (4.85 vs. 4.12 in LC) is a commonly reported effect of elevated dietary PUFA in pork and is attributable to the deposition of carotenoid pigments naturally present in rapeseed oil and flaxseed (Smet et al., 2004). However, none of these colour differences reached statistical significance ($p > 0.05$), suggesting that the supplementation levels used do not produce commercially unacceptable meat colour. Water holding capacity (WHC) showed a gradual increase across treatment groups (71.25% in LC to 72.95% in L3), with no statistically significant differences ($F(3.86) = 1.84$, $p = 0.145$). These values are within the normal range for pork *Longissimus dorsi* (Honikel, 1998), and indicate that the dietary treatments did not adversely affect the ability of the muscle to retain water, which is relevant for drip loss during storage and processing yield.

CONCLUSIONS

Combined dietary supplementation with rapeseed oil and ground flaxseed did not significantly affect ADG, ADFI, or FCR in growing or finishing pigs ($p > 0.05$), confirming nutritional safety of these PUFA-rich ingredients at the tested levels.

Carcass quality improved significantly with supplementation: mean backfat thickness decreased (L2 and L3, $p < 0.05$) and lean meat percentage increased linearly, from 56.80% (LC) to 59.80% (L3), representing commercially meaningful gains under the EUROP grading system.

Meat quality parameters (pH, colour, WHC) remained within normal ranges in all groups. The L3 diet reduced the dietary n-6/n-3 ratio from 22.1:1 to 2.2:1, well within current guidelines (≤4:1). L3 (2% RO + 2% GF) is the most effective combination for improving carcass composition without compromising productive performance. Limitations include the absence of pork fatty acid profiling, use of a single genotype and production site, and residual ME differences between groups (up to 0.59 MJ/kg). Future work should address these aspects and expand to additional genotypes.

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