Dietary Supplementation to Improve the Growth of Intrauterine Growth-Restricted Pigs

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https://doi.org/10.34776/afs16-48 Date of publication: 8 April 2025

Morphological characteristics of a piglet affected by intrauterine growth restriction (Photo: Agroscope).

Abstract

Genetic selection in pig production improves sow prolificacy, but it also increases the number of piglets born with a low birth weight and those affected by intrauterine growth restriction (IUGR). These piglets typically show lower survival rates and stunted growth. The aim of this study was to evaluate the effects of a starter diet supplemented with probiotics, medium-chain triglycerides, and grape seed antioxidants on the growth of lightweight and IUGR piglets. The brain-to-liver weight ratio of 115 piglets was calculated to determine the degree of IUGR in each animal. Additionally, pigs were categorised as either heavy or light based on their body weight at weaning. The trial began 1 week after weaning and lasted for 4 weeks. The control group was fed a standard starter diet, while the treatment group received a diet with probiotics, medium-chain triglycerides, and antioxidants. Body weight and average daily gain were monitored throughout the trial. The results showed that pigs from the treatment group had significantly higher body weight and average daily gain by day 28 compared to the control group. However, lightweight pigs and those with elevated brain-to-liver weight ratios, indicating IUGR, consistently exhibited poorer growth outcomes, regardless of treatment. These findings show that while dietary supplementation improves growth performance, more targeted strategies are needed to meet the specific needs of lightweight and IUGR-affected pigs and enhance production efficiency.

Key words: *Bacillus*, brain-to-liver weight ratio, grape seed, mid-chain triglycerides.

Introduction

Over the last few decades, genetic selection in pig production has aimed at increasing sow prolificacy (Kemp et al., 2018). However, alongside the increase in litter size, there has been an increase in the number of piglets born with low birth weight and those affected by intrauterine growth restriction (IUGR) (Farmer and Edwards, 2022). Piglets affected by IUGR exhibit a higher brain-to-liver weight ratio (BrW/LW) at birth due to the "brain-sparing effect," a mechanism that redirects blood flow towards the brain to face chronic oxygen and nutrient deprivation in the uterus (Cohen et al., 2015). These piglets have higher mortality rates because of their lower vitality at birth, reduced glycogen reserves for thermoregulation, and inability to compete for adequate colostrum intake (Farmer & Edwards, 2022). If IUGR piglets survive the neonatal period, they often face reduced feed efficiency and long-term growth limitations, and they require more time to reach slaughter weight (Ruggeri et al., 2024a). Given these challenges and the fact that they can constitute up to 30% of a litter, IUGR piglets have significant impacts on overall production efficiency, as there is currently no effective treatment to mitigate the adverse effects of IUGR.

In Li et al.'s (2018) study, dietary supplementation with *Bacillus amyloliquefaciens* was shown to enhance the average daily weight gain (ADG) and feed efficiency in IUGR piglets. Moreover, the supplementation improved intestinal morphology, reduced inflammatory responses, and regulated the microbiota in the small intestine of the affected piglets.

Zhang et al. (2016) demonstrated that mid-chain triglycerides supplementation in IUGR piglets can improve energy metabolism and mitochondrial biogenesis in the liver and enhance ADG and feed efficiency.

Grape seed procyanidins, known for their potent antioxidant properties due to their free radical-scavenging activity, have attracted considerable attention in pig production (Hao et al., 2015). Hao et al. (2015) demonstrated that supplementing weaned piglets with grape seed procyanidins can reduce diarrhoea, enhance immune response, and improve antioxidant capacity.

This study aimed to investigate the impact of a starter diet supplemented with probiotics (*Bacillus mix*), mid-chain triglycerides, and grape seeds on the growth performance of IUGR and lightweight piglets.

Materials and methods

Animal selection

This research was carried out at the UFA swine research facility in Hendschiken, Switzerland. The study included 115 piglets (50 females and 65 males) born from 18 sows in two farrowing batches. The pigs were followed from birth until 5 weeks postweaning. The birth body weight (BtW) of each piglet was recorded on the farrowing day. To capture specific morphometric traits, videos of all the piglets were recorded one day (± 1) after birth using a camera (RealSense depth camera D435i, Intel, USA) as described by Ruggeri et al. (2024b). From each video, two image frames were selected for each piglet. In the first frame (frame 1), the piglet is depicted from the right side, while in the second frame (frame 2), it is shown from a top view (Fig. 1) (Photo: Roberta Ruggeri, Agroscope).

Frame 1 Frame 2

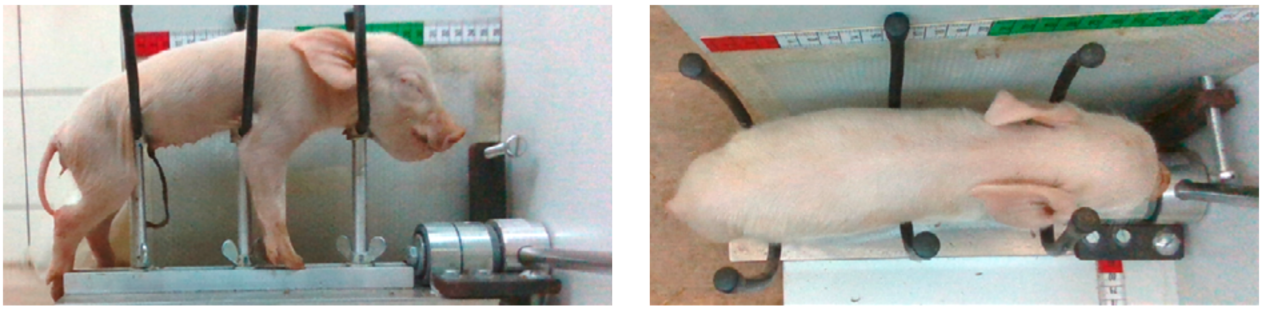


Fig. 1 | Images of a piglet captured by video in two frames to collect body measurements. Frame 1 (left) presents the piglet from the right lateral view, while frame 2 (right) shows the piglet from the top view. Picture from Ruggeri et al. (2024b).

Two morphometric traits were measured for each piglet: the distance between the ears (EE2) from frame 2 (Fig. 2) (Photo: Roberta Ruggeri, Agroscope), and the abdominal area delimited by a square (L) from frame 1 (Fig. 3) (Photo: Roberta Ruggeri, Agroscope).

Frame: 2 – Body measure: EE

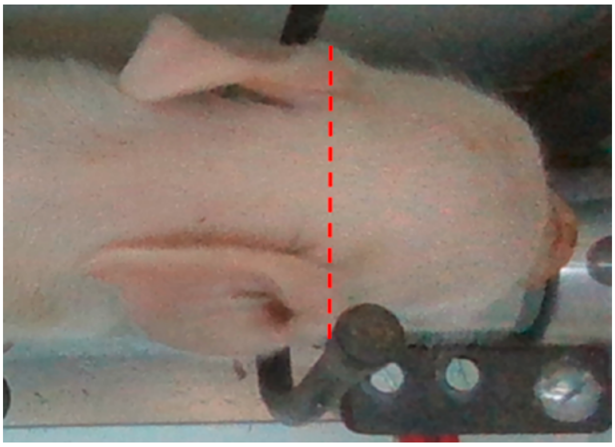


Fig. 2 | Body measurements collected to estimate the weight of the brain of the piglets. Abbreviation: EE2 = distance in pixels between the medial edge of the ears, seen from above. Picture from Ruggeri et al. (2024b).

Frame: 1 – Body measure: L

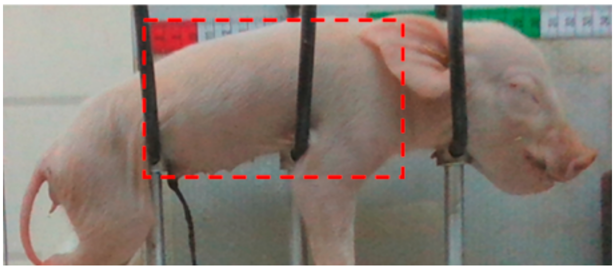


Fig. 3 | Body measurements collected to estimate the weight of the liver of the piglets. Abbreviation: L = area in pixels of the body delimited by a square from the caudal edge of the head to the caudal edge of the abdomen, seen from the side. Picture from Ruggeri et al. (2024b).

The three regression equations below were used (developed at Agroscope, Ruggeri et al., 2024b), to estimate the brain (BrW) and liver weights (LW), as well as the BrW/LW, which represents the best indicator to assess the degree of IUGR in pigs, from two morphometric traits (EE2 and L), and the BtW of the piglets.

1. $BrW = 18.8 + 7.02 \times BtW + 0.04 \times EE2$
2. $LW = -10.9 + 33.2 \times BtW + 0.0002 \times L$
3. $\log(BrW/LW) = 0.831 + -0.4 \times BtW + -0.0008 \times EE2 + -7.224e^{-06} \times L$

The piglets were fed a pre-/early post-weaning diet from 10 days before weaning to 1 week after weaning. Subsequently, they were offered a starter diet for 4 weeks. Before the starter diet was administered, the pigs were divided into two categories—heavy (n = 56; BW = 9.6 kg ± 1.81 [mean + SD]) and light (n = 59; BW = 6.2 kg ± 1.73)—based on their body weight (BW) at weaning.

The trial started 1 week after weaning and lasted for 4 weeks. The control (CON) group (heavy-CON; n = 28; light-CON; n = 29) received a basic starter diet, and the treated (TRT) group (heavy-TRT; n = 28; light-TRT; n = 30) received a starter diet supplemented with probiotics (SOLPREME®, Chr. Hansen A/S, Denmark – 400 g), mid-chain triglycerides (Entero-Nova®, Eastman, Kingsport, USA – 2 kg), and antioxidant compounds (Vitanox®, Nuscience, Belgium- 500 g). All diets administered to the pigs during the experiment were formulated at UFA, Switzerland.

The individual BW of the pigs was recorded at weaning and on days 1, 14, and 28 of the trial. The ADG was calculated from weaning to day 1 of the trial, from day 1 to day 14 of the trial, from day 15 to day 28 of the trial, and from day 1 to day 28 of the trial. The feed intake was calculated per pen from day 1 to day 14 of the trial, from day 15 to day 28 of the trial, and from day 1 to day 28 of the trial.

Statistical analysis

All calculations and statistical analyses were performed using Rstudio (version 4.0.2). The data on BW and ADG were analysed with linear mixed-effect models using the "lmer" function of the lme4 package. The category (heavy, light), treatment (TRT, CON), and sex (female, castrate) were considered fixed effects, and the litter of origin, repetition, and pen were considered random effects. The three-way interaction between the fixed effects was consistently assessed and removed if non-significant. The pig was treated as the experimental unit.

In addition, the effect of the BrW/LW on the BW and ADG was evaluated with linear mixed-effect models using the "lmer" function of the lme4 package, including the BrW/LW, the treatment (TRT, CON), and sex (female, castrate) as fixed effects, and the litter of origin, repetition, and pen as random effects. The three-way interaction between the fixed effects was consistently assessed and removed if non-significant. The pig was considered the experimental unit.

The data on feed intake were analysed with linear models using the "lm" function. Predictors included category (heavy, light), treatment (TRT, CON), and sex (female, castrate). The three-way interaction between the predictors was consistently assessed and removed if non-significant. The pen was considered the experimental unit.

Results

The average BrW/LW ratios for pigs in the heavy (n = 56) and light (n = 59) groups were 0.58 ± 0.13 and 0.72 ± 0.14 [harmonic mean ± SD], respectively (Table 1). The TRT pigs showed a higher ($p = 0.05$) BW compared to the CON pigs on day 28 of the trial. In addition, TRT pigs exhibited a higher ADG from day 1 to day 28 of the trial ($p = 0.01$) and from day 15 to day 28 of the trial ($p < 0.001$, Table 2).

Regardless of the treatment, light pigs consistently showed significantly lower BW ($p < 0.001$) and ADG ($p < 0.001$) at all time points, except for the period from weaning to the beginning of the trial, during which there was only a tendency ($p < 0.07$) for a higher ADG in light pigs compared to heavy pigs (Table 2). Similarly, the BrW/LW was negatively correlated ($p < 0.01$) with the BW and ADG of the pigs at all time points (Graphs 1–8), regardless of the treatment.

Regarding feed intake, light pigs consistently showed significantly lower feed intake ($p < 0.001$) and average daily feed intake ($p < 0.001$) compared to heavy pigs. However, among the light pigs, the TRT pens showed a greater feed intake ($p < 0.01$) compared to the CON pens from day 1 to day 28 of the trial.

Table 1 | **Average brain-to-liver weight ratio (BrW/LW) at birth and body weight (BW) at weaning of light and heavy piglets.**

	Category[1]		Sex[2]	
Item	Heavy	Light	1	2
Number of pigs	56	59	65	50
BrW/LW[3]	0,58 ± 0,13	0,72 ± 0,14	0,63 ± 0,14	0,67 ± 0,14
BW at weaning, kg	9,6 ± 1,81	6,2 ± 1,73	8,02 ± 1,81	7,60 ± 1,78

[1] Category: heavy = piglets with a high body weight (BW) at weaning; light = piglets with a low BW at weaning.
[2] Sex: 1 = castrate; 2 = female.
[3] BrW/LW = brain-to-liver weight ratio at birth.

Table 2 | Effect of classifying the pigs based on treatment (TRT, CON), weaning body weight (heavy, light), and sex (1, 2) on the body weight and average daily gain (ADG) from weaning to the end of the trial.

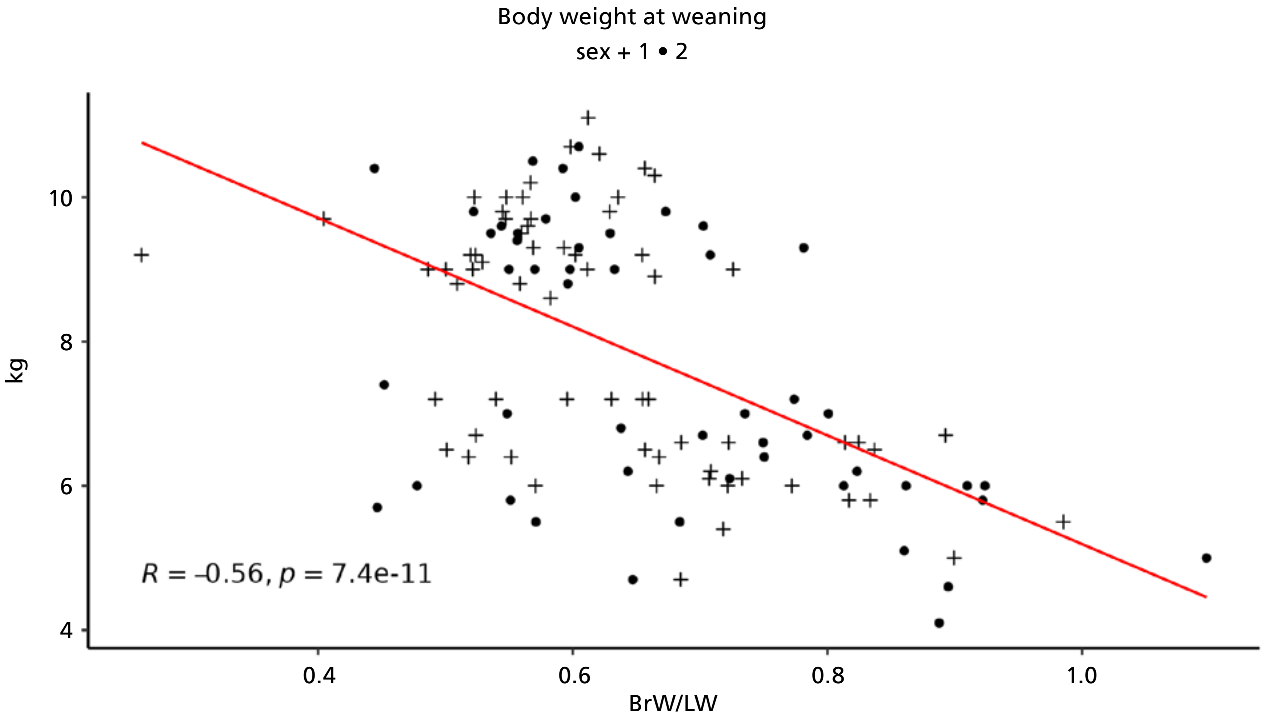
	Treatment[1]		Category[2]		Sex[3]			P-value[4]		
Item	CON	TRT	Heavy	Light	1	2	SEM[5]	Treatment	Category	Sex
Number of pigs	58	59	57	60	66	51				
Body weight, kg										
Weaning	-	-	9,6	6,2	8,0	7,9	0,14	-	<0,001	0,32
Day 1	-	-	10,1	6,9	8,5	8,6	0,14	-	<0,001	0,47
Day 14	13,0	13,0	15,1	10,9	12,8	13,2	0,21	0,99	<0,001	0,14
Day 28	19,9	20,9	23,2	17,7	20,1	20,8	0,46	0,05	<0,001	0,14
ADG, g/d										
Weaning to day 1	-	-	77	103	74	106	18,6	-	0,07	0,03
Day 1 to day 14	322	324	359	287	314	332	9,28	0,87	<0,001	0,11
Day 15 to day 28	493	560	573	480	514	539	23,0	<0,001	<0,001	0,21
Day 1 to day 28	408	422	466	383	414	436	15,3	0,01	<0,001	0,11

[1] Treatment: CON = normal starter diet; TRT = starter diet supplemented with Solpreme (probiotics), Entero Nova (mid chain fatty acids) and Vitanox (antioxidants).
[2] Category: heavy at weaning; light at weaning.
[3] Sex: 1 = castrate; 2 = female
[4] P-value for the main effect of the treatment, category and sex.
[5] Pooled SEM.

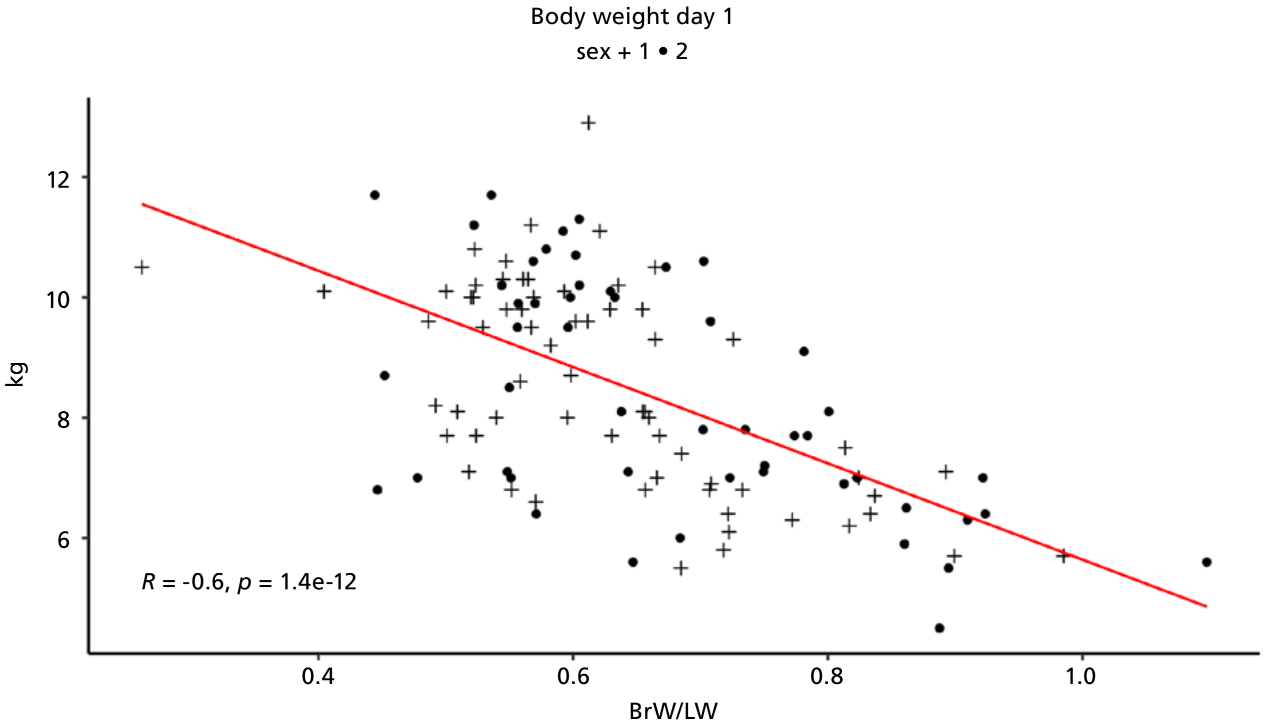
Table 3 | Effect of classifying the pigs based on treatment (TRT, CON), weaning body weight (heavy, light), and sex (1, 2) on feed intake (FI) and average daily feed intake (ADFI) per pen from weaning to the end of the trial.

	Treatment and Category[1]				Sex[2]		P-value[3]		
Item	heavy-CON	heavy-TRT	light-CON	light-TRT	1	2	SEM[4]	Treatment * Category	Sex
Day 1 to day 14									
FI per pen, kg	112,7[a]	128,6[b]	95,5[c]	95,6[c]	108	108	1,09	< 0,001	0,99
ADFI per pen, kg	8,05[a]	9,20[b]	6,81[c]	6,85[c]	7,7	7,7	0,08	< 0,001	0,98
Day 15 to day 28									
FI per pen, kg	188[a]	175[b]	153[c]	166[b]	171	170	1,91	< 0,001	0,58
ADFI per pen, kg	13,4[a]	12,5[b]	11,0[c]	11,9[b]	12,2	12,1	0,14	< 0,001	0,57
Day 1 to day 28									
FI per pen, kg	300[a]	303[a]	249[b]	262[c]	279	278	1,079	< 0,001	0,28
ADFI per pen, kg	10,72[a]	10,84[a]	8,88[b]	9,34[c]	9,98	9,92	0,0385	< 0,001	0,28

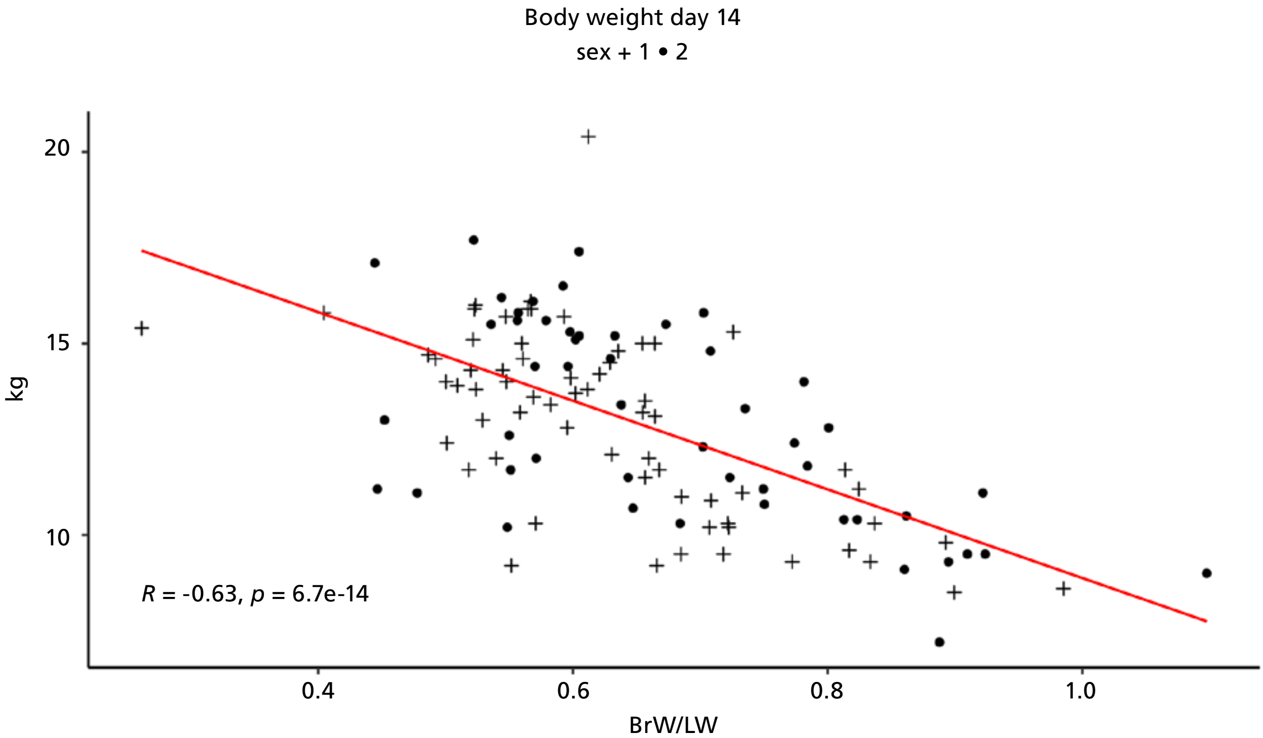
[1] Treatment: CON = normal starter diet; TRT = starter diet supplemented with Solpreme (probiotics), Entero Nova (mid chain fatty acids) and Vitanox (antioxidants).
[2] Category: heavy at weaning; light at weaning.
[3] Sex: 1 = castrate; 2 = female
[4] P-value for the main effect of the treatment, category and sex.
[5] Pooled SEM.



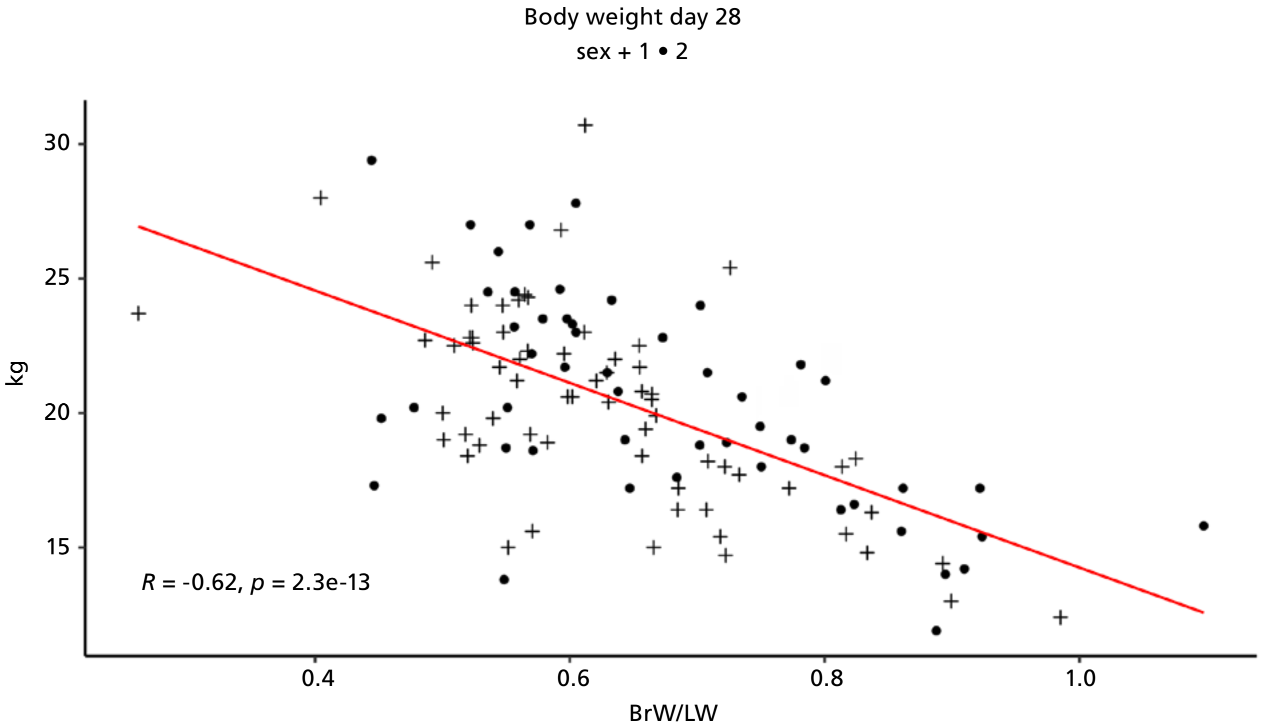
Graph 1 | Effect of brain weight-to-liver weight ratio and sex (1, 2) on body weight at weaning. Abbreviations: BrW/LW = brain-to-liver weight ratio; 1 = castrate; 2 = female.



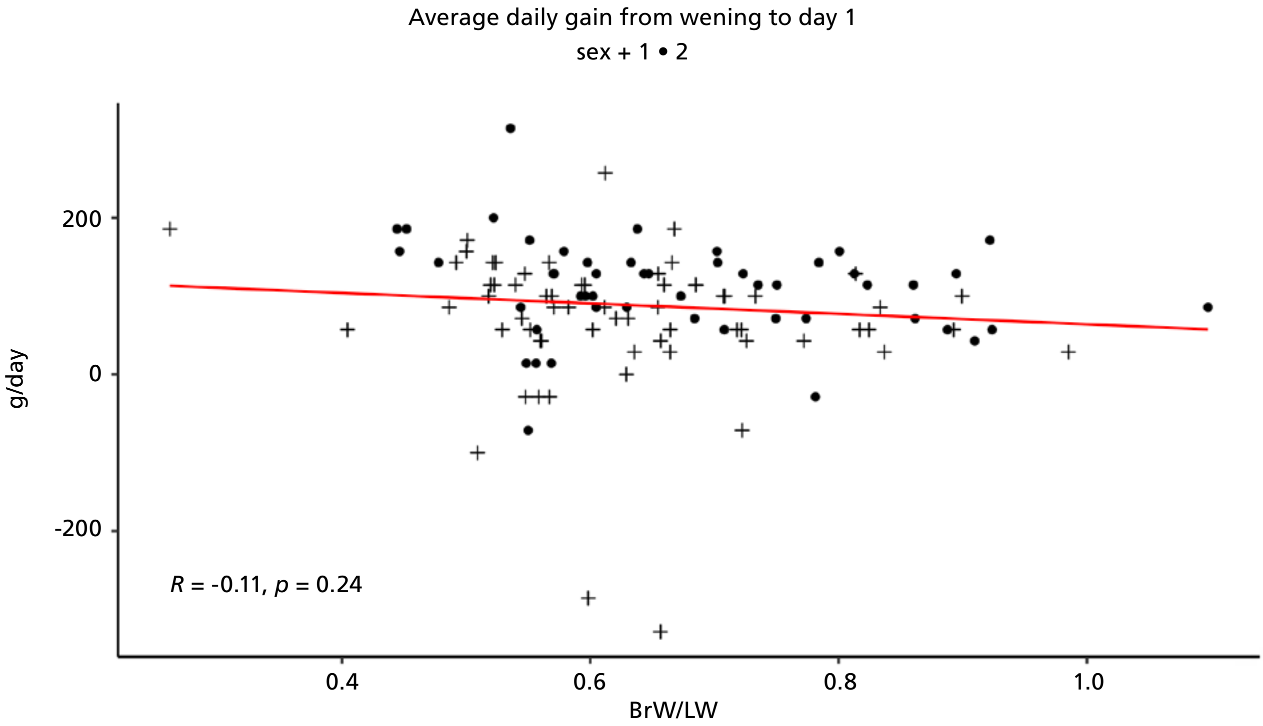
Graph 2 | Effect of brain weight-to-liver weight ratio and sex (1, 2) on body weight at the start of the trial (day 1). Abbreviations: BrW/LW = brain-to-liver weight ratio; 1 = castrate; 2 = female.



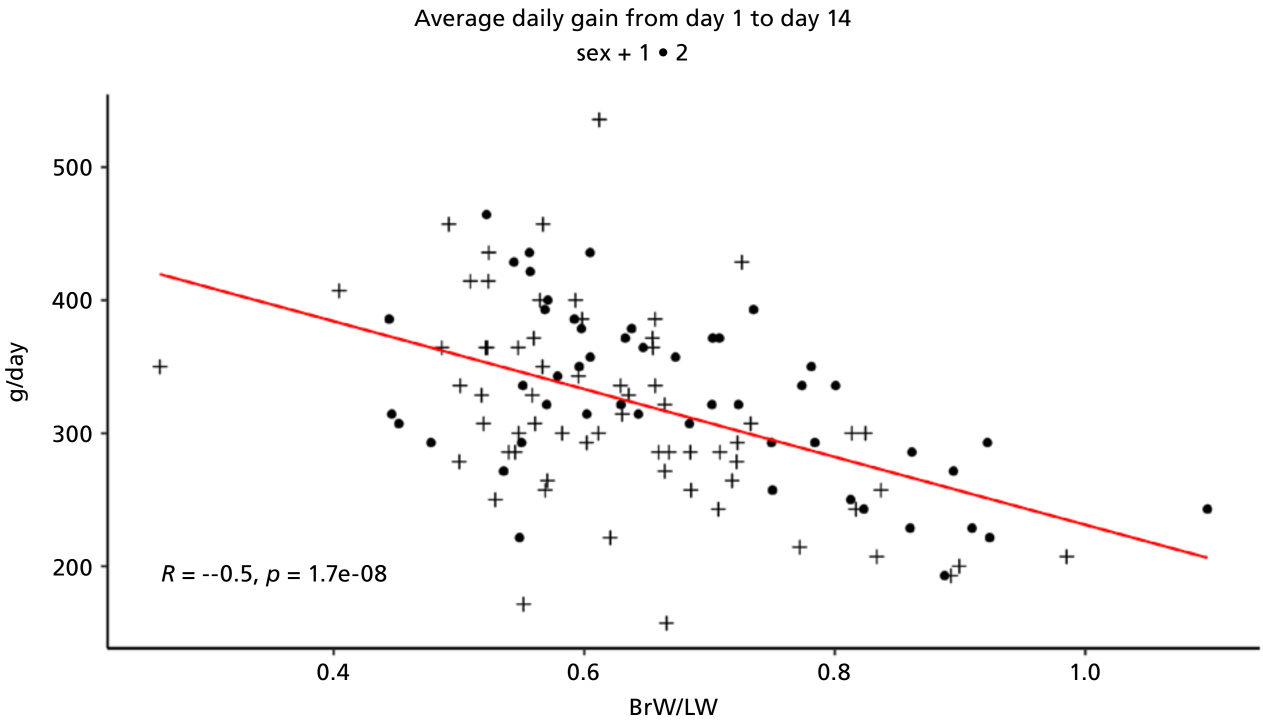
Graph 3 | Effect of brain weight-to-liver weight ratio and sex (1, 2) on body weight at day 14 of the trial. Abbreviations: BrW/LW = brain-to-liver weight ratio; 1 = castrate; 2 = female; CON = control group; TRT = treated group.



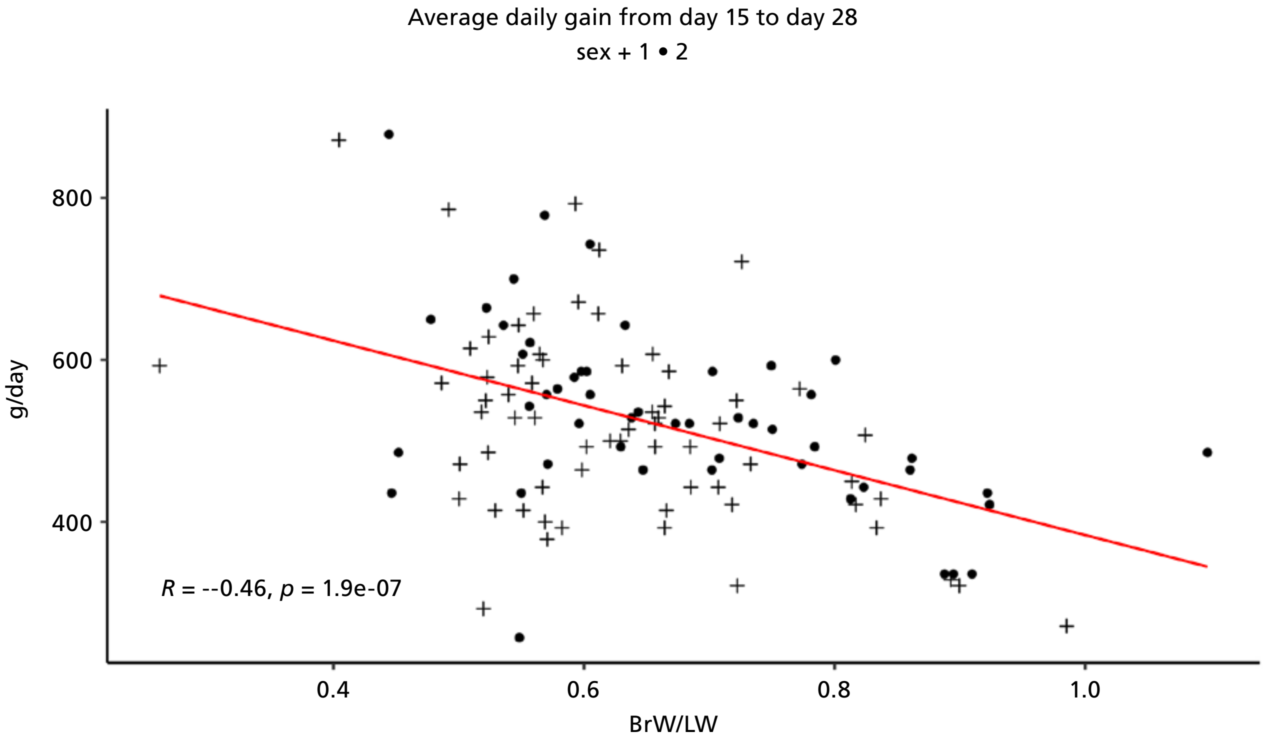
Graph 4 | Effect of brain weight-to-liver weight ratio and sex (1, 2) on body weight at day 28 of the trial. Abbreviations: BrW/LW = brain-to-liver weight ratio; 1 = castrate; 2 = female; CON = control group; TRT = treated group.



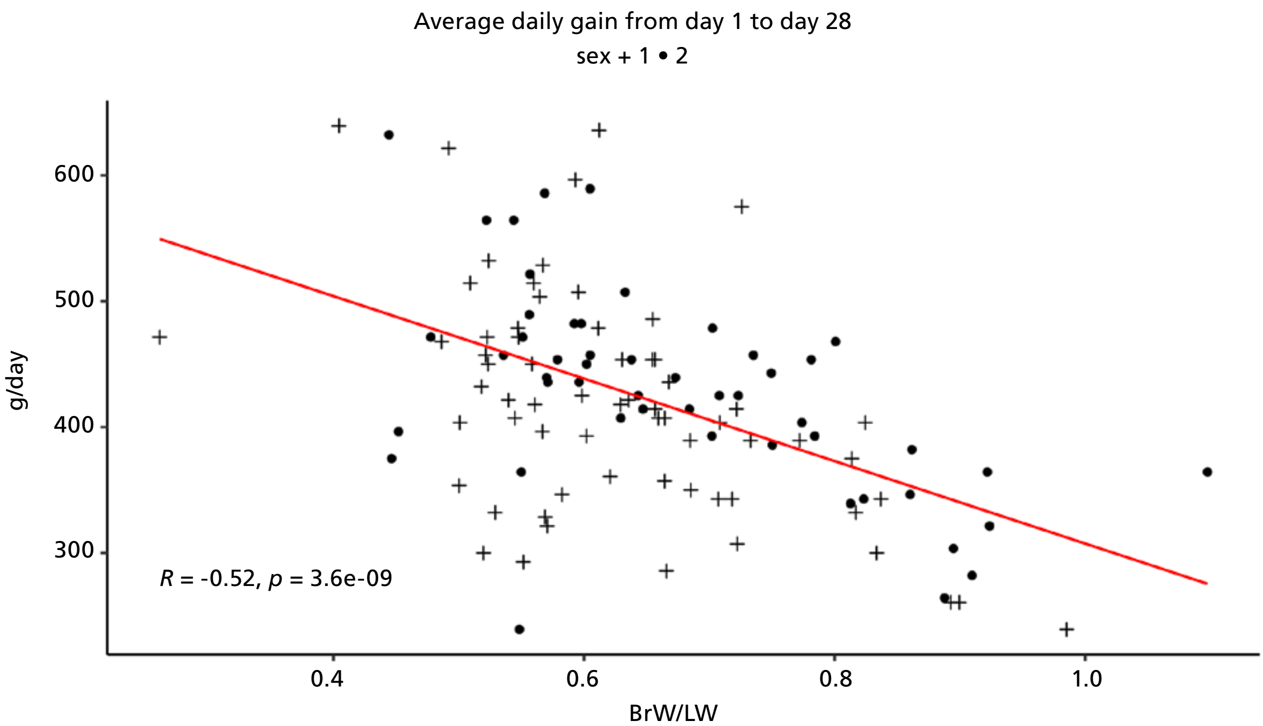
Graph 5 | . Effect of brain weight-to-liver weight ratio and sex (1, 2) on average daily gain (ADG) from weaning to the start of the trial. Abbreviations: Abbreviations: BrW/LW = brain-to-liver weight ratio; 1 = castrate; 2 = female.



Graph 6 | Effect of brain weight-to-liver weight ratio and sex (1, 2) on average daily gain (ADG) from day 1 (start of the trial) to day 14 of the trial. Abbreviations: BrW/LW = brain-to-liver weight ratio; 1 = castrate; 2 = female.



Graph 7 | . Effect of brain weight-to-liver weight ratio and sex (1, 2) on average daily gain (ADG) from day 15 to day 28 of the trial. Abbreviations: BrW/LW = brain-to-liver weight ratio; 1 = castrate; 2 = female; CON = control group; TRT = treated group.



Graph 8 | Effect of brain weight-to-liver weight ratio and sex (1, 2) on average daily gain (ADG) from day 1 (start of the trial) to day 28 of the trial. Abbreviations: BrW/LW = brain-to-liver weight ratio; 1 = castrate; 2 = female; CON = control group; TRT = treated group.

Discussion

The results of this study indicate that supplementation of starter diets with probiotics, mid-chain triglycerides, and antioxidants significantly enhances the growth performance of both heavy and light pigs. The TRT group exhibited a higher BW and ADG by day 28 of the trial compared to the CON group, demonstrating the efficacy of the supplemented diet in promoting better growth outcomes. This improvement is consistent with previous research suggesting the benefits of probiotics (Li et al., 2018; Pu et al., 2020) and nutritional supplements, such as mid-chain triglycerides (Zhang et al., 2016) and antioxidants (Feng et al., 2018), in enhancing gut health and overall growth performance in piglets.

However, regardless of dietary treatment, pigs that were light at weaning consistently exhibited lower BW and ADG from day 1 to day 28 of the trial compared to their heavy counterparts. Similarly, there was a negative correlation between the BrW/LW and both BW and ADG at all time points. Pigs with a higher BrW/LW, indicative of more severe IUGR, had poorer growth outcomes, in agreement with the existing literature on the consequences of IUGR in pigs (Alvarenga et al., 2013; Ruggeri et al., 2024a; Santos et al., 2022).

The growth improvements observed in TRT pigs suggest that the supplemented diet may help mitigate some adverse effects of low BW and IUGR, although it does not completely overcome the growth limitations associated with these conditions. Even though TRT diets enhanced growth, the persistent differences between light and heavy pigs and the worse performance in pigs with a high BrW/LW indicate that more targeted strategies might be necessary to comprehensively address the specific needs of IUGR-affected pigs.

Conclusion

In conclusion, while dietary supplementation with probiotics, mid-chain triglycerides, and antioxidants has shown promise in improving the growth performance of piglets, the ongoing challenges faced by lightweight and IUGR piglets necessitate further research. Future studies should explore additional or alternative interventions that could more effectively support the growth and development of IUGR-affected piglets, ultimately enhancing the overall efficiency of pig production systems.

Acknowledgements

This research received funding from the European Union's Horizon 2020 research and innovation programme under a Marie Sklodowska-Curie grant (agreement no. 955374).
The authors thank the animal caretakers from the piggery of UFA, Hendschiken, for their technical support.

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