Universitat Autònoma de Barcelona

THE INFLUENCE OF FEEDING BEHAVIOUR HABITS OF GROWING-FINISHING PIGS ON PERFORMANCE AND FEED UTILIZATION

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CERTIFICAN:

Que la memoria titulada "**The influence of feeding behaviour habits of growing-finishing pigs on performance and feed utilization**", presentada por Marta Fornós Inglès con la finalidad de optar al grado de Doctor en Veterinaria, ha sido realizada bajo su dirección y, considerándola terminada, autorizan su presentación en acto público para ser juzgada por la correspondiente comisión.

I para que conste, firman la presente en Bellaterra, 21 de Junio de 2022.

Dr. Josep Gasa Gasó	Dr. Vicente Rodríguez Estévez	Dra. Encarnación Jiménez Moreno

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Resumen

El engorde de cerdos bajo condiciones intensivas busca la máxima eficiencia en términos productivos y económicos. No obstante, existe una gran variabilidad individual que unida a prácticas de manejo estresantes, pueden menguar la eficiencia productiva. Uno de los factores que afectan a la variabilidad y la productividad es el comportamiento alimentario. Por tanto, resulta importante conocer el comportamiento alimentario más beneficioso en términos de eficiencia alimentaria. Por otra parte, si se consigue reducir el nivel de estrés de los cerdos de engorde, se puede minimizar el gasto energético que este comporta y, en consecuencia, mejorar el bienestar de los animales y sus resultados productivos.

Los objetivos de la presente tesis son: primero, ampliar el conocimiento sobre el comportamiento alimentario registrado con máquinas de alimentación electrónica, con especial énfasis en describir su influencia sobre los resultados productivos y de canal, el uso de la energía y la proteína del pienso de cerdos de engorde (**capítulos 4, 5 y 6**); segundo, analizar el efecto de la inclusión de una mezcla de extractos de plantas con propiedades calmantes sobre el comportamiento alimentario, los resultados productivos y el bienestar de cerdos de engorde bajo un ayuno prolongado (**capítulo 7**).

Primero se estudió el efecto de la presentación del pienso y de las condiciones ambientales sobre el comportamiento alimentario y los resultados productivos (**capítulo 4**). Así, mientras que bajo condiciones de estrés por calor los cerdos de crecimiento (18-70 kg PV) mantuvieron la ingesta diaria gracias a la adaptación de su comportamiento alimentario, reduciendo el tamaño e incrementando el número de visitas al comedero, los cerdos de acabado (70 a 120 kg PV) solamente redujeron el tamaño de las visitas, disminuyendo su ingesta diaria y, en consecuencia, penalizando los resultados productivos. Por otra parte, los cerdos alimentados con harina dedicaron más tiempo a comer (82.4 vs 52.8 min/d, $P < 0.0001$) debido a un menor ritmo de ingesta que los cerdos alimentados con pienso granulado (22.8 vs 34.7 g/min, $P < 0.0001$).

Seguidamente, para conocer el grado de repetibilidad de los parámetros que definen el comportamiento alimentario a nivel individual, se propuso un nuevo cálculo llamado "mantenimiento" (**capítulo 5**). Así, teniendo en cuenta que biológicamente los cerdos cambian su comportamiento alimentario con la edad, los resultados del nuevo cálculo informan de en qué medida un cerdo mantiene individualmente su comportamiento alimentario entre un período y el siguiente a lo largo del engorde. Para su estudio se dividió el engorde en seis periodos de 14 días y se calculó el "mantenimiento" entre periodos consecutivos. Los resultados obtenidos muestran que, excepto la ingesta diaria de pienso, cuyo "mantenimiento" disminuyó con la edad de los cerdos hasta un 50% el último mes de engorde, el resto de parámetros (tiempo dedicado a comer, número de visitas al comedero, tamaño de visita y ritmo de ingesta) presentaron un "mantenimiento" bastante elevado (>70% de cerdos mantuvieron el comportamiento alimentario). Sin embargo, bajo cambios en las condiciones ambientales, al pasar de condiciones de termoneutralidad a estrés térmico, se observó una caída del "mantenimiento" del número de visitas del 86 al 74% y del tamaño de las visitas del 86 al 63% (un 26 y un 37% de los cerdos cambiaron ambos parámetros de comportamiento alimentario, respectivamente).

Los altos porcentajes de "mantenimiento" registrados, permitieron estudiar la influencia del comportamiento alimentario a lo largo del engorde sobre los resultados productivos y de canal, y sobre el uso de la energía y la proteína de la dieta (**capítulo 6**). Según el comportamiento alimentario y la productividad, los cerdos se distribuyeron en tres clusters, diferenciados por el nivel y el ritmo de ingesta. Respecto al nivel de ingesta, los cerdos con un consumo mayor (1.90 vs 1.71 kg/d) y visitas de mayor ingesta (356 vs 268 g/visita) tuvieron un crecimiento (890 vs 767 g/d), peso vivo final (127 vs 112 kg PV), peso de canal (97.5 vs 84.0 kg), rendimiento de canal (76.7 vs 75.3%) y profundidad de lomo (69 vs 60 mm) significativamente mayor que los cerdos con un nivel de ingesta inferior ($P < 0.05$). Adicionalmente, los cerdos con un nivel de ingesta mayor, alcanzaron la máxima deposición de proteína seis días antes que los cerdos con un nivel de ingesta inferior (d62 vs d68 de engorde), junto con un nivel de retención de grasa mayor. Por otra parte, un mismo nivel de ingesta diaria con un ritmo menor de ingesta (35.0 vs 39.7 g/min) influenció positivamente sobre el crecimiento (823 vs 767 g/d), el índice de conversión (2.11 vs 2.22 kg/kg), la profundidad de lomo (65 vs 60 mm) y el espesor de grasa dorsal (16 vs 14 mm) ($P < 0.05$). Además, con el mismo nivel de ingesta, los cerdos que comieron más lentamente obtuvieron una mayor deposición de proteína y grasa, siendo más eficientes en términos energéticos que los cerdos con un ritmo de ingesta superior.

Finalmente, para la consecución del segundo objetivo, se estudió el efecto de la inclusión de una mezcla comercial de extractos de plantas con propiedades calmantes sobre el comportamiento alimentario, los resultados productivos y el bienestar de cerdos de acabado (del día 84 hasta el día 130 de engorde) (**capítulo 7**). El extracto de plantas empleado se compone principalmente de amapola de california (*Eschscholzia califórnica*), lúpulo (*Humulus lupulus*) y flor de la pasión (*Passiflora incarnata*). Para evaluar el efecto de la mezcla bajo condiciones estresantes, los cerdos fueron sometidos a un ayuno largo (42h). Así, los cerdos suplementados con el extracto de plantas obtuvieron un consumo medio diario superior (2.30 vs 2.15 kg/d, $P < 0.05$) y tendieron a un crecimiento más alto (783.5 vs 724.5 g/d, $P = 0.08$) que los cerdos control. Sin embargo, no se obtuvieron diferencias en índice de conversión y el efecto de la inclusión del extracto de plantas sobre la canal fue limitado. Tras el ayuno, los cerdos suplementados con el extracto mostraron un consumo mayor (28%) en las 48 horas posteriores, junto con un nivel inferior de lesiones en la piel (8.6 vs 26.5% de cerdos con lesiones severas en la piel, $P < 0.05$) y una menor variabilidad en el consumo medio diario en los siguientes días comparado con los cerdos control.

En resumen, los resultados obtenidos muestran que el comportamiento alimentario influye en la alta variabilidad de rendimiento individual mostrada por los cerdos de engorde. Los resultados indican que los cerdos más eficientes, en términos productivos y económicos, son aquellos con un nivel de ingesta medio y con un ritmo de ingesta menor, o bien los cerdos con un nivel de ingesta mayor en el caso de que el objetivo sean pesos al sacrificio más elevados. En referencia al uso de extracto de plantas con propiedades calmantes, los resultados indican que es una buena estrategia para reducir el estrés y, con ello, mejorar los resultados productivos durante la etapa de acabado.

Resum

L'engreix de porcs sota condicions intensives busca la màxima eficiència en termes productius i econòmics. No obstant, existeix una gran variabilitat individual que juntament amb pràctiques de maneig estressants poden minvar l'eficiència productiva. Un dels factors que afecta la variabilitat i la productivitat és el comportament alimentari. Per tant, resulta important conèixer el comportament alimentari més beneficiós en termes d'eficiència alimentària. Altrament, si s'aconsegueix reduir el nivell d'estrès dels porcs d'engreix es pot minimitzar la despesa energètica que aquest suposa i, en conseqüència, millorar el benestar i els resultats productius dels animals.

Els objectius de la present tesi són: primer, ampliar el coneixement sobre el comportament alimentari, registrat amb màquines d'alimentació electrònica, amb especial èmfasi en descriure la seva influència sobre els resultats productius i de canal, l'ús de l'energia i proteïna del pinso dels porcs d'engreix (**capítols 4, 5 i 6**). En segon lloc, analitzar l'efecte de la inclusió d'una mescla d'extractes de plantes amb propietats calmants sobre el comportament alimentari, els resultats productius, i el benestar de porcs d'engreix sota un dejú prolongat (**capítol 7**).

Primer es va estudiar l'efecte de la presentació del pinso i les condicions ambientals sobre el comportament alimentari i els resultats productius (**capítol 4**). Sota condicions d'estrès per calor, mentre els porcs en creixement (18-70 kg PV) van mantenir la seva ingesta diària gràcies a l'adaptació del seu comportament alimentari reduint la mida de les visites i incrementant el seu nombre, els porcs d'acabat (70 a 120 kg PV) solament van reduir la mida de les visites, reduint la seva ingesta diària i en conseqüència penalitzant els resultats productius. Per altra banda, els porcs alimentats amb farina van dedicar més temps a menjar (82.4 vs 52.8 min/d, $P < 0.0001$) degut a un menor ritme d'ingesta que els porcs alimentats amb pinso granulat (22.8 vs 34.7 g/min, $P < 0.0001$).

Seguidament, per conèixer el grau de repetibilitat dels paràmetres que defineixen el comportament alimentari a nivell individual, es va proposar un nou càlcul anomenat

"manteniment" (**capítol 5**). Tenint en compte que biològicament els porcs canvien el seu comportament alimentari amb l'edat, els resultats del nou càlcul informen de en quina mesura un porc individual manté el comportament alimentari entre un període i el següent al llarg de l'engreix. Es va dividir l'engreixada en sis períodes de 14 dies i es va calcular el "manteniment" entre períodes consecutius. Els resultats obtinguts mostren que, excepte la ingesta diària de pinso, que els seu "manteniment" conforme els porcs creixen va anar disminuint fins a percentatges de solament un 50% l'últim mes d'engreixada, la resta de paràmetres (temps dedicat a menjar, nombre de visites, mida de visita i ritme d'ingesta) van presentar un "manteniment" força alt (>70% dels porcs van mantenir el seu comportament alimentari). Però, davant de canvis en les condicions ambientals, quan les condicions van canviar de termoneutralitat a estrès per calor, es va observar una caiguda del "manteniment" del nombre de visites del 86 al 74% i de la mida de les visites del 86 al 63% (un 26 i un 37% dels porcs van canviar ambdós paràmetres, respectivament).

Els alts percentatges de "manteniment" obtinguts, van permetre estudiar la influència del comportament alimentari al llarg de l'engreixada sobre els resultats productius i de canal i sobre l'ús de la energia i la proteïna de la dieta (**capítol 6**). Segons el comportament alimentari i la productivitat els porcs es van distribuir en tres clústers, diferenciats per el nivell i el ritme d'ingesta. Respecte al nivell d'ingesta, els porcs que van menjar més (1.90 vs 1.71 kg/d) i amb visites de major mida (356 vs 268 g/visita), van obtenir un nivell de creixement (890 vs 767 g/d), pes viu final (127 vs 112 kg PV), pes de canal (97.5 vs 84.0 kg), rendiment de canal (76.7 vs 75.3%) i profunditat de llom (69 vs 60 mm) significativament més elevats que els porcs amb un nivell d'ingesta menor (P < 0.05). Addicionalment, els porcs amb un nivell d'ingesta major, van arribar a la màxima deposició de proteïna sis dies abans que els porcs amb un nivell d'ingesta menor (d62 vs d68 d'engreixada) juntament amb un nivell de retenció de greix major. Per altra banda, un mateix nivell d'ingesta diària amb un ritme d'ingesta menor (35.0 vs 39.7 g/min) va influenciar positivament el nivell de creixement (823 vs 767 g/d), l'índex de conversió (2.11 vs 2.22 kg/kg), la profunditat de llom (65 vs 60 mm) i l'espessor de greix dorsal (16 vs 14 mm) (P < 0.05). A més, amb el mateix nivell d'ingesta, els porcs que van menjar més lentament van obtenir una major deposició de proteïna i greix, essent més eficients en termes energètics que els porcs amb un ritme d'ingesta superior.

Finalment, per assolir el segon objectiu, es va estudiar l'efecte de la inclusió d'una mescla comercial d'extractes de plantes amb propietats calmants sobre el comportament alimentari, els resultats productius i el benestar de porcs d'acabat (des del dia 84 al dia 130 d'engreixada) (**capítol 7**). L'extracte de plantes està format bàsicament per rosella de Califòrnia (*Eschscholzia californica*), llúpol (*Humulus lupulus*) i passiflora (*Passiflora incarnata*). Per a avaluar l'efecte de la mescla sota condicions estressants els porcs van ser sotmesos a un dejú llarg (42 h). Els porcs suplementats amb l'extracte de plantes van obtenir un consum mig diari superior (2.30 vs 2.15 kg/d, $P < 0.05$) amb una tendència a un creixement més alt (783.5 vs 724.5 g/d, $P = 0.08$) que els porcs control, però no es van detectar diferències entre tractaments en índex de conversió junt amb un efecte limitat sobre la canal. Després del dejú, els porcs suplementats van mostrar un consum major (28%) durant les 48 hores posteriors juntament amb un nivell inferior de lesions a pell (8.6 vs 26.5% porcs per corral amb lesions severes a la pell, $P < 0.05$) i amb menys variabilitat en el consum els dies consecutius al dejú que els porcs control.

En global, els resultats obtinguts mostren que el comportament alimentari influeix en la alta variabilitat del rendiment individual mostrada pels porcs d'engreix. Els resultats indiquen que els porcs més eficients en termes productius i econòmics són aquells amb un nivell d'ingesta mig amb un ritme d'ingesta baix o bé els porcs amb un nivell d'ingesta alt en el cas que l'objectiu siguin pesos de sacrifici elevats. En referència a l'ús d'extractes de plantes amb propietats calmants, els resultats indiquen que és una bona estratègia per a reduir l'estrès i en conseqüència millorar els resultats productius durant l'etapa d'acabat.

Summary

Rearing growing-finishing pigs under intensive conditions search for the maximum efficiency in terms of production and economics. Nevertheless, a large variability among individuals together with farm management stressors for the pigs may penalize the productive efficiency. One of the factors that influences variability and performance is the feeding behaviour. Then, it is important to know the most beneficial feeding behaviour in terms of feed efficiency. On the other hand, with a reduction in the stress level of growing-finishing pigs, the energy waste would be minimized and consequently, the welfare and performance of animals may be improved.

The objectives of the present PhD are: in the first place, to expand knowledge regarding feeding behaviour, registered with feeding automatic systems, with a special interest in describing its influence on performance, carcass and dietary energy and protein utilization in growing-finishing pigs (**chapter 4, 5 and 6**). In second place, to analyse the influence of the inclusion of a herbal extract blend with calming properties on feeding behaviour, performance and welfare of growing-finishing pigs under a long fasting period (**chapter 7**).

Firstly, the effect of physical feed form and environmental conditions on feeding behaviour and performance of growing-finishing pigs was studied (**chapter 4**). Under heat stress conditions, while growing pigs (18-70 kg BW) maintained their daily feed intake thanks to the adaptation of their feeding behaviour by reducing the size and increasing the number of feeder visits, finishing pigs (70 to 120 kg BW) only reduced the size of feeder visits, reducing daily feed intake and consequently, their performance results were penalized. On the other hand, mash-fed pigs spent more time eating (82.4 vs 52.8 min/d, $P < 0.0001$) due to the lower feeding rate (22.8 vs 34.7 g/min, $P < 0.0001$) than pellet-fed pigs.

Then, to know the repeatability degree of the parameters that define the feeding behaviour at individual level, a new approach named "maintenance" was proposed (**chapter 5**). Taking into account that biologically pigs change their feeding behaviour

with age, the results of the new approach inform us about in which measure an individual pig maintains its feeding behaviour between two consecutive periods throughout the growing-finishing period. The growing-finishing period was divided into six periods of 14 days each and the "maintenance" between consecutive periods was calculated. The results obtained show that, except for the average daily feed intake whose maintenance decreased as pigs grew until only a 50% in the last month of the growing-finishing period, the other parameters (time spent eating, number of feeder visits, visit size and feeding rate) had high "maintenance" values (>70% of the pigs maintaining their feeding behaviour habits). But, under changes in environmental conditions, from thermoneutral to heat stress conditions, a decrease in the number of feeder visits from 86 to 74% and in the size of the feeder visits from 86 to 63% was observed (26 and 37% of pigs changed both feeding behaviour habits, respectively).

The high values of "maintenance" obtained, permitted us to analyse the influence of feeding behaviour habits during the growing-finishing period on performance, carcass quality traits and dietary energy and protein utilization (**chapter 6**). Depending on feeding behaviour habits and performance, a three clusters partition was obtained which permitted us to know the influence of the level of average daily feed intake and feeding rate on performance, carcass quality traits and dietary energy and protein utilization. Regarding the average daily feed intake, pigs that ate more (1.90 vs 1.71 kg/d) with larger feeder visits (356 vs 268 g/visit), obtained significantly greater growth (890 vs 767 g/d), final BW (127 vs 112 kg BW), carcass weight (97.5 vs 84.0 kg), carcass yield (76.7 vs 75.3%) and loin depth (69 vs 60 mm) than pigs eating less ($P < 0.05$). Moreover, pigs with a higher average daily feed intake achieved the maximum daily protein deposition six days before pigs eating less (d62 vs d68 of fattening) together with a higher fat retention level. On the other hand, eating the same average daily feed intake but slower (35.0 vs 39.7 g/min) increased growth rate (823 vs 767 g/d), feed conversion ratio (2.11 vs 2.22 kg/kg), loin depth (65 vs 60 mm) and backfat thickness (16 vs14 mm) ($P < 0.05$). In addition, with the same average daily feed intake, pigs eating slower obtained a higher protein and fat deposition, being more efficient in energy terms than pigs eating faster.

Finally, to achieve the second objective, the effect of the inclusion of a commercial herbal extracts blend based on california poppy (*Eschscholzia californica*), hop (*Humulus lupulus*) and maypop (*Passiflora incarnata*) from day 84 to day 130 of fattening (sacrifice day) on feeding behaviour, performance and welfare of finishing pigs was studied (**chapter 7**). To assess the effect of the herbal extract blend under a stressor, pigs were fasted for 42h. Pigs fed with the herbal extracts blend had a higher average daily feed intake (2.30 vs 2.15 kg/d, $P < 0.05$) and tended to grow more (783.5 vs 724.5 g/d, $P = 0.08$) than control pigs, but with limited effects on feed conversion ratio and carcass quality traits. After the fasting period, pigs fed with the herbal extracts blend had 28% more feed intake the following 48 hours together with a lower level of skin lesions (8.6 vs 26.5% of pigs per pen with severe skin lesions, $P < 0.05$) and with lower variability in the feed intake day by day compared to control pigs.

To sum up, the results obtained show that feeding behaviour habits influence the performance variability among growing-finishing pigs. The results indicate that the most efficient pigs in productive and economic terms are those with a medium feed intake level and eating slower or pigs with a higher feed intake level in the case that the objective is to obtain heavier pigs. Regarding the use of herbal extracts blends with calming properties, the results indicate that it is a good strategy to reduce stress level and in consequence, improve the performance results of finishing pigs.

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Abbreviations

ADFI	average daily feed intake
ADG	average daily gain
ANOVA	analysis of variance
ATTD	apparent total tract digestibility
BW	body weight
CC	canonical correlation
CP	crude protein
D	Duroc
DFI	daily feed intake
DM	dry matter
F	female
FBHs	feeding behaviour habits
FCR	feed conversion ratio
FR	feeding rate
GABA	gamma aminobutyric acid
GE	gross energy
GH	group housing
H	Hampshire
I	Individual
L	Landrace
LD	lipid deposition
LW	Large White
M	male
ME	metabolizable energy
MEm	metabolizable energy for maintenance
MS	meal size
NE	net energy
NEFA	non-esterified fatty acids
OLS	ordinary least square
p	period

P	Pietrain
PCA	principal component analysis
PD	protein deposition
RA	repeatability
RH	relative humidity
SE	standard error
SID Lys	standardized ileal digestible lysine
TD	time spent eating per pig and day
THI	temperature humidity index
TMs	total meals per pig and day
TVs	total feeder visits per pig and day
VS	feeder visit size
Vd	feeder visit duration
Y	Yorkshire

CHAPTER 1.

Introduction

Pork is the second-most consumed meat worldwide and a global increase is predicted of around 17% from 2021 to 2029 (Racewicz et al., 2021). Rearing growing-finishing pigs under intensive conditions led to maximum growth and performance, according to their genetic potential. This approach, throughout the last decades, produced leaner and less fat slaughtered pigs, usually in a shorter time, with higher average daily gain and lower average daily feed intake (Correa et al., 2006). However, critical issues regarding pig welfare and rearing system sustainability still exist and must be addressed (Ekkel et al., 1995; Maes et al., 2020; Alonso et al., 2020; Rauw et al., 2020). Therefore, the search for strategies to improve the efficiency and welfare of pigs is of the utmost interest.

One of the issues which affects efficiency is the different individual responses that grouped pigs may give to the same production conditions, which produce a high variability of pigs arriving at the slaughter-house (López-Vergé et al, 2018). The use of precision feeding systems is a promising strategy to reduce variability and to increase system efficiency, since it allows us to feed pigs in a way closer to their nutrient requirements (Pomar and Remus, 2019; Gaillard et al., 2020). Another factor that may influence the existing variability among productive results obtained by different pigs of the same batch are the differences in feeding behaviour habits (FBHs) (Carcò et al., 2018), which influence nutrient digestibility and growth performance outcomes (de Haer and de Vries, 1993; Hyun et al., 1997; Gonyou and Lou, 2000; Lu et al., 2017). In addition, other production factors such as environmental conditions or physical feed form may modify pigs' efficiency (Renaudeau et al., 2011; Vukmirovic et al., 2017). However, the literature shows little proof of their impact on FBHs of growing-finishing pigs. Therefore, since FBHs are related with performance, it may follow that the effect of those production conditions on the efficiency and welfare may be partially explained by changes in FBHs.

On the other hand, growing-finishing pigs are exposed to many stressors that can have a negative impact on their welfare and performance. In fact, pigs suffer from acute social and metabolic stress during management strategies that break the stable social group within a pen (e.g. when mixing pigs at the entrance of the fattening period or when removing the heavier pigs within a pen to the slaughter-house) or during fasting periods, respectively (Coutellier et al., 2007; Fredriksen and Hexeberh, 2009; Ott et al., 2014). Thus, the use of plants with calming effects, such as california poppy (*Eschscholzia californica*), hop (*Humulus lupulus*) and maypop (*Passiflora incarnata*) (Soulimani et al., 1997; Dhawan et al., 2003; Schiller et al., 2006; Franco et al., 2012; Fedurco et al., 2015) may be a strategy to influence positively the welfare and performance of growing-finishing pigs reared under intensive conditions.

The present thesis uses growing-finishing pigs reared in intensive conditions and fed with an automatic feeding system. The main interest was, first to study the effect of different production conditions (environmental conditions or physical feed form) on FBHs and its influence on pigs' performance and feed efficiency, and second, to analyse the effect of the dietary inclusion of a herbal extracts blend with calming properties on the welfare and performance of grouped-housed finishing pigs subjected to sudden stress.

CHAPTER 2.

Literature review

Part of this chapter (from 2.1 to 2.2.2.3) has been published in *Animals*:

Fornós, M.; Sanz-Fernández, S.; Jiménez-Moreno, E.; Carrión, D.; Gasa, J. and V. Rodríguez-Estévez. **The Feeding Behaviour Habits of Growing-Finishing Pigs and Its Effects on Growth Performance and Carcass Quality: A Review**. *Animals* **2022**, 12(9), 1128; doi.org/10.3390/ani12091128.

2.1. Feeding behaviour habits of growing-finishing pigs

2.1.1. Definition of concepts

Feeding behaviour habits (FBHs) of growing-finishing pigs describe the distribution of the daily feed intake in terms of daily number of feeder visits (TVs), size of feeder visits (VS), time spent eating (TD) or rhythm of ingesta (FR), among others (Table 2.1). It is important to be aware that a determinate number of feeder visits conducted consecutively within a period of time by the same pig are often clustered into one meal with different criteria among authors. The definition of the time and sequence determining a meal is the main disagreement among authors. In fact, that period varies from one minute (Andretta et al., 2016a) to almost half an hour (28.3 min) (Hyun et al., 1997).

Table 2.1. Feeding behaviour habits and the criteria used to compute them.

Parameter	Nomenclature	Criterion
Average daily feed intake (kg/d)	ADFI	Total feed consumed per pig and day
Feeder visits per day (n/d)	TVs	Total number of feeder visits per pig and day
Meals per day (n/d)	TMs	Total number of meals per pig and day
Time spent eating (min/d)	TD	Total minutes spent eating per pig and day
Visit duration (min/feeder visit)	Vd	Time spent eating per feeder visit
Visit size (g/feeder visit)	VS	Feed consumed per feeder visit
Meal size (g/meal)	MS	Feed consumed per meal
Feeding rate (g/min)	FR	Feed intake per minute spent eating

When studying FBHs of growing-finishing pigs, the relation between the different FBHs parameters is of interest (Table 2.2). De Haer and Merks, (1992) and Labroue et al. (1997) suggested two types of pigs according to their number and size of meals: "*nibbler*" pigs (many short meals every day) and "*meal eater*" pigs (a few long meals every day). This pig classification is supported by the strong and negative correlations reported between meal size (MS) and TVs (De Haer and Merks, 1992; Labroue et al., 1994; Young and Lawrence, 1994; Hyun et al., 1997; Fernández et al., 2011; Garrido-Izard et al., 2020) indicating the existence of pigs eating their daily feed intake (DFI) in few large meals (*meal eater*s) and pigs eating their DFI in many smaller meals (*nibbler pigs*). Moreover, Fernández et al. (2011) also found strong and positive correlations between VS and duration of feeder visits (Vd) in all the breeds studied (Duroc, Landrance, Large White, Pietrain; $r \geq 0.87$), suggesting no differences in terms of FR between *nibbler* and *meal eater* pigs. Furthermore, those authors also suggested distinguishing pigs by their FR as *fast* or *slow eaters*. This classification is supported by the strong and negative correlation reported between FR and TD, indicating that pigs with a higher FR spend less time eating (De Haer and Merks, 1992; Labroue et al., 1994; Young and Lawrence, 1994; Hyun et al., 1997; Rauw et al., 2006; Fernández et al., 2011; Garrido-Izard et al., 2020). On the other hand, low correlations have been reported between TVs and MS with TD and FR (De Haer and Merks, 1992; Labroue et al., 1994; Young and Lawrence, 1994; Hyun et al., 1997; Rauw et al., 2006; Fernández et al., 2011; Garrido-Izard et al., 2020).

Therefore, the correlations of the reviewed scientific data suggest and support the four feeding behaviour typologies suggested by Fernández et al. (2011) in growing-finishing pigs based on the number and size of daily feeder visits (*nibbler* and *meal eater* pigs) and on the rhythm of ingesta (*fast* and *slow eater* pigs): *nibbler-fast eater, nibbler-slow eater, meal-fast eater and meal-slow eater pig.*

Table 2.2. Correlation results between feeding behaviour habits obtained in different studies.

	TVs (feeder visits/d)[1] or TMs (meals/d)[2]							**TD (minutes spent eating/d)[3]**							**VS (feed consumed/visit)[4] or MS (feed consumed /meal)[5]**						
References[6]	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**1**	**2**	**3**	**4**	**5**	**6**	**7**
TD (minutes spent eating/d)[3]	0.50	-0.02	0.25	0.17	-0.06	-0.29 to 0.14	0.48														
VS (feed consumed/visit)[4] or MS (feed consumed /meal)[5]	-0.76	-0.43***	-0.78***	-0.84*	-	-0.84*to -0.77*	-0.84	-0.16	-0.01	-0.04	0.01	-	-0.05 to 0.30*	-0.35							
FR (feed consumed/min)[7]	-0.20	-0.09	0.08	-0.26*	-0.1	-0.24 to 0.30	-0.31	-0.66	-0.76***	-0.59***	-0.79*	-0.31***	-0.78* to -0.67*	-0.83	0.25	0.27***	0.14	0.34*	-	-0.08 to 0.23	0.42

[1] TVs (total number of feeder visits per pig and day). [2]TMs (total number of meals per pig and day according to each paper methodology; where a meal is: the successive feeder visits within five minutes (De Haer and Merks, 1992); the successive feeder visits within two minutes (Labroue et al., 1994): the successive visits within 28.3 min intervals (Hyun et al., 1997). Young and Lawrence, (1994), Rauw et al. (2006), Fernández et al. (2011) and Garrido-Izard et al. (2020) analysed the daily total number of feeder visits. [3] TD (total minutes spent eating per pig and day). [4] VS (feed consumed per feeder visit per pig). [5] MS (feed consumed per meal per pig). [6] References: (1) De Haer and Merks, 1992 (Dutch Landrace, 25-35 to 100 kg BW, boars and gilts), (2) Labroue et al., 1994 (Large White and French Landrace, from 35 to 95-100kg BW, boars and castrated males), (3) Young and Lawrence, 1994 (Large White x Landrace, initial weight of 32 kg BW, males and females), (4) Hyun et al., 1997 (PIC Line 26 males x Camborough females, from 27 to 82kg BW, boars, barrows and gilts), (5) Rauw et al., 2006 (Duroc, from 38 to 130kg BW, barrows), (6) Fernández et al., 2011 (Pietrain) and (7) Garrido-Izard et al., 2020 (Landrace, 35-50 to 107-165kg BW, males). [7]FR (feed intake per minute spent eating). *, **, *** stand for $P < 0.05$, $P < 0.01$ and $P < 0.001$.

2.1.2. Automatic feeding systems to record feeding behaviour habits of growing-finishing pigs

Different types of automatic feeding systems exist in the market to record FBHs of group-housed growing-finishing pigs. In these systems, pigs are individually identified with a data-carrying transponder with a unique code per pig detected by the reader system installed in the trough (Maselyne et al., 2014). Most of the systems record the start and end time, the duration and the amount of feed ingested in each feeder visit. Pig body weight (BW) can be registered by the installation of a load cell; from these data, the different FBHs parameters can be calculated.

One of the available automatic feeding systems is the IVOG-Station (Individual feed intake recording "in group housing", Instentec B.V., Marknesse, the Netherlands; Figure 2.1). This system consists of a dry-single space feeder placed on a load cell with an adjustable fence that provides head and neck protection for the pig in front of the feeder. This system has been used in the studies of De Haer and Merks, (1992), De Haer et al. (1993), De Haer and de Vries, (1993), Georgsson and Svendsen, (2001,2002), Rauw et al. (2006) and Fernández et al. (2011).

Figure 2.1. IVOG – Station for individual feed intake recording in group housing (Instentec B.V., Marknesse, the Netherlands) used in De Haer and Merks, (1992), De Haer et al. (1993), De Haer and de Vries, (1993), Georgsson and Svendsen, (2001,2002), Rauw et al. (2006) and Fernández et al. (2011) studies (Source: www.insentec.eu).

Another type of automatic feeding system is the Compident Pig-MLP (Schauer Agrotonic, Austria; Figure 2.2); which can feed growing-finishing pigs ad libitum and ration up to four different feeds at the same time. Carcò et al. (2018) used this system provided with lateral barriers to avoid competition among pigs during the feeder visit together with a gate placed in front of the trough that permits only one pig inside the feeder. In the study of Garrido-Izard et al. (2020) the Compident MLP (Schauer Agrotonic GmbH, Austria) was also used and was equipped with an individual animal scale with lateral barriers to determine individual animal weight from 35 to 120 kg BW by measuring the weight of the front and back parts of the pig.

A) B)

Figure 2.2. Compident MLP (Schauer Agrotonic GmbH, Austria) used in the study of Garrido-Izard et al. (2020). (A) Weighing scale (B) Feeding station used during the experiment (Source: Garrido-Izard et al., 2020).

Labroue et al. (1994) used a similar system to the one used by Garrido-Izard et al. (2020) referred to as "ACEMA 48" feeders (Figure 2.3). This system consists of a trough that weighs the feed and a gate to avoid the entrance of more than one pig into the trough at the same time. Feed is weighed before and after each visit and if the amount of remaining feed after the visit of a pig is below 400 g the hoper is refilled up to 1200 g.

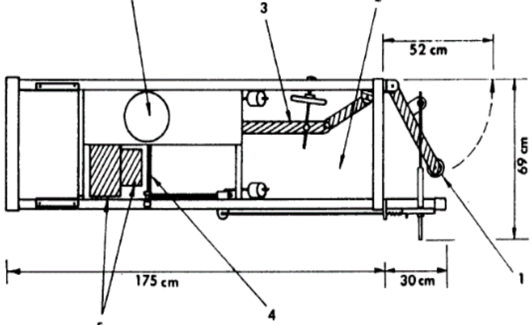

Figure 2.3. Electronic feeding station refered as ACEMA "48" (developed by Centre d'Etudes du Machinisme Agricole, du Génial Rural et des Eaux et Forêts and ACEMO, France) used in the study of Labroue et al., (1994). (1) Access door to the feeder. (2) Access corridor to the trough. (3) Adjustable side. (4) Trough door. (5) Feed hopper. (6) Mechanism to fill up the trough. (Source: Labroue et al., 1994).

Hyun et al. (1997) used an automatic feeding system (F.I.R.E., Hunday Electronics, Newcastle-upon-Tyne, UK) which consists of a trough connected to a load cell equipped with a full-length protective crate in front of the trough to prevent the entrance of more than one pig at the same time. Hyun and Ellis, (2001,2002) used a similar automatic feeding system with a crate in front of the trough (Osborne Industries, Osborne, KS). On the other hand, Brown-Brandl et al. (2013) developed a system to record the TD per pig and day in a commercial trough by a radio-frequency identification system in growing-finishing pigs with the objective to analyse FBHs under a feeder competency similar to the one existing under commercial conditions (Figure 2.4).

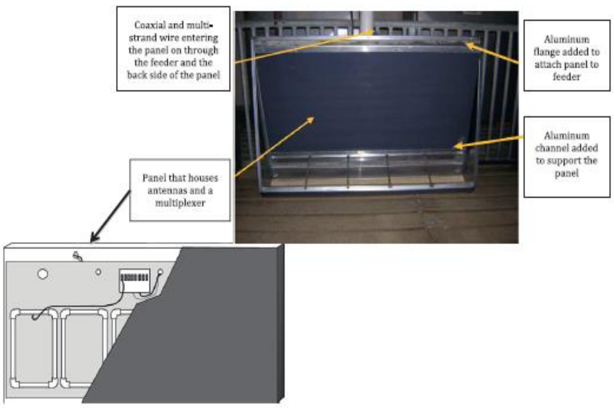

Figure 2.4. Schema of the panel and a photo of the panel after installation (Brown-Brandl et al., 2013).

It is known that the type of automatic feeding system used influences FBHs of growing-finishing pigs (Georgsson and Svendsen, 2002; Maselyne et al., 2015). The existence or not of lateral barriers to protect the head and neck while the pig is eating, or the presence or not of a gate to prevent the access of more than one pig to the feeder influence FBHs. In fact, the model of the meta-analysis of Averós et al. (2012) predicted that the use of protection barriers within individual feeders increased TD, reduced TVs, FR and feed conversion ratio (FCR) compared to when using feeders without protection barriers. Moreover, Bruininx et al. (2001), comparing weaning pigs allotted in the IVOG feeding station versus pigs allotted in commercial single-space dry feeders for 34 days, obtained higher average daily feed intake (ADFI) during the first 13 days for the pigs reared in the IVOG system but for the remaining 21 days and overall the average daily gain (ADG) and FCR did not differ between systems. Those results are partially in agreement with those obtained in growing-finishing pigs, in which a higher ADFI and FCR were obtained in pigs fed with IVOG stations compared to the ones fed with conventional feeders (Georgsson and Svendsen, 2001); whereas similar ADG but lower ADFI and FCR were reported in growing- (Hyun and Ellis, 2001) and finishing-pigs (Hyun and Ellis, 2002) fed by electronic feeders compared to those pigs fed by conventional feeders. The reasons for the lower ADFI or improved FCR in pigs fed by electronic feeders compared to conventional feeders, may be a consequence of lower feed waste due to the design of the feeder or because only one pig can access the trough of the automatic feeding systems at one time, reducing the competency in the feeder if it is compared to conventional feeders, suggesting that ADFI may be overestimated in pigs fed by conventional feeders.

2.1.3 The relation between feeding behaviour habits with performance and carcass quality traits

In the present subsection, the available scientific data regarding the influence of FBHs on performance and carcass quality traits of growing-finishing pigs is presented (Tables 2.3, 2.4 and 2.5). Broadly speaking, the reported correlations are moderate with a maximum of 0.70 between MS and ADFI.

ADFI is directly related with energy and nutrient intake (Nyachoti et al., 2004), whereas FBHs such as VS and total number of meals (TMs) or TVs affect the digestibility of nutrients (De Haer and de Vries, 1993; Jia et al., 2021). It follows that the use of feed energy and nutrients depend on different metabolic mechanisms, which may be modified by FBHs such as meal frequency (Le Naou et al., 2014; Chassé et al., 2021). In humans, Toschke et al. (2005) and Schwarz et al. (2011) showed that, besides caloric intake, meal frequency is an additional factor that affects BW and composition. Whilst in pigs recent research indicates that MS and FR are the two FBHs most strongly and positively related with ADFI, ADG and BW. However, with little effect on FCR (De Haer and Merks, 1992; Labroue et al., 1994; Hyun et al., 1997; Rauw et al., 2006; Fernández et al., 2011; Carcò et al., 2018; Garrido-Izard et al., 2020).

Table 2.3. Correlation results between the feeding behaviour habits and the average daily feed intake (ADFI).

	ADFI (kg of feed/d)[1]								
References[2]	1	2	3	4	5	6	7	8	9
TVs (feeder visits/d)[3] or TMs (meals/d)[4]	0.48	-0.06	-0.16**	0.07	-0.28*	-0.19**	-0.11 to 0.01	-0.003	0.20
TD (minutes spent eating/d)[5]	0.59	0.55**	0.26***	0.51***	0.25*	0.28***	-0.02 to 0.39*	-0.14	0.28
VS (feed consumed/visit)[6] or MS (feed consumed/meal)[7]	0.03	0.02	0.42***	0.40**	0.70*	-	0.28* to 0.43*	0.20*	0.21
FR (feed consumed/min)[8]	0.17	0.21**	0.37***	0.21	0.31*	0.26***	0.32* to 0.59*	0.51***	0.27

[1] ADFI (average daily feed intake). [2] References: (1) De Haer and Merks, 1992 (Dutch Landrace, 25-35 to 100 kg BW, boars and gilts), (2) De Haer et al., 1993 (Dutch Landrace and Great Yorkshire, 25-35 to 10 kg BW, boars and gilts), (3) Labroue et al., 1994 (Large White and French Landrace, from 35 to 95-100kg BW, boars and castrated males), (4) Young and Lawrence, 1994 (Large White x Landrace, initial weight of 32 kg BW, males and females), (5) Hyun et al., 1997 (PIC Line 26 males x Camborough females, from 27 to 82kg BW, boars, barrows and gilts), (6) Rauw et al., 2006 (Duroc, fro m 38 to 130kg BW, barrows), (7) Fernández et al., 2011 (Pietrain), (8) Carcò et al., 2018 (Topigs Talent x PIC, from 86 to 145kg BW, barrows) and (9) Garrido-Izard et al., 2020 (Landrace, 35-50 to 107-165kg BW, males). [3]TVs (total number of feeder visits per pig and day). [4] TMs (total number of meals per pig and day according to each paper methodology; where a meal is: the successive feeder visits within five minutes (De Haer and Merks, 1992): the successive feeder visits within two minutes (Labroue et al., 1994): the successive feeder visits within 28.3 min intervals (Hyun et al., 1997). Young and Lawrence, (1994), Rauw et al. (2006), Fernández et al. (2011) and Garrido-Izard et al. (2020) analysed the daily total number of feeder visits per pig. [5]TD (total duration spent eating per pig and day). [6] VS(amount of feed intake per feeder visit). [7]MS (amount of feed intake per meal). [8]FR (feed intake per minute spent eating). *, **, *** stand for $P < 0.05$, $P < 0.01$ and $P < 0.001$.

Labroue et al. (1997) results suggested that breeding to increase appetite would lead to *fast meal* eater pigs instead of *nibbler* pigs and concluded that MS and FR are the two FBHs parameters most related with performance and are correlated with ADG. In agreement with these results, Carcò et al. (2018) found that FR is the most highly correlated FBH with ADFI, final BW and ADG; however, it is not correlated with gain to feed ratio and they suggested that the manipulation of FR would affect feed intake and in consequence growth performance. In the same direction, Andretta et al. (2016a) found a negative correlation between MS and FR with gain to feed ratio, suggesting that higher MS and FR influence nutrient utilization negatively, probably as a consequence of its effects on the passage rate or digestive enzyme activity (De Haer and de Vries, 1993; De Haer et al., 1993). However, only four studies have been found regarding the influence of MS and FR on feed efficiency and all have reported low correlations (Labroue et al., 1994; Hyun et al., 1997; Carcò et al., 2018; Garrido-Izard et al., 2020). The only FBH with significant influence on FCR is TD with a positive correlation (Labroue et al., 1994; Hyun et al., 1997; Carcò et al., 2018; Garrido-Izard et al., 2020); which suggests that pigs spending a shorter time eating have better FCR. To sum up, the correlations reported by the reviewed authors suggest that increases in FR are associated with higher ADFI, higher ADG and less TD; in addition, increases in MS are associated with higher ADFI and higher growth rates. However, these increases in FR and MS did not show any influence on feed efficiency.

Table 2.4. Correlation results between feeding behaviour habits and growth parameters obtained in different studies.

	ADG (g/d)[1]						Final BW (kg)		FCR (kg/kg)[2]			
References[3]	**1**	**2**	**3**	**4**	**5**	**6**	**3**	**6**	**2**	**3[a]**	**6[a]**	**7[a]**
TVs (feeder visits/d)[4] or TMs (meals/d)[5]	0.18**	0.01	-	-0.16*	-0.26* to -0.09	-0.07	-0.02	-0.11	0.00	0.14	-0.11	0.18
TD (minutes spent eating/d)[6]	-0.06	0.17***	0.02	0.19**	0.12 to 0.39*	-0.25*	-0.01	-0.25*	0.15**	-0.24*	-0.22*	0.33
VS (feed consumed/visit)[7] or MS (feed consumed/meal)[8]	0.41**	0.19***	0.38*	-	0.28* to 0.54*	0.25*	0.29*	0.27**	0.02	-0.29*	0.12	-0.08
FR (feed consumed/min)[9]	0.50**	0.20***	0.32*	0.38***	0.10 to 0.43*	0.54***	0.35*	0.52***	-0.00	0.06	0.15	-0.16

[1] ADG (average daily gain). [2] FCR (feed conversion ratio). [3] References: (1) De Haer et al., 1993 (Dutch Landrace and Great-Yorkshire, 25-35 to 100 kg BW, boars and gilts), (2) De Haer and Merks, 1992 (Large White and French Landrace, from 35 to 95-100kg BW, boars and castrated males), (3) Hyun et al., 1997 (PIC Line 26 males x Camborough females, from 27 to 82kg BW, boars, barrows and gilts), (4) Rauw et al., 2006 (Duroc, from 38 to 130kg BW, barrows), (5) Fernández et al., 2011 (Pietrain), (6) Carcò et al., 2018 (Topigs Talent x PIC, from 86 to 145kg BW, barrows) and (7) Garrido-Izard et al., 2020 (Landrace, 35-50 to 107-165kg BW, males). [4]TVs (total feeder visits per pig and day). [5] TMs (total meals per pig and day according to each paper methodology; where a meal is: the successive feeder visits within five minutes (De Haer et al., 1993): the successive feeder visits within two minutes (De Haer and Merks, 1992): the successive visits within 28.3 min intervals (Hyun et al., 1997). Rauw et al. (2006), Fernández et al. (2011), Carcò et al. (2018) and Garrido-Izard et al. (2020) analysed the daily number of feeder visits. [6]TD (total duration spent eating per pig and day). [7] VS (amount of feed intake per feeder visit). [8]MS (amount of feed intake per meal). [9]FR (feed intake per minute spent eating). *, **, *** stand for $P < 0.05$, $P < 0.01$ and $P < 0.0001$.

Many authors have reported significant correlations between TVs and performance (De Haer and Merks, 1992; Labroue et al., 1994; Hyun et al., 1997; Rauw et al., 2006; Fernández et al., 2011). In fact, De Haer and Merks, (1992) and De Haer et al. (1993) found a positive correlation of TVs with ADFI and ADG, respectively; whereas Labroue et al. (1994), Hyun et al. (1997), Rauw et al. (2006) and Fernández et al. (2011) reported negative correlations, with neither of the cited studies showing an influence on FCR. Moreover, Schulze et al. (2003) concluded that TVs is independent from growth performance in boars. However, several authors have analysed the effect of feeding frequency (feeding pigs at certain intervals of time during the day) on the performance of growing-finishing pigs with contradictory results. In the 70s Allee et al. (1972) reported that 22 kg BW pigs fed ad libitum were less efficient than pigs fed a single daily meal (2h/24h). A later study with heavier pigs (from 25-35 to 100 kg BW) also concluded that the more efficient pigs individually housed have fewer meals per day and shorter TD with higher MS (De Haer et al., 1993). In addition, Le Naou et al. (2014) observed that 30 kg BW pigs allotted in individual cages and fed with the same amount of feed twice per day improved their ADG by 6.4% and their FCR by 4% compared to pigs fed 12 times per day; results in agreement with Liu et al. (2016). These results could be explained because pigs performing fewer meals per day may reduce their maintenance requirements (Sharma et al., 1973). However, energy requirements for maintenance change depending on the physical activity of the pig. In fact, compared to resting, when a sow is standing she almost doubles her body heat production (Noblet et al., 1993) and Mc Donald et al. (1988) reported that body heat production rate increases by 95% above the resting level when a 40 kg BW pig is standing. Van Milgen et al. (2000) observed that body heat production due to activity represents between 8 and 13% of the metabolizable energy intake in growing pigs. Therefore, the hypothesis is that more meals per day would increase energy requirements for maintenance and therefore, penalize performance. In addition, pigs fed once or twice a day are generally less sensitive to the excitation associated with the distribution of feed than animals receiving multiple small meals, using less energy (Friend and Cunningham, 1964). However, Schneider et al. (2011) studying the effect of restricted feeding frequency for 6 to 2 meals per day with a similar amount of feed provided in both treatments (68 and 114 kg BW pigs allotted in pens of 10 pigs) observed a positive effect of the number of meals, with an increase in ADG and an improvement in FCR. Similarly, Colpoys et al. (2016) obtained lower ADG and ADFI in growing gilts fed twice per day than fed ad libitum with no effect on FCR. Those results are partially in agreement with those reported by Jia et al. (2021), who concluded that feeding the same DFI by one, two or five times a day modifies digestion processes and performance. In fact, ADG together with the apparent total tract digestibility of protein and fat improved with five feeding times per day compared to feeding once per day, however, those pigs had poorer FCR (Jia et al., 2021). Therefore, the reviewed studies indicate that the feeding regimen, specifically daily feeding times which may be compared to TVs or TMs in ad libitum fed growing-finishing pigs, the system most used in commercial conditions, influence performance results. However, when modifying the feeding regimen frequency strategy, MS and FR may be also modified and both are strongly correlated with ADFI and ADG, although not with FCR.

To sum up, most of the reviewed papers show a positive influence of TD, MS and FR on ADFI, but only MS and FR are positively related with ADG. Moreover, the influence of TVs on ADFI and ADG is not clear and most correlations between FBHs and FCR are low and contradictory.

On the other hand, despite the great economic interest in achieving pigs with specific carcass quality traits, few studies have analysed the influence of FBHs on carcass quality traits (Table 2.5). The three studies found report strong and positive correlations between ADFI, MS, and FR with backfat thickness; whereas one out of the two studies found show a strong and negative influence between ADFI, MS and FR with lean percentage (De Haer et al., 1993; Labroue et al., 1994; Carcò et al., 2018). These results suggest that pigs eating faster in larger meals are fatter than pigs eating slower in smaller meals. In the same direction, Rauw et al. (2006) studying growing-finishing pigs (Duroc barrows) allotted in group and fed ad libitum, observed that those pigs which ate faster, ate more and spent less time eating had higher fat deposition values than those eating slower. Similarly, Kavlak and Uimari, (2019) reported positive correlations between FR and backfat thickness and Toschke et al.

(2005) and Stote et al. (2007) concluded that large energy intake meals led to higher adipose tissue deposition compared to eating in smaller meals in humans. In addition, Carcò et al. (2018) observed a high influence of FR on carcass quality traits in grouped housed barrows. In fact, it was observed that pigs eating faster (52.1 to 118.9g/min) and more (ADFI of 2.85 kg/d) had significantly higher carcass weights (16%), a higher proportion of fat in the carcass (14%) and 4% lower proportions of carcass lean cuts than pigs eating slower (12.6 vs 38.2g/min) and less (ADFI of 2.29 kg/d). By contrast, Colpoys et al. (2016) did not find any correlation between FR, ADFI, ADG, protein or fat deposition and lean deposition, estimated by X-ray tomography; although the study was conducted with a small number of gilts fed ad libitum or twice a day. On the other hand, low correlations have been reported between TVs and TD with carcass quality traits (De Haer et al., 1993; Labroue et al., 1994; Carcò et al., 2018). In short, although with only few studies, all show similar results regarding the correlation between FBHs and carcass quality traits, suggesting that the pigs that eat more, with higher MS and faster have thicker backfat thickness and lower lean percentage values.

Table 2.5. Correlations results between feeding behaviour habits and carcass quality traits obtained by different studies.

	Backfat thickness (mm)			Loin depth (mm)	Lean percentage (%)	
References[1]	**1**	**2**	**3**	**3**	**1**	**3**
ADFI[2]	0.35**	0.36***	0.59***	0.04	-0.39**	-0.07
TVs (feeder visits/d)[3] or TMs (meals/d)[4]	-0.15*	-0.07	0.06	-0.01	0.06	0.04
TD (minutes spent eating/d)[5]	-0.05	0.08	-0.05	-0.01	-0.03	0.06
VS (feed consumed/visit)[6] or MS (feed consumed/meal)[7]	0.33**	0.16**	0.09	0.08	-0.21**	-0.05
FR (feed consumed/min)[8]	0.35**	0.13*	0.27*	-0.028	-0.29**	-0.06

[1]References (1) De Haer et al., 1993 (Dutch Landrace and Great Yorkshire, 25-35 to 100 kg BW, boars and gilts), (2) Labroue et al., 1994 (Large White and French Landrace, from 35 to 95-100kg BW, boars and castrated males) and (3) Carcò et al., 2018 (Topigs Talent x PIC, from 86 to 145kg BW, barrows). [2] ADFI (average daily feed intake). [3]TVs (total number of feeder visits per pig and day). [4] TMs (total number of meals per pig and day according to each paper methodology; where a meal is: the successive feeder visits within five minutes (de Haer et al., 1993): the successive feeder visits within two minutes (Labroue et al., 1994). Carcò et al. (2018) analysed the daily number of feeder visits. [5]TD (total duration spent eating per pig and day). [6] VS (amount of feed intake per feeder visit). [7]MS (amount of feed intake per meal). [8]FR (feed intake per minute spent eating). *, **, *** stand for $P < 0.05$, $P < 0.01$ and $P < 0.001$.

To our knowledge, only four studies have analysed the influence of FBHs on fat and lean deposition (Table 2.6). In terms of fat deposition, the three found studies reported positive and significant correlations between TD and fat deposition (Rauw et al., 2006; Colpoys et al., 2016; Carcò et al., 2018), whereas two out of the four cited studies reported positive and significant correlations between ADFI and FR with fat deposition. On the other hand, the correlations between FBHs and lean deposition are moderate to low. In fact, De Haer et al. (1993) and Carcò et al. (2018) found significant and positive correlations between ADFI and body lean tissue and protein deposition, respectively. While only Colpoys et al. (2016) found a significant correlation of 0.35 between TD and body lean tissue and only Carcò et al. (2018) reported a significant correlation between FR and body protein deposition. In brief, the results suggest that the FBHs that may influence fat deposition are ADFI, TD, MS and FR. However, results are scarce and controversial regarding the relationship between FBHs and lean or protein deposition.

Table 2.6. Correlations between feeding behaviour habits and body composition obtained by different authors.

	Body fat deposition (g/d)				Body lean deposition (g/d)		
References[1]	1	2	3	4*	1	3	4*
ADFI (kg of feed/d)[2]	0.51**	0.68***	-	-0.15	0.37**	-	0.23*
TVs (feeder visits/d)[3]	-	-0.20**	-	-0.07	-	-	-0.04
TD (minutes spent eating/d)[4]	-	0.21***	0.42*	0.36***	-	0.35*	0.16
VS (feed consumed/meal)[5]	-	-	-	0.26*	-	-	0.15
FR (feed consumed/minute)[6]	-	0.29***	-0.21	0.43***	-	-0.20	0.41***
ADG (g/d)[7]	-	0.66***	-	-	-	-	-

[1]References (1) De Haer et al., 1993 (Dutch Landrace and Great Yorkshire, 25-35 to 100 kg BW, boars and gilts), (2) Rauw et al., 2006 (Duroc, from 38 to 130kg BW, barrows), (3) Colpoys et al., 2016 (Topics Talent x PIC, from 55 to 112 kg BW, female) and (4) Carcò et al., 2018 (Topigs Talent x PIC, from 86 to 145kg BW, barrows). *Carcò et al. (2018) calculated lipid and protein retention (g/d). [2] ADFI (average daily feed intake). [3]TVs (total number of feeder visits per pig and day). [4] TD (total duration spent eating per pig and day). [5] VS (amount of feed intake per feeder visit). [6]FR (feed intake per minute spent eating). [7]ADG (average daily gain). *, **, *** stand for $P < 0.05$, $P < 0.01$ and $P < 0.0001$.

2.2. Factors affecting feeding behaviour habits of growing-finishing pigs

2.2.1. Internal factors

2.2.1.1. Age

Pigs change their FBHs with age. As pigs grow, ADFI increases; however, the magnitude of the ADFI increase is variable among studies. Labroue et al. (1994; Figure 2.5) and Andretta et al. (2016a) reported an increase in ADFI of around 60% in pigs of similar BW, from 35 to 95-100 kg BW and from 30 to 100 kg BW, respectively; whereas Carcò et al. (2018; Figure 2.6) reported a smaller quadratic increase in ADFI in pigs from 47 to 145 kg BW.

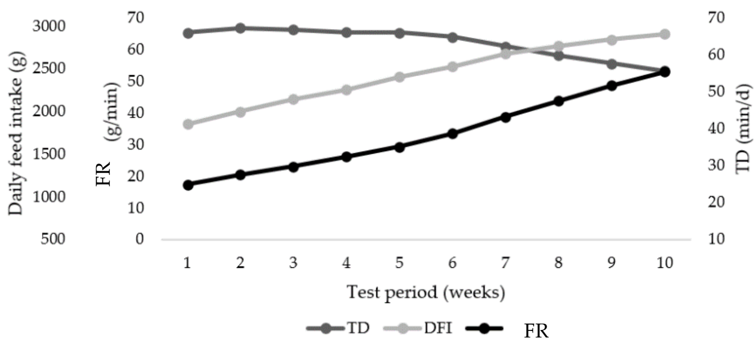

Figure 2.5. Evolution of daily feed intake (DFI), time spent eating (TD) and feeding rate (FR) throughout the experimental period of Large White and French Landrace pigs (Adapted from: Labroue et al., 1994).

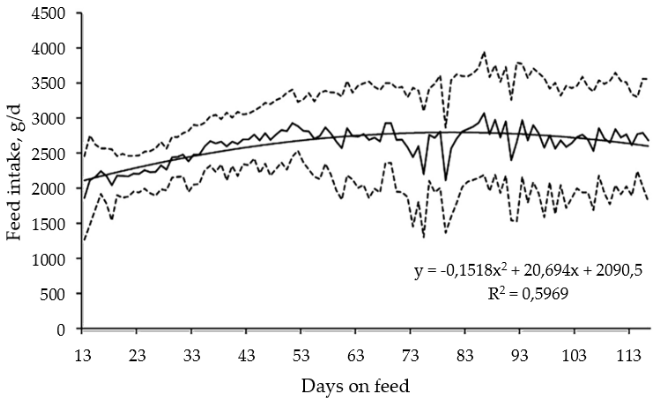

Figure 2.6. Daily feed intake of growing pigs with increasing days on feeding regimes (n = 92, Mean = thick line; mean ± standard deviation = dotted line, trend = thin line; pigs from 47 to 145 kg BW (Adapted from: Carcò et al., 2018).

On the other hand, pigs eat their ADFI from frequent feeder visits in weaned pigs to few and larger visits in sows together with an increase in FR (Auffray and Marcilloux, 1980; Bigelow and Houpt, 1988). The changes in TVs and VS may be due to larger stomach size as pigs grow. In fact, stomach size increases from 30 mL to 3.5 L from birth to a finishing pig (Lærke and Hedemann, 2012). Therefore, it could be hypothesized that 20 kg BW pigs ingesta is limited by their stomach capacity and in consequence, they carry out a higher number of small feeder visits to achieve the desired ADFI. In terms of TVs or TMs, Labroue et al. (1994) reported an increase in TVs of 28% in pigs from 40 to 60 kg BW and a reduction of 11% in pigs from 60 to 90 kg BW; whereas Hyun et al. (1997) and Gonyou and Lou, (2000) obtained a reduction of 17 in TMs and of 24% in TVs, respectively, in pigs of similar BW. In addition, Andretta et al. (2016a) and Carcò et al. (2018; Figure 2.7) reported small variations in terms of TMs and TVs as pigs grew with large variability among pigs, respectively.

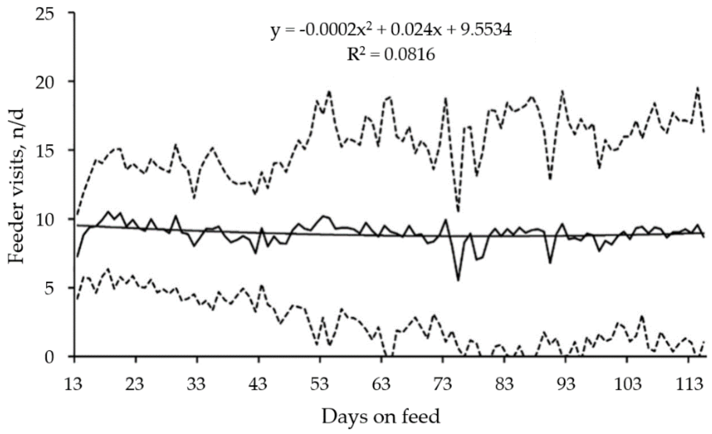

Figure 2.7. Feeder visits of growing pigs with increasing days on feeding regimes (n = 92, Mean = thick line; mean ± standard deviation = dotted line, trend = thin line; pigs from 47 to 145 kg BW (Adapted from: Carcò et al., 2018).

In addition, increases from 45 to 123% in MS have been found in the available scientific data (Labroue et al., 1994; Hyun et al., 1997; Andretta et al., 2016a; Carcò et al., 2018; Figure 2.8). In particular, Andretta et al. (2016a) reported an increase from 194 to 301 g/feeder visit.

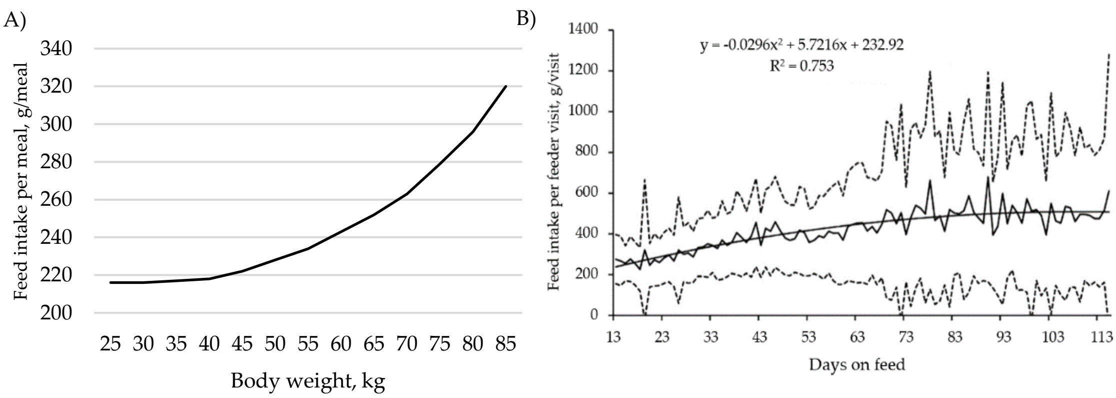

Figure 2.8. A) Regression of feed intake per meal on body weight (BW); feed intake per meal = 257.2 (SE 26.28) - 2.50 (SE 1.003) BW + .38 (SE .009) BW^2, R^2 = 0.14 (Adapted from: Hyun et al., 1997). B) Feed intake per visit of growing pigs with increasing days on feeding regimes (n = 92, Mean = thick line; mean ± standard deviation = dotted line, trend = thin line; pigs from 47 to 145 kg BW (Adapted from: Carcò et al., 2018).

On the other hand, reductions from 5 to 45% in TD (Figure 2.9) together with increases from 22 to 133% in FR as pigs grow have been reported (Labroue et al., 1994; Hyun et al., 1997; Gonyou and Lou, 2000; Andretta et al., 2016a). As an example, Gonyou and Lou, (2000) concluded that 40kg BW pigs spend 16% more time eating (102 vs 85.6 min/d, 40 and 80 kg BW pigs, respectively) and eat 22% slower (35.6 vs 43.5 g/min, 40 and 80 kg BW pigs, respectively) than 80kg BW pigs. By contrast, Brown-Brandl et al. (2013) reported an increase in TD up to 95-105 days of age with a plateau at 76.7 min/day and pig in grouped-housed growing-finishing pigs.

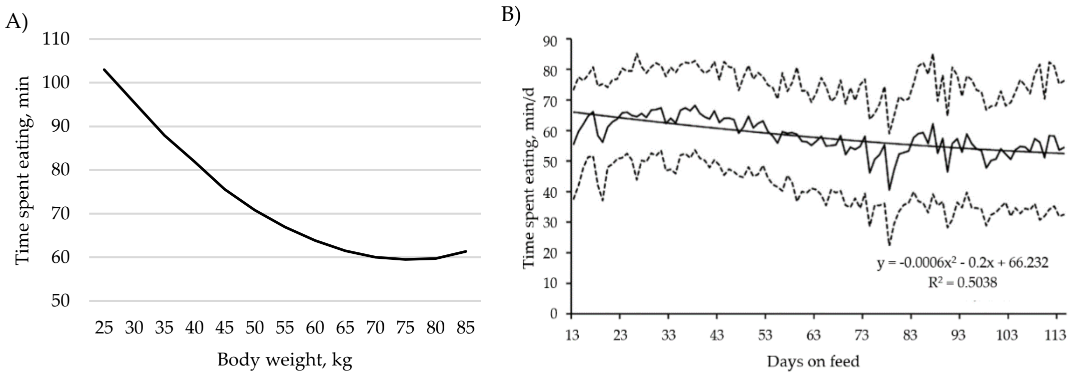

Figure 2.9. A) Regression of feeder occupation time per day = 136.9 (SE 6.71) - 1.66 (SE .256) BW + .009 (SE .0023) BW^2, R^2 = 0.24 (Adapted from: Hyun et al., 1997). B) Feeding time of growing pigs with increasing days on feeding regimes (n =92, Mean = thick line; mean ± standard deviation = dotted line, trend =thin line; pigs from 47 to 145 kg BW (Adapted from: Carcò et al., 2018).

In particular, Andretta et al. (2016a) reported an increase in FR from 31.4 g/min to 50.2 g/min in pigs from 30 to 100 kg BW. Hyun et al. (1997) adjusted FR evolution to a linear increase from 25 to 85 kg BW, whereas Carcò et al. (2018) adjusted a quadratic evolution in pigs from 47 to 145 kg BW, with larger variability among individuals during the last 40 days of fattening (Figure 2.10).

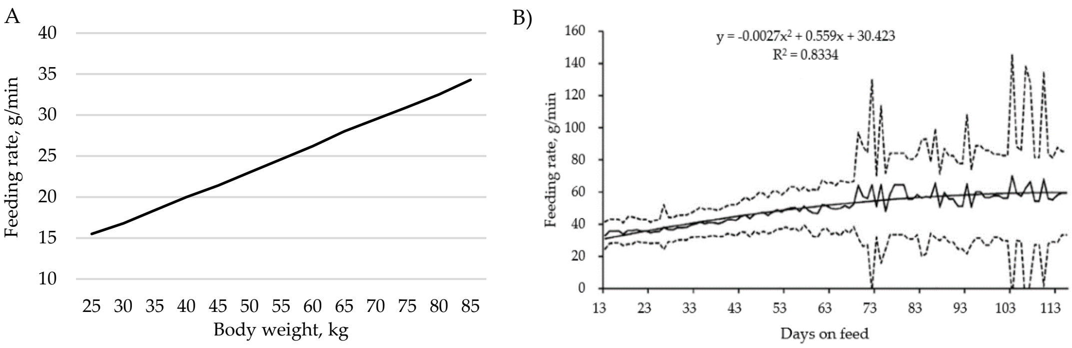

Figure 2.10. A) Regression of feeding rate on body weight (BW); feeding rate = 8.32 (SE .616) + .378 (SE .011) BW, R^2 = 0.43 (Adapted from: Hyun et al., 1997). B) Feeding rate of growing pigs with increasing days on feeding regimes (n =92, Mean = thick line; mean ± standard deviation = dotted line, trend =thin line; pigs from 47 to 145 kg BW (Adapted from: Carcò et al., 2018).

For instance, as growing-finishing pigs grow, ADFI, VS, MS and FR increase, whereas small variations or even decreases in TVs, TMs and TD have been reported (Labroue et al., 1994; Hyun et al., 1997; Gonyou and Lou, 2000; Andretta et al., 2016a; Carcò et al., 2018). However, a large variability in the percentage of increase or decrease in all FBHs patterns exists among studies (Table 2.7).

Table 2.7. Effect of age on the feeding behaviour habits of growing-finishing pigs.

References	Initial and final BW, kg	ADFI (kg of feed/d)[1]	TVs (feeder visits/d)[2]	TMs (meals/d)[3]	TD (minutes spent eating/d)[4]	VS (feed consumed/ feeder visit)[5]	MS (feed consumed/ meal)[6]	FR (feed consumed/min)[7]
Labroue et al., 1994**	35 to 95-100kg	1.75 to 2.81 (increased by 60%)	From 40 to 60kg: from 14 to 18 (increased by 28%) From 60 to 90kg: from 18 to 16 (reduced by 11%)		From 63.7 to 49.6 (reduced by 22%)		From 278 to 621 (increased by 123%)	From 28.6 to 58.8 (increased by 106%)
Hyun et al., 1997	27 to 82kg	1.55 to 1.9kg/d (increased by 23%)		From 7.25 to 6 (reduced by 17%)	From 109 to 60 (reduced by 45%)		From 220 to 320 (increased by 45%)	From 15 to 35 (increased by 133%)
Gonyou and Lou, 2000	40 vs 80kg	-	40 kg BW: 55.6 80 kg BW: 42.2 (reduced by 24%)		40 kg BW: 102 80 kg BW: 85.6 (reduced by 16%)	-	-	40 kg BW: 35.6 80 kg BW: 43.5 (increased by 22%)
Andretta et al., 2016a	30 to 100kg	2.13 to 3.4 (increase by 60%)		From 11 to 11.3 (increased by 3%)	From 68.3 to 65.1 (reduced by 5%)		From 194 to 301 (increased by 55%)	From 31.4 to 50.2 (increased by 60%)
Carcò et al., 2018	47 to 145 kg	Increased	Small variations		Reduced	Increased		Increased

[1]ADFI (average daily feed intake). [2]TVs (total number of feeder visits per pig and day). [3]TMs (total number of meals per pig and day according to each paper methodology; where a meal is: the successive feeder visits within two minutes (Labroue et al., 1994): the successive visits within 28.3 min intervals (Hyun et al., 1997): the successive feeder visits within one minute (Andretta et al., 2016a). Gonyou and Lou, (2000) reported the number of entrances into the feeder and Carcò et al. (2018) reported the daily number of feeder visits.[4]TD (total minutes spent eating per pig and day). [5]VS (feed consumed per feeder visit). [6]MS (feed consumed per meal). [7]FR(feed intake per min spent eating). **Predicted values from a model.

As FBHs change with age, its predictability is of interest. The repeatability approach is an intra-class correlation which is defined as the proportion of the total variance due to variability between individuals (Falconer and Mackay, 1996; Hyun et al., 1997; Everitt, 2005) and takes values between 0 and 1. The greater the repeatability value is, the greater the parameter evaluated can be predicted. The repeatability coefficient (RA) is estimated as:

$$\text{RA} = \frac{\sigma_u^2}{\sigma_u^2 + \sigma^2}$$

De Haer and Merks, (1992) and Hyun et al. (1997) computed the repeatability estimates in group-housed growing-finishing pigs and found the lowest repeatability values (< 0.3) for ADFI, both in short (2-week) and longer periods (from 25 to 100 kg BW and from 27 to 80 kg BW pigs, respectively). In a short period, both authors found medium-high repeatability values for TVs, TD, MS and FR (between 0.35 and 0.61). However, in longer periods they found lower and more variable values. Knowledge of the repeatability of FBHs under different production conditions is of interest in order to know if FBHs are maintained throughout the growing-finishing period and can be related to productive outcomes.

2.2.1.2. Breed

Breed influences FBHs of growing-finishing pigs (De Haer and de Vries, 1993; Labroue et al., 1997; Fernández et al., 2011). Fernández et al. (2011) classified Large White and Pietrain pigs as nibbler pigs owing to more frequent and smaller feeder visits per day than Duroc and Landrace pigs. These results are in keeping with the findings of Labroue et al. (1997) who reported more frequent smaller feeder visits for Large White pigs than Landrace pigs. Likewise, Baumung et al. (2006) observed that Large White pigs eat their ADFI in more TVs, with less TD and lower FR, whereas Landrace pigs tend to eat their DFI in fewer, larger feeder visits. In addition, Quiniou et al. (1999) concluded that Pietrain pigs eat their DFI in more frequent, smaller meals than Meishan pigs, with Large White pigs in an intermediate position. On the other hand, Landrace and Large White pigs are *fast eater* pigs, they spend less TD with higher FR than Duroc and Pietrain pigs (Fernández et al., 2011). In agreement with those results, Labroue et al. (1997) reported smaller differences in terms of FR with an average of 39.9 g/min for Large White pigs and 41.5 g/min for Landrace pigs. Theoretically, Fernández et al. (2011) described the eating pattern of different breeds as follows: Duroc pigs eat in large meals at a slow rate, Landrace pigs eat in large meals at a fast rate, Large White pigs eat in small meals at a fast rate and Pietrain pigs eat in small meals at a slow rate.

2.2.1.3. Sex

In terms of performance and carcass quality traits, differences among sexes have been reported. Most of the studies found in the literature have reported similar ADFI between females and males with males with higher ADG and in consequence, better FCR than females (Table 2.8). In terms of carcass quality traits, discrepancies between sexes have been found regarding their carcass composition, whereas the studies found report lower carcass yield and higher carcass weights for males than females (Table 2.8). These differences might be due to the different breeds or sacrifice weights among studies.

Table 2.8. Summary of the reviewed results comparing performance and carcass traits of growing-finishing pigs between sexes.

Reference	**Breed[1]**	**Kg BW**	**Final BW, kg**	**ADFI[2]**	**ADG[3]**	**FCR[4]**	**Lean vs Backfat thickness**	**Carcass yield**	**Carcass weight, kg**
Quiniou et al., 2010	(P x LW) x (L x LW)	63 days of age to 110kg	M[5] = 120.5 F[5] = 113.3	CM[5] > M = F	M = CM > F	M < F < CM	M = F in lean depth, backfat thickness and lean content	M < F	M > F
Hyunh et al., 1997	PIC Line 26 M x Camborouh F	23kg to 80 kg	M = 82.5 F = 79	No differences	M = CM > F	M < CM < F	-	-	-
De Haer and de Vries, 1993	Dutch L and Great GY	25 to 100kg	DL: M = 102.7 / F = 100.7 GY: M = 105.1 / F = 98.6	M = F	M > F	M < F	DL M leanner than DL F GY F leaner than GY M	-	-
Blanchard et al., 1999	Three genotypes (with 0, 0.25 and 0.50 D inclusion level)	30 to 90 kg		M = F	M > F	M < F	Lean and subcutaneous fat growth rates M = F	-	-
Averós et al., 2012	LW and L, LW x L D, P, H, D x P, D x H	From 20 to 100 kg		No differences between sexes	No differences between sexes	Gradual reduction of FCR in M and F with increasing feeder space allowance	-	-	-
López-Vergé et al., 2018	P x (L x LW)	30 to 90 kg	M = 91.4 F = 90.8	-	M = F, however M tended to reach market BW earlier than F	-	-	-	-
Gispert et al., 2010	(L x D) x P	117 kg	M = 111.6 F = 107.9	-	M = F	-	No differences in carcass lean between F and M	M < F	M =F
Moore et al., 2013	[LW x (L x D)]	From 20 to 53kg	M = 52.9 F = 53.4	M < F		M < F			
		From 50 to 100 kg	M = 103.5 F = 103.0	M = F	M > F	M < F	Backfat thickness: M = F	M < F	M < F

[1] (D) Duroc, (H) Hampshire, (LW) Large White, (L) Landrace, (P) Pietrain, (Y) Yorkshire. [2] (ADFI) Average daily feed intake. [3] (ADG) Average daily gain. [4] (FCR) Feed conversion ratio. [5] (CM) Castrated males, (F) Females, (M) Males.

The meta-analysis of Averós et al. (2012) did not show differences in terms of FBHs between sex. Similarly, Hyun et al. (1997) only found differences between sexes in TMs, being higher for castrated males than for entire males and females; whereas Andretta et al. (2016a) reported no differences in terms of TMs between castrated males and females. On the other hand, Cross et al. (2020) observed that females spend on average 6.2 min per day less in the feeder than castrated males; a result in line with the findings of Brown-Brandl et al. (2013). Moreover, Pichler et al. (2020) observed bigger and longer meals for growing-finishing entire males than for females with no other FBH showing differences between sex. On the contrary, Young and Lawrence, (1994) observed a tendency for smaller and shorter feeder visits in entire males than females. In addition, Andretta et al. (2016a) reported a 19.23% smaller MS for females compared to castrated males. Furthermore, Labroue et al. (1994; Table 2.9) reported lower MS, ADFI and TD in entire males than in castrated males with no significant differences in terms of TMs, TVs and FR between both groups. What is more, Andretta et al. (2016a) indicated that females had a 6.6% lower FR than castrated males (39.9 vs 42.7 g/min, females and castrated males, respectively).

Table 2.9. Feeding behaviour habits by sex (LSM ± SE) (Adapted from: Labroue et al., 1994).

Traits	Boars	Castrated males
Number visits/d	15 ± 1[a]	14 ± 1[a]
Feed intake/meal (g/meal)	373 ± 8[a]	467 ± 16[b]
Time per meal (min)	10.2 ± 0.2[a]	12.3 ± 0.4[b]
Number meals/d	6.4 ± 0.1[a]	6.0 ± 0.2[a]
Feed intake/d (g/d)	2172 ± 15[a]	2539 ± 31[b]
Eating time/d (min/d)	57.7 ± 0.6[a]	66.0 ± 1.3[b]
Rate of feed intake (g/min)	40.4 ± 0.4[a]	41.2 ± 0.9[a]

LSM (±SE): Least squares means (± Standard Error). On the same line, values with different superscripts are significantly different (t-test; $P < 0.05$).

The contradictory results regarding the effect of sex on FBHs of growing-finishing pigs could be due to the different level of competition access to the feeder among studies.

To sum up, despite the inconsistencies between studies of the impact of sex and breed on FBHs, data indicate that both factors may influence FBHs. The results concerning sex effect are confusing, suggesting that other factors, internal or external, are more deeply involved hiding any possible sex effect. Most of the authors concluded that FBHs are a specific feature of each breed. Therefore, when comparing FBHs results of different scientific data sources, age, sex and breed should be considered.

2.2.2. External factors

2.2.2.1. Environmental conditions

The predicted increase in the frequency of hot days (Rojas-Downing et al., 2017) is an important issue in pig production due to the high susceptibility of pigs to high temperatures on account of limited sweat glands and thick subcutaneous adipose tissue layer (Baumgard and Rhoads, 2013; Mayorga et al., 2019). Pigs also have a lower capacity to pant compared to other animals (Hyunh et al., 2005). Moreover, a meta-analysis, which includes publications from 1970 to 2009, showed that genetic selection for growth and lean carcasses increased the negative effects of heat stress (Renaudeau et al., 2011). In fact, the total body heat production of growing pigs has increased in the last decades owing to selection for leanness (Brown-Brandl et al., 2004). Heat stress penalizes pig performance because of the reduction in growth, increase in mortality, penalization of feed efficiency and carcass quality by increasing lipid and decreasing protein deposition (Baumgard and Rhoads, 2013; Ross et al., 2015) together with welfare issues (Hyunh et al., 2005). Although various advances have been made in nutrition, cooling systems, etc. performance continues to be penalized during hot seasons.

The impact of temperature on pigs' performance has been widely studied and the primary consequence is the reduction in ADFI when temperature increases (Quiniou et al., 2000; Le Bellego et al., 2002). Pearce et al. (2013) housed individually crossbred gilts in a climate-controlled room and animals were exposed to: 1) thermal-neutral conditions (TN) (20 °C: 35-50% Relative Humidity, RH) with ad libitum intake, 2) heat stress conditions (35 °C: 20-35% RH) with ad libitum intake and 3) pair-fed to DFI levels of the heat stress pigs but in TN conditions. Pigs under heat stress conditions had an immediate DFI reduction that was maintained for the seven days compared to TN pigs which did not (Figure 2.11).

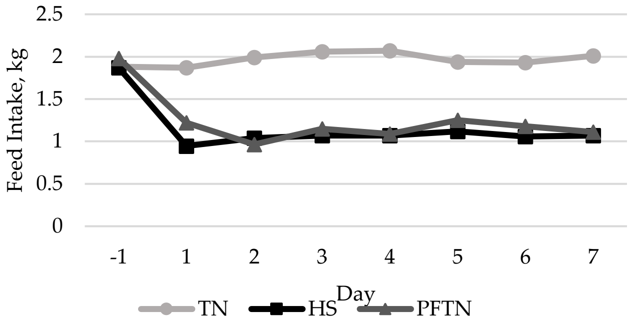

Figure 2.11. Effects of ad libitum feed intake in thermal-neutral conditions (TN; 20 °C), ad libitum feed intake in heat stress conditions (HS; 35 °C), and pair feeding in thermal-neutral conditions (PFTN) on the temporal changes in feed intake in growing pigs (Adapted from: Pearce et al., 2013).

Renaudeau et al. (2008) reported that the effect of high temperatures on performance depends on its intensity and length (Figure 2.12). In fact, in individually penned growing pigs the increase in environmental temperature from 24 to 36 °C resulted in a quadratic decrease in ADFI and ADG in the 20 days of exposure: with a decrease of 90g/d per °C between 24 and 32 °C and of 128g/d per °C between 32 and 36 °C. FCR was not affected between 24 and 32 °C but was penalized at 36 °C.

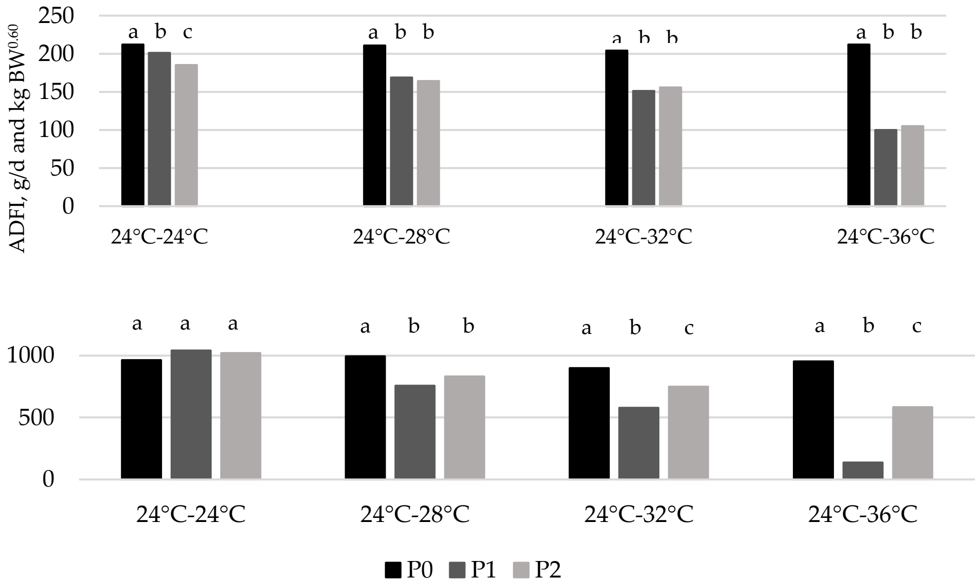

Figure 2.12. Effect of temperature level on average daily feed intake (ADFI, g/d and kg $BW^{-0.60}$) and average daily gain (ADG, g/d) in growing pigs over the acclimation period (P0; 10 days at 24 °C), P1 (eleven days at a certain temperature) and P2 (eleven more days at a certain temperature). Within each treatment, least square means with a different letter are affected ($P < 0.05$) by the duration of exposure (Adapted from: Renaudeau et al., 2008).

In a later meta-analysis, Renaudeau et al. (2011) also concluded that high temperatures have a curvilinear effect on ADFI and ADG and that this effect is more pronounced in heavier than lighter pigs (Figure 2.13).

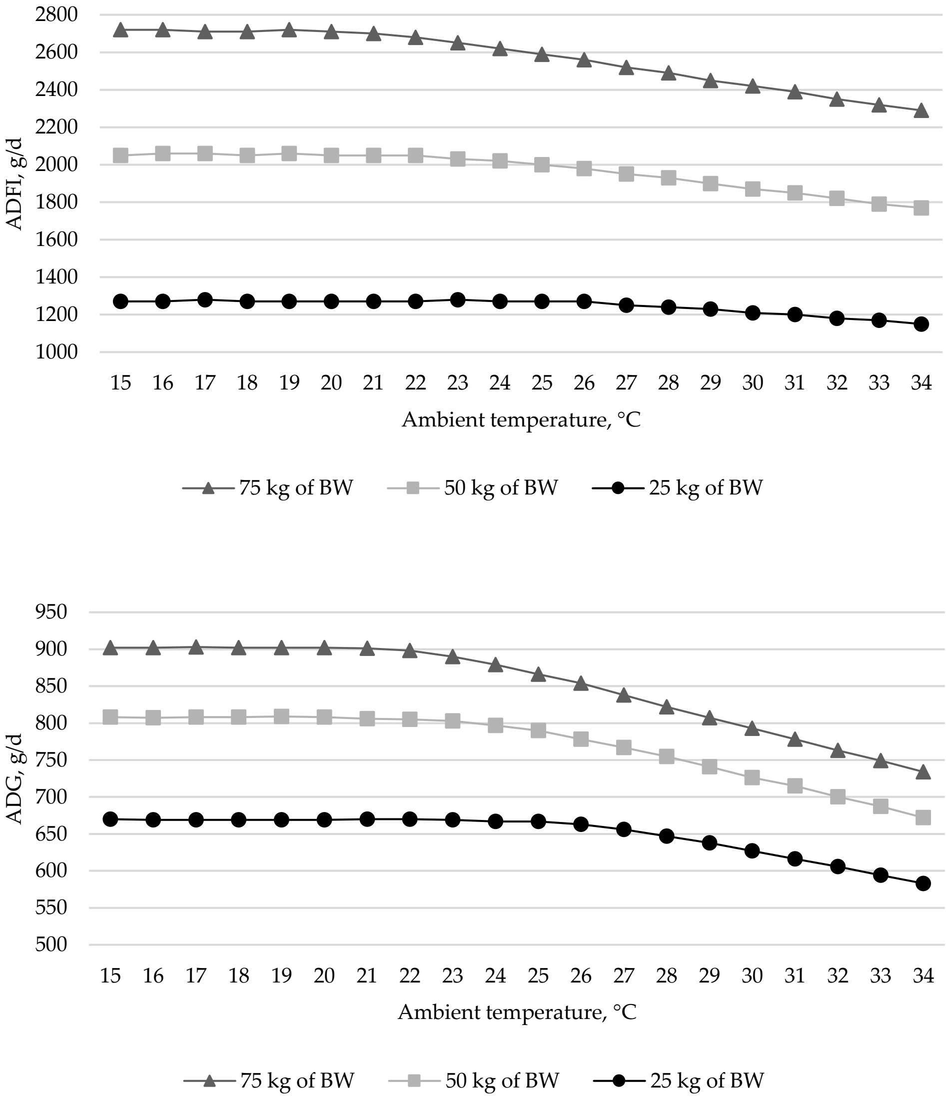

Figure 2.13. Effects of ambient temperature and pig body weight (BW) on average daily feed intake (ADFI) and average daily gain (ADG) (Adapted from: Renaudeau et al., 2011).

Le Bellego et al. (2002) reported a reduction of 12% and 17% of ADFI when the temperature was increased from 22 to 29 °C in the growing phase (27 to 64k BW pigs) and in the finishing phase (64 to 100 kg BW), respectively. Quiniou et al. (2000) obtained similar results, with a reduction of 17% in ADFI when the temperature increased from 19 to 29 °C in 63 kg BW pigs. Whereas Kerr et al. (2003) reported a 14% reduction in ADFI when temperature increased from 23 to 33 °C in pigs from 23 to 36 kg BW. The decrease in ADFI due to hot conditions is the main cause of the fall in ADG (Huynh et al., 2005). Le Bellego et al. (2002) showed a reduction of 10% and 16% in ADG when the temperature was increased from 22 to 29 °C in the growing phase (27 to 64k BW pigs) and in the finishing phase (64 to 100 kg BW), respectively. Whereas Kerr et al. (2003) observed a numerical reduction by 81 g/d in ADG (-21%), penalizing FCR when temperature was increased from 23 to 33 °C in pigs from 23 to 36 kg BW. Therefore, the reduction in ADFI owing to high temperature is clear. However, a large variability in the level of ADFI decrease exists between studies as those experiments were carried out under different conditions which are known to affect ADFI such as age, breed, diet composition, intensity and duration of high temperatures, among others (Quiniou et al., 2000; Renaudeau et al., 2008).

An interesting meta-analysis with data from 1980 to 2010 under different environmental conditions studied climate change impact on pig performance and found a significant effect of heat stress on ADG and ADFI in growing and finishing pigs (Hortenhuber et al., 2020; Table 2.10). The meta-analysis published by da Fonseca de Oliveira et al. (2018) also concluded that ADG is reduced from 654 to 596 g/d and ADFI from 2.141 to 1.875 g/d in growing-finishing pigs kept at thermoneutral environment (18 to 25 °C) and at high ambient temperature (29 to 35 °C), respectively.

Table 2.10. Effect of heat stress on production treats (Adapted from: Hortenhuber et al., 2020).

	Significance difference between thermoneutral and heat stress conditions	**Average change per 1 °C Temperature change**	**Average change per 1 THI Unit**
	Growing pigs (30-60 kg body mass)		
Body mass gain	yes	-2.4%	-2.2%
Feed intake	yes	-1.8%	-1.6%
Feed conversion ratio	yes	+0.6%	+0.6%
	Finishing pigs (> 60 kg body mass)		
Body mass gain	yes	-4.2%	-3.2%
Feed intake	yes	-3.2%	-2.3%
Feed conversion ratio	yes	+1.1%	+0.9%

Moving on to the effect of environmental conditions on body composition, Le Bellego et al. (2002; Figure 2.14) analysed the effect of high ambient temperature on protein deposition (PD), lipid deposition (LD) and energy utilization in barrows from 25 to 65 kg BW and concluded that heat stress directly affects PD and the partitioning of energy gain between PD and LD. In particular, Figure 2.14 shows that feeding pigs with the same ME intake, had a higher PD at 23 °C than at 30 °C (165 vs 143 g/d, respectively), indicating that the reduction in PD during heat stress is not directly caused by the reduction in DFI, but to a limitation to reach the maximum PD. Those results are in line with the findings of Brown-Brandl et al. (2000) who observed a higher LD and lower PD in pigs from 25 to 101 kg BW under heat stress conditions compared to pigs manually fed restricted at the same level at thermoneutrality. Hence, this limitation in PD under heat stress explains why carcasses of finishing pigs that have been fed *ad libitum* during summer are fatter and that PD and LD depend on both ambient temperature and feeding level (Le Bellego et al., 2002). Moreover, during periods of inadequate nutrient intake or disease, skeletal muscle amino acids may be mobilized to provide substrates to support energy metabolism and acute-phase protein synthesis limiting lean tissue accretion (Ross et al., 2015). In fact, Kerr et al. (2003) showed lower concentrations of protein in the empty body of pigs at 33 °C than pigs housed at 23 °C from 23 to 35 kg BW. Whereas Renaudeau et al. (2008) reported a numerical decrease in backfat thickness between 24 and 36 °C with a significant lower value at 36 °C (7.7 vs 9.2 mm) in 50 kg BW Large White pigs.

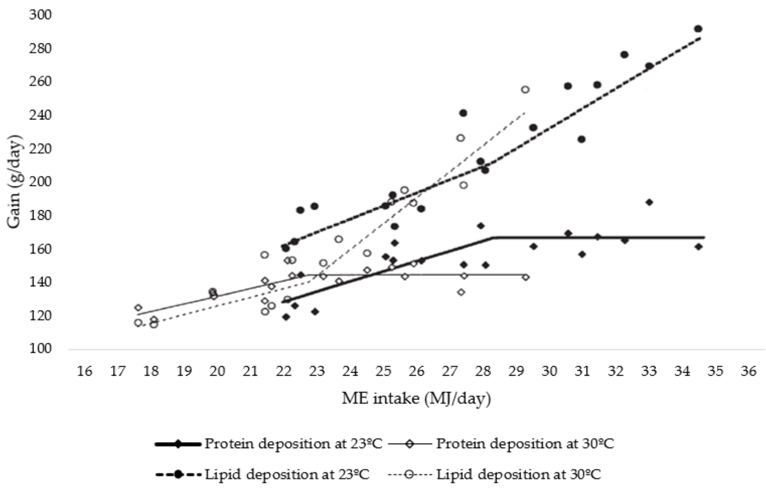

Figure 2.14. Effect of temperature and metabolizable energy (ME) intake on protein and lipid deposition in 24 to 65 kg BW barrows (Adapted from: Le Bellego et al., 2002).

However, few studies have analysed the effect of environmental conditions on FBHs of growing-finishing pigs (Table 2.11). In growing pigs ((Large White x Landrace) x Pietrain, from 21 to 30 kg BW), Collin et al. (2001) reported a reduction of 33% in ADFI, of 32% in MS and of 27% in TD with a negative impact on BW gain (-37%) after thirteen consecutive days at 33 °C compared to the control group reared at 23 °C. In heavier pigs (Pietrain x Large White, 62 kg BW), a decrease of 24% in ADFI, of 21% in TVs and of 28% in TD were observed when the temperature was increased from 19 to 29 °C with three or four consecutive days at 19, 22, 25, 27 or 29 °C (Quiniou et al., 2000). In fact, Cross et al. (2020) observed a reduction of approximately four minutes in TD when growing-finishing pigs were under heat stress conditions. The reduction in ADFI under heat stress is probably a strategy to reduce body heat production (Cervantes et al., 2018), which comes from maintenance, physical activity, and feed intake (Kerr et al., 2003).

Table 2.11. The effect of environmental conditions on the feeding behaviour habits of growing-finishing pigs.

Reference	Environmental challenge	BW (kg)	Breed[1]	Density (m²/pig)	Floor type	I / GH[2]	ADFI (kg of feed/d)[3]	TVs (feeder visits/d)[4]	TD (minutes spent eating/d)[5]	MS (feed consumed/meal)[6]	FR (feed consumed/min)[7]
Quiniou et al., 2000	From 19 °C to 29 °C (three-four consecutive days at 19,22,25,27 or 29 °C)	62 kg	P x LW	1.2 (3 pigs/pen)	Metal slatted	GH	Reduced by 24%*	Reduced by 21%**	Reduced by 28%***	Reduced by 17%	=
Collin et al., 2001	13 days at 33 °C vs at 23 °C	From 21 kg to 30 kg BW	(LW x L) x P	0.73 (5 pigs/pen)	Metal slatted	GH	Reduced by 30%**	Reduced by 30%	Reduced by 27%**	Reduced by 32%*	=
Cross et al., 2020	Ambient temperatures from May 2014 to April 2016	Four groups (n = 240) 4-month grow-out period	D, L and Y	0.80 (40 pigs /pen)	No data	GH	No data	Reduced in L pigs	4 min/d less at emergency THI level	No data	No data

[1] (D) Duroc, (L) Landrace, (LW) Large White, (P) Pietrain, (Y) Yorkshire. [2] (I) Individual or (GH) Group Housing. [3] ADFI (average daily feed intake, kg/d). [4] TVs (total number of feeder visits per pig and day). [5]TD (total duration spent eating per pig and day). [6]MS (feed consumed per meal per: according to each paper methodology, a meal is considered one meal the successive feeder visits for 2 minutes (Quiniou et al., 2000; Collin et al., 2001). Cross et al. (2020) analysed the number of daily feeder visits). [7] FR (feed intake per minute spent eating). * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$.

Moreover, the feed intake schedule changes under different environmental conditions. Under hot conditions pigs reduce their physical activity (Kerr et al., 2003) and spend more time lying and less time eating (Brown-Brandl et al., 2001). Cross et al. (2020) observed that under thermoneutral conditions most feeder activities were carried out from 6:00 to 19:00, while when pigs were suffering heat stress a peak feeding activity appeared between 6:00 and 9:00, a reduction during mid-day, and another peak of feeder activity between 18:00 and 21:00 in all breeds and genders studied (Figure 2.15 and 2.16).

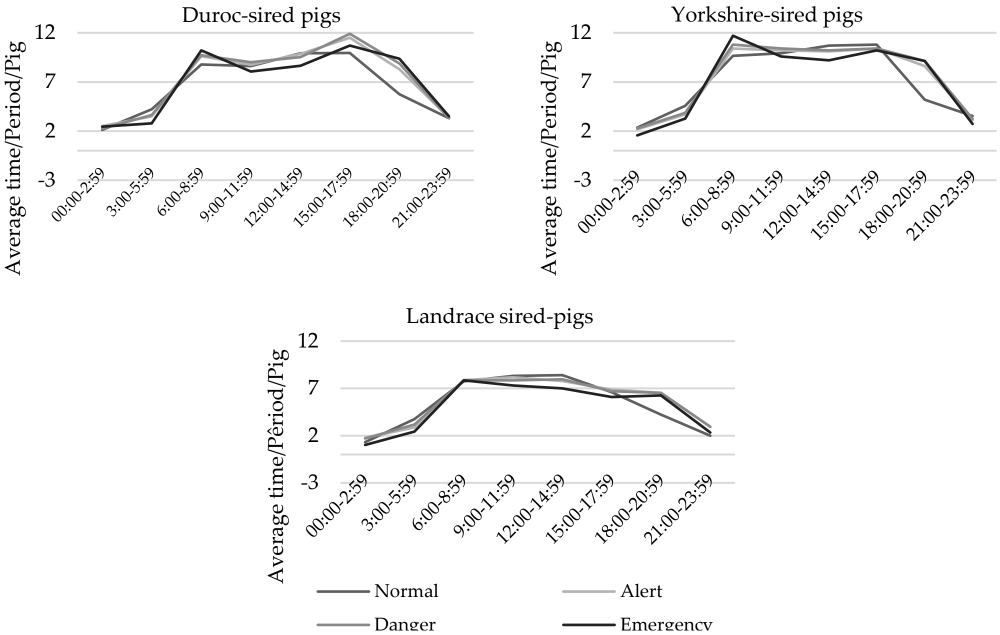

Figure 2.15. Average time spend in the feeder per pig in 3-h periods beginning at 00:00-2:59, 3:00-5:59, etc in three breeds of pigs under normal (< 23.32 ⁰C), alert (from 23.22 to 26.10 ⁰C), danger (from 26.11 to 28.87 ⁰C) and emergency (> 28.88 ⁰C) THI (temperature humidity index) (Adapted from: Cross et al., 2020).

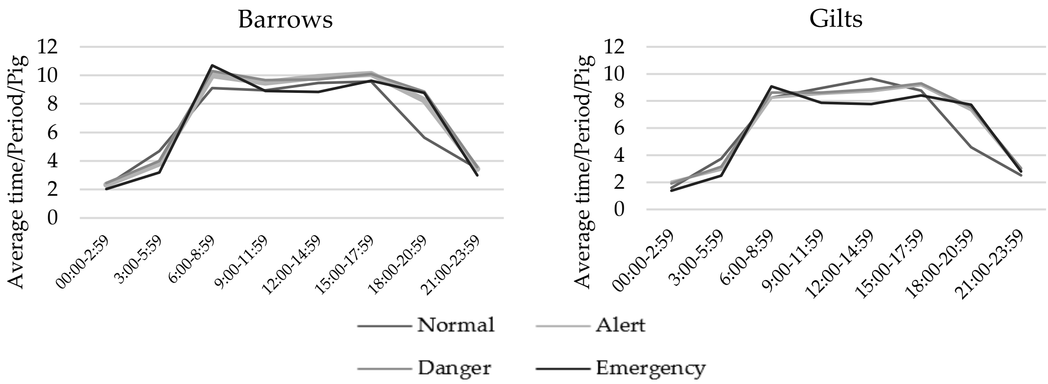

Figure 2.16. Average time spend in the feeder per pig in 3-h periods beginning at 00:00-2:59, 3:00-5:59, etc by sex and under normal (< 23.32 ⁰C), alert (from 23.22 to 26.10 ⁰C), danger (from 26.11 to 28.87 ⁰C) and emergency (> 28.88 ⁰C) THI (temperature humidity index) (Adapted from: Cross et al., 2020).

2.2.2.2. Diet composition, feed form and feed distribution

Several studies have analysed the effect of diet composition on FBHs of growing-finishing pigs (Carcò et al., 2018; Quemeneur et al., 2020). The main factor that modifies ADFI of a pig is diet energy content; a pig fed with a low energy diet eats more feed per day compared to a pig fed with a high energy diet in order to achieve the required daily energy (Smit et al., 2021). The easiest way to dilute energy content is to increase dietary fiber level; this strategy reduces stereotypic behaviour and enhances welfare by generating a satiety effect that reduces feed motivation (de Leeuw et al., 2008; Kallabis and Kaufmann et al., 2012). In fact, pigs fed with a low nutrient density diet spend more time eating per day and per feeder visit with a lower FR compared to pigs fed with a high nutrient density diet (Pichler et al., 2020). In addition, Quemeneur et al. (2020) concluded that the inclusion of fiber (a mix of wheat, soy and sugar beet pulp fibers) decreases meal frequency and increases MS. On the other hand, lysine content in the diet reduced the number and increased the length and size of feeder visits (Hyun et al., 1997). Carcò et al. (2018) observed that pigs increased their DFI and tended to increase FR with reduced amino acid content in the diet to achieve nutritional requirements. Furthermore, the flavour and palatability of feed may stimulate pigs' appetite. In fact, the inclusion of flavouring additives such as dextrose increases pigs' ADFI, although discrepancies concerning this fact are found in literature (Nyachoti et al., 2004). On the other hand, Iberian finishing pigs under extensive conditions depending on natural resources without compound feed remain active, foraging acorns and grass an average of 369 min per day, which is approximately 60% of winter daylight hours; this kind of slow eating would be very dependent on natural diet (Rodríguez-Estévez et al., 2010a).

As far as feed form is concerned, growing-finishing pigs can be fed with different physical feed forms (mash or pelleted feed), with different water level availability in the feeder (dry feeders or wet-dry feeders) and with different feed distribution systems (ad libitum or restricted). Therefore, in this section a review of the available scientific data regarding the effect of those factors on FBHs and performance of growing-finishing pigs is presented. Usually, pigs fed in pelleted feed have lower

ADFI with improved ADG thanks to lower feed waste and better nutrient digestibility compared to pigs fed with mash (Rojas et al., 2016; Vukmirovic et al., 2017). In fact, Rojas et al. (2016) reported improved apparent ileal digestibility of gross energy (GE), dry matter (DM), and most indispensable amino acids and the apparent total tract digestibility (ATTD) of GE on pellet-fed pigs compared to un-pelleted fed pigs.

Regarding the influence of feed form on FBHs (Table 2.12), Mac Donald and Gonyou, (2000) reported that growing-pigs (35-45 kg BW pigs) and finishing-pigs (90-100kg BW) spend more time eating when feed is in dry mash than in dry pellet form. On average, pellet-fed pigs spent 11.5% less time eating than mash-fed pigs. Those results are in agreement with Li et al. (2017) who reported a 23.5% and a 37.1% reduction of TD in growing and finishing pigs, respectively, with pigs fed in pellet compared to pigs fed in mash; besides that, together with a higher FR and a lower feeder occupancy rate. These results are in concordance with Laitat et al. (2004), who observed that weaned pigs needed more time to achieve the same DFI when feeding a mash diet than a pelleted diet due to lower FR.

Mac Donald and Gonyou, (2000) and Li et al. (2017) analysed the combined effect of feed form (mash vs pellet) and water availability (dry vs wet-dry feeders) in growing-finishing pigs. In both, growing (20 to 60 kg BW) and finishing (60 to 100kg BW) pigs, Li et al. (2017) observed an interactive effect of feed form and water availability, with the dry-mash fed pigs spending a longer time eating due to their lower FR than any other treatment. Those results are consistent with the previous findings of Mac Donald and Gonyou (2000). In addition, Gonyou and Lou, (2000) also observed that growing-finishing pigs fed ad libitum by wet-dry feeders spent 17% less time eating than pigs fed by dry feeders, suggesting that growing-finishing pigs prefer wet-dry to dry feeders (Smit et al., 2021). Besides that, pigs fed by wet-dry feeders had higher ADFI, ADG and pigs were less lean. In the Li et al. (2017) study, the effect of feed form and water availability on performance was analysed in growing and in finishing pigs. In both phases, water availability did not influence FCR, the most efficient pigs being those fed a pelleted diet. Additionally, FBHs of growing-finishing pigs differed when the same feed was offered: dry or dry feed diluted with water (88.6 vs 27.8%

dry matter, dry and dry-feed diluted, respectively) twice per day; growing-finishing pigs fed with dry feed diluted with water spent around 50% less time than pigs fed with dry feed with no differences in terms of performance (Zoric et al., 2015).

On the other hand, the meta-analysis of Averós et al. (2012) reported that pigs fed restrictively ate in longer feeder visits and were more active, perhaps because the pigs visited the feeder to check whether there was feed available, than pigs fed ad libitum. On extensive farms, in which pigs have access to restricted feed together with ad libitum access to fodder and grass, the FBHs of pigs depends on a large number of factors such as dietary supplementation, grazing management, and grass quality, among others (Rivero et al., 2019).

Table 2.12. Effect of feed form on the feeding behaviour habits of growing-finishing pigs.

Reference	**Breed[1]**	**Phase and Kg BW**	**Floor space allowance (m^2/pig)**	**Feed form and distribution**	**TD (minuts spent eating/d)[2]**		**FR (g of feed consumed/min)[3]**	
					Pellet	**Mash**	**Pellet**	**Mash**
MacDonald and Gonyou, 2000	No data	25-35 to 91-100 kg BW	95, 110 and 125% feeder capacity 80, 102.5 and 125% feeder capacity	Mash-Pellet Dry-wet/dry feeder Adlibitum	Dry: 68.9^{b} Wet-dry: 65.5^{b}	Dry: 78.6^{a} Wet-dry: 69.7^{b}	No data	
Laitat et al., 2004	P x (LW x L)	8 to 26kg BW	0.67, 0.5 and 0.4	Mash-Pellet Ad libitum	112.8^{b}	175.2^{a}	6.0	3.9
Zoric et al., 2015**	D x (Y x L)	20 to 115 kg BW	0.8	Liquid-dry feed	Dry: 8.6 ± 2.7 min Liquid: 3.6 ± 1.3 min		-	-
Li et al., 2017	No data (PIC)	20 to 60 kg BW	0.54	Mash-Pellet Dry-wet/dry feeder Ad libitum	Liquid: 3.6±1.3 min	Dry: 106.9^{a} Wet-dry: 71.6^{b}	Dry: 25.9^{b} Wet-dry:27.2^{b}	Dry: 19.7^{c} Wet-dry: 33.4^{a}
		60 to 100kg BW	0.76		Dry: 67.0^{b} Wet-dry: 65.1^{b}	Dry: 106.5^{a} Wet-dry: 66.6^{b}	Dry: 39.5^{a} Wet-dry: 43.4^{a}	Dry: 25.6^{b} Wet-dry: 46.7^{a}

[1] (D) Duroc, (L) Landrace, (LW) Large White, (P) Pietrain, (Y) Yorskshire. [2]TD (total time spent eating per pig and day). [3]FR (feed intake per minute spent eating). *Values with different superscripts differ ($P < 0.1$). **Mean effective time per feeding, i.e, when first pig left the trough.

2.2.2.3. Group size and feeder space allowance

The EU Directive 2008/120/EC determines a minimum stocking density of 0.65 m^2/pig up to 110 kg BW for growing-finishing pigs, which is an important factor, as it is demonstrated that it affects stress levels of growing-finishing pigs (Cornale et al., 2015). In addition, later studies have observed that increasing group size in growing-finishing pigs in an adequate pen floor space and feeder ratio does not impact on their welfare and growth performance (Schmolke et al., 2003). These results suggest that an important factor is feeder access competence. In fact, it has been observed that individually housed pigs eat their ADFI in smaller, more frequent meals, spending more TD on account of a lower FR than group-housed pigs (De Haer and Merks, 1992; Bornett et al., 2000). Moreover, when increasing the group size from two to 12 growing pigs per pen (from 27 to 48 kg BW) with the same stocking density of 0.9 m^2/pig and with a single-space feeder, pigs reduce TD and increase FR with lower ADFI and ADG with no effect on FCR (Hyun and Ellis, 2001). Whereas when increasing group size from 5 to 20 pigs per pen in 34 kg BW pigs for 29 days keeping the same stocking density of 1.06 m^2/pig with a single-space feeder, pigs eat their DFI in fewer and larger feeder visits with higher FR with no impact on performance results (no differences in ADFI, ADG and FCR) (Nielsen et al., 1995). In finishing pigs, the increase from two to 12 pigs in group size increased TD, MS and FR and reduced TVs with no effect on ADFI, ADG or FCR (Hyun and Ellis, 2002). Therefore, these results suggest that growing-finishing pigs may modify their FBHs due to the feeder-space restricted situation rather than due to the increase in group size. In fact, Averós et al. (2012) predicted that pigs fed under feeder space-restricted conditions increase their FR, make shorter feeder visits and reduce TD, results in agreement with Gonyou and Brumm (2001). In fact, Nielsen et al. (1999) suggested that FR may be used as an indicator of social constraint. Therefore, not only is pen floor space important, but it is also important to have the correct feeder ratio. In fact, an insufficient ratio of feeders in group-housed growing-finishing pigs may limit the achievement of pigs' nutritional requirements. However, what does an adequate feeder ratio mean? Linear feeder space is defined as "the linear cm of feeder available per pig within a pen" (total feeder length per pen/total pigs per pen). PIC, (2019) recommends a minimum between 4.7 and 5.0 cm per pig for dry feeders and between 2.9 and 3.1 cm for wet-dry feeders in pigs from 27 kg BW to target BW to minimize feed waste without decreasing pigs' ADFI. In fact, Smit et al. (2021) observed that 3.4 cm of linear feeder space per pig in wet-dry feeders is enough as they obtained the same growth and final BW with lower ADFI than pigs with one more extra feeder, suggesting that the extra feeder allowed pigs to waste feed. Moreover, Morrison et al. (2003) compared growing entire males pigs housed in deep-litter (pen of 200 pigs with 1 m^2/pig and 8.3 pigs/feeding space) vs pigs housed in a conventional system (pen of 45 pigs with 0.70 m^2/pig and 8.5 pigs/feeding space) from 20 to 22 weeks of age and observed that pigs housed in deep-litter spend less TD, with fewer and larger feeder visits, with a lower frequency of social interactions around the feeder compared to pigs in conventional treatment, concluding that the competence between pigs in the conventional system may be responsible for the shorter and more frequent feeder visits and that pigs are able to modify their FBHs in order to maintain performance under limitations in feeder space. In this sense, Rodríguez-Estévez et al. (2010b) found that free range pigs modified their foraging group size depending on the grazed resource, with 5.0 animals/group when pigs were grazing in an open pasture versus 5.8 when they were eating acorns under an oak crown because they were conditioned by the crown space to avoid competition when foraging, sharing a mean grazing surface to forage acorns of 8.9 m^2/pig.

On the other hand, growing-finishing pigs show two peaks of feed intake throughout the day (one in the morning and another in the afternoon) (Hyun et al., 1997; Bornett et al., 2000; Andretta et al., 2016a), which has also been observed in free range finishing pigs grazing natural resources (Rodríguez-Estévez et al., 2009). During these two peaks, which are accentuated under heat stress conditions (Cross et al., 2020), competition access to the feeder increases. In fact, increasing group size from 10 to 30 pigs increased feeder occupancy rates due to increased feeding activity during the night and at midday (Walker et al., 1991), whereas increasing group size from 18 to 22 with an extra feeder allowed pigs to eat according to their preferent diurnal pattern instead of eating at other moments of the day (Smit et al., 2021). Moreover, the hierarchy within a pen also influences FBHs by fewer and larger visits for the higherranking pigs than the lower-ranking pigs (Hoy et al., 2012). Therefore, under feeder space restrictions, the hierarchy may distinctly modify FBHs. These results highlight the importance of analysing FBHs at an individual level.

2.2.2.4. The effect of the fasting period

Fasting finishing pigs for 12-16 hours before being sacrificed in the slaughter-house is common practice with benefits on the mortality during transport (Averós et al., 2008), on the risk of carcass contamination at the slaughter-house (Saucier et al., 2007) or on meat quality by reducing the incidence of pale-soft-exudative (PSE) meat (Guàrdia et al., 2004; Driessen et al., 2020). However, under intensive farming conditions not all the pigs in a barn are loaded to the slaughter-house at one time; so, pigs remaining in the pen suffer feeding-fasting intervals which are known to be a metabolic stress factor with negative effects on performance (Veum et al., 1970; Martínez-Miró et al., 2016). In addition, when some of the pigs in a pen go to the slaughter-house the pen hierarchy is broken causing social group disorders with negative effects on welfare (Fredriksen and Hexeberg, 2009; Bünger et al., 2015). Depending on the length of the fasting there are different negative effects on stress response (Martínez-Miró et al., 2016), pig performance (Veum et al., 1970), carcass traits and meat quality (Faucitano et al., 2010). Fasted animals use endogenous glucose, lipids, and amino acids to produce ATP for cellular processes (Secor and Carey, 2016; Figure 2.17). During the fasting period, glucose levels can drop and enter a catabolic state that will require the use and production of alternative energy sources such as non-esterified fatty acids (NEFA), beta-hydroxybutirate and glycerol for energetic needs (Razdan et al., 2001) which are metabolites used to analyse the level of stress. In fact, Toscano et al. (2007) observed higher levels of NEFA after 27 h of feed deprivation compared to control pigs with no differences in blood cortisol level. Those results agree with Ott et al. (2014) findings which observed no differences in cortisol in saliva after 24 h of feed deprivation in 21 and 31 kg BW pigs compared to the day before feed deprivation. However, they found higher levels of stress biomarkers such as haptoglobin and chromogranin A together with a higher number of skin lesions. In addition, Toscano et al. (2007) provided data of the effect of 57 h of feed deprivation on physiological and behavioural responses in finishing pigs and showed the first behavioural changes after 45 h of fasting with more position changes, oral nasal pen manipulations and walking in feed-deprived pigs than in control pigs. Nevertheless, deprived pigs maintained a reduced but stable plasma glucose level, indicating their efficient catabolic state by using alternative energy sources.

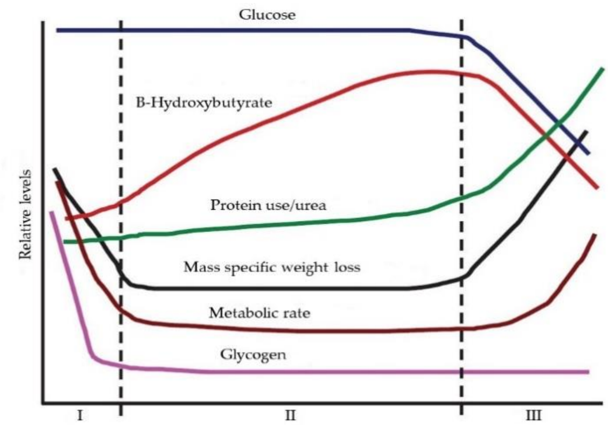

Figure 2.17. Characteristic profiles of metabolic variables during the three phases of fasting, including plasma concentrations of glucose, β-hydroxybutyrate, urea, protein utilization, mass-specific body bass loss, metabolic rate and tissue concentrations of glycogen (Adapted from: Secor and Carey, 2016).

Beattie et al. (2002) did not observe differences in ADG, ADFI and FCR between pigs without feed deprivation, 12 h feed deprivation and 20 h feed deprivation prior to transport to the slaughter-house. However, fasting for 20 h reduced BW immediately prior to transport by 2.2 kg compared to 12 h fasted pigs and reduced carcass weight by 1 kg, without an effect on backfat depth at P2 position and lean percentage. However, an increase in dressing yield from 75.4 to 77.3% with feed withdrawals from 0 to 20 h was reported, respectively. Frobose et al. (2010) showed a linear decrease in BW and backfat depth together with a linear increase in percentage lean and a quadratic increase in carcass yield as feed withdrawal time increased from 7, 24, 36 and 48 h before sacrifice. Beattie et al. (2002) observed that pigs fasted for 20 h spent significantly more time at the feeder post fasting, particularly marked during the first 2-3 h when access to the feed was restored. However, pigs with 12 h of feed withdrawal had very similar FBHs to the ones observed before feed restriction.

On the other hand, pigs reared in intensive productive conditions may be fasted more than once in their last weeks of the growing-finishing period before being sacrificed. Pigs of a batch can be loaded for weeks and all pigs that remain on the farm after any batch has been loaded to the slaughter-house will suffer more than one fasting period. Veum et al. (1970) studied the effect of feeding-fasting intervals on finishing pigs. The results showed that, as the severity of fasting-feeding intervals increased (from feeding ad libitum to 1, 2 or 3 days fasting), ADG was progressively reduced together with a penalization of feed efficiency, except in pigs fed one-day ad libitum and one-day fasting which did not differ from pigs fed continuously ad libitum. In terms of carcass quality traits, a reduction in dressing percentage, carcass weight and backfat thickness and an increase in lean percentage were observed as fasting days increased. Moreover, in practice, feed disruptions also occur as a result of human error or equipment malfunction with negative consequences for performance (Brumm et al., 2005). In fact, a 20-hour weekly interruption to feed access throughout the growing-finishing period reduced ADFI and ADG with lighter pigs at slaughter-house compared to pigs that were never out-of-feed (Brumm and Colgan, 2006).

2.3. Herbal extracts with calming effect as a strategy to improve pig welfare and performance

During the 19th century and early 20th, huge progress in the development of chemical analytical methods was made, enabling better knowledge of the bioactive components of plants (Hanczakowska and Szewczyk, 2007). The use of herbal feed additives is of interest because they are natural constituents of feeds, do not contain residual effects, are eco-friendly and have minimum drug resistance problems. Herbal extracts also have limitations such as difficulty to quantify and standardize the extracts. In addition, chemical composition is often complex and variable and is affected by harvesting conditions (location, soil type, weather conditions, altitude and season during which the plant is grown, harvesting procedure and storage conditions). Moreover, plant extracts may contain 20 to 60 components in different concentrations (Burt et al., 2004) and are highly variable in their active compounds.

Herbal extracts have been widely used in pigs as feed additives with different objectives such as antioxidative, antimicrobial or growth promoters, among others (Windisch et al., 2008). The use of herbs in growing-finishing pigs dates back to the 1980s when Gajewczyk and Akincza, (1988) observed anti-inflammatory, digestant activity and enhanced by 10% weight gains and dressing percentage with marigold (*Calendula officinalis*) and chamomile (*Chamomilla recutita L)* flowers extracted residues (Hanczakowska and Szewczyk, 2007). Since then, many studies with different plants have been carried out.

Hanczakowska and Swiatkiewicz, (2012) reported an improvement in the ileal epithelium structure, increasing the villus weight, together with a faster growth rate and final BW in piglets fed with a herbal extract based on sage (*Salvia officinalis*), lemon balm (*Melissa officinalis*), nettle (*Urtica dioica*) and coneflower (*Echinacea purpurea*). Furthermore, Hanczakowska et al. (2017) reported improvements in the oxidative stability of growing-finishing pigs meat after six months of storage by feeding the pigs with 500 or 1000 mg of hop/kg of feed.

It follows that herbs are strong candidates to improve growth performance and meat quality. Maypop (*Passiflora incarnata)*, california poppy (*Eschscolzia californica)* and hop *(Humulus lupulus)* are plants which produce calming effects in mice and humans (Soulimani et al., 1997; Dhawan et al., 2003; Schiller et al., 2006; Franco et al., 2012; Fedurco et al., 2015). The complete composition of the above herbal plants is not clear. However, the effect of the main bioactive components such as flavonoids in maypop (Wohlmuth et al., 2010; Miroddi et al., 2013), alkaloids such as protopine and allocryptopine in california poppy (Fedurco et al., 2015; Al-Snafi et al., 2017) and alpha-acids and flavonoids in hop (Benkherouf et al., 2020) are described. Briefly, alkaloids and flavonoids act as inhibitory neurotransmitters such as the known neurotransmitter gamma-aminobutyric acid (GABA) by binding the $GABA_A$ receptors, pentameric transmembrane proteins that, once activated, hyperpolarize the cell and therefore, the neuron activity is interrupted promoting an inhibitory activity in the nervous system (Johnston, 2015; Çiçek, 2018).

This section is a review of the composition, mode of action and effects of maypop, california poppy and hop plants in different animal species in order to better understand the effect of each, and to know if the combination of these three herbal extracts might be a good strategy in reducing the negative effect of stressors such as fasting or mixing pigs in intensive pig production systems, thanks to their calming effect. A summary table of the results obtained by different authors on the effect of maypop, california poppy and hop plants on different species is presented at the end of the present section (Table 2.13).

2.3.1. Maypop (*Passiflora incarnata*)

The genus *Passiflora* (*Passifloraceae* family) consists of 500 species mostly found in warm and tropical regions (Patel et al., 2009). *Passiflora incarnata*, whose popular name is maypop, passion fruit or passion flower, is one of the species and is a perennial plant that can grow up to 10 m, with three-lobed leaves and attractive flowers (Patel et al., 2009). Maypop is a native of the United States, and Central and South America, where the plant was used by native Americans to treat insomnia, hysteria, epilepsy and as a mild analgesic (National institute of Diabetes and Digestive and Kidney Diseases, 2020). Now, maypop is popular thanks to its sedative and anxiolytic effects (Dantas et al., 2017) and is used to treat insomnia, anxiety and depression in humans (Janda et al., 2020). In Spain, its use is very widespread and can be found as a simple drug for infusions, in tablets and capsules, and as fresh plant suspension (Tránsito, 2001). The anxiolytic effect of maypop was reported in the experiment conducted by Miyasaka et al. (2007) in which a reduction in pre-surgical anxiety together with no evidence of safety concerns was detected. In another study, the effect of maypop on anxiety was compared with oxazepam in 36 patients with generalized anxiety disorder and reported no differences in the effect of both treatments (Akhondzadeh et al., 2001). Moreover, a systematic review evaluated maypop in terms of neuropsychiatric effects and concluded that the plant reduced anxiety levels with no adverse effects (Janda et al., 2020).

Figure 2.18. Maypop, *Passiflora incarnata*.

The maypop plant contains several bioactive compounds, such as flavonoids, maltol, cynogenetic glycosides and indole alkaloids (Sarto et al., 2018). However no standardised composition has been defined and various chemical constituents necessary to achieve specific pharmacological effects remain unknown. The mechanisms of action of the different compounds present in the plant remain unclear. It is known that flavonoids (representing 2.5% of the compounds) and at a certain amount of GABA have a synergic action, by acting as inhibitory neurotransmitters, which increases the membrane permeability, raising GABA levels and leading to a positive modulation of $GABA_A$ receptors acting in the central nervous system (Miroddi et al., 2013).

As reported in humans, studies in animals suggest that maypop extracts have sedative and anxiolytic effects. In mice, Soulimani et al. (1997) observed a sedative effect of an aqueous extract at 400mg/kg BW and anxiolytic properties of a hydroalcoholic extract at 400mg/kg BW administrated intraperitoneally. Those results agree with the findings obtained by Dhawan et al. (2001) who reported an equivalent effect of maypop methanol extract at a dose of 125mg/kg BW administered orally to that of diazepam (2mg/kg administrated orally) in mice. Capasso and Sorrentino, (2005) found a prolonged sleep and a reduction in the motility in mice by combining kava (*Kava kcava*) and maypop. Dhawan et al. (2003) evaluated the effects of methanol extract of leaves of maypop in the central nervous system of mice showing sedative, anticonvulsant, and central nervous system-depressant effects at a dose of 200mg/kg. However, Shinomiya et al. (2005) did not observe any effect on the sleep quality of rats with the oral administration of maypop at any dose evaluated (300, 1000 and 3000 mg/kg BW).

In post-weaning piglets, the inclusion of 1kg/Tn of maypop in the diet did not affect growth performance but decreased body lesions thanks to its calming effect compared to the control group (Pastorelli et al., 2020). Two studies analysed the inclusion of a herbal compound based on valerian (*Valeriana officinalis)* and maypop with different results and conducted by different protocols. So, Peeters et al. (2006) studied a compound at 2.5g/L in water, evaluating skin lesions in the slaughter-house (106 kg BW) after different acute stressors such as fasting for 18h, mixing and transport; while Casal-Plana et al. (2017) tested the herbal compound in feed at 2000mg/kg in growing-finishing pigs (from 65 to 110 kg BW), periodically assessing skin lesions in the farm. What is more, Peeters et al. (2006) observed no differences in plasma cortisol together with an increase of shoulder lesions in pigs supplemented by the herbal compound while Casal-Plana et al. (2017) observed fewer social interactions, less negative behaviour and fewer skin lesions in supplemented pigs than in control pigs.

2.3.2. California poppy (*Eschscholzia californica*)

Eschscholzia californica (*Papaveraceae* family), whose popular name is california poppy, is a perennial plant with seeds of different colours and native of the Western United States and Mexico but is now widely cultivated around the world (Wilts et al., 2018). california poppy was the first named specie of the genus *Eschscholzia* and was used in the 60s by Californian inhabitants for its sedative and analgesic properties (Cheney, 1964). Hanus et al. (2004) assessed the clinical efficacy of the combination of *Crataegus oxyacantha,* california poppy and magnesium in mild-to-moderate anxiety disorders and they found positive results in humans. Abdellah et al. (2020) also found an increase in sleeping time and a decrease in anxiety score administering orally a combination of 80 mg of california poppy and 32 mg of *Valerian* extract/day for four weeks in humans.

Figure 2.19. California poppy, *Eschscholzia californica* (Wilts et al., 2018).

The activity of California poppy is mainly due to the action of multiple alkaloids. However, the quantities of these alkaloids needed for the desired effects is not clear and there exists a large variability between plants (Fedurco et al., 2015). Protopine and allocryptopine are the two main alkaloids (Vincieri et al., 1988), which may reach a capacity to bind μ-opioid receptors (Fedurco et al., 2015; Al-Snafi, 2017), acting as weak stimulators of the biding $GABA_A$ receptors agonists in the rat brain (Kardos, 1986). N-methyllaurotetanine is another alkaloid isolated from this plant species, which acts as an antagonist to the serotonin $5HT_{1A}R$ receptor (Gafner et al., 2006).

Moreover, Fedurco et al. (2015) showed the presence of (S)-reticuline, a compound that may be transformed into morphine binding μ-opioid receptors.

Rolland et al. (1991) administered a plant aqueous extract, orally and intraperitoneally from 100 mg/kg to 200 mg/kg BW; mice increased their sleeping time and reduced their spontaneous movement activity. At a dose of 25 mg/kg BW, the aqueous extract showed anxiolytic effect with an increase in behavioural parameters in a staircase test and in the light/dark choice situation test. Moreover, in a later study Rolland et al. (2001) reported analgesic dose-dependent (200, 400 and 800 mg/kg) effect of the aqueous alcohol (60%) extract by driving a writhing test in mice (Figure 2.20). In a writhing test, pain is induced by injection of irritants such as in this case with the administration of acetic acid 1.2% into the peritoneal cavity of mice. Then, mice react with a characteristic stretching behaviour called writhing which is described as stretch, tension to one side, extension of hind legs, or contraction of the abdomen so that the abdomen of the mice touches the floor or turning of the trunk. Therefore, a decrease in the frequency of writhings indicates analgesic activity (Dzoyem et al., 2017).

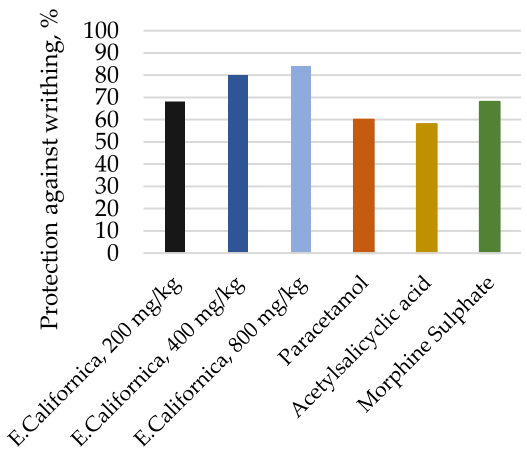

Figure 2.20. Influence of *Eschscholzia Californica* extract, paracetamol and acetylsalicylic acid and morphine sulphate on the writhing and stretching induced in mice by acetic acid 1.2% solution (writhing test), 200, 400, 800 *Eschscholzia Californica* (200, 400 and 800 mg/kg BW); Paracetamol (68 mg/kg BW); ASA acetylsalicylic acid (68 mg/kg BW); Morphine Sulphate (1.15 mg/kg BW). ** $P < 0.01$ (Adapted from: Rolland et al., 2001).

In addition, Vincieri et al. (1988) noticed an increased sleeping time and a reduction in locomotor activity with 130 mg/kg BW administered intraperitoneally in mice. In addition, Fedurco et al. (2015) also observed mild sedative effects with an oral administration of 10 mg/kg BW in mice. However, no studies have been found in pigs.

2.3.3. Hop (*Humulus lupulus*)

Humulus lupulus (Cannabaceae family; Figure 2.21), whose popular name is hop, is native to Eurasia and used in the manufacture of beer for its bitter and aromatic properties (Chadwick et al., 2006). Hop preparation has been widely used in humans in the US and in Europe to treat anxiety and sleep disorders thanks to its hypnotic-sedative effect, generally in combination with other sedative drugs (Tránsito, 2001; Chadwick et al., 2006; Franco et al., 2012). In fact, Franco et al. (2012) and Kyrou et al. (2017) showed an improvement in night sleep quality with hop extracts provided orally in different doses.

Figure 2.21. Hop cones of the female hop plant (Hrnčič et al., 2019).

In terms of composition, more than 1000 chemicals have been identified in the hop plant (Chadwick et al., 2006). The sedative effect of the hop is attributed to several compounds; flavonoid such as 6-prenylnaringenin (Meissner and Haberlein, 2006; Benkherouf et al., 2020), terpene myrcenol (Aoshima et al., 2006) and the oxidative degradation products of the bitter acids (Zanoli and Zavatti, 2008); all together acting in the central nervous system to increase the activity of the neurotransmitter GABA (Zanoli and Zavatti, 2008). In addition, hop is also known for its antioxidant and anti-inflammatory effects (Hanczakowska et al., 2017; Sangiovanni et al., 2019) attributed to its polyphenols, essential oils and bitter acid compounds (Gerhäuser et al., 2002; Hrnčič et al., 2019).

Many studies with different animal species, doses and ways of administration of hop extracts have been conducted. Different authors (Bravo et al. 1974; Lee et al. 1993) found a decrease in motor activity in mice. Zanoli et al. (2005) also observed an increase pentobarbital induced sleeping time in rats. Schiller et al. (2006) had similar results in rats increasing ketamine induced sleeping time together with a reduction in the locomotor activity with a dose between 200 and 500 mg/kg of ethanolic and CO_2 hop extracts administered orally. However, no studies regarding the calming effects have been found in pigs.

Moreover, Narvaez et al. (2011) reported lower ruminal methane emissions without impairing the fermentability of feed and Cornelison et al. (2006) reported improvement in broilers' performance by dietary hop inclusion. On the other hand, a reduction in the voluntary feed intake was reported in rabbits (Grueso et al., 2013). Results with pigs are contradictory. So, Williams et al. (2007) reported no improvement in growth performance in piglets fed with hop; results in agreement with Hanczakowska et al. (2017) who showed no significant differences in performance between growing pigs fed with the inclusion of 500 vs 1000 mg of hop/kg of feed. However, pigs fed with 1000 mg of hop/kg of feed tended to reduce FCR and significantly reduced liver weight compared to its lower level and control pigs. Whereas Sbardella et al. (2016) reported an improvement in the efficiency of feed utilization with the addition of hop β-acids at 360 mg/kg to weaning piglets due to an improvement in fat digestibility. In addition, after six months frozen, the meat oxidative stability was reduced together with a higher colour stability when hop was added to the diet (Hanczakowska et al., 2017) thanks to its antioxidant capacity. Those results agree with an earlier study by Hanczakowska and Swiatkiewicz, (2006) in finishing pigs and with Villalobos-Delgado et al. (2015), who reported a significant antioxidant effect of hop on lamb patties. However, the meat of the pigs fed with the higher dose tasted worse than the meat of other groups (500 vs 1000 mg of hop/kg of diet) (Hanczakowska et al., 2017).

Although there are discrepancies between studies, which may be due to different factors such as the extraction procedure, the way of administration or the dose used, the calming effect of those three plants (california poppy, maypop and hop) appears in all studies together with some positive results in performance and meat oxidation.

In humans, different combinations of these herbal extracts are used to treat sleep or anxiety disorders. As an example, Biogenesis® company commercializes a combination of aminoacids, botanicals and melatonin to treat sleep disorders named Sleep factor® (Biogenesis, USA), which is composed of hops and maypop with other plants such as chamomille (*Matricaria recutita)* and Skullcap (*Scutellaria laterflora*). Another product for humans based on the combination of california poppy and valerian is Phytostandard® (PiLeJe Laboratoire, France). This product was analysed by Abdellah et al. (2020), who concluded that the combination is a good strategy to treat insomnia in adults by reporting an increase in night sleep duration and a reduction in the anxiety score. However, it is difficult to determine the individual effect of each plant in these combinations. In addition, in a study of 40 adults with insomnia, they were treated with a mixture of melatonin, vitamin B6 and extracts of california poppy, lemon balm and passion flower for two weeks and their sleep quality improved with no adverse effects (Lemoine et al., 2019). On the other hand, a review with the objective to determine the effectiveness of herbal remedies on insomnia reported that the combination of valerian and hops had a significant effect on reducing sleep latency. Nevertheless, insufficient evidence was found for the maypop and california poppy combination effect on treating insomnia in humans (Antoniades et al., 2012).

Table 2.13. Results of the literature reviewed of the effect of *Passiflora incarnata, Humulus lupulus and Eschsholzia californica* on different animal species.

Scientific name	Specie	Administration	Dose	Sedative/sleeping time	Locomotor activity	Anxiety	Social interactions and skin lesions	Performance	Reference
Passiflora incarnata	mice	Intraperitoneally	400 – 800 mg/kg BW	Increased (aqueous extract, 400 mg/kg BW)		Increased (hydroalcoholic extract, 400 mg/kg BW)			Soulimani et al.,1997
	mice	Oral	125 – 200 mg/kg BW of methanol extract			Reduced (125 mg/kg BW)			Dhawan et al., 2001
	mice	Intraperitoneally	100 - 200 - 300 – 400 mg/kg BW	Increased					Dhawan et al., 2003
	mice	subcutaneous injection	50mg *kava kava* - 250mg *Passiflora incarnata* - 100mg kava + 250mg *Passiflora incarnata*	Increased (combination)	Reduced				Capasso and Sorrentino, 2005
	rat	Oral	300 - 1000 - 3000 mg/kg BW	No effect					Shinomiya et al., 2005
	piglets	Oral	1 kg/Tn of feed				Reduced body lesions	no effect	Pastorelli et al., 2020
	growing pigs	Oral	2000 mg/kg of feed				Reduced social interactions and skin lesions	no effect	Casal-Plana et al., 2017
	finishing pigs	Oral	2.5 g/L of water				Increased shoulder and loin lesions		Peeters et al., 2006
Eschsholzia californica	mice	oral and intraperitoneally	Aqueous extract (100 - 200 mg/kg BW)	Increased	Reduced				Rolland et al., 1991
			Aqueous extract (25 mg/kg)			Reduced			
	mice	Intraperitoneally	130 mg/kg BW	Increased	Reduced				Vincieri et al., 1988
	mice	Oral	10mg/kg B	Increased					Fedurco et al., 2015

Table 2.13. *Cont.*

Scientific name	Specie	Administration	Dose	Sedative/sleeping time	Locomotor activity	Anxiety	Social interactions and skin lesions	Performance	Reference
Humulus lupulus	mice	intraperitoneally	1 ml/20g BW	Increased	Reduced				Bravo et al., 1974
	mice	intraperitoneally	100-250-500 mg/kg BW		Reduced (>250mg/kg)				Lee et al., 1993
	mice	Oral	200 – 500 mg/kg BW, of ethanolic and CO2 hop extracts	Increased	Reduced				Schiller et al., 2006
	rat	Oral	minimal dose of 10 mg/kg BW (until 3 times per day)	Increased					Zanoli et al., 2005
	broiler	Oral	0.5 - 1.0 - 1.5 - 2.0 lbs/Tn of feed					+	Cornelison et al., 2006
	rabbit	Oral	500m/kg of feed of whole hops					Reduced feed intake	Grueso et al., 2013
	ruminant	Oral	50 - 100 - 200 - 400 μg/mL					+	Narvaez et al., 2011
	lamp patties	Oral	2 g of infused hop/kg - hop powder dispersion (2g hop/kg)					Reduced meat oxidation	Villalobos-Delgado et al., 2015
	piglets	Oral	1kg/Tn - 10kg/Tn of feed					small effect	Williams et al., 2007
	piglets	Oral	120 - 140 - 360 mg/kg BW hop β-acids					Reduced FCR	Sbardella et al., 2016
	growing-finishing pigs	Oral	500 - 1000 mg of hop/kg of diet					reduce FCR and ↓meat oxidation (1000 mg/kg)	Hanczakowska et al., 2017
	finishing pigs	Oral	1000 mg/kg of feed of lemon balm or hop water extracts					Reduced meat oxidation	Hanczakowska et al., 2006

CHAPTER 3.

Hypothesis and objectives

3.1. Hypothesis

The experiments presented in this PhD dissertation are part of a collaborative project between Cargill SLU, the Animal Nutrition and Welfare Service from the Department of Animal and Food Science of the Universitat Autònoma de Barcelona and the Department of Animal Production of the Universidad de Córdoba.

In Chapter 2 a bibliographic review of current knowledge regarding different aspects of the FBHs of growing-finishing pigs is presented. The influence of FBHs on performance and carcass quality traits of growing-finishing pigs is still not clear but the available scientific data suggest that FBHs influence productive parameters. Moreover, it is known that physical feed form and environmental conditions influence growth performance of growing-finishing pigs. However, little is known about their effects on FBHs. Therefore, since FBHs are related with performance it was hypothesized that the effect of some production conditions (environmental conditions, physical feed form or sex), which affect performance and carcass quality traits, may be partially explained by changes in FBHs.

On the other hand, an increase in the demand for more welfare in the production systems used in the UE exists and different management strategies have been implemented in the field such as toys for growing-finishing pigs or a determinate density, among others. Moreover, the available literature explains that common practices with benefits on productive parameters such as fasting period before sacrifice are also stressor factors for pigs. Besides, the inclusion of plants with calming properties such as H*umulus lupulus, Eschscholzia californica* and *Passiflora incarnata* in the diet of growing-finishing pigs could reduce their stress levels, affect their daily activity and therefore their energy waste with a positive impact on performance results and welfare indices.

3.2. General objectives

The present thesis focusses on two main objectives:

> **First:** to analyse the influence of FBHs and their feasible variability on feed efficiency, energy utilization, growth performance and carcass quality traits of growing-finishing pigs.

Second: to analyse the effect of the dietary inclusion of an innovative herbal extracts blend on FBHs, performance and welfare of growing-finishing pigs.

3.3. Specific objectives

From those two general objectives, four specific aims were defined; three to develop the first and one related to the second objective:

1) To evaluate the effect of environmental conditions and physical feed form on performance and FBHs of group-housed growing-finishing pigs.
2) To analyse the repeatability and to present a new approach to assess the maintenance level of FBHs during the growing-finishing period under different environmental conditions and physical feed form.
3) To evaluate the influence of FBHs on performance results, feed efficiency, energy utilization and carcass quality traits of group-housed growing-finishing pigs.
4) To evaluate the effect of the dietary inclusion of a calming herbal extracts blend on FBHs, growth performance, carcass quality traits and welfare of finishing pigs after a prolonged fasting period.

3.4. Results structure

To reach those objectives the results are presented in four chapters devoted to:

Chapter 4: Study the effect of environmental conditions (heat stress) and physical feed form (mash vs pelleted) on performance and FBHs of group-housed growing-finishing pigs (Objective 1.1).

Chapter 5: Work out a new approach (“maintenance”) to detecting and measuring the changes in the FBHs of group-housed growing-finishing pigs and compare it with the classic repeatability concept (Objective 1.2).

Chapter 6: Study the distribution of female growing-finishing pigs by their FBHs and their relationship with performance, feed utilization and carcass quality traits (Objective 1.3).

Chapter 7: Study the effect of adding a dietary calming herbal extracts blend on FBHs, growth performance, carcass quality traits and skin lesions of group-housed finishing pigs after a prolonged fasting period (Objective 2.1).

In a final chapter, before reaching the conclusions, a general discussion (**Chapter 8**) tries to discuss and integrate the whole results, to identify design and methodologic mistakes and to propose future challenges and perspectives.

CHAPTER 4.

The effect of environmental conditions and physical feed form on performance and feeding behaviour habits of group-housed growing-finishing pigs

Article sent to the *Spanish Journal of Agricultural Research:*

Fornós, M., López-Vergé, S., Jiménez-Moreno, E., Rodríguez-Estévez, V., Carrión, D. and J. Gasa. **The effect of environmental conditions and physical feed form on the performance and the feeding behaviour habits of group-housed growing-finishing pigs.**

4.1. Abstract

The present work aimed to determine the effect of environmental conditions and physical feed form on the performance and FBHs of group-housed growing-finishing pigs. Two trials were conducted (n = 72). In the Hot-Temperate/Pelleted trial (HT-P) pigs were half the time (from day 31 to 72 of fattening) under hot conditions and half the time (from day 73 to 114 of fattening) under thermoneutral conditions. Whereas in the Temperate-Hot/Mash trial (TH-M) pigs were half the time under thermoneutral conditions and half the time under hot conditions. TH-M pigs obtained poorer performance results due to a reduction in the ADFI caused by hot conditions during the finishing phase compared to HT-P pigs. Whereas similar hot conditions hardly affected the ADFI during the growing phase. Growing pigs under hot conditions increased TVs and reduced VS, whereas finishing pigs maintained TVs and reduced VS. Pigs fed with mash spent more time eating owing to the lower FR ($P < 0.0001$) compared to pelleted feed. Results confirm that under hot conditions young pigs adapt their FBHs to reach enough ADFI for optimal growth whereas larger pigs do not reach the required ADFI.

Keywords: *feeding behaviour habits, environmental conditions; physical feed form; growing-finishing pig*

4.2. Objective

Performance results of growing-finishing pigs are affected by environmental conditions and physical feed form. However, although is known that FBHs of growing-finishing pigs influence nutrient digestibility, few data exist regarding the effect of environmental conditions and physical feed form during a long interval and under commercial conditions on the FBHs of growing-finishing pigs. The present work aimed to determine the effect of environmental conditions and physical feed form on the performance and FBHs of group-housed growing-finishing pigs.

4.3. Material and methods

4.3.1. Experimental design

Two trials were conducted to study the effect of the physical feed form over FBHs of growing-finishing pigs. Both trials were conducted in the same farm located in the north-east of Spain in two consecutive years (2018 and 2019) feeding the same diet in pellet or in mash form, respectively, and environmental conditions inside the barn were also measured. The diet physical form results were only partially reliable, and we noticed that environmental conditions were involved. In fact, in the first trial, which started in June (hot season) and finished in October (temperate season) (124 days), pigs were fed a pelleted diet (Hot-Temperate/Pelleted trial, HT-P); while the second trial (Temperate-Hot/Mash trial, TH-M), which started in March (temperate season) and finished in July (hot season) (119 days), pigs were fed the same diet in mash (Temperate-Hot/Mash trial, TH-M). Consequently, although a 2x2 final experimental design is produced "a posteriori" and do not allow to clearly differentiate physical feed form from environmental conditions, the results are still useful, especially in commercial conditions.

4.3.2. 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, HT-P and TH-M pigs, respectively). With two pens of intact males and four pens of females in HT-P trial and four pens of intact males and two pens of females in 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 concrete floor and open air ventilation with automatic temperature probe controlled curtains. The stocking density per pen was 0.91 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 the experimental period up to 15 pigs were discarded; an entire pen of 12 males due to caudophagia episodes 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-house). The common diet was based on wheat-corn and soybean meal and was formulated to contain: 2,460 Kcal NE/kg, 16% CP and 1.08% SID Lys for phase I; 2,500 kcal NE/kg, 15.4% CP and 1.01% SID Lys for phase II; and 2,500 kcal NE/kg, 14.6% CP and 0.92% SID Lys for phase III.

Indoor ambient RH and air temperature were measured every ten minutes during all the experimental period with a data logger testo 175 H1 (Testo SE and Co. KGaA). 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:

$$THI\ (°C) = Tmax°C - 0.55 - (0.0055*RH\ (Tmax°C - 14.5))$$

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

4.3.3. Performance

Individual performance was analysed from day 0 of the growing-finishing period until 12h before sacrifice. Pigs were weighed individually on arrival at the farm and 12h before sacrifice to calculate ADG. Feed intake was recorded individually each time that the pig entered to the automatic feeding system. From these data ADFI and 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-h post-mortem in the slaughter-house.

4.3.4. Feeding behaviour habits

After 30 days of pre-experimental period of adaptation to the automatic feeding system, FBHs were analysed for 84 days in 6 periods of 14 days each (p1-p6). The mean pigs BW at starting p1 were 42.3 ± 4.06 and 40.8 ± 4.5 kg for HT-P and TH-M trial, respectively ($P = 0.06$). The automatic feeding system recorded individual feed intake, time, and pig BW for each feeder visit. From these data total feeder visits (TVs, total number of feeder visits per day, visits/d), total duration (TD, time spent eating per day, min/d), visit size (VS, amount of feed intake per feeder visit, kg/visit) and feeding rate (FR, g of feed intake per minute spent eating, g/min) were calculated.

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

4.3.5. Statistical analysis

All data were analysed using SAS statistical software (SAS version 9.4©; SAS institute Inc., Cary, NC; USA). Growth performance, carcass quality traits and FBHs were analysed 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 parameters studied was the pig. Results are presented as LS means ± Standard Error (SE). Significance was stablished at $P < 0.05$ for all the analyses, while a tendency was considered between $P \geq 0.05$ and < 0.10. When the probability of the main effects and its interaction were significant, Tukey's HSD test adjustment was used to separate means.

4.4. Results

4.4.1. Environmental conditions

The indoor average temperatures were 28.1 °C, 25.5 °C in the trial HT-P, and 23.5 °C, 27.3 °C in the TH-M trial, for p1-p2-p3 and p4-p5-p6, respectively. The boxplot of

Figure 4.1 shows that the median THI values for p1-p2-p3 in the HT-P trial and for p4-p5-p6 in the TH-M trial were close to emergency level for pigs (THI ≥ 30). It may follow that pigs were suffering heat stress throughout p1-p2-p3 and p4-p5-p6 in the HT-P and TH-M trials, respectively. While in p4-p5-p6 in the HT-P trial and p1-p2-p3 in the TH-M trial pigs were under thermoneutral conditions with the median THI values between normal and moderate level for pigs (THI < 27.8 and between 27.8 and ≤ 28.8, respectively).

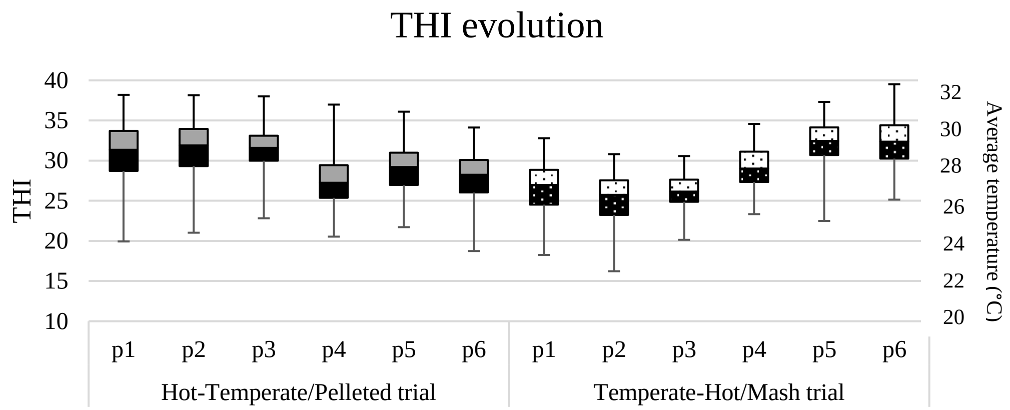

Figure 4.1. Boxplot (minimum, maximum, median, first and third percentiles) of the Temperature Humidity Index (THI) of each period (p1 to p6) in Hot-Temperate/Pelleted (HT-P; June-October) trial and Temperate-Hot/Mash (TH-M; March-July) trial. Dotted lines indicate the average temperature in °C per season and trial (right axis).

4.4.2. Performance

No interaction between trial and sex was found in any performance parameter (Table 4.1). The initial BW was lower for HT-P than for TH-M trial (16.5 vs 17.9 kg, respectively; $P < 0.0001$) with no differences between males and females ($P > 0.1$). With only five extra fattening days, the final BW was higher in HT-P trial (119.9 kg) than in TH-M trial (106.9 kg) and higher for males (122.9 kg) than for females (112.4 kg; $P < 0.0001$). In HT-P trial, ADFI and ADG were higher ($P = 0.006$ and < 0.0001, respectively) and FCR lower ($P < 0.0001$) than in TH-M trial. Whereas ADFI was unaffected by sex ($P > 0.1$), males obtained a higher ADG and a lower FCR than females ($P < 0.0001$; Table 4.1).

Carcass yield (%) was unaffected by treatments (Table 4.1) 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 in HT-P than in TH-M trial ($P < 0.0001$). However, lean percentage (62.6 vs 63.9%) was higher in TH-M trial ($P = 0.0001$). Hot carcass weight and backfat thickness were also higher in males than in females in HT-P trial ($P < 0.02$) and not in TH-M trial (significant interaction, $P < 0.03$)

Table 4.1. Growth and carcass quality traits by trial, sex and its interaction.

	HT-P[1] Sex				TH-M[2] Sex				*P-Value*		
Item	**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	16.48	0.987	16.52	0.903	17.91	0.759	17.91	0.598	<0.0001	0.90	0.93
Final BW, kg	128.21	8.522	117.71	1.205	108.37	1.216	103.96	1.425	<0.0001	<0.0001	0.068
ADFI[4], kg/d	1.78	0.173	1.76	0.127	1.65	0.164	1.72	0.131	0.006	0.28	0.12
ADG[5], kg/d	0.901	0.0670	0.816	0.0630	0.760	0.0701	0.723	0.0581	<0.0001	<0.0001	0.076
FCR[6], kg/kg	1.97	0.097	2.16	0.125	2.17	0.208	2.39	0.135	<0.0001	<0.0001	0.75
Carcass quality traits											
N	12		46		46		24				
Carcass yield, %	75.11	0.707	75.62	0.202	75.11	0.696	77.65	1.145	0.21	0.059	0.21
Hot carcass weight, kg	96.32[a]	2.087	89.06[b]	1.020	81.26[c]	0.959	80.47[c]	0.881	<0.0001	0.003	0.015
Backfat thickness, mm	17.17[a]	0.760	15.05[b]	0.377	12.57[c]	0.314	12.51[c]	0.320	<0.0001	0.020	0.028
Loin depth, mm	66.33	2.354	63.75	0.819	57.55	0.878	56.68	0.982	<0.0001	0.15	0.48
Lean percentage, %	61.51	0.761	62.90	0.333	63.93	0.262	63.83	0.356	0.0001	0.13	0.078

[1] HT-P (Hot-Temperate/Pelleted trial). [2] TH-M (Temperate-Hot/Mash trial). [3] SE (Standard Error). [4] ADFI (Average daily feed intake). [5] ADG (Average daily gain). [6] FCR (Feed conversion ratio).

4.4.3. Feeding behaviour habits: mean values and time evolution

No significant interaction between trial and sex was found in any FBH analysed (Table 4.2). On average, HT-P pigs did more TVs with 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 ($P < 0.0001$). The only FBH affected by sex was FR being higher for females than for males (29.7 vs 26.6, *P* = 0.0006).

Table 4.2. Results of the feeding behaviour habits by trial, sex and its interactions.

	HT-P[1] Sex				TH-M[2] Sex				*P*-Value		
Item	**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				
TVs[4], feeder visits/d	8.6	1.10	9.7	1.03	7.3	1.05	6.6	1.05	<0.0001	0.86	0.05
TD[5], min/d	55.0	1.04	50.7	1.02	82.5	1.03	82.3	1.03	<0.0001	0.18	0.17
VS[6], kg/ feeder visit	0.207	1.0787	0.196	1.0355	0.249	1.0552	0.296	1.0539	<0.0001	0.36	0.05
FR[7], g/min	32.2	1.04	37.3	1.02	21.9	1.03	23.6	1.03	<0.0001	0.0006	0.23

[1] HT-P (Hot-Temperate/Pelleted trial). [2] TH-M (Temperate-Hot/Mash trial). [3] SE (Standard Error). [4] TVs (total number of feeder visits per pig and day). [5] TD (time spent eating per pig and day). [6] VS (amount of feed intake per feeder visit). [7] FR (g of feed intake per minute spent eating).

ADFI had a similar evolution for both trials, during p1-p2-p3, up to 60-70 kg BW (Figure 4.2). However, while in the HT-P trial ADFI continued to increase during p4-p5-p6, in the TH-M trial ADFI was progressively maintained.

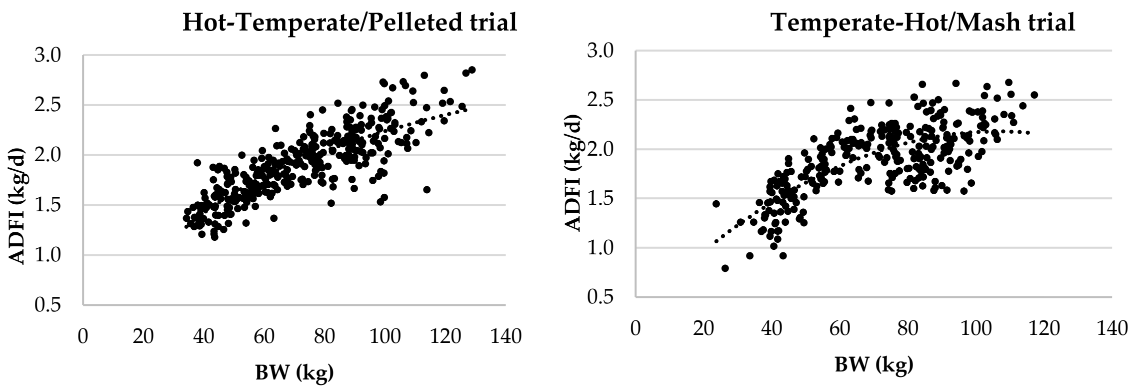

Figure 4.2. ADFI (average daily feed intake, kg/d) adjustment by trial (Hot-Temperate/Pelleted; ADFI = $2.6424(1-e^{0.0188*BW})$ and Temperate-Hot/Mash; ADFI = $2.4171(1-e^{0.0236*BW})$.

TVs and VS in HT-P trial were adjusted to an exponential equation: $y = a*eb*BW$ whereas in TH-M trial were adjusted to a linear equation: $y = a*BW + b$ (Figure 4.3A and 4.3C). TD and FR followed a linear equation in both trials: $y = a*BW + b$ (Figure 4.3B and 4.3D). As pigs grew TVs and TD decreased while VS and FR increased in both trials. The reduction of the number of TVs was higher in HT-P than in TH-M trial (by 67 vs 38%, respectively: Figure 4.3A). Whereas in terms of TD both trials had a similar reduction of 38%, even though TH-M pigs spent more time eating during all the experimental periods than HT-P pigs (Figure 4.3B). Throughout the periods studied VS increased by 419% in HT-P trial but only by 144% in 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 TH-M pigs at 100 kg BW and overpassing it at 120 kg BW (Figure 4.3C). HT-P pigs had a higher FR than TH-M pigs throughout all the periods analysed (Figure 4.3D) and the FR increase was similar in both trials (168 vs 144% in TH-M and HT-P, respectively).

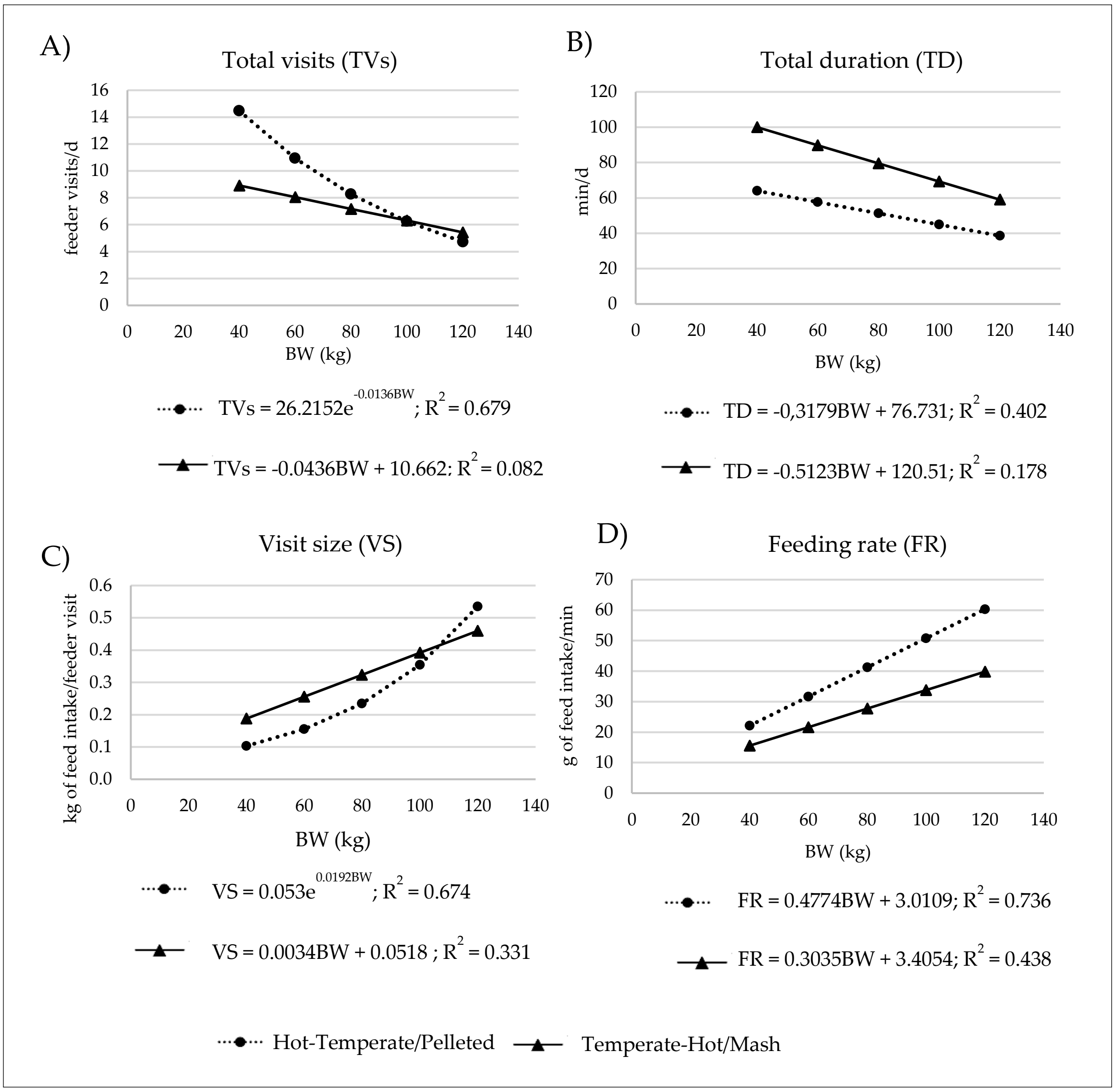

Figure 4.3. Evolution of the feeding behaviour habits (FBHs) of pigs from 40 to 120 kg BW comparing Hot-Temperate/Pelleted and Temperate-Hot/Mash trials. TVs, total number of feeder visits per day (A); TD, time spent eating per day (B); VS, amount of feed intake per feeder visit (C) and FR, g of feed intake per minute spent eating (D).

4.5. Discussion

Environmental conditions and physical feed form are factors that affect pig performance (Renaudeau et al., 2011; Rojas and Stein, 2017; Vukmirovic et al., 2017). The present study analyses the combined effect of both factors, although it is not able to fully differentiate between them. Growing-finishing pigs fed with pelleted feed, compared to mash, usually determines lower apparent ADFI with improved ADG thanks to a better nutrient digestibility and lower feed waste (Rojas and Stein, 2017; Vukmirovic et al., 2017). The characteristics of the feeders used in this study minimised feed waste for both physical feed forms and a lower ADFI was obtained with pigs fed in mash (TH-M) compared to pigs fed in pellet (HT-P), although the differences were due only to the second part of the experiments (p4-p5-p6). Those results may be the consequence of the high THI in those experimental periods in TH-M, although similar THI conditions measured during the first part of the experiments (p1-p2-p3 in HT-P) did not affect ADFI of younger pigs. In fact, the decrease in feed intake is a widely known effect under heat stress (Baumgard and 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. (2021), comparing 30 vs 23 °C observed a reduction of 31% and 26% in the ADFI in growing pigs and finishing pigs, respectively. Le Bellego et al. (2002), comparing 29 vs 22 °C, found an ADFI reduction of 12 and 17%, for growing (27 to 65 kg BW) and finishing pigs (65 to 100 kg BW), respectively, associated with a decrease of the ADG (10 and 16%, respectively). However, feed efficiency and energy cost of gain were unaffected. The effect of heat stress on feed efficiency may depend on the temperature threshold to which the pigs are exposed, the pig's BW itself, and even the different sensibility to hot environments due to the genotype (Renaudeau et al., 2011). These results cited above agree with the results in the present study in which when hot conditions occurred during the last three periods a higher impact on the ADFI was observed, determining a higher impact of hot conditions in heavier than in lighter pigs. Moreover, 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 (González-Rivas et al., 2020) and, in consequence, FCR can be penalized (Olczak et al., 2015; Ross et al., 2015; Anderson et al., 2020; Serviento et al., 2020). In fact, TH-M pigs had a lower ADG than HT-P pigs penalizing FCR by 200g, a result that could be explained due to the combined effect of high THI in heavier pigs and the mash physical feed form which is known to penalize FCR compared to pellet-fed pigs (Li et al., 2017; Rojas and Stein, 2017).

Under heat stress, protein deposition is lower than at thermoneutrality 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 and Ajuwon, 2018). The results of the present study show that the reduction in ADFI is associated with a lower ADG, backfat thickness and loin depth together with a higher lean percentage of carcasses. Those results are in accordance with Correa et al. (2006), who reported that fast growing pigs were fatter than the slow growing ones. Furthermore, since carcass composition relates to nutrient provision and growth potential (van Milgen et al., 2000; Kerr et al., 2003), the differences in carcass composition raises the possibility that pigs with different growth rates currently fed with the same feed have probably different requirements (Aymerich et al., 2020). It would follow that less feed consumption, although do not maximize protein deposition, still causes a higher proportional reduction of fat retention, producing leaner carcasses.

Moreover, several pig FBHs changes have been reported in the literature, both under heat stress conditions (Quiniou et al., 2000; Collin et al., 2001) and under different physical feed form (Laitat et al., 2004; Li et al., 2017). Changes in FBHs could affect pigs' performance (Rinaldo and Mourot, 2001; Kerr et al., 2003; Serviento et al., 2020) and modify carcass quality traits (Rinaldo and Mourot, 2001; Pearce et al., 2013). Since in the present study the only FBH affected by sex was FR, which was higher for females than for males, the present work is focused on the combined effect of environmental conditions and physical feed form on FBHs. 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 and Gonyou (2000) reported that finishing pigs fed a mash diet spent a 20% more of TD than pigs fed a pelleted diet. And 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 those obtained in the present work in which pigs fed with mash spent a longer TD and had lower FR during all the periods studied, regardless of the environmental conditions than pigs fed with pellet. The average TD obtained by 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 results are lower than those obtained by Rauw et al. (2006), Li et al. (2017) and Carcò et al. (2018) in group-housed pellet-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 and de Vries, 1993; Labroue et al., 1999; Bornett et al., 2000). Moreover, TH-M pigs at 40 kg BW obtained a similar average TD as Li et al. (2017) in growing pigs fed mash feed under thermoneutral conditions (100 vs 106.9 min/d, TH-M pigs at 40kg BW and Li et al. (2017), respectively). However, Li et al. (2017) reported a higher TD of 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 weighing 80kg BW). Therefore, it appears that high THI values reduce the TD in heavier pigs as reported by Quiniou et al. (2000). Furthermore, in the present study HT-P pigs had a similar FR values throughout the experimental period (22.1 and 41.2 g/min at 40 and 80 kg BW) than the reported under thermoneutral conditions (Rauw et al., 2006) 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, Li et al. (2017) reported in mash-fed pigs under thermoneutral conditions a FR of 19.7 and 25.6 g/min in growing and finishing pigs, respectively. Similar values as the obtained in the present study in which TH-M pigs had a FR of 15.5 and 27.7 g/min at 40 and 80 kg BW, respectively. In fact, Quiniou et al. (2000) and Collin et al. (2001) reported no effect of hot conditions on FR in young and heavier pigs. As expected, and in concordance with the literature cited, TD decreased and FR increased linearly as pigs grew (Labroue et al., 1994; Hyun et al., 1997; Rauw et al., 2006; Carcò et al., 2018), however, TD was slightly reduced when hot conditions occurred in heavier pigs.

Increasing the temperature from 23 to 33 °C, TVs and MS decreased in 20 kg BW pigs (Collin et al., 2001). Quiniou et al. (2000) also reported a reduction of TVs but in terms of MS only a numerically 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 had a larger number of TVs and a lower VS; while in heavier pigs, the number of TVs was not affected, but VS was reduced. Since no literature has been found regarding the effect of physical feed form on TVs and VS, it is hypothesized that under heat stress pigs reduce their VS as a mechanism to reduce body heat production after eating (Cervantes et al., 2018). As pigs grow, in both trials TVs were reduced and VS increased in agreement with the literature found (Labroue et al., 1994; Hyun et al., 1997; Andretta et al., 2016a; Carcò et al., 2018). However, our results suggest that due to environmental conditions, the reduction in TVs and the increase in VS were less pronounced in TH-M trial than in HT-P trial being by -38 vs -67% in TVs and by 144 vs 419% in VS, respectively.

The results show that FBHs may be modified by both, physical feed form and environmental conditions, although it appears that environmental conditions mainly affected TVs and VS, and physical feed form mainly modified TD and FR.

CHAPTER 5.

A new approach to detecting and measuring changes in the feeding behaviour habits of group-housed growing-finishing pigs

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5.1. Abstract

The present work aims to estimate the methods of repeatability and of a new non-parametric approach based on typifying individuals into classes and quantifying (%) the pigs in a group that show similar FBHs in consecutive periods ("maintenance"). Both methods were estimated over six consecutive 14-day periods in two trials of group-housed growing–finishing pigs (n = 60 each). The first trial started in summer and ended in autumn, and pigs were fed a pelleted diet (HT-P). The second trial started in spring and ended in summer, and the same diet was fed mash (TH-M). The ADFI obtained the lowest repeatability and maintenance values, and it progressively decreased as pigs grew, independent of environmental conditions or physical feed form, whereas the maintenance and repeatability of TVs and VS decreased when environmental conditions changed from temperate to hot, and mash-fed pigs had higher maintenance and repeatability values for TD than pellet-fed pigs. In conclusion, the new approach (maintenance) is a tool that is complementary to the classic repeatability concept and is useful for analysing the evolution of FBHs across periods of time at the individual level.

Keywords: *feeding behaviour habits; repeatability; growing-finishing pigs; environmental conditions; physical feed form*

5.2. Objectives

Since repeatability measures FBHs at the group level, and large variability among individuals has been reported (Carcò et al., 2018), it is of interest to develop a complementary approach to characterize which individuals change their FBHs as they grow. This approach may help to analyse if all the pigs of a pen modify their FBHs under specific external changes or if the hierarchy within a pen influences FBHs. In fact, high-ranking animals perform fewer and larger feeder visits compared with low-ranking pigs (Hoy et al., 2012). Therefore, the individual identification of the pigs that maintain or do not maintain their FBHs over time and under different external conditions proves to be of interest. Consequently, the objectives of the present work are:

1) to describe how to estimate FBHs repeatability

2) to define and compute a new complementary concept, named "maintenance"

3) to calculate and analyse both indicators, repeatability and maintenance, throughout the growing–finishing period of grouped-housed pigs in two trials conducted under different environmental conditions and using different physical feed forms (mash and pellets).

5.3. Material and Methods

5.3.1. Experimental approach design

The data base of the two growing–finishing pig trials conducted in **Chapter 4** was used to analyse the repeatability and the maintenance of FBHs. Both trials were conducted on the same farm located in the north-east of Spain in two consecutive years (2018 and 2019). In each trial, the first 30 days of fattening were used as a period of adaptation to the automatic feeding system. After this first period, FBHs were analysed for 84 days divided in six periods of 14 days each (p1–p6) from day 31 to day 114 of fattening. Both trials were carried out under commercial conditions, and the environmental conditions of the trials differed, although the temperature was regulated by open-air ventilation with automatic temperature-probe-controlled curtains. The first trial started in June with an average temperature of 30.7 °C on day 31 of fattening (the first three periods were classified as hot season) and finished in October with an average temperature of 21.2 °C on day 114 (the last three periods were classified as temperate season), and pigs were fed with pellet (Hot Temperate/Pelleted trial; HT-P). The second trial started in March with an average temperature of 22.8 °C on day 31 of fattening (the first three periods were classified as temperate season) and finished in July with an average temperature of 29.4 °C on day 114 (the last three periods were classified as hot season), and pigs were fed the same diet in mash (Temperate Hot/Mash trial; TH-M). The experimental unit for all the analyses was the pig.

5.3.2. Animals and housing conditions

A total of 60 crossbred Pietrain × (Landrace × Large White) pigs of 60 ± 3 days old and coming from the same nursery facility were used in each trial. On arrival, pigs were split into three initial BW groups, and four pigs in each BW group were allotted to each pen of 12 pigs at random (16.5 ± 0.91 and 17.9 ± 0.72 kg (mean ± SD) for HT-P and TH-M pigs, respectively). Five pens per trial were used (Table 5.1).

Table 5.1. Schema of the pigs used in each trial.

Trials analysed	Pigs per trial	Pens per trial	In each pen, four pigs of each body weight group
Hot-Temperate/Pelleted (HT-P)	60	5 pens of 12 pigs each	Light Medium Heavy
Temperate-Hot/Mash (TH-M)	60	5 pens of 12 pigs each	Light Medium Heavy

Each pen (12 m^2) was equipped with an automatic feeding system (Nedap ProSense®; Groenlo, The Netherlands), one nipple with a water cup, totally slatted concrete floor and open-air ventilation with automatic temperature-probe-controlled curtains. An enrichment item (pieces of wood at the end of chains) categorised as a suboptimal material was provided in each pen (European Commission, 2016). The stocking density per pen was 0.91 m^2/pig (excluding the space occupied by the automatic feeding system), which is above the minimum space per pig set by European legislation 2008/120/EC. Pigs were given ad libitum access to water and feed during all the experimental periods. Five pigs were discarded during the experimental periods: two pigs due to lameness problems in the HT-P trial and three pigs, one due to recording-system problems and two due to respiratory disorders, in the TH-M trial. Hence, the final data regarded 58 pigs for the HT-P trial and 57 pigs for the TH-M trial.

To evaluate the environmental conditions, the indoor relative humidity and temperature were measured every ten minutes throughout the experimental period with a data logger testo 175 H1 (Testo SE and Co. KGaA®, Germany). The daily average temperature-humidity index (THI) of the experimental period was calculated using the equation proposed by Lallo et al. (2018), where T = temperature in °C, and RH = relative humidity in percentage:

$$THI\ (°C) = Tmax(°C) - (0.55 - (0.0055RH)(Tmax(°C) - 14.5))$$

From the THI results, four categories of heat stress were defined according to Marai et al. (2001): normal (THI < 27.8), moderate (THI between 27.8 and 28.8), severe (THI between 28.9 and 29.9) and emergency zone (THI ≥ 30).

In both trials, the same common diet in a 3-phase feeding program was fed; feeding programs differed only in the physical feed form, being pellets in the HT-P trial and mash in the TH-M trial. The diets, based on wheat-corn and soybean meal, were formulated to fulfil the FEDNA (2013) requirements.

5.3.3. Feeding behaviour habits

On the first day of the pre-experimental period, after allotting the pigs into the pens, all pigs were individually identified with an electronic full duplex ear tag, which permitted control access to the automatic feeding system by providing a unique identifier for each pig through the radio frequency identification marker located on the tag. With this individual identification, the pig's code, date, time, feed intake and BW of each feeder visit were recorded. The BW of the pigs was recorded by a scale that weighed the front and back parts of the pig placed in front of the feeder during each feeder visit. The mean BW of the pigs at the start of p1 (day 31 of fattening) was 42.3 ± 4.06 and 41.4 ± 4.81 kg for the HT-P and TH-M trials, respectively (P = 0.24). The registered data allowed us to calculate: 1) individual daily feed intake (DFI; kg/d), 2) total feeder visits (TVs; total number of feeder visits per pig per day; visits/d), 3) total visit duration (TD; time spent eating per pig and day; min/d), 4) feeder visit size (VS; amount of feed intake per feeder visit, calculated as DFI/TVs; kg/visit) and 5) feeding rate (FR; g of feed intake per minute spent eating, calculated as (DFI*1000)/TD; g/min). Calculations were performed for the six experimental periods of 14 days each from days 31 to 114 of the growing–fattening period for both trials (HT-P and TH-M). The average of each FBH per pig per period was calculated. In each trial, the changes in the FBHs of two consecutive periods (from p1 to p6) were calculated using two kinds of indicators, repeatability and maintenance, as explained below.

5.3.3.1. Feeding behaviour habits' repeatability

Linear mixed effects models, also named components of variance models and random intercept models in the literature, provide a useful framework for understanding different sources of biological variation and for quantifying the reproducibility of measurements in different periods. After fitting the underlying model, repeatability (RA) is defined as the ratio of between-subject component variance to the total residual variance (Falconer and Mackay, 1996; Hyun et al., 1997). In the present study, RA was computed for each FBH y (ADFI, TVs, TD, VS and FR on a logarithmic scale) in six pairs of consecutive periods. Natural logarithms were applied to reduce asymmetry and heavy low tails, as the log-scaled data adjust better to the Gaussian distribution, as noted by Hyun et al. (1997).

The model equation is $y_{it} = \beta_0 + \beta_0 \rho_t + u_i + \varepsilon_{it}$, where y_{it} is the log-scaled FBH measured for individual i in period t ; ρ_t is a binary indicator (0 if $t = j$ and 1 if $t = j + 1$); u_i are assumed to be random-centred Gaussian variables with variance σ^2_u representing a between-subject component; and ε_{it} are random-centred Gaussian variables with variance σ^2_u representing a within-subject component. It is assumed that all random variables are independent of each other. Box plots and qq plots were applied to the data before and after the logarithmic transformation to check the improvement, and the normality and homogeneity of residual variances were checked using the Shapiro–Wilks and Levene's tests, respectively.

In this frame, the repeatability was estimated as:

$$\mathrm{RA} = \frac{\sigma_u^2}{\sigma_u^2 + \sigma^2}$$

Thus, RA is the proportion of the total variance due to the variability between individuals and is an intra-class correlation (Everitt, 2005) taking values between 0 and 1. The rpt function of the rptR R-library was used in this case (Stoffel et al., 2017; R Core Team, 2021). Notice that the RA index above is defined by means of a random intercept model which includes time (period) as a two-level factor. It agrees with the named "consistency" repeatability index in the work by Biro and Stamps, (2015). Another index, called "conditional" repeatability (Biro and Stamps, 2015), could be computed on a random intercept and slope model, allowing a different regression line for each individual to be obtained in this way. Because the present longitudinal analysis is reduced to five pairs of consecutive periods, and a specific model is adjusted for each given pair and physical feed form, the random and slope–intercept model should be discarded. In fact, these models produce a perfect fit for any pair of consecutive measurements, so the residual variance estimate is zero, and the repeatability index equals to one anywhere. In any case, all these underlying models assume a constant residual variability over time, which is not always sustainable and is a drawback of this methodology. The next point is an alternative, assumption-free attempt to estimate repeatability in the broadest sense, that is, the extent to which individual differences in FBHs persist over time.

5.3.3.2. Feeding behaviour habits' maintenance

The second developed procedure also aims at measuring and comparing the changes in FBHs but offers a different point of view of the same data, since it does not imply adjusting any model or imposing constraints. The method has two steps; the first one consists of giving a characterization of the pigs that show similar FBHs in two different periods; the second step consists of computing the percentage of pigs in this category, which is called maintenance.

In order to clarify what the statement "a pig maintains or not a determinate FBH in two consecutive periods" means, taking into account that descriptive means and standard deviations change from one period to another, it is proposed to use data standardisation (z-scores). Starting from log-scaled data (y_{it}) corresponding to a given FBH, the z-score is calculated as usual, centring with respect to the trial mean and dividing by the trial standard deviation:

$$z_{it} = \frac{y_{it} - \mu_t}{\sigma_t}$$

It should be noted that, to exclude excessive influential observations, the sample mean and the standard sample deviation are *trimmed* (Wilcox, 2012). It follows that for each variable, period and trial, mean and standard deviation are estimated on the subset of values in the range *Md* ± *2IQR*, where *Md* is the median, and *IQR* is the interquartile range; then, z-scores are computed for the whole sample values. z-scores are interpreted as the numbers of standard deviations from the mean of the observation. Each z-score explains the position of the pig in the group in response to y, specifying the number of standard deviations by which the response of this animal deviates from the mean to the right (+) or to the left (-). As z-scores are unit-free, they may be compared even if they come from different periods.

Consequently, a pig maintains its FBHs during two consecutive periods at the level of a pre-set value δ, if the distance between the two consecutives z-scores is less than δ: $|z_{it} - z_{it+1}| \leq \delta$. Then, maintenance is defined as the percentage of pigs in the trial that satisfy this condition.

The above inequality expresses a condition on the distance between two standard punctuations, a particular case of Mahalanobis distance (Mahalanobis, 1958) that is defined on multivariate measures, and the particular univariate case was considered here. Maintenance results depend monotonically on threshold δ. The smaller δ is, the more restrictive is the maintenance condition; therefore, the smaller the maintenance values are. In the present work, after calculating different δ values, δ = 0.75 was used as it fitted the profiles of the repeatability estimates of the FBHs of growing–finishing pigs as they grew. Consult the Appendix A for our statistical arguments in relation to this point. An example of usage and some theoretical considerations around threshold δ = 0.75 are discussed in the Appendix A.

5.4. Results

5.4.1. Environmental Conditions

In the HT-P trial, the median THI values of p1, p2 and p3 were above the THI emergency level (THI > 30), whereas in p4, p5 and p6, the median THI values were below the moderate THI level (< 28.8). In the TH-M trial, the median THI values in p1, p2 and p3 were below the normal THI level (< 27.8), whereas in p4, the median THI value was in the moderate level (between 27.8 and 28.8), and in p5 and p6, the median THI values were above the THI emergency level (THI > 30). The THI levels obtained suggest that pigs were under heat stress during p1-p2-p3 and p4-p5-p6 of the HT-P and TH-M trials, respectively, and these were the periods named hot seasons; on the other hand, during p4-p5-p6 and p1-p2-p3 of the HT-P and TH-M trials, respectively, pigs were under thermoneutral conditions, and both sets of periods were named temperate seasons. Moreover, the average temperature for each season was calculated, being 28.0 and 25.5 °C for the hot and temperate seasons, respectively, of the HT-P trial and 23.5 and 27.3 °C for the temperate and hot season, respectively, of TH-M. The highest sudden changes in THI and temperature in both trials happened between p3 and p4.

5.4.2. Main descriptive statistics of feeding behaviour habits per period and trial

Table 5.2 includes a summary of the main descriptive statistics of FBHs per period and trial (expressed as mean). HT-P pigs performed a greater number of TVs than TH-M pigs throughout the periods studied, together with a larger decrease from p1 to p6 compared with the TH-M trial (52% vs. 24%, respectively). HT-P pigs spent less time eating than TH-M pigs in all the periods analysed, and the reduction in time was greater in the HT-P trial (32% vs. 26%, respectively). VS increased as pigs grew in both trials with increases of 214% and 103% in the HT-P and TH-M trials, respectively. HT-P pigs had a higher FR than TH-M pigs in all the periods analysed with increases of 121% and 114% in the HT-P and TH-M trials, respectively. However, to calculate the maintenance, the trimmed mean and trimmed standard deviation at a log-scale of each FBH analysed (TVs, TD, VS and FR) by period are needed, and these are shown in Table 5.3.

Table 5.2. Mean of the feeding behaviour habits by trial and period.

		Mean					
		p1[1]	p2[1]	p3[1]	p4[1]	p5[1]	p6[1]
HT-P[2]	TVs[3], feeder visits/d	14.2	12.8	11.5	9.3	7.4	6.8
	TD[4], min/d	63.7	60.6	56.0	52.5	47.6	43.4
	VS[5], kg/feeder visit	0.115	0.143	0.182	0.248	0.316	0.361
	FR[6], g/min	23.7	27.9	33.6	39.5	46.1	52.3
TH-M[2]	TVs[3], feeder visits/d	8.6	7.9	8.2	7.6	6.8	6.5
	TD[4], min/d	99.2	91.9	85.7	80.9	67.0	73.9
	VS[5], kg/feeder visit	0.187	0.225	0.246	0.324	0.295	0.380
	FR[6], g/min	15.2	18.4	23.9	28.3	28.7	32.6

[1] Six periods of 14 days each (p1-p6) from day 31 to day 114 of fattening. [2] (HT-P) Hot-Temperate/Pelleted and (THM-M)Temperate -Hot/Mash trial. [3] TVs (Total number of feeder visits per pig and day). [4] (TD) Total time spent eating per pig and day. [5] (VS) Amount of feed intake per feeder visit. [6] (FR) Feed intake per minute spent eating.

Table 5.3. Trimmed mean and trimmed standard deviation of the feeding behaviour habits by trial and period. Standardized *z*-scores are obtained from these descriptive statistics.

		Trimmed mean (trimmed SD[1])					
		p1[2]	p2[2]	p3[2]	p4[2]	p5[2]	p6[2]
HT-P[3]	TVs[4], feeder visits/d	2.6 (0.3)	2.4 (0.2)	2.4 (0.3)	2.2 (0.3)	1.9 (0.3)	1.9 (0.3)
	TD[5], min/d	4.1 (0.1)	4.1 (0.1)	4.0 (0.1)	4.0 (0.1)	3.8 (0.1)	3.8 (0.2)
	VS[6], kg/feeder visit	-2.198 (0.317)	-1.974 (0.276)	-1.753 (0.345)	-1.448 (0.365)	-1.207 (0.337)	-1.082 (0.358)
	FR[7], g/min	3.2 (0.2)	3.3 (0.2)	3.5 (0.2)	3.7 (0.2)	3.8 (0.2)	3.9 (0.2)
TH-M[3]	TVs[4], feeder visits/d	2.6 (0.3)	2.4 (0.4)	2.4 (0.4)	2.2 (0.3)	1.9 (0.4)	1.9 (0.3)
	TD[5], min/d	4.1 (0.3)	4.1 (0.3)	4.0 (0.3)	4.0 (0.3)	3.8 (0.3)	3.8 (0.3)
	VS[6], kg/feeder visit	-2.198 (0.360)	-1.974 (0.419)	-1.753 (0.455)	-1.448 (0.391)	-1.207 (0.366)	-1.082 (0.325)
	FR[7], g/min	3.2 (0.3)	3.3 (0.3)	3.5 (0.3)	3.7 (0.3)	3.8 (0.3)	3.9 (0.3)

[1] Trimmed Standard deviation. [2] Six periods of 14 days each (p1-p6) from day 31 to day 114 of fattening. [3] (HT-P) Hot-Temperate/Pelleted and (TH-M) Temperate-Hot/Mash trial. [4] TVs (Total number of feeder visits per pig and day). [5] TD (Total time spent eating per pig and day). [6] VS (Amount of feed intake per feeder visit). [7] FR (Feed intake per minute spent eating).

5.4.3. Repeatability and Maintenance of the average daily feed intake

Figure 5.1 shows the repeatability and maintenance values of the ADFI in both trials and between consecutive periods. In the HT-P trial (Figure 5.1a), ADFI repeatability and maintenance showed a similar evolution during the experimental period. From p1–p2 to p2–p3, the repeatability and maintenance values of the ADFI increased from 0.64 to 0.75 and from 59 to 71%, respectively. From p3–p4 to p5–p6, the repeatability and maintenance values of the ADFI decreased progressively from 0.73 to 0.44 and from 71 to 50%, respectively. In the TH-M trial (Figure 5.1b), ADFI repeatability and maintenance values decreased progressively from 0.90 to 0.45 and from 91 to 51%, respectively.

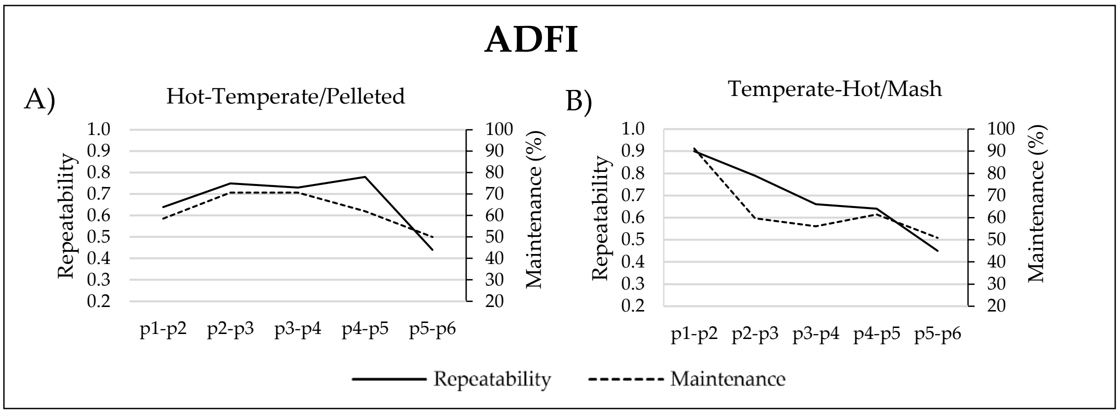


Figure 5.1. Repeatability (left axis) and maintenance (right axis) of the average daily feed intake (ADFI) during two consecutive 14-day periods from p1 to p6 (six periods of 14 days each from day 31 to day 114 of fattening) and by trial: (A) Hot-Temperate/Pelleted trial and (B) Temperate-Hot/Mash trial. The average temperature on day 31 and on day 114 of fattening was of 30.7 and 21.2 °C in the Hot-Temperate/Pelleted trial and of 22.8 and 29.4 °C in the Temperate-Hot/Mash trial, respectively.

5.4.4. Repeatability and Maintenance of the daily number of feeder visits, time spent eating, visit size and feeding rate in the Hot-Temperate/Pelleted trial

The repeatability and maintenance values between consecutive periods of TVs, TD, VS and FR of the HT-P trial are shown in Figure 5.2. TVs repeatability and maintenance increased gradually throughout the experimental period from 0.80 to 0.89 and from 69 to 85%, respectively (Figure 5.2A). The repeatability of TD started at 0.79 from p1 to p2, increased to 0.83 from p2 to p3 and progressively decreased to 0.45

from p5 to p6. On the other hand, in terms of maintenance, the lowest value was obtained from p3 to p4, with 64% of the pigs maintaining their TD, and the highest value was obtained from p4 to p5, with 85% of the pigs maintaining their TD between both periods (Figure 5.2B). VS repeatability and maintenance values showed a parallel progressive increase throughout the experimental period from 0.78 to 0.87 and from 74% to 89%, respectively (Figure 5.2C). The evolution of the repeatability and maintenance of FR also made similar progress until p4, starting with the values of 0.83 and 78% from p1 to p2 and increasing up to 0.92 and 95% from p2 to p3, respectively. In contrast, from p4 to p5 and from p5 to p6, the repeatability values decreased to 0.63 and 0.68; meanwhile, maintenance increased to 88 and 91%, respectively (Figure 5.2D).

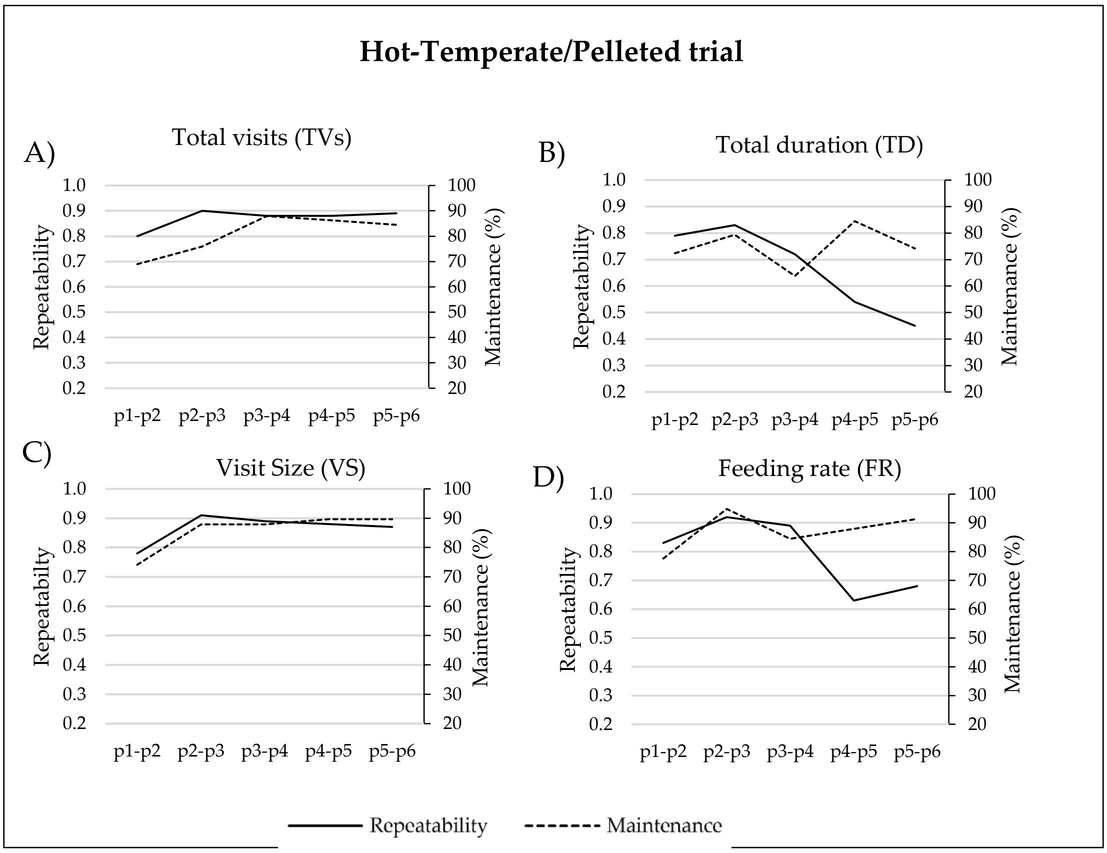


Figure 5.2. Repeatability (left axis) and maintenance (right axis) of total number of feeder visits per day, TVs (A); time spent eating, TD (B); amount of feed intake per feeder visit, VS (C) and g of feed intake per minute spent eating, FR (D) over two consecutive 14-day periods from p1 to p6 (six periods of 14 days each from day 31 to day 114 of fattening) in the Hot-Temperate/Pelleted trial (the average temperatures were of 30.7 and 21.2 °C on day 31 and on day 114 of fattening).

5.4.5. Repeatability and Maintenance of the daily number of feeder visits, time spent eating, visit size and feeding rate in the Temperate-Hot/Mash trial

The repeatability and maintenance values of TVs, TD, VS and FR over consecutive periods in the Temperate-Hot/Mash trial are shown in Figure 5.3. The repeatability and maintenance of TVs started from p1 to p2 with a repeatability of 0.83 and 74% of the pigs maintaining their TVs and increased up to 0.89 and 86% from p2 to p3, respectively. From p3 to p4, TVs repeatability and maintenance decreased to 0.74 and 74% and progressively increased to 0.88 and 91% from p5 to p6, respectively (Figure 5.3A). The repeatability and maintenance of TD progressively decreased throughout the experimental period from 0.95 to 0.83 and from 100 to 91%, respectively (Figure 5.3B). The repeatability and the maintenance values of VS were above 0.78 and 85% across all periods, except from p3 to p4, in which they decreased to 0.28 and 63%, respectively (Figure 5.3C). The repeatability and maintenance values of FR were above 0.88 and 91%, respectively, across all the periods analysed (Figure 5.3D).

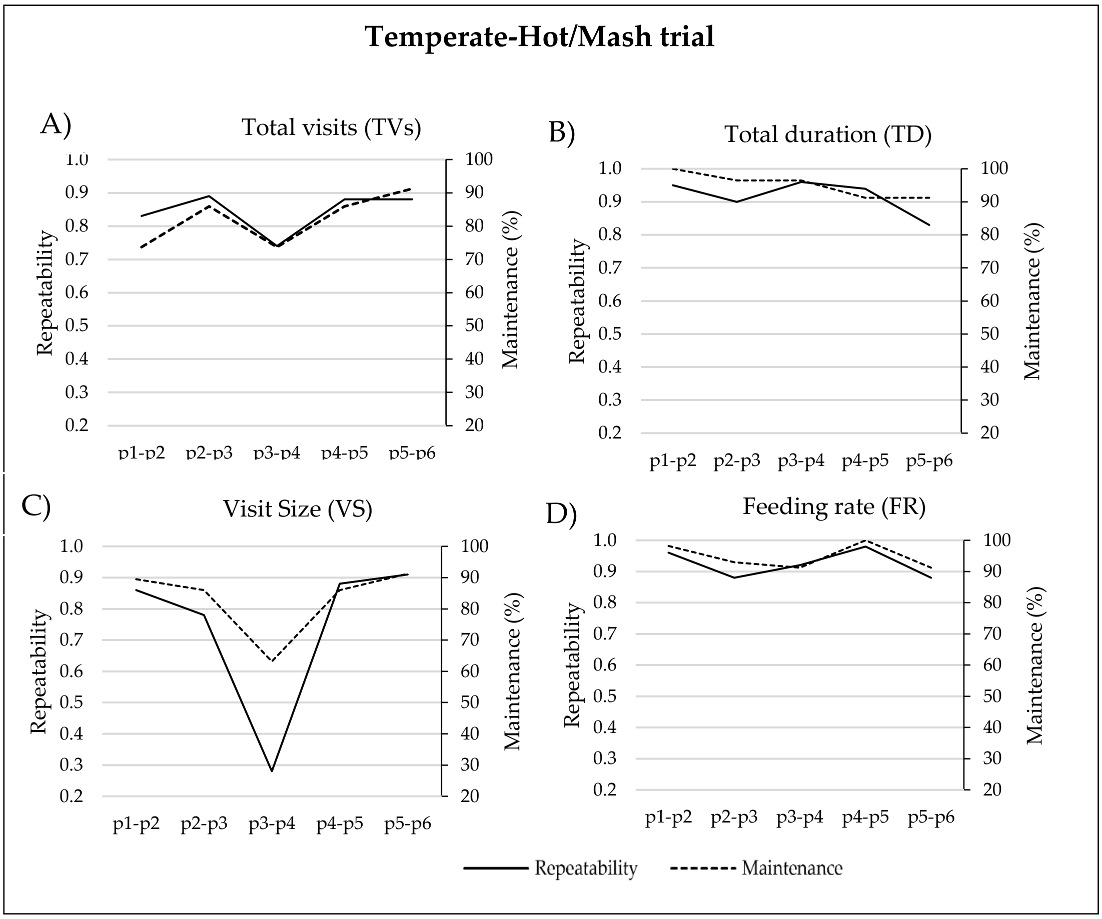


Figure 5.3. Repeatability (left axis) and maintenance (right axis) of total number of feeder visits per day, TVs (A); time spent eating, TD (B); amount of feed intake per feeder visit, VS (C) and g of feed intake per minute spent eating, FR (D) over two consecutive 14-day periods from p1 to p6 (six periods of 14 days each from day 31 to day 114 of fattening) in the Temperate-Hot/Mash trial (the average temperatures were of 22.8 and 29.4 °C on day 31 and on day 114 of fattening).

5.5. Discussion

5.5.1. Repeatability vs. Maintenance

The two approaches used to characterize and assess the changes in growing–finishing pigs' FBHs as they grow, repeatability and maintenance, provide complementary information that is not identical but similar and highly congruent. In fact, the maintenance concept may be defined as an alternative but complementary method to the repeatability ratio. Repeatability describes the FBHs degree of permanence on a group scale. A low repeatability value of a specific FBH in a determined group of animals means that this value is poorly predictable over time. However, this low repeatability result could be due to the fact that most animals in the group have low repeatability values or that a low number of pigs have extremely low repeatability coefficients. The latter was observed from p3 to p4 in the TH-M trial, in which the low repeatability of 0.28 of VS was a conse-quence of only 37% of the pigs that did not maintain their VS feeding habits across both periods. Therefore, the main contribution to the maintenance concept is that it brings in-formation at the individual level, which makes it an interesting and applicable tool for fields in which it is especially valuable to pay attention to the individuality of animals, such as in the assessment of the welfare of growing–finishing pigs. In fact, Bus et al. (2021) observed that reduced welfare is associated with deviations in FBHs. However, those au-thors reported that a large variability in FBHs among individuals exists and should be well understood before the variation that represents pig welfare can be interpreted, a case in which the use of the maintenance approach is of interest. In addition, feeder space in-fluences the growth performance (López-Vergé et al., 2018) and FBHs (Fornós et al., 2022a) of growing–finishing pigs. However, to our knowledge, no data have been published regarding the influence of feeder space at the individual level, and maintenance may be a useful tool to better understand the relation between feeder space and growth performance. Moreover, the maintenance approach could also be used to better understand the influence of the hierarchy within a pen on the welfare, FBHs and performance of pigs reared under different housing conditions. In the present study, the maintenance approach allowed us to identify which pigs maintained their FBHs and which did not across specific periods, and from this individual characterization, the computation of maintenance as a percentage of pigs that did not change their FBHs provided useful information at the group level. The main advantage of repeatability is that it is a traditional concept (Bell et al., 2009; White et al., 2013), which is thoroughly used to analyse FBHs in growing–finishing pigs (De Haer and Merks, 1992; Hyun et al., 1997). Furthermore, repeatability is calculated by fitting a variance component model (Everitt, 2005), which is available in any statistical software. The main drawback is that the method involves fitting a parametric model with constraints (Gaussianity and equal variances, which are difficult to sustain in different periods), to then calculate what proportion of the residual variance is explained by the variability between subjects, which is a fairly abstract notion.

Moreover, inference on repeatability is usually based on bootstrapping, which is asymptotically consistent but does not provide general guarantees in small samples. The maintenance procedure is based on intuitive notions and is a non-parametric calculation that does not require any underlying model or any restriction on data distribution. Moreover, percentage values are easy to interpret. However, one drawback is that maintenance calculation depends on a somewhat arbitrary threshold related to the expected evolution of the values of the studied FBHs. In the present study, the selected threshold value was 0.75 (there is a brief technical discussion in Appendix A).

To sum up, maintenance is a parameter complementary to the more classical repeatability concept; it represents a step forward to identify which percentage of individually growing–finishing pigs maintain their FBHs over time. In addition, the maintenance approach is a new tool that may be used to better understand the effect of social feeding dynamics of animals within a pen.

5.5.2. Production factors that modify the Repeatability and Maintenance of feeding behaviour habits

In both experiments, the time evolution of the repeatability and maintenance of most registered FBHs evolved in a parallel shape (see figures 5.1, 5.2 and 5.3). The repeatability values of the ADFI (Figure 5.1) were usually the lowest among the evaluated FBHs. Inde-pendently of the environmental conditions and physical feed form, ADFI repeatability decreased as the pigs' BW increased, obtaining the lowest values at the end of the experi-ments, from p5 to p6 (0.45). Previous findings also reported the lowest repeatability values for the ADFI (De Haer and Merks, 1992; Hyun et al., 1997). Those studies found values of 0.21, 0.27 and 0.26 over 10-, 5- and 2-week periods, respectively (Hyun et al., 1997), and 0.09, 0.14 and 0.29 from 25 to 100 kg BW over 4- and 2-week periods, respectively (De Haer and Merks, 1992). The decrease in the repeatability values obtained in the present study as pigs grew was also observed in the maintenance values, which started with 74% of the pigs maintaining their ADFI feeding habits from p1 to p2 and decreased to 50% from p5 to p6. Those results are in line with the findings obtained by Carcò et al. (2018), who observed a higher variability in the ADFI of older pigs than in that of younger pigs. Therefore, it follows that as pigs grow, the individual predictability of the ADFI becomes more difficult.

Environmental conditions and physical feed form influence the FBHs of growing–finishing pigs under commercial conditions (Quiniou et al., 2000; Collin et al., 2001; Li et al., 2017); consequently, they could modify their repeatability and maintenance values. In the present study, it was impossible to separate the effects of environmental conditions and physical feed form on FBHs. However, it is still interesting to discuss the changes in the repeatability and maintenance of the FBH parameters obtained in both experiments separately in order to compare and explain the value of the data generated by both approaches together.

For instance, hot conditions jeopardize the performance results and modify the FBHs of growing–finishing pigs (Quiniou et al., 2000; Collin et al., 2001; Averós et al., 2012; da Fonseca de Oliveira et al., 2018). However, the bibliography does not illustrate the impact of environmental conditions on the repeatability and maintenance of the FBHs of growing–finishing pigs. In the present study, small changes in terms of FBHs were observed when environmental conditions changed from hot to temperate (HT-P trial, from p3 to p4). In fact, the only FBH affected was TD, with 36% of the pigs changing their TD. On the other hand, when the environmental conditions changed from temperate to hot in the TH-M trial (from p3 to p4), the repeatability of TVs and VS decreased to 0.74 and 0.28, due to the fact that 26 and 37% of the pigs modified their TVs and VS feeding habits, respectively. TD and FR repeatability and maintenance were not affected (> 0.83 repeatability and > 91% maintenance values). Furthermore, the changes in the TVs and VS feeding habits were maintained during the hot season with repeatability values above 0.88 and maintenance values above 85% (TH-M trial, from p4 to p6), suggesting a form of FBHs adaptation. The observed TVs and VS changes agree with the findings obtained by Quiniou et al. (2000), who observed that group-housed 63 kg BW pigs reduced their TVs and MS and maintained their FR with an increase in the temperature from 19 to 29 °C; however, they also found changes in TD.

Although the effect of physical feed form on repeatability and maintenance is co-founded by the differences in environmental conditions, pigs fed mash obtained higher TD repeatability and maintenance values (> 0.83 and > 91%, respectively) than pigs fed pellets (< 0.83 and < 85%, respectively) for all the periods analysed. According to Laitat et al. (2004) and Li et al. (2017), mash-fed pigs eat more slowly; consequently, they need more time to reach the desired DFI than pellet-fed pigs, which could be the cause of the higher feeder occupancy rate in mash-fed pigs compared with pellet-fed pigs in the present study (70% and 45% for mash and pellets in the present study, respectively). Therefore, we hypothesize that with higher occupancy rates, the hierarchy of the pigs within a pen may limit the FBHs of low-ranking pigs.

5.6. Appendix A

5.6.1. Example of usage

To illustrate the complete procedure, consider the TH-M trial and two specific periods, $t = 1$ and $t + 1 = 2$, as an example and take the parameter ADFI:

1. Take $y_1 = \log(ADFI_1)$ and $y_2 = \log(ADFI_2)$, and let μ_1, σ_1, and μ_2, σ_2 be the respective trimmed means and standard deviations in the TH-M trial. Then, for each individual in this trial, calculate their z-scores in the two periods:

$$z_{i1} = \frac{y_{i1} - \mu_1}{\sigma_1} \text{ and } z_{i2} = \frac{y_{i2} - \mu_2}{\sigma_2}$$

2. Take a threshold δ, and compare the consecutive scaled positions; if $|z_{i1} - z_{i2}| \leq \delta$, we say that the analysed pig maintained the ADFI feeding behaviour at level δ, from period 1 to period 2;
3. Finally, compute the maintenance value as a percentage of individuals whose measurements satisfy the inequality;
4. The larger the maintenance value is, the better the reproducibility of FBHs (ADFI, in this example) is from one time interval to the subsequent one in this trial.

5.6.2. Technical note on the δ = ¾ threshold

Let Z_1 and Z_2 be the standardized scores representing a given feeding parameter in any pair of consecutive periods and suppose that the scores fit a standard Gaussian distribution well. Moreover, assume that these two random variables are independent, that is, the maintenance of feeding habits is due to chance. In that case, $\frac{z_1 - z_2}{\sqrt{2}} \sim N(0,1)$, and the probability of $|Z_1 - Z_2| \leq \delta$ can be easily computed:

$$\pi_\delta = P\{|Z_1 - Z_2| \leq \delta\} = 2 \cdot \Phi\left(\frac{\delta}{\sqrt{2}}\right) - 1,$$

where Φ is the standard Gaussian cumulative distribution function. For $\delta = 3/4, \pi_\delta \approx 0.4$; therefore, a maintenance value of about 0.4 may be due to chance. On the contrary, a maintenance value over 0.51 is shown to be significant at the risk level of 0.05. Indeed, the upper tail bound for a confidence of 0.95 and a sample of size $n = 58$ is

$$\pi_\delta + z_{0.95} \cdot \sqrt{\pi_\delta(1 - \pi_\delta)/n)} \approx 0.51,$$

where $z_{0.95}$ represents the standard Gaussian 95th percentile. Thus, a maintenance value of 51% or more is considered significant and due to feeding habit persistence. This is the case for TVs, TD, VS and FR, which show significant maintenance in all pairs of consecutive periods in both trials, whereas ADFI maintenance from p5 to p6 in both trials is not significant.

These technical arguments and the fact that repeatability and maintenance show congruent profiles are enough to consider $\delta = 3/4$ a reasonable choice.

CHAPTER 6.

The influence of the feeding behaviour habits on the performance, feed utilization and carcass quality of group-housed growing-finishing pigs

6.1. Abstract

MS and FR are the two FBHs most correlated with performance results, but, being positively correlated with ADFI, the effect of those FBHs may be confounded by the ADFI. Moreover, limited literature exists regarding the influence of FBHs on feed utilization and nutrient partition of growing-finishing pigs. The objective of the present study is to classify group-housed growing-finishing pigs fed ad libitum into clusters to explore and describe the existence of different groups of pigs with similar ADFI but different FBHs or the inverse, showing then the influence of FBHs on the performance, feed utilization and carcass quality traits. A total of 48 female pigs were used. Canonical correlation (CC) as a pre-processing step, followed by *k*-means clustering on the canonical scores were combined and a three clusters partition was obtained: medium feed intake-*fast eater* pigs (MFI-*fast eater*), medium feed intake–*slow eater* pigs (MFI-*slow eater*), and high feed intake-*fast eater* pigs (HFI-*fast eater*). The obtained results suggest that the ADFI and the FR influenced the performance results. Regarding ADFI, HFI-*fast eater* pigs ate more, in larger feeder visits and had higher ADG, final BW, greater loin depth and achieved the maximum energy level retained as protein six days before than MFI-*fast eater* pigs with no differences in FCR and backfat thickness. However, the observed differences in terms of productive parameters cannot be totally attributed to ADFI due to that visit size differed among both clusters. Regarding FR, MFI-*slow eater* pigs ate slower and had better FCR outcomes together with greater backfat thickness, loin depth and better growth energy efficiency than MFI-*fast eater* pigs; suggesting that, provided the same ADFI, a lower FR could enhance feed utilization and therefore, improve the performance results. In conclusion, the obtained results suggest that to assess the influence of FBHs on the performance, ADFI must be taken into account and the FR may influence feed utilization.

Keywords: *feeding behaviour habits; growing-finishing pig; nutrient utilization; performance; carcass traits; feed utilization; energy efficiency*

6.2. Objective

Results presented in **Chapter 4** and **5** indicate that FBHs of grouped growing-finishing pigs are modified by several production factors (such as feed physical form or environmental conditions, **Chapter 4**) and are highly variable within the group. However, since most of the FBHs performed high repeatability and were individually maintained along the growing-finishing period (**Chapter 5**), it follows that the study of the relationship between FBHs and performance or carcass quality traits is of high interest. Therefore, the aim of the present study is to analyse the influence of the FBHs on growth performance, feed utilization and carcass quality traits of group-housed growing-finishing female pigs by dividing pigs into different clusters derived from their FBHs and performance measurements.

6.3. Materials and Methods

6.3.1. Experimental design and Animals

In this study, the effect of the FBHs on performance, feed utilization and carcass quality traits of growing-finishing pigs from d0 to d124 of fattening is analysed. The experiment was conducted in a farm located in the north-east of Spain with a total of 48 crossbred Pietrain × (Landrace × Large White) female pigs, 60 ± 3 days old coming from the nursery facilities. At arrival, pigs were individually weighed and split into three initial BW groups with an average of 15.5 ± 0.3 kg for the light group, 16.4 ± 0.4 kg for the medium group and 17.5 ± 0.4 kg for the heavy group. Four pigs of each BW group were allotted at random at each pen of 12 pigs each. The average initial BW (d0) was of 16.5 ± 0.9 kg. Each pen (12 m^2) was equipped with an automatic feeding system (Nedap ProSense®, The Netherlands), one nipple with water cup, a totally slatted concrete floor and open-air ventilation with automatic temperature probe-controlled curtains. The stocking density per pen was of 0.91 m^2/pig (excluding the space occupied by the automatic feeding system). Pigs were given ad libitum access to water and feed during the experimental period. A pelleted diet based on corn-wheat-white sorghum and soybean meal 47% was formulated to contain 2,454 kcal NE/kg, 16.4% CP and 1.08% SID Lys from d0 to d26; 2,431 kcal NE/kg, 15.4% CP and 0.98% SID Lys from d27 to d103 and 2,437 kcal NE/kg, 14.7% CP and 0.93% SID Lys from d104 to d124. During the experimental period, two pigs were discarded due to lameness. Therefore, the final dataset consisted of 46 pigs.

6.3.2. Feeding behaviour habits parameters

The FBHs were analysed from d31 to d114 of fattening (84 days), after 30 days of pre-experimental period for adaptation to the automatic feeding system. Pigs were individually identified with an electronic ear tag. The mean pigs BW at d31 was 37.1 ± 3.16 kg. The automatic feeding system recorded individual feed intake, time, and pig BW for each feeder visit. The registered data allowed to calculate at the individual level: 1) ADFI, 2) total feeder visits (TVs, total number of feeder visits per day), 3) total duration (TD, time spent eating per day), 4) visit size (VS, amount of feed intake per feeder visit) and 5) feeding rate (FR, g of feed intake per minute spent eating).

6.3.3. Growth parameters and carcass quality traits

Pigs were individually weighed at arrival (d0) and before the loading of pigs to the slaughter-house (d124 of fattening) to calculate ADG at an individual level, whereas the individual ADFI was calculated from the data registered by the automatic feeding system of each feeder visit. From both parameters, the individual FCR was calculated. Pigs were individually identified throughout the sacrifice process in a commercial slaughter-house to maintain individual traceability. Hot carcass weight of each pig was measured and was used to calculate carcass yield (%). The backfat thickness (mm) and loin depth (mm) were measured at the level of 3/4 last ribs, at 6 cm from the midline 1h post-mortem by a Fat-O-Meat'er probe (Frontmatec A/S, Herlev, Denmark).

6.3.4. Energy and protein utilization calculations

To calculate the energy and nutrient utilization at different stages of the growing-finishing period, the fattening period (d31 to d124) was divided into seven periods of 14 days each except period 7 which was of 9 days (p1 to p7).

Those parameters were calculated at the individual level:

1. The **daily energy intake (kcal/day)** was calculated for each period by multiplying the amount of feed intake by the energy content of the feed (kcal ME/kg of feed) fed each phase and divided by the days of the period or for all the experimental period (from d31 to d124) by the addition of the energy intake of the seven periods and divided by 93 days.
2. The **energy utilization** was calculated by two models: A) factorial method (Noblet et al., 1999; Kloareg et al., 2006; Schinckel et al., 2009; Remus et al., 2020a) and B) NRC (2012). The caloric value used to convert retained protein and fat to net energy was 5.7 and 9.4 kcal/g, respectively (Velayudhan et al., 2015).

A) Factorial method:

The **daily energy used for maintenance** (**MEm, kcal/day)** was calculated from pig's mean body weight (BW) following the equation:

MEm, kcal/pig and day (Noblet et al., 1999): $MEm = 229.92 * BW^{0.601}$

The **daily energy retained (Net Energy, NE) as protein and fat (kcal/day)** for all the experimental period (from d31 to d124 of fattening) was calculated with the following equations, being EBW empty body weight:

Energy as body protein at d31 and d124, kcal/pig (Remus et al., 2020a):

$$Body\ energy\ as\ protein, \frac{kcal}{pig} = [(0.221676 * \text{BW}) + (-0.0004202 * BW^2)] * 5700$$

Energy as body fat at d31 and d124, kcal/pig (Kloareg et al., 2006):

$$Body\ energy\ as\ fat, \frac{kcal}{pig} = [(0.0855 + (0.0073 * \text{Backfat thickness})) * (\text{EBW})] * 9400$$

EBW = $0.914*BW^{1.008}$ (kloareg et al., 2006)

Backfat in mm estimated as: $(0.06929*BW^{0.6655})*10$ (Schinckel et al., 2009)

B) NRC method:

The **daily energy used for maintenance** (**MEm, kcal/day)** was calculated from pig's mean BW following the equation:

MEm, kcal/pig and day: $MEm = 197 * BW^{0.6}$

The **daily energy retained as protein and fat (NE, kcal/day)** for each period and for all the experimental period (from d31 to d124 of fattening) was calculated with the following equations, being Pd protein deposition (g/d).

$$Body\ protein\ deposition, \frac{kcal}{pig}\ and\ day = [\ (137*(0.7066) + (0.013289*BW) - (0.0001312*BW^2) + (2.8627*10^{-7}*BW^3)]\ *5.7.$$

$$Body\ fat\ deposition, \frac{kcal}{pig}\ and\ day = [\frac{\text{daily ME intake} - \text{daily MEm} - (\text{Pd} * 10.6)}{12.5}] * 9.4$$

For both methods the **total energy retained as protein and fat (NE, kcal/d),** the **gross (*Kge*) and growth (*Kf*) energy efficiency** and the **gross efficiency of crude protein (*Kcp*)** were calculated for each pig.

1) The total daily **NE retention** (kcal/d) was calculated using the protein and fat deposition equations.
    a) **Factorial model:** (NE retention (protein+fat) on day 124 – NE retention (protein+fat) on day 31) / 93 experimental days.
    b) **NRC model:** Working out the defined integral of protein and fat deposition equations between the first and the last experimental days of the period and dividing the difference of both values by the experimental days of the period.
2) The ***Kge*** (%/100) was calculated by dividing the total NE retained as protein and fat (kcal/d) by the total ME intake (kcal/d) for each period (by NRC) and overall (by factorial and NRC).
3) The ***Kf*** (%/100) was calculated by dividing the total NE retained as protein and fat by the difference between the daily ME intake and the MEm, for each period (by NRC) and overall (by factorial and NRC).
4) The ***kcp*** (%/100) was calculated by dividing the total protein retention (kg) by the total protein intake (kg) for each period (by NRC) and overall (by factorial and NRC).

6.3.5. Clusters

The individual FBHs (ADFI, TVs, TD, VS, FR) on one hand, and the productive parameters (ADFI, ADG, FCR) and carcass quality traits (carcass yield, backfat thickness, loin depth) on the other, were pre-processed by means of CC analysis (Härdle and Simar, 2015) with the aim of extracting the canonical dimensions explaining better the correlation between the FBHs block (X) and the performance block (Y). CC is considered a denoising step to obtain more stable clusters. The *k-means* clustering algorithm (Kassambara, 2017; González and Déjean, 2021) was then performed on the canonical X-scores and Y-scores. Principal Component Analysis (PCA, Le et al., 2008; Kassambara, 2020) allows visualizing clusters in one or more two dimensional maps. As k-means algorithm aims to find a partition characterized by low intra-clusters dispersion and high inter-clusters distances, the following indicator can be used to compare different solutions:

$$I = \frac{1}{K} \sum_{i=1}^{K} \max_{j \neq i} \left(\frac{s_i + s_j}{d\,(m_i, m_j)} \right),$$

where K is the number of clusters, s_i is the square root of the within-cluster-i sum of squares and m_i is the cluster-i center. The lower I the better the solution is. In the present study, I (three clusters) = 2.12 and I (four clusters) = 2.27. For this reason, but especially for the interpretability of the results, the three clusters partition was selected. The clusters characteristics are described in the results section. Similar approaches, combining clustering methods and dimension reduction methods, as CC or PCA among others, can be found in the literature (Pandolfi et al., 2018; Karlsson et al., 2022).

The evolution of the average daily energy intake, energy retained as fat and protein at the individual level depending on the day and including cluster as a factor was adjusted by two methods: Ordinary Least Square (OLS) and linear mixed (fixed and random) effects model (Everitt and Hothorn, 2011). As the individual unobserved characteristics may influence the pattern of responses, mixed effects models are needed, which include unobserved variables to express the individual performance and control the correlation between the repeated measurements on the same unit (Everitt and Hothorn, 2011). The two models were compared in a likelihood ratio test. All the procedures described in this block has been done with R (R Core Team, 2021).

6.3.6. Statistical inference on cluster means

The differences among cluster means were analysed using SAS software (SAS version 9.4©; SAS institute Inc., Cary, NC; USA). For each productive parameter, carcass quality trait and FBH, an anova MIXED procedure was applied to test for significant differences among cluster means. Shapiro-Wilk and Levene tests were used to check for normality and homocedasticiy, respectively. VS and backfat thickness were changed to approximately conform to normality by a log transformation. The experimental unit for all parameters studied was the pig. Results are presented as LS means ± SE unless otherwise is indicated. For all the presented statistical models, significance was stablished at $P < 0.05$ for all parameters, while a tendency was considered between $P \geq 0.05$ and < 0.10. When the probability of the main effects was significant, Tukey's HSD test adjustment was used to separate treatment means.

6.4. Results

6.4.1. Productive parameters, carcass quality traits and feeding behaviour habits by cluster

The obtained clusters' sizes were 18, 18 and 10 for MFI-*fast eater* pigs, MFI-*slow eater* pigs and HFI-*fast eater* pigs, respectively. Figure 6.1 shows two biplots, superimposing a score graph for individuals with a loading graph for variables, on the first four principal components that captured the 91.1% of the inertia of productive performance data. Figure 6.1A, although being a partial view, explaining a 66.6% of the performance inertia, it clearly permits visualizing the three-cluster partition, with MFI-*slow eater* pigs in an intermediate position. HFI-*fast eater* pigs had higher ADFI, ADG, carcass yield and loin depth values than MFI-*slow eater* and MFI-*fast eater* pigs; whereas MFI-*fast eater* pigs had a poorer FCR than MFI-*slow* and HFI-*fast eater pigs*. The shortest arrows, backfat thickness and carcass yield need a supplementary biplot on axes 3 and 4 (Figure 6.1B) which captured the remaining 23.6% of the performance inertia, to better understand that MFI-*slow eater pigs* present the highest backfat thickness (Table 6.2).

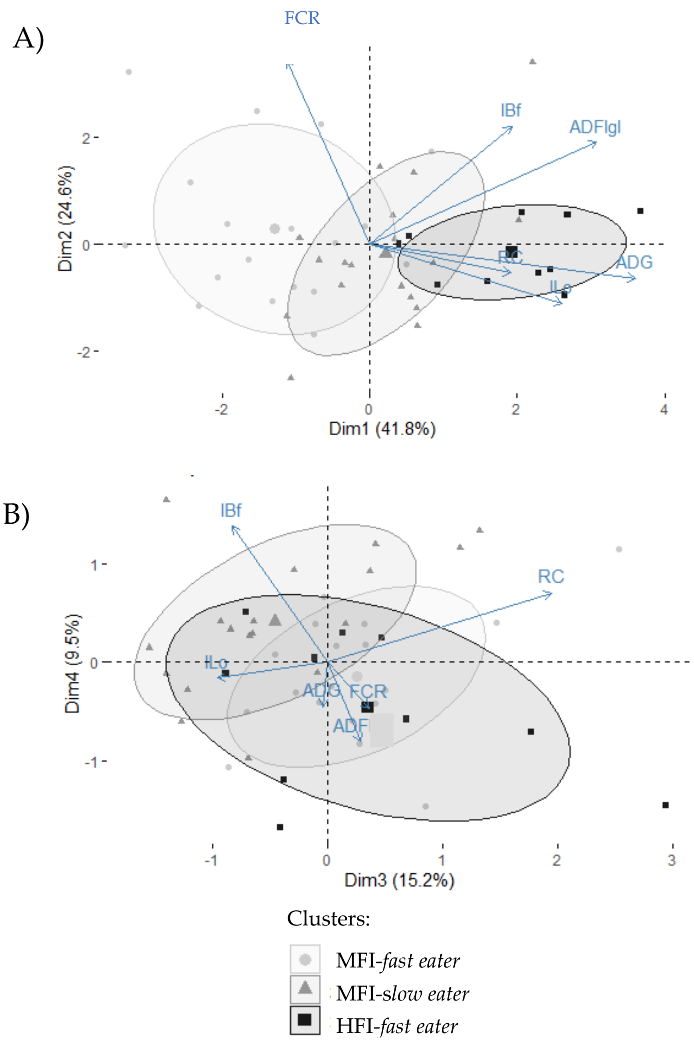


Figure 6.1. Two-dimensional PCA map showing individuals and variables (Feed conversion ratio (FCR) of dimensions 1-2 (A) and 3-4 (B). Backfat thickness (IBf). Average daily feed intake (ADFI). Average daily gain (ADG). Carcass yield (RC). Loin depth (ILo).) The three clusters partition: medium feed intake-*fast eater* pigs (MFI-*fast eater*), medium feed intake-*slow eater* pigs (MFI-*slow eater*) and high feed intake-*fast eater* pigs (HFI-*fast eater*) is also shown by means of confidence ellipses including about the 90% of the most central data.

In Table 6.1, the average BW ± SE by cluster and per period is shown. In p1, no significant differences among clusters (P = 0.11) were observed, with BW ranging from 40.3 ± 0.81 kg in MFI-*slow eater* pigs to 42.9 ± 1.09 kg in HFI-*fast eater* pigs. From p2 to p7, HFI-*fast eater* pigs had higher BW than MFI-*fast* and *slow eater* pigs ($P < 0.05$). When comparing MFI pigs, from p5 to p6, the *slow eaters* had numerically greater BW than the *fast eater* pigs, a difference that in p7 is significantly different with 111.5 ± 1.20 kg BW for the *slow eater* pigs and 106.4 ± 1.20 kg BW for the *fast eater* pigs ($P < 0.0001$).

Table 6.1. Average body weight (BW) of pigs for each cluster and period.

	MFI-*fast eater* pigs	MFI-*slow eater* pigs	HFI-*fast eater* pigs	*P-value*
n	18	18	10	
BW at p1, kg BW	42.2 ± 0.81	40.3 ± 0.81	42.9 ± 1.09	0.11
BW at p2, kg BW	51.9^{b} ± 0.91	50.9^{b} ± 0.91	55.7^{a} ± 1.22	0.01
BW at p3, kg BW	62.3^{b} ± 1.03	61.3^{b} ± 1.03	68.3^{a} ± 5.42	0.0006
BW at p4, kg BW	72.8^{b} ± 1.11	72.3^{b} ± 1.11	80.8^{a} ± 1.49	<0.0001
BW at p5, kg BW	83.7^{b} ± 1.15	85.2^{b} ± 1.15	93.3^{a} ± 1.55	<0.0001
BW at p6, kg BW	94.9^{b} ± 1.14	97.3^{b} ± 1.14	106.2^{a} ± 1.53	<0.0001
BW at p7, kg BW	106.4^{c} ± 1.20	111.5^{b} ± 1.20	120.1^{a} ± 1.61	<0.0001

The BW average ± SE (Standard Error) is shown.

Productive parameters, carcass quality traits and FBHs results by cluster are shown in Table 6.2. No significant differences between clusters were shown for BW on day 0 ($P > 0.1$). On day 124, HFI-*fast eater* pigs were the heaviest (127.1 kg BW) and MFI-*fast eater* pigs the lightest (111.6 kg BW) with MFI-*slow eater* pigs in an intermediate position (118.6 kg BW; $P < 0.0001$). The highest ADFI and ADG values were obtained by HFI-*fast eater* pigs ($P < 0.0001$), whereas the FCR from the best to the worst result was for MFI-*slow* eater pigs, HFI-*fast eater* pigs and MFI-*fast eater* pigs (2.11, 2.14 and 2.22 kg/kg, respectively; $P < 0.05$).

In terms of carcass quality traits, the higher hot carcass weight and carcass yield were obtained by HFI-*fast eater* pigs ($P < 0.0001$ and $P < 0.05$, respectively). The greater backfat thickness was obtained by MFI-*slow* eater pigs, followed by HFI-*fast eater* pigs and by MFI-*fast eater* pigs (15.99, 14.99 and 13.72 mm, respectively; $P < 0.05$), whereas HFI-*fast eater* pigs had the greatest loin depth (68.68 mm), followed by MFI-*slow* eater pigs (64.74 mm) and by MFI-*fast eater* pigs (60.01 mm; $P < 0.0001$).

No significant differences between treatments were shown for TVs ($P = 0.25$). HFI-*fast eater* and MFI-*slow eater* pigs spent more time eating per day than MFI-*fast eater* pigs (47.9, 48.0 and 42.5 min/d, respectively; $P = 0.027$). HFI-*fast eater* pigs ate their daily feed in larger feeder visits than MFI-*fast eater* and MFI-*slow* eater pigs (356.0, 267.7

and 273.1 g/visit, respectively; P = 0.0004), whereas HFI-*fast eater* and MFI-*fast eater* pigs ate faster than MFI-*slow* eater pigs (42.0, 39.7 and 35.0 g/min, respectively; P = 0.0013).

Table 6.2. Performance, carcass traits and feeding behaviour habits by clusters.

	MFI-*fast eaters*	SE[1]	MFI-*slow eaters*	SE[1]	HFI-*fast eaters*	SE[1]	*P*-value
N	18		18		10		
Productive parameters							
Days of fattening, d	124		124		124		
BW at d 0, kg	16.3	1.01	16.5	1.01	16.6	1.02	0.65
BW at d 124, kg	111.6[c]	1.36	118.6[b]	1.36	127.1[a]	1.82	<0.0001
ADFI[2], kg/d	1.71[b]	0.025	1.74[b]	0.025	1.90[a]	0.033	<0.0001
ADG[3], g/d	0.767[c]	0.0102	0.823[b]	0.0102	0.890[a]	0.0138	<0.0001
FCR[4], kg/kg	2.22[a]	1.012	2.11[b]	1.012	2.14[ab]	1.017	0.014
Carcass quality traits							
Hot carcass weight, kg	84.0[c]	1.12	89.4[b]	1.12	97.5[a]	1.51	<0.0001
Carcass yield, %	75.3[b]	0.30	75.4[b]	0.30	76.7[a]	0.40	0.016
Backfat thickness, mm	13.72[b]	1.036	15.99[a]	1.036	14.99[ab]	1.048	0.01
Loin depth, mm	60.01[c]	1.064	64.74[b]	1.064	68.68[a]	1.427	<0.0001
Feeding behaviour habits							
TVs, total feeder visits, visits/d	6.3	0.16	6.0	0.16	5.8	0.22	0.25
TD, total time spent eating, min/d	42.5[b]	1.53	48.0[a]	1.53	47.9[a]	2.05	0.027
VS, visit size, g/visit	267.7[b]	1.04	273.1[b]	1.04	356.0[a]	1.06	0.0004
FR, feeding rate, g/min	39.7[a]	1.14	35.0[b]	1.14	42.0[a]	1.53	0.0013

[1] SE (Standard Error). [2] ADFI (average daily feed intake). [3] ADG (average daily gain). [4] FCR (feed conversion ratio). LSmeans corrected by least squares.

6.4.2. Energy, protein and fat partitioning and utilization by clusters

The results of the energy and protein and fat partitioning are shown in Table 6.3. The results of energy retained as protein and as fat are expressed in kcal/d, being somehow synonymous of protein and fat retention, respectively, expressed in g/d. The average daily MEm and daily energy retained as fat and as protein of all the experimental period were calculated by the Factorial and the NRC method. In addition, the protein and fat partition were also calculated in sub-periods (p1-p3, p4-p7) by the NRC method. HFI-*faster* pigs had the highest ME intake and MEm (P < 0.0001). The factorial method results indicated that when energy retained as protein and as fat were calculated separately, the order of clusters from higher to lower energy retained as protein and as fat was: HFI-*fast eater*, MFI-*slow eater* and MFI-*fast eater* pigs; whereas the highest NE retention was shared by MFI-*slow* and HFI-*fast eater* pigs ($P < 0.0001$). The NRC method indicated that, overall, MFI-*fast eater* pigs retained more energy as protein, followed by MFI-*slow eater* pigs and HFI-*fast eater* pigs; whereas HFI-*fast eater* pigs retained more energy as fat ($P < 0.001$). However, while no differences between clusters were observed from p1 to p3 in terms of energy retention as protein; from p4 to p7 HFI-*fast eater* pigs showed the lowest energy retained as protein. In terms of energy retained as fat, from p1 to p3 HFI-*fast eater* pigs had the highest energy retained as fat, but from p4 to p7 HFI-*fast eaters* did not differ from MFI-*slow eater* pigs ($P < 0.001$).

Table 6.3. Energy, protein and fat partitioning and utilization by cluster.

		MFI-*fast eater* pigs	**SE[1]**	**MFI-*slow eater* pigs**	**SE[1]**	**HFI-*fast eater* pigs**	**SE[1]**	***P-value***
ME intake, kcal/d		6054 [b]	90.6	6248 [b]	90.6	6853 [a]	121.6	<0.0001
Factorial								
MEm[2], kcal/d	p1-p7	2965 [b]	23.7	2970 [b]	23.7	3136 [a]	31.8	<0.0001
NE[3] as protein retention, kcal/d	p1-p7	667 [c]	10.8	741 [b]	10.8	797 [a]	14.4	<0.0001
NE[3] as fat retention, kcal/d	p1-p7	1786 [c]	37.3	2020 [b]	37.3	2250 [a]	50.0	<0.0001
NE[3] retention (prot and fat), kcal/d	p1-p7	2214 [b]	58.2	2631 [a]	58.2	2705 [a]	78.0	<0.0001
NRC								
MEm[2], kcal/d	p1-p7	2530 [b]	20.2	2534 [b]	20.2	2675 [a]	27.1	0.0001
NE[3] as protein retention, kcal/d	p1-p7	827 [a]	1.4	821.16 [b]	1.369	809.16 [c]	1.837	<0.0001
	p1-p3	842	1.4	838	1.4	842	1.9	0.18
	p4-p7	814 [a]	3.0	807 [a]	3.0	782[b]	4.0	<0.0001
NE[3] as fat retention, kcal/d	p1-p7	1518[b]	65.7	1673[b]	65.7	2036[a]	88.1	0.0001
	p1-p3	1248[b]	57.8	1116[b]	57.8	1598[a]	77.6	<0.0001
	p4-p7	1719[b]	94.8	2102[a]	94.8	2361[a]	127.3	0.0005
NE[3] retention (prot and fat), kcal/d	p1-p7	2344[b]	65.0	2494[b]	65.0	2844[a]	87.3	0.0002

[1] SE (Standard Error). [2] MEm (metabolizable energy used for maintenance, kcal/d). [3] NE (Net energy, kcal/d). LSmeans corrected by least squares.

Table 6.4 shows the *Kge, Kf* and *Kcp* calculated overall by the factorial and NRC methods and by sub-periods by the NRC method (p1-p3 and p4-p7) by cluster. Regarding *Kge*, MFI-*fast eater* pigs were the less efficient, sharing letter with MFI-*slow eater* pigs when the NRC method was applied overall and from p1 to p3 ($P < 0.01$); whereas from p4 to p7, MFI-*fast eater* pigs had the lowest *kge* value ($P = 0.006$). On the other hand, MFI-*slow eater* pigs obtained the higher *Kf* value when the factorial method was applied ($P = 0.0014$), whereas HFI-*fast eater* pigs obtained the highest *Kf* overall and from p1 to p3, sharing letter with MFI-*slow eater* pigs from p4 to p7 with the NRC method (P = 0.0001). Lastly, overall, MFI-*slow eater* pigs were the most efficient pigs in terms of protein utilization, sharing letter with the NRC method with MFI-fast eater pigs ($P < 0.05$); whereas from p1 to p3 HFI-*fast eater* pigs had the lowest *Kcp* value ($P < 0.0001$) and from p4 to p7 the obtained order of clusters from the most to the less efficient in protein utilization was: MFI-*fast eater* pigs, MFI-slow eater pigs and HFI-*fast eater* pigs ($P < 0.0001$).

Table 6.4. Energy and protein efficiency by cluster

			MFI-*fast eater* pigs	**SE[1]**	**MFI-*slow eater* pigs**	**SE[1]**	**HFI-*fast eater* pigs**	**SE[1]**	***P-value***
***Kge*[2]**	**Factorial**	p1-p7	0.37 [b]	0.007	0.42 [a]	0.007	0.40 [a]	0.009	<0.0001
	NRC	p1-p7	0.38 [b]	0.005	0.39 [b]	0.005	0.41 [a]	0.006	0.0039
		p1-p3	0.39 [b]	0.005	0.38 [b]	0.005	0.41 [a]	0.007	0.0015
		p4-p7	0.38 [b]	0.006	0.40 [a]	0.006	0.41 [a]	0.008	0.0062
***Kf*[3]**	**Factorial**	p1-p7	0.72 [b]	0.016	0.81 [a]	0.016	0.73 [b]	0.021	0.0014
	NRC	p1-p7	0.65 [b]	0.002	0.66 [b]	0.002	0.67 [a]	0.003	0.0001
		p1-p3	0.65 [b]	0.002	0.64 [b]	0.002	0.66 [a]	0.004	0.0006
		p4-p7	0.66 [b]	0.002	0.67 [a]	0.002	0.68 [a]	0.003	0.0002
***Kcp*[4]**	**Factorial**	p1-p7	0.44[b]	0.007	0.47[a]	0.007	0.44[b]	0.009	0.0207
	NRC	p1-p7	0.50[a]	0.007	0.49[a]	0.007	0.44[b]	0.009	<0.0001
		p1-p3	0.58[a]	0.009	0.60[a]	0.009	0.52[b]	0.013	<0.0001
		p4-p7	0.45[a]	0.008	0.42[b]	0.008	0.38[c]	0.011	<0.0001

[1] SE (Standard Error). [2] *Kge* (gross energy efficiency, %/100). [3] *Kf* (growth energy efficiency, %/100). [4] *Kcp* (gross crude protein utilization, Kcp, %/100. LSmeans corrected by least squares.

6.4.3. Time evolution of the energy intake and the energy retention as fat and protein by cluster

The evolution of the daily energy intake (ME), energy retention as protein and as fat (NE) by cluster have been evaluated by OLS and by a second order mixed effects model. The *P-value* ($P < 0.0001$) associated with the likelihood ratio test indicated that the mixed effects model is preferred over the OLS one for daily energy intake, energy retained as protein and as fat (Data not shown). The details of the mixed effects model equations are described in Appendix A.

The daily energy intake and energy retained as fat fitted to a linear equation (Figure 6.2, 6.3 and 6.4). In fact, the evolution of the energy retained as fat follows a parallelism with the evolution of the daily energy intake with MFI-*slow eater pigs* showing the steepest slope, followed by the HFI-*fast eater* and MFI-*fast eater* pigs with the less pronounced slope (44, 39 and 29 are the slopes of the daily energy intake and 20, 16 and 11 are the slopes of the daily energy retained as fat of MFI-*slow eater pigs*, HFI-*fast eater* and MFI-*fast eater*, respectively). Notice that a larger variability is observed in the energy retained as fat than in the daily energy intake. In addition, HFI-*fast eater* pigs showed the higher daily energy intake and energy retained as fat in all the experimental periods compared to MFI pigs; however, due to the steeper slope, MFI-*slow eater pigs* achieved closed values to HFI-*fast eater* pigs on the last period.

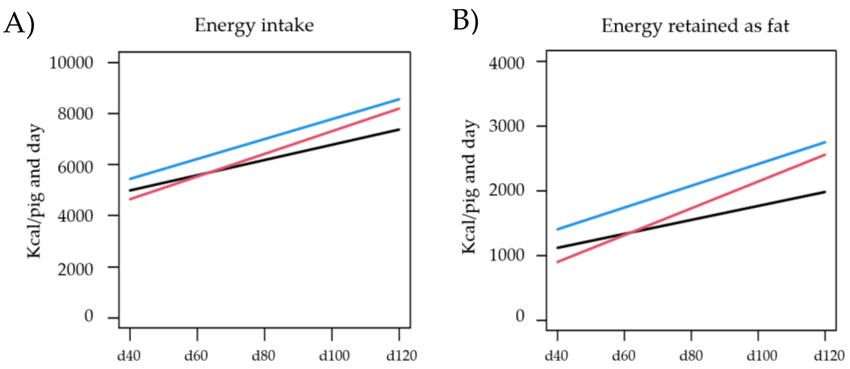


Figure 6.2. Linear mean evolution of the daily energy intake (A; kcal/pig and day) and daily energy retained as fat (B; kcal/pig and day) by cluster. MFI-*fast eater* pigs (black line), MFI-*slow eater* pigs (red line) and HFI-*fast eater* pigs (blue line).

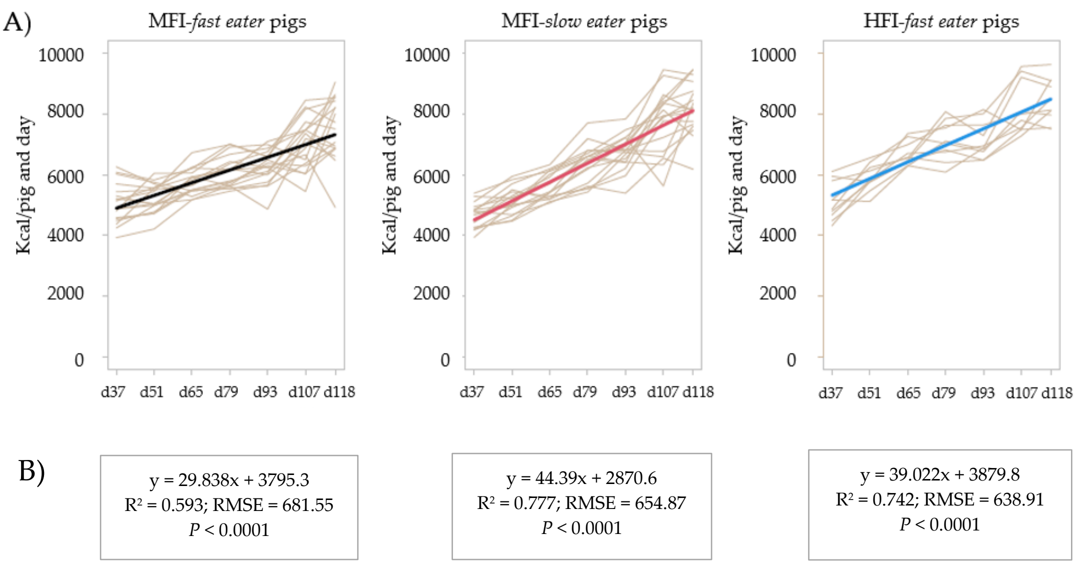


Figure 6.3. Average daily energy intake individual lines (kcal/pig and day) observed (A, in the top row, the thickest solid line is the regression line showing the mean evolution) and regression equation (B, in the bottom row: $y = b_{0j} + b_{1j}d$) in the three clusters (MFI-*fast eater*, MFI-*slow eater* pigs and HFI-*fast eater* pigs).

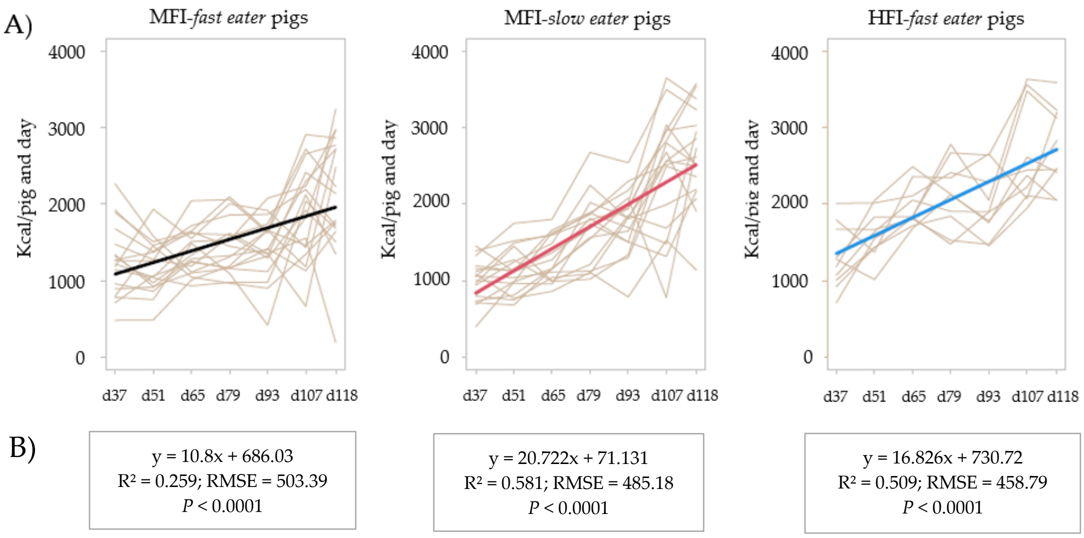


Figure 6.4. Daily energy retained as fat individual lines (kcal/pig and day) observed (A, in the top row, the thickest solid line is the regression line showing the mean evolution) and regression equation (B, in the bottom row: $y = b_{0j} + b_{1j}d$) in the three clusters (MFI-*fast eater*, MFI-*slow eater* pigs and HFI-*fast eater* pigs).

The energy retained as protein fitted to a quadratic equation (Figure 6.5 and 6.6). Although the maximum protein deposition was similar between clusters (854.6 kcal/d for MFI-*fast eater* pigs, 856.3 kcal/d for MFI-*slow eater* pigs and 853.4 kcal/d for HFI-*fast eater* pigs which correspond to 149.9, 150.2 and 149.7 g of protein/d, respectively), HFI-*fast eater* pigs achieved the maximum energy retained as protein six days before compared to MFI pigs (on day 62 HFI-*fast eater* pigs and on day 68 MFI pigs). In addition, the energy retained as protein started to decline before in HFI-*fast eater* pigs compared to MFI pigs.

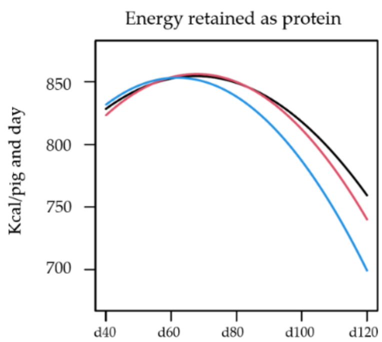
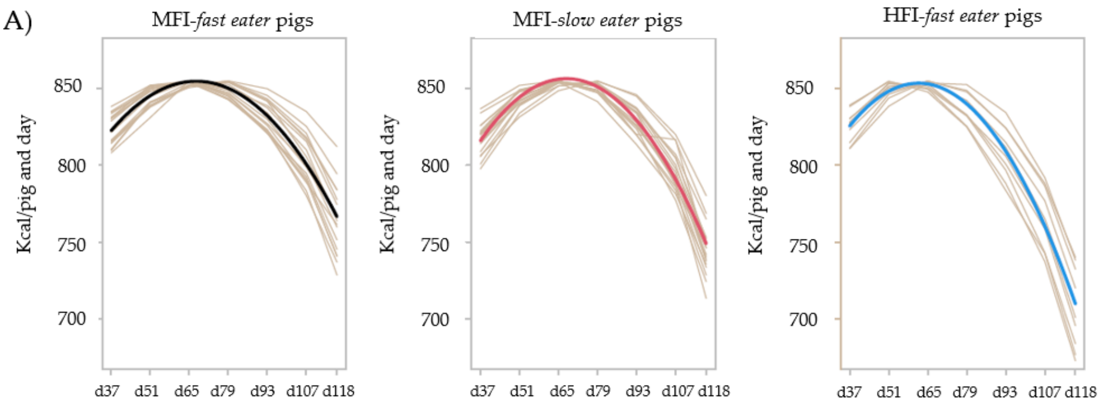


Figure 6.5. Quadratic mean evolution of the daily energy retained as protein (kcal/pig and day) by cluster. MFI-*fast eater* pigs (black line), MFI-*slow eater* pigs (red line) and HFI-*fast eater* pigs (blue line).

A)



B)

$y = -0.0346x^2 + 4.672x + 696.9$
$R^2 = 0.865$; RMSE = 11.69
$P < 0.0001$

$y = -0.0427x^2 + 5.7862x + 660.09$
$R^2 = 0.928$; RMSE = 9.99
$P < 0.0001$

$y = -0.0455x^2 + 5.6168x + 679.84$
$R^2 = 0.922$; RMSE = 14.60
$P < 0.0001$

Figure 6.6. Daily energy retained as protein individual lines (kcal/pig and day) observed (A, in the top row, the thickest solid line is the regression parabola showing the mean evolution) and quadratic equation (B, in the bottom row: $y = b_{0j} + b_{1j}d + b_{1j}d^2$) in the three clusters (MFI-*fast eater*, MFI-*slow eater* pigs and HFI-*fast eater* pigs).

6.5. Discussion

Grouped growing-finishing pigs allocated in a pen show different types of FBHs (Hoy et al., 2012). The correlations between FBHs of growing-finishing pigs has led to classifying pigs by their size and number of meals per day as *nibbler* pigs (many short meals) and *meal eater* pigs (a few long meals) and by their FR (*fast* or *slow* eater pigs; Fornós et al. 2022a). In the present study, three types of pigs distinguished by their ADFI and FR have been obtained: pigs eating the same ADFI by different FR (MFI-*fast eater* pigs and MFI-*slow eater* pigs) and pigs with a higher ADFI eating fast (HFI-*fast eater* pigs). However, pigs with a high ADFI eating slowly (HFI-*slow eaters*) were not obtained. We hypothesize that the competition access to the feeder could have made the achievement of a high ADFI by a slow rhythm of ingesta impossible or that with the observed positive correlation between FR and ADFI (Fornós et al., 2022a), biologically those type of pigs possibly do not exist. Those different FBHs are regulated by dietary and non-dietary factors (Fernández et al., 2011; Chassé et al., 2021). Regarding dietary factors, MS and the time between two meals are regulated by three types of regulators: distention, osmotic and hormonal which depending on the diet composition ones are more important than others (Chassé et al., 2021). When receptors detect distention, the FR decreases increasing MS and time between meals (Lepionka et al., 1997). However, in contrast to those physiologic cause-consequence mechanisms, in the present study, HFI-*fast eater* pigs ate in larger feeder visits but with the same FR than MFI-*fast eater* pigs, indicating that FR was not modified by MS. The discrepancy between the results of the present study and the physiologic cause-consequence mechanisms that regulate hunger may be due to stocking density (non-dietary factor). In fact, Nielsen et al. (1999) concluded that FR could be used as a good indicator of social constraint. Moreover, compared to group-housed growing-finishing pigs, individually housed pigs visit the feeder more times and eat smaller amounts each time (De Haer et al., 1993). Therefore, these data suggest that FBHs of group-housed growing-finishing pigs is influenced by dietary factors but also by housing conditions such as stocking rate.

On the other hand, a large variability among individuals exists in terms of FBHs (Carcò et al., 2018). However, FBHs of each pig seems to be maintained over time (Fernández et al., 2011; Fornós et al., 2022b), allowing us to analyse the influence of FBHs throughout the fattening period on performance and feed utilization. The ADG of growing-finishing pigs is positively correlated with VS (r = 0.49, $P < 0.001$; non-published data) and FR (r = 0.36, $P < 0.05$, non-published data), however, both parameters are also positively correlated with ADFI (r = 0.45, $P < 0.01$ and r = 0.59, $P < 0.001$, respectively, non-published data). Thus, the influence of the two aforementioned FBHs on performance may be confounded by the ADFI level (Fornós et al. 2022a). In the present study, the distribution of pigs in three clusters allowed us to discuss separately the influence of the ADFI level by comparing HFI-*fast eater* vs MFI-*fast eater* pigs and the influence of the FR by comparing MFI-*fast eater* and MFI-*slow* eater pigs, both on the performance, feed utilization, energy efficiency and carcass quality traits.

Several studies have reported that the **level of ADFI** is positively correlated with ADG, protein and fat deposition with discrepancies among studies in the correlation between ADFI and FCR, highlighting the importance of achieving the desired ADFI (Fernández et al., 2011; Patience et al., 2015; Godinho et al., 2018; Hou et al., 2022). In the present study, HFI-*fast eater* pigs ate 190 g of feed/d, gained 123 g of BW/d, weighed 15.5kg BW and had 8.7 mm more of loin depth than MFI-*fast eater* pigs. Moreover, although the differences were not statistically significant, the FCR of HFI-*fast eater* pigs was 80 g lower and had 1.3 mm more of backfat thickness than MFI-*fast eater* pigs. However, HFI-*fast eater* pigs ate in larger feeder visits than MFI-*fast eater* pigs. Therefore, as VS is related with feed digestibility (De Haer et al., 1993; Chassé et al., 2021), those productive differences cannot be attributed only to the higher ADFI. Therefore, the impact of ADFI and VS on productive parameters cannot be separately understood but the results obtained confirm that pigs eating more with bigger feeder visits have some productive advantages, a result in agreement with Fernández et al. (2011).

Regarding feed utilization, Ewaoluwagbemiga et al. (2021) observed that the more protein efficient pigs were those eating in shorter and smaller meals with lower ADFI. But, as ADFI is strongly correlated with production parameters (Kavlak and Uimari, 2019) it is not possible to separate the effect of MS and ADFI. Therefore, better protein utilization could be due to smaller meals or to the closer ADFI to the requirements of pigs, which allows pigs to reach the maximum protein deposition. In the present study, in terms of energy retained as protein and as fat and energy utilization some discrepancies have been obtained depending on the calculation model used (NRC or Factorial method). The discrepancies might be due to: the different estimation obtained for MEm or, because of the fast evolution in genetic selection for leaner pigs. Thus, knowledge of the body composition of actual pig lines at different ages to develop prediction equations of protein and fat deposition with non-invasive methodologies such as computed tomography are of huge interest (Carabús et al., 2016). In terms of energy deposition as protein, from p1 to p7, HFI-*fast eater* pigs had higher daily protein deposition rates than MFI-*fast eater* pigs by the Factorial method but lower by NRC method. A difficult discrepancy to explain due to the lack of in vivo body composition measurements. Another reason for discrepancy may be that the equations used to obtain the NRC protein retention curve used only pigs' BW and predicted very close figures of daily maximum protein retention among pigs (see figure 6.5), which probably could not be the case in practice.

Moreover, the NRC method allows us to calculate nutrients utilization by periods, indicating that the observed differences were due to the lower protein retention from p4 to p7 together with a higher fat retention of HFI-*fast eater* pigs compared to MFI-*fast eater* pigs. A result in agreement with Godinho et al. (2018) who reported a negative correlation between backfat thickness and protein deposition and a positive correlation between growth and lipid deposition. In fact, HFI-*fast eater* pigs achieved six days before the maximum daily protein retention (62 vs 68 days of fattening) with a steeper decreasing slope from p4 to p7 for protein deposition and a steeper increasing slope from p4 to p7 for fat deposition than MFI-*fast eater* pigs. HFI-*fast eater* pigs weighed around 70 kg on day 62 of fattening, whereas MFI-*fast eater* pigs weighed around 60 kg on day 68 of fattening. Those results suggest that the level of ADFI may have increased growth, anticipating the achievement of the maximum protein retention, results that support previous findings of the influence of energy supply on the level of energy retained as protein and fat deposition (van Milgen et al., 2008). After those calculations and due to the high importance of producing leaner pigs in the current market, it would be of interest to relate the amino acids requirements and the BW at which pigs achieve the maximum protein retention, in order to select the most efficient pigs and the feeding program to obtain leaner and cost-efficient pigs (Remus et al., 2020b).

On the other hand, the improvement in efficiency to convert dietary protein to animal protein is of great interest to reduce nitrogen losses to the environment (Millet et al., 2018). With the results of the present study, HFI-*fast eater* pigs reached before the maximum protein deposition than MFI-*fast eater* pigs, suggesting that from that point, HFI-*fast eater* pigs were probably fed by a larger amount of amino acids than the required. Consequently, the excess of amino acids intake was probably not converted into animal protein and was excreted via manure increasing energy waste to eliminate the fed nitrogen in excess (van Milgen et al., 2021) and increasing fat deposition. Those cause-consequence mechanisms indicate that the prediction of the maximum level protein retention is paramount to fed pigs by their individual amino acids requirements (Millet et al., 2018). The above explanation is proven by the lower *kcp* of HFI-*fast eater* compared to MFI-*fast eater* pigs from p4 to p7.

Regarding **FR,** it is positively correlated with ADFI, ADG, final BW and backfat thickness but with low influence on FCR (Fornós et al. 2022a). Carcò et al. (2018) reported in group-housed pigs from 85 to 145 kg BW that pigs eating faster, ate more, had heavier final BW, greater ADG, greater estimated protein gains and greater estimated lipid retention than pigs eating slower. As exposed before with VS, the results of Carcò et al. (2018) cannot be totally attributed to FR as pigs also had a higher ADFI. In the present study, the influence of FR on productive parameters can be analysed due to the obtention of two clusters of pigs eating the same ADFI but with different FR (39.7 vs 35 g/min, MFI-*fast eater* and MFI-*slow eater* pigs, respectively). In terms of productive parameters, MFI-*slow eater* pigs grew 56 g/d more, obtained 110 g less in FCR, had 2.27 mm more of backfat thickness and 4.73 mm more of loin depth than MFI-*fast eater* pigs. Those results suggest that eating slower may improve nutrients digestibility which could explain the better FCR, backfat and loin depth outcomes. In agreement with our results, Andretta et al. (2016a) obtained a strong and positive correlation between FR and FCR. Moreover, they also reported a strong and negative correlation between FR and crude protein efficiency. In the present study, the results indicated that with the same energy intake and MEm, MFI-*slow eater* pigs retained more energy as protein and fat, in consequence, those pigs had a higher *kfe* than MFI-*fast eater* pigs. The results obtained suggest that the utilization of nutrients may be improved with a lower FR, probably due to the effects on the passage rate of ingesta and on the digestive enzymes action (De Haer and de Vries, 1993; De Haer et al., 1993; Solà-Oriol et al., 2010). To our knowledge, several studies have analysed the influence of MS or fibre on the passage rate of ingesta and feed digestibility (Huting et al., 2021). However, no studies have been found analysing the influence of the FR on feed digestibility. Therefore, we hypothesize that eating the same amount of ADFI slowly causes a smaller but more constant supply of feed to the digestive tract throughout the day which may improve nutrients digestibility by reducing the amount of feed to digest within a time and therefore reducing the ratio of feed quantity to available digestive enzymes, enhancing enzymes action. Consequently, the loss of energy and the excretion on non-absorbed nutrients are reduced thanks to the higher amount of disponible digested feed to be absorbed by intestinal enterocytes. Therefore, the efficiency in protein and fat absorption is enhanced, increasing protein and fat retention. In fact, despite discrepancies between the factorial and NRC methods results, the results suggest that overall, MFI-*slow eater* pigs were more efficient in terms of protein deposition than MFI-*fast eater* pigs. However, from p4 to p7 the results were the inverse, which could indicate that due to higher growth rates and BW of the MFI-*slow eater* pigs compared to the MFI-*fast eater* pigs, most pigs of the former ones achieved before the maximum protein deposition than MFI-*fast eater* pigs.

6.6. Appendix A

The evolution of energy intake (ME) and energy retention as protein and as fat (NE) have been evaluated by OLS regression and mixed effects models. The coefficient estimates obtained by both methods coincide, but SE values and *P*-values slightly differ showing the mixed effects model lower SE and consequently more significance (lower *P*-values, although not shown due to the simpler stars code), respectively (Table 6.5).

Table 6.5. Regression results: Ordinary least squares and mixed linear effects models are fitted for average daily energy intake, energy retained as fat and as protein by cluster.

	Average daily energy intake		**Average daily energy retained as fat**		**Average daily energy retained as protein**	
	OLS[1]	**Linear mixed effects**	**OLS[1]**	**Linear mixed effects**	**OLS[1]**	**Linear mixed effects**
Constant (b_{01})	3,795.339***	3,795.339***	686.027***	686.027***	696.904***	696.904***
	(179.314)	(149.297)	(131.871)	(110.221)	(9.401)	(4.642)
MFI-*slow eaters*[2] (a_{02})	-924.724***	-924.724***	-614.897***	-614.897***	-36.814***	-36.814***
	(253.588)	(211.137)	(186.494)	(155.876)	(13.295)	(6.564)
HFI-*fast eaters*[3] (a_{03})	84.475	84.475	44.695	44.695	-17.067	-17.067**
	(300.050)	(249.821)	(220.662)	(184.435)	(15.731)	(7.767)
Day (b_{11})	29.838***	29.838***	10.800***	10.800***	4.672***	4.672***
	(2.155)	(2.073)	(1.585)	(1.526)	(0.262)	(0.140)
MFI-*slow eaters*:day (a_{12})	14.552***	14.552***	9.922***	9.922***	1.114***	1.114***
	(3.048)	(2.932)	(2.241)	(2.158)	(0.371)	(0.198)
HFI-*fast eaters*:day (a_{13})	9.184**	9.184***	6.026**	6.026**	0.945**	0.945**
	(3.606)	(3.470)	(2.652)	(2.553)	(0.439)	(0.234)
Day^2 (b_{12})					-0.035***	-0.035***
					(0.002)	(0.001)
MFI-*slow eaters*:day^2 (a_{22})					-0.008***	-0.008***
					(0.002)	(0.002)
HFI-*fast eaters*:day^2 (a_{23})					-0.011***	-0.011***
					(0.003)	(0.002)

[1] OLS (Ordinary least squares model). [2] (MFI-*slow eaters)* Medium feed intake-*slow eater* pigs. [3] (HFI-*fast eaters*) High feed intake-*fast eater* pigs. Results are shown as coefficient estimates (Standard Error). Asterisks indicate the degree of significance *P < 0.1; **P < 0.05; ***P < 0.01. Notice that: for each productive parameter, the likelihood ratio test confirmed the significance of mixed models with respect to OLS (P < 0.01).

From a therorical point of view, mixed effects models are the most appropriate in this repeated measurement setting. In our case, the mixed effects model equation can be written in terms of the day *d* and two dummies (D_2 = 1 in cluster MFI-*slow eater* pigs and zero in the other clusters and D_3 = 1 in cluster HFI-*fast eater* pigs and zero in the other clusters; noticing that the cluster MFI-*fast eater* pigs is represented by $D_2 = D_1 = 0$).

The first order model formula, adjusted to the average daily energy intake and to the energy retained as fat is:

$$y_i = b_{01} + a_{02}D_2 + a_{03}D_3 + b_{11}d + a_{12}D_2d + a_{13}D_3d \quad + u_i + v_id + e,$$

and the second order model for the energy retained as protein is:

$$y_i = b_{01} + a_{02}D_2 + a_{03}D_3 + b_{11}d + a_{12}D_2d + a_{13}D_3d + b_{21}d^2 + a_{22}D_2d^2 + a_{23}D_3d^2 + u_i + v_id + w_id^2 + e$$

where u_i, v_i and w_i represent random effects of individual unit i and e the global random effect. A multivariate Gaussian distribution it is assumed on the random effects, allowing correlations between u_i, v_i and w_i (for a given unit i)

In each cluster, the evolution of the daily energy intake and the energy retained as fat is described by a linear equation, derived from the model. For each productive indicator and each cluster (j = 1, 2 and 3), the straight-line equation is $y \quad = b_{0j} + b_{1j}d$, where d = day. For j = 1 (MFI-*fast eater* pigs), the regression line coefficients are explicit in Table 6.5, but for j = 2 (MFI-*slow eater* pigs) and j = 3 (HFI-*fast eater* pigs), the parameters can be calculated using the coefficients on the dummy regressors: $b_{kj} = b_{k1} + a_{kj}$, where $k = 0{,}1$ moves on the straight line intercept and slope (Table 6.5). The regression equations for the ADFI and the energy retained as fat calculated by those coefficients for each cluster are shown in Figure 6.3B and Figure 6.4B, respectively.

In each cluster, the evolution of the energy retained as protein is described by a quadratic equation. In each cluster (j = 1, 2 and 3), the parabola equation is $y = b_{0j} + b_{1j}d + b_{1j}d^2$, where d = day. For j = 1 (MFI-*fast eater* pigs), the coefficients of the parabola are explicit in Table 6.5, but for j = 2 (MFI-*slow eater* pigs) and j = 3 (HFI-*fast* *eater* pigs), the parameters can be calculated using the coefficients on the dummy regressors: $b_{kj} = b_{k1} + a_{kj}$, where $k = 0,1,2$ moves on the parabola coefficients (Table 6.5). The regression equations calculated by those coefficients for each cluster are shown in Figure 6.6B.

CHAPTER 7.

Effect of a dietary calming herbal extracts blend on growth performance, carcass quality, feeding behaviour habits and welfare of group-housed finishing pigs

Article sent to the *Applied Animal Behaviour Science:*

Fornós, M., Jiménez-Moreno, E., Gasa, J., Rodríguez-Estévez, V. and D. Carrión. **Effect of a dietary calming herbal extracts blend on growth performance, carcass quality and feeding behaviour of group-housed finishing pigs.**

7.1. Abstract

Unexpected feed disruptions during the growing-finishing period impact negatively on the growth performance of pigs. For example, after loading the heavier pigs of a barn to the slaughter-house, the pigs remaining on the farm suffer feeding-fasting intervals which induce metabolic stress, pen hierarchy is broken and in consequence pig performance and welfare may be impaired. Herbal extracts of plants such as *Eschscholzia californica*, *Humulus lupulus* and *Passiflora incarnata* have shown sedative properties in mice and humans. However, little is known about their effects on pigs. Therefore, in the present work it is hypothesized that the use of a calming herbal extracts blend (HE) based on these three plants could improve welfare and performance of finishing pigs after a long fasting thanks to its calming effect by reducing the number of aggressions and modifying their FBHs. A total of 72 pigs were divided into two treatments: 1) Control group and 2) HE group (HE was added at a level of 0.2%) from day 84 to 130 of fattening. A feeding fasting period of 42 hours was used as a stressor, starting on day 110. HE inclusion tended to increase ADG by 8.1% (P = 0.077), ADFI by 6.9% ($P < 0.05$) and loin depth by 3 mm ($P < 0.05$). The next four days after the fasting period pigs fed with HE had a greater ADFI and TD ($P <$ 0.1). Moreover, less severe skin lesions were observed in pigs fed with the HE diet after fasting ($P < 0.05$). In conclusion, the present work provides positive evidence of the use of calming herbal extracts on finishing pigs' performance and welfare.

***Keywords**: calming herbals extract; fasting; feeding behaviour; finishing pig*

7.2. Objective

Growing-finishing pigs fed ad libitum should have uninterrupted access to the feed during all the fattening period, however, in practice feed disruptions occur owing to human error or equipment malfunctions with negative consequences on growth performance and welfare. California poppy (*Eschscholzia californica*), hop (*Humulus lupulus*) and maypop (*Passiflora incarnata*) plants are known for their calming effect in mice and humans. The combination of these plants with sedative effects at certain proportions could have synergic or additive effects and mitigate the negative effects of stressors such as feeding-fasting intervals in finishing pigs. Therefore, the objective of the present study is to analyse the effect of the dietary inclusion of a commercial herbal extracts blend (HE) based on california poppy, hop and maypop plant extracts on the growth performance, FBHs, aggressiveness of finishing pigs after a prolonged fasting period.

7.3. Material and methods

7.3.1. Animals and housing conditions

A total of 72 Pietrain x (Landrace x Large white) 10-week old pigs (48 intact males and 24 females) were used in the present study which lasted 46 days (from day 84 to day 130 of fattening). On arrival pigs were sexed and split into three initial BW groups with an average of 15.59 ± 0.27 kg for the lightest pigs, 16.38 ± 0.22 kg for the medium pigs and 17.32 ± 0.32 kg for the heaviest group. Four pigs of each BW group were allotted at random to each pen, with 12 pigs in each (24 intact males and 12 females per treatment). The average initial BW was 16.43 ± 0.79 kg for control pigs and 16.44 ± 0.75 kg for HE pigs.

Each pen was equipped with one automatic feeding system (Nedap ProSense®, The Netherlands), one nipple with a water cup and a totally slatted floor. The dimensions of the pens were 2.37 m width x 5.08 m length and the stocking density per pen was 0.91 m^2/pig, excluding the space occupied by the automatic feeding system.

During the experiment, three pigs were discarded due to lameness (two pigs of the control group) and respiratory disorders (one pig of the HE group), and their data were removed from the database; thus, the final dataset consisted of 69 pigs.

7.3.2. Herbal extracts blend and experimental diets

The HE blend studied (ConverMax®, Cargill SLU) is a mineral feed solution based on california poppy, hop and maypop herbal extracts. All pigs were fed with a mash diet in a 3-phase feeding program (starter phase, in the period from day 1 to 39; growing phase, in the period from day 40 to 83; and finishing phase, in the period from day 84 to 130 of fattening). A common basal diet based on wheat-corn-triticale, soybean meal and sunflower meal was formulated to contain 2,480 kcal NE/kg, 16.1% CP and 1.08% SID Lys for starter phase, 2,460 kcal NE/kg, 15.5% CP and 0.99% SID

Lys for growing phase and 2,460 kcal NE/kg, 15.0% CP and 0.93% SID Lys for finishing phase. In the finishing phase (from day 84 until the end of the experiment; day 130), half of the pigs received the common basal diet without HE added (control group), while the other half received the same basal diet with HE added at a level of 0.2% (HE group).

HE was offered from day 84 until day 130 of fattening and a fasting period of 42 hours started on day 110 at 18:00 h and finished on day 112 at 12:00 h. The pigs were then fed ad libitum with the treatment until day 130 of fattening. On day 131, pigs were individually weighed and slaughtered. Pigs had ad libitum access to water and feed during the entire experimental period (except feed during the 42 hours fasting period).

7.3.3. Growth parameters and carcass quality traits

During the experimental period individual BW of the pig and feed supply were recorded each time that every pig entered the automatic feeding system and, from these data, ADG, ADF and FCR were calculated. Mortality and removals were registered during the experimental period. Pigs were individually weighed on day 84 and on day 131 before the loading of pigs to the slaughter-house.

All pigs were slaughtered maintaining 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 of each pig was measured 1 h post-mortem and was used to calculate carcass yield (%). The backfat thickness (mm) and loin depth (mm) were measured at a level of the last 3-4 ribs, at 6 cm from the midline 1h post-mortem by a Fat-O-Meat'er probe (Frontmatec A/S, Herlev, Denmark).

7.3.4. Feeding behaviour habits

Automatic feeding systems recorded individual feed intake and time spent eating in each feeder visit. From these data, the individual FBHs were calculated (Table 7.1) and analysed in seven day-periods from day 84 until 130 except for the period of pre-fasting (from day 105 to 109), fasting (from day 110 to 112) and post-fasting (from day 113 to 116). In addition, FBHs were analysed daily in the period from day 105 to 116.

Table 7.1. Individual feeding behaviour habits and the criteria used to compute them.

Parameter	Abbreviation used	Criterion
Average daily feed intake (kg/d)	ADFI	Total feed consumed per pig and day
Feeder visits per day (n/d)	TVs	Number of feeder visits with per pig and day
Time spent eating (min/d)	TD	Total time spent eating per pig and day
Visit size (kg/visit and day)	VS	Total feed consumed per feeder visit per pig
Visit duration (min/visit)	Vd	Duration of each effective feeder visit
Feeding rate (g/min)	FR	Feed intake per minut spent eating

7.3.5. Skin lesions

The total number of lesions (fresh wounds and scratches) of the right side of the body of each pig were evaluated two days post-fasting according to the following scale adapted from Welfare Quality protocol (Welfare Quality, 2009) with two levels per pig: 1) up to ten visible lesions and 2) more than ten visible lesions. Finally, the percentage of pigs classified into each level of skin lesions was determined for every pen.

7.3.6. Statistical analysis

The experiment was conducted as a completely randomized block design with two treatments (Control vs HE). Data were analysed using SAS software (SAS version 9.4©; SAS institute Inc., Cary, NC; USA). Shapiro-wilk test was used to examine the normality of the distributions and Levene's test was used to examine homogeneity of variances. The inclusion of HE, sex and its interaction were included in the model as fixed effects, while the automatic feeding system, as a random effect. The experimental unit for all parameters studied was the pig, except for skin lesions; in this last case the experimental unit was the pen with 12 pigs in each. Results are presented as LS means ± SE unless otherwise indicated. Significance was established at $P < 0.05$ for all the analyses, while a tendency was considered between $P \geq 0.05$ and < 0.10. When the probability of the main effects and its interaction were significant, Tukey's HSD test adjustment was used to separate treatment means.

Growth performance parameters (BW, ADG, ADFI and FCR), feed intake for weekly FBHs and carcass quality traits (hot carcass weight, carcass yield, backfat thickness, loin depth and lean percentage) were analysed using the MIXED procedure. While effective TVs, TD, VS, Vd and FR were analysed using the GLIMMIX procedure because of the absence of normality using a Poisson distribution. Data on skin lesions were analysed using a Chi-square test.

For the daily analysis of the FBHs from day 105 to 116; ADFI, TVs, TD and FR showed a parametric distribution and were analysed as repeated measures by using the MIXED procedure. The structure of the error (co)variance matrix used were AR(1) for feed intake and ANTE(1) for TVs, TD and FR. VS and Vd presented a non-parametric distribution and were also analysed as repeated measures by using the GLIMMIX procedure. The structure of the error (co)variance matrix used was the Variance Components for VS and CS structure for Vd.

7.4. Results

No interaction between treatment and sex was found for any parameter studied. Therefore, the results of the main factors are presented.

7.4.1. Growth parameters and carcass quality traits

No significant differences between treatments were shown for BW on days 84 and 130 of fattening ($P > 0.1$; Table 7.2). Pigs fed with the HE diet tended to have a greater ADG (783.5 vs. 724.5 g/d; $P = 0.077$) and had a higher ADFI (2.30 vs. 2.15 kg/d; $P < 0.05$) than pigs fed with the control diet (Table 7.2). However, no significant differences between treatments were observed for FCR ($P > 0.1$). Males had a higher final BW (112.7 vs 106.8 kg; $P < 0.05$), a greater ADG (810.7 vs 697.3 g/d; $P < 0.05$) and a lower FCR (2.82 vs 3.23 kg/kg; $P < 0.05$) than females (Table 7.2). No significant differences between sex were observed for ADFI ($P > 0.1$; Table 7.2).

No significant differences between treatments were shown in any carcass quality trait except for loin depth, which was higher for HE than for control pigs (56.03 vs 53.02 mm; $P < 0.05$; Table 7.2). No significant differences between sexes were shown in carcass weight and loin depth ($P > 0.05$; Table 7.2). However, males tended to have lower carcass yield (75.64 vs 76.68%; $P = 0.064$) and had greater backfat thickness (14.02 vs 12.42 mm; $P < 0.05$) and lower lean percentage than females (62.04 vs 63.82%; $P < 0.05$; Table 7.2).

Table 7.2. Effect of the inclusion of the herbal extracts blend (HE) on growth performance in the period from day 84 to day 130 of fattening and carcass quality traits at day 131 of fattening.

	Treatment			Sex		*P-value*[1]	
Item	**Control**	**HE**	**SEM**[2]	**Male**	**Female**	**Treatment**	**Sex**
Productive parameters							
N	34	35		45	24		
BW[3] at day 84, kg	75.2	74.9	1.31	75.4 ±1.08[3]	74.7 ±1.49	0.87	0.73
BW[3] at day 130, kg	108.5	110.9	1.87	112.7 ±1.55	106.8 ±2.13	0.36	0.030
ADFI[4], kg/d	2.15	2.30	0.049	2.24 ±0.040	2.21 ±0.056	0.044	0.64
ADG[5], g/d	724.5	783.5	0.23	810.7 ±0.19	697.3 ±0.26	0.077	0.001
FCR[6], kg/kg	3.02	3.03	0.095	2.82 ±0.079	3.23 ±0.108	0.92	0.004
Carcass quality traits							
Hot carcass weight at day 131, kg	82.20	84.89	1.381	85.20 ±1.147	81.89 ±1.571	0.17	0.094
Carcass yield, %	75.75	76.56	0.003	75.64 ±0.003	76.68 ±0.004	0.14	0.064
Backfat thickness, mm	13.08	13.36	0.399	14.02 ±0.332	12.42 ±0.454	0.62	0.006
Loin depth, mm	53.02	56.03	1.002	53.34 ±0.832	55.71 ±1.140	0.037	0.097
Lean percentage, %	62.84	63.02	0.419	62.04 ±0.348	63.82 ±0.476	0.76	0.004

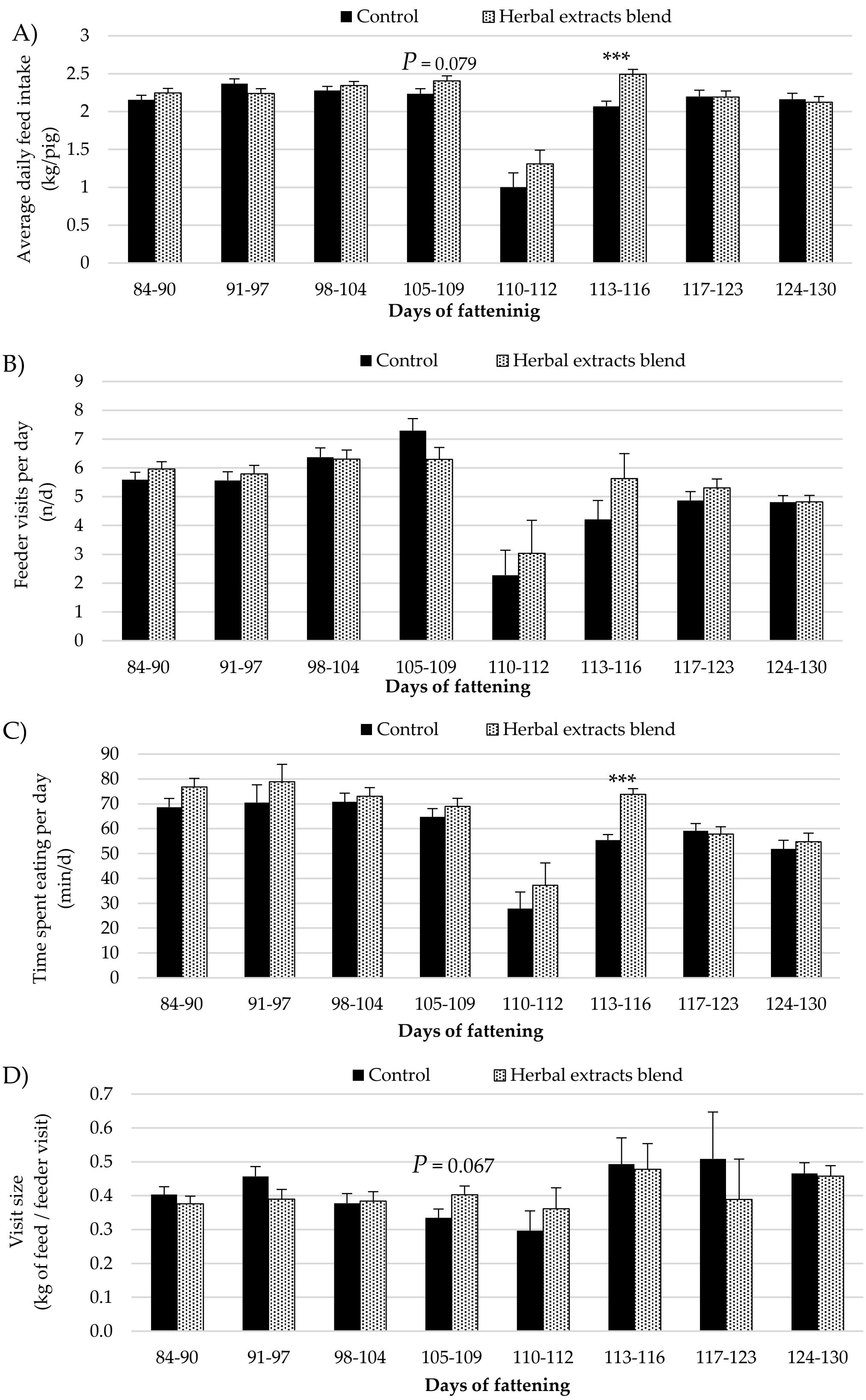
[1] Treatment by sex interaction was not significant for any parameter studied. [2] SEM (Standard Error of the Mean). [3] BW (Body Weight). [4] ADFI (Average Daily Feed Intake). [5] ADG (Average Daily Gain). [6] FCR (Feed Conversion Ratio). LSmeans corrected by least squares.

7.4.2. Feeding behaviour habits

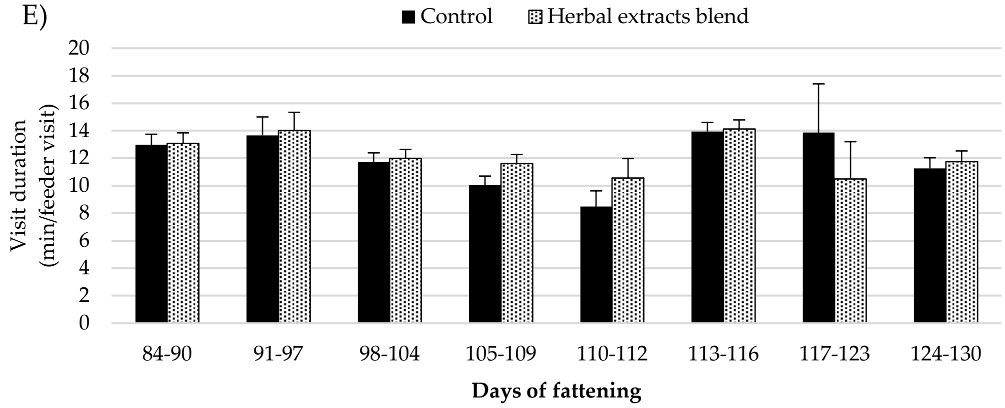
For the first 21 days of the finishing phase (from day 84 to 104), no significant differences between treatments were observed for ADFI (Figure 7.1A) or any FBH studied ($P > 0.1$; Figures 7.1B to F).

In the period from day 105 to 109, pigs fed with the HE tended to have a greater ADFI than control pigs (2.40 vs. 2.23 kg/d; $P = 0.079$; Figure 7.1A). No differences between treatments for TVs, TD, Vd and FR were observed ($P > 0.1$; Figures 7.1B, C, E and F). Pigs fed with the HE tended to have bigger VS (0.403 vs 0.335 kg/effective visit; $P = 0.067$; Figure 7.1D). In the period from day 110 to 112, no FBH showed significant differences between treatments ($P > 0.1$; Figure 7.1A to F).

In the period from day 113 to 116, pigs fed with the HE had a greater ADFI than pigs fed with the control diet (2.49 vs 2.07 kg/d; $P < 0.001$; Figure 7.1A). No differences between treatments were detected for TVs ($P > 0.1$; Figure 7.1B). Pigs fed with the HE spent a longer time eating than pigs fed with the control diet (74 vs 55 min/d; $P < 0.001$; Figure 7.1C). No differences in VS, Vd and FR were observed between treatments ($P > 0.1$; Figures 7.1 D to F). In the period from day 117 to 130, no significant differences were shown between treatments for any FBH studied ($P > 0.1$; Figure 7.1A to F).


A)
■ Control ▨ Herbal extracts blend
Average daily feed intake (kg/pig)
P = 0.079
***
84-90 91-97 98-104 105-109 110-112 113-116 117-123 124-130
Days of fatteninig
B)
■ Control ▨ Herbal extracts blend
Feeder visits per day (n/d)
84-90 91-97 98-104 105-109 110-112 113-116 117-123 124-130
Days of fattening
C)
■ Control ▨ Herbal extracts blend
Time spent eating per day (min/d)
***
84-90 91-97 98-104 105-109 110-112 113-116 117-123 124-130
Days of fattening
D)
■ Control ▨ Herbal extracts blend
Visit size (kg of feed / feeder visit)
P = 0.067
84-90 91-97 98-104 105-109 110-112 113-116 117-123 124-130
Days of fattening

E)



F)

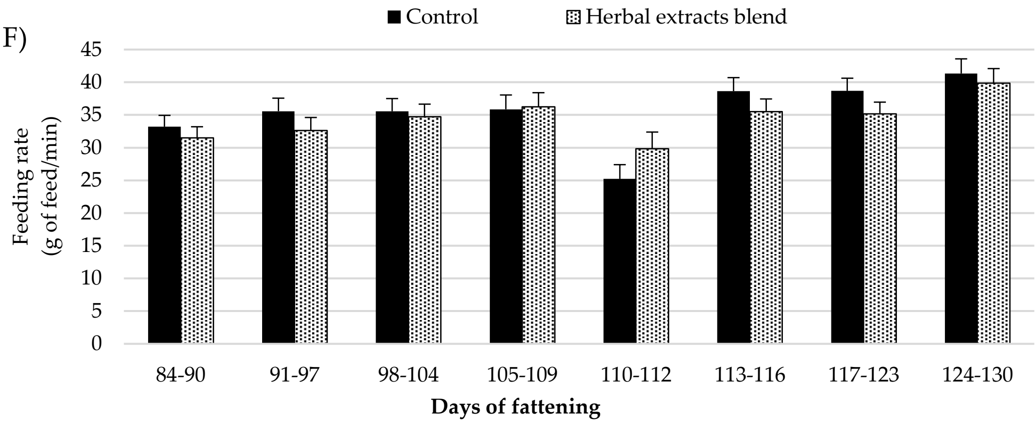


Figure 7.1. Effect of the inclusion of the herbal extracts blend into a diet analysed by periods on (A) average daily feed intake (ADFI); (B) feeder visits per day; (C) time spent eating per day; (D) visit size; (E) visit duration; (F) feeding rate. Pigs were fasted from day 110 at 18:00h until day 112 at 12:00h. Results are presented as mean ± S.E. *P-values* are presented by * $P <$ 0.05; ** $P < 0.01$; *** $P < 0.001$. When $P \geq 0.05$ and < 0.1 its value is indicated.

In the period from day 105 to 116, on the daily basis, only one tendency was observed for the ADFI at day 105; HE pigs had a greater ADFI than control pigs (2.45 and 2.10 kg/d for HE and control pigs, respectively; $P = 0.053$; Figure 7.2A). No significant differences between treatments were observed for any other FBH studied during the first six days ($P > 0.1$; Figures 7.2 B and C). On days 112 and 114 pigs fed with the HE had a higher ADFI (Figure 7.2A) than control pigs (1.92 vs 1.25 and 2.56 vs 2.04 kg/d for HE- and control group at day 112 and 114, respectively; $P < 0.01$) and on day 115, pigs fed with the HE tended to have a higher ADFI (2.57 vs 2.21 kg/d; $P = 0.060$). On days 112 and 114 pigs fed with the HE spent a longer time eating in effective feeder visits (Figure 7.2B) than the control group (53.4 vs 34.1 and 75.9 vs 52.7 min/d for HE and control group, respectively; $P < 0.001$) while a tendency was observed on day 113 (70.3 vs 55.8 min/d for HE and control group, respectively; $P = 0.055$). No significant differences on days 115 and 116 were observed between treatments for TD ($P > 0.1$; Figure 7.2 B). No significant differences between treatments were observed for VS ($P > 0.1$; Figure 7.2C) or for any other FBH for that period on the daily basis (data not shown).

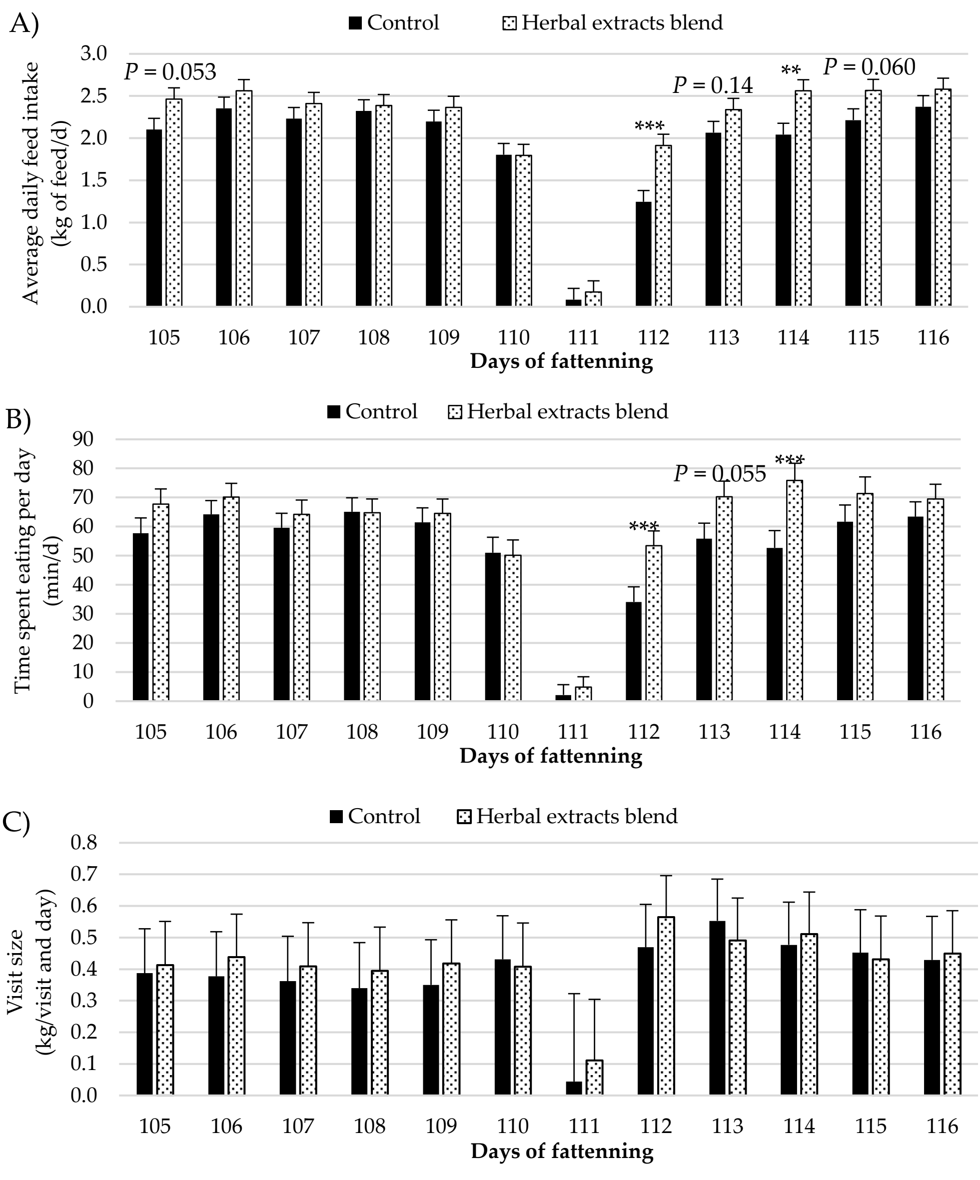


Figure 7.2. Effect of the inclusion of the herbal extracts blend into a diet analysed daily before and after a fasting period (from day 110 at 18:00 to day 112 at 12:00) on (A) average daily feed intake (ADFI); (B) time spent eating per day; (C) visit size. Pigs were fasted from day 110 at 18:00h until day 112 at 12:00h. Results are presented as mean ± S.E. *P-values* are presented by * $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$. When $P \geq 0.05$ and < 0.1 its value is indicated.

On the other hand, pigs fed with the HE had a lower variability of ADFI day by day after the fasting period than control pigs (Figure 7.3).

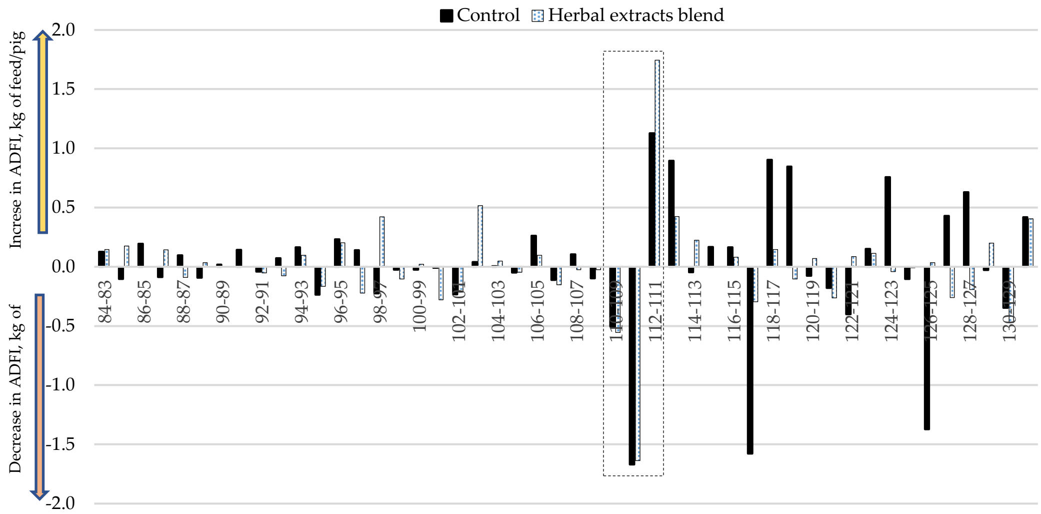


Figure 7.3. Individual daily difference of feed intake from day 84 to day 130 of control and herbal extract blend fed pigs. The fasting period started on day 110 at 18:00h and finished on day 112 at 12:00h (rectangle with dashes).

During the first 21 days of the finishing phase (from day 84 to 104) no significant differences between sex were observed for any of FBH studied (data not shown; $P > 0.1$) except for the FR that was higher for males than for females ($P < 0.05$; Figure 7.4).

After the first 21 days of the finishing phase, few sex effects were observed on the FBHs. In the period from day 105 to 109, males had a greater ADFI than females (2.43 vs 2.21 kg/d; $P < 0.05$), tended to have a higher TVs (7.32 vs 6.28 visits/d; $P = 0.081$) and had a higher FR ($P < 0.01$; Figure 7.4).

In the period from day 110 to 112, no differences between sex were observed for any FBH studied ($P > 0.1$). In the period from day 113 to 123, males had a higher ADFI than females (2.48 vs 2.08 kg/d; $P < 0.05$) and had a higher FR ($P < 0.05$; Figure 7.4). Moreover, in the period from day 124 to 130, males tended to have a higher FR than females ($P = 0.072$; Figure 7.4). Overall, males had a higher FR than females (38.01 vs 31.89 g/min; $P < 0.05$; Figure 7.4).

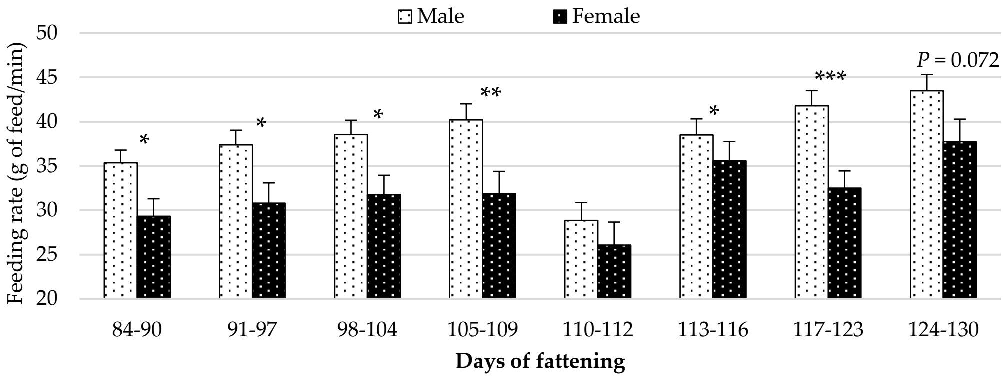


Figure 7.4. Weekly feeding rate (g/min) by sex. Pigs were fasted from day 110 at 18:00h until day 112 at 12:00h. Results are presented as LSmean ± S.E. *P-value*s are presented by * $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$. When $P \geq 0.05$ and < 0.1 its value is indicated.

7.4.3. Skin lesions

Pigs fed with the HE had lower severe skin lesions (level 2) than the control pigs ($P < 0.05$). While a 26.5% of control pigs per pen obtained more than 11 skin visible lesions, only an 8.6% of HE pigs per pen were scored on that level (Figure 7.5).

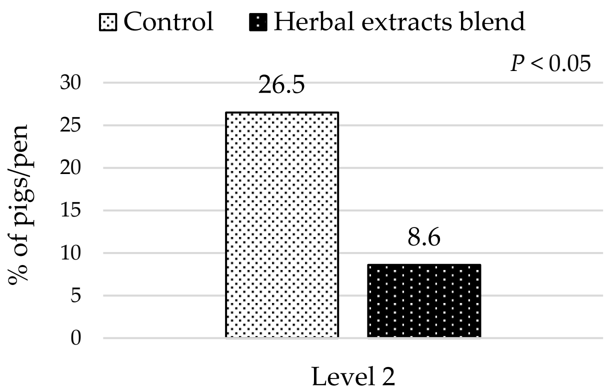


Figure 7.5. Percentage of pigs per pen showing more than eleven skin visible lesions (level 2) by treatment (Control vs Herbal extracts blend).

7.5. Discussion

Pigs fed with the HE blend diet had a higher ADFI and tended to grow 8.1% faster than pigs fed with the control diet. However, there was no impact of using the HE on FCR. Casal-Plana et al. (2017) observed heavier pigs when an HE blend based on maypop and valerian at a level of 2g/kg was supplemented in the period from 16 to 24 weeks of age. In addition, Pastorelli et al. (2020) reported an increase in ADFI and

ADG at around 9% in weaned pigs weighing from 10 to 25 kg and fed with 1 kg of maypop extract per ton of feed as compared to a control group. On the contrary, Hanczakowska et al. (2017) showed a reduction in ADG with an inclusion of 1 kg of hop dried water extract per ton of feed in growing pigs in comparison to its lower level (500 g of hop dried water extract per ton of feed) without any effect on FCR.

In the present study, limited effects in carcass quality traits were found in relation to the HE inclusion. The only difference found in carcass quality traits was an increase of 3 mm in loin depth in pigs supplemented with the HE. These results disagree with those reported by Hanczakowska et al. (2017) who observed an 11.6% lower protein deposition in 70 kg pigs fed with 1 kg of hop dried water extract per tone of feed than control pigs. Moreover, Casal et al. (2018) showed a tendency to have a thicker backfat over the gluteus medius muscle in pigs supplemented with an HE blend based on valerian and maypop. These findings indicate that the inclusion of plant extracts with a calming effect influences growth performance and carcass quality traits of growing-finishing pigs at different levels of inclusion. However, the large variation in the composition of the compounds of the plant extracts makes it difficult to compare their efficiency (Liu et al., 2018) and no other studies regarding the effect of california poppy, hop and maypop inclusion in the diet on finishing pigs performance and carcass quality traits have been found.

Regarding the sex, in the present study, males weighed 5.9 kg more at the end of the experimental period, grew 16% faster and improved FCR by 13% compared to females without any effect on ADFI in line with the results found by Quiniou et al. (2010) in 115 kg (Pietrain x Large White) x (Landrace x Large White) pigs. Similar results have been observed in other pigs' genotypes as 100 kg Dutch Landrace and Great Yorskshire pigs (De Haer and de Vries, 1993) and 90 kg Duroc crossbred pigs (Blanchard et al., 1999). However, López-Vergé et al. (2018) observed similar ADG between males and females in 90 kg Pietrain x (Landrace x Large White) pigs. In terms of carcass quality traits, the males in the present study tended to have lower carcass yield than females; results that agree with those reported in studies of other genotypes such as crossbred sired by Large White (Quiniou et al., 2010; Moore et al., 2012) or Pietrain (Gispert et al., 2010; Quiniou et al., 2010).

Many factors can affect FBHs such as feed treatments, housing conditions, health, environment (Nyachoti et al., 2004; Maselyne et al., 2015), breed and sex (De Haer and de Vries, 1993; Labroue et al., 1999). However, no other studies have been found regarding the effects of the inclusion of herbal extracts with calming properties on the FBHs of pigs. In the present study, during the first 21d of the finishing period without any external stressor, the effect of the inclusion of the HE blend on the FBHs was limited. However, during the following four days after 42h of fasting, ADFI and TD were increased in pigs fed with the HE blend in concordance with a lower skin lesion severity. Only fresh wounds and scratches were considered for these scores and these values are indicative of fights after long-term feeding deprivation.

Besides that, it is known that fasting induces oxidative stress to the intestinal mucosa which could damage epithelial function (Ferraris and Carey, 2000) and in addition, an atrophy of the intestinal mucosa and villous-crypt have been observed in young pigs fasted for 1.5 days (Lallès and David, 2011). Therefore, the antioxidant and anti-inflammatory effect of hop (Hrnčič et al., 2019) could reduce the negative impact on the cellular oxidative stress caused by fasting and in consequence improve performance results.

Moreover, the lower skin lesion severity observed in HE pigs in the present study is indicative of the positive sedative and anxiolytic properties of the main components of california poppy, hop and maypop (Soulimani et al., 1997; Rolland et al., 2001; Schiller et al., 2006). Similarly, Casal-Plana et al. (2017) showed lower body lesions and social negative interactions in pigs supplemented with valerian and maypop in the period from 16 to 24 weeks of age. However, Peeters et al. (2006) reported an increase in shoulder and loin lesions in pigs supplemented with a herbal extracts blend based on valerian and maypop after few stressors (18 h of fasting, mixing and transporting the pigs to the slaughter-house); which could be an effect of the sum of stressors and the extract concentration. In addition, fights between pigs increase energy expenditure and result in an increase of energy requirement for maintenance (Heetkamp et al., 2002). Therefore, a lower number of aggressions thanks to the HE with a calming effect accompanied by an increased voluntary energy intake of the pigs after a stressor could have provided an additional energy to growth in agreement with the results of the present study.

The FBHs affected by sex were TVs in the periods from day 105 to 109 of fattening and FR throughout the entire experimental period. Males had a higher TVs than females, in disagreement with the results observed by De Haer and de Vries, (1993) who obtained a lower number of meals by males than females, whereas Hyun et al. (1997) did not observe any differences between sexes. On the other hand, males consumed feed faster (in a range of 8.3 and 28.6%) than females during the experimental period. The current results agree with Andretta et al. (2016a) who indicated that females had a 6% lower FR than castrated males. However, no differences in FR between sex (intact males vs. females) were observed by De Haer and de Vries, (1993), Young and Lawrence, (1994) and Hyun et al. (1997). The higher ADG together with a better FCR obtained in the present study by males compared to females might be positively related to the faster FR, in agreement with the findings by Labroue et al. (1997). Moreover, De Haer et al. (1993) reported that the FR was not only positively correlated with ADG but also with backfat thickness and was negatively correlated with lean content. Results in concordance with those obtained in the present study in which males grew faster, had 1.6 mm more of backfat thickness and tended to have 1.78 points less in lean content than females.

CHAPTER 8.

General discussion

The results of this PhD dissertation provide evidence that the FBHs of growing-finishing pigs are modified by production conditions such as feed physical form (mash and pellet) and environmental conditions (temperate and hot) (**Chapter 4**). On the other hand, previous studies have analysed the repeatability of FBHs of growing-finishing pigs at group level; however, no methods to analyse the repeatability at an individual level have been found before. Therefore, **Chapter 5** includes a new approach, named "maintenance", which allows to calculate the degree of permanence of FBHs between determinate periods of time at an individual level.

The maintenance approach has been applied to two trials of growing-finishings pigs under different feed physical forms and environmental conditions. The results indicated that maintenance is a useful, complementary approach to classic repeatability and that feed physical form influenced time spent eating and feeding rate maintenance, whereas changes in environmental conditions modified the repeatability and maintenance of the number and size of feeder visits.

In **Chapter 6**, since most FBHs performed high repeatability values and were maintained at an individual level throughout the growing-finishing period, the influences of FBHs on feed, energy and protein utilization, performance and carcass quality traits were studied. The results obtained provide evidence that different types of pigs according to their FBHs exist and that the two FBHs of growing-finishing pigs most related with feed efficiency, performance and carcass quality traits are ADFI and feeding rate.

Finally, the results of **Chapter 7** demonstrate that the inclusion of a dietary calming herbal extracts blend influences FBHs, aggressiveness and performance of growing-finishing pigs after a long fasting period used as a stressor.

As the main results have already been broadly discussed in each chapter, the present section focuses on: 1) a critical assessment of experimental designs, 2) the implications and future perspectives of the results obtained regarding the influence of FBHs on the performance of growing-finishing pigs, and 3) the implications and field results of the inclusion of the innovative herbal extracts blend presented in **Chapter 7** on the welfare and performance of finishing pigs.

8.1. Critical assessment of the experimental designs

The availability of automatic feeding systems has permitted us to study in more detail the understanding of FBHs of growing-finishing pigs. It is important to be aware that the type of feeder and the stocking density influence FBHs of growing-finishing pigs (**Chapter 2**). In the present thesis, the automatic feeding system used allowed only one pig to enter inside the feeder due to the lateral barriers of the scale (Nedap ProSense®; Figure 8.1). Therefore, the results obtained in the present thesis regarding the influence of FBHs on performance and feed utilization are of great interest. However, the values of FBHs obtained may differ from FBHs of growing-finishing pigs allotted in other kinds of feeders without lateral barriers due to feeder competition access. Moreover, the pigs in the studies showed in the present thesis were stocked at a density of 0.89 m^2/pig (excluding the space occupied by the automatic feeding system); which is a lower stocking density than that found in most commercial farms, where it is 0.65 m^2/pig in concordance with the minimum space per pig set by European legislation 2008/120/EC (European Comission, 2008).

Figure 8.1. Automatic feeding system (Nedap ProSense®, The Netherlands) used in the studies presented in the present PhD disseration.

The main objective of the study presented in **Chapter 4** was to analyse the effect of feed physical form on FBHs and performance of growing-finishing pigs. Since pigs were kept in commercial conditions, the desired experimental design could not be used. It was not possible to feed the two diets (mash and pelleted) in the same experiment and two consecutive experiments were carried out. When the two experiments were finished, the different environmental conditions between the two trials did not permit to fully differentiate the effect of environmental conditions and the effect of feed physical form. Therefore, although the obtained data are of interest for commercial conditions, studies comparing pigs eating the same diet fed in pellet or in mash with the same environmental conditions were not performed and, consequently, data do not allow to differentiate the effects of diet form and environmental conditions precisely. In fact, with the current scenario of high prices of raw materials and energy sources, the knowledge of production costs of pigs fed with mash or with pellet form is of interest and to our knowledge, few studies exist regarding this issue. Although the same diet fed in mash penalizes performance compared to fed in pellet, it is important to take into account the additional cost of pelleting. In economic terms, the performance penalization when feeding pigs in mash could be financially compensated due to the lower manufacturing cost.

On the other hand, the same database of the two trials of **Chapter 4** were used to implement the new approach named maintenance (**Chapter 5)**; whereas for the aims of **Chapter 6**, a trial under thermoneutral conditions was conducted with the aim of understanding the influence of FBHs on feed utilization, growth performance and carcass quality traits. The trial of **Chapter 6** was conducted with 48 female pigs. Therefore, the sex effect has not been studied. So, as differences among FBHs have been observed between sexes (**Chapter 2**), further trials with balanced males, castrated males and females would be of interest.

Moreover, farm managements such as the load to slaughter-house of the heavier pigs within a pen and the fasting period before going to the slaughter-house are some of the practices habitually conducted in any commercial farm; however, those examples mentioned are also social and metabolic stressors for the pigs, respectively (Fredriksen and Hexeberg, 2009; Ott et al., 2014; Martínez-Miró et al., 2016; Driessen et al., 2020). Focusing on the fasting period, this was the stressor used to assess the effect of a calming herbal extracts blend (HE) on FBHs, skin lesions and performance of finishing pigs (**Chapter 7**); depending on its length (Driessen et al., 2020) it may represent an economic issue due to production outcomes penalization (Brumm and Colgan, 2006; Pierozan et al., 2021) or due to carcass downgrading, especially in meat products in which the integrity of the skin is vital (Vitali et al., 2021). It is important to highlight that in the study presented in **Chapter 7**, a long fasting period of 42 h was used; whereas in practice, the fasting period is normally extended between 12 and 18h, with the guidelines for the optimal length of fasting period depending on several factors such as environmental conditions (Driessen et al., 2020). Therefore, we suggest that the evaluated herbal extracts blend should be assessed under fasting periods of a length used in practice.

8.2. Future perspectives of knowledge regarding the influence of feeding behaviour habits on nutrient utilization and performance results

The results of the studies conducted in the present thesis (**Chapters 4, 5 and 6**) provide new knowledge to better understand the influence of environmental conditions and feed physical form on FBHs and on its repeatability and maintenance together with the influence of FBHs on nutrient utilization and performance results of growing-finishing pigs, being a step forward in the search for the most efficient pigs by their FBHs.

Firstly, except for ADFI, which independently of environmental conditions and feed physical form, decreased as pigs grew, with only 50% of the pigs maintaining their ADFI during the last month of the fattening period, the other FBHs analysed (time spent eating, number of feeder visits, visit size and feeding rate) had medium-high repeatability and maintenance values under constant environmental conditions and physical feed form. Therefore, the influence of FBHs on performance throughout the growing-finishing period is feasible.

Secondly, three clusters of pigs by their FBHs and growth performance results were obtained: MFI-*fast eater*, MFI-*slow eater* and HFI-*fast eater* pigs. Being ADFI and feeding rate, the two main FBHs that distinguished the clusters. Growth performance, carcass parameters, nutrient and energy utilization among clusters have been discussed in **Chapter 6**, whereas energetic and economic costs are discussed in this section (Table 8.1). To calculate the economic cost, the price of 307 €/Tn of feed was used (SIP Consultors, personal communication, 2021). MFI-*fast eater* pigs had the highest energetic cost, being by 7.13% and 6.4% higher than MFI-*slow eaters* and by

9.8% and 9.9% higher than HFI-*fast eaters* in terms of MKcal of feed/kg BW gained and MKcal of feed/kg of carcass, respectively ($P < 0.0001$); whereas in terms of economic cost, MFI-*fast eater* pigs also had the highest cost and MFI-*slow eater pigs* the lowest, but with HFI-*fast eater* pigs in an intermediate position ($P < 0.05$).

Table 8.1. Energetic and economic cost by clusters of pigs distinguished by their feeding behaviour habits and growth performance.

	MFI-*fast* *eaters*	SE[1]	MFI-*slow* *eaters*	SE[1]	HFI-*fast* *eaters*	SE[1]	*p*-value
N	18		18		10		
Energetic cost							
Kg of feed/kg carcass	2.52[a]	0.033	2.41[b]	0.033	2.42[b]	0.044	0.04
Mkcal intake/kg BW gained	2477[a]	21.4	2312[b]	21.4	2255[b]	28.7	<0.0001
Mkcal intake /kg carcass	2807[a]	22.6	2637[b]	22.6	2554[b]	30.3	<0.0001
Economic cost							
€/kg BW gained	0.68[a]	0.008	0.65[b]	0.008	0.66[ab]	0.011	0.015
€/carcass weight	0.76[a]	0.009	0.74[b]	0.009	0.74[b]	0.013	0.038

[1]SE: Standard error. LSmeans corrected by least squares.

To our knowledge, no other studies have been found regarding the influence of FBHs on production costs. However, the economic costs obtained calculated with our data (**Chapter 6)** reinforce the performance parameters obtained, suggesting that both, MFI-*slow eater* and HFI-*fast eater* pigs are the most efficient pigs in terms of productive and economic results. If the target BW is around 115 kg BW, growing-finishing females eating an average of 1.74 kg of feed/d at a rhythm of 35 g of feed/minute spent eating are the most efficient pigs in performance and economic terms; whereas if the target BW is around 125 kg BW, growing-finishing females eating an average of 1.90kg of feed/d with an average visit size of 356 g had the same low energetic and economic cost as MFI-*slow eater* pigs.

On the other hand, those results indicate that the level of ADFI and feeding rate are the two most important FBHs that influence the economic and performance results of growing-finishing pigs. Regarding ADFI, the results of the present study cannot separate if pigs eating a higher level but eating in smaller visit sizes could obtain different performance results. However, in the bibliographic review presented in **Chapter 2**, most of the studies found a positive correlation between visit size and ADFI; which suggests that group-housed pigs eating an average of 1.90 kg of feed/d they do it in large meals, whereas pigs eating that amount trough smaller feeder visits probably do not exist. Concerning feeding rate, pigs with the same ADFI but eating slower were more efficient in performance and economic terms than the ones eating faster; suggesting that feed utilization was improved when eating at a rhythm of 35g/min compared to a rhythm of 39.7 g/min. We hypothesize that a slower feeding rate may improve feed utilization and, therefore, improve feed digestibility; however, to our knowledge, no literature exists regarding the influence of feeding rate on feed passage rate and its digestibility through the gastrointestinal tract. Therefore, studies analyzing digestibility in vivo at different points of the gastrointestinal tract of pigs eating the same ADFI by different feeding rates are of interest.

Furthermore, links between FBHs and genomic regions of chromosomes have been found (Reyer et al., 2017). This is a great scientific discovery because if further studies confirm that ADFI and feeding rate are related with better performance, nutrients utilization and economic cost outcomes, the selection of pigs by their FBHs is of the utmost interest in order to improve feed efficiency, reduce livestock emissions and production costs.

Regarding livestock emissions, in the present thesis, the MFI-*slow eater* pigs were the most efficient in terms of protein deposition (**Chapter 6**); a result in agreement with Andretta et al. (2016a), who found a negative correlation between protein efficiency and feeding rate. In addition, Groenestein et al. (2003) when studying gestating sows fed by an automatic feeding system observed a 10% lower ammonia emission if the feeding time started in the afternoon instead of in the morning due to a change in the sow activity pattern. The above-mentioned study brings some light to the fact that FBHs of growing-finishing pigs may influence greenhouse gas emissions.

On the other hand, feeding pigs the nearest to their requirements as possible is a key factor to obtain efficient pigs in productive, economic and sustainability terms

(Monteiro et al., 2017; Pomar and Remus, 2019). However, it is not that easy, as in most cases, farmers are forced to feed the pigs as a group of animals due to production facilities. Therefore, the feeding of pigs through automatic feeding systems is an interesting strategy to feed the pigs individually according to their nutritional requirements. In fact, Andretta et al. (2016b) observed that feeding growing-finishing pigs with 100% of their estimated lysine requirements reduced digestible lysine intake by 26%, nitrogen excretion by 30% and the feeding cost by 10% compared to pigs fed by a three-phase feeding program with fixed nutritional values. Andretta et al. (2016b) used a mathematical model to predict expected BW, feed intake and daily weight gain for the next day together with lysine requirements calculations by adding maintenance and growth requirements to estimate lysine requirements. Therefore, although more research is needed, the results of the present thesis indicate that the FBHs may influence feed efficiency and that precision feeding based on FBHs could be a good strategy to reduce production cost and environmental emissions, providing an option to produce pork in a more economical and sustainable way.

8.3. Implications and future perspectives of the use of a calming herbal extracts blend on growing-finishing pigs

Our initial hypothesis (**Chapter 7**) was that the inclusion of a dietary calming herbal extracts blend may reduce the stress level of finishing pigs during stressor periods and in consequence, improve welfare by reducing aggressiveness, and growth performance by modifying FBHs and reducing energy maintenance requirements of group-housed finishing pigs. The results obtained in **Chapter 7** showed that after a long fasting period, the pigs fed with the herbal extracts blend had fewer severe skin lesions, ate more and spent more time eating the following four days after the fasting period than control pigs; providing positive evidence of the use of herbs with calming effect on finishing pigs. Moreover, the lower variability in ADFI for the consecutive days after the fasting period of the pigs fed with the herbal extracts blend suggests a positive influence of this extract on the feed intake recovery pattern after a perturbation.

The robustness of pigs is a complex concept that includes the response to and the recovery after a perturbation such as the fasting period (Nguyen-Ba et al., 2020). In growing-finishing pigs, compensatory feed intake after a perturbation has been observed by other researchers (Veum et al., 1970; Nguyen-Ba et al. 2020). In fact, pigs fasted for alternative days (two or three days for every day of ad libitum feeding) increased their feed intake to 150, 161 and 165% on the days that they had access to ad libitum feed compared to pigs fed ad libitum continuously (Veum et al., 1970); a compensatory feed intake to achieve their energy requirements (Li and Patience, 2017). This compensatory feed intake allows the pigs to gradually approach the target cumulative feed intake, suggesting that although suffering perturbing factors, pigs can recover the needed cumulative feed intake. However, during the recovery period, in the current research it has been observed that pigs suffer changes in their FBHs (**Chapter 7**), which may modify physical mechanisms such as feed passage rate, emptying rate or stomach size that may influence the digestibility and therefore, the efficiency of the diet nutrients' utilization. Although in the Nguyen-Ba et al. (2020) study, the ADG of the pigs was not reported, Veum et al. (1970) observed that the ADG decreased progressively as the fasting period was increased from fasting alternative days to fasting two or three days for every day of ad libitum feeding, impairing the efficiency of feed utilization in pigs that were fasted two or three days every day of ad libitum feeding compared to control and pigs fasted alternative days. Moreover, stomach, intestinal tract weight and water intake are influenced by length of fasting and feed form (Veum et al., 1970; Saucier et al., 2007), and most of the found studies report higher gastrointestinal tract weight as the fasting period increases, due to higher compensatory feed intake, which may penalize carcass yield (Faucitano et al. 2010). In the study presented in **Chapter 7**, pigs fed with the herbal extracts blend diet increased their feed intake to 123% compared to control pigs. Moreover, those pigs ate more similar ADFI during the days after the fasting period, spending more time eating with no differences in terms of visit size and feeding rate than the control pigs. The similar ADFI throughout the following days after the fasting period achieved by the herbal extracts blend pigs could be the reason of the 0.81 points more in carcass yield compared to control pigs thanks to a lower increase in stomach weight.

To better understand the positive effect of the studied calming herbal extracts blend, a future study analysing FBHs, performance, robustness, digestibility and gastrointestinal tract weight after a perturbance such as a fasting period during the fattening period is worth noting.

The results obtained in **Chapter 7** provide evidence of the positive effect of the studied herbal extracts blend inclusion on feed intake, growth and welfare of finishing pigs; however, no differences among treatments were obtained in FCR, one of the most important performance indicators. The non-observed effect on FCR in the current study could be due to production factors that may hide the improvement of FCR of growing-finishing pigs. Those factors may be housing conditions (group size, stocking density, feeder ratio, space allowance, environmental conditions, feeder type), pig traits (sex, breed, initial and final BW), feed characteristics (feed composition, feed distribution, physical feed form) or welfare conditions (health, management stressors), among others (Averós et al., 2012; Pierozan et al., 2016). When evaluating dietary additives, knowledge of factors that may limit additive impact on performance results is of great importance to predict the possible range of improvements on each farm.

A meta-analysis with 29 trials across Europe was conducted to understand if the stocking density (< vs > $0.7 m^2$/pig) or sex (females and castrated males vs females and intact males) influence the effect of the calming herbal extracts blend inclusion on the performance of growing-finishing pigs (Quemeneur et al., 2021, Appendix A). The results showed an influence of both factors on the performance improvement by the herbal extracts blend. In fact, farms were grouped in four groups with different FCR's improvements by the herbal extracts blend inclusion; ranging from a penalization of 10 g to an improvement of 130 g. In conclusion, the calming herbal extracts blend inclusion does not always produce similar performance enhancements since the different production conditions within farms interfere with the response.

8.4. Appendix A

The current meta-analysis has been presented in Journées Recherche Porcine:

Quemeneur, K.; Fornós, M.; Carrión, D.; Lechevestrier, Y.; Mantovani, G.; Le Gall, M. **Effect de facteurs d'élevage et des caractéristiques des animaux sur la résponse zootechnique à un mélange d'extraits végétaux à activité calmente chez le porc en engraissement**. *Journées Recherche Porcine*, **2022**, 53, 223-224.

A meta-analysis with 29 trials in different commercial farms across Europe was conducted to evaluate the impact of the dietary inclusion of the herbal extracts blend evaluated in **Chapter 7** at a level of 2 kg/Tn of feed on the performance of growing-finishing pigs reared in different farms. The main aim was to understand if the stocking density (< vs > 0.7 m^2/pig) or sex (females and castrated males vs females and intact males) could influence the response to the calming herbal extracts blend inclusion on performance. The physical feed form differed in the trials, however, within a trial both groups were fed in mash or in pelleted feed. The performance results analysed were: ADFI, ADG and FCR. A PCA and a clustering proceeding were conducted based on the differences between the performance results (ADFI, ADG and FCR) of herbal extracts blend pigs and control pigs. Moreover, an ANOVA test was conducted to analyse the performance results within groups and a Chi^2 test was conducted on stocking density and sex (Data not shown).

The hierarchical classification distinguished four groups with 7 trials in Group 1, 13 trials in Group 2, 7 trials in Group 3 and 2 trials in Group 4. The PCA of Figure 8.2 captures 75% of the variability in the database. The second axis explain 27% of the variability which is mainly due to FCR result difference.

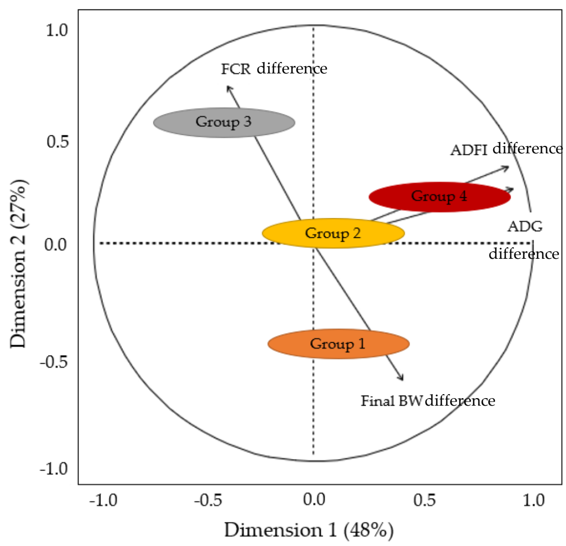


Figure 8.2. Two-dimension principal components analysis based on the differences between the herbal extracts blend and the control group performance results. FCR difference (Feed conversion ratio herbal extracts blend pigs – FCR control pigs). ADFI difference (Average daily feed intake herbal extracts blend pigs – ADFI control pigs). ADG difference (Average daily gain herbal extracts blend pigs – ADG control pigs). Final BW difference (Final Body Weight herbal extracts blend pigs - Final BW control pigs).

The distribution of sexes among groups is presented in Figure 8.3. In Group 1, most of the farms reared castrated males and females; whereas in Group 2, most of the farms reared intact males and females. The distribution of farms in Group 3 was mostly balanced in terms of sex. Lastly, farms in Group 4 reared only castrated males and females.

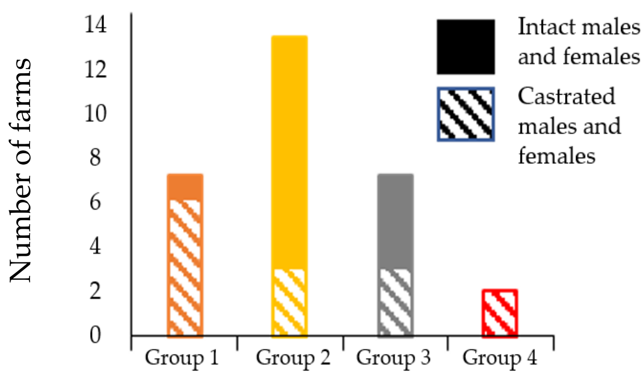


Figure 8.3. Distribution of sexes among groups.

The FCR of control group pigs and the difference in the FCR between herbal extracts blend and control pigs by group are shown in Figure 8.4A and B, respectively. In

Group 1, the inclusion of the herbal extracts blend improved by 200 g the FCR of control group which was 2.74 kg/kg. This large improvement may be due to the higher proportion of castrated males and females than intact males and females together with stocking density ≤ 0.70 m²/pig, production factors that may penalize FCR and have provided a large margin of improvement. In Group 2, the inclusion of the herbal extracts blend improved by 50 g the FCR of control group which was 2.56 kg/kg. In this case, the small improvement may have been a consequence of the fact that the control group already had good performance outcomes and most of the farms had intact males. In Group 3, the inclusion of the herbal extracts blend did not improve the FCR of control group pigs which was 2.69 kg/kg. A difficult result to explain in terms of sex due to the fact that the farms were balanced. Therefore, other production factors such as the breed used may have had an impact. In Group 4, in which all the pigs were a combination of castrated males and females, the inclusion of the herbal extracts blend improved by 130 g the FCR of control group pigs which was 2.55 kg/kg together with an increase in ADFI and ADG levels which were already high in the control group, with an average ADFI of 4kg of feed/d and ADG of 900 g/d.

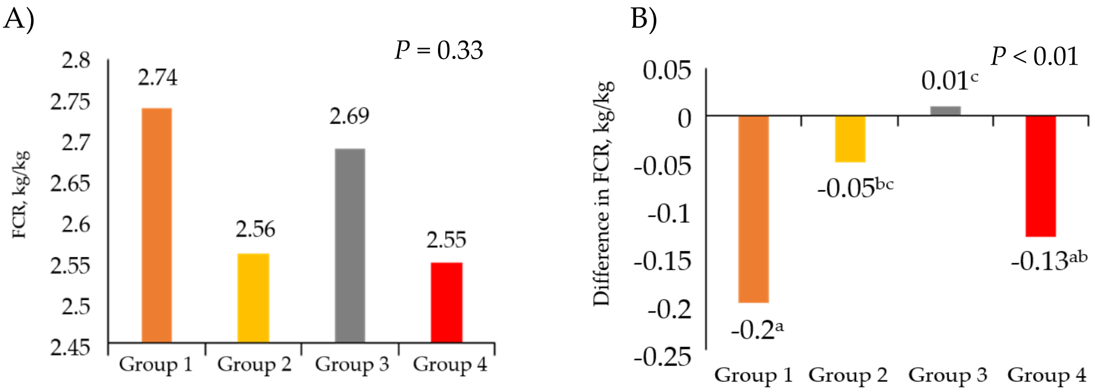


Figure 8.4. Control group feed conversion ratio (FCR) (A) and difference in the FCR between herbal extracts blend and control pigs (B) by group.

In conclusion, under commercial conditions it is not easy to obtain similar performance improvements (FCR in this case) due to the calming herbal extracts blend inclusion since the different production conditions within farms may interfere with the response. It appears that stocking density and sex are important factors that influence the stress level and, consequently, FCR of growing-finishing pigs.

CHAPTER 9.

Conclusions

From the results presented in **Chapter** 4, 5, 6 and 7, the following conclusions have been obtained:

A.- Related to the feeding behaviour habits (FBHs) of growing finishing pigs:

First: Heat stress modifies feeding behaviour habits of growing-finishing pigs, having a higher negative impact on the performance of older pigs. Compared to growing pigs, finishing pigs maintain the number of feeder visits (visits/day) but reduce their size (g of feed/visit) under heat stress, decreasing the optimum average daily feed intake and penalizing performance.

Second: Independently of environmental conditions, physical feed form (mash vs pellet) influences feeding behaviour habits of growing-finishing pigs. Pigs fed with mash form have a lower feeding rate (22.8 vs 34.7 g/min) compared to pigs fed with pellet form, spending a longer time eating (82.4 vs 52.8, min/d) and, consequently, requiring a larger feeder space.

Third: "Maintenance" is a new and complementary concept to the classic repeatability approach, which is defined as the percentage of pigs in a group which do not change a given feeding behaviour habit. This new approach allows a better understanding and characterization, at the individual level, of a specific feeding behaviour habit between two consecutive periods of time, showing if a pig maintains or not that feeding behaviour habit.

Fourth: Excluding the average daily feed intake, whose repeatability and maintenance decrease down to 0.45 and 50% throughout the growing-finishing period, respectively; most of the remaining feeding behaviour habits have a high repeatability (higher than 0.7) and maintenance (higher than 70%) throughout the whole growing-finishing period. However, this tendency may be modified by changes in environmental conditions or physical feed form.

Fifth: In growing pigs (around 70 kg BW), when environmental conditions change from temperate to heat stress, repeatability and maintenance of total feeder visits (number of visits/day) and visit size (g of feed/visit) decrease, whereas the time spent eating (min/d) and the feeding rate (g of feed/min) are not modified. Furthermore, those changes are maintained while heat stress conditions last, suggesting a capacity of feeding behaviour habits adaptation.

Sixth: Three types of pigs were identified according to their feeding behaviour habits and performance. These have been named as medium feed intake-*fast eater* pigs (MFI-*fast eater*), medium feed intake–*slow eater* pigs (MFI-*slow eater*), and high feed intake-*fast eater* pigs (HFI-*fast eater*). The main differences found in their feeding behaviour habits concerned daily feed intake (kg of feed/d) and feeding rate (g of feed/min).

Seventh: Pigs eating more (HFI-*fast eater* pigs) have significantly higher growth rates, final BW, carcass weight, carcass yield and loin depth compared to pigs eating less (MFI-*fast eater* pigs). Pigs eating more (HFI-*fast eater* pigs) perform the same number (visits/d) but larger feeder visits (356.0 vs 267.7 g/visit), achieve the maximum daily protein retention earlier (d62 vs d68 of fattening) and retain more fat at the end of the growing-finishing period.

Eight: When comparing feeding rate of pigs eating equivalent daily amounts of feed (MFI-*fast eater* vs MFI-*slow eater*), pigs eating slower (MFI-*slow eater*) have significantly higher growth rate, better feed conversion ratio, greater loin depth and backfat thickness, together with higher protein and fat retention and energy efficiency, suggesting that pigs eating the same amount of feed but slower may improve feed utilization and performance.

Ninth: If feeding behaviour habits were inheritable, selection for efficiency would lead to MFI-*slow* and HFI-*fast eater* pigs, the latter being those for heavier target carcass weights.

B.- Related to the inclusion of an innovative herbal extracts blend in the diet:

Tenth: The use of a calming herbal extracts blend based on *Eschscholzia californica*, *Humulus lupulus* and *Passiflora incarnata*, have a positive effect on performance and welfare of growing-finishing pigs. Results indicate a significant improvement in feed intake and average daily gain with limited effects on feed conversion ratio and carcass quality traits. A minimal consumption of the herbal extracts blend of 21 days is needed to observe those improvements.

Eleventh: The calming herbal extracts blend increased by 28.4% the average daily feed intake in the first 48h after a long fasting period (42 h) together with a reduction on the aggressiveness and a lower intake variability for the consecutive days until their sacrifice (a period of 18 days).

CHAPTER 10.

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