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RESEARCH ARTICLE

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Effect of environmental conditions and feed forms on the performance and feeding behavior of group-housed growing-finishing pigs

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Abstract

Aim of study: To investigate the influence of environmental conditions and feed forms on productivity and feeding behavior of growing-finishing pigs.

Area of study: Farm located in the North-East of Spain (42°03'11.0"N 2°06'59.5"E).

Material and methods: Two trials were conducted (n = 72 pigs each). In the Hot-Temperate/Pelleted trial (HT-P), pigs were half the time under hot conditions (average temperature Ta=28.1ºC) and half the time under thermoneutral conditions (Ta=25.5ºC) and were fed in pellet. In the Temperate-Hot/Mash trial (TH-M), pigs were half the time under thermoneutral conditions (Ta=23.5ºC) and half the time under hot conditions (Ta=27.3ºC) and were fed in mash. Productivity and feeding behavior were registered.

Main results: Hot conditions during the finishing period in TH-M trial reduced by 118 g/d growth rate and increased feed conversion ratio (2.28 vs. 2.07 kg/kg) compared to HT-P trial ($p < 0.001$) due to feed intake reduction. Growing pigs under hot conditions and fed in pellet increased total feeder visits (12.8 vs. 7.9 visits/d) and reduced visit size (147 vs. 230 g/visit, $p < 0.001$); whereas finishing pigs under hot conditions and fed in mash only tended to reduce visit size (308 vs. 332 g/visit, $p = 0.08$). Pigs fed with mash ate slower (22.8 vs. 34.8 g/min) than pelleted-fed pigs ($p < 0.001$), independently of environmental conditions.

Research highlights: Feed form and environmental conditions affect both feeding behavior and performance of growing-finishing pigs. Unfortunately, due to a design weakness, it was not possible to obtain the sharp effect of both factors.

Additional key words: feeder visits; feeding rate; heat stress; mash; visit size; pellet; time spent eating

Abbreviations used: ADFI (average daily feed intake); ADG (average daily gain); BW (body weight); FCR (feed conversion ratio); FR (feeding rate); HT-P (Hot-Temperate/Pelleted trial); MS (meal size); TD (total duration); THI (temperature humidity index); TH-M (Temperate-Hot/Mash trial); TV (total feeder visits); VS (visit size).

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Introduction

The feeding behavior of growing-finishing pigs may influence nutrient digestibility, performance and carcass traits (de Haer & de Vries, 1993a; Andretta et al., 2016; Carcò et al., 2018). Feeding behavior may be defined by variables such as average daily feed intake (ADFI), total number of feeder visits per day (TV), time spent eating per day (TD), visit size (VS) and feeding rate (FR) among others (de Haer & Merks, 1992). It is known that the feeding behavior of pigs is affected by many factors such as housing conditions (de Haer & de Vries, 1993a; Bornett et al., 2000), diet composition (Brouns et al., 1994), feed form (Li et al., 2017), ambient temperature (Quiniou et al., 2000), sex (Andretta et al., 2016) or age (Carcò et al., 2018). For instance, as pigs grow, ADFI, meal size (MS) and FR increase, whereas small variations or decreases in TV and TD have been reported with differences in the average and the evolution of those feeding behavior patterns among studies (Fornós et al., 2022).

On the other hand, it has been demonstrated that providing pelleted feed to pigs enhances pig performance compared to feeding the same diet in mash owing to an improvement in nutrient digestibility or a reduction in feed wastage (De Jong et al., 2016; Rojas & Stein, 2017; O'Meara et al., 2020). Moreover, an increase in the TD and feeder occupancy rate together with a reduction in the FR in pigs fed mash diets compared with pigs fed pelleted diets has been reported in the literature (Laitat et al., 2004; Li et al., 2017).

Pigs are highly susceptible to heat stress due to their limited number of sweat glands and high quantity of adipose tissue (Baumgard & Rhoads, 2013). Under heat stress, metabolic mechanisms to dissipate heat are activated and ADFI and pigs´ activity decrease (Quiniou et al., 2000; Collin et al., 2001; Le Bellego et al., 2002; Hyun, 2005). The ADFI reduction due to heat stress can increase with age and pig's body weight (BW) (Quiniou et al., 2000; Renaudeau et al., 2011). In fact, Le Bellego et al. (2002) reported a reduction of the ADFI by 260 and 540 g/d in growing and finishing pigs, respectively, when temperature increased from 22 to 29°C, and Dos Santos et al. (2018) reported a reduction of the ADFI by 640 and 700 g/d in growing and finishing pigs, respectively, when temperature increased from 23 to 30°C. Moreover, changes in the feeding behavior due to hot conditions have been observed in young and growing-finishing pigs that could explain part of the negative impact of heat stress on pig performance (Quiniou et al., 2000; Collin et al., 2001; Nyachoti et al., 2004). A reduction in the TD and MS have been reported in finishing pigs under heat stress (Quiniou et al., 2000; Serviento et al., 2020). Young pigs under high temperatures reduced their TD by 34% and their MS by 32% (Collin et al., 2001), whereas heavier pigs reduced their TD by 28% and their TV by 20% (Quiniou et al., 2000). However, few studies have been published regarding the effect of heat stress on the feeding behavior of growing-finishing pigs during a long period of time and under commercial conditions.

Therefore, the present work investigates the combined effect of environmental conditions and feed forms on the performance and the evolution of the feeding behavior of group-housed growing-finishing pigs.

Material and methods

Experimental design

Two trials were conducted on the same farm, located in the North-East of Spain (Perafita, Barcelona), in two consecutive years (2018 and 2019). The trials were originally designed to study the effect of feed form on the performance and the feeding behavior. For this reason, the same diet was fed in pellet form in one trial and in mash form in the other trial. However, as these two trials were conducted at two different times of year with different environmental conditions (temperature and relative humidity) inside the barn, this was considered as an additional main factor in this study. Consequently, this study examined two combinations of feed forms and environmental conditions, however it was unable to distinguish between the two factors. In the first trial, pigs were fed in pellets and the trial started in June (average temperature Ta=28.9ºC) and finished in October (Ta=23.3ºC) (124 days; Hot-Temperate/Pelleted trial, HT-P). In the second trial pigs were fed in mash and the trial started in March (Ta=23.5ºC) and finished in July (Ta=28.1ºC) (119 days; Temperate-Hot/Mash trial, TH-M).

Animals, housing conditions and diets

A total of 72 crossbred Pietrain × (Landrace × Large White) pigs, 60 ± 3 days old, coming from the same nursery facilities, were used in each trial and were grouped in six non-mixed sex pens of 12 pigs each (16.5 ± 0.91 and 17.9 ± 0.70 kg BW, mean ± SD in HT-P and TH-M trials, respectively). Animals were distributed in two pens of intact males and four pens of females in the HT-P trial and four pens of intact males and two pens of females in the TH-M trial. Each pen (12 m^2) was equipped with an automatic feeding system (Nedap ProSense®, The Netherlands), one nipple with water cup, totally slatted floor and open-air ventilation with automatic temperature probe-controlled curtains. The stocking density per pen was 0.89 m^2/pig, excluding the space occupied by the automatic feeding system. The first day of the experimental period all pigs were individually identified with an electronic ear tag. Pigs had ad libitum access to water and feed during all the trial. During the experimental period up to 15 pigs were discarded: an entire pen of 12 males due to caudophagia and two females due to lameness in trial HT-P, and one male due to respiratory disorders in trial TH-M.

In both trials, pigs were fed with a common diet in a 3-phase feeding program (Phase I, in the period from day 1 to day 39; Phase II, in the period from day 40 to day 83; and Phase III, in the period from day 84 to slaughter).

Ingredients and calculated composition of the feeds are described in Table 1.

Indoor ambient relative humidity and air temperature were registered every ten minutes throughout the experimental period with a data logger testo 175 H1 (Testo SE & Co. KGaA, Titisee-Neustadt, Germany). From these data the temperature humidity index (THI) was calculated for each day of the experimental period using the equation of Lallo et al. (2018), where T = Temperature in °C and RH = relative humidity in percentage:

$$THI\ (°C) = T_{max}°C - 0.55 - (0.0055*RH\ (T_{max}°C - 14.5))$$

THI was used to assign heat stress levels to four categories according to Marai et al. (2001): thermoneutral conditions (THI < 27.8), moderate (THI between 27.8 and 28.8), severe (THI between 28.9 and 29.9) and emergency zone (THI ≥ 30).

Table 1. Ingredients and calculated composition (as fed basis) of the feeds used for Phase I (in the period from day 1 to day 39), Phase II (in the period from day 40 to day 83) and Phase III (in the period from day 84 to slaughter).

	Phase I	Phase II	Phase III
Ingredient composition, %			
Corn	30.00	31.73	31.44
White sorghum	15.00	20.00	20.00
Soybean meal 47%	13.14	11.01	8.05
Wheat	16.57	15.00	15.00
Rice bran	6.00	8.00	8.00
Sunflower		2.42	5.00
Peas	15.00	8.00	8.00
Animal fat	1.01	0.50	1.00
Calcium carbonate	0.87	1.04	1.33
Monocalcium phosphate	0.42	0.35	0.31
Sodium chloride	0.50	0.45	0.50
Lysine sulphate	0.76	0.76	0.71
DL-Methionine	0.19	0.18	0.13
L-Threonine	0.18	0.22	0.18
L-Tryptophan	0.04	0.03	0.03
L-Valine	0.01		
Vitamine-mineral premix[1]	0.30	0.30	0.30
Calculated composition			
Dry matter, %	87.45	87.41	87.79
Net energy, kcal/kg	2454	2431	2437
Neutral detergent fiber, %	8.19	9.01	9.69
Starch, %	36.30	34.15	33.86
Crude fat, %	3.77	3.67	4.16
Crude protein, %	16.42	15.37	14.71
SID Lys[2], %	1.08	0.98	0.93
Total Ca[3]	0.58	0.63	0.74
STTD P[4], %	0.29	0.26	0.25

[1]6-phytase (500 FTU/kg). Provided per each kg of feed: 4,000 IU vitamin A, 800 IU vitamin D3, 10 IU vitamin E, 2.5 mg vitamin B2, 2.0 mg vitamin B6, 0.02 mg vitamin B12, 15 mg niacin, 10 mg pantothenic acid, 100 mg choline from choline chloride, 100 mg Zn from zinc oxide, 50 mg Mn from manganese oxide, 200 mg Fe from iron sulphate, 5 mg Cu from copper sulphate, 10 mg Cu from chelate of glycine hydrate, 0.2 mg Se from sodium selenite and 1.0 mg I from potassium iodide.[2]SID Lys: standardized ileal digestible lysine. [3]Total calcium: [4]STTD P: standardized total tract digestible phosphorus.

Performance

Individual performance was analyzed from day 0 of the growing-fattening period until 12 h before slaughter. Pigs were weighed individually on arrival at the farm (day 0 of the growing-finishing period), at the beginning of p1 (day 30 of the growing-finishing period) and 12 h before slaughter (day 124 of fattening for HT-P trial and day 119 of fattening for TH-M trial) with an external scale to calculate the average daily weight gain (ADG). Feed intake was recorded individually each time that the pig entered to the automatic feeding system. From these data ADFI and the feed conversion ratio (FCR) were calculated. Individual carcass traits were obtained in both trials at slaughtering (day 125 and day 120 of the experiment, for HT-P and TH-M trials, respectively). All pigs were slaughtered maintaining the individual traceability. Before the slaughtering process, pigs were stunned in a CO_2 chamber and then immediately exsanguinated in a vertical position. Hot carcass weight was measured and used to calculate carcass yield (%). Backfat thickness (mm), loin depth (mm) and lean percentage were recorded by a Fat-O-Meat'er probe (Frontmatec A/S, Herlev, Denmark) at the level of 3/4 last ribs, at 6 cm from midline one-hour post-mortem in the slaughterhouse.

Feeding behavior

After 30 days of adaptation to the automatic feeding system (0-30 days of the growing-finishing period), feeding behavior patterns were analyzed for 84 days in 6 periods of 14 days each, three periods for the growing period (p1-p2-p3) and three periods for the finishing period (p4-p5-p6). This period division allowed us to study the evolution of the feeding behavior. The mean pigs´ BW at the beginning of p1 was 42.3 ± 4.06 and 40.8 ± 4.5 kg for HT-P and TH-M trial, respectively ($p = 0.06$). For each period, the automatic feeding system recorded individual feed intake, time, and pig BW for each feeder visit. From these data TV, TD, VS and FR were calculated.

In each trial, the evolution along the experimental period of each feeding behavior pattern was adjusted to the model that best fitted. In the case of ADFI evolution, this was adjusted to the equation recommended by BSAS ($ADFI = a(1-e^{b*BW})$; Whittemore et al., 2003).

Statistical analysis

All data were analyzed using SAS statistical software (SAS 9.4©; SAS institute Inc., Cary, NC, USA). Growth performance, carcass traits and feeding behaviors were analyzed using the MIXED procedure. Normality and homogeneity variances were examined using the Shapiro-Wilk and Levene's tests, respectively. Trial, sex, and its interaction were included in the model as fixed effects while pen was included as a random effect. The experimental unit for all the variables studied was the pig. Results are presented as LS means ± standard error (SE). Significance was established at $p < 0.05$ for all the analyses, while a tendency was considered between $p \geq 0.05$ and $p < 0.10$. When the probability of the main effects and its interaction were significant, Tukey's HSD test adjustment was used to separate means.

Results

Environmental conditions

The indoor average temperatures were 28.1°C, 25.5°C in trial HT-P, and 23.5°C, 27.3°C in TH-M trial, for p1-p2-p3 (growing period) and p4-p5-p6 (finishing period), respectively. The boxplot of Fig. 1 shows that the median THI values along the growing period in trial HT-P and along the finishing period in trial TH-M were close to the emergency level for pigs (THI ≥ 30). It can be assumed from this that pigs were suffering heat stress during these periods. However, in the finishing period of trial HT-P and in the growing period of trial TH-M pigs were under thermoneutral conditions, since the median THI values were between the thermoneutral and the moderate level for pigs (THI < 27.8 and between 27.8 and 28.8, respectively).

Performance

No interaction between trial and sex was found in any performance index parameter (Table 2). The initial BW was lower for the HT-P than for the TH-M trial (16.5 vs 17.9 kg, respectively; $p < 0.001$) with no differences between males and females ($p > 0.1$). The final BW was higher ($p < 0.001$) in the HT-P trial (119.9 kg) than in the TH-M trial (106.9 kg) and higher ($p < 0.001$) for males (122.9 kg) than for females (112.4 kg) considering both trials. In the HT-P trial, ADFI and ADG were higher ($p = 0.006$ and $p < 0.001$, respectively) and FCR lower ($p < 0.001$) than in the TH-M trial. Whereas when considering both trials, ADFI was unaffected by sex ($p > 0.1$) and males obtained a higher ADG and a lower FCR than females ($p < 0.001$; Table 2).

Carcass yield (%) was unaffected by treatments (Table 2) but hot carcass weight (90.6 vs 80.9 kg), backfat thickness (15.5 vs 12.6 mm) and loin depth (64.3 vs 57.3 mm) were higher ($p < 0.001$) in the HT-P than in the TH-M trial. However, lean percentage (62.6 vs 63.9 %) was higher in the TH-M trial ($p = 0.001$). Hot carcass weight and backfat thickness were also higher in males than in females ($p < 0.02$) in the HT-P trial and not in the TH-M trial (significant interaction $p < 0.03$).

Table 2. Growth and carcass traits by trial, sex, and its interaction.

Item[2]	HT-P[1]				TH-M[1]				p-value		
	Males	SE[3]	Females	SE[3]	Males	SE[3]	Females	SE[3]	Trial	Sex	Trial*Sex
Growth performance											
n	12		46		47		24				
Experimental period, d	124		124		119		119				
Initial BW, kg	16.5	0.987	16.5	0.903	17.9	0.759	17.9	0.598	<0.001	0.900	0.93
Final BW, kg	128	8.52	118	1.205	108	1.216	104	1.430	<0.001	<0.001	0.068
ADFI, kg/d	1.78	0.173	1.76	0.127	1.65	0.164	1.72	0.131	0.006	0.280	0.120
ADG, kg/d	0.901	0.067	0.816	0.063	0.760	0.070	0.723	0.058	<0.001	<0.001	0.076
FCR, kg/kg	1.97	0.097	2.16	0.125	2.17	0.208	2.39	0.135	<0.001	<0.001	0.750
Carcass traits											
n	12		46		46		24				
Carcass yield, %	75.1	0.707	75.6	0.202	75.1	0.696	77.7	1.150	0.21	0.059	0.210
Hot carcass weight, kg	96.3[a]	2.09	89.1[b]	1.020	81.3[c]	0.959	80.5[c]	0.881	<0.001	0.003	0.015
Backfat thickness, mm	17.2[a]	0.760	15.1[b]	0.377	12.6[c]	0.314	12.5[c]	0.320	<0.001	0.020	0.028
Loin depth, mm	66.3	2.350	63.8	0.819	57.6	0.878	56.7	0.982	<0.001	0.150	0.480
Lean percentage, %	61.5	0.761	62.9	0.333	63.9	0.262	63.8	0.356	<0.001	0.130	0.078

[1] HT-P (Hot-Temperate/Pelleted trial) and TH-M (Temperate-Hot/Mash trial). [2] BW: body weight; ADFI: average daily feed intake; ADG: average daily gain; FCR: feed conversion ratio. [3]SE: standard error

Table 3. Results of feeding behavior by trial, sex, and its interaction.

Item[2]	HT-P[1]				TH-M[1]				p-value		
	Males	SE[3]	Females	SE[3]	Males	SE[3]	Females	SE[3]	Trial	Sex	Trial*Sex
n	12		46		47		24				
Experimental period, d	84		84		84		84				
TV, feeder visits/d	8.6	1.100	9.7	1.030	7.3	1.050	6.6	1.050	<0.001	0.86	0.05
TD, min/d	55.0	1.040	50.7	1.020	82.5	1.030	82.3	1.030	<0.001	0.18	0.17
VS, kg/feeder visit	0.207	1.078	0.196	1.036	0.249	1.055	0.296	1.054	<0.001	0.36	0.05
FR, g/min	32.2	1.040	37.3	1.020	21.9	1.030	23.6	1.030	<0.001	<0.001	0.23

[1] HT-P (Hot-Temperate/Pelleted trial) and TH-M (Temperate-Hot/Mash trial). [2] TV: total number of feeder visits per day; TD: time spent eating per day; VS: amount of feed intake per feeder visit; FR: g of feed intake per minute spent eating. [3]SE: standard error.

Feeding behavior patterns: mean values and time evolution

No significant interaction between trial and sex was found in any feeding behavior pattern analyzed (Table 3). On average, HT-P pigs did more TV and smaller VS (9.1 vs 6.9 daily feeder visits and 0.201 vs 0.272 kg/visit), with a higher FR (34.7 vs 22.8 g/min) and spending less TD (52.8 vs 82.4 min/d) than TH-M pigs ($p < 0.001$). The only feeding behavior pattern affected by sex was FR being higher for females than for males (29.7 vs 26.6, $p < 0.001$) in both trials. During the growing period (up to 60-70 kg BW, Fig. 2), ADFI had a similar trend in both trials. However, while in HT-P trial ADFI continued to increase during the finishing period, in TH-M trial ADFI was progressively stabilized (Fig. 2).

Both TV and VS in the HT-P trial were adjusted to an exponential equation: $y = a*e^{b*BW}$ whereas in the TH-M trial they were adjusted to a linear equation: $y = a*BW + b$ (Fig. 3A and 3C). On the other hand, TD and FR followed a linear equation in both trials: $y = a*BW + b$ (Fig. 3B and 3D). As pigs grew, TV and TD decreased while VS and FR increased in both trials. The reduction of the number of TV was higher in the HT-P than in the TH-M trial (by 67 vs 38%, respectively, Fig. 3A). Whereas in terms of TD both trials had a similar reduction of 38%, even though TH-M pigs spent more time eating throughout the experimental periods than HT-P pigs (Fig. 3B). For the duration of the periods

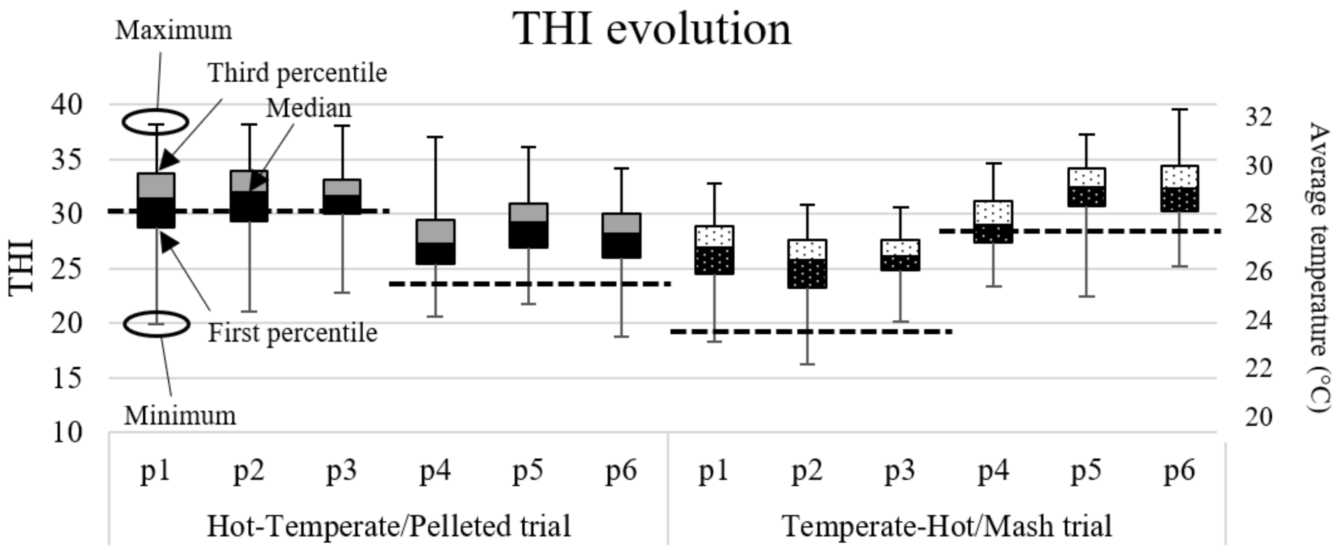

Figure 1. Boxplot (minimum, maximum, median, first and third percentiles) of THI (Temperature Humidity Index) of each period (p1 to p6) in Hot-Temperate/Pelleted (HT-P; June-October) trial and Temperate-Hot/Mash (TH-M; March-July) trial. Dotted lines indicate the average temperature in °C per season and trial (right axis).

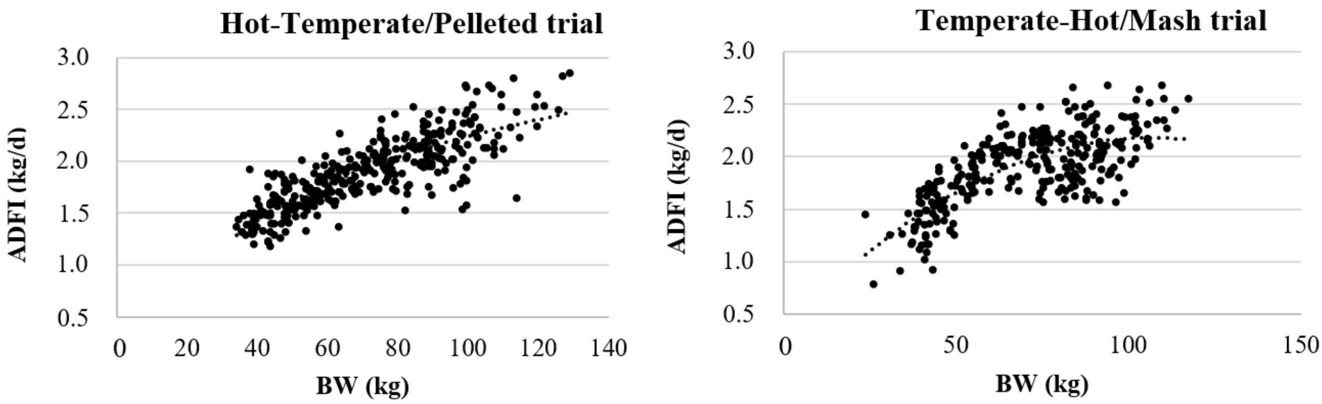

Figure 2. Average daily feed intake (ADFI, kg/d) adjustment by trial (Hot-Temperate/Pelleted; ADFI = 2.6424(1-$e^{0.0188*BW}$) and Temperate-Hot/Mash; ADFI = 2.4171(1-$e^{0.0236*BW}$).

studied VS increased by 419% in the HT-P trial but only by 144% in the TH-M trial. From 40 to 80 kg BW, HT-P pigs had a smaller VS than TH-M pigs. However, VS in HT-P pigs was accentuated from 80 kg BW reaching the same VS than as TH-M pigs at 100kg BW and overpassing it at 120 kg BW (Fig. 3C). Pigs of the HT-P trial had a higher FR than TH-M pigs throughout all the periods analyzed (Fig. 3D) and the FR increase was similar in both trials (168 vs 144% in TH-M and HT-P trial, respectively).

Discussion

It is known that environmental conditions and feed form are factors that affect pig performance and feeding behavior (Quiniou et al., 2000; Collin et al., 2001; Renaudeau et al., 2011; Rojas & Stein, 2017; Vukmirovic et al., 2017). In the present study, these two factors (environmental conditions and feed form) are mixed, with only one feed form per environmental condition. This is a weakness of the study that does not allow to clearly differentiate both effects. Therefore, the present study analyses the combined effect of both factors, which is still interesting, specially under commercial conditions.

In the present study, differences in pig performance were obtained with pigs from HT-P trial presenting a greater ADFI and ADG and a lower FCR than pigs from TH-M trial from the beginning to the end of the growing-finishing period. The literature describes that growing-finishing pigs fed with pelleted feeds, compared to mash, usually result in lower ADFI with improved ADG thanks to a better nutrient digestibility and lower feed waste (Rojas & Stein, 2017;

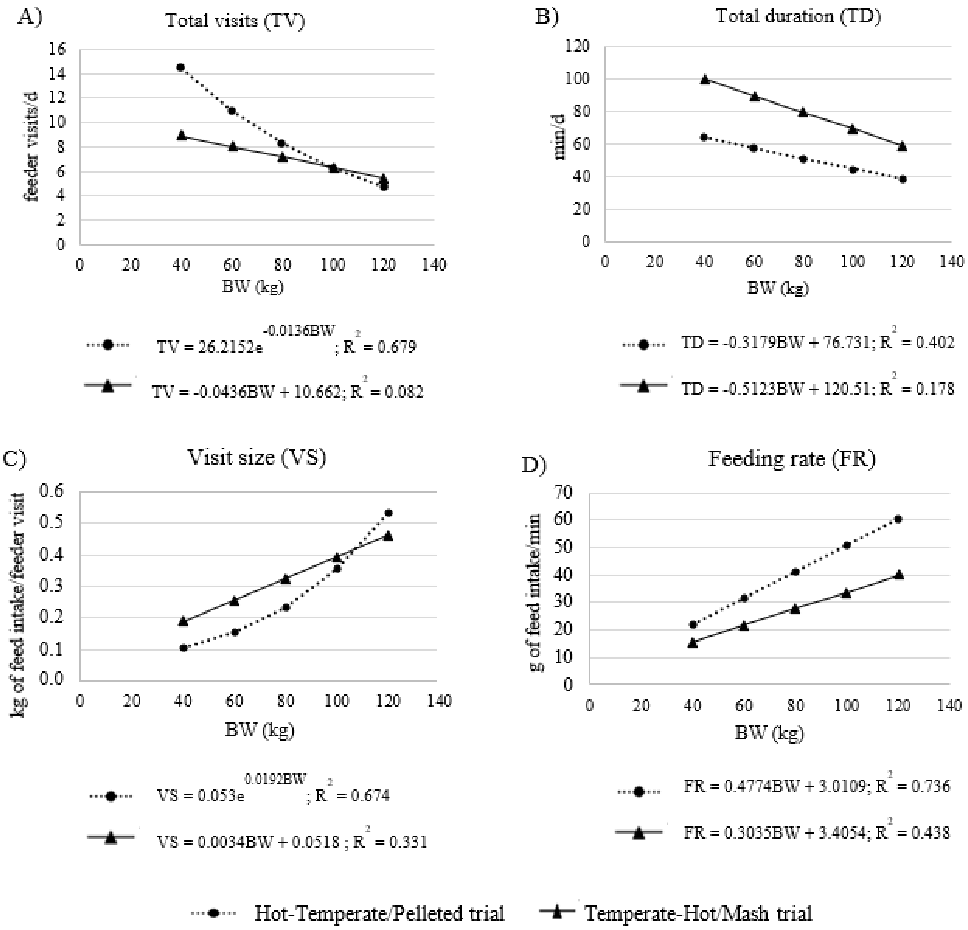

Figure 3. Evolution of the feeding behaviors patterns of pigs from 40 to 120 kg BW comparing Hot-Temperate/Pelleted and Temperate-Hot/Mash trials. TV, total number of feeder visits per day (A); TD, time spent eating per day (B); VS, amount of feed intake per feeder visit (C) and FR, g of feed intake per minute spent eating (D). BW, body weight.

Vukmirovic et al., 2017). The characteristics of the feeders used in the present study minimized feed waste for both feed forms; in fact, a lower ADFI was obtained with pigs fed in mash (TH-M) compared to pigs fed in pelleted feed (HT-P). The lower ADFI in TH-M pigs compared to HT-P pigs may be mostly explained by that TH-M pigs were under hot conditions (high THI) during the last 42 days of the finishing period, the stage with the highest amount of feed intake of all the growing-finishing period, and not due to that the feed was provided in mash form. We would expect a higher ADFI in pigs fed in mash than in pigs fed in pelleted form under thermoneutral conditions. Those results indicate that hot conditions have a greater negative impact on finishing pigs than on growing pigs as similar THI conditions measured during the growing period of HT-P trial did not affect the ADFI of younger pigs. In this regard, the decrease in feed intake is a widely known effect under heat stress, with a more pronounced effect on heavier than on lighter pigs (Renaudeau et al., 2011; Baumgard & Rhoads, 2013; da Fonseca de Oliveira et al., 2018).

Feed intake increases body temperature after eating, which would explain why heat stressed growing-finishing pigs reduce their feed intake (Cervantes et al., 2018). Dos Santos et al. (2018), comparing the performance of pigs housed at 30°C vs 23°C, observed a reduction of 640 and 700 g/d in the ADFI in growing pigs and finishing pigs, respectively. Le Bellego et al. (2002) also found, when comparing pigs housed at 29°C vs 22°C, a reduction in ADFI of 260 and 540 g/d, for growing (27 to 65 kg BW) and finishing pigs (65 to 100 kg BW), respectively, associated with a decrease in the ADG (110 and 180 g BW/d, respectively), but with no effect on feed efficiency or energy cost of gain. Under heat stress pigs activate mechanisms to dissipate the body heat such as an increase in the respiration rate implying a higher energy maintenance cost (Gonzalez-Rivas et al., 2020) and, in consequence, FCR may be penalized (Olczak et al., 2015; Ross et al., 2015; Anderson et al., 2020; Serviento et al., 2020). In fact, in the present study TH-M pigs had a lower ADG than HT-P pigs penalizing FCR by 200 g. This result could be explained by the combined effect of high THI in heavier pigs and the mash feed form, two factors known to penalize pigs´ growth performances (Li et al., 2017; Rojas & Stein, 2017).

Under heat stress, protein deposition is lower than in thermoneutral conditions due to the higher cost of protein deposition compared to lipid deposition (Brown-Brandl et al., 2000; Kouba et al., 2001; Le Bellego et al., 2002; Qu & Ajuwon, 2018). However, in the present study, HT-P pigs grew more, obtained higher backfat thickness and loin depth together with a lower lean percentage of carcasses than TH-M pigs. Therefore, the results obtained suggest that the differences obtained in carcass quality between both trials were more influenced by the growth rate than by the environmental conditions. In fact, our results are in accordance with the findings of Correa et al. (2006), who reported that fast growing pigs were fatter than the slow growing ones.

Several pig feeding behavior changes have been reported in the literature, both under heat stress conditions (Quiniou et al., 2000; Collin et al., 2001) and under different feed forms (Laitat et al., 2004; Li et al., 2017). Changes in the feeding behavior could affect pigs' performance (Rinaldo & Maurot, 2001; Kerr et al., 2003; Serviento et al., 2020) and modify carcass traits (Rinaldo & Maurot, 2001; Pearce et al., 2013). In the present study, sex affected FR but not the rest of feeding behaviors studied, thus, this discussion is focused on the combined effects of environmental conditions and feed forms on feeding behavior. In general, pigs need more time to achieve the same feed intake when feeding a diet in mash form than in pelleted form due to the lower FR (Laitat et al., 2004). In fact, Mac Donald & Gonyou (2000) reported that finishing pigs fed a mash diet spent a 20% more of TD than pigs fed a pelleted diet. Also, Li et al. (2017) reported a higher TD together with a lower FR and a higher feeder occupancy rate in growing-finishing pigs fed with mash than with pelleted feed. Those results coincide with the ones obtained in the present work in which pigs fed with mash (TH-M pigs) spent a longer TD and had lower FR during all the periods studied, regardless of the environmental conditions, than pigs fed with pelleted feed (HT-P pigs). The average TD obtained in HT-P pigs was close to the values obtained under thermoneutral conditions by Labroue et al. (1994), who reported 63.7 and 49.6 daily minutes spent eating with 40 and 90 kg BW pigs, respectively. However, our TD results are lower than those obtained by Rauw et al. (2006), Li et al. (2017) and Carcò et al. (2018) in group-housed pelleted fed pigs under thermoneutral conditions. Discrepancies could be explained by the genotype and housing conditions, factors which are known to affect the TD of growing-finishing pigs (de Haer & de Vries, 1993a,b; Labroue et al., 1999; Bornett et al., 2000). In this regard, Carcò et al. (2018) used 96 Topigs Talent × PIC pigs with a stocking density of 1.8 m^2/pig fed with a Compident Pig – MLP (Schauer Agrotonic, Austria); Rauw et al. (2006) used Duroc pigs fed with a Hokofarm, IVO-G (Marknesse, the Netherlands) feeder; and Li et al. (2017) used PIC Canada Ltd pigs with a stocking density of 1.0 m^2/pig and fed by crystal spring feeders (St Agatha, Manitroba, Canada). On the other hand, the average TD of TH-M pigs at 40 kg BW was similar to the TD reported by Li et al. (2017) in growing pigs fed mash feed under thermoneutral conditions (100 vs 106.9 min/d for TH-M pigs at 40 kg BW and Li et al., 2017, respectively). However, Li et al. (2017) reported a longer TD (106.5 min/d) in heavier pigs (60 to 100 kg BW) compared to the 79 min/d registered under heat stress conditions in the present study (TH-M pigs during the finishing period). Hence, those results indicate that hot conditions reduce the TD of finishing pigs fed in mash. Furthermore, in the present study HT-P pigs had similar FR values throughout the experimental period (22.1 and 41.2 g/min at 40 and 80 kg BW) than the ones reported by Rauw et al. (2006) under thermoneutral conditions but lower than values reported by Labroue et al. (1994) and Li et al. (2017) in group-housed pelleted fed pigs. On the other hand, in the present study, TH-M pigs had a FR of 15.5 and 27.7 g/min at 40 and 80 kg BW, respectively. This is a similar result to the one obtained by Li et al. (2017) in mash-fed pigs under thermoneutral conditions (19.7 and 25.6 g/min in growing and finishing pigs, respectively). Quiniou et al. (2000) and Collin et al. (2001) also reported no effect of hot conditions on FR in young and heavier pigs. As expected, and in concordance with the literature cited (Labroue et al., 1994; Hyun et al., 1997; Rauw et al., 2006; Carcò et al., 2018), in the present study, TD decreased and FR increased linearly as pigs grew; however, the decrease in TD was more pronounced when hot conditions occurred during the last 42 days of the finishing period.

On the other hand, in general, increasing the temperature from 23 to 33°C decreases TV and MS in pigs (Collin et al., 2001). Quiniou et al. (2000) also reported a reduction in TV but in terms of MS only a numerical decrease was reported when the temperature increased from 19 to 29°C in heavier pigs. Those results are partially in agreement with those obtained in the present study in which young pigs under high THI values (HT-P pigs) had a greater number of TV and a lower VS; while in heavier pigs (TH-M pigs), the number of TV was not affected, but VS was reduced. Since no literature has been found regarding the effect of feed form on the TV and VS, it is hypothesized that under heat stress, pigs reduce their VS as a mechanism to reduce the body heat production after eating (Cervantes et al., 2018). As pigs grew, in both trials (HT-P and TH-M) and independently of the temperature, the TV was reduced and VS increased in agreement with the literature (Labroue et al., 1994; Hyun et al., 1997; Andretta et al., 2016; Carcò et al., 2018). However, our results suggest that due to the environmental conditions, the reduction in the TV and the increase in VS were less pronounced in the TH-M trial than in the HT-P trial being by -38 vs -67% in TV and by 144 vs 419% in VS, respectively. Then, feeding behavior may be modified by both, feed form and environmental conditions, although it appears that environmental conditions mainly affected the TV and VS, and feed form modified the TD and the FR.

The present study analyzed the combined effect of environmental conditions and feed form over feeding behavior and performance of growing-finishing pigs. Although the experimental design did not allow us to fully differentiate between both factors, hot environmental conditions during the finishing period decreased the ADFI of pigs fed in mash form, while similar hot conditions during the growing period in pigs fed in pellet form hardly affected feed intake. This was due to the fact that growing pigs reduced the VS and increased the TV as a strategy to achieve the desired ADFI. On the other hand, pigs fed with a mash diet spent more time eating per day to achieve the desired ADFI due to a lower FR compared to pelleted feed, independently of the environmental conditions. Finally, from a practical point of view THI and pigs' BW should be considered to analyze the information from feeding stations to establish alerts and/or implement feeding strategies to mitigate heat stress effects on performance.

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References

Anderson LE, Holt JP, van Heugten E, Poole DH, 2020. Changes in growth performance, feeding behaviors, and posture behaviors of growing pigs subjected to low-intensity heat stress. J Anim Sci 98: 3-3. https://doi.org/10.1093/jas/skaa278.006

Andretta I, Pomar C, Kipper M, Hauschild L, Rivest J, 2016. Feeding behavior of growing-finishing pigs reared under precision feeding strategies. J Anim Sci 94: 3042-3050. https://doi.org/10.2527/jas.2016-0392

Baumgard LH, Rhoads RP, 2013. Effects of heat stress on postabsorptive metabolism and energetics. Annu Rev Anim Biosci (1): 7.1-7.27. https://doi.org/10.1146/annurev-animal-031412-103644

Bornett HLI, Morgan CA, Lawrence AB, Mann J, 2000. The effect of group housing on feeding patterns and social behaviour of previously individually housed growing pigs. App Anim Behav Sci 70: 127-141. https://doi.org/10.1016/S0168-1591(00)00146-5

Brouns F, Edwards SA, English R, 1994. Effect of dietary fiber and feeding system on activity and oral behavior of group-housed gilts. App Anim Behav Sci 39: 215-223. https://doi.org/10.1016/0168-1591(94)90157-0

Brown-Brandl TM, Nienaber JA, Turner LW, Yen JT, 2000. Manual and thermal induced feed intake restriction on finishing barrows. I: Effects on growth, carcass composition, and feeding behavior. Trans Asae 43: 987-992. https://doi.org/10.13031/2013.2996

Carcò G, Gallo L, Dalla Bona M, Latorre MA, Fondevila M, Schiavon S, 2018. The influence of feeding behaviour on growth performance, carcass and meat characteristics of growing pigs. Plos One 13(10): e0205572. https://doi.org/10.1371/journal.pone.0205572

Cervantes M, Antoine D, Valle JA, Vasquez N, Camacho RL, Bernal H, et al., 2018. Effect of feed intake level on the body temperature of pigs exposed to heat stress conditions. J Therm Biol 76: 1-7. https://doi.org/10.1016/j.jtherbio.2018.06.010

Collin A, van Milgen J, Dubois S, Noblet J, 2001. Effect of high temperature on feeding behaviour and heat production in group-housed young pigs. Br J Nutr 86: 63-70. https://doi.org/10.1079/BJN2001356

Correa JA, Faucitano L, Laforest JP, Rivest J, Marcoux M, Gariepy C, 2006. Effects of slaughter weight on carcass composition and meat quality in pigs of two different growth rates. Meat Sci 72: 91-99. https://doi.org/10.1016/j.meatsci.2005.06.006

da Fonseca de Oliveira AC, Vanelli K, Sotomaior CS, Weber SH, Costa LB, 2018. Impacts on performance of growing-finishing pigs under heat stress conditions: a meta-analysis. Vet Res Commun 43: 37-43. https://doi.org/10.1007/s11259-018-9741-1

De Jong JA, DeRouchey JM, Tokach MD, Dritz SS, Goodband RD, Woodworth JC, et al., 2016. Evaluating pellet and meal feeding regimens on finishing pig performance, stomach morphology, and carcass characteristics. J Anim Sci 94: 4781-4788. https://doi.org/10.2527/jas.2016-0461

De Haer LCM, Merks JWM, 1992. Relevance of eating pattern for selection of growing pigs. Patterns of daily feed intake in growing pigs. Thesis Dissertation, Van de Landbouwuniversiteit, Wageningen, pp: 19-44.

De Haer LCM, De Vries AG, 1993a. Feed intake patterns and feed digestibility in growing pigs housed individually or in groups. Livest Prod Sci 33: 277-292. https://doi.org/10.1016/0301-6226(93)90008-6

De Haer LCM, De Vries AG, 1993b. Effects of genotype and sex on the feed-intake pattern of group-housed growing pigs. Livest Prod Sci 36: 223-232. https://doi.org/10.1016/0301-6226(93)90055-M

dos Santos LS, Pomar C, Campos P, da Silva WC, Gobi JDP, Veira AM, et al., 2018. Precision feeding strategy for growing pigs under heat stress conditions. J Anim Sci 96: 4789-4801. https://doi.org/10.1093/jas/sky343

Fornós M, Sanz-Fernández S, Jiménez-Moreno E, Carrión D, Gasa J, Rodríguez-Estévez V, 2022. The feeding behaviour habits of growing-finishing pigs and its effects on growth performance and carcass quality: A review. Animals 12(9): 1128. https://doi.org/10.3390/ani12091128

Gonzalez-Rivas PA, Chauhan SS, Ha M, Fegan N, Dunshea FR, Warner RD, 2020. Effects of heat stress on animal physiology, metabolism, and meat quality: A review. Meat Sci 162: 13. https://doi.org/10.1016/j.meatsci.2019.108025

Hyun Y, Ellis M, McKeith FK, Wilson ER, 1997. Feed intake pattern of group-housed growing-finishing pigs monitored using a computerized feed intake recording system. J Anim Sci 75: 1443-1451. https://doi.org/10.2527/1997.7561443x

Hyun TTT, 2005. Heat stress in growing pigs. Doctoral thesis. Wageningen Institute of Animal Science, Wageningen.

Kerr BJ, Yen JT, Nienaber JA, Easter RA, 2003. Influences of dietary protein level, amino acid supplementation and environmental temperature on performance, body composition, organ weights and total heat production of growing pigs. J Anim Sci 81: 1998-2007. https://doi.org/10.2527/2003.8181998x

Kouba M, Hermier D, Le Dividich J, 2001. Influence of a high ambient temperature on lipid metabolism in the growing pig. J Anim Sci 79: 81-87. https://doi.org/10.2527/2001.79181x

Labroue F, Gueblez R, Sellier P, Meuniersalaun MC, 1994. Feeding-behavior of group-housed large white and landrace pigs in french central test stations. Livest Prod Sci 40: 303-312. https://doi.org/10.1016/0301-6226(94)90097-3

Laitat M, Vandenheede M, Desiron A, Canart B, Nicks B, 2004. Influence of diet form (pellets or meal) on the optimal number of weaned pigs per feeding space. J Swine Health Prod 12: 288-295.

Lallo CHO, Cohen J, Rankine D, Taylor M, Cambell J, Stephenson T, 2018. Characterizing heat stress on livestock using the temperature humidity index (THI) prospects for a warmer Caribbean. Reg Environ Change 18: 2329-2340. https://doi.org/10.1007/s10113-018-1359-x

Le Bellego L, van Milgen J, Noblet J, 2002. Effect of high temperature and low-protein diets on the performance of growing-finishing pigs. J Anim Sci 80: 691-701. https://doi.org/10.2527/2002.803691x

Li YZZ, McDonald KA, Gonyou HW, 2017. Determining feeder space allowance across feed forms and water availability in the feeder for growing-finishing pigs. J Swine Health Prod 25: 174-182. https://doi.org/10.54846/jshap/972

Mac Donald KAM, Gonyou HW, 2000. Effect of feed presentation on the feeding behaviour of grower/finisher pigs. Prairie Swine Centre Inc, Annual Research Report, pp: 25-26.

Marai IFM, Ayyat MS, Abd El-Monem UM, 2001. Growth performance and reproductive traits at first parity of New Zealand White female rabbits as affected by heat stress and its alleviation under Egyptian conditions. Trop Anim Health Prod 33: 451-462. https://doi.org/10.1023/A:1012772311177

Nyachoti CM, Zijlstra RT, de Lange CFM, Patience JF, 2004. Voluntary feed intake in growing-finishing pigs: A review of the main determining factors and potential approaches for accurate predictions. Can J Anim Sci 84: 549-566. https://doi.org/10.4141/A04-001

O'Meara FM, Gardiner GE, O'Doherty JV, Lawlor PG, 2020. The effect of feed form and delivery method on feed microbiology and growth performance in grow-finisher pigs. J Anim Sci 98: 11. https://doi.org/10.1093/jas/skaa021

Olczak K, Nowicki J, Klocek C, 2015. Pig behaviour in relation to weather conditions - A review. Ann Anim Sci 15: 601-610. https://doi.org/10.1515/aoas-2015-0024

Pearce SC, Gabler NK, Ross JW, Escobar J, Patience JF, Rhoads RP, et al., 2013. The effects of heat stress and plane of nutrition on metabolism in growing pigs. J Anim Sci 91: 2108-2118. https://doi.org/10.2527/jas.2012-5738

Qu H, Ajuwon KM, 2018. Adipose tissue-specific responses reveal an important role of lipogenesis during heat stress adaptation in pigs. J Anim Sci 96: 975-989. https://doi.org/10.1093/jas/sky022

Quiniou N, Dubois S, Noblet J, 2000. Voluntary feed intake and feeding behaviour of group-housed growing pigs are affected by ambient temperature and body weight. Livest Prod Sci 63: 245-253. https://doi.org/10.1016/S0301-6226(99)00135-9

Rauw WM, Soler J, Tibau J, Reixach J, Raya LG, 2006. Feeding time and feeding rate and its relationship with feed intake, feed efficiency, growth rate, and rate of fat deposition in growing Duroc barrows. J Anim Sci 84: 3404-3409. https://doi.org/10.2527/jas.2006-209

Renaudeau D, Gourdine JL, St-Pierre NR, 2011. A meta-analysis of the effects of high ambient temperature on growth performance of growing-finishing pigs. J Anim Sci 89: 2220-2230. https://doi.org/10.2527/jas.2010-3329

Rinaldo D, Mourot J, 2001. Effects of tropical climate and season on growth, chemical composition of muscle and adipose tissue and meat quality in pigs. Anim Res 50: 507-521. https://doi.org/10.1051/animres:2001142

Rojas OJ, Stein HH, 2017. Processing of ingredients and diets and effects on nutritional value for pigs. J Anim Sci Biotech 8: 13. https://doi.org/10.1186/s40104-017-0177-1

Ross JW, Hale BJ, Gabler NK, Rhoads RP, Keating AF, Baumgard LH, 2015. Physiological consequences of heat stress in pigs. Anim Prod Sci 55: 1381-1390. https://doi.org/10.1071/AN15267

Serviento AM, Labussiere E, Castex M, Renaudeau D, 2020. Effect of heat stress and feeding management on growth performance and physiological responses of finishing pigs. J Anim Sci 98: 15. https://doi.org/10.1093/jas/skaa387

Vukmirovic D, Colovic R, Rakita S, Brlek T, Duragic O, Sola-Oriol, D, 2017. Importance of feed structure (particle size) and feed form (mash vs. pellets) in pig nutrition - A review. Anim Feed Sci Tech 233: 133-144. https://doi.org/10.1016/j.anifeedsci.2017.06.016

Whittemore CT, Hazzledine MJ, Close WH, 2003. Nutrient requirement standards for pigs. British Society of Animal Science, Penicuik.