UNIVERSIDADE ESTADUAL PAULISTA - UNESP
CÂMPUS DE JABOTICABAL

LINHAS GENÉTICAS E SISTEMA DE ALIMENTAÇÃO DE PRECISÃO COMO ALTERNATIVA SUSTENTÁVEL PARA PRODUÇÃO DE SUÍNOS EM PAÍSES DE CLIMA TROPICAL

Luan Sousa dos Santos
Zootecnista

2018

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LUAN SOUSA DOS SANTOS – nascido em Dourados – MS, no dia 03 de dezembro de 1990. Zootecnista com ênfase em nutrição e produção de não ruminantes, pela Universidade Federal da Grande Dourados (UFGD). Durante a graduação obteve três bolsas de iniciação científica e uma de voluntário (CNPq e Fundect - MS), sendo orientado pela Profa. Dra. Fabiana Ribeiro Caldara. Durante a graduação, também atuou por três anos como voluntário no Programa de Educação Tutorial (PET-ZOO) da UFGD sendo orientado pelo Prof. Dr. Rodrigo Garófallo Garcia. Em março de 2013 iniciou o curso de Mestrado pelo Programa de Pós-Graduação em Zootecnia, na Faculdade de Medicina Veterinária e Zootecnia da Universidade Estadual Paulista “Júlio de Mesquita Filho” (FMVZ–UNESP), Campus de Botucatu, como bolsista da Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP, nº 13/18619-7). Obteve o título de Mestre em Zootecnia em 16 de fevereiro de 2015 sob a orientação do Prof. Dr. Dirlei Antonio Berto. Iniciou seu doutorado no mês de março de 2015 sob a orientação do Prof. Dr. Luciano Hauschild, onde também foi bolsista da FAPESP (nº 15/05241-1). Durante os períodos de junho de 2017 a junho de 2018 realizou um ano de doutorado sanduíche no centro de pesquisa Agri-food Canadá (BEPE – FAPESP, nº 17/10278-7) sob a supervisão do Dr. Candido Pomar.

Epígrafe

Every time you find some humor in a difficult situation…

You win!

Unknown Author

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À minha mãe Edna e minhas irmãs Fran e Flávia pelo apoio e amor incondicional.

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SUMÁRIO

Página

LINHAS GENÉTICAS E SISTEMA DE ALIMENTAÇÃO DE PRECISÃO COMO ALTERNATIVA SUSTENTÁVEL PARA PRODUÇÃO DE SUÍNOS EM PAÍSES DE CLIMA TROPICAL

RESUMO – A criação de suínos em países em desenvolvimento, localizados em regiões de clima tropical predominantemente quente com investimento reduzido em infraestrutura, expõem os animais a condições de estresse por calor. Por sua vez, o estresse por calor gera perdas significativas na produção animal, principalmente para suínos, devido à sua capacidade limitada de dissipar calor. Além disso, as disseminações de vetores de doenças devido à alta temperatura também aumentam os desafios na suinocultura. O investimento para climatização completa de uma instalação pode acarretar no aumento do custo de produção e preços menos competitivos para o suinocultor. Nesse sentido, a escolha de uma genética adequada atreladas a um bom plano nutricional torna-se indispensável na suinocultura mundial. Dessa forma, com essa tese objetivou-se avaliar os efeitos do estresse por calor primeiramente em diferentes genéticas. Após definir-se a genética mais sensível ao estresse por calor, foi realizado um segundo estudo utilizando duas técnicas de nutrição (convencional e de precisão) para avaliação das respostas de desempenho e composição corporal dos animais. No primeiro estudo o objetivo foi avaliar a robustez no desempenho e composição corporal de progênies provenientes de duas genéticas pai (G) comumente utilizadas mundialmente (AGPIC 327: Hampshire puro e AGPIC 337: linhagem sintética) submetidos ao estresse por calor (33ºC). Um total de 24 suínos machos castrados (peso inicial de 32,0 ± 2,0 kg) foram alojados em baias individuais e então submetidos a um dos dois ambientes (AT), sendo eles termoneutro a 22ºC (TN) e alta temperatura a 33ºC (HT). O consumo de ração e ganho de peso foram avaliados semanalmente durante todo período experimental (55 dias). A composição corporal foi avaliada durante os dias 27 e 55 do experimento por meio de um equipamento de densitometria óssea de raio-X duplo. Durante os dias 0 e após cada avaliação de composição corporal, a gordura de cobertura e a profundidade de músculo também foram mensuradas por meio de um equipamento

de ultrassonografia. Como esperado, animais submetidos ao estresse por calor reduziram o consumo de ração (35%; P < 0,01) em relação aos animais em ambiente termoneutro durante ambas fases experimentais (0-27 e 28-55 dias). Ainda em ambiente de estresse por calor, animais de linhagem sintética reduziram o consumo de ração em 50%, enquanto em animais Hampshire, essa redução foi de aproximadamente 24% (P < 0,05 para a interação G × AT). Nos dias 27 e 55, o peso corporal, teor de lipídios, fósforo e conteúdo mineral ósseo reduziram (P < 0,05) em animais submetidos ao estresse por calor quando comparados com animais em ambiente termoneutro. Nesses mesmos dias, sob estresse por calor a gordura de cobertura foi 26% menor em animais sintéticos quando comparados com Hampshire (P < 0,10 para a interação G × AT). Temperaturas elevadas influenciaram ambas as genéticas avaliadas. Nesse primeiro estudo pode-se concluir que potenciais interações entre linhas comerciais e ambiente podem influenciar o desempenho e a composição de carcaça de suínos em estresse por calor de maneira inversa ao esperado em condições termoneutras. No segundo estudo objetivou-se avaliar as respostas dos suínos submetidos a sistemas de nutrição de precisão individual diária (IPF) e convencional de alimentação por fases (CON) em termos de desempenho, balanço de nutrientes, parâmetros séricos e padrões de refeição de animais criados em condições termoneutras (TN: 23 °C) e condições de estresse térmico (HT: 30 °C). Os animais em cada tratamento foram distribuídos nos tratamentos experimentais de acordo com os pesos iniciais (12 animais por tratamento com 41,0 ± 4,87 kg de peso corporal). O experimento durou 55 dias (fase I – 0 ao 27º dia e fase II – 28º ao 55º dia). Os suínos no grupo CON receberam em cada fase uma mistura constante de dietas com alta e baixa densidade de nutrientes suprindo as exigências nutricionais estimadas do grupo, enquanto os animais IPF receberam diariamente uma mistura personalizada fornecendo a quantidade estimada de nutrientes. O conteúdo mineral ósseo, massa magra e gorda foram avaliados por meio de absorciometria de raio-X duplo no início e final de cada fase. Os dados foram analisados incluindo os seguintes efeitos fixos: sistema de alimentação (FS), temperatura ambiente (AT) e suas interações. Os suínos sob HT apresentaram redução (P < 0,01) no consumo diário de ração em 28%, no ganho diário de peso em 25%, no ganho de proteína em 14% e o ganho de lipídio em 14% em comparação aos

animais sob TN. Em relação ao tratamento CON, animais IPF reduziram (P < 0,05) a ingestão de lisina (19%), proteína (16%) e P (14%) sem prejudicar (P > 0,05) a composição corporal. A excreção de nitrogênio foi 24% menor (P < 0,05) nos animais do grupo IPF, quando comparada com os suínos CON, com a mesma eficiência de retenção de nitrogênio durante todo o período. O tempo de alimentação, a taxa de consumo de ração e o consumo de ração por refeição foram 15% menores (P < 0,05) em suínos criados sob HT do que sob condições TN. Os níveis de haptoglobina foram afetados pela AT, mostrando um aumento de 70% e 43% na HT aos 28 dias e 55 dias do experimento, respectivamente. Os suínos criados sob condições de HT apresentaram concentração de albumina sérica 10% menor (P < 0,05) aos 55 dias do que aqueles em condições TN. Para as concentrações séricas de ureia, animais no sistema IPF apresentaram níveis 28% menores (P < 0,01) do que os suínos CON. Embora as condições de HT tenham reduzido consideravelmente o crescimento dos animais e ativado suas respostas inflamatórias, foi demonstrado que o sistema IPF é uma excelente ferramenta para alcançar a adequada utilização de nutrientes tanto em condições HT como em TN, sem comprometer a composição corporal dos animais.

Palavras-chave: estresse por calor, melhoramento genético, nutrição de precisão, robustez

GENETIC LINES AND PRECISION FEEDING SYSTEM AS A SUSTAINABLE ALTERNATIVE FOR SWINE PRODUCTION IN TROPICAL CLIMATE COUNTRIES

ABSTRACT - Developing countries, located in regions of predominantly warm tropical climate with little investment in infrastructure, expose animals to heat stress conditions. In turn, heat stress generates significant losses in animal production, especially for pigs, because of their limited ability to dissipate heat. In addition, the spread of disease vectors by heat also increases the challenges in swine farming. The investment for complete climatization of a facility can lead to an increased production costs and less competitive prices for the pig farmer. Because of this, the choice of an appropriate genetic linked to a good plan of nutrition become indispensable in the swine industry worldwide. Thus, with this thesis we aimed to evaluate the effects of heat stress first on different genetics. After defining the genetics most sensitive to heat stress, a second study was performed using two nutrition techniques (conventional and precision feeding) to evaluate the performance responses and body composition of the animals. In the first study the objective was to evaluate the robustness in the performance and body composition of progenies from two sire genotypes (G) commonly used worldwide (AGPIC 327: pure Hampshire and AGPIC 337: synthetic line) under heat stress (33 ºC). A total of 24 barrows (initial weight 32.0 ± 2.0 kg) were housed in individual pens and then submitted to one of two environments (AT), being thermoneutral at 22 ºC (TN) and high temperature at 33 ° C (HT). Feed intake and weight gain were evaluated weekly throughout the experimental period (55 days). The pigs' body composition was assessed at 28 and 56 days of the experiment through a dual X-ray bone densitometry equipment. During days 0 and after each assessment of body composition, the back fat thickness and the muscle depth were also measured by an ultrasound equipment. As expected, animals submitted to heat stress reduced feed intake (35%; $P < 0.01$) in relation to the animals in the thermoneutral environment during both experimental phases (0-27 and 28-56 days). Also in a heat stress environment, synthetic line animals reduced their feed intake by 50%, while in Hampshire animals, this reduction was approximately 24% ($P < 0.05$ for G × AT interaction). On days 27 and 55, body weight, composition of lipids, phosphorus, and bone mineral content reduced ($P < 0.05$) in animals submitted to heat stress when compared to animals in thermoneutral environment. On these same days, under heat stress the back fat thickness was 26% lower in synthetic animals when compared to Hampshire ($P < 0.10$ for the G × AT interaction). Higher temperatures influenced both genetics evaluated. In this first study, it can be concluded that potential interactions between commercial lines and the environment might influence the performance and composition of pig carcasses in heat stress inversely as expected under thermoneutral conditions. The objective of the second study was to evaluate the responses of individual daily precision feeding (IPF) and conventional phase systems (CON) in terms of performance, nutrient balance, serum parameters and meal patterns of pigs raised under thermoneutral conditions (TN: 23 °C) and heat stress conditions (HT: 30 °C). The animals in each treatment were distributed in the experimental treatments according to their initial weights (12 animals per treatment and 41.0 ± 4.87 kg body weight). The experiment lasted 55 days (phase I - 0 to 27 days and phase II - 28 to 55 days). The pigs in the CON group received at each phase a constant mixture of diets with high and low nutrient density, meeting the nutritional requirements of the group, while the IPF animals received daily a personalized mixture providing the estimated amount of nutrients. Bone mineral content, lean and fat mass were assessed by a dual X-ray bone densitometry equipment at the beginning and at the end of each phase. The data were analyzed including the following fixed effects: feed system (FS), ambient temperature (AT) and their interactions. The effects of AT were significant ($P < 0.01$), reducing daily feed intake by 28%, daily weight gain by 25%, protein gain by 14% and lipid gain by 14% in animals under HT compared to TN. In relation to CON treatment, IPF animals reduced their lysine intake (19%), protein intake (16%) and P intake (14%) without compromising ($P > 0.05$) the body composition. Nitrogen excretion was 24% lower ($P < 0.05$) in the IPF group when compared to CON pigs, with the same nitrogen retention efficiency throughout the experimental period. Feeding time, feed intake rate and feed consumption per meal were 15% lower ($P < 0.05$) in pigs raised under HT than under TN conditions. During the second growth phase, only feeding time, feed intake rate and feed consumption per meal decreased ($P < 0.05$) in pigs under HT conditions during the nocturnal and diurnal periods. Haptoglobin levels were affected by AT, showing a 70% and 43% increase in HT at 28 and 55 days of the experiment, respectively. The pigs raised under HT conditions presented a 10% lower serum albumin concentration ($P < 0.05$) at 55 days than those in TN conditions. For serum urea concentrations, animals in the IPF system presented 28% lower levels ($P < 0.01$) than the CON pigs. Although HT conditions have considerably reduced the growth of the animals and activated their inflammatory responses, it has been demonstrated that the IPF system is an excellent tool to achieve adequate nutrient utilization in both HT and NT conditions without compromising the animals' body composition.

Keywords: genetic improvement, heat stress, precision feeding, robustness

Lista de abreviaturas

AA	Amino acids
ADFI	Average daily feed intake
ADG	Average daily gain
AIPF	Automatic and intelligent precision feeder
AT	Temperatura do ambiente/Ambient temperature
BLUP	Melhor predição linear não-viesada/Best linear unbiased prediction
BW	Body weight
Ca	Calcium
CON	Alimentação convencional/Conventional feeding
CP	Crude protein
DXA	Dual X-ray absorptiometry
FI	Feed intake
FS	Sistema de alimentação/Feed system
G	Genéticas/Genetics
g/d	Grams per day
G:F	Gain to feed ratio
h	Hour
HAM	Hampshire purebred
HT	Estresse térmico/Heat stress
IPF	Alimentação de precisão individual diária/Individual precision feeding
Lys	Lysine
N	Nitrogênio/Nitrogen
P	Fósforo/Phosphorus
PIC	Pig improvement company
SEM	Standard error of the mean

SID Standardized ileal digestible

STTD Standardized total tract digestible

SYN Synthetic line

T Temperature

TN Termoneutro/Thermoneutral

Lista de Tabelas

Página

Lista de Figuras

Página

CAPITULO 1 – Considerações gerais

1.1 Introdução

No sistema industrial de produção de suínos a alimentação apresentou aproximadamente 76,98% dos custos totais de produção em janeiro de 2019 segundo o relatório da central de inteligência de aves e suínos - CIAS. Mesmo representando um custo elevado, pesquisas em alimentação e nutrição estão focadas em estudar principalmente três aspectos: 1) a composição nutricional e digestibilidade dos ingredientes; 2) exigências nutricionais dos animais e, 3) a resposta animal em termos de retenção e excreção de nutrientes (Whittemore, 2001).

As exigências de um nutriente podem ser definidas como sua quantidade necessária para atingir objetivos específicos de produção como maximizar o ganho de peso, ganho de tecido magro e melhorar a conversão alimentar (Fuller, 2004). Entretanto, a intensificação da indústria tem forçado os nutricionistas a desenvolverem estratégias nutricionais com menor impacto sobre a produção de calor dos animais (dietas de menor incremento calórico). Além disso, busca-se também o desenvolvimento de tecnologias que permitem aos animais o máximo aproveitamento dos nutrientes utilizados, seja por meio de comedouros que minimizam os desperdícios até o uso de aditivos que melhoram a digestibilidade dos alimentos. Apesar de todos os desafios em conhecer as exigências nutricionais dos animais de forma mais precisa, mudanças constantes ocorrem na prática. O melhoramento genético e os sistemas de cruzamentos que buscam melhorar a eficiência produtiva, resultam em mudanças na composição de tecido magro e gordura dos animais, em conjunto com certa resistência a fatores estressantes. Dessa forma, os resultados dos cruzamentos podem diferenciar as exigências e respostas de crescimento dos animais em condições adversas de estresse, mas não mudam de maneira expressiva em condições ideais de criação.

Portanto, existe uma pressão para realização de pesquisas direcionadas para uma nutrição mais eficiente (“Nutrição de Precisão”) com o objetivo de estimar as exigências nutricionais de acordo com a necessidade individual dos animais, considerando seu estado fisiológico frente às diversas condições de produção. A variação dos valores nutritivos dos ingredientes e das exigências nutricionais dos animais podem prejudicar a utilização de alguns modelos matemáticos que integram métodos para estimar exigências, conduzindo a recomendações inapropriadas no que se refere aos aportes nutricionais necessários à obtenção de respostas desejadas. Além disso, a maioria dos modelos atuais (Black et al., 1986, EFG, 2006, Inraporc, 2006) simulam o crescimento ou estimam exigências nutricionais de um animal representativo de uma população a partir de informações coletadas previamente de populações com pouca variabilidade entre animais.

Portanto, o presente estudo aportará informações importantes para avaliar e adaptar o sistema de alimentação de precisão à condições ambientais de alta temperatura, utilizando-se uma genética mais sensível, contribuindo assim para a sustentabilidade e viabilidade dos sistemas de produção de suínos em países de clima tropical.

1.2 Revisão de literatura

1.2.1 Estresse por calor

Em países de clima tropical e subtropical, animais de produção são frequentemente expostos a condições de estresse por calor, que comprometem seu bem-estar e desempenho. Em suínos em crescimento, temperaturas ambientes superiores a 25 ºC (temperatura superior a faixa de conforto térmico) induzem respostas de dissipação e de diminuição de produção de calor interno (aumento da frequência respiratória e diminuição do consumo de alimento) que, por sua vez, resultam em menor eficiência produtiva e reprodutiva (Renaudeau et al., 2012; Campos et al., 2014). Para compreender melhor a dinâmica, na Figura 1.1 são exemplificados os mecanismos utilizados para manutenção da temperatura corporal normal.

A região entre os números 2 – 3 representa a zona de conforto térmico, em que praticamente nenhum mecanismo adicional é exigido para manutenção da temperatura corporal, sendo apenas os ajustes comportamentais e fisiológicos suficientes. À medida que a temperatura se eleva, a perda de calor latente é altamente necessária, enquanto o mecanismo para perda de calor sensível torna-se ineficiente. Entre as regiões 3 – 4, os animais ainda são capazes de manter a temperatura corporal normal, reduzindo perdas de calor sensível e aumentando as perdas de calor latente. Os mecanismos de perda de calor sensível envolvem principalmente a condução utilizando o piso, ou as grades/paredes da instalação, e a convecção pela diferença entre temperatura da pele e do ar. Já os mecanismos para perda de calor latente podem ser evaporativas, quando os animais aumentam a taxa respiratória para liberar calor na forma de vapor, ou pela pele. Quando as perdas de calor pela respiração tornam-se menos eficientes, é comum que os animais utilizem a umidade das fezes, urina ou qualquer outra fonte para aumentar as perdas evaporativas pela pele (Bracke, 2011; Huynh et al., 2004).

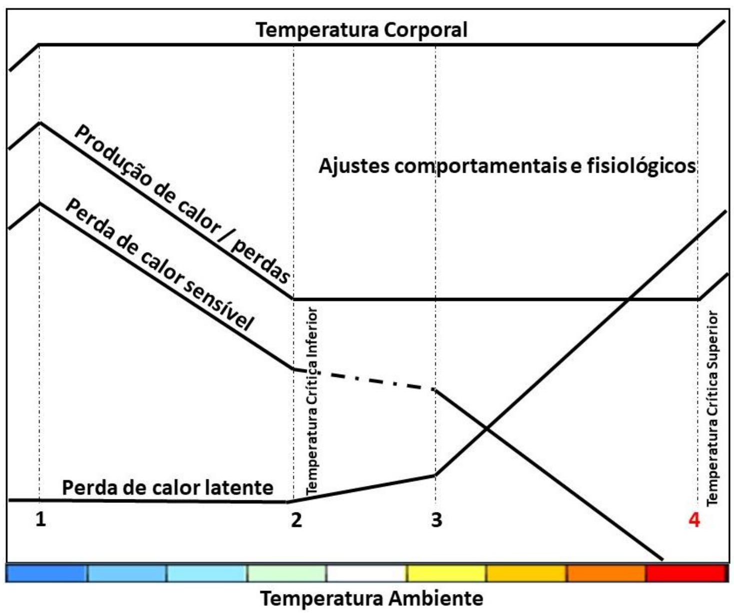

Figura 1.1. Conceitos gerais da regulação térmica em suínos. Adaptado de Mount (1979).

Em uma meta-análise, utilizando 47 estudos publicados entre 1960 a 2009, cada grau Celsius de aumento na temperatura ambiente entre 25 e 30 ºC, reduz em 45 e 25 g por dia do consumo de alimento e ganho de peso, respectivamente, em suínos de 50 kg de peso vivo (Renaudeau et al., 2011). Além disso, diversos estudos têm demostrado que, além de mudanças comportamentais e de apetite, o estado metabólico e fisiológico dos animais também é alterado em situações de estresse por calor. Suínos expostos a altas temperaturas possuem elevados menores níveis circulantes de hormônios tireoidianos e, consequentemente, menor metabolismo basal (Bernabucci et al., 2010). Apresentam também menores níveis circulantes de hormônios anabólicos, resultando em menor potencial de deposição de proteína e gordura na carcaça (Le Bellego et al., 2002; Rhoads et al., 2013).

Em termos de nutrição animal, os efeitos do ambiente térmico no metabolismo dos animais e suas exigências nutricionais são raramente levados em consideração. Majoritariamente, as dietas são formuladas em função da fase de crescimento dos animais, independentemente das interações animal-ambiente e das características intrínsecas de cada indivíduo (nível de ingestão, taxa de crescimento, composição corporal, estado hormonal e metabólico). Para suínos em crescimento, por exemplo, uma única dieta é fornecida para animais entre 30 e 50 kg de peso corporal (dieta crescimento I) e outra para animais entre 50 e 70 kg de peso corporal (dieta crescimento II; Rostagno et al., 2011). Além disso, nesses programas de alimentação, os nutrientes são geralmente fornecidos em excesso, com o intuito de suprir as exigências dos animais com maior demanda nutricional em um grupo de indivíduos. Essa prática, porém, conduz à formulação de dietas com alto valor termogênico por conta do excesso de aminoácidos e muitas vezes inapropriadas para regiões de clima quente. Além disso, também pode ocorrer o fornecimento de dietas com alto impacto ambiental, visto que os nutrientes não utilizados pelo animal devido a limitações biológicas são em grande parte excretados no ambiente (Pomar et al., 2010; Pomar et al., 2014).

1.2.2 Avanços genéticos

A utilização de melhores raças disponíveis, em conjunto com melhoramento genético por meio de seleção e de sistemas de cruzamentos, são os principais meios disponíveis para melhorar a eficiência produtiva e reprodutiva dos suínos. O uso de cruzamentos aponta como principais vantagens a produção de heterose, a incorporação de material genético desejável em apenas uma ou duas gerações e a utilização da complementaridade, associando-se características desejáveis de duas ou mais raças ou linhagens. Mas isso só é possível graças ao grande avanço do melhoramento genético nos últimos anos, apresentando em seu estado atual a busca por melhorias na saúde (dando resistência às doenças e defeitos congênitos), melhoria na qualidade da carne, e nas características de produção (prolificidade, habilidade materna, conversão alimentar e taxa de crescimento). Entretanto, as atenções dos produtores e indústrias são voltadas naturalmente nas melhorias em três pontos principais: redução da gordura, melhoria da eficiência alimentar com favorecimento do crescimento do tecido magro e na qualidade da carcaça. É interessante destacar, que grandes companhias de genéticas vêm avançando nos investimentos e objetivos do melhoramento, incluindo características cada vez mais desejáveis na seleção, que vão além dos três pontos citados anteriormente. Portanto, ao longo desse tópico serão introduzidos os principais avanços genéticos na suinocultura, ilustrados pela Figura 1.2.

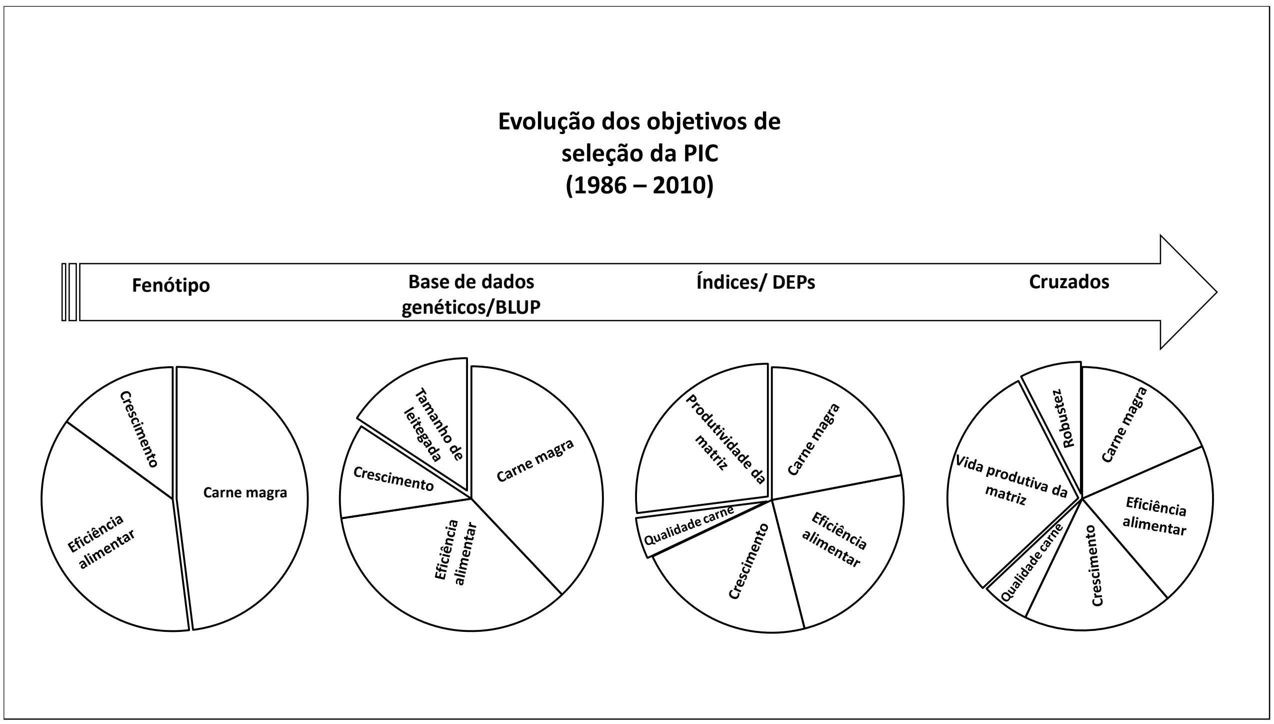

Figura 1.2. Evolução dos objetivos de seleção e os avanços tecnológicos utilizados da empresa Pig Improvement Company (PIC). Adaptado pelo autor de "The Pig Improvement Company – Sheep Breeders Round Table 2011".

Nos anos 90, com o avanço do melhoramento genético, algumas técnicas e metodologias possibilitaram a introdução de modelos matemáticos com o intuito de avaliar e aumentar parâmetros de seleção. Uma dessas técnicas fornece estimativas não viesadas de efeitos genéticos, recomendados na seleção de características reprodutivas com grande eficiência em características de baixa herdabilidade. Portanto, o BLUP do inglês “Best Linear Unbiased Prediction” traduzido para “Melhor Predição linear Não-Viesada” é recomendada para a predição dos valores genéticos, tomados como aleatórios, criando uma matriz de parentesco a partir das informações dos animais. Além disso, essa metodologia é destacada como uma das responsáveis para detectar melhoras no tamanho da leitegada e outras taxas de fertilidade (Whittemore, 2006).

Outro avanço na linha do tempo da evolução do melhoramento genético destaca o uso das tecnologias de marcadores moleculares. Essas tecnologias complementam as decisões de programas estatísticos voltados para a seleção genética (envolvendo análises quantitativas, controle de sêmen e reprodução artificial). Um marcador genético pode ser definido como um segmento específico e conhecido de DNA, que associa a presença de um ou mais genes a um efeito importante sobre determinada característica. Assim, o uso de marcadores genéticos constitui um mecanismo direto para identificação do genótipo (constituição genética) dos suínos para características de interesse. Um exemplo prático dessa metodologia foi a implantação da técnica para identificação do chamado Gene Halotano (Fujii et al., 1991), o qual permitiu uma seleção que vai além dos objetivos de seleção anteriores agregando-se o aspecto qualitativo da carne produzida.

Os marcadores genéticos foram além dos objetivos iniciais e permitiram identificar com alta precisão, por exemplo, os indivíduos mais prolíficos dentro de uma mesma linha ou raça, possibilitando também uma seleção em ambos os sexos, para características que só se expressam em um deles (ex. tamanho da leitegada). A vantagem dos testes de DNA para marcadores que afetam certos parâmetros permitiu identificar com precisão e agilidade em relação ao método BLUP, o genótipo de cada indivíduo, produzindo descendentes com o genótipo desejado e sem falhas na identificação. Outros exemplos do uso de marcadores de DNA para doenças já são utilizados comercialmente. Por exemplo, a PIC implementou comercialmente um marcador para que animais sejam resistentes à Escherichia Coli-F18 (Knap, 2005).

Outro exemplo interessante e mais atual, foi uma edição genômica que interrompe a produção de uma proteína específica (CD 163), tornando os animais imunes à síndrome respiratória e reprodutiva suína. Essa pesquisa levanta um gasto anual com a doença de 600 milhões de dólares nos EUA, e foi realizada pela empresa GENUS PLC em parceria com as universidades do Missouri e do Kansas (Prather et al., 2017). Apesar de pesquisas genéticas que podem eliminar os efeitos negativos de determinados patógenos serem importantes para o futuro da suinocultura, nem todos os problemas poderão ser eliminados. Knap (2005) destaca que os casos em que apenas um gene é envolvido na defesa ou causa de determinados patógenos são relativamente simples de serem executados. O mesmo autor também relata que para a maioria das outras doenças pode ocorrer o desencadeamento de reações imunes complexas, envolvendo uma série de genes, tornando o desenvolvimento dos marcadores cada vez mais desafiador. Portanto, nota-se um esforço em aprimorar as linhas genéticas disponíveis no mercado, adequando-se essas linhas aos desafios que surgem ao longo dos anos.

Mesmo com todas as tecnologias desenvolvidas e citadas anteriormente, uma estratégia que vem ganhando grande destaque nos programas de seleção genética é a busca por linhas robustas, para produzirem sem grande impacto negativo nas mais variadas condições de alojamento.

1.2.3 Robustez

Animais robustos são definidos como aqueles que combinam alto potencial de produção com resiliência a estressores externos, de modo que sua produtividade não seja afetada em uma ampla variedade de condições adversas às ideais de criação (Knap, 2005). Portanto, a preocupação pela busca de linhagens genéticas mais robustas tem obtido grande interesse por parte dos produtores especialmente considerando-se que a produção animal em países de clima tropical e temperado estão modificando suas atividades para larga escala, sem investimento prévio no aumento das instalações. Essa estratégia eleva a densidade de produção, com o intuito de aumentar a lucratividade, resultado de um menor investimento em instalações e nutrição. Dessa forma, pode ocorrer uma maior pressão de infecção nas instalações, desafiando o crescimento dos animais.

Para compreender o conceito de robustez de uma determinada característica, espera-se que um animal de alguma forma desafiado, apresente o desempenho equivalente às condições normais/ideais de criação. Portanto, espera-se que se tracejarmos uma linha entre a resposta do animal em uma condição normal, até sua resposta em uma condição adversa, a inclinação dessa linha seja o mais suave possível. Para exemplificar, a Figura 1.3 retrata a resposta para o ganho de peso médio dos animais A e B. O gráfico apresenta o ganho de peso médio, partindo de um ponto de conforto e desafiados por altas temperaturas de forma intercalada ao longo das semanas. Note que o animal A apresenta uma inclinação quase inexistente no ganho de peso ao longo das semanas de estresse por calor, enquanto uma inclinação muito alta é evidenciada pelo animal B. Isso nos leva a conclusão que o animal B é muito mais sensível aos fatores de temperatura, não apresentando robustez para o ganho de peso.

Um fator envolvido na maior sensibilidade de suínos ao calor, é a sua seleção para alta deposição de proteína, principalmente em condições sem desafios, nas quais os animais acabam expressando todo seu potencial de produção, sem que um teste de resiliência ao calor seja executado. Um ponto interessante seria imaginar que animais selecionados por possuírem melhor eficiência alimentar, poderiam apresentar melhor resistência ao calor, uma vez que sua mantença seria menor. Entretanto, Rauw et al. (2017) destacam que a longa seleção para animais com alta eficiência em ambiente termoneutro não contribuiu para melhorar a tolerância ao calor.

Um estudo que exemplifica muito bem essa dinâmica das exigências de mantença entre animais de desempenho convencional e de alto desempenho foi apresentado por Knap (2000), por meio de um modelo dinâmico. Esse estudo é apresentado na Figura 1.4, e retrata a interação entre as temperaturas ambiente (muito fria e muito quente), e as exigências de mantença para ambas as genéticas (convencional e alto desempenho). Note que animais de alto desempenho, fora das regiões críticas de conforto térmico em até 5 ºC (explicados anteriormente no tópico “Estresse por calor”) apresentam mudanças nas exigências de mantença muito maiores do que animais de desempenho convencional.

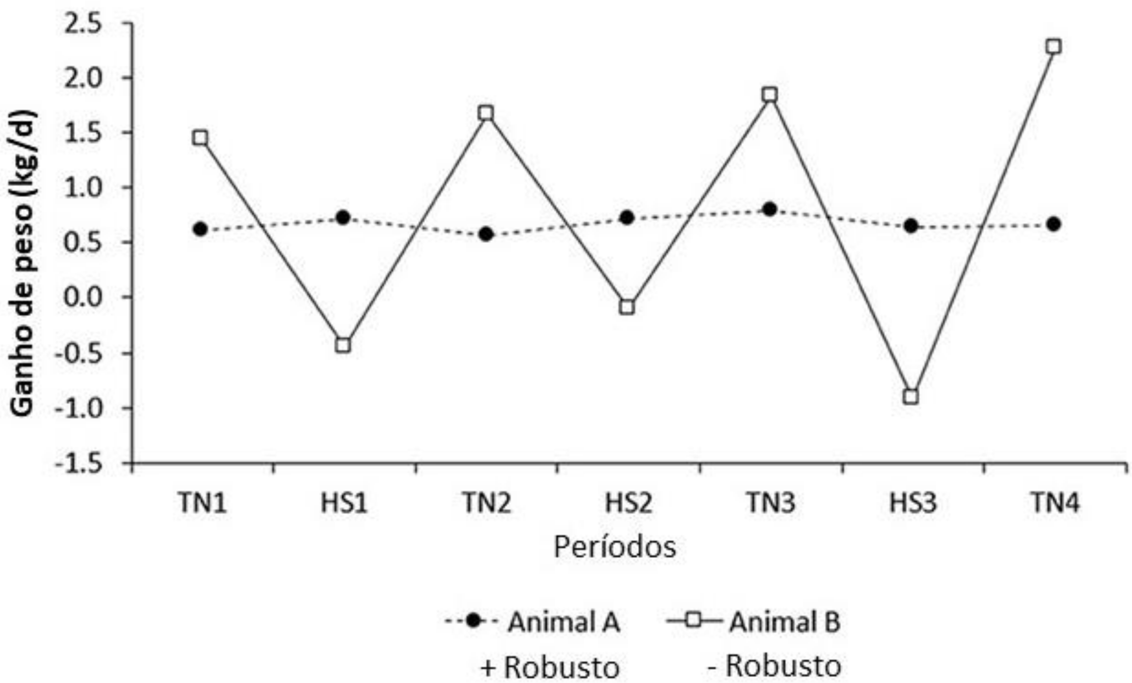

Figura 1.3. Representação do ganho de peso médio de dois animais A e B, retratando os efeitos do estresse de calor intermitente (HS) após períodos em termoneutralidade (TN) ao longo das semanas experimentais. Adaptado de (Rauw et al., 2017).

Em geral, podemos esperar que no futuro, com todas as tecnologias disponíveis, os animais serão robustos, adaptados a diferentes ambientes e saudáveis (Mormède et al., 2011). Para robustez, a seleção ocorrerá principalmente por animais que consigam manter altas taxas de crescimento mesmo sob condições de estresse por calor (Rauw et al., 2017).

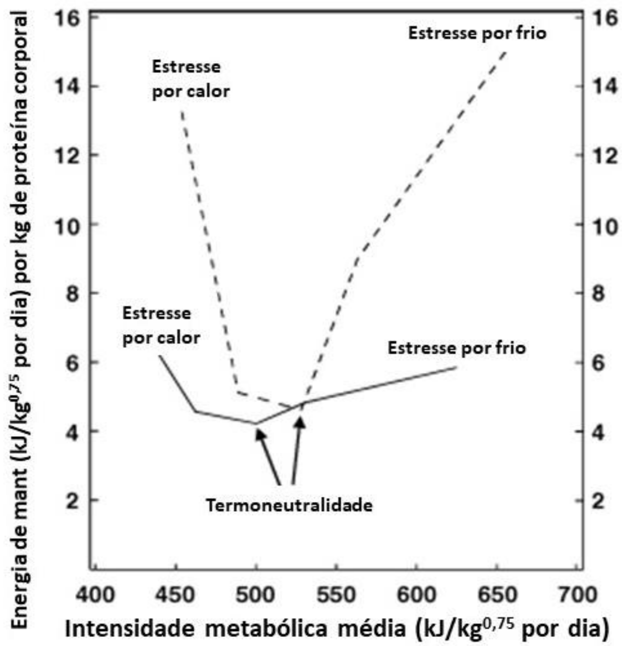

Figura 1.4. Mudanças nas exigências de energia de mantença simuladas por unidades de massa corporal proteica em animais de desempenho convencional (——) e animais de alto desempenho (------). Adaptado de Knap (2000).

1.2.4 Programas nutricionais atuais

Enquanto o animal do futuro não está claramente disponível, algumas estratégias nutricionais podem ser utilizadas em animais mais sensíveis ao estresse por calor, principalmente nas estações onde ocorrem as maiores temperaturas. Essas estratégias estão focadas no balanço adequado de nutrientes, com o objetivo de diminuir o incremento calórico da dieta, sem que haja redução nutricional que atrapalhe o desempenho dos animais. Entretanto, de acordo com o sistema de alimentação utilizado, podem ocorrer resultados distintos em relação à dieta e o desempenho de animais em estresse por calor.

A seguir, a Figura 1.5 ilustra como o sistema de alimentação por fases impacta no fornecimento de nutrientes em excesso na maior parte da fase ao longo do crescimento de suínos. Na indústria, esse sistema por fases basicamente se estabelece pelo balanço entre a quantidade de nutrientes dos ingredientes com as exigências nutricionais dos animais (Patience et al., 1995). As dietas estabelecidas são fornecidas em um número sucessivo de fases (diminuindo-se as concentrações de nutrientes, na linha pontilhada) aos animais com o objetivo de atender suas exigências em função da idade ou peso vivo. Entretanto, esse sistema resulta em períodos de fornecimento inadequado de nutrientes para mais (área superior à curva de exigência) ou para menos (área inferior à curva de exigência).

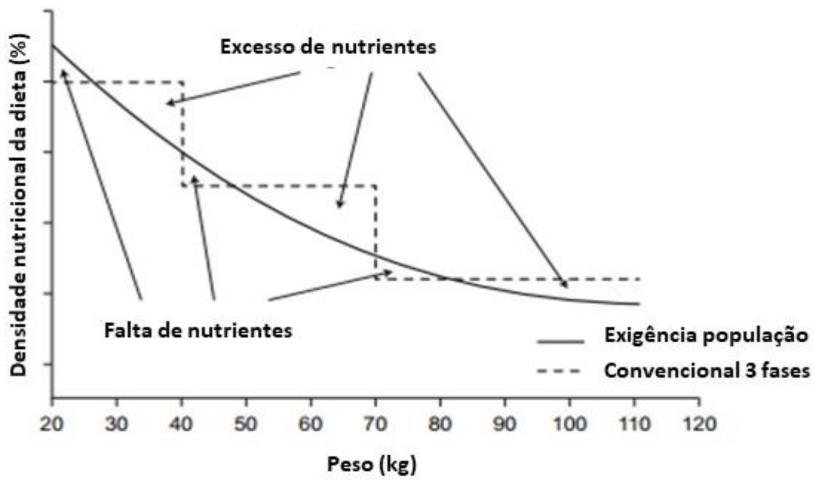

Figura 1.5. Conceito de nutrição por fases ilustrando as mudanças constantes de exigências nutricionais de suínos. Fonte: Patience (2012).

Considerando-se que a exigência de uma população diminui ao longo da evolução do peso dos animais, um sistema de alimentação capaz de adequar diariamente os níveis nutricionais dentro de uma população poderia reduzir consideravelmente o excesso de nutrientes. Apesar do sistema de alimentação com mudanças diárias na concentração de nutrientes para grupos de animais ser um conceito antigo, sua utilização na prática é pouco realizada. Alguns autores relatam um aumento dos custos de produção quando equipamentos robotizados para a mistura e diluição das dietas são utilizados (Patience, 2012; MLC, 2004). Entretanto, uma pesquisa recente demonstrou que essa tecnologia pode trazer vantagens nos custos de formulação de dietas devido à redução no uso de nutrientes em excesso (Pomar et al., 2014).

Dentro dessa lógica de alimentar os animais por fases, as exigências utilizadas para formular as dietas têm sido estimadas pelos métodos empírico e fatorial. No empírico, as exigências nutricionais são estabelecidas para maximizar ou minimizar um ou vários parâmetros de desempenho. No fatorial, as exigências diárias são estimadas pela soma das exigências para mantença e produção (Fuller e Chamberlain, 1982). Modelos de crescimento que utilizam o método fatorial também estimam as exigências para um indivíduo representativo de uma população. Na produção animal esses métodos têm sido utilizados para estimar as exigências de uma população com base em um único indivíduo (fatorial) ou na resposta da população (empírico). Um aspecto normalmente esquecido é que a resposta de uma população a ingestão de um nutriente em um dado ambiente é dependente da resposta de cada animal. Entretanto, as exigências nutricionais de cada animal não podem ser estimadas a partir da resposta de população ou de um único indivíduo. A resposta de um indivíduo à ingestão de um nutriente é diferente em forma e magnitude da população (Pomar et al., 2003). Desse modo, os métodos atuais não consideram as diferenças entre as populações ou entre os animais de uma população e as mudanças que poderão aparecer durante o curso do crescimento ao estimar um nível ideal de nutriente na dieta. Em relação ao desempenho, ambos os métodos (fatorial ou empírico) apresentarão resultados satisfatórios. Mas quando comparados aspectos econômicos (custos na formulação e armazenamento de dietas) ou ambientais (excreção de nutrientes em excesso), os sistemas de alimentação atuais dificilmente poderão ser otimizados.

1.2.5 Nutrição de precisão

A nutrição de precisão desenvolvida ao longo desse trabalho, tem por finalidade melhorar ou ajustar dietas de forma mais próxima as exigências individuais dos animais. Consequentemente, espera-se uma utilização adequada de ingredientes na formulação de forma sustentável, uma vez que excessos podem ser evitados. A nutrição de precisão também é definida de forma conceitual, na qual considera-se a variabilidade entre indivíduos de uma mesma população (Wathes et al., 2008). Esta variabilidade resulta das diferenças entre os animais no que se refere à genética, idade, peso, entre outros. Além dessa variação intrínseca ao animal existe também a variação extrínseca. Nesse último caso são fatores externos que influenciam o desempenho dos animais e as exigências nutricionais. Dessa forma, com tantos efeitos podendo influenciar em qualquer meio, é natural que ocorram diferentes reações individuais, resultando em aumento da variabilidade entre os animais (Wellock et al., 2004).

Portanto, nos aproximamos da nutrição de precisão quando alguns aspectos como considerar a variabilidade dos animais na avaliação da resposta biológica e nos programas nutricionais são utilizados (Knap, 2000, Pomar et al., 2003, Hauschild et al., 2010). A aplicação do conceito pode ser dependente do uso de sistemas integrados, nos quais algumas informações captadas em tempo real por equipamentos são transformadas em valores úteis ao produtor. Um exemplo desse tipo de sistema foi a adequação de vídeo imagens para predição do peso corporal de suínos (Parsons et al., 2007).

Para alimentação de precisão individual criado por Hauschild et al. (2012), o modelo de ajuste individual diário de ração é realizado por meio dos valores preditos de consumo e ganho de peso para o próximo dia utilizando-se equações empíricas de modelagem recursiva (Figura 1.6). Esses valores preditos são utilizados na segunda parte do modelo, no qual uma equação fatorial (somando-se as exigências de mantença e de produção) possibilita a determinação da exigência nutricional individual para o próximo dia. A partir da exigência do animal e sua informação de consumo para o próximo dia, as concentrações nutricionais são calculadas de forma que uma dieta seja formulada. Dessa forma, a ração formulada para o dia seguinte de cada animal, deverá ter uma concentração de aminoácidos para atingir a quantidade exigida de acordo com o consumo predito. As informações das exigências individuais diárias ocorridas em uma população de 24 animais durante 55 dias podem ser observadas na Figura 1.7.

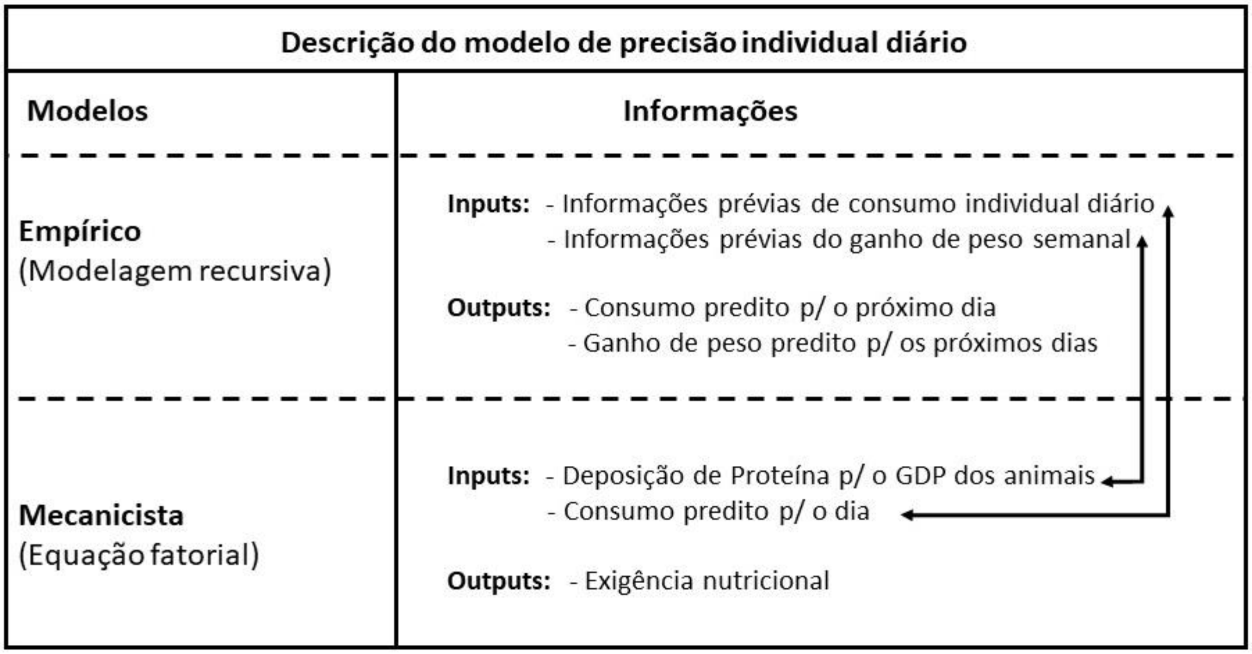

Figura 1.6. Descrição do modelo de alimentação de precisão individual diário desenvolvido por Hauschild et al. (2012).

No caso da alimentação, sistemas de precisão são uma abordagem essencial para melhorar a eficiência de utilização do N, P e outros nutrientes, diminuindo assim a excreção desses elementos no meio ambiente. Uma vez que com a excreção dos nutrientes em excesso, além de elevar o custo de produção final do produtor, também podem contaminar o meio-ambiente pelo processo de eutrofização das águas. Entretanto, a eficiência desses sistemas no que se refere a nutrição está relacionada a uma determinação precisa do valor nutritivo dos alimentos e das exigências nutricionais dos animais. Também é fundamental uma formulação de dietas que ajuste de forma concomitante o aporte de nutrientes às exigências dos animais. Esse ajuste requer o conhecimento das exigências nutricionais de uma população em função da sua variabilidade animal, atual estado sanitário e de conforto, da evolução do consumo e do crescimento no tempo (Pomar et al., 2009).

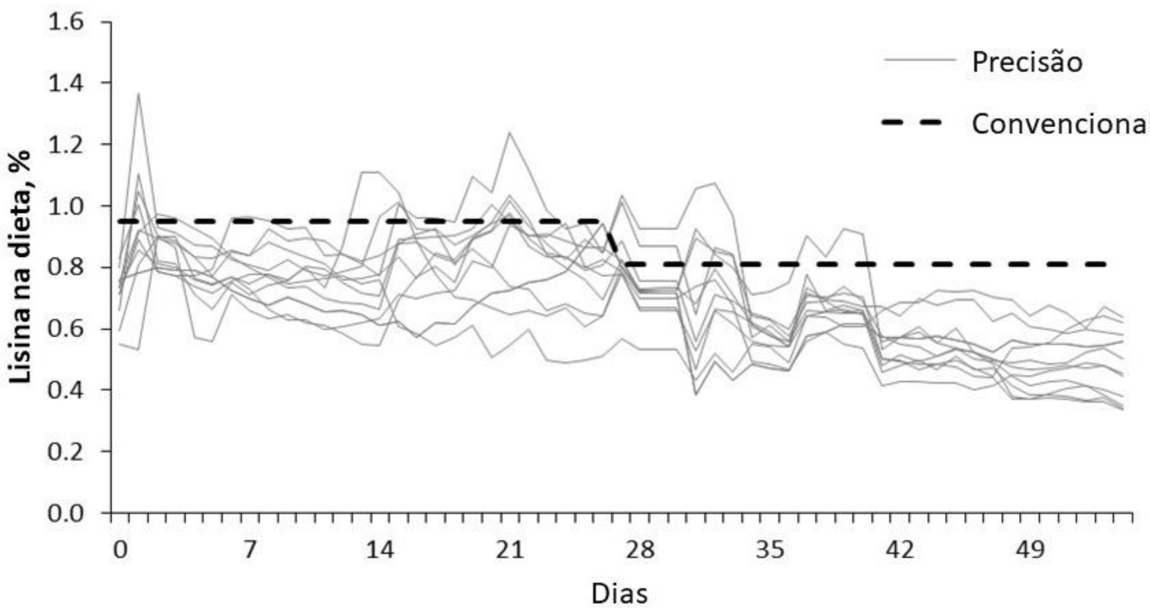

Figura 1.7. Exemplo da exigência diária de lisina individual para animais mantidos em ambiente termoneutro durante 55 dias e representação da quantidade fornecida para animais em sistema de alimentação convencional de duas fases. Fonte: Arquivo pessoal.

1.2.6 Problemática do tema pesquisado

A adequação dos sistemas de alimentação para suínos criados em clima tropical é uma necessidade para que a suinocultura torne-se sustentável e mais rentável. As sugestões de modificações nutricionais e de ingredientes para animais em estresse por calor no sistema de alimentação convencional, ainda possuem certos fatores controversos. Um desses fatores é que mesmo utilizando estratégias para amenizar o incremento calórico da dieta, as mesmas ainda apresentam certos períodos em que há um aporte nutricional fora das exigências da população (durante longos períodos de tempo). Portanto, devemos considerar que estratégias no sistema convencional trazem na verdade “uma redução do excesso de nutrientes” e não um uso adequado de nutrientes como é o caso da nutrição de precisão. Dessa forma, as estratégias nutricionais que antes faziam sentido no sistema convencional, poderiam ser deixadas de lado, uma vez que atenderíamos as exigências individuais e diárias de cada animal.

1.2.7 Perspectivas

Como dito anteriormente, a nutrição de precisão busca o uso adequado de nutrientes. Dessa forma, há uma redução dos custos na formulação das dietas e na excreção desses nutrientes no meio ambiente. Diversos estudos publicados no Canadá, comprovaram a eficácia desse sistema em condições ideais de temperatura (Andretta et al., 2014; Andretta et al., 2016). Diante disso, espera-se uma versatilidade da utilização dessa estratégia no Brasil, adequando-se às linhas genéticas disponíveis ao produtor. Além disso, não devemos esperar o avanço das tecnologias chegarem ao produtor para serem pesquisadas. Em um futuro próximo, essas tecnologias estarão disponíveis no mercado com custos acessíveis. Portanto, as pesquisas atuais nessa linha, garantirão que quando a tecnologia estiver disponível, os modelos já estejam desenvolvidos e prontos para serem utilizados nas mais variadas condições práticas de criação.

1.2.8 Estruturação da tese

Os ensaios experimentais foram realizados no Laboratório de Estudos em Suinocultura da UNESP/FCAV – Jaboticabal (2015 e 2016). Já a análise dos resultados para elaboração dos artigos ocorreu em parceria com o AGRIFOOD Canadá (2017 e 2018). Para responder a problemática dos temas estudados, esse estudo foi dividido em duas partes. A primeira parte avaliou as respostas de desempenho sob estresse por calor de progênies de duas linhas genéticas, sendo uma delas amplamente utilizada no Brasil. Já a segunda parte consistiu na avaliação da genética mais sensível ao calor, sendo então submetida aos sistemas de alimentação de precisão individual diário e convencional por fases durante a fase de crescimento. Ambas as partes são apresentadas em forma de capítulos.

1.2.9 Objetivos

Parte I – Avaliação das respostas de progênies de duas linhas genéticas

- Determinar a linha genética mais sensível ao calor em relação as suas reduções no desempenho e na composição corporal para utilização na parte II da tese;

- Estabelecer a relação entre as reduções obtidas em ambiente termoneutro e de estresse por calor, tendo uma ideia de robustez de cada linha genética utilizada;

Parte II – Aplicação da técnica da nutrição de precisão individual em animais em ambiente termoneutro e em animais submetidos ao estresse por calor

- Comparar os sistemas de alimentação convencional e individual em ambiente termoneutro e de estresse por calor.
- Avaliar redução do aporte de proteína, aminoácidos e de fósforo em condições termoneutras e de estresse por calor por meio do uso do sistema individual de precisão em relação ao convencional;
- Avaliar se o desempenho e balanço de nutrientes é influenciado pelos sistemas de alimentação nos diferentes ambientes.

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CAPITULO 2 - Performance and carcass composition of pigs from two sire lines are differently affected by ambient temperature [1]

[1] Este capítulo encontra-se nas normas correspondentes para ser submetido à revista Journal of Animal Science

Running head: Pigs sire line responses in constant heat stress

Performance and carcass composition of pigs from two sire lines are differently affected by ambient temperature[1]

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ABSTRACT: This study compared the responses of pigs from two sire lines reared under constant thermoneutral and high ambient temperature conditions. A total of 24 castrated barrows (initial BW = 32.0 ± 2.0 kg) progenies from two genetic lines (Hampshire purebred line: HAM or Synthetic line: SYN) mated with Camborough dams were allotted to individual pens and assigned to one of two constant temperatures (Thermoneutral 22ºC: TN; High temperature 33ºC: HT). Feed intake and body weight were recorded weekly during the trial. Body composition was assessed at days 27 and 55 by dual-energy X-ray densitometry scanner. At d-0 and after each scan, backfat thickness and muscle depth were also measured. Nitrogen and phosphorus excretion were estimated as the difference between retention (obtained from densitometry measurements) and intake. As expected, HT pigs reduced ADFI (35%; $P < 0.01$) than TN pigs during both experimental phases (0-27 and 28-55 d). During the second growth phase, the ADG of SYN pigs under HT was reduced by 50%, while for HAM pigs, this reduction was around 24% ($P < 0.05$ for the interaction between G ×AT). On d 27 and 55, pigs BW, body lipid, phosphorus, and bone mineral content were reduced ($P < 0.05$) in HT compared to TN ambient. In these same days, the backfat thickness was 26% lower in SYN compared to HAM pigs in HT conditions ($P < 0.10$ for the interaction G × AT). On d 55, in HAM pigs, body protein content was 11% lower from TN to HT conditions, while this reduction was of 30% in SYN pigs ($P < 0.05$ for the interaction G × AT). Despite both genetics being affected by the high temperature, robustness selection from purebred Hampshire showed pigs less affected by extreme heat stress conditions when compared to a synthetic line. The present findings suggest that individual farm conditions are one of the first steps to be considered before implementing a genetic line.

Keywords: genetic, Hampshire, heat stress, robustness, synthetic line

INTRODUCTION

When exposed to a hot environment, the reduced gradient temperature between the body surface and the environment limit pigs ability to dissipate heat (NRC, 1981). Therefore, they have to rely on evaporative heat loss to thermoregulate. Decreased feed intake, reduced activity level, and metabolic changes are also observed in heat stressed pigs in an attempt to reduce metabolic heat production (Campos et al., 2017). Strategies for cooling purposes have been used in pig farms over the years. However, decreased feed intake and growth rate due to heat stress are still inducing significant production losses in the pig industry (St-Pierre et al., 2003; Baumgard and Rhoads, 2013). Furthermore, animals selected for improved lean tissue accretion produce more metabolic heat and tend to be more susceptible to heat stress than unselected lines (Brown-Brandl et al., 2001), which is also more affected by the intensification of animal production (Campos et al., 2017).

Concerning this aspect, pigs can be selected for an adequate growth performance even in heat stress conditions, once that a genetic component of this phenomenon exists. However, one important point that results in difficulty for genetic industries is that the genetic component for heat stress can be masked by the almost inexistent effect of temperature in nucleus farms (Misztal, 2017). Despite more than 50% of world pig production occurring in tropical and subtropical regions (FAO, 2010), the impact of high ambient temperatures is not limited to these regions. For example, temperate climate countries can present ambient temperatures above the thermoneutral zone during summer (Renaudeau et al., 2012). In this regard, one important commercial aspect for pig production is that they can be adapted to specific conditions or selected for robustness, which they are able to perform in different conditions (Knap, 2005) or as the pigs ability to function in the presence of internal and external challenges without major changes (Rauw and Gomez-Raya, 2015).

In this study, we aimed to evaluate the growth performance, body composition and physiological responses of progenies from two sire lines (Hampshire and a synthetic line) maintained under two constant temperatures (thermoneutral: 23ºC and constant heat stress: 33ºC). The robustness potential between both genetics was also evaluated considering animals that were less affected by higher temperatures.

MATERIALS AND METHODS

The experimental procedures were reviewed and approved by the Institutional Animal Care and Use Committee at Sao Paulo State University, SP, Brazil (No. 16744/15).

Experimental design and diets

The experiment utilized a total of 24 castrated barrows (26.8 ± 3.9 kg) progeny of two different sire lines: Hampshire-based line (HAM), resulting from AGPIC 327 sire crossed with AGPIC Camborough dam; and a synthetic line (SYN; Large White × Landrace × Duroc × Pietrain) resulting from AGPIC 337 sire crossed with AGPIC Camborough dam. Thorough adaptation (7 d) and experimental (55 d) periods pigs were housed in individual and adjustable metabolic pens (0.72 m^2) with partially slatted floor. Pens were equipped with one feeder and one nipple-type drinker. At the beginning of adaptation period, pigs from each genetic were randomly assigned to one of two climatic-controlled rooms: thermoneutral (22 ºC; TN) or heat stress (33 ºC; HT) and allowed to acclimatize to the ambient temperature, management, individual pens and experimental diet. The experimental design considered the effects of genetic lines (G; HAM and SYN) and ambient temperature (AT; TN and HT) in a 2 × 2 factorial design. Temperature in the TN and HT rooms were maintained constant during the entire experiment through air conditioning and electric fan heaters. During the experiment, ambient temperature and relative humidity in the rooms were recorded every 10 min using two data logger (HOBO, Onset Computer Corporation, Bourne, MA). Irrespective of the room, glass windows and fluorescent lamps provided approximately 12 h of light.

The experimental period was divided into two feeding phases (0-27 and 28-55 d). Feeds for each phase were based on corn and soybean meal formulated to meet NRC (2012) nutritional recommendations for growing pigs (Table 1). Pigs were fed ad libitum and had free access to fresh water throughout the adaptation and experimental period.

Performance and body composition

Animals were weighed weekly at 0730 h without fasting. Feed intake was measured daily considering the difference between feed provided and feed refusals.

At d 27 and 55 of the experiment, total body lean, body fat, bone mineral content and bone mineral density were measured by dual-energy X-ray absorptiometry “DXA” scan (Hologic Discovery, Hologic, Inc., Bedford, MA, USA; Fig 1). Eight-hour fasting animals were anesthetized by intramuscular injections of xylazine (1.5 mg/kg) and ketamine (15 mg/kg). At d 0 and after each scan, backfat thickness and muscle depth were measured in the anesthetized animals in prone position using ALOKA equipment (500v series with a linear probe of 3.5-MHZ, 13.5-cm; Aloka Ultrasound Company, Wallingford, CT) between the third and fourth last ribs at 4-5 cm from the midline.

Measurements and sampling procedures

During the experimental period, body and rectal temperatures, and respiratory rate were measured in all pigs, at 0900 and 1600 h, twice a week. Body temperature was accessed by thermographic images from the superior left side of each pig, using an infrared camera (Flir SC660, Portland, OR, USA). The images were analyzed and temperature of specific regions of pigs body (dorsal, flank, nape and total body temperature) were measured using a specific software-program (Flir Tools 5.12 software; Fig 2). Rectal temperatures were measured using a digital thermometer (G-Tech, São Paulo, Brazil). Respiratory rate was visually determined by counting flank movements over a period of 30 seconds and corrected for 1 min, exclusively when pigs were resting. At 0700 h of d 0, 27 and 55, blood samples were collected in 5mL-tubes via the jugular vein of all pigs and the serum was separated from whole blood by centrifugation at 1500×g for 10 min. The identified samples were stored at -20 ºC until analysis.

Analytical procedures

Total nutrient intake for each phase was obtained considering the feed concentration provided and the total feed intake for each pig. The DXA body lean and fat mass were converted to protein [body protein content (g) = −1384 + 0.216 × DXA lean (g)] and lipid values [body lipid content (g) = 2825 + 1.009 × DXA fat (g)] as suggested by

Pomar and Rivest. (1996). The P content was estimated assuming 18% of P abundance in DXA bone mineral content, 1.014% in lean tissue and 0.05% in the fat content (Létourneau-Montminy et al., 2015). Total levels of acid glycoprotein, albumin, ceruloplasmin, haptoglobin, IgG, PM23000, and transferrin were accessed in sodium dodecyl sulfate-polyacrylamide gel electrophoresis (Weber and Osborn, 1969). The values of acute phase proteins after electrophoresis were corrected by serum total protein analysis, which was determined using a commercial reagent (biuret method) and performed by semi-automatic spectrophotometry (Labmax Plenno, Brazil). The same semi-automatic apparatus was used for the quantification of the urea concentration in serum (UV urea enzymatic kinetic method). Both commercial reagent kits were purchased from Labtest Diagnostica, Brazil.

Statistical analysis

Data were analyzed as a mixed model with the fixed effects of G, AT and their interactions in each feeding phase by the MIXED procedure of SAS (version 9.3; SAS inst. Inc., Cary, NC). Differences among fixed effects were considered statistically significant with $P \leq 0.05$ and trends with $0.05 < P \leq 0.10$. The individual pig was considered the experimental unit and the initial BW was used as a covariate when significant in the model. The model was: $Yijk = \mu + \alpha i + \beta j + (\alpha\beta)ij + eijk$, where Yijk = observed variable (observation for the kth animal from the (i,j)th cell), μ = mean, αi = ith factor G effect, βj = jth factor AT effect, (αβ)ij = (i,j)th G × AT interaction effect and eijk = random error of kth observation from (i,j)th. The GROUP statement was used to equal the variance between means when convenient based on the smaller akaike information criterion (AIC). The linear contrast for comparing physiological responses between four periods was also calculated.

RESULTS

The ambient temperature in TN and HT rooms were 22.2 ± 0.9ºC and 33.3 ± 1.8ºC, respectively. In that same order, relative humidity was 83 ± 6.4% and 69 ± 5.6%. Pigs under TN conditions consumed feed and gained weight according to the expected performance throughout the entire trial. Pigs under HT conditions consumed and gained less than in TN, and a SYN pig died during the second phase, this pig data was removed from analysis.

Performance

During the second phase, SYN pigs reduced the ADG in 50% when compared their performance between TN to HT conditions, whereas in HAM pigs this reduction was 24% ($P < 0.05$ for the interaction G × AT). Except for the interaction aforementioned, there were no differences for ADFI, ADG neither G:F ratio among genetics for any experimental phase. Between pigs raised in TN and under HT conditions, the average daily feed intake reduced 25% and 41% ($P < 0.01$) during the first and second experimental phases, respectively (Table 2).

Body composition

The initial BW and loin depth (d 0) were not different between G or AT (Table 3). On d 0, backfat thickness of HAM pigs was 9% higher than SYN pigs ($P = 0.05$), while in

HT conditions this variable was also 9% higher ($P < 0.05$) than in TN conditions. On d 27, SYN pigs presented 16% lower backfat thickness in HT than in TN condition, whereas HAM pigs increased 4% their backfat thickness ($P = 0.05$ for the interaction between G × AT on d 27). Yet on this same day, body lipid and body protein content for pigs under HT were 12% and 21% lower, respectively, compared to TN ($P < 0.01$), whereas phosphorus and bone mineral content were 14% and 19% lower, respectively ($P < 0.05$).

On d 55, ambient temperature reduced ($P < 0.01$) BW and body lipid content by 20% for HT compared to TN ambient, whereas these reductions for phosphorus and bone mineral content were 27% and 31%, respectively ($P < 0.05$). Comparing pigs under TN with HT conditions, backfat thickness was reduced 3% in HAM pigs, whereas in this same condition, SYN pigs were impacted in 43% ($P < 0.10$ for the interaction between G × AT). On this same day, body lipid content from TN to HT was 10% lower in HAM and 43% lower in SYN pigs, and body protein content was 11% lower in HAM and 28% lower in SYN pigs ($P < 0.05$ for the interaction between G × AT).

Serum parameters, acute phase protein, and physiological responses

On d 0, genetic effects increased ($P < 0.05$) urea concentration and PM23000 in 25% and 30% for HAM pigs compared to SYN pigs. In this same period, temperature effects ($P < 0.05$) showed that pigs in HT condition had 27% greater ceruloplasmin levels, while haptoglobin reduced 24% compared to TN condition.

On d 27, HAM pigs showed albumin concentration 17% lower from TN to HT conditions, while in SYN pigs, this reduction was 9% ($P < 0.05$ for the interaction between G × AT). High temperature reduced ($P < 0.05$) serum urea (42%), haptoglobin (30%) and transferrin (14%) in HT compared to TN ambient. Genetic effects increased ($P < 0.05$)

total protein (12%), ceruloplasmin (28%) and transferrin concentrations (21%) in HAM compared to SYN pigs.

On d 55, HAM pigs showed greater serum urea concentration than SYN pigs (32%; $P < 0.05$). For ambient temperatures, pigs under HT conditions altered ($P < 0.05$) serum urea (-30%), total protein (-13%), albumin (-20%), IgG (+21%), PM23000 (-18%) and transferrin (-21%) compared to pigs under TN conditions. A genetic effect tended ($P < 0.10$) to increase ceruloplasmin levels by 22% for HAM compared to SYN pigs.

HAM pigs showed higher ($P < 0.01$) rectal temperature than SYN pigs, while both genetics decreased linearly ($P < 0.01$) this variable from the first to the fifth experimental period (Table 5). The dorsal temperature increased linearly ($P < 0.05$) between the five periods, while respiratory rate decreased linearly ($P < 0.01$) in this same period. Ambient temperature effects increased ($P < 0.01$) all physiological parameters in HT when compared to TN pigs.

DISCUSSION

Characteristics of both genetic lines

Pigs from HAM and SYN sire lines have been selected to adequate growth performance with efficient lean production. Hampshire progenies had the ADG 10% lower than SYN pigs in TN conditions. The differences between both genetics also can reflect their time for maturing weight. Synthetic pigs that use the Pietrain breed, generally present early maturing weight than HAM pigs (Hazzledine, 2007), hence, these synthetic pigs may present a greater performance in TN conditions. However, Rauw et al. (2017) suggested that the best-performing animals during heat stress are likely those that are not highly superior for growth in thermoneutral conditions, once that the production traits results in high production of metabolic heat. Therefore, the pig industry is moving toward select robust animals, e.g., “pigs that combine high production potential with resilience to stressors, allowing for unproblematic expression of a high production potential in a wide variety of environmental conditions” defined by Knap (2005).

Genetic impact between TN and HT conditions

Different responses between genetics were found when pigs were kept under TN or HT conditions. In fact, HT compromised the performance of SYN pigs with a higher magnitude than in HAM pigs. However, this response observed for HAM pigs might be related to their robustness potential. Nonetheless, the capacity of pigs to perform at high ambient temperature was decreased by both genetics. Feed intake is reduced in HT conditions, which negatively affects the growth rate. The reduction of feed intake in heat-stressed pigs presented in our study was compared to a previous meta-analysis from Renaudeau et al. (2011). These results from literature suggested that pigs under constant heat stress conditions decrease their voluntary feed intake in 640g from 23º to 34ºC, whereas, in our study, this reduction between the same temperatures was 805g. This slight difference between this meta-analysis and our study may be related to the housing conditions (group to individually housed, respectively). The reduced feed intake in heat-stressed pigs is employed because digesting nutrients generates heat, and this extra caloric production can be ameliorated by reducing feed intake (Bernabucci et al., 2009). This strategy is well described in studies comparing the temperature impacts and it has been defined as the thermic effect of feed (West, 2003). Because no interactions between

G × AT were found for ADFI, both genetics presented similar mechanisms to reduce their thermal effect of feed in HT conditions.

The decrease in ADFI because of the HT may deviate some nutrients as amino acids from growth to physiological alterations, which may impair the performance of pigs (Cervantes et al., 2016). These alterations also can include catabolic hormones as epinephrine, cortisol, glucagon (Bianca, 1965; Beede and Collier, 1986), insulin (Campos et al., 2014; Pearce et al., 2013a), heat shock proteins (Kamanga-Sollo et al., 2011; Pearce et al., 2015) and a suppression of mRNA abundance of genes involved in the lipolytic cascade (Kellner et al., 2016). However, the reduction in feed intake reported in the literature can be contrasting. For example, Pearce et al. (2013a) found reduced feed intake (about 46%) in pigs under heat stress conditions, whereas the ADG was compromised by 78%. Cervantes et al. (2016) reported that heat-stressed pigs consumed 20% less feed, whereas a similar reduction (about 23%) was evidenced in ADG. In the present experiment, these aforementioned reductions between ADFI and ADG in SYN pigs were according to Cervantes et al. (2016). However, between TN and HT conditions, HAM pigs reduced their ADFI by 37%, but surprisingly the ADG was only 24% less during the second experimental phase. For SYN pigs, these reductions during the same experimental phase were 45% for ADFI and 50% for ADG (e.g., only 5% of the reduced ADG does not appear to be explained by the reduction in ADFI). Even though the average daily gain of SYN pigs was according to the feed reduction, the composition of the weight gain in HT pigs might have been altered, once that the direct effects of heat stress may also alter the hierarchy of tissue synthesis (Baumgard and Rhoads, 2013). Some studies reported that the HT reduces muscle mass and increases adipose tissue (Close et al., 1971; Stahly et al., 1979) because of changes in metabolism, redox balance, and inflammatory signaling (Ganesan et al., 2016). Modern genotypes such as we used in this study have been selected over years based on market production traits. This selection with less lipid deposition and superior protein deposition (consequently more heat production), may contribute to a decreased ability of pigs to cope with the heat stress (Brown-Brandl et al., 2001). Interestingly, comparing pigs raised under TN with pigs under HT conditions, the body protein and body lipid content was reduced in lower proportion in HAM than SYN pigs. In other words, these reductions were more intense for SYN than for HAM pigs, suggesting that SYN pigs might present a lower ability to perform under HT conditions. Comparing both genetics in TN and HT, body lipid content reduced 43% and 10%, whereas body protein content was reduced by 28% and 11% for SYN and HAM pigs, respectively. In this case, the carcass lipid-to-protein ratio decreases in SYN pigs, meaning the carcass become leaner. Leaner carcass seems to be sought by the industry, the fact that SYN pigs were leaner in HT conditions suggests an imbalance caused by the heat burden, which impaired their adequate lipid deposition. Despite non-significant, SYN pigs had also a marked reduced feed intake under HT (-170g/d of feed on average) compared to HAM pigs. As suggested by Le Bellego et al. (2002), the feed intake restriction in heat stress conditions has a lower effect on pig’s protein deposition than the same restriction in pigs under TN conditions. Furthermore, these authors also reported that any extra metabolic energy intake in heat-stressed pigs benefits exclusively lipid deposition. In this case, heat stress may have possibly affected post-absorptive protein metabolism, however, genetics have a large influence for attenuating the effect of heat stress on body composition, although it was evidenced only during the second experimental phase.

In this study, pigs exposed to HT doubled their respiratory rate compared with TN pigs. This result was in good agreement with a previous work of Pearce et al. (2014), which evidenced a two-fold higher respiratory rate in HT compared to TN pigs. However, our results also showed a visual gradual decline in breath rate over time of exposure to heat stress, which might possibly decrease their ability to eliminate heat during the second phase. A similar decline of breath rate was also reported in previous studies (Morrison and Mount, 1971; Giles et al., 1991; Renaudeau et al., 2013), however, in these studies, the decreased respiratory rate was attributed by these authors with a consequence of a long-term acclimation to heat stress. Even though the gradual reduction of respiratory rate has been related to the acclimation to heat stress, pigs under these conditions rely on this mechanism once that latent heat loss becomes less efficient in HT (Mount, 1979). The respiratory rate has an efficiency of about 18 and 21 g/d of evaporated water for each extra breath per minute (Kamada and Notsuki, 1987; Renaudeau et al., 2013), therefore, with high temperature pigs increase their respiratory rate for losing heat by evaporative heat loss (Lopez et al., 1991).

Another interesting point is that a higher rectal temperature was evidenced in HAM pigs (which may confuse with lower acclimation to HT). However, it may be related to their higher serum urea concentration compared to SYN pigs. The metabolic pathway for deamination of unused AA expend amounts about 4.9 MJ/kg of protein deaminated (Whittemore, 1983), increasing heat production. Nevertheless, HAM pigs performed better than SYN pigs under HT conditions.

An interaction between AT × G showed that SYN pigs under HT had a reduced level of acid glycoprotein, whereas HAM pigs had no acid glycoprotein changes at day 55. Despite acid glycoprotein be related to an acute phase protein in dogs (Ohwada and Tamura, 1993; Hochepied et al., 2003), a previous study suggested that this acute phase protein does not appear to respond to inflammatory models in pigs (Eckersall et al., 1996). Surprisingly, this acid glycoprotein concentrations, however, seemed to be influenced by other factors, including breed type. In agreement with our study, Kahlisch et al. (2009) looking at a ConA-binding form of pig acid glycoprotein showed a slight decrease in Pietrain breed, whereas Hampshire breed had no change in this form of acid glycoprotein after infection with Actinobacillus pleuropneumoniae.

Short-term response of pigs during the first days of exposure to high ambient temperature is associated with negative impacts on intestinal integrity and physiology, which may impair their absorptive capacity (Pearce et al., 2014). This reduced intestinal integrity can increase lipopolysaccharide in portal (Hall et al., 2001) and systemic blood (Pearce et al., 2013b,c), which in turn may be related to alterations in the acute phase proteins evaluated in this study. The acute phase proteins response between genetics reported that SYN pigs had lower ceruloplasmin and transferrin levels than HAM pigs, whereas haptoglobin was reduced in HT at 0 d and 27 d of the experiment. Haptoglobin and ceruloplasmin have been used to detect inflammatory or infections levels in pigs (Hall et al., 1992; Eckersall et al., 1996). A previous study comparing disease resistance between pure breeds showed a lower resistance in Hampshire breeds (Henryon et al., 2001). However, the higher levels of acute phase proteins showed in HAM pigs may suggest their greater ability to maintain an adequate growth even under heat stress conditions, because they might already have a pre-mounted defense for inflammatory response. Lower haptoglobin levels were also evidenced in a study of Campos et al. (2014), in this case, acclimated pigs challenged with LPS under heat stress had lower haptoglobin levels than challenged pigs under thermoneutral conditions. Similar reductions of haptoglobin with heat-stressed calves was also evidenced by Kim et al. (2018), however, these authors suggested that environmental stressful situations do not always elevate signs of acute stress indicators. Despite acute phase proteins have been an important field to explain the challenges imposed to heat-stressed pigs, these findings should be interpreted with caution. Heegaard et al. (2013) highlighted that different breeds of the same species might show different acute phase response patterns with specific acute phase proteins. Therefore, the absence of some acute phase responses might not always mean that animals were not in an inflammatory challenge.

CONCLUSION

In this present paper, we have described the impact of constant heat stress in pigs selected for characteristics for robustness compared to their responses under thermoneutral conditions. Despite both genetics being affected by the high temperature, HAM sired pigs were more robust to heat stress conditions when compared to SYN sired pigs. Altogether, these data suggest that heat stress may present direct and indirect effects on carcass characteristics, and information on genetic lines during chronic heat stress such as evidenced in tropical climates is fundamental for pig producers do not have surprises on the final product. Finally, these findings suggest that individual farm conditions are one of the first steps to be considered before implementing a genetic line, once that the more adequate genetic for HT conditions are not always the best performing genetic under thermoneutral conditions.

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Table 1. Ingredient and nutritional composition of the experimental diets.

Item	Phase 1	Phase 2
Ingredients, %		
Corn	74.15	76.62
Soybean meal	20.46	18.37
Soybean oil	1.62	1.52
Dicalcium phosphate	1.35	1.25
Limestone	0.71	0.68
Dextrin	0.5	0.5
Salt	0.17	0.17
L-Lys sulfate	0.41	0.35
DL- Met	0.13	0.11
L-Thr	0.14	0.12
L-Trp	0.04	0.03
L-Val	0.04	0.03
Choline (60%)	0.06	0.06
Vitamin and mineral premix [1]	0.2	0.2
Calculated nutritional composition [2], %		
Metabolizable energy, MJ/kg	13.84	13.85
Net energy, MJ/kg	10.9	10.95
Crude protein	15.6	14.9
STTD phosphorus	0.34	0.32
Calcium	0.68	0.63
Sodium	0.09	0.09
SID Lys	0.95	0.86
SID Met	0.4	0.37
SID Met+Cys	0.48	0.45
SID Thr	0.63	0.58
SID Trp	0.19	0.18
SID Val	0.72	0.68
SID Ile	0.65	0.62
SID Leu	1.32	1.27

[1]Supplied per kilogram of diet (as fed-basis): vitamin A, 8750 IU; vitamin D, 1250 IU; vitamin E, 12.5 mg; vitamin K3, 2.5 mg; vitamin B12, 27.5 µg; niacin, 35 mg; calcium pantothenate, 15 mg; pyridoxine (B6), 1.25 mg; thiamine (B1), 1 mg; cooper, 22.5 mg; iodine, 0.31 mg; iron, 120 mg; manganese, 62.5 mg; selenium, 0.19 mg; and zinc, 120 mg.
[2]Values for growing pigs estimated from gross composition of the ingredients according to NRC (2012).
STTD= standardized total tract digestible
SID = standardized ileal digestible

Table 2. Performance and net energy intake of progenies from Hampshire purebred line (HAM) and Synthetic line (SYN) under thermoneutrality (22 ºC) and heat stress conditions (33ºC)[1].

	22 ºC		33 ºC			*P*-value		
Variable	HAM	SYN	HAM	SYN	SEM	G	AT	G*AT
Phase 1 (0 to 27 d)								
ADFI, kg/d	2.01	1.92	1.48	1.31	0.117	0.23	<0.01	0.70
ADG, kg/d	0.83	0.91	0.61	0.61	0.586	0.31	<0.01	0.43
G:F, kg/kg	0.43	0.47	0.45	0.47	0.021	0.13	0.67	0.69
Phase 2 (28 to 55 d)								
ADFI, kg/d	2.49	2.55	1.56	1.39	0.114	0.58	<0.01	0.29
ADG, kg/d	0.92	1.00	0.70	0.50	0.059	0.29	<0.01	0.02
G:F kg/kg	0.39	0.39	0.42	0.35	0.049	0.32	0.84	0.34
Overall performance (0 to 55 d)								
ADFI, kg/d	2.25	2.23	1.52	1.35	0.106	0.34	<0.01	0.43
ADG, kg/d	0.85	0.94	0.64	0.58	0.033	0.56	<0.01	0.01
G:F, kg/kg	0.40	0.42	0.45	0.43	0.036	0.89	0.23	0.53

G = Genetic; AT = Ambient temperature.

[1]Least square means of 6 pigs per treatment.

Table 3. Body composition of progenies from Hampshire purebred line (HAM) and Synthetic line (SYN) under thermoneutrality (22 ºC) and heat stress conditions (33 ºC)[1].

	22 ºC		33 ºC			*P*-value		
Variable	HAM	SYN	HAM	SYN	SEM	G	AT	G*AT
Day 0								
BW, kg	33.5	33.3	28.9	31.8	2.33	0.54	0.18	0.48
Backfat thickness, cm	1.07	1.01	1.21	1.07	0.050	0.05	0.05	0.35
Loin Depth, cm	2.90	2.95	2.87	3.01	0.142	0.44	0.91	0.74
Day 27								
BW, kg	55.7	56.4	48.7	48.5	2.19	0.91	<0.01	0.82
Backfat thickness, cm	1.31	1.30	1.37	1.09	0.088	0.05	0.29	0.05
Loin Depth, cm	4.23	4.24	4.18	3.74	0.211	0.23	0.15	0.22
Body lipid content, kg[2]	12.69	12.29	11.29	10.60	0.601	0.26	<0.01	0.76
Body protein content, kg[2]	8.57	8.88	6.51	7.24	0.693	0.38	<0.01	0.72
Phosphorus content, kg[3]	0.169	0.167	0.151	0.138	0.0136	0.45	0.04	0.60
Bone mineral content, kg	0.692	0.667	0.595	0.507	0.0662	0.29	0.02	0.54
Day 55								
BW, kg	81.9	83.2	68.0	63.7	3.24	0.62	<0.01	0.37
Backfat thickness, cm	1.68	1.81	1.62	1.27	0.159	0.37	0.03	0.07
Loin depth, cm	5.18	5.36	4.56	4.63	0.192	0.48	<0.01	0.77
Body lipid content, kg[2]	15.59	16.94	14.12	11.88	0.890	0.48	<0.01	0.01
Body protein content, kg[2]	11.86	13.23	10.73	10.30	0.466	0.24	<0.01	0.04
Phosphorus content, kg[3]	0.293	0.284	0.229	0.188	0.0225	0.18	<0.01	0.40
Bone mineral content, kg	1.153	1.086	0.880	0.672	0.1067	0.12	<0.01	0.42

G = Genetic; AT = Ambient temperature.

[1]Least square means of 6 pigs per treatment.

[2]Estimated according to Pomar and Rivest (1996) from dual-energy X-ray absorptiometry measurements.

[3]Estimated according to Létouneau-Montminy et al. (2015).

Table 4. Blood urea, total protein and acute phase protein of progenies from Hampshire purebred line (HAM) and Synthetic line (SYN) under thermoneutrality (22ºC) and heat stress conditions (33ºC)[1].

	22 ºC		33 ºC			*P*-value		
	HAM	SYN	HAM	SYN	SEM	G	AT	G*AT
Day 0								
Urea, mg/dl	16.67	14.5	18.8	13.8	1.79	0.05	0.68	0.42
Total Protein, g/dl	5.68	5.57	5.57	5.45	0.285	0.68	0.68	0.97
Acid Glycoprotein, mg/ml	0.0722	0.0703	0.0822	0.0633	0.00926	0.29	0.88	0.38
Albumin, mg/ml	37.37	35.67	33.43	35.47	2.058	0.94	0.34	0.39
Ceruloplasmin, mg/ml	0.49	0.503	0.652	0.611	0.0661	0.81	0.03	0.64
Haptoglobin, mg/ml	0.573	0.461	0.436	0.351	0.0663	0.10	0.04	0.81
IgG, mg/ml	9.84	9.65	10.00	8.26	0.935	0.28	0.49	0.39
PM23000, mg/ml	1.28	1.09	1.46	1.02	0.158	0.02	0.66	0.34
Transferrin, mg/ml	5.39	5.34	5.64	5.09	0.305	0.33	0.98	0.41
Day 27								
Urea, mg/dl	23.4	19.8	11.67	13.2	1.921	0.59	<0.01	0.18
Total Protein, g/dl	5.43	4.68	4.94	4.61	0.234	0.02	0.22	0.35
Acid Glycoprotein, mg/ml	0.0614	0.0600	0.0527	0.0493	0.00598	0.684	0.11	0.87
Albumin, mg/ml	33.49	30.15	27.64	27.32	1.695	0.26	0.01	0.04
Ceruloplasmin, mg/ml	0.533	0.371	0.474	0.418	0.053	0.04	0.90	0.29
Haptoglobin, mg/ml	0.467	0.452	0.339	0.307	0.0696	0.69	0.03	0.89
IgG, mg/ml	9.17	7.09	9.05	9.57	0.784	0.35	0.16	0.12
PM23000, mg/ml	1.34	1.03	1.18	1.20	0.146	0.17	0.99	0.16
Transferrin, mg/ml	5.01	3.98	4.15	3.56	0.229	<0.01	<0.01	0.33
Day 55								
Urea, mg/dl	26.17	20.80	19.17	13.50	2.249	0.01	<0.01	0.94
Total Protein, g/dl	5.79	5.76	5.21	4.81	0.304	0.46	0.01	0.52
Acid Glycoprotein, mg/ml	0.068	0.082	0.068	0.0314	0.01116	0.31	0.03	0.03
Albumin, mg/ml	34.53	36.79	28.98	27.95	2.586	0.81	0.01	0.53
Ceruloplasmin, mg/ml	0.553	0.488	0.666	0.508	0.0743	0.06	0.24	0.40
Haptoglobin, mg/ml	0.253	0.313	0.420	0.326	0.0772	0.76	0.12	0.17
IgG, mg/ml	8.56	8.53	10.70	9.99	0.843	0.52	0.05	0.81
PM23000, mg/ml	1.42	1.36	1.29	1.00	0.106	0.14	0.04	0.30
Transferrin, mg/ml	5.59	5.66	4.72	4.13	0.336	0.38	<0.01	0.26

G = Genetic; AT = Ambient temperature.

[1]Least square means of 6 pigs per treatment.

Table 5. Corporal and rectal temperatures, and breath rate of progenies from Hampshire purebred line (HAM) and Synthetic line (SYN) under thermoneutrality (22ºC) and heat stress conditions (33ºC)[1].

	Period[2]					G			AT[3]		
	1	2	3	4	Contrast	HAM	SYN	P-value	22º	33º	SEM[4]
Temperature, ºC											
Rectal	40.0	39.6	39.7	39.3	L**	39.7	39.5	<0.01	38.8	40.3	0.14
Dorsal	38.0	37.7	38.5	38.0	L*	38.1	38.1	0.93	36.4	39.8	0.27
Flank	38.2	37.8	38.6	37.9	NS	38.2	38.1	0.36	36.5	39.8	0.28
Nape	38.6	38.0	38.8	38.4	NS	38.5	38.5	0.74	37.2	39.8	0.33
Whole body	38.3	37.8	38.6	38.1	NS	38.3	38.2	0.52	36.7	39.8	0.25
Breath Rate, bpm	54.7	57.2	56.2	41.8	L**	51.0	51.3	0.82	33.4	69.0	3.51

G = Genetic; AT = Ambient temperature; L = Linear contrasts between periods; NS = Non-significant.

[1]Least square means of 6 pigs per treatment.

[2]Periods correspond from pooled means of each animal from the morning and the afternoon at day 0 (period 1); days 7, 14 and 21 (period 2); days 28, 35 and 42 (period 3); days 48 and 54 (period 4).

[3]Ambient temperature significant for all variables ($P < 0.01$).

[4]Pooled standard error of the mean.

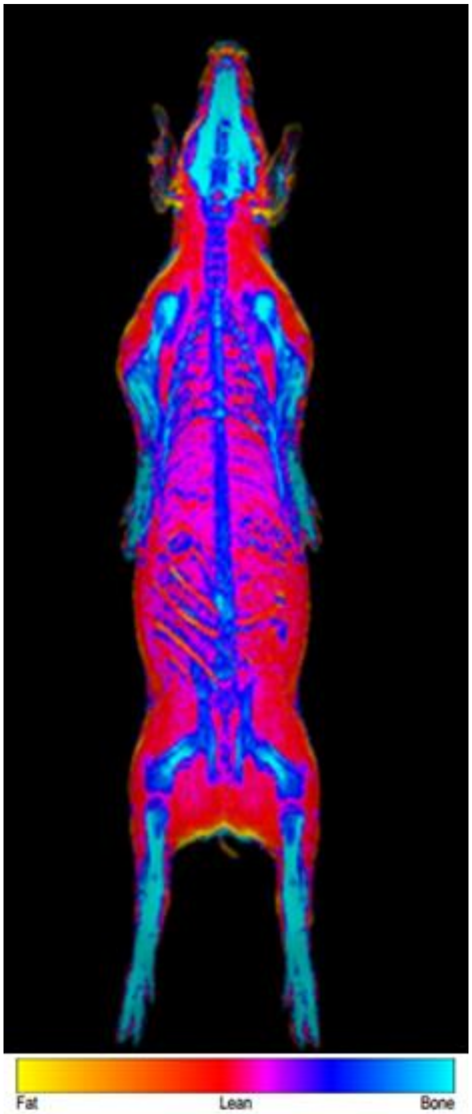

Figure 2.1. Dual X-ray image illustrating the pigs' body composition.

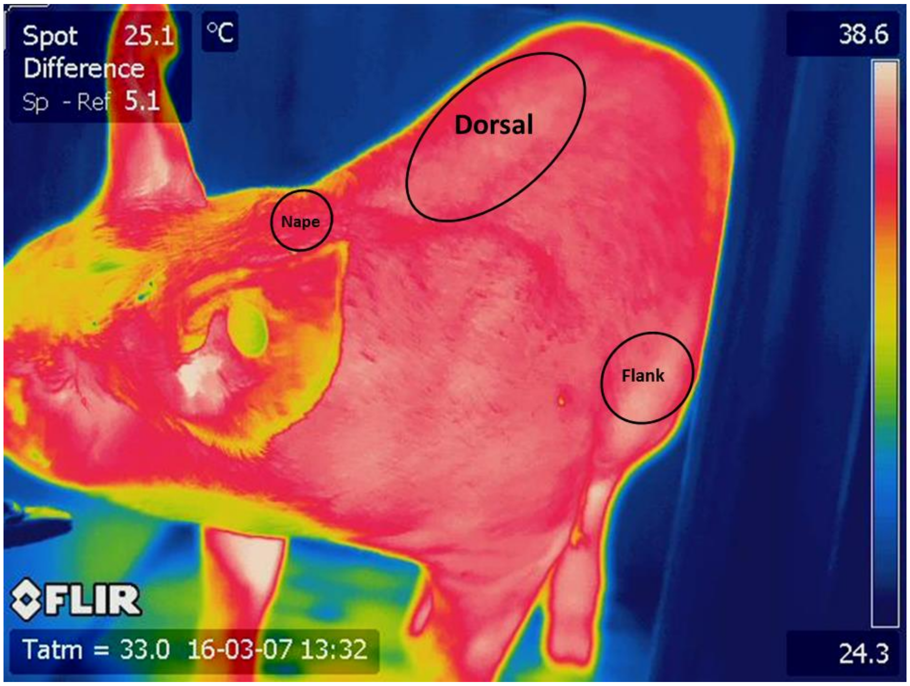

Figure 2.2. Example of thermografic image and regions measured.

CAPÍTULO 3 - Precision feeding strategy for growing pigs under heat stress conditions[1].

[1] Esse capítulo corresponde ao artigo científico publicado na revista Journal of Animal Science 11:4789-4801, 2018.

Running head: Precision feeding for heat-stressed pigs

Precision feeding strategy for growing pigs under heat stress conditions[1]

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ABSTRACT: This study evaluated the responses of individual daily precision (IPF) and conventional two-phase (CON) feeding systems in terms of pig growth performance, nutrient balance, serum parameters, and meal patterns of growing pigs reared under thermoneutral (TN: 23 °C) and heat stress (HT: 30 °C) conditions. The animals in each treatment were assigned on the basis of equal BW to the experimental treatments (12 animals per treatment at 41.0±4.87 kg of BW). The experiment lasted 55 days (phase one from d 0 to 27 and phase two from d 28 to 55). Pigs fed CON received within each phase a constant blend of diets with high and low nutrient density supplying the estimated nutrient requirements of the group, while the IPF pigs received daily a personalized blend providing the estimated amount of nutrients according to individual feed intake and body weight information. Body mineral content, lean and fat masses were assessed through dual-energy X-ray absorptiometry at the beginning and end of each phase. Data were analyzed using a linear mixed effect model, with fixed effects of the feeding system (FS), temperature (AT), and the two-way interaction between FS and AT and random effects of blocks. In relation to CON pigs, IPF pigs reduced ($P < 0.05$) Lys (19%), protein (16%) and P (14%) intake without impairing ($P > 0.05$) body composition. Nitrogen excretion was 24% lower ($P < 0.05$) in IPF pigs, than in CON pigs; however, both groups had similar N retention efficiency thoroughly the trial. Amount of time feeding, feed intake rate, and feed intake per meal was 15% lower ($P < 0.05$) in pigs raised under HT than under TN conditions. During the phase two, only amount of time feeding, feed intake rate, and feed intake per meal were decreased ($P < 0.05$) in pigs under HT conditions during nocturnal (2000 to 0500 h) and diurnal (0501 to 1959 h) periods. Haptoglobin levels were affected by the AT, showing an increase of 70% and 43% in HT at 28d and 55d of the experiment, respectively. Pigs raised under HT conditions had 10% lower ($P < 0.05$) serum albumin concentration at d 55 than those under TN conditions. For serum urea concentrations, IPF pigs had 28% lower ($P < 0.01$) levels than CON pigs. Even though HT conditions considerably reduced growth performance and activated inflammatory responses in growing pigs, IPF was not able to rescue performance during HT, however, it was equally effective at improving nutrient utilization and maintaining body composition in HT and TN conditions.

Keywords: heat stress, nutrition, nutrient utilization, precision feeding, reduced protein, tropical conditions.

INTRODUCTION

Heat-stressed pigs reduce voluntary feed intake, body weight gain (Quiniou et al., 2000; Huynh et al., 2005), and nutrient use efficiency (Pearce et al., 2013). Many studies have been performed to understand the metabolism and identify the ideal environment and management practices (feeding and nutrition, housing, etc.) that will optimize the production of pigs in hot environments. Reducing ambient temperature is expensive and sometimes unprofitable in tropical areas. Nutritional studies have suggested changes to the conventional group phase-feeding program (CON), in which pigs' diets are formulated with low protein levels to reduce the heat increment, and increase and improve nutrient intake with adequate concentrations in terms of AA (Le Bellego et al., 2002a; Kerr et al., 2003). However, CON does not account for variation between individuals, and diets are usually formulated to optimize population performance, with most of the pigs receiving more nutrients than they actually need (Hauschild et al., 2010). Taking into consideration voluntary feed intake and growth, precision feeding has been proposed as an alternative, because it would enable managers to provide individual animals with diets that meet but do not exceed their requirements (Pomar et al., 2014). This approach has shown a reduced crude protein and P provision, resulting in a lower excretion of the aforementioned components in the environment (Pomar et al., 2014; Andretta et al., 2014 and 2016a). Although this strategy seems to be a feasible way to cope with the consequences of heat stress in pigs, there are no studies on the subject in the current literature. This study was therefore conducted to evaluate the responses of IPF and CON feeding systems in terms of pig growth performance, nutrient balance, serum parameters, and meal patterns of growing pigs reared under thermoneutral and heat stress conditions.

MATERIALS AND METHODS

The protocol for this experiment was approved by the Institutional Animal Care and Use Committee at São Paulo State University, SP, Brazil (No. 16744/15).

Animals, Housing, and Experimental Design

This experiment was conducted at the Swine Research Facility of São Paulo State University, Brazil. Forty-eight barrows (Agroceres PIC, Rio Claro, Brazil) with an average initial BW of 34.0±4.41 kg were assigned on the basis of equal BW to two experimental rooms (TN: thermoneutral, 23 °C constant; and HT: high temperature, 30 °C constant) in a single 24 m^2 pen with a fully slatted plastic floor. Thermostat-controlled heaters were used to raise the ambient temperature to 30 °C in the HT room. In the TN ambient assigned room, temperature was controlled through air conditioning. Both rooms used an exhaust fan with air movement capacity of 115 m^3/min to perform air renewal. Pigs were acclimated to room temperature for nine days prior to the experimental period and received a highly concentrated commercial diet. This strategy was employed in order to reduce the variation caused by the physiological adaptations during the first week of exposure to high temperatures as demonstrated by Campos et al. (2014). Approximately 12 hours of natural lighting were provided by glass windows. The animals in each treatment were assigned on the basis of similar BW to the experimental treatments (12 animals per treatment at 41.0 ± 4.87 kg of BW) in two complete blocks. Each block included six pigs per treatment also considering animals with similar BW, and blocks started 1 day apart. The experiment lasted 55 days (phase one from d 0 to 27 and phase two from d 28 to 55). In each room, water and pelleted feed were provided *ad libitum* by four nipple drinkers and two automatic feeders (Automatic and Intelligent Precision Feeder [AIPFs]; University of Lleida, Spain, Pomar et al., 2011). All animals were equipped with an exclusive transponder (plastic button tag containing passive transponders of radio frequency identification; Allflex, Joinville, SC, Brazil) that was inserted in the right ear of each pig using the specific tagger pliers, and pigs were adapted to the automated feeders before the trial. Each AIPF consisted of a single-space feeder in which precision Archimedes screw conveyors delivered and simultaneously blended volumetric amounts of up to four feeds stored in independent containers located in the upper part of the AIPF (Pomar et al., 2011). The AIPF identifies each pig when its head is introduced into the feeder and then delivers feeds in response to each animal request according to the assigned experimental feeds (see Dietary Treatments section). In this way, any pig in the pen could access any of the feeders and receive the feed prescribed for that animal. The pigs were weighed weekly and feed and water were provided ad libitum throughout the experiment.

Dietary Treatments

Two experimental diets were formulated on the basis of standard recommendations for NE, standardized ileal digestible (SID) AA, standard total tract digestible (STTD) of P, and total Ca (NRC, 2012; Table 1). Diet A (high nutrient density) was formulated to satisfy the requirements of one of the most demanding pigs (1.20% of SID Lys) at the beginning of the growing trial and diet B (low nutrient density) to satisfy the requirements of one of the least demanding pigs (0.40% of SID Lys) at the end of the growth trial. Through the use of the AIPF, pigs in the precision feeding (IPF) group received a personalized blend of feeds A and B on a daily basis to target sufficient SID Lys to meet their Lys requirement as estimated by the model proposed by Hauschild et al. (2012). This model has one main empirical and one main mechanistic model component. The empirical model component estimates the expected feed intake (FI), BW, and daily gain of the starting day based on historical individual FI and BW pig information collected before and during the trial. The estimates of FI, BW, and gain are used as inputs to the mechanistic model which uses factorial equations to estimate optimal Lys concentrations required to meet the pigs requirements for maintenance and growth. The details of this model and its application have been previously described (Hauschild et al., 2012; Pomar et al., 2015). Also through the use of the AIPFs, pigs fed in the conventional (CON) group received a constant blend of diets A and B in each phase to meet the SID Lys requirements of the 80th-percentile pig in the group (Hauschild et al., 2010) determined during the first three days of the phase.

Performance and Body Composition

On the first day of the adaptation period and at the end of each feeding phase (d -9, 27, and 55), total body lean, body fat, bone mineral content, and bone mineral density were measured by dual-energy X-ray absorptiometry (DXA) (Hologic Discovery, Hologic, Inc., Bedford, MA, USA). Animals were fasted for eight hours before anesthetized by intramuscular injection of xylasine (1.5 mg/kg) and ketamine (15 mg/kg). Anesthetized pigs were scanned in prone position (from head to tail) and the experimental blocks were scanned one day apart. After each scan, backfat thickness and muscle depth were measured on the DXA scan table in the anesthetized animals in prone position using ALOKA® equipment (500v series with a linear probe of 3.5 MHZ, 13.5 cm) between the third and fourth last ribs at 4–5 cm from the midline. The scan on the first day of the adaptation period was also used as a test scan to determine problems with the procedure, to ensure adequate recovery of the animals and to avoid problems with the forecast of feed intake.

Meal Pattern

For the assessment of meal patterns, the information of each feeder visit (initial, final time, and feed intake) were continuously registered. Visits of the same pig at intervals lower than 1 min were considered a single meal. The AIPF configuration allotted 15 g of feed per feed request throughout the trial. A 40-second latency time decreasing progressively up to 20-second between solicitations were used from the beginning to the end of the experiment to avoid feed waste and ensure sufficient ingestion time. Feeding behavior data on days when the pigs were manipulated (i.e. submitted to scan and sample collections) were removed from the dataset. The diurnal (from 0501 h to 1959 h) and nocturnal (2000 h to 0500 h) meal pattern data obtained for each animal were summarized as: amount of time feeding (min), number of meals, feed intake rate (g/min), feed intake per meal (g), and feeding time per meal (min).

Serum Sampling, Chemical Analysis, and Calculations

On the morning of the last day of the phase (d 27 and d 55), blood samples were collected (5 ml) via the jugular vein of all the pigs and the serum was separated from the whole blood by centrifugation at 1500xg for 10 min. The identified samples were stored at -20 °C until analysis.

Thermographic images from the superior left side of each pig were taken at days 14, 18, 41 and 45 of experiment at 0800 and 1500h using an infrared camera (Flir SC660, Portland, OR, USA) and the whole body temperature values were assessed using an adequate software (Flir Tools 5.12 software).

Prior to formulating the diets, samples of ground soybean meal and corn were analyzed by Near Infrared Reflectance Spectroscopy for composition of crude protein, ether extract, starch, crude fiber, and total AA and P. To assess the total AA of diets A and B, high-performance liquid chromatography was used (White et al., 1986). The feeds were assayed for dry matter (Method 930.15; AOAC, 2007), ether extract (Method 920.39, AOAC, 2007), ash (Method 942.05, AOAC, 2007), acid and neutral detergent fibers (Van Soest and Robertson, 1979), and total protein as N x 6.25 (Method 990.03, AOAC, 2007) at the Animal Nutrition Laboratory (“LANA” São Paulo State University, Department of Animal Science, Brazil).

Total nutrient intake was obtained considering the daily feed concentration provided and the daily feed intake for each pig. Individual body protein, lipid, and P for each period were obtained by calculating the difference between the beginning and end of each phase. The DXA body lean and fat masses were converted to total body protein and lipid mass (kg) according to Pomar and Rivest (1996). Total body P value was estimated assuming 18%

of P in DXA bone mineral content, 1.04% in lean tissue and 0.05% in the fat content (Létourneau-Montminy et al., 2015). The initial values for all DXA measurements were adjusted for day 0 of the experiment instead of -9 days. This adjustment consisted of the proportional percentage of BW for each DXA variable on the day of the scan and the BW from the first day of the experiment. Phosphorus efficiency was calculated by dividing P deposition by P intake, while N efficiency was calculated by dividing protein deposition by intake.

Total levels of ceruloplasmin, transferrin, albumin, and haptoglobin were accessed in sodium dodecyl sulfate-polyacrylamide gel electrophoresis (Weber and Osborn, 1969). The values of acute-phase proteins after electrophoresis were corrected by serum total protein analysis determined using the biuret method with a commercial reagent Labtest® and performed by semi-automatic spectrophotometry (Labmax Plenno, Lagoa Santa, Brazil).

Statistical Analysis

Data were analyzed by experimental phase as a mixed model with the fixed effects of feeding systems (FS), ambient temperature (AT) and their interactions using the SAS MIXED procedure (version 9.3; SAS inst. Inc., Cary, NC). Differences among fixed effects were considered statistically significant with $P < 0.05$. The individual pig was considered the experimental unit in all instances and the initial BW was used as a covariate between AT when significant in the model. The model was: $Yijk = \mu + \alpha i + \beta j + (\alpha\beta)ij + eijk$, where Yijk is the observed variable (observation for the k^{th} animal from the $(i,j)^{th}$ cell), μ is the overall mean, αi is the effect of the i^{th} level of the FS factor, βj is the effect of the j^{th} level of the AT factor, (αβ)ij is the interaction of the i^{th} level of FS with the j^{th} level of AT, and eijk is the random error of k^{th} observation from $(i,j)^{th}$ including the blocks as random effect. The GROUP statement was used to equalize the variance between means when convenient, based on the smaller akaike information criterion.

RESULTS AND DISCUSSION

The temperature in the TN and HT rooms was 23 ± 1.4 °C and 30 ± 2.2 °C, respectively. Relative humidity was 75 ± 5.4% and 62 ± 6.3%, respectively. Pigs under TN conditions consumed feed and gained weight as expected. However, under HT conditions, five pigs had health disorders (two foot infections, one sudden death, and two animals with weakness and anorexia, totaling two in the CON and three in the IPF treatments). These pigs were removed from the trial.

After the adaptation period, next day SID Lys requirements were estimated daily for each pig following the requirement for the pig that represented the 80th percentile of the population in each room (Fig. 1). This concept of feeding pig populations according to the requirements of the 80th percentile pig of the population was suggested by Hauschild et al. (2010) to maximize the population response in terms of ADG. These authors also reported that because CON feeding does not take into account individual pig variations, many pigs receive more nutrients than they require. In our study, the 80th percentile strategy was applied in each room, because of the reduction in ADFI and ADG for pigs reared under HT conditions. The diet concentrations for the CON treatment showed values of TN 0.95% and HT 1.10% of SID Lys during the first phase, and TN 0.81% and HT 0.86% of SID Lys during the second phase (Fig. 1).

Performance, Body Composition, and Nutrient Balance

The effect of temperature. No interaction between feeding systems and temperature was observed for performance, body composition, or nutrient balance. However, pigs under HT conditions increased (P < 0.01) their superficial body temperature compared to TN pigs (Fig. 2). During the first feeding phase, pigs raised under HT conditions decreased (P < 0.01) ADFI and ADG by -31% (Table 2). During the second phase, however, the impact of HT on ADFI and ADG was lower than during the previous phase with reductions (P < 0.01) of -26% and -18%, respectively. The reduction in ADFI during the second feeding phase was around 100 g/°C, with a 7 °C difference between the HT and TN rooms. Consistent with our results, the ADFI reported by previous studies showed a decrease of 99 g/°C when temperatures rose above 25.5 °C (Huynh et al., 2005), but decreases can vary depending on the breed, BW (Renaudeau et al., 2011), housing (Hyun and Ellis, 2001), and other factors. The lack of functional sweat glands forces pigs to increase their respiratory rate to increase heat loss during hot temperatures (Curtis, 1983). The upper critical temperature can be defined as the temperature at which pig heat production is equal to the maximum capacity of the pigs to lose heat (Holmes and Close, 1985). These authors also reported that one of the first strategies of heat-stressed pigs is to reduce physical activity and feed intake. These strategies are employed by pigs to balance heat production and dissipation in order to avoid body temperature increases.

The ADG of HT animals was 310 g/d lower than TN animals during the first phase and 175 g/d lower during the second phase. However, during previous studies done by Campos et al. (2014), 60 kg pigs were maintained for 14 days at 30 °C, and they reduced ADG by 316 g/day, in comparison with pigs raised at thermoneutrality. It is expected that pigs with a higher BW would be more affected by HT. However, the ADG during the second phase was less affected, which may be due to the fact that the animals adapted after being exposed to high temperatures during the adaptation (7 days) and first experimental phase (27 days). These results offer compelling evidence of a biphasic profile of physiological responses (i.e., respiratory rate, skin temperature, and rectal temperature), previously characterized by Renaudeau et al. (2010), where the physiological responses increase faster in the primary phase (short-term heat acclimation) than in the subsequent phase (long-term acclimation). This subsequent phase of acclimation is characterized by these same authors as a gradual decrease in physiological responses.

In terms of body composition, the pigs reared under HT conditions had reduced ($P < 0.05$) lipid deposition (-40%) compared with the pigs reared under TN conditions during the overall growth period. The reduction in lipid deposition, and protein to a lesser degree, has been observed in pigs raised at high temperatures (Christon, 1988; Rinaldo and Le Dividich 1991; Le Bellego et al., 2002b). That reduction in lipids and protein deposition is associated with the poor performance of the pigs reared under HT conditions, which had a lower BW than those reared under TN conditions at the end of the experiment. When lipid deposition is reported per unit of ADG, the pigs reared under HT conditions showed, in relation to those reared under TN conditions, a reduction of 13%

and 27% during the first and second experimental phases, respectively. Le Bellego et al. (2002b) indicated that feeding pigs at high temperatures with diets formulated for pigs raised under thermoneutral conditions can result in an inadequate provision of nutrients as a result of the lower feed intake, which further contributes to the reduction of protein and lipid deposition. Kellner et al. (2016) demonstrated that the lower energy intake of heat-stressed pigs resulted in a higher lipid catabolism than in underfed pigs reared under HT conditions. Normally, the reduction of fatty acids in the tissue is dependent on albumin (Vernon and Clegg, 1985), which is an acute-phase protein that decreased in the pigs reared under HT conditions during the second phase (see Table 5).

In our experiment, the pigs reared under HT conditions reduced ($P < 0.05$) P retention during all feeding phases; however, P retention efficiency was not affected at any time during the experimental period. It has been previously observed that high water consumption and evaporation for cooling under HT conditions increase P losses and therefore, mineral retention (Holmes and Grace, 1975; Christon, 1988). Moreover, increased water consumption is necessary to enhance the pigs' ability to dissipate excess body heat (Patience et al., 2005). The observed reduction in P retention under HT in our study may be also related to the lower P intake in addition to the physiological adaptations to thermal environment. This is supported by the fact that P retention efficiency was similar in pigs reared under HT and TN conditions.

The effect of feeding technique. When compared with CON pigs, IPF pigs had a similar ADFI but reduced ($P < 0.05$) nutrient intake in both feeding phases (i.e., 19% for Lys, 16% for CP, and 14% for P) (Table 3). This reduction in nutrient intake did not impair lipid and protein deposition and thus, the pigs' final body composition. Feed intake is expected to be reduced in heat-stressed pigs because digestion and nutrient metabolic utilization generate heat, this heat being defined as the thermic effect of feed (West, 2003). The impact of feed composition on heat production was highlighted by Noblet et al. (1999), who estimated that in growing pigs, each gram of dietary protein contributes to 1.7 kcal of heat production. Furthermore, excess and imbalanced protein needs to be deaminated and excreted, generating 1171 kcal/kg in heat loss (Whittemore, 1983). As expected, the IPF pigs reduced protein intake by 49 g/d and 35 g/d, during the first and second experimental phases, respectively. Feeding pigs without excess nutrients, especially protein, is therefore recommended for pigs reared under HT conditions to reduce heat production. In this study, it was expected that the reduced nutrient provision to the IPF pigs would allow ADFI to be maintained under HT. Indeed, previous studies have shown decreased heat production in pigs reared under HT conditions receiving reduced CP diets (Kerr et al., 2003). However, despite the decreased heat production, reduced CP diets did not impact ADFI or ADG (Le Bellego et al., 2002a; Kerr et al., 2003; Morales et al., 2018), which is consistent with our results.

An optimal nutrient allowance in heat-stressed animals is a challenge because pigs reduce feed intake and, consequently, ADG. To maintain an adequate supply of nutrients in the pigs reared under HT conditions, it is necessary to reduce nutrient excesses and adapt the nutrient concentration of the feeds to the reduced feed intake. Adapting the feed to the HT reduced feed intake is difficult. White et al. (2015) found an overpredicted FI for the pigs reared under HT conditions, which led to an underestimation of nutritional requirements when the NRC (2012) model was used. An overpredicted estimation of FI may result in inadequate diets, which may compromise the pigs' growth even further. In our study, most of the pigs received the amount of nutrients required for maintenance and growth given that these pigs' nutrient requirements were estimated using the actual ADFI and ADG, using the 80th percentile in the CON pigs, as suggested by Hauschild et al. (2010), or estimated in real time in the IPF pigs, as suggested by Hauschild et al. (2012). The adequate supply of nutrients can be confirmed by the fact that the pigs in both feeding systems had similar body composition. In a previous study (Kerr et al., 2003), the use of low-protein diets supplemented with industrial AA was not sufficient to improve the lean and fat deposition in growing pigs under HT. This confirms that many other strategies, such as reduced physical activity, thermal regulation, and other adaptations are used by pigs reared under HT conditions in an attempt to reduce heat production, minimize the feed intake reduction (NRC, 1981). However, under such HT conditions, feed intake was not improved in the IPF pigs. Because the CON pigs had a similar FI to that of the IPF pigs but they ate higher levels of protein, they received a higher dietary heat load than the IPF pigs. On the other hand, the feeding behavior alterations may presumably be the major strategy used for *ad libitum* pigs reared under HT conditions to avoid reductions in FI, which is discussed later in this paper.

Feeding pigs with daily tailored diets reduced ($P < 0.05$) N excretion by 24% and P excretion by 13%. Similar results for reduced excretion of nutrients in precision fed pigs were observed in pigs raised under thermoneutral conditions (Pomar et al., 2014; Andretta et al., 2014; Andretta et al., 2016a), which corroborates that, as observed under thermoneutral conditions, feeding pigs with daily tailored diets in hot environments can reduce lysine intake by 19% and nitrogen excretion by 26% without compromising pigs' performance.

Feeding Behavior

Two daily periods were used for the feeding behavior analysis based on natural daily light (Fig. 3 and 4). Natural light and dark periods (provided through the glass windows in each room) were the same in both experimental rooms and temperatures were kept constant during the day to allow proper feeding behavior comparisons between treatments. Diurnal activity was measured between 0501 and 1959 h and nocturnal activity between 2000 and 0500 h. The thresholds between diurnal and nocturnal periods were established considering that light appeared at sunrise and disappeared 1 hour after sunset (i.e., sunrise was around 0520 h and sunset around 1858 h during the trial). It was also assumed that pigs needed 1h per day to eat their feed and considering that two feeders were available in each room (12 pigs/feeder), the 15h of diurnal activity time was sufficient to allow pigs to eat during daylight hours.

During the first feeding phase, nocturnal amount of time feeding (min) for the IPF pigs was 40% lower under TN than HT conditions, while this reduction was 8% in the CON pigs ($P < 0.10$ for the interaction between temperature and feeding system). During the second feeding phase, in the IPF pigs, the diurnal and nocturnal feed intake rate (g/min) was 9% lower under HT than TN conditions, while this reduction was 20% and 17% in the CON pigs for diurnal and nocturnal periods, respectively ($P < 0.05$ for the interaction between temperature and feeding system). These interactions suggest that the IPF pigs raised under HT conditions eat less at night than the CON pigs. Andretta et al. (2016b) did not find any differences in the feeding behavior between the IPF and CON pigs raised under TN conditions. It is plausible and consistent with our findings that the feeding behavior of pigs reared under thermoneutral conditions and receiving adequate diets is not affected by feeding systems. However, apart from the physiological adaptations to high temperatures, pigs also modify their feeding behavior in order to attenuate the thermic effect of feeding over the day. Reducing the size of meals (Quiniou et al. 2000) and nocturnal eating can help pigs to maintain homeothermy at high ambient temperatures.

High temperatures reduced ($P < 0.05$) diurnal amount of time feeding, diurnal feed intake, diurnal and nocturnal feed intake rates, and feed intake per meal during the first growing phase. The diurnal period was also preferred for pig feeding activities in previous studies (Andretta et al., 2016b; Quiniou et al., 2000). Despite the fact that heavier pigs have more difficulty dissipating heat than lighter ones, the number of nocturnal and diurnal meals and the diurnal amount of time feeding were not affected by ambient temperature during the second phase. It seems that the pigs reared under HT may have adapted to that condition during the second phase, and despite the pigs still being affected by the temperature, they returned to a normal number of meals, managing only their amount of time feeding and volume of feed ingested. Waltz et al. (2014) noted that pigs raised in high temperatures reduce their physical activity in order to avoid heat production even if this adaptation can have negative consequences on feeding activities.

Serum Urea, Protein, and Acute Phase Protein Responses

High temperatures reduced ($P < 0.05$) serum urea concentrations by 23% and increased total protein concentrations by 5%, while the IPF strategy reduced ($P < 0.01$) serum urea concentrations by 28%. These reductions in serum urea concentrations result from the reduction of protein intake at high temperatures or in IPF in relation to the control treatments given that urea is an end-product of AA catabolism (Whang et al., 2000; Eggum, 1970). Andretta et al. (2016a) also found that in relation to conventionally fed pigs, pigs fed a daily tailored diet reduced protein intake and, concomitantly, plasma urea concentration.

The inflammatory responses of pigs were studied because high ambient temperature may affect the immune function (Lacetera, 2012), and serum haptoglobin concentration was chosen as an indicator of the intensity of immune activation (Murata et al., 2004). Indeed, serum haptoglobin increased in the pigs reared under HT conditions ($P < 0.05$) at 28 d and 55 d of the experiment in relation to those reared under TN conditions by 70% and 43%, respectively (Table 5). These results confirm the activation of the immune system caused by the chronic exposure to HT. Besides these results, we expected that lowering protein deamination in the IPF pigs could contribute to reducing heat stress in HT, but no differences in haptoglobin concentrations were observed between feeding systems.

Serum albumin is a negative acute phase protein and its concentration in serum decreases in mammalian species under stress (Mackiewiczs, 1997). Moreover, heat-stressed animals show increased renal buffering capabilities via H+ excretion and urine acidification (Patience et al., 2005), while the blood flow is redistributed away from the gastrointestinal tract (Bell, 1993; Hall et al., 2001). Renal and gastrointestinal changes can result in decreased hepatic synthesis and compromise albumin synthesis (Kaneko, 1997). Serum albumin in the CON pigs was decreased ($P < 0.05$) by 10% under HT at day 55 of the experiment. With the decrease in serum albumin, their unused pool of amino acids may be directed to generate positive acute phase proteins and other important mediators of inflammation (Paltrinieri, 2008). These responses can support the fact that even after 55 d in high temperatures, pigs use different adaptive mechanisms to cope with the constant heat stress, which may explain why these pigs had higher levels of haptoglobin under these conditions compared with the pigs under TN conditions.

The results of this study indicate that pigs exposed to constant high temperatures reduce feed intake and growth performance and that these responses are similar in conventional and precision feeding systems. Feeding individual pigs with daily tailored diets, however, improves N and P efficiency and reduces their excretion without compromising the pigs' body composition. Nonetheless, the CON fed pigs reared under HT ate more feed at night than the IPF pigs, probably in an attempt to dissipate the extra heat resulting from the excess dietary protein. Precision feeding is an effective approach to reduce nutrient intake and excretion, but its effectiveness in mitigating the negative impact of high temperatures on feed intake and growth performance may appear when pigs are unable to dissipate the extra heat by modifying their feeding behavior.

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Table 1. Ingredient inclusion and nutritional values of the experimental diets

Item	A	B
Ingredient composition, as-fed basis, %		
Corn	64.91	92.59
Soybean meal	30.93	-
Dicalcium phosphate	1.35	0.39
Limestone	1.00	0.51
Dextrin	0.50	0.50
Vitamin premix.[1]	0.25	0.25
Salt	0.17	0.18
L-Lysine sulfate (54.6%)	0.58	0.44
DL- Methionine	0.15	-
L-Threonine	0.10	0.05
L-Tryptophan	-	0.03
Kaolin	-	5.00
Choline chloride (60%)	0.06	0.06
Chemical composition, %		
DM	90.30	89.90
ME[2], kcal/kg	3318	3195
NE[2], kcal/kg	2478	2557
Crude protein	19.24	7.11
Lys	1.34	0.47
Met	0.34	0.12
Thr	0.77	0.34
SID[2] Lys[3]	1.20	0.40
SID Met[3]	0.40	0.13
SID Met + Cys[3]	0.67	0.25
SID Thr[3]	0.71	0.24
STTD[4] phosphorus[3]	0.33	0.12
Calcium[2]	0.80	0.30

[1]Supplied per kilogram of diet (as-fed basis): vitamin A, 8750 IU; vitamin D, 1250 IU; vitamin E, 12.5 mg; vitamin K3, 2.5 mg; vitamin B12, 27.5 µg; niacin, 35 mg; calcium pantothenate, 15 mg; pyridoxine (B6), 1.25 mg; thiamine (B1), 1 mg; copper, 22.5 mg; iodine, 0.31 mg; iron, 120 mg; manganese, 62.5 mg; selenium, 0.19 mg; and zinc, 120 mg.

[2]SID = standardized ileal digestible.

[3]Values estimated from the ingredients gross composition according to NRC (2012).

[4]STTD = standardized total tract digestible.

Table 2. Performance and body composition of pigs fed according to individual daily precision (IPF) and conventional two-phase (CON) feeding systems under two thermal conditions (23 and 30 °C) [1]

	23 °C		30 °C			*P* - value		
Item	IPF	CON	IPF	CON	SEM	T	FS	T*FS
Initial conditions								
BW, kg	42.2	43.1	38.6	40.2	1.37	0.02	0.36	0.81
Backfat thickness, cm	1.0	1.0	0.9	0.9	0.04	0.02	0.54	0.61
Loin muscle depth, cm	3.3	3.4	3.0	3.3	0.20	0.31	0.36	0.74
Body lipid[2], kg	10.1	9.4	9.5	9.4	0.42	0.52	0.35	0.52
Body protein[2], kg	6.0	5.8	5.8	5.5	2.25	0.32	0.31	0.89
Body bone mineral[2], kg	5.7	5.6	5.2	5.6	1.95	0.22	0.38	0.29
Phase 1 (0 to 27 d) – Performance and final conditions								
ADFI, kg/d	2.09	2.05	1.45	1.41	0.07	<0.01	0.59	0.99
ADG, kg/d	0.98	1.00	0.69	0.67	0.04	<0.01	0.98	0.60
G:F, kg/kg	0.47	0.49	0.48	0.47	0.01	0.63	0.86	0.36
Protein gain, g/d	165	176	138	139	12.9	0.01	0.62	0.65
Lipid gain, g/d	266	271	182	141	19.0	<0.01	0.40	0.29
BW, kg	68.5	68.6	60.4	58.8	1.23	<0.01	0.56	0.52
Backfat thickness, cm	1.4	1.3	1.0	1.0	0.04	<0.01	0.20	0.48
Loin muscle depth, cm	5.4	5.5	5.0	5.1	0.12	<0.01	0.70	0.90
Body protein[2], kg	10.4	10.5	9.5	9.3	0.21	<0.01	0.98	0.60
Body lipid[2], kg	17.2	16.7	13.7	12.8	0.41	<0.01	0.12	0.68
Body bone mineral[2], kg	8.5	8.9	7.7	8.1	0.21	<0.01	0.07	0.90
Phase 2 (28 to 55 d) – Performance and final conditions								
ADFI, kg/d	2.74	2.65	1.96	2.03	0.07	<0.01	0.92	0.47
ADG, kg/d	0.94	0.96	0.75	0.80	0.04	<0.01	0.49	0.75
G:F, kg/kg	0.34	0.37	0.38	0.39	0.01	0.10	0.30	0.77
Protein gain, g/d	115	125	106	117	7.8	0.31	0.20	0.91
Lipid gain, g/d	346	311	198	192	20.4	<0.01	0.35	0.51
BW, kg	94.7	95.3	81.4	81.3	2.2	<0.01	0.93	0.87
Backfat thickness, cm	1.7	1.7	1.3	1.4	0.07	<0.01	0.83	0.38
Loin muscle depth, cm	6.0	6.4	6.0	6.1	0.17	0.43	0.24	0.52
Body protein[2], kg	13.6	14.0	12.4	12.6	0.35	<0.01	0.42	0.81
Body lipid[2], kg	26.9	25.4	19.2	18.2	0.62	<0.01	0.19	0.81
Body bone mineral[2], kg	11.5	12.5	10.3	10.7	0.22	<0.01	0.10	0.47
Overall Performance (0 to 55 d)								
ADFI, kg/d	2.42	2.35	1.71	1.72	0.07	<0.01	0.70	0.58
ADG, kg/d	0.96	0.98	0.72	0.74	0.03	<0.01	0.94	0.86
G:F, kg/kg	0.41	0.43	0.43	0.42	0.01	0.11	0.67	0.21
Protein gain, g/d	140	150	122	128	7.8	0.02	0.31	0.79
Lipid gain, g/d	305	288	184	163	17.7	<0.01	0.31	0.90

[1]T = temperature; FS = feeding system; T*FS = temperature vs feeding system interaction. Least square means of 12 pigs per treatment, except for IPF at 30 °C and CON at 30 °C for which the data are means of 9 and 10 pigs, respectively. [2]Body protein and lipid estimated according to Pomar and Rivest (1996) from dual-energy X-ray absorptiometry measurements (DXA). Body mineral content estimated by DXA.

Table 3. Net energy, protein and phosphorus intake and nitrogen and phosphorus balance and efficiency of pigs fed according to individual daily precision (IPF) or conventional two-phase (CON) feeding systems under two thermal conditions (23 and 30 °C) [1]

	23 °C		30 °C			*P* - value		
Item	IPF	CON	IPF	CON	SEM	T	FS	T*FS
Phase 1 (0 to 27 d)								
NE intake MJ/d	23.2	22.3	14.9	14.6	0.81	<0.01	0.46	0.73
SID[2] Lys intake, g/d	19.0	21.6	12.2	16.0	0.69	<0.01	<0.01	0.44
CP intake, g/d	303	334	194	243	11.9	<0.01	<0.01	0.48
N retention, g/d	26.4	28.2	22.1	22.2	1.80	0.01	0.62	0.64
N excretion, g/d	22.1	25.1	10.3	16.8	1.86	<0.01	0.02	0.39
P intake, g/d	9.7	10.5	6.2	7.6	0.37	<0.01	<0.01	0.50
P retention, g/d	2.4	2.8	1.8	2.1	0.21	<0.01	0.09	0.80
P excretion, g/d	7.3	7.7	4.4	5.5	0.32	<0.01	0.03	0.35
N retention efficiency, %	53.1	51.5	66.9	57.5	5.19	0.04	0.22	0.38
P retention efficiency, %	24.7	26.3	28.7	26.8	2.81	0.35	0.93	0.45
Phase 2 (28 to 55 d)								
NE intake MJ/d	29.1	28.0	20.8	21.5	0.79	<0.01	0.85	0.45
SID[2] Lys intake, g/d	16.7	20.1	13.5	16.1	0.47	<0.01	<0.01	0.61
CP intake, g/d	280	322	221	256	7.5	<0.01	<0.01	0.79
N retention, g/d	18.5	20.1	16.9	18.8	1.25	0.31	0.20	0.91
N excretion, g/d	26.3	31.5	18.4	22.2	0.81	<0.01	0.01	0.66
P intake, g/d	9.3	10.5	7.2	8.3	0.24	<0.01	0.02	0.89
P retention, g/d	2.4	2.9	2.1	2.1	0.12	0.02	0.38	0.33
P excretion, g/d	6.9	7.5	5.2	6.2	0.26	<0.01	0.03	0.64
N retention efficiency, %	41.1	39.8	47.3	46.1	2.43	0.02	0.62	0.98
P retention efficiency, %	26.5	27.5	28.6	24.2	2.44	0.82	0.50	0.29
Overall (0 to 55 d)								
NE intake MJ/d	26.2	25.2	18.0	18.1	0.71	<0.01	0.63	0.53
SID[2] Lys intake, g/d	18.0	20.9	13.1	16.2	0.65	<0.01	<0.01	0.92
CP intake, g/d	291	328	208	249	7.5	<0.01	<0.01	0.83
N retention, g/d	22.3	24.1	19.5	20.5	1.25	0.02	0.31	0.79
N excretion, g/d	24.2	28.3	14.4	19.5	1.11	<0.01	<0.01	0.75
P intake, g/d	9.5	10.5	6.7	7.9	0.24	<0.01	<0.01	0.79
P retention, g/d	2.4	2.9	1.9	2.1	0.10	<0.01	0.10	0.37
P excretion, g/d	6.9	7.6	5.3	6.2	0.23	<0.01	0.03	0.80
N retention efficiency, %	47.4	45.7	56.4	51.7	2.55	0.02	0.26	0.62
P retention efficiency, %	26.2	27.1	26.2	24.6	1.22	0.43	0.81	0.39

[1]T = temperature; FS = feeding system; T*FS = temperature vs feeding system interaction. Least square means of 12 pigs per treatment, except for IPF at 30 °C and CON at 30 °C for which the data are means of 9 and 10 pigs, respectively.
[2]SID = standardized ileal digestible.

Table 4. Meal patterns of pigs fed according to individual daily precision (IPF) and conventional two-phase (CON) feeding systems under two thermal conditions (23 and 30 °C) [1]

	23 °C		30 °C			*P* - value		
Item	IPF	CON	IPF	CON	SEM	T	FS	T*FS
Phase 1 (0 to 27 d)								
Diurnal								
Amount of time feeding, min	66	69	50	50	4.95	0.01	0.77	0.78
Feed intake, g	1650	1721	1085	1037	115.01	<0.01	0.90	0.54
Meals	9.5	8.6	7.1	6.6	0.84	<0.01	0.31	0.79
Feed intake rate, g/min	24.9	25.3	22.5	20.7	0.81	<0.01	0.34	0.13
Feed intake meal, g	183	208	154	164	14.78	0.01	0.20	0.58
Nocturnal								
Amount of time feeding, min	22.0	18.3	13.2	16.9	2.34	0.02	0.98	0.07
Feed intake, g	524.7	424.4	282.6	341.5	55.69	<0.01	0.67	0.10
Meals	3.4	2.7	2.3	2.8	0.56	0.24	0.80	0.22
Feed intake rate, g/min	23.5	23.9	21.6	20.1	0.89	<0.01	0.47	0.25
Feed intake meal, g	191	180	122	126	16.86	<0.01	0.92	0.86
Phase 2 (28 to 55 d)								
Diurnal								
Amount of time feeding, min	68.6	68	61	65	5.23	0.29	0.70	0.61
Feed intake, g	2049	2094	1640	1626	163.8	<0.01	0.91	0.83
Meals	8.5	7.3	7.9	7.9	0.88	0.98	0.46	0.48
Feed intake rate, g/min	29.8	30.1	27	24.9	0.77	<0.01	0.48	0.03
Feed intake meal, g	254	304	213	227	31.1	0.02	0.20	0.47
Nocturnal								
Amount of time feeding, min	22	22	12.8	17.8	3.26	0.02	0.37	0.37
Feed intake, g	621.3	562.8	324.1	426.4	74.98	<0.01	0.74	0.23
Meals	2.7	2.2	2.2	2.6	0.53	0.97	0.87	0.31
Feed intake rate, g/min	27.8	30	25.3	23.9	0.79	<0.01	0.56	0.02
Feed intake meal, g	296	384	152	171	39.2	<0.01	0.14	0.35
Overall (0 to 55 d)								
Diurnal								
Amount of time feeding, min	68	68.4	55.9	59.2	4.96	0.02	0.72	0.86
Feed intake, g	1859	1917	1376	1346	86.71	<0.01	0.91	0.70
Meals	9.0	7.9	7.5	7.3	0.79	0.15	0.38	0.58
Feed intake rate, g/min	28	28.2	24.7	23.2	0.8	<0.01	0.35	0.26
Feed intake meal, g	217	252	185	197	21.45	0.02	0.19	0.51
Nocturnal								
Amount of time feeding, min	22	19.1	13	17.4	2.49	0.02	0.72	0.09
Feed intake, g	575.4	497.1	304.4	386.1	61.75	<0.01	0.97	0.14
Meals	3.0	2.5	2.3	2.7	0.54	0.58	0.86	0.25
Feed intake rate, g/min	25.6	26.9	23.3	22.1	0.66	<0.01	0.96	0.07
Feed intake meal, g	239	261	138	148	22.43	<0.01	0.38	0.76

[1]Diurnal period from 0501 h to 1959 h; Nocturnal period with low luminosity and less activity from 2000 h to 0500 h. Least square means of 12 pigs per treatment, except for IPF at 30 °C and CON at 30 °C for which the data are means of 9 and 10 pigs, respectively.

Table 5. Serum concentration of urea, total protein and acute-phase protein of pigs fed according to individual daily precision (IPF) and conventional two-phase (CON) feeding systems under two thermal conditions (23 and 30 °C) [1]

	23 °C		30 °C			*P* - value		
Item	IPF	CON	IPF	CON	SEM	T	FS	T*FS
27 days								
Urea (mg/dl)	29.0	28.8	20.3	24.4	2.33	<0.01	0.39	0.35
Total protein (g/dl)	6.178	6.21	6.29	6.76	0.175	0.05	0.14	0.19
Haptoglobin (mg/ml)	0.298	0.229	0.371	0.524	0.0739	0.01	0.56	0.13
Albumin (mg/ml)	40.06	39.56	36.86	40.5	1.678	0.46	0.31	0.18
55 days								
Urea (mg/dl)	22.8	28.9	18.9	24.6	1.90	0.02	<0.01	0.91
Total protein (g/dl)[2]	6.562	6.556	7.100	6.383	0.179	0.29	0.04	0.04
Haptoglobin (mg/ml)	0.260	0.244	0.404	0.317	0.0612	0.04	0.32	0.49
Albumin (mg/ml)	45.33	43.67	39.97	40.17	2.041	0.02	0.70	0.62

[1]T = temperature; FS = feeding system; T*FS = temperature vs feeding system interaction. Least square means of 12 pigs per treatment, except for IPF at 30 °C and CON at 30 °C for which the data are means of 9 and 10 pigs, respectively.
[2]Temperature × feeding system interactions ($P < 0.05$) were found for total protein IPF ($P = 0.032$), 30 °C ($P = 0.006$).

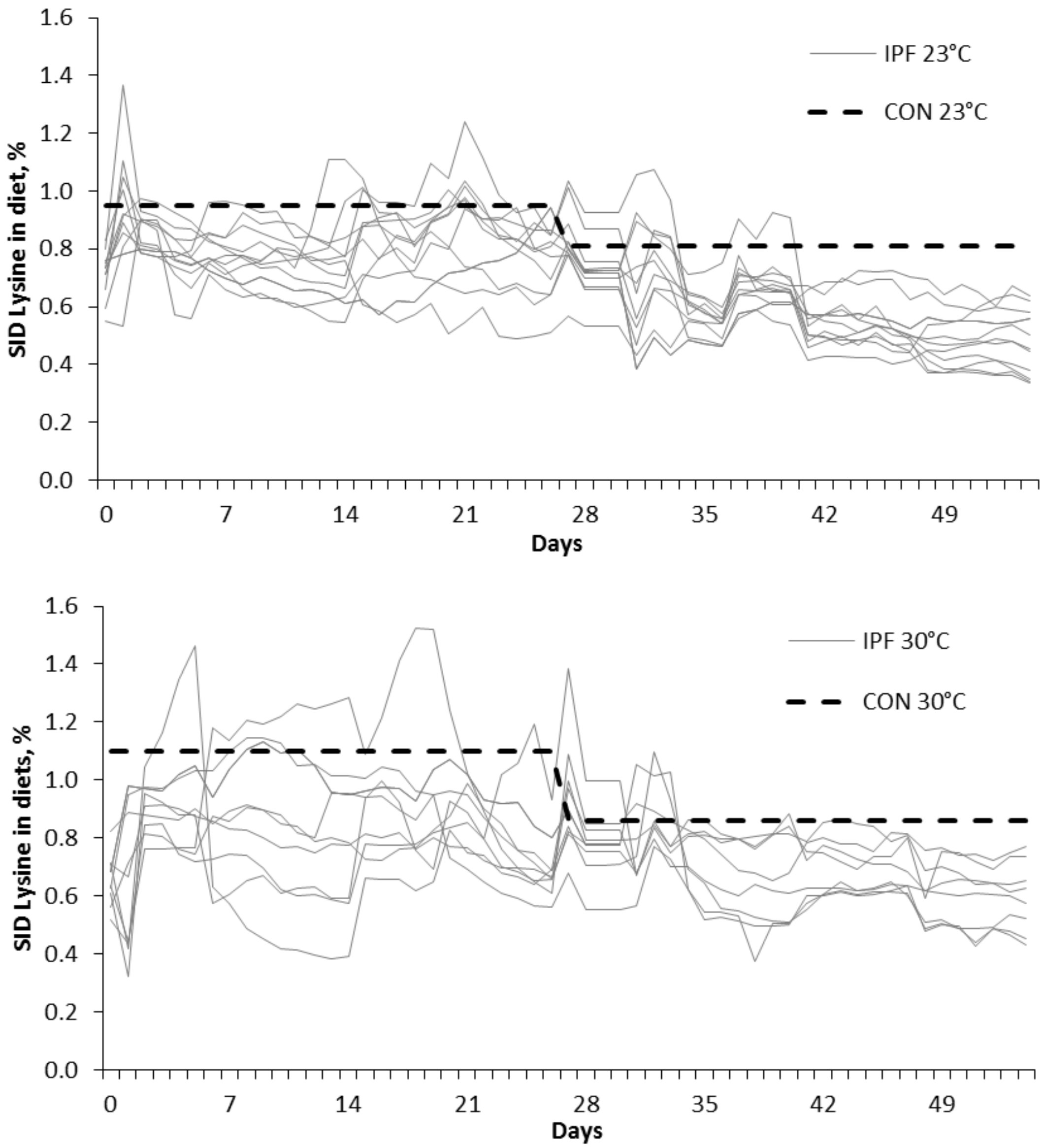

Figure 3.1. Estimated requirement levels of standardized ileal digestible (SID) lysine provided daily for pigs fed according to individual daily precision (IPF) and conventional two-phase (CON) feeding systems under two thermal conditions (23 and 30 °C).

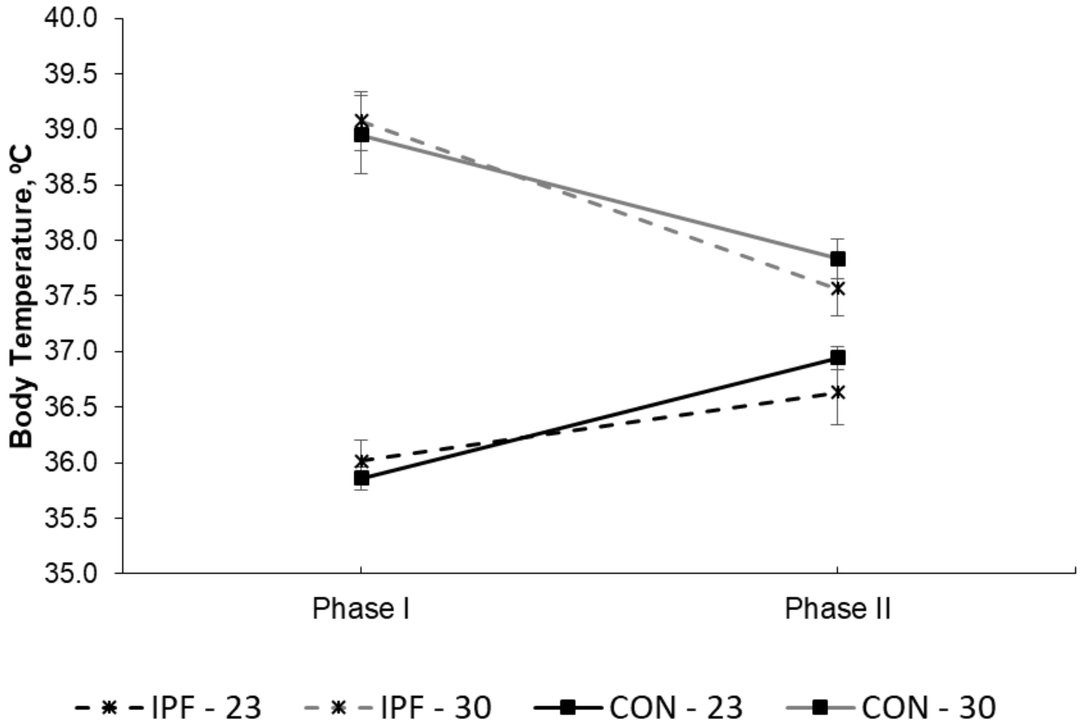

Figure 3.2. Average of body temperature in pigs fed according to individual daily precision (IPF) and conventional two-phase (CON) feeding systems under two thermal conditions (23 and 30 °C). Ambient temperature was significant ($P < 0.001$) during both experimental phases.

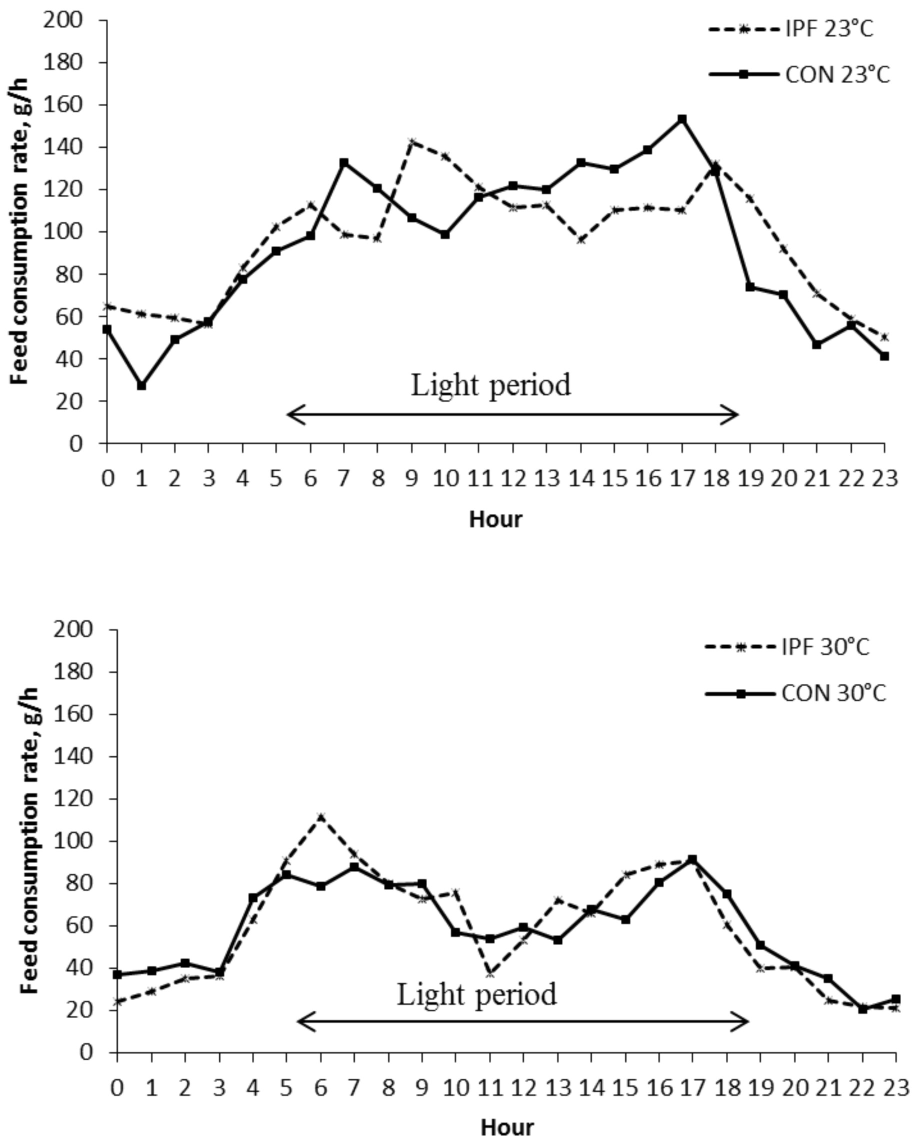

Figure 3.3. Average feed intake during the hours of the day in pigs fed according to individual daily precision (IPF) and conventional two-phase (CON) feeding systems under thermoneutral (23 °C) and heat stress (30 °C) conditions (days 0 to 27). Light period from 0520 to 1858 h.

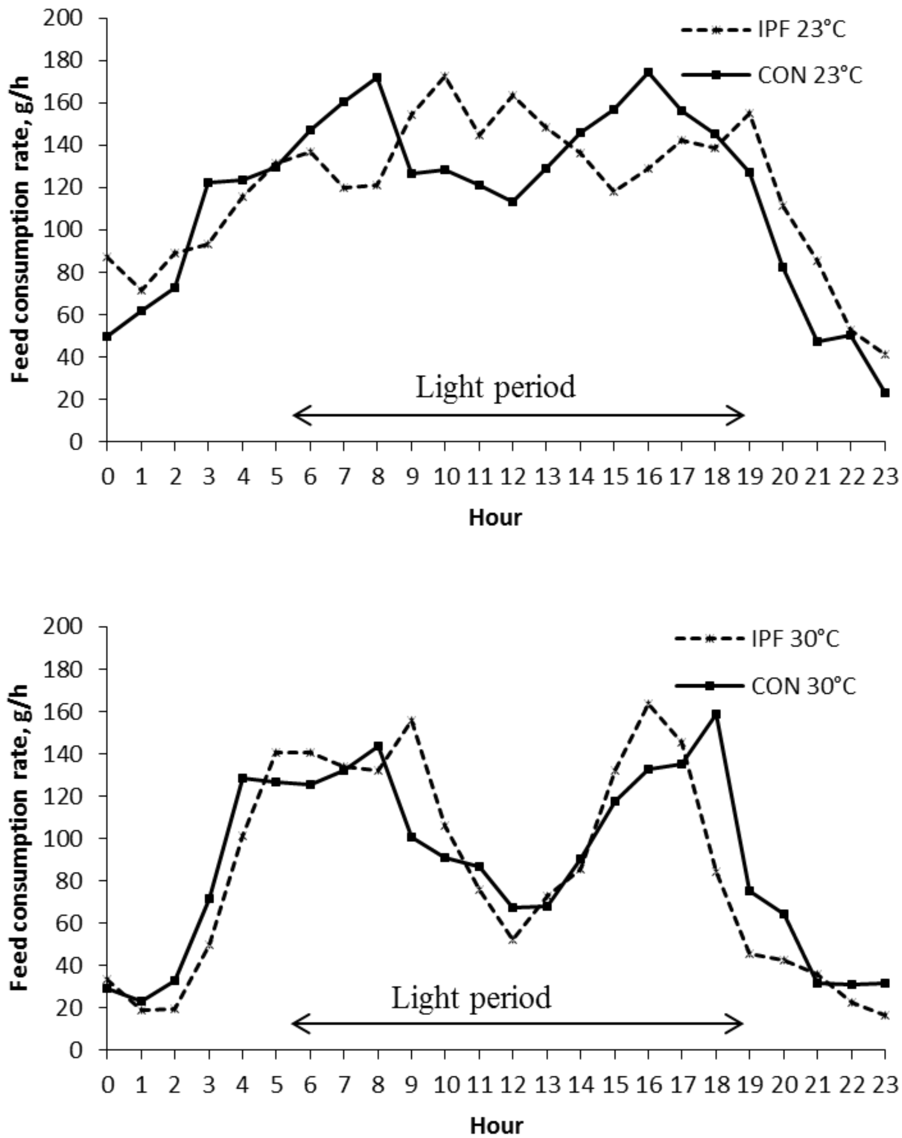

Figure 3.4. Average feed intake during the hours of the day in pigs fed according to individual daily precision (IPF) and conventional two-phase (CON) feeding systems under thermoneutral (23 °C) and heat stress (30 °C) conditions (days 28 to 55). Light period from 0520 to 1858 h.

Capítulo 4 – Considerações finais

A decisão das melhores condições para otimizar as respostas dos animais na produção de suínos deve ser estudada pelo produtor com cautela. No Brasil, as condições de clima da região sul sempre foram referência para produzir suínos com investimentos mínimos para climatização. Entretanto, apesar de provado que temperaturas constantes acima da termoneutralidade impactam diretamente na produção e bem estar dos animais, existem outros fatores que precisam receber a devida atenção. Os sistemas atuais de produção de suínos acabam resultando em respostas que variam de 70 até 130% do preconizado pela companhia genética em média (diferentemente do de aves que alcançam o desempenho sugerido pelas companhias genéticas na prática). Essas divergências nas respostas de desempenho estão relacionadas principalmente com as condições sanitárias, níveis nutricionais das dietas, manejos inadequados e ambiência.

No segundo capítulo desse trabalho foi discutido como uma decisão de linha genética pode influenciar no desempenho dos animais. Geralmente, os produtores negligenciam as condições ambientais do seu sistema, apostando alto e erroneamente nas genéticas de maior produção. Uma decisão incorreta pode resultar em um desempenho ainda mais comprometido, uma vez que animais de alto desempenho podem exigir uma atenção maior às condições de ambiente e principalmente nutricionais. É interessante destacar que para avaliar o efeito da temperatura nos experimentos demonstrados no capítulo 2 e 3, um ambiente com renovação de ar constante de baixo desafio sanitário foi elaborado. Portanto, na Figura 4.1 é ilustrado como os animais foram mantidos em ambos os ambientes térmicos durante o experimento do terceiro capítulo.

Atualmente, grande parte dos processos de produção animal já possuem sistemas de automação. Dentre os mais comuns, destacam-se os silos para armazenamento das rações, com linhas específicas para abastecimento dos comedouros. Além desses, outros equipamentos estão disponíveis para monitorar, alimentar e controlar o ambiente dos animais. Granjas mais tecnificadas também acompanham os avanços no desempenho dos animais, com base no consumo de ração e ganho de peso dos lotes.

Diante dessa realidade, um sistema de alimentação de precisão diário poderia ser implementado no Brasil, sem a necessidade de equipamentos mais avançados.

Figura 4.1. Ilustração da baia coletiva dotada de dois alimentadores automáticos.

Na Figura 4.2 é ilustrado como um comedouro para mistura em tempo real de dietas poderia ser utilizado. Brevemente, dois silos com dietas de alta e baixa concentração nutricional seriam utilizadas para fornecimento contínuo de ração aos comedouros. Um sistema dosador encontrado no interior dos comedouros possibilitariam a mistura das dietas nas proporções para alcançar os níveis nutricionais exigidos pela média do grupo em cada dia específico.

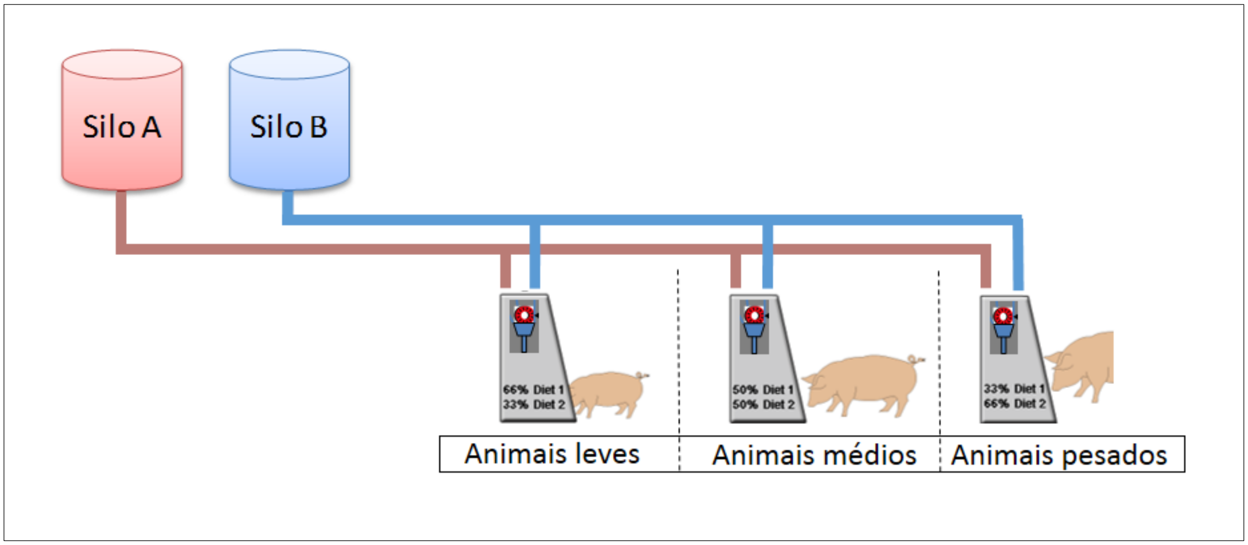

Figura 4.2. Exemplo do comedouro para diluição das dietas diárias para os grupos de suínos.

Para produtores que têm a preocupação ou o cuidado de não apostarem em um sistema em que duas dietas deveriam ser formuladas especialmente para esse propósito da alimentação de precisão, existe uma outra opção. Basicamente, um sistema de teste poderia ser realizado utilizando-se diluições das dietas formuladas para as fases do sistema convencional. Nesse sistema, diariamente uma proporção baixa da dieta da próxima fase seria incorporada a dieta atual para adequação dos níveis nutricionais diários preconizados para os determinados grupos de animais.

Conforme visto previamente, e diante das constantes discussões relacionadas à nutrição animal, sabemos que a alimentação representa um dos fatores mais onerosos na produção animal. Dentre todos os fatores responsáveis pela queda no desempenho dos animais, o sistema de alimentação de precisão foi o que apresentou as respostas mais consistentes mesmo em condições adversas (por exemplo: em ambiente de estresse térmico com uma genética mais sensível). Portanto, esses resultados sugerem que o produtor pode se antecipar em relação à eficiência de seu sistema, fornecendo os nutrientes de maneira adequada, mesmo que uma decisão equivocada na escolha da genética do plantel tenha sido previamente realizada. Um exemplo disso seria a implementação antecipada de um sistema de alimentação de precisão em uma granja que optou previamente por uma genética inadequada às suas condições. Nesse caso poderia ocorrer uma antecipação da economia de ingredientes que seriam fornecidos em excesso, enquanto ocorre uma troca do material genético da granja.