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High levels of standardized ileal digestible amino acids improve feed efficiency in slow-growing pigs at late grower-finisher stage

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Abstract

Slow-growing pigs negatively affect production efficiency in conventional pig farms by increasing the occupation time of the facilities and being a limiting factor for the All-In/All-Out swine production systems. This subset of pigs is usually managed with the rest of the pigs, and their nutrient requirements may not be fulfilled. The purpose of the present study was to compare the productive performance of slow- and fast-growing pigs to different standardized ileal digestible (SID) amino acids (AA) dietary levels at late grower–finisher stage. A total of 84 pigs were weighed, tagged, and classified as slow-growing (SG; $n = 48$; 24.1 ± 1.38 kg) or fast-growing pigs (FG; $n = 36$; 42.7 ± 1.63 kg) at 11 weeks of age. Pigs were housed in mixed sex pens ($n = 8$ SG+6 FG/pen) equipped with feeding stations to record daily feed intake per individual pig. Pigs were assigned to three dietary treatments resulting in a 2 × 3 factorial arrangement at 15 weeks of age. Isoenergetic diets were formulated by increasing the ideal protein profile based on the following SID lysine (Lys) levels: 0.92%, 1.18% and 1.45%. Pigs were weighed bi-weekly until 21 weeks of age. Fast-growing pigs were 33.7 kg heavier, gained 255 g/day and consumed 625.5 g/day more than SG pigs ($p < 0.001$). No interaction or diet effects were observed for final body weight, average daily gain and average daily feed intake ($p > 0.05$). However, feed conversion ratio was 0.3 lower for SG pigs fed 1.45% SID Lys/AA compared to SG pigs fed 0.92% SID Lys/AA ($p = 0.002$). Feed conversion ratio was not different within the FG pigs' dietary treatments ($p > 0.05$). The efficiency of SG pigs may be improved when dietary SID AA levels are increased from 0.92 up to 1.45% SID Lys/AA. Thus, nutrient requirements may vary depending on growth rate at the same age, and SG pigs may require higher dietary SID AA levels than FG pigs to achieve similar productive performance.

KEYWORDS
growth performance, growth rate, lysine, pig, requirements, swine

1 | INTRODUCTION

Pigs that, at the same age, are smaller than the rest of the batch and require additional time to be sent to slaughter in conventional pig farms are often referred to as slow-growing (SG) pigs (Collins et al., 2017; Douglas Edwards et al., 2014a; Douglas et al., 2014; He et al., 2016). It is estimated that between 10% and 12.5% of pigs on a given batch are SG pigs (Calderón Díaz, Diana, et al., 2017; Camp Montoro et al., 2020; He et al., 2016). This subset of pigs increases weight heterogeneity within batch (Fix et al., 2010; López-Vergé et al., 2018a; Paredes et al., 2012) and poses a management challenge to pig producers because it increases the occupation time of the facilities and makes All-In/All-Out difficult to implement in swine production systems (Calderón Díaz, Diana, et al., 2017; Patience et al., 2004). Moreover, SG pigs are prone to have high mortality rates (Calderón Díaz, Boyle, et al., 2017; Larriestra et al., 2006; Muns et al., 2016) and may spread disease in a farm if they are deferred to the subsequent batch of pigs (Calderón Díaz, Diana, et al., 2017). Furthermore, SG pigs are associated with increased risk of carcass penalties in the abattoir as a result of higher fat content due to prolonged time in the facilities to reach the target slaughter weight (Gondret et al., 2006; He et al., 2016; Rehfeldt et al., 2008). The extended occupation time in the farm facilities leads to increased feed costs and to produce fewer pigs per place per year, impacting the efficiency of the production cycle and farm's profitability (Douglas Edwards et al., 2014a; Douglas et al., 2014; López-Vergé et al., 2018a; Patience et al., 2004).

The continuous genetic advancement in pig production has led to increased litter size at birth resulting in increased numbers of light birth weight piglets (Beaulieu et al., 2010; Quiniou et al., 2002). Those pigs are at high risk of being SG pigs considering that birth body weight (BW) is one of the most critical factors for postnatal performance (Douglas et al., 2013; He et al., 2016). Moreover, weaning BW has been indicated as a critical factor for lifetime post-weaning growth performance (Collins et al., 2017; Smith et al., 2007; Wolter & Ellis, 2001) and low weaning BW has also been related to SG pigs (Camp Montoro et al., 2020). Nevertheless, previous studies reported that SG pigs can exhibit compensatory growth and partially catch up with their big counterparts (Douglas et al., 2013; López-Vergé et al., 2018b). Thus, there has been an increasing amount of literature assessing management and/or nutritional strategies to improve the slow-growing pigs' performance over the production cycle, mostly focused at nursery (Douglas et al., 2014; Huting et al., 2019; Vieira et al., 2015) and the beginning of the grower–finisher phase (Aymerich et al., 2020; Douglas, Edwards, & Kyriazakis, 2014b). In addition, few studies have shown effects on the growth of slow-growing pigs during the grower–finisher phase by carrying out phase feeding strategies based on a weight basis or equivalent feed consumption instead of age (Hawe et al., 2020; López-Vergé et al., 2018b).

There is a growing body of literature that recognizes that SG pigs are as feed efficient as their big counterparts (Camp Montoro et al., 2020; Collins et al., 2017; Paredes et al., 2014). An important question is whether SG pigs' feed efficiency could be improved by increasing the standardized ileal digestible (SID) amino acids (AA) dietary levels based on the ideal protein profile during the grower-finisher stage. Standard nutritional tables (De Blas et al., 2013; NRC, 2012; PIC, 2016) have previously established the SID AA requirements for the average grower–finisher pig; however, there is no information regarding specific SID AA requirements for the SG pigs. Aymerich et al. (2020) observed that SG pigs may use more efficiently high dietary SID lysine (Lys) levels based on the ideal protein profile compared to fast-growing (FG) pigs. However, it is not clear yet at which SID Lys/AA levels the SG pigs maximize their performance. Understanding how productive performance is affected by increasing the dietary SID Lys/AA levels on SG and FG pigs may help pork producers to make better management and feeding strategies.

In the present study, we hypothesized that SG pigs would have an improved productive performance in response to an increase of the dietary SID Lys/AA levels, while FG pigs would show a saturated response, in a high sanitary status farm. Therefore, the aim of the study was to compare the productive performance of SG and FG pigs to an increase of dietary SID Lys/AA levels in isoenergetic diets at late grower-finisher stage.

2 | MATERIALS AND METHODS

2.1 | Animals, diets and experimental design

The experiment received ethical approval from the Teagasc Animal Ethics Committee (TAEC 204/2018) and it was conducted at the Teagasc Pig Research Facility in Fermoy, Co. Cork, Ireland. A total of 421 pigs born within 1 week were followed per pen as intact litters from birth until 11 weeks of age. Pigs were weaned at approximately 28 days and received a starter diet [20.0% crude protein (CP), 12.3 MJ of net energy (NE) and 1.40% SID Lys per kg of feed] for 7 days, link diet (19.0% CP, 11.0 MJ/NE and 1.28% SID Lys per kg of feed) for 18 days and soya bean meal–barley–wheat-based nursery diet (17.8% CP, 10.6 MJ/NE and 1.04% SID Lys per kg of feed) for 28 days. At 11 weeks of age, a total of 84 pigs [48 females and 36 males; Danish Duroc × (Large White ×Landrace)] out of 324 pigs were weighed, ear tagged individually and classified by growth rate as SG (n = 48; 24.1 ± 1.38 kg) or FG pigs (n = 36; 42.7 ± 1.63 kg). Criteria selection was based on the upper and lower quartile of the BW population distribution from the batch of pigs used for this study. Pigs were matched according to gender, litter size, and pen of origin. At 11 weeks of age, pigs were moved to the finisher accommodation and they were housed in 6 mixed sex pens (n = 14 pigs per pen; 0.81 m^2/pig) with fully slatted plastic floor equipped with one nipple drinker and individual feeding stations (MLP-ECO, ASR 500, Schauer) to record daily individual feed intake. Water and pelleted feed were provided ad libitum. Temperature was controlled by a mechanical ventilation system with fan speed and air inlet area regulated by a climate controller. Pens were enriched with a larch wood post. Pigs were fed ad libitum a soya bean meal–maize–wheat-based finisher diet (16.2% CP, 9.7 MJ/NE and 0.92% SID Lys per kg of feed) from 11 to 15 weeks of age. Pigs were assigned to three different dietary treatments in a 3 × 2 factorial arrangement at 15 weeks of age. Diet and growth rate (SG or FG) were considered as fixed factors, and pig as the experimental unit. Each diet was assigned to two pens, each pen containing 8 SG (40.1 ± 1.72 kg) and 6 FG (63.2 ± 2.04 kg) pigs. Diets were formulated by increasing the ideal protein profile (van Milgen & Dourmad, 2015) based on the following SID Lys levels: 0.92%, 1.18% and 1.45% (Table 1). All three diets were isoenergetic (9.68 MJ/kg NE) based on wheat, maize and soya bean meal, and were formulated to meet or exceed the minimum nutrient requirements (NRC, 2012). Shown in Table 1 are the analysed compositions of selected nutrients contained in the three experimental diets. The experiment finished at 21 weeks of age when FG pigs were sent to slaughter after reaching target slaughter weight which was set at 110 kg of BW as per normal practice in Irish pig farms.

2.2 | Feed analysis

Feed samples of each diet were collected from the feeders and analysed for dry matter, crude ash, crude protein, crude fibre and fat at the Dairy Gold Feed Laboratory (Lombardstown, Co. Cork,Ireland). Dry matter was determined by oven drying for 4 h at 103°C (Thiex, 2009). Crude ash was determined via combustion in a muffle furnace at 550°C (Thiex et al., 2012). Crude protein was determined as N × 6.25 using the Automated Kjeldahl method (Thiex et al., 2002). Crude fibre was measured by a Fibertec semi-automatic system using the gravimetric method (Thiex, 2009). Fat was determined using light petroleum ether and Soxtec instrumentation (Thiex, 2009). Total AA profile was analysed based on high performance liquid chromatography technique (Otter, 2012) at the Sciantec Analytical Services (Stockbridge Technology Centre, Cawood,Yorkshire, UK).

2.3 | Body weight, feed intake and feed efficiency traits

Pigs were individually weighed using a digital scale (R323, Rinstrum, Langenfeld, Germany) every 2 weeks from 15 to 21 weeks of age. Feed intake was recorded individually on a daily basis. Average daily gain (ADG), average daily feed intake (ADFI) and feed conversion ratio (FCR; $\frac{\text{kg of feed consumed}}{\text{kg of BW gain}}$) were calculated for every 2 weeks interval. Average daily feed intake was multiplied by the NE density of the diet to calculate the energy intake (EI; MJ NE/day). Moreover, metabolic BW (MBW) was calculated for each animal as $BW^{0.6}$ (Noblet et al., 1999; NRC, 2012). Finally, three feed efficiency ratio traits were calculated based on Calderón Díaz, Berry, et al. (2017):

Relative growth rate (RGR):

$$100 \times \left[(\log10\,\text{BW at end of trial} - \log10\,\text{BW at start of trial}) / (\text{age at end of trial} - \text{age at start of trial})\right]$$

Kleiber ratio (KR), which relates ADG to the cost of maintenance energy:

$$\text{KR} = \text{ADG}/\text{MBW}$$

Energy conversion ratio (ECR):

$$\text{ECR} = \text{EI}/\text{ADG}$$

2.4 | Data management and statistical analysis

Each pig was considered as the experimental unit for all data analyses. All analyses were carried out using SAS v9.4 (SAS Institute Inc., Cary, NC, USA). Data were tested for normality using the Shapiro–Wilk test and by examining the normal probability plot. The analysed model included diet, growth rate group and their interaction, and sex as fixed effects, and pig as random effect. Models for BW, ADG, ADFI, FCR, MBW, EI, RGR, KR and ECR variables were analysed using general linear mixed model accounting for repeated measurements in PROC MIXED of SAS v9.4 (SAS Institute Inc., Cary, NC, USA). Multiple means comparisons were done using Tukey–Kramer's correction in all cases. Alpha level for determination of significance was 0.05, and trends were identified as alpha of 0.10. Results for fixed effects are reported as least square means ± SEM.

3 | RESULTS

Final BW, ADG and ADFI did not show an interaction or diet effect during the whole period of the trial (all $p > 0.05$; Table 2). Nevertheless, FG pigs were 33.7 kg heavier than SG pigs at 21 weeks of age ($p < 0.001$; Table 2). Moreover, FG pigs gained 255 g more per day ($p < 0.001$) and consumed 625.5 g more per day ($p < 0.001$) than SG pigs from 15 to 21 weeks of age (Table 2). Feed conversion ratio showed an interaction tendency between SID Lys/AA dietary treatments and growth rate group. Feed conversion ratio was 0.3 lower for SG pigs fed the 1.45% SID Lys/AA dietary treatment compared to the SG pigs fed the 0.92% SID Lys/AA dietary treatment ($p = 0.002$; Figure 1); however, FCR did not differ within the FG pigs fed with the different SID Lys/AA dietary treatments ($p > 0.05$; Figure 1).

Final MBW and EI did not show an interaction or diet effect during the whole period of the trial (all $p > 0.05$; Table 3). However, FG pigs had 3.3 kg of MBW more than SG pigs at 21 weeks of age ($p < 0.001$; Table 3), and FG pigs had an EI of 6 MJ NE/day more than SG pigs from 15 to 21 weeks of age ($p < 0.001$; Table 3). The KR did not differ between treatments from 15 to 21 weeks of age ($p > 0.05$; Table 3). Nevertheless, RGR was 0.10 higher for SG pigs compared to FG pigs ($p < 0.001$; Table 3). Moreover, ECR showed an interaction tendency between SID Lys/AA dietary treatments

TABLE 1 Ingredients and calculated and analysed nutrient composition on an as-fed basis of the three dietary treatments fed in grower-finisher pigs from 15 to 21 weeks of age

	Diets		
	0.92% SID Lys/AA	1.18% SID Lys/AA	1.45% SID Lys/AA
Ingredients, g/kg			
Wheat	435.0	318.5	310.0
Maize	300.0	370.0	360.0
Soya bean meal 48	171.0	210.0	220.0
Soya bean hulls	71.0	70.0	68.0
Vegetable oil	0.00	0.90	0.80
Calcium carbonate	11.0	11.0	11.0
Dicalcium phosphate anhydrous	1.00	1.00	1.00
Sodium chloride	3.00	3.00	3.00
L-Lysine HCl	3.75	5.90	9.10
L-Threonine	1.70	3.10	4.95
DL-Methionine	0.93	1.63	2.53
L-Tryptophan	0.15	0.60	1.05
L-Valine	0.00	1.30	3.10
L-Arginine	0.00	1.60	4.00
Vitamin and trace mineral mixture[a]	1.47	1.47	1.47
Calculated / Analysed Composition, % as fed or as specified			
Dry matter, analysed	88.10	87.70	87.70
NE, MJ/kg	9.67	9.68	9.70
Crude protein, analysed	15.90	17.60	18.30
Total Lys, analysed	1.02	1.22	1.44
Total Thr/Lys ratio, analysed	0.70	0.70	0.73
Total Met/Lys ratio, analysed	0.32	0.32	0.33
Total Trp/Lys ratio, analysed	0.13	0.13	0.14
Total Val/Lys ratio, analysed	0.67	0.67	0.68
Total Arg/Lys ratio, analysed	0.89	0.82	0.73
Total Lys	1.03	1.29	1.57
SID Lys	0.92	1.18	1.45
SID Thr/Lys ratio	0.70	0.70	0.70
SID Met/Lys ratio	0.34	0.34	0.34
SID Trp/Lys ratio	0.19	0.19	0.19
SID Val/Lys ratio	0.69	0.69	0.69
SID Arg/Lys ratio	0.96	0.96	0.96
Fat, analysed	2.70	2.90	2.50
Crude fibre, analysed	4.10	4.40	4.00
NDF	14.60	14.30	14.10
Calcium	0.68	0.69	0.69
Digestible phosphorus	0.23	0.23	0.23
SID Lys:NE, g/MJ	0.95	1.21	1.50

Abbreviations: NE, net energy; NDF, neutral detergent fibre; SID, standardized ileal digestible.

[a]Provided per each kg of feed: 60 mg Copper sulphate, 80 mg Ferrous sulphate monohydrate, 50 mg Manganese oxide, 100 mg Zinc oxide, 0.5 mg Potassium iodate, 0.4 mg Sodium selenite, 2 MIU Vitamin A, 0.5 MIU Vitamin D_3, 40 MIU Vitamin E, 4 mg Vitamin K, 0.015 mg Vitamin B_{12}, 2 mg Riboflavin, 12 mg Nicotinic acid, 10 mg Pantothenic acid, 2 mg Vitamin B_1, 3 mg Vitamin B_6.

TABLE 2 Effect of increasing the standardized ileal digestible lysine based on the ideal protein profile (SID Lys/AA) on final body weight (BW), average daily gain (ADG) and average daily feed intake (ADFI) (least square means ± SEM) from 84 grower–finisher pigs grouped by diet and growth rate from 15 to 21 weeks of age

	0.92% SID Lys/AA		1.18% SID Lys/AA		1.45% SID Lys/AA			*p*-value		
Trait	SG	FG	SG	FG	SG	FG	SEM	Growth rate	Diet	Interaction
BW, kg										
15 weeks	41.0	64.2	39.5	61.7	39.7	63.6	1.88			
21 weeks	79.0[b]	111.8[a]	77.2[b]	111.3[a]	78.5[b]	112.9[a]	1.89	<0.001	0.712	0.953
ADG, g	910.0[b]	1149.7[a]	910.9[b]	1183.6[a]	951.4[b]	1204.1[a]	32.05	<0.001	0.335	0.873
ADFI, g	2073.3[b]	2618.6[a]	1952.3[b]	2527.0[a]	1936.8[b]	2696.1[a]	89.07	<0.001	0.463	0.440

Abbreviations: SG, slow growth rate; FG, fast growth rate.
[a,b]Within rows, significant differences between groups ($p < 0.05$).

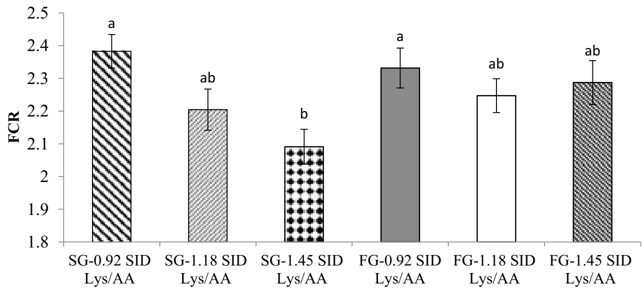

FIGURE 1 Effect of increasing the standardized ileal digestible lysine based on the ideal protein profile (SID Lys/AA) on feed conversion ratio (FCR) from 84 grower–finisher pigs grouped by growth rate (SG, slow-growing; FG, fast-growing) and diet (0.92%, 1.18%, 1.45% SID Lys/AA) from 15 to 21 weeks of age. [a,b]Significant differences between treatments ($p < 0.05$)

and growth rate group. Energy conversion ratio was 2.7 lower for SG pigs fed the 1.45% SID Lys/AA dietary treatment compared to the SG pigs fed the 0.92% SID Lys/AA dietary treatment ($p = 0.003$; Table 3); however, ECR did not differ within the FG pigs fed with the different SID Lys/AA dietary treatments ($p > 0.05$; Table 3).

4 | DISCUSSION

Birth and weaning body weight are two of the most critical factors affecting productive performance (Collins et al., 2017; Douglas et al., 2013; He et al., 2016). Slow-growing pigs have been related to a low birth and weaning BW (Camp Montoro et al., 2020; Douglas et al., 2013), although they can exhibit several degrees of compensatory growth and partially catch up with their big counterparts (Douglas et al., 2013; López-Vergé et al., 2018b). Knowing that slow-growing pigs have a lower feed intake, but are as feed efficient as their big counterparts, Camp Montoro et al. (2020), set the basis for our hypothesis that slow-growing pigs' performance may be improved by increasing the dietary SID Lys/AA levels in the late grower-finisher stage. It is worth to mention that the present study has been carried out in a high sanitary status farm and selected fast- and slow-growing pigs were in good health conditions, although we cannot rule out subclinical issues in some individuals. The latter could be a reason for slow growth due to low health conditions which may affect specific amino acid requirements of the pigs such as methionine, threonine and tryptophan (van der Meer et al., 2016), and the efficiency of nitrogen utilization for body protein deposition (van der Meer et al., 2020). Nevertheless, the increased dietary SID Lys/AA levels should be helpful in case of pigs with subclinical issues.

Fast-growing pigs weighed, gained and consumed considerably more than slow-growing pigs, which is in line of previous studies (Camp Montoro et al., 2020; Douglas et al., 2013; He et al., 2016) and states the importance of the slow-growing pigs' management to reduce the body weight variability within a batch (López-Vergé et al., 2018a). Although fast-growing pigs gained much more than slow-growing pigs, slow-growing pigs had a high relative growth rate during the trial period. This finding is in accordance with previous literature and further supports the idea that relative growth rate tends to be greater in lighter body weight animals, although it does not necessarily mean that those pigs are more efficient (Calderón Díaz, Berry, et al., 2017). Nevertheless, slow-growing pigs improved their feed and energy conversion ratio when dietary SID AA levels were increased from 0.95% to 1.45% SID Lys/AA, while no improvement was observed in the fast-growing pigs. The Kleiber ratio did not differ between growth rates which means that both fast- and slow-growing pigs have the same growth for the same cost of energy maintenance (Tedeschi et al., 2006). Therefore, a possible explanation for the slow-growing pigs' improvement in terms of feed efficiency may rely on that nutrient requirements were better matched in the 1.45% than the 0.92% SID Lys/AA diet due to their body weight or physiological stage, while fast-growing pigs' nutrient requirements are already matched in the 0.92% SID Lys/AA diet (López-Vergé et al., 2018b). So, increasing the SID AA levels in the diet of slow-growing pigs may match better their nutrient requirements optimizing their protein deposition and feed efficiency.

Although SID Lys/AA levels used in the present study differ from other studies, Aymerich et al. (2020) pointed out that slow-growing pigs may improve their growth performance by increasing from 0.80% to 1.20% the dietary SID Lys levels in isoenergetic diets,

TABLE 3 Effect of increasing the standardized ileal digestible lysine based on the ideal protein profile (SID Lys/AA) on final metabolic body weight (MBW), energy intake (EI), relative growth rate (RGR), Kleiber ratio (KR) and energy conversion rate (ECR) (Least square means ± SEM) from 84 grower–finisher pigs grouped by diet and growth rate from 15 to 21 weeks of age

	0.92% SID Lys/AA		1.18% SID Lys/AA		1.45% SID Lys/AA			*p*-value		
Trait	SG	FG	SG	FG	SG	FG	SEM	Growth rate	Diet	Interaction
MBW, kg										
15 weeks	9.3	12.1	9.1	11.9	9.1	12.1	0.21			
21 weeks	13.7[b]	17.0[a]	13.6[b]	16.9[a]	13.7[b]	17.1[a]	0.21	<0.001	0.757	0.964
EI, MJ NE/day	20.1[b]	25.3[a]	19.0[b]	24.5[a]	18.8[b]	26.2[a]	0.86	<0.001	0.466	0.433
Ratio feed efficiency traits										
RGR	0.69[a]	0.58[b]	0.70[a]	0.61[b]	0.72[a]	0.61[b]	0.02	<0.001	0.221	0.828
KR	74.2	74.8	75.2	78.0	78.1	78.3	1.82	0.422	0.140	0.768
ECR	23.0[a]	22.5[a]	21.3[a,b]	21.8[a,b]	20.3[b]	22.2[a,b]	0.56	0.187	0.017	0.107

Abbreviations: FG, fast growth rate; SG, slow growth rate.

[a,b]Within rows, significant differences between groups ($p < 0.05$).

while fast-growing pigs showed a saturated response to increased dietary SID Lys levels from 28 to 63 kg of body weight. Nonetheless, this finding is contrary to that of Douglas et al. (2014b), who found that slow-growing pigs failed to improve their performance increasing the total Lys dietary levels from 0.98% to 1.48% during the first 30 days post-weaning period. It is difficult to explain this discrepancy, but it might be related to the experimental design itself and the management of the pigs during the lactation period where all the pigs in the study were cross-fostered into a litter according to their birth weight within the first 48 h, reducing limiting factors such as competition for access to teats during suckling, and receiving also supplementary milk. This management could have had a post-weaning effect, not observed when pigs are kept in intact litters. Other reasons may be an unbalanced AA diet when increasing SID Lys to such levels, or the sanitary conditions of the farm where the study was carried out. Low sanitary conditions and subclinical infections may affect the amino acids requirements and efficiency of protein deposition in pigs (van der Meer et al., 2016, 2020). Despite that study of Douglas et al. (2014b), other studies carried out during the nursery period also observed that high specifications diets targeted to slow-growing pigs improved their productive performance (Beaulieu et al., 2010; Douglas et al., 2014).

Taken together the results from the present study and the ones from previous studies (Aymerich et al., 2020; Beaulieu, Aalhus, et al., 2010; Douglas et al., 2014), it can therefore be assumed that the slow-growing pigs may require higher SID Lys/AA requirements than previous established for average grower–finisher pigs (De Blas et al., 2013; NRC, 2012; PIC, 2016). Therefore, the present study suggests that requirements for pigs are different depending on the growth rate at the same age, and further research should be undertaken to assess and establish the nutrient requirements for those pigs with reduced growth rate. The scope of this study was limited in terms of number of treatments and several questions remain unanswered as for example which is the plateau where slow-growing pigs achieve their maximum performance.

Despite the fact that slow-growing pigs were more efficient when increasing the dietary SID AA levels, final body weight and average daily gain were only numerically different from other slow-growing pigs' dietary treatments. This may be explained by the fact that total growth is mainly related to feed intake, while lean deposition, which highly affects feed efficiency, is more related to feed composition and total amino acids' supply (Patience et al., 2015). López-Vergé et al. (2018b) investigated a feed management strategy for the slow-growing pigs based on changing the feeds on the basis of an equivalent feed consumption to the average pigs, instead of age, during the whole grower–finisher period. With this strategy based on feeding the diets in terms of feed consumption and body weight, slow-growing pigs increased their growth rate and partially catch up with their big counterparts, decreasing the variability within the batch. Future research might explore the application of high specific diets and/or the accuracy in feeding management to the slow-growing pigs starting from the nursery or the beginning of the grower-finisher period, giving time to this subset of pigs to partially catch up their big counterparts by fulfilling their nutrient requirements.

Noteworthy, increasing the protein diet to such levels may increase the levels of NH_3 and affect the environment and farm sustainability (Lee et al., 2020; Liu et al., 2015). Then, to reach the described levels of SID Lys/AA may not be feasible, although the environmental impact could be minimized by formulating diets using synthetic amino acids which allows to reduce the crude protein levels while maintaining the nutrient requirements, performance and carcass quality (Prandini et al., 2013). Moreover, it would be crucial but challenging to identify the slow-growing pigs early in life (Camp Montoro et al., 2020) and re-grouping them in separated pens with a tailored management/nutritional strategy. Although mixing may have a negative effect on productive performance (Camp Montoro et al., 2021), high specification diets from weaning onwards may improve the slow-growing pigs' productive performance (Aymerich et al., 2020; Beaulieu, Aalhus, et al., 2010; Douglas et al., 2014). Ultimately, further studies could be focused on undertaking an economic assessment of the cost/gain of the slow-growing pigs fed with high specification diets to have a better knowledge of its worthy and feasibility in commercial diets.

5 | CONCLUSION

This study set out to compare the productive performance between slow- and fast-growing pigs to different levels of dietary SID AA in isoenergetic diets at late grower-finisher stage. Slow-growing pigs' feed efficiency is improved when dietary SID AA levels are increased from 0.92% up to 1.45% SID Lys/AA. Such a response is not present in fast-growing pigs. Thus, nutrient requirements may vary depending on growth rate at the same age, and slow-growing pigs may require higher dietary SID AA levels than fast-growing pigs to present a better productive performance. Further work needs to be done to establish the nutrient requirements for slow-growing pigs and investigate new nutritional strategies towards slow-growing pigs.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

J.C.M, D.S.O and E.G.M conceived and designed the study. J.C.M collected the data. J.C.M and E.G.M analysed the data. J.C.M drafted the manuscript. E.G.M, D.S.O, R.M, J.G and N.L reviewed and edited the manuscript. E.G.M supervised the study. All authors have read and agreed to the published version of the manuscript.

ANIMAL WELFARE STATEMENT

This study received ethical approval from the Teagasc Animal Ethics Committee (TAEC 204/2018). The authors confirm that they have followed the European Union Directive 2010/63 on the protection of animals used for scientific purposes.

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