UNIVERSIDADE FEDERAL DO RIO GRANDE DO SUL
FACULDADE DE MEDICINA VETERINÁRIA
PROGRAMA DE PÓS-GRADUAÇÃO EM CIÊNCIAS VETERINÁRIAS

"MANEJO ALIMENTAR DE FÊMEAS SUÍNAS NO PERÍODO GESTACIONAL E PRÉ-INSEMINAÇÃO" IMPACTOS PRODUTIVOS E REPRODUTIVOS

ANDRÉ LUIS MALLMANN

PORTO ALEGRE

2020

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Orientador: Prof. Fernando Pandolfo Bortolozzo

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Porto Alegre, 24 de janeiro de 2020.

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RESUMO

O aumento na quantidade de ração na fase inicial de gestação, na fase final de gestação (*bump feeding*) e pré-inseminação (*flushing*) é um manejo tradicional utilizado com diferentes propósitos nas granjas. Os benefícios produtivos com o seu uso em fêmeas contemporâneas, sob condições comerciais, são controversos e por vezes escassos. Entretanto, todos possuem impacto econômico considerável. Assim, os objetivos do presente trabalho foram avaliar o impacto de diferentes manejos alimentares aplicados durante a fase gestacional e a eficiência do *flushing* pré-inseminação sobre o desempenho reprodutivo de leitoas. O primeiro estudo avaliou, em um modelo dose-resposta, o efeito do *bump feeding* sobre o peso ao nascimento (PN) e desempenho reprodutivo. Para isso, 977 leitoas foram alimentadas com 1,8, 2,3, 2,8 ou 3,3 kg/d a partir do dia 90 de gestação até o parto. O PN tendeu a aumentar quadraticamente (P=0,083), enquanto a produção de colostro e o consumo de ração das fêmeas durante a lactação reduziram linearmente (P≤0,016), à medida que a quantidade de ração fornecida foi aumentada. O desempenho reprodutivo subsequente não diferiu entre os tratamentos (P>0,135). Seguindo na tentativa de melhorar o PN, foi realizado um segundo estudo, onde foram avaliados os efeitos de duas quantidades de ração (1,8 ou 3,5 kg/d) ofertadas em duas fases gestacionais (fase 1 – dia 22 até o dia 42; fase 2 – dia 90 até o dia 110). Não foram encontradas diferenças no peso dos leitões ao nascimento (P≥0,153). No entanto, leitoas alimentadas com 3,5 kg/d na fase final de gestação apresentaram menor percentual de leitões com <1000g (P=0,031), e não foram encontrados efeitos dos tratamentos na eficiência placentária (P=0,320). O terceiro estudo avaliou os efeitos de diferentes quantidades de ração (1,8, 2,5 ou 3,2 kg/d) ofertadas na fase inicial de gestação (dia 6 até o dia 30) sobre o desempenho ao parto de primíparas (OP1) e secundíparas (OP2). O desempenho ao parto também foi avaliado de acordo com as reservas corporais das fêmeas ao desmame. A taxa de parto tendeu a ser afetada linearmente com o aumento na quantidade de ração em fêmeas OP1 (P=0,085). Leitões nascidos totais foram afetados quadraticamente em fêmeas OP1 (P=0,049), enquanto que para fêmeas OP2 houve uma tendência de redução linear com o aumento na quantidade de ração ofertada (P=0,082). Os leitões nascidos totais e a taxa de parto para ambas OP não foram afetados pela interação entre a classe de reserva corporal ao desmame e o tratamento aplicado (P>0,103). O quarto estudo verificou o efeito do *flushing* no período pré-inseminação sobre o desempenho reprodutivo de leitoas. Foram avaliados os efeitos de duas quantidades de ração (2,1 ou 3,6 kg/d) ofertadas durante dois ciclos estrais (ciclo1 – entre o 1º e 2º estro, ciclo 2 – entre o 2º e 3º estro). No 2º estro, leitoas alimentadas com 3,6 kg/d durante o ciclo 1 apresentaram 1,9 folículo a mais que fêmeas alimentadas com 2,1 kg/d (P=0,032). Já o número de ovulações no 3º estro foi influenciado pela quantidade de ração fornecida em ambos os ciclos (P<0,009). A sobrevivência embrionária foi afetada negativamente nas fêmeas que consumiram 3,6 kg/d no 2º ciclo (P=0,026), enquanto o número de embriões totais e viáveis foi influenciado apenas pela quantidade de ração consumida no 1º ciclo após a puberdade (P≤0,001).

Palavras-chave: Fase inicial da gestação, *bump feeding*, *flushing*, leitoas, porcas, primíparas e secundíparas.

ABSTRACT

Increasing the feed amount earlier in gestation, late in gestation (bump feeding) and before breeding (flushing) is a strategy used with different purposes in breeding farms. The productive profits of using these strategies in modern females under commercial conditions are controversial and sometimes scarce, even though all of them have a considerable economic impact. Thus, the objectives of the present study were to evaluate the impact of different feeding strategies performed during the gestational phase and the efficiency of the flush feeding strategy before breeding on reproductive performance of gilts. The first study evaluated, in a dose-response model, the effect of bump feeding strategy on the piglets birth weight (PBW) and reproductive performance. A total of 977 gilts were fed 1.8, 2.3, 2.8, and 3.3 kg/d from day 90 of gestation until farrowing. The PBW tended to increase quadratically (P=0.083), whereas the colostrum yield and the voluntary feed intake during lactation reduced linearly (P≤0.016) as the feed amount offered during late gestation increased. Subsequent reproductive performance did not differ among treatments (P>0.135). Following the attempt to improve PBW, a second study was performed to evaluate the effects of two feed amounts (1.8 or 3.5 kg/d) offered during two gestational phases (phase 1 – day 22 to 42; phase 2 – day 90 to 110). No differences among treatments were observed on PBW (P≥0.153), although, gilts fed 3.5 kg/d in phase 2 had fewer piglets with <1000g (P=0.031). No differences were observed on the placental efficiency among treatments (P=0.320). The third study evaluated the effects of three different feed amounts (1.8, 2.5 and 3.2 kg/d) offered earlier in gestation (day 6 to day 30) on farrowing performance of parity 1 (PO1) and 2 (PO2) sows. The performance at farrowing was also evaluated according to the body reserves at the previous weaning. Farrowing rate tended to be affected by the increase in feed amount provided in PO1 females (P=0.085). Litter size was affected quadratically in PO1 females (P=0.049), whereas, in PO2, it tended to reduce linearly, as the feed amount was increased (P=0.082). The litter size and the farrowing rate were not affected by the interaction between the class of body reserve at weaning and feed amount provided (P>0.103). The fourth study verified the effects of the flush feeding strategy before breeding on reproductive performance of gilts. The effects of two feed amounts (2.1 or 3.6 kg/d) offered during two estrous cycles (cycle 1 – between 1st and 2nd estrous; cycle 2 – between 2nd and 3rd estrous) were evaluated. Gilts fed 3.6 kg/d during cycle 1 had 1.9 more follicles at 2nd estrous than gilts fed 2.1 kg/d (P=0.032). The ovulation rate at 3rd estrous was influenced by the feed amount provided in both estrous cycles (P<0.009).

Embryo survival was negatively affected when gilts were fed 3.6 kg/d during cycle 2 (P=0.026), whereas the number of total embryos and vital embryos was affected only by the feed amount provided during cycle 1 (P≤0.001).

***Keywords*:** Early gestation phase, *bump feeding*, *flushing*, gilts, sows and young parity sows.

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1 INTRODUÇÃO

A capacidade reprodutiva da fêmea suína é tradicionalmente mensurada pelo número de leitões desmamados por ano, o qual é afetado diretamente por diversos fatores, tais como o número de dias não produtivos, duração da lactação, intervalo desmame-estro, tamanho da leitegada e mortalidade pré-desmame (LUCIA JR et al., 2000). A fêmea suína determina a capacidade produtiva do sistema e, apesar da baixa participação numérica em sistemas desde a produção de leitões até a terminação, responde por 20% da quantidade total de ração consumida (BALL et al., 2008), representando 15 a 17% do custo total gasto com ração (SOLÀ-ORIOL; GASA, 2017).

Fazendo um contraponto entre o número de leitões que a fêmea desmama por ano e a quantidade de ração necessária para a produção desse leitão, chega-se a um valor que, em sistemas menos eficientes, pode ser superior a 40 kg de ração/leitão enquanto que para granjas de excelência, essa quantidade fica ao redor dos 35 kg de ração/leitão ou menos. Essa análise evidencia que há oportunidades tanto na eficiência produtiva, pela melhora nos índices reprodutivos, que levam a um aumento no número de desmamados, quanto na estratégia alimentar adotada, pela redução na quantidade de ração fornecida. Considerando que o ciclo produtivo da fêmea é dividido em gestação, lactação e intervalo desmame-estro, e que a fêmea permanece em cada um desses momentos por 80, 15 e 5% do tempo, respectivamente, fica evidente que as grandes oportunidades do ponto de vista alimentar residem no período gestacional.

O período gestacional da fêmea suína contempla diferentes fases, cada uma com as suas próprias características. Assim, a alteração no manejo alimentar em cada fase tem diferentes enfoques. Na fase inicial-intermediária da gestação (inseminação até os 75 dias) o foco é garantir que não ocorram perdas no potencial produtivo visto que o período é reprodutivamente o mais sensível (GEISERT; SCHMITT, 2002). Por outro lado, esse período é também utilizado para recuperação das reservas corporais (NRC, 2012), principalmente em fêmeas jovens, primíparas (OP1) e secundíparas (OP2) que sabidamente são mais sensíveis às perdas corporais na lactação. Apesar de as estratégias alimentares terem sido amplamente exploradas, a literatura é escassa quando se trata dessas categorias (LEAL et al., 2019). Assim, há a necessidade de se avaliar a interação entre a quantidade de ração fornecida e o estado corporal da fêmea ao desmame sobre o desempenho reprodutivo de modo a estabelecer a estratégia que garanta o máximo do potencial.

Quando se trata da fase final de gestação (a partir do dia 70), o objetivo é justamente aumentar o aporte nutricional, uma vez que os nutrientes são priorizados para o crescimento fetal (THEIL et al., 2014). Apesar de ser prudente pensar que a maior ingestão de nutrientes pela fêmea proporcionará maior suprimento fetal e consequentemente, maior peso ao nascer, estudos tem mostrado que em porcas, este efeito não ocorre ou é mínimo e por vezes até controverso (GONÇALVES et al., 2016a). Para as leitoas, são encontrados efeitos positivos com a realização do aporte nutricional, mesmo que modestos (GONÇALVES et al., 2016a). Entretanto, ainda há a necessidade de se estabelecer a quantidade máxima, a qual a fêmea responderá para melhorar o peso dos leitões ao nascer, considerando também os impactos dessa estratégia sobre desempenho da fêmea. Há também a necessidade de se investigar os efeitos do aporte nutricional na fase final de gestação em fêmeas que foram submetidas a um aporte nutricional na fase de maior desenvolvimento vascular e placentário (fase inicial de gestação; (REYNOLDS; REDMER, 1995; VALLET et al., 2009a). Segundo Reynolds; Redmer (1995), é necessário um desenvolvimento vascular adequado capaz de suportar o aporte nutricional fornecido para a fêmea na fase final de gestação.

Outro momento com potencial impacto no desempenho reprodutivo é o período pré-inseminação das leitoas, denominado de *flushing. O flushing* consiste em fornecer um aporte nutricional para a leitoa, por um período mínimo de 14 dias prévios à inseminação artificial, com o objetivo de normalizar a taxa ovulatória (WENTZ et al., 2007). Essa estratégia é utilizada em todo sistema produtivo, embora os dados que comprovem a sua eficiência sejam antigos (BELTRANENA et al., 1991; PERUZZO, 2000). Somado a isso, vale salientar que os trabalhos foram realizados com fêmeas alimentadas restritamente durante a fase de crescimento e recria devido à alta deposição de gordura. Entretanto, a fêmea moderna tem um perfil de alta deposição de carne magra, e é preconizado atualmente que seja alimentada à vontade nas fases anteriores à seleção (PIC, 2016). Assim, cabe uma reavaliação da eficiência dessa estratégia, inclusive com análise sobre os efeitos na qualidade folicular e luteal, aspectos esses que podem interferir positivamente no desenvolvimento dos conceptos.

Sendo assim, a justificativa central para a realização dos experimentos propostos por este projeto, é a necessidade de se melhorar o peso ao nascimento dos leitões, considerando também os reflexos sobre o desempenho da fêmea contemporânea. Para isso, foram conduzidos experimentos com o foco na fase pré-inseminação de leitoas, fase final de gestação de leitoas e a associação de alterações na fase inicial e final da gestação de forma conjunta para todas as ordens de parto.

2 CAPÍTULO I - REVISÃO BIBLIOGRÁFICA

2.1 Aspectos fisiológicos relacionados à fêmea suína gestante

2.1.1 Fase inicial-intermediária da gestação – dia 0 até o dia 75

Há na literatura diferentes formas de se caracterizar as fases do período gestacional. De um modo geral, considera-se como fase inicial-intermediária da gestação, o período compreendido entre a cobertura e o 75º dia de gestação. O objetivo nessa fase é proporcionar condições adequadas de modo que se atinja máximo desempenho reprodutivo, longevidade e bem-estar (MENEGAT et al., 2018).

A fecundação é o marco inicial da gestação, sendo caracterizada por uma complexa cascata de eventos, que envolvem interações específicas entre espermatozoides e oócitos para, posteriormente, iniciar a fase de desenvolvimento embrionário e fetal (SENGER, 2003). No dia 10 de gestação, os blastocistos possuem um formato esférico, ao redor de 2 mm. A partir desse momento as mudanças são ainda mais rápidas, evoluindo para uma formação tubular de aproximadamente 200 mm nas próximas 24 – 48 horas (SENGER, 2003). Após a fecundação, o reconhecimento embrio-materno é um dos principais eventos que determinará o estabelecimento gestacional, ocorrendo por volta do dia 12. Essa fase de rápida transição na morfologia do concepto seguido da implantação na parede uterina representa um dos períodos de maior perda embrionária (POPE; FIRST, 1985). A maioria das perdas pré-natais ocorrem na fase embrionária, sendo 20-30% nas primeiras três semanas, 15 a 20% entre a quarta e sexta semana de gestação e 5 a 10% no terço final de gestação (FORD et al., 2002). Segundo Foxcroft; Town (2004), assume-se que a competição por fatores bioquímicos, no início do desenvolvimento embrionário, e a competição pela superfície placentária sejam os dois mecanismos principais que ocasionam a mortalidade embrionária. Entretanto, os fatores que podem levar à morte embrionária podem começar antes mesmo da ovulação, especialmente em fêmeas com muitas ovulações. Isso porque fêmeas que ovulam mais podem apresentar maior heterogeneidade na maturação folicular e oocitária o que, consequentemente, está associado com maior variabilidade no tamanho dos embriões (diversidade embrionária) na fase de desenvolvimento precoce (GEISERT; SCHMITT, 2002).

Além dessa intensa transformação a nível celular, a fase inicial da gestação contempla também a placentação, que se caracteriza por uma extensa angiogênese nos tecidos maternos e fetais, marcada por um extenso aumento no fluxo sanguíneo uterino e umbilical (REYNOLDS; REDMER, 1995). É nessa fase que ocorre a formação do leito vascular, o qual dará suporte para o crescimento exponencial do feto na fase final de gestação. De acordo com Freking et al. (2007), a massa placentária cresce continuamente entre o dia 20 e 60 – 70 de gestação e após isso, poucos acréscimos são percebidos. Vonnahme et al. (2001) citam que quando ocorreu o esmagamento de fetos no dia 40 de gestação, houve acréscimo na massa placentária dos fetos remanescentes, embora não tenha havido acréscimo no peso ao nascer. Já Vallet et al. (2009a) consideram que a maior parte da massa placentária está formada até o dia 35 de gestação, uma vez que após esse período o acréscimo foi de apenas 10%.

Posteriormente ocorre a formação das fibras musculares primárias e secundárias dos fetos (FOXCROFT; TOWN, 2004). Segundo estes mesmos autores, a miogênese ocorre em duas etapas. A primeira é a formação das fibras primárias, entre 25 e 55 dias de gestação, não sendo influenciada pela nutrição, mas pela seleção genética. A segunda é a formação e hiperplasia das fibras secundárias, que ocorre dos 55 até os 90 dias de gestação. São dois eventos importantes já que, segundo Dwyer et al. (1993), há uma relação positiva entre o número de fibras secundárias com o desenvolvimento pós-natal, isto é, há um crescimento mais rápido e eficiente dos leitões com maior número de fibras secundárias.

Por outro lado, a fase inicial de gestação é comumente utilizada para recuperação das reservas corporais (YOUNG et al., 2004a; NRC, 2012), especialmente nas fêmeas jovens – primíparas e secundíparas – classes essas mais vulneráveis ao catabolismo lactacional e subsequentes prejuízos reprodutivos. De acordo com Goodband et al. (2013), o ganho de peso da fêmea é alcançado quando se tem uma alimentação em níveis superiores aos necessários para mantença e crescimento dos tecidos fetais, fluidos e conceptos. Por esse motivo indica-se a recuperação do estado corporal da fêmea até o dia 70 de gestação, período em que ainda não há grandes necessidades além da mantença (JI et al., 2005; GOODBAND et al., 2013). Isso implica em fornecer quantidades maiores de ração, fato esse que por muitos anos tem sido evitado dado o seu impacto na sobrevivência embrionária (JINDAL et al., 1996). Assim, definir uma estratégia alimentar que considere tanto o aspecto reprodutivo quanto o estado corporal do animal passa a ser um desafio e por isso, tem sido tema de inúmeros trabalhos nos últimos anos (para revisão LEAL et al., 2019).

2.1.2 Fase final da gestação – dia 75 - parto

O período que compreende a fase final da gestação (últimos 40-45 dias), também chamado de terço final, é caracterizado como o momento onde o crescimento fetal e mamário se acentuam (VONNAHME et al., 2001; MCPHERSON et al., 2004; JI et al., 2005). Durante toda a fase gestacional, há um aumento progressivo no crescimento fetal; entretanto, é nesta fase da gestação que o crescimento é acelerado (Figura 1).

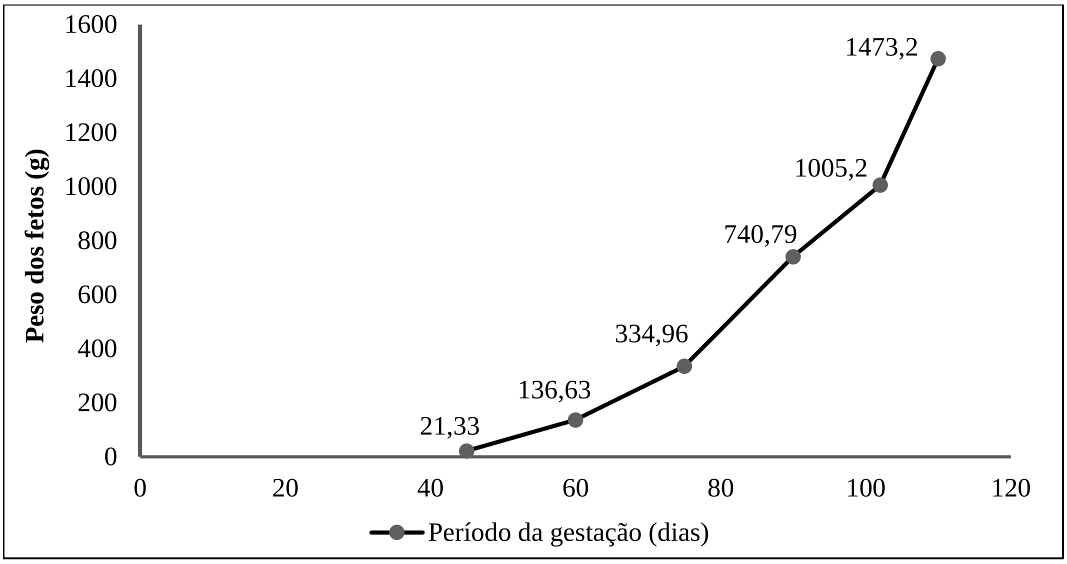

Figura 1- Peso fetal em diferentes dias da gestação. Adaptado de Mcpherson et al. (2004).

Mcpherson et al. (2004) estudaram a deposição de nutrientes nos tecidos fetais e concluíram que até o 69° dia, houve um acréscimo de 0,25 g/dia de proteína no feto e, após isso, a deposição passou a ser de 4,63 g/dia, indicando um crescimento de ordem cúbica à medida que a gestação progride. Com isso, os autores inferiram que, para fêmeas que possuem leitegadas com 12 leitões, a deposição proteica diária será de 3 g/dia antes do 69° dia e de 55,6 g/dia após o 69° dia de gestação. Em um estudo semelhante, Ji et al. (2005) avaliaram as alterações fetais e da glândula mamária de leitoas durante a gestação. Foi evidenciado que o peso das fêmeas aumenta quadraticamente, enquanto a espessura de toucinho (ET) aumenta linearmente, à medida que a gestação avança. A alteração na taxa de crescimento dos fetos foi no 69° dia de gestação uma vez que antes desse período, o acréscimo no peso individual do feto e da leitegada foi de 4,1 e 45,3 g/dia e posteriormente, o acréscimo passou a ser de 29,6 e 310,5 g/dia, respectivamente. Baseados nessas alterações biológicas, os autores sugerem uma divisão no período gestacional em duas fases: início da gestação (0 a 70 dias) e final da gestação (após os 70 dias).

Considerando o crescimento acelerado dos leitões no terço final de gestação, tem-se sugerido por anos o aporte nutricional com o objetivo de aumentar a disponibilidade de nutrientes. A nutrição embrio-fetal pode ocorrer de duas formas: 1) através das áreas de troca especializadas (complexos areolares) localizadas na superfície placentária. 2) pelo transporte sanguíneo direto, que ocorre através de dobras microscópicas que se desenvolvem na superfície do endométrio, fazendo a ligação com o epitélio do trofoblasto e caracterizando um ponto de contato entre os capilares maternos e fetais (VALLET et al., 2009b). Assim, os principais mecanismos de nutrição fetal são a difusão simples, difusão facilitada e transporte ativo (FRIESS et al., 1980). A escolha do mecanismo pelo qual o nutriente será transferido é determinada pelo peso molecular e composição química. Por exemplo, oxigênio e CO_2 são transferidos entre as membranas placentárias por difusão facilitada, sendo a taxa de difusão dependente do gradiente de concentração na superfície da membrana (VILLEE, 1965). Já a glicose é considerada um composto polar, não sendo facilmente difundido pelas membranas placentárias, fazendo com que seja necessário um grupo de proteínas responsáveis por realizar o transporte entre membranas (para revisão, VALLET et al., 2009b).

Hipoteticamente, com o aporte nutricional para a fêmea, aumenta-se por consequência o aporte nutricional para o feto. Essa estratégia comumente denominada de *bump feeding* é amplamente utilizada na suinocultura, com o objetivo de aumentar o peso dos leitões ao nascimento. No entanto, a partir de resultados recentes de ausência de efeito positivo da prática de *bump feeding* sobre o peso ao nascer, em fêmeas com leitegadas grandes ou pequenas (MALLMANN et al., 2018), especula-se que as fêmeas modernas tenham um limite na transferência de nutrientes para o feto, talvez por apresentarem um limite de resistência à insulina, hormônio responsável pela entrada da glicose nas células (PÈRE; ETIENNE, 2018). Deve ser considerado, também, que o tamanho da leitegada tem aumentado de forma acelerada, embora não acompanhado na mesma intensidade pela capacidade uterina e pelo fluxo sanguíneo materno (PÈRE; ETIENNE, 2000). Em conjunto, a eficiência placentária e a nutrição materna são fatores importantes que afetam o crescimento fetal, muito embora esse processo também dependa da interação com outros fatores como ambiente, genética, capacidade uterina e tamanho da leitegada (ASHWORTH et al., 2001).

2.2 Plano alimentar para a fêmea suína moderna

Nos últimos anos, a seleção genética focou no aumento do tamanho da leitegada e a deposição de carne magra na carcaça. Com isso, a composição corporal foi alterada, traçando um novo perfil de fêmeas que passaram a ter como característica a prolificidade e a baixa deposição de gordura corporal (BROWN-BRANDL et al., 2004; KIM et al., 2013). Fêmeas modernas tem como característica o menor consumo, melhor eficiência alimentar e são mais resilientes às perdas do período lactacional (KIM et al., 2013).

Essas alterações no perfil das fêmeas refletem diretamente sobre as exigências nutricionais, as quais são determinadas pela demanda para mantença e ganho materno, bem como para o crescimento fetal e uterino (COLE; CLOSE, 2001; KIM et al., 2005). Dietas que não atendem adequadamente as exigências maternas têm impacto negativo sobre a longevidade, resistência a doenças, número de leitões nascidos, peso ao nascimento e número de leitões desmamados (BALL et al., 2008), mortalidade de leitões, uniformidade das leitegadas e perdas corporais na lactação (FOXCROFT, 2008). Por outro lado, as exigências da fêmea suína são estabelecidas por equações elaboradas na década de 90 e, com base nessa mudança no perfil da fêmea contemporânea, fica evidente a necessidade de atualização.

O programa alimentar comumente utilizado no período gestacional é o fornecimento de ração restrita, para garantir adequadas condições de escore corporal e para evitar excessivos acúmulos de gordura. Entretanto, são realizadas alterações na quantidade de ração fornecida de acordo com características específicas nos diferentes momentos da gestação (SOLÀ-ORIOL; GASA, 2017). Segundo Ball et al. (2008), nos últimos 40 anos, trabalhos envolvendo nutrição de porcas resultaram em menos de 1% de todas as publicações no assunto. Isso porque trabalhos com fêmeas são extensos, necessitam de um alto número de animais para se evidenciar diferenças estatísticas e a inclusão de critérios de resposta como peso ao nascimento, longevidade e desempenho produtivo tornam os estudos complexos (GOODBAND et al., 2013). Apesar das dificuldades, diversas tentativas ocorreram com o intuito de aproximar os níveis nutricionais das dietas das exigências das fêmeas (NRC, 2012; GOODBAND et al., 2013).

Conforme pode ser evidenciado na Figura 2 a demanda proteica em cada fase gestacional é dependente das necessidades. Na fase inicial, as demandas são para recuperação da condição corporal e desenvolvimento placentário, enquanto no terço final de gestação, a demanda para crescimento fetal e mamário é muito superior aos períodos anteriores, o que se assemelha à demanda por energia.

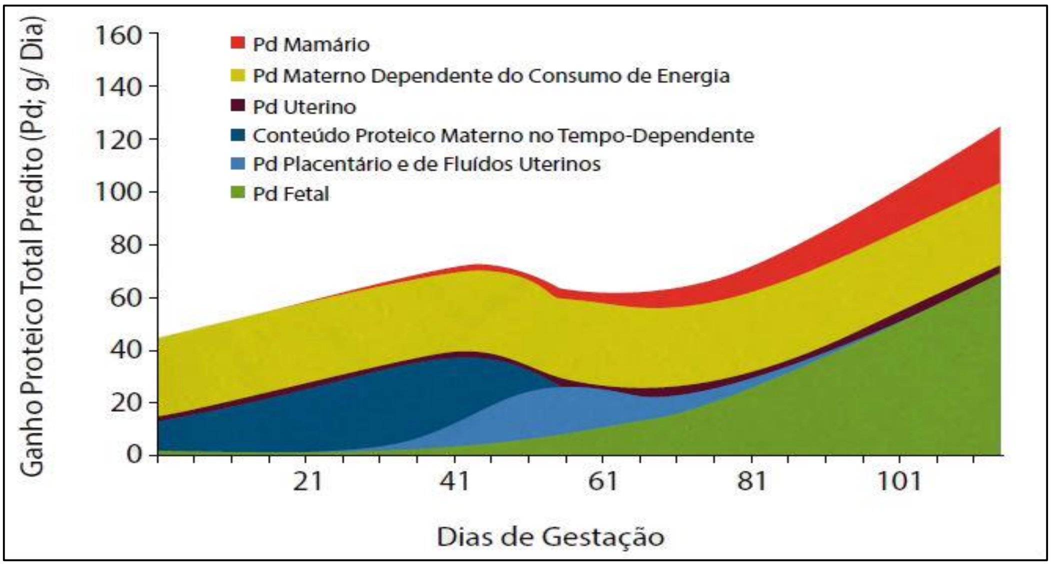

Figura 2- Estimativa de deposição proteica (g/dia) de acordo com o período gestacional. Adaptado de NRC, (2012).

2.2.1 Alimentação da fêmea gestante na fase inicial da gestação

A alimentação da fêmea suína no período pós-inseminação tem sido tema de diversos estudos realizados nas últimas duas décadas. Por muitos anos tem sido recomendado a restrição alimentar nesse período, dado o seu potencial impacto negativo sobre a sobrevivência embrionária e desempenho reprodutivo. Em um estudo conduzido por Jindal et al. (1996), foi avaliado o impacto de diferentes quantidades de ração em diferentes momentos após a inseminação. Nesse trabalho, todas as leitoas recebiam 2,5 kg/dia no período prévio à inseminação artificial e até o momento em que houve alteração nas quantidades. A mudança nas quantidades de ração foi realizada em três momentos após a inseminação: grupo 1 (N1) passou a receber 1,9 kg de ração por dia logo após a inseminação, grupo 2 (N2) recebeu 1,9 kg/dia a partir do terceiro dia e grupo 3 (H3) recebeu 2,6 kg/dia a partir do terceiro dia após a inseminação. As quantidades foram oferecidas até o dia 15 após a inseminação. A sobrevivência embrionária foi de 84,7, 74,0 e 64,5% para N1, N2 e H3, respectivamente, havendo diferença significativa entre o N1 e H3. Segundo esses autores, a redução da sobrevivência poderia estar relacionada com a diminuição dos níveis circulantes de progesterona nas fêmeas que consomem maiores quantidades de ração. Isto se explica pelo fato de que, quanto maior for a ingesta nutricional, maior será o fluxo sanguíneo hepático para a metabolização dos nutrientes e, consequentemente, maior será a metabolização de progesterona circulante (PRIME; SYMONDS, 1993).

Entretanto, em uma revisão publicada recentemente, Leal et al. (2019) concluíram que, em 75% dos trabalhos realizados, o efeito negativo sobre o desempenho reprodutivo não é mais visualizado e por isso a restrição alimentar não deve mais ser aplicada. Além disso, os autores demonstram haver benefícios reprodutivos com o aumento na quantidade de ração fornecida às fêmeas. Quesnel et al. (2010) avaliaram o efeito de duas quantidades de ração (2 kg *vs.* 4 kg por dia), ofertadas durante os primeiros 7 dias após a primeira inseminação de leitoas, e não encontraram diferenças na sobrevivência embrionária aos 27 dias de gestação (87% *vs.* 84%; P > 0,37). Athorn et al. (2013) conduziram um estudo com dois níveis de alimentação, baixo (1,5 kg/d) ou alto (2,8 kg/d), a partir do primeiro dia de gestação, e observaram maior sobrevivência embrionária nas fêmeas que receberam maiores quantidades de ração em comparação com as que receberam quantidades menores de ração (92 *vs.* 77 %; P < 0,05). Da mesma forma, Hoving et al. (2011) avaliaram o desempenho reprodutivo de fêmeas OP 1 e OP 2 quando submetidas a três tratamentos nutricionais na fase inicial de gestação (dia 3 a 32 de gestação): 1) controle – 2,5 kg/d de ração; 2) *plus feed*: 3,25 kg/d de ração; 3) *plus protein*: 2,5 kg/d + 30% de aminoácidos digestíveis. Os autores observaram um aumento (P < 0,05) no número total de leitões nascidos nas fêmeas do tratamento *plus feed*, em comparação às fêmeas controle e *plus protein* (15,2; 13,2; 13,6, respectivamente). Além disso, as matrizes do grupo *plus feed* apresentaram maior percentual de leitegadas com mais de 17 leitões nascidos, quando comparadas ao grupo controle (28 *vs.* 7%), o que demonstra maior sobrevivência embrionária e fetal. Esses autores citam o mecanismo direto de fornecimento de progesterona para o útero, evitando os efeitos do aumento da taxa de metabolização quando do maior consumo de alimento.

Embora os resultados recentes tenham demonstrado haver benefícios com o aporte nutricional na fase inicial da gestação, a literatura que contempla as fêmeas jovens, primíparas e secundíparas, é escassa. Exceto o trabalho realizado por Hoving et al. (2011), os demais foram realizados com leitoas, categoria essa que não sofre com o catabolismo lactacional. O catabolismo lactacional acomete principalmente as primíparas e dependendo do grau em que ocorre, pode ser determinante para o desempenho reprodutivo subsequente. Além disso, não há como comparar o metabolismo de uma fêmea desmamada com uma leitoa em início de vida produtiva. Esses dois fatores são cruciais e que evidenciam a necessidade de um trabalho na fase inicial de gestação nessa classe de fêmeas.

2.2.2 Alimentação da fêmea gestante na fase final da gestação

No terço final da gestação, as dietas devem atender a demanda das fêmeas, garantindo uma condição corporal ideal e evitando, assim, que elas entrem em um estado de catabolismo. Nesta fase, o *bump feeding* é uma prática amplamente difundida e consiste no aumento do fornecimento de ração (em torno de 1 kg) para fêmeas gestantes, dos 90 dias de gestação até o parto (GONÇALVES et al., 2016a). Este manejo tem como objetivo melhorar o peso ao nascimento dos leitões. Porém, esta prática tem sido abordada em vários estudos e os efeitos sobre o peso ao nascimento são discretos.

O NRC (1998) não previa nenhuma alteração nos níveis de energia e aminoácidos fornecidos às fêmeas durante a gestação. No entanto, em sua última versão, o NRC já apresenta um modelo em que há a estimativa das necessidades das fêmeas para o início da gestação (até 90 dias) e outra para o terço final (Tabela 1; NRC, 2012).

Tabela 1- Exigência diária de lisina digestível (g/dia) e energia metabolizável (EM, Mcal/dia).

	NRC (2012)				Rostagno (2017)			
Fase da Gestação	Leitoas		Porcas[1]		Leitoas		Porcas	
	Lis	EM	Lis	EM	Lis	EM	Lis	EM
Início (< 90 dias)	10,6	6,7	7,8	6,9	11,6	6,3	9,4	7,9
Final (> 90 dias)	16,7	7,9	13,1	8,2	15,3	7,0	18,1	8,7

[1]Considerando fêmeas de terceiro parto

Quando as dietas não atendem à demanda, as fêmeas podem entrar em catabolismo, mobilizando proteína e gordura das suas reservas para providenciar um adequado suporte, tanto aos conceptos e glândula mamária, quanto para a mantença (AHERNE; WILLIAMS, 1992). Por essas razões, alguns estudos foram conduzidos baseados na alteração dos níveis ou quantidades em diferentes momentos da gestação.

Em um estudo cooperativo que contemplou oito centros de pesquisa e 1080 leitegadas, o aumento de 1,36 kg/dia a partir do 90º dia de gestação mostrou-se eficaz, melhorando em 39 g o peso ao nascer (CROMWELL et al., 1989). Efeito semelhante, porém, superior (86 g), foi encontrado quando ocorreu a suplementação com 0,9 kg adicionais (2,1 *vs.* 3,0 kg/dia) na quantidade diária de leitoas no terço final de gestação o que, no entanto, não foi evidenciado em pluríparas (SHELTON et al., 2009). Hughes; Van Wettere (2012) aumentaram em 0,7 kg/dia nas últimas três ou seis semanas e encontraram um acréscimo de 30 e 60 g no peso ao nascer respectivamente.

Recentemente, Mallmann et al. (2018) compararam o fornecimento de duas quantidades de ração (1,8 *vs.* 2,2 kg/dia) na fase final de gestação (a partir do dia 90) de leitoas e porcas. Não foram encontrados efeitos positivos sobre o peso médio dos leitões ao nascimento para leitoas (1252 *vs.* 1269 g) e para porcas (1360 *vs.* 1355 g). Vale considerar que no grupo das porcas, houve 0,7 leitão a mais no tamanho da leitegada no grupo que recebeu 2,2 kg/dia, ocasionando uma diferença de 1091 g no peso total da leitegada ($P < 0,05$). O fato de que tenha havido aumento de 1091 g no peso total da leitegada, sem afetar negativamente o peso médio ao nascer, mostra que a oferta de 400 g a mais para as fêmeas que consumiram 2,2 kg/d foi capaz de evitar a redução de peso dos leitões, que poderia ter ocorrido em consequência do aumento do tamanho da leitegada. Já na categoria das leitoas, acredita-se que o aporte nutricional pode ter sido insuficiente para aumentar o peso ao nascer.

Gonçalves et al. (2016b) distribuíram 741 leitoas e 362 porcas em dois diferentes níveis de lisina (10,7 e 20 g) e dois níveis de energia (5,90 e 8,85 Mcal EM/dia). O aumento no nível de energia a partir dos 90 dias de gestação melhorou em 30 g o peso ao nascer quando foram considerados apenas os leitões nascidos vivos independente da ordem de parto, mas houve um acréscimo de 2,1% no índice de natimortalidade quando consideradas apenas as pluríparas. Em outro estudo, o incremento nos níveis de lisina (28 g *vs.* 35 g/dia) a partir 85º dia de gestação de leitoas também não aumentou o peso dos leitões ao nascer (MAGNABOSCO et al., 2013). Contrariamente, o peso aumentou quando o nível de inclusão da lisina na dieta de porcas passou de 0,45% para 0,65% ou 0,74% (ZHANG et al., 2011). Recentemente, Thomas et al. (2018) conduziram um estudo no modelo dose-resposta, com diferentes níveis de lisina (11; 13,5; 16 e 18,5 g/dia SID Lis) durante a gestação, e observaram que o peso das fêmeas aumentou linearmente à medida que a quantidade de lisina aumentou, sem, no entanto, encontrar efeito positivo sobre o peso dos leitões ao nascimento. Em outra abordagem, na chamada nutrição de precisão, Buis (2016) não encontrou efeitos sobre o desempenho reprodutivo de fêmeas alimentadas em uma curva alimentar ajustada semanalmente de acordo com as suas exigências, em comparação ao outro grupo que foi alimentado com uma quantidade fixa de 2,2 kg/dia, durante todo o período gestacional.

O NRC (2012) considera que o aumento no aporte energético diário pode trazer benefícios para o ganho de peso do leitão. Entretanto, deve-se ter o cuidado com potenciais problemas que podem ocorrer associados a isso, como por exemplo, prejuízos na lactação subsequente, principalmente pelo impacto no consumo voluntário durante a lactação.

Os fatores que exercem efeito sobre o consumo voluntário na lactação foram descritos por Eissen et al. (2000) e Mellagi et al. (2010), e segundo estes autores, além da importância do peso da fêmea ao parto, a composição corporal (proteína e gordura) também apresenta uma importante interação com a ingestão alimentar. Estienne et al. (2000) compararam 3 grupos de fêmeas de acordo com a ET: magras (<20mm), médias (20-25mm) e gordas (>25mm). As fêmeas magras apresentaram maior consumo de ração na lactação (5,4; 4,5 e 4,3, kg/dia respectivamente) e apresentaram menor perda de gordura do parto até o desmame (1,8; 4,7 e 6,7 mm respectivamente). Mallmann et al. (2018) avaliaram o consumo na lactação de dois grupos de fêmeas alimentados com 1,8 e 2,2 kg/dia a partir do dia 90 de gestação e evidenciaram que o grupo de fêmeas que consumiu mais ração na gestação, consumiu em média 320 g a menos por dia na fase lactacional. Recentemente, Ren et al. (2017) forneceram diferentes quantidades de ração (0,5; 1,0; 1,5 e 2,0 vezes a mantença) em três períodos de sete dias em diferentes momentos da gestação (27-34; 55-62; 83-90 dias) e da mesma forma, encontraram uma correlação negativa entre a gordura corporal ao parto e o consumo de ração na lactação (r = - 0,35; Figura 3).

A relação entre a quantidade de gordura e peso corporal com o consumo de ração pode ser explicado fisiologicamente pela interação de alguns mecanismos regulatórios que atuam sinergicamente (para revisão, EISSEN et al., 2000; MELLAGI et al., 2010). O principal deles é conhecido como mecanismo de *turnover* da gordura corporal - teoria lipostática (WILLIAMS, 1998). Através do *turnover* há uma constante liberação de ácidos graxos e glicerol para a corrente sanguínea, e quanto maior for a deposição de gordura no corpo, maior será essa liberação (EISSEN et al., 2000). A taxa de metabolização da gordura é utilizada pela fêmea como sinal do seu estado metabólico, havendo interferência sobre o apetite e consequentemente sobre o consumo de ração (WILLIAMS, 1998).

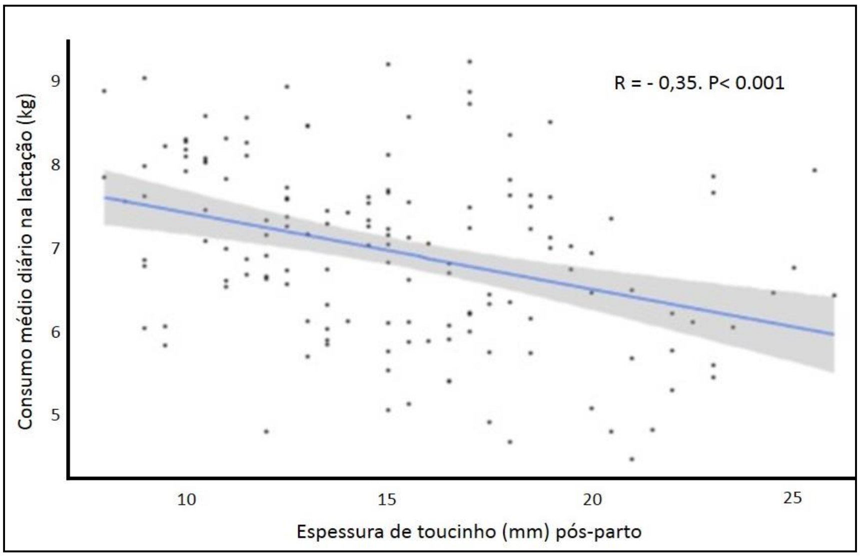

Figura 3- Relação entre a gordura corporal (espessura de toucinho) e o consumo de ração na lactação (Adaptado de REN et al., 2017).

Vale considerar que a exigência estabelecida para a fêmea deve ser aquela em que o nível nutricional seja capaz de maximizar os aspectos econômicos (PESTI et al., 2009), e não o ganho de peso corporal da fêmea (GONÇALVES et al., 2015), visto que ganhos de peso exagerados na gestação geram consequências negativas nas fases subsequentes (WELDON et al., 1994; SHELTON et al., 2009; BUIS, 2016) e implicam diretamente no aumento dos custos de produção (SHELTON et al., 2009). Os diferentes resultados encontrados na literatura evidenciam pouca melhora no peso ao nascimento quando ocorre a manipulação no plano nutricional, principalmente quando esta é restrita a apenas uma fase da gestação e sobretudo em porcas, além de não haver consistência nos resultados entre os diferentes estudos (CAMPOS et al., 2012). No entanto, fica necessário estabelecer se o uso dessa estratégia ainda se faz necessário para leitoas, visto que os trabalhos demonstram haver efeitos positivos, apesar de modestos. Além disso, é importante estabelecer os impactos do uso dessa estratégia para além do peso ao nascer, considerando o impacto sobre fatores não contemplados nos estudos já realizados como o desempenho da fêmea na lactação, no desempenho subsequente e na retenção da fêmea no plantel.

2.2.3 Alimentação da leitoa pré-cobertura – *Flushing*

Flushing é um termo que caracteriza uma estratégia alimentar utilizada no ciclo anterior a cobertura das leitoas com o objetivo de normalizar o número de ovulações

(COX et al., 1987; BELTRANENA et al., 1991). Tradicionalmente, faz-se um aumento na quantidade de ração, na quantidade de energia ou faz-se a substituição da fonte energética utilizada (BELTRANENA et al., 1991; PERUZZO, 2000; ALMEIDA et al., 2014) por um período mínimo de 14 dias prévio ao estro de cobertura.

Aumentos na quantidade de ração ofertada aumentam o fluxo sanguíneo hepático, o que resulta no aumento da metabolização de esteroides (estradiol e progesterona), o que em consequência irá reduzir o feedback negativo sobre o eixo hipotalâmico hipofisário estimulando a liberação de GnRH (ASHWORTH; ANTIPATIS, 1999). De acordo com Ferguson et al. (2003) leitoas submetidas ao manejo do *flushing* por 19 dias tem maior número de pulsos de LH e maiores níveis de insulina e IGF-1. Insulina e IGF-1 são importantes por atuarem localmente nos ovários, aumentando a absorção de nutrientes com consequente estímulo a atividade celular (PRUNIER; QUESNEL, 2000).

Em um estudo conduzido por Beltranena et al. (1991), leitoas foram alimentadas de forma restrita (2 kg; L) ou à vontade (H) durante a fase de recria até atingir o estro da puberdade. Após isso, até o segundo estro, o grupo L foi subdivido permanecendo metade das fêmeas na alimentação restrita (LL) e outra metade recebeu um aporte de 0,8 kg (LH); enquanto o grupo H permaneceu sendo alimentado à vontade (HH). No 2ª estro, fêmeas do grupo LH apresentaram 2 ovulações a mais que fêmeas do grupo LL (12 *vs.* 14); enquanto na comparação entre LL e HH o aumento no número de ovulações foi ainda maior, 12 *vs.* 14,7, respectivamente. Já Almeida et al. (2014) modificaram a fonte energética da dieta, sendo uma a base de amido (20%) e outra onde houve a inclusão de óleo de soja (8,6%). As duas dietas foram isoenergéticas e fornecidas à vontade do dia 8 do ciclo até o estro seguinte. Ao abate, fêmeas alimentadas com a dieta baseada em amido apresentaram 2,6 ovulações a mais, em comparação ao outro grupo (16,4 *vs.* 13,8). Apesar do aumento substancial, fica difícil extrapolar os dados para a realidade da suinocultura visto que o trabalho não apresentou um grupo controle com alimentação restrita ou à vontade considerando dietas comumente utilizadas à base de milho e soja. Em estudo semelhante, Peruzzo (2000) avaliaram o efeito sobre o desempenho de leitoas quando a ração foi fornecida restritamente, à vontade, com ou sem a adição de energia na dieta (sacarose). Na comparação entre fêmeas alimentadas restritamente e fêmeas alimentadas à vontade, houve um incremento de 1,96 ovulação com o aumento na quantidade de ração fornecida. Já quando comparamos os grupos alimentados à vontade com ou sem adição de açúcar, não foram encontradas diferenças na taxa ovulatória. Recentemente, Silva et al. (2019) demonstraram não haver impacto sobre os nascidos totais de leitoas submetidas ao *flushing* com ração gestação (3,14 Mcal/kg e 0,88% Lis) ou com ração lactação (3,49 Mcal/kg e 1,3% Lis). Com isso, fica evidente que os efeitos positivos alcançados no desempenho reprodutivo se dão mais pelo aumento na quantidade de ração fornecida, do que pela mudança no perfil energético da dieta.

No passado, as fêmeas eram alimentadas restritamente devido à sua alta capacidade de deposição de gordura na carcaça. Já as fêmeas de genótipo moderno são alimentadas à vontade durante o seu desenvolvimento por terem sido selecionadas geneticamente para deposição de carne magra na carcaça. Comparando as fêmeas utilizadas no decorrer dos anos, é possível visualizar a mudança ocorrida no estado corporal. No estudo realizado por Beltranena et al. (1991), aos 170 dias de idade as fêmeas pesaram 98,9 kg com uma ET de 13,1 mm; enquanto que no trabalho realizado por Peruzzo (2000), as fêmeas com a mesma idade pesaram 113,7 kg e tiveram 16,2 mm de ET. Alguns anos após, fêmeas utilizadas por Kummer et al. (2009) pesaram 100,5 kg com 10,0 mm de ET aos 165 dias de idade e recentemente, no trabalho realizado por Walter (2018) fêmeas em idade semelhante pesaram 101,6 kg com uma ET de 9,2 mm.

Outro ponto importante é a possível melhoria da qualidade folicular que pode ser alcançada com o uso do *flushing* em leitoas. Aumentos na quantidade de ração ofertada elevam os níveis circulantes de IGF-1 e insulina (PRUNIER; QUESNEL, 2000), hormônios estes que atuam diretamente sobre o folículo estimulando o seu crescimento, melhorando assim a sua qualidade no momento da ovulação (ASHWORTH; ANTIPATIS, 1999; FERGUSON et al., 2003). Em consequência, folículos de melhor qualidade são associados positivamente com a qualidade do corpo lúteo (SOEDE et al., 1998). Recentemente, Da Silva et al. (2017) demonstraram haver também uma associação positiva entre a qualidade do corpo lúteo com o peso dos leitões ao nascimento. Nesse estudo, para cada 1 mm acrescido no tamanho do corpo lúteo, houve acréscimo de 37 g no peso dos leitões ao nascimento.

Desconsiderando o trabalho realizado por Silva et al. (2019) no qual houve comparação de dietas com maior ou menor quantidade de energia, é oportuno questionar se o efeito positivo alcançado em trabalhos realizados no passado (BELTRANENA et al., 1991; PERUZZO, 2000) ainda são alcançados nas fêmeas de linhagens modernas. Além disso, dada a relação quadrática entre a taxa ovulatória e o número de embriões demonstrada por Da Silva et al. (2017), o questionamento que fica é se o uso do *flushing* na fêmea moderna tem potencial de melhoria na qualidade folicular, luteal e embrionária podendo posteriormente se refletir na qualidade do leitão ao nascimento.

3 CAPÍTULO II – PRIMEIRO ARTIGO CIENTÍFICO

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Impact of feed intake during late gestation on piglet birth weight and reproductive performance: a dose-response study performed in gilts

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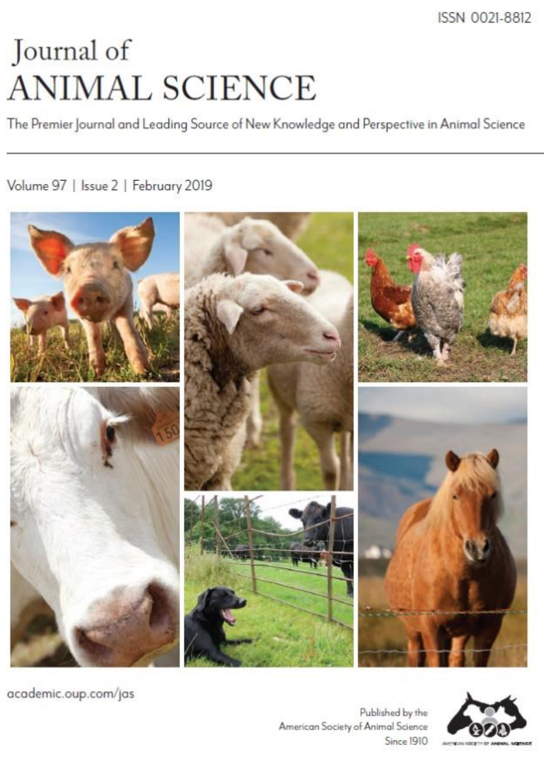

Running head: Gestation nutrition and piglet birth weight

Impact of feed intake during late gestation on piglet birth weight and reproductive performance: A dose-response study performed in gilts

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ABSTRACT

The effects of increasing feed intake (1.8, 2.3, 2.8, and 3.3 kg/d) during late gestation of gilts on piglet birth weight and female reproductive performance were evaluated. A total of 977 gilts were fed a diet based on corn-soybean meal (3.29 Mcal ME per kg and 0.64% standardized ileal digestible lysine) from day 90 of gestation until farrowing. Gilts were weighed on days 90 and 112 of gestation, at farrowing and weaning. Born alive and stillborn piglets were weighed within 12 h of birth. Colostrum yield (**CY**), lactation feed intake, and litter growth rate were measured in a randomly selected subsample of 245 gilts. The data were analyzed using generalized linear mixed models. As expected, gains in body weight (**BW**) were different at day 112 (P < 0.001) with the greatest values observed in the 3.3 kg/d treatment. As feed intake increased during late gestation, BW, body condition score **(BCS)**, backfat **(BF)**, and caliper unit also increased between day 112 and weaning (P < 0.001). No differences were found among treatments in total number of piglets born, mummified fetuses, sum of born alive and stillborn piglets, and within-litter birth weight CV (P > 0.05). Tendencies for quadratic effect of feed intake were observed for born alive piglets (P = 0.079), average birth weight of piglets (P = 0.083), and litter weight (P = 0.059). Gilts with lower feed intake during late gestation

had reduced percentages of stillborn piglets than gilts with greater feed intakes. The CY decreased linearly ($P < 0.05$) as the feed intake was increased. No differences among treatments were found at weaning in individual piglet weight and litter weight, as well as in percentage of weaned piglets ($P > 0.05$). Lactation feed intake decreased as gestation feeding level increased ($P < 0.05$). No differences in the subsequent cycle were observed among treatments for farrowing rate, retention rate up to the next farrowing, number of total piglets born, born alive, stillborn piglets, and mummified fetuses ($P > 0.05$). In conclusion, increased feed intake from day 90 of gestation until farrowing resulted in increased maternal BW gain and stillborn rate, but reduced CY and lactation feed intake. A slight increase in birth weight was observed for the 2.3 kg/d treatment. Furthermore, litter growth and subsequent female reproductive performance were not affected by feed intake during late gestation.

Key words: birth weight, dose response, feeding, gilts, late gestation, nutrition

INTRODUCTION

The intense genetic improvement over the last years has resulted in increased litter size. However, as the number of piglets born has increased, the birth weight has decreased due to a greater competition for nutrients in the intrauterine environment (Town et al., 2005; Foxcroft et al., 2006). Low-birth-weight piglets have several negative implications during their lifetime, such as greater pre-weaning mortality (Quiniou et al., 2002), greater mortality during nursery period when associated with a reduced colostrum intake (Ferrari et al., 2014), reduced weaning weight and subsequent market weight (Quiniou et al., 2002; Fix et al., 2010; Alvarenga et al., 2012), and decreased reproductive performance (Magnabosco et al., 2016).

There are several nutritional strategies to improve the birth weight of piglets such as the supplementation of L-carnitine at early gestation (Ramanau et al., 2008), L-arginine throughout the gestational period (Mateo et al., 2008; Quesnel et al., 2014), and lysine or energy levels during late gestation (Gonçalves et al., 2016b). Another strategy is called "bump feeding" and involves increased daily feed intake during the late gestational period (Cromwell et al., 1989; Shelton et al., 2009; Soto et al., 2011; Mallmann et al., 2018). In general, feeding during the early gestational period is focused on the recovery of body condition score (**BCS**), whereas at late gestation it is focused on exponential development of the fetus (NRC, 2012). However, studies have failed to demonstrate great improvement in birth weight, or have found results that are controversial, indicating how difficult it is to manipulate the birth weight of piglets through maternal nutritional intervention.

The benefits or the real necessity of the bump feeding practice during late gestation have not been elucidated. Generally, results were controversial and did not show benefits with this strategy (Campos et al., 2012; Gonçalves et al., 2016a). When studies were conducted with sows, no increase in the birth weight was found (Shelton et al., 2009; Soto et al., 2011, Greiner et al., 2016). However, some researchers have found better results when the study was conducted with gilts (Shelton et al., 2009; Soto et al., 2011). Although Gonçalves et al. (2016b) reported a moderate improvement in piglet birth weight associated with the increase in energy intake, in our previous study (Mallmann et al., 2018) the increase in feed intake had no improved the birth weight, regardless of the female category (sows or gilts).

A greater feed intake during gestation represents a challenge for sows because those achieving greater body weight (**BW**) may experience negative implications during the subsequent lactational period, mainly a reduction in voluntary feed intake (Eissen et al., 2000; Shelton et al., 2009; Mallmann et al., 2018). Lower feed intake and consequent greater BW loss impair the subsequent reproductive performance (Koketsu et al., 1997, 2017), although few studies regarding bump feeding have considered this effect. It has also been reported that females submitted to a bump feeding practice exhibit greater stillborn rates (Gonçalves et al., 2016b), and show no benefits on lactation performance and retention rate on the subsequent cycle (Gonçalves et al., 2016b; Mallmann et al., 2018).

The main aim of this study was to verify if the bump feeding practice is necessary for hyper-prolific gilts, establishing the maximum daily feed intake to improve the birth weight. Another objective was to identify the effects of feed intake on colostrum yield (**CY**), voluntary feed intake during lactation, growth performance of litters, and subsequent female reproductive performance. A dose-response study might elucidate the benefits of this practice, not only for piglet birth weight but also for female reproductive performance.

MATERIALS AND METHODS

The protocol used in this study was approved by the Ethics Committee of Animal Utilization (CEUA) of the Federal University of Rio Grande do Sul (UFRGS), under the process no. 31653.

Location

The study was conducted in a pig farm with 2,200 females, in the Midwest of Santa Catarina State (27º00'15" –S, 51º14'32" –W), Brazil, between January and April, which corresponds to summer and early fall in the southern hemisphere. The average, minimum, and maximum temperatures in the region, during the period of study, were 21.0, 11.1, and 35.6 ºC, respectively, and the average relative humidity was 86.3%.

Animals and Diets

The gilts were individually housed (2.20 × 0.60 m), with automatic feeders, and ad libitum access to water. During all the stages of gestation, the diet was a corn-soybean-based meal with 3.29 Mcal ME per kg, 13.4% crude protein (**CP)**, and 0.64% standardized ileal digestible Lysine (**SID Lys**). From day 0 to day 4 of gestation, the gilts were fed 1.8 kg/d of the feed. According to the methodology proposed by Young et al. (2004), from day 5 to day 35, gilts with the BCS (1 to 5 scale) of 2 and 3 were fed 2.7 and 2.1 kg/d of the diet, respectively. From day 36 to day 89 of gestation, all gilts received 1.8 kg/d of the diet.

Dietary samples were collected weekly for sixteen weeks and analyzed in triplicates for CP, total AA and dry matter (Methods described in CBAA, 2017 which is based on **AOAC** – Official Methods of Analysis of AOAC International methodologies, 19th edition, 2012). Samples were also analyzed for crude fiber, ash, ether extract, calcio, and phosphorus (CBAA, 2017 and AOAC Int., 2012). The analyzed diet was considered consistent with formulated values based on analytic variability (Table 2).

Experimental and Treatment Design

On day 89 of gestation, a total of 977 gilts (Landrace × Large White) were selected according to the following characteristics: general health status; BCS between 2.5 and 4.5 (1–5 scale; Young et al., 2004), and age >190 days at first service. The selected females were weighed individually and randomly assigned, according to their BW, into 4 feed amounts, to be fed from day 90 of gestation to farrowing: 1.8 kg/d (5.9 Mcal ME per day and 11.5 g/d SID Lys); 2.3 kg/d (7.6 Mcal ME per day and 14.7 g/d SID Lys); 2.8 kg/d (9.2 Mcal ME per day and 17.9 g/d SID Lys), and 3.3 kg/d (10.9 Mcal ME per day and 21.1 g/d SID Lys) of a corn-soybean-based diet (Table 1; 3.29 Mcal ME per day, 13.4% CP, and 0.64% SID Lys). The NRC (2012) recommendation for gilts from day 90 of gestation to farrowing is a feed amount of 2.53 kg/d (3.3 Mcal ME per day, 0.69% SID Lys), which corresponds to an effective daily energy intake of 7.9 Mcal ME/d. In a dose-response arrangement, our study intended to have lower and greater levels, ranging from 5.9 to 10.9 Mcal ME per day. All females were fed manually twice a day, at 7:00 and 15:00. Feed wastage during the treatment period was recorded daily after the meal. The females that did not consume the total amount of daily feed offered (31 gilts from 3.3 kg/d and 7 gilts from 2.8 kg/d levels) over the treatment period were excluded from the study.

Females were moved on day 112 to the farrowing room where they kept on receiving the gestation diet until farrowing. Females were individually switched to the lactation diet as they farrowed. All gilts were weighed and submitted to BCS, backfat thickness (**BF**)**,** and Caliper evaluations on day 89 (before the onset of the experimental period), day 112 of gestation (moving from gestation to farrowing), and at weaning. All weighing was performed with a 500 g precision scale (EW6, Tru Test, Auckland, New Zealand). The measurements of BF were performed in the P2 point (6.5 cm away from the midline of the vertebral column at the last rib level) with A-mode ultrasonography (Renco Lean Meter–Renco Corporation, Minneapolis, MN) within a range of 2 mm. Caliper unit was measured at the same BF point with the Caliper equipment in a unit range from 1 to 25 (Knauer and Baitinger, 2015). The birth weight of the born alive and stillborn piglets was recorded within 12 h of birth, using a scale with a resolution of 1 g. The mummified fetuses were not weighed; however, the number was recorded to be included in total number of piglets born.

Lactation Performance

A random subsample of 245 gilts was used to evaluate CY, voluntary feed intake during lactation, and performance of females and their litters. All farrowings were followed to ensure all the procedures were performed adequately and that both oxytocin and obstetric manual intervention were not used. Females subjected to these interventions were removed from the subsample evaluation.

The CY was calculated as the sum of colostrum intake by each piglet within a litter. Colostrum intake was estimated using the equation described by Devillers et al. (2004), based on piglet weight difference between the weight at 24 h after birth and the weight at birth, before the first colostrum intake. Colostrum intake period and the time to first suckling were used as fixed times, 1,440 min and 30 min, respectively. In our study, piglets that died within 24 h of birth were not included in the evaluation, and piglets that had lost weight during the 24 h were considered as having had no colostrum intake. A drying powder was used to dry the body, the umbilical cord was not shortened, and each piglet was identified with a numerical ear tag.

The cross-fostering of piglets was performed within 24 h of birth after having been recorded and weighed. Each piglet was fostered according to the dietary treatment of the respective dam. Few changes were performed because Mac Rebel practices were adopted by the farm: only piglets weighing less than 900 g were excluded and piglets were included to equalize the litter numerically. After cross-fostering, no piglets were added to the litters, and deaths and removals were recorded. All the piglets were weighed at weaning.

The post-farrowing weight of females was recorded within 12 h after the last piglet was born to evaluate the effects of the feed intake on weight loss of the females during lactation.

Females were individually housed (2.20 × 0.70 m) during lactation with ad libitum access to water. The lactation diet (3.43 Mcal ME per kg, 21.7% CP, and 1.27% SID Lys; Table 1) was provided 4 times a day from farrowing until weaning, through the manual filling of the feed box. However, if they showed more appetite, more feed was added into the feed box. The maximum daily feed amount was 9 kg. The feed wastage was weighed and recorded every day to measure the average lactation feed intake. Four-day intervals were used for analyses (day 0 to 3, 4 to 7, 8 to 11, and 12 to 15 day of lactation), except for the last interval (16–20 days) with 5 d, because the duration of lactation was 20.1 ± 1.5 d.

Subsequent Female Reproductive Performance

Estrus detection was performed once a day after weaning and weaning-to-estrus interval (**WEI**) was recorded after estrus confirmation by female standing reflex in the presence of a boar. Born alive piglets, stillborn piglets, and mummified fetuses in the subsequent farrowing were recorded. Data concerning the litter size of females that returned to estrus after post-weaning insemination were not included in the statistical analyses.

Statistical Analysis

The Statistical Analysis System software, version 9.3 (SAS Inst. Inc., Cary, NC), was used to perform the statistical analysis. All models included dietary treatment as a fixed effect. The week of onset of the feed treatment was included as a random effect, except in the non-parametric models. Polynomial contrasts were used to evaluate the linear and quadratic effects of the dose-response (different feed amounts offered daily).

The following variables were analyzed using the GLIMMIX procedure fitted assuming a normal distribution: BW; BF; Caliper unit at different time periods, and the respective gains and losses; total number of piglets born; born alive piglets; sum of born alive and stillborn piglets; CY; WEI; litter weight, and individual piglet weight at birth, cross-fostering, and weaning. The results of differences in body measures (i.e., gain or loss) are presented in three periods: Period 1 (from day 90 to day 112 of gestation) and Period 2 (from day 112 of gestation to weaning), and overall period (from day 90 of gestation to weaning).

A model with repeated measures was used for the analysis of voluntary feed intake during lactation. Treatments (gestation feed level), time (lactation interval), and the interaction between these two factors were included as fixed effects in the model.

The percentage of stillborn and mummified fetuses, and the percentage of piglets weighing less than 1000 g were analyzed as non-parametric distributions using the NPAR1WAY procedure. The comparison among treatments was performed using the Kruskal–Wallis test. The percentage of females bred until day 7 after weaning, farrowing rate, and retention rate until second parity were analyzed as binary distributions using the GLIMMIX procedure.

The results were considered significant at $P \leq 0.05$, and the tendency at $0.05 < P \leq 0.10$. Each female was considered as an experimental unit in all the analyses.

RESULTS

BW, BCS, BF, and Caliper unit Gain During Late Gestation

No differences were found among treatments at the onset of the experiment ($P > 0.428$) for age at insemination (229.5 ± 0.63), BW (185.8 ± 0.44), BCS (3.52 ± 0.01), BF (13.21 ± 0.08 mm), and Caliper unit (14.96 ± 0.75).

During Period 1 (day 90 to day 112 of gestation), changes in BW, BCS, BF, and Caliper unit increased linearly with the increase in feed intake (Table 3; $P < 0.001$). Gilts from 1.8 kg/d treatment lost BCS, BF, and Caliper unit. During the Period 2 (from day 112 to weaning), all the treatments resulted in BW, BCS, BF, and Caliper losses (linear;

P < 0.001); greater feed intake during late gestation resulted in greater body reserve losses. Losses of BW, BCS, BF, and Caliper unit were also observed in all treatments during overall period (day 90–weaning). The losses reduced as the feed intake during late gestation increased (linear; *P* < 0.001).

Litter Size and Piglet Birth Weight

No effect of feed intake during late gestation was found on total number of piglets born, mummified fetuses, sum of born alive and stillborn piglets, and within-litter birth weight CV (Table 3; *P* > 0.05), whereas a tendency of quadratic effect was observed on the number of born alive piglets (*P* = 0.079). Furthermore, females fed 1.8 kg/d had a lower percentage of stillborn piglets than those of other treatments, which were not different from each other. Individual piglet birth weight and litter weight tended (Table 3; quadratic effect) to increase in gilts fed 2.3 kg/d (*P* = 0.083 and *P* = 0.059, respectively).

Colostrum Yield, Voluntary Feed Intake, and Lactational Performance

The number of piglets weighed after birth (13.5 ± 0.36) and at 24 h post-farrowing (13.0 ± 0.35), considered in the measurement of CY, exhibited similar values among treatments (*P* > 0.05). Likewise, the mortality of piglets during the first 24 h was also similar among treatments (2.86 ± 0.55 %; *P* > 0.05). Other subsample results are shown in Table 4. As feed intake increased during late gestation, CY decreased linearly (*P* < 0.05; Table 4). Maternal BW at post-farrowing increased with increase in feed intake during late gestation (linear; *P* < 0.001). Voluntary feed intake during lactation decreased linearly with the increase in feed intake during late gestation (*P* < 0.05); consequently, the BW loss at first lactation increased (linear; *P* < 0.001). No differences among treatments were found at weaning for individual piglet weight, litter weight, and the percentage of weaned piglets (Table 4; *P* > 0.05).

Subsequent Reproductive Performance

Among the 977 gilts analyzed at the first farrowing, 16 were removed due to sickness or death during lactation and were not considered for the subsequent farrowing rate. A tendency of a significant decrease was observed for WEI (linear; *P* = 0.082, Table 3) as the gestation feed intake increased. The percentage of females bred up to 7 days after weaning, farrowing rate, and retention rate until the next farrowing were not affected by the feed intake ($P > 0.05$). There were also no differences among treatments for total number of piglets born and born alive piglets in the subsequent cycle ($P > 0.05$).

DISCUSSION

Changes in Body Measures

The current study demonstrated that the increase in the feed intake during late gestation (day 90 to 112) resulted in a linear increase in BW, BCS, BF, and Caliper unit. All the levels of feed intake resulted in BW gain. However, the females fed 1.8 kg/d (5.9 Mcal per day) exhibited reduced BCS, BF, and Caliper unit, whereas females fed 2.3 kg/d (7.6 Mcal per day) showed reduced Caliper units. The requirements for maintenance during late gestation shows little change in comparison with increments necessary to support the growth of fetal tissue, mammary tissue, placenta, and fluids (NRC, 2012). The fetal growth rate changes from a 0.25 g/d before day 69 to 4.63 g/d after day 69 of gestation (Mcpherson et al., 2004), and mammary gland growth rate changes from 0.08 g/d before day 75 to 1.5 g/d after the day 75 of gestation (Ji et al., 2005). Considering the six pools proposed by the NRC (2012), the requirements for gilts in late gestation increase from approximately 7.0 Mcal per day on day 90 of gestation to 8.5 Mcal per day before farrowing. Goodband et al. (2013) suggested that the energy requirements to avoid maternal tissue catabolism in late gestation must increase by 1.5–2.3 Mcal/d, which is equivalent to an incremental feed intake increase of around 0.5 to 0.75 kg/d. Thus, the results of our study confirm that 1.8 kg/d (5.9 Mcal per day) was insufficient because the values of BCS, BF, and Caliper unit for females of this treatment reduced from day 90 to day 112 of gestation. The fact that gilts fed 2.3 kg/d (7.6 Mcal per day) did not lose BF in late gestation, with an energy intake slightly lower than requirements for this phase (NRC, 2012), suggests that there might be an overestimation for gilts requirements during late gestation. Nonetheless, it is important to consider that gilts are still growing and their lower BW gain until farrowing or greater body reserve losses for the overall period might have negative consequences for their lifetime performance. The farrowing rate after first weaning and retention rate until third parity have been negatively affected in females that gained less weight between mating and first weaning (Lesskiu et al., 2015). The importance of an adequate body weight at first farrowing for the lifetime performance was pointed out by Kim et al. (2016) who reported greater retention rate and number of piglets born alive over six parities in females with 210 kg (among groups ranging from 190 to 240 kg) at day 109 of first gestation.

Greater BW gain during late gestation was linearly associated with body reserves losses during lactation. Although the BW at weaning was still linearly affected by gestation feeding level, the negative correlation between gain during gestation and loss during lactation affected the magnitude of difference among treatments. The difference of 12.4 kg between the two extreme treatments (3.3 and 1.8 kg/d) on day 112 was reduced to 6.1 kg at weaning. In other studies, gilts with greater feed intake during late gestation were also found to lose more weight during lactation (Amdi et al., 2013; Mallmann et al., 2018). Amdi et al. (2013) reported that gilts fed 1.8 kg/d during gestation did not lose weight during lactation, whereas gilts fed 2.5 or 3.5 kg/d lost weight. Likewise, Kim et al. (2016) showed greater BW and BF losses during lactation when gilts had greater pre-farrowing BW. In our study, females were found to lose 0.54 kg BW during lactation per 1 kg of gain during gestation, when 2.3, 2.8, and 3.3 kg/d feed intakes were compared with 1.8 kg/d.

Female Performance at Farrowing

Although the stillborn rate is not always affected by feed intake during late gestation of gilts (Gonçalves et al., 2016b; Mallmann et al., 2018), more stillborn piglets were reported in sows receiving greater energy levels (Gonçalves et al., 2016b). The negative effect of excessive body condition on the survival of piglets at birth is already known because overweight gilts (Amaral Filha et al., 2010) and sows that were too fat (Oliviero et al., 2010) before farrowing showed a greater rate of stillborn piglets. Similarly, Lavery et al. (2018) associated the high BF with a reduction in born alive piglets. In the present study, the farrowing length was not measured. However, females that are too fat have prolonged parturitions and greater rates of stillborn piglets (Oliviero et al., 2010), suggesting that females fed 1.8 kg/d might have had lower percentages of stillborn piglets because they were lighter and leaner before farrowing, hence found to be less prone to farrowing problems.

Contrarily to the results of other studies (Cromwell et al., 1989; Shelton et al., 2009; Gonçalves et al., 2016b), only marginal increases in the average piglet birth weight and total litter weight were observed in gilts that received 2.3 kg/d. Recently, in a study with 2 different feed intakes, 1.8 and 2.2 kg/d from day 90 to farrowing, in sows and gilts, no increase in piglet birth weight was observed (Mallmann et al., 2018). However, the increase in daily feed intake during other gestational periods has resulted in increased birth weight in gilts (Amdi et al., 2013) and sows (Ren et al., 2017). It is important to mention that in those studies the treatments were performed during other gestational periods, with females of different parities or with few females in each treatment, compared with the present study. No improvement in the piglet birth weight was achieved with greater feed intakes (2.8 and 3.3 kg/d), in our study, indicating that the crowding of embryos in hyper-prolific females can establish the programming of a low-birth-weight phenotype as suggested by Foxcroft (2012). As insulinemia is lower in sows with more fetuses (Père and Etienne, 2018), our results reinforce the previous assumption that the transfer of nutrient to fetuses in hyper-prolific females can be reduced because they develop a limited insulin resistance (Mallmann et al., 2018); a limited nutrient transfer to growing fetuses seems to occur even in females with greater feed intake.

Colostrum Yield

Our study demonstrated average values of CY similar to those reported in other studies (Devillers et al., 2007; Foisnet et al., 2010; Quesnel et al., 2011). Foisnet et al. (2010) reported a CY of 3.2 kg (range of 0.8–4.8 kg) for the first-parity sows. Similarly, Decaluwé et al. (2013) reported a CY of 3.2 kg (range of 1.6–5.0 kg) in sows of parities 1–7. Colostrum yield is extremely variable and influenced by some factors of different origins, such as environmental factors and characteristics of piglets and sows (Devillers et al., 2007; Foisnet et al., 2010; Quesnel et al., 2011). The association between the mobilization of body reserves during late gestation and CY has not been confirmed to be consistent. Sows (parities 1–7) with BF loss between days 85 and 109 of gestation produced 113 g more colostrum for each 1 mm of extra BF loss (Decaluwé et al., 2013). However, in the same study, females that exhibited BF loss between day 109 of gestation and day 1 after farrowing had lower CY, mainly for parities 4–7. The authors suggested that the high catabolic state in older sows likely inhibited the colostrum production at a full potential. Contrarily, in the present study, the CY was greater for females receiving 1.8 kg/d, which we consider was the only treatment that did not fulfill the requirements for gilts, based on their BF deposition (NRC, 2012). It seems that the mobilization of body reserves compensated for the deficiency in daily feed intake of gilts fed 1.8 kg/d during their first gestation. Loisel et al. (2014) showed a positive correlation between CY and free fatty acids measured before parturition, which suggests that a low or negative energy balance can enhance the CY to a certain extent, mainly for young sows. The fact that females fed 1.8 kg/d lost BF may indicate that this fat mobilization was prioritized for CY, because colostrum synthesis occurs mainly during the last week of gestation (Devillers et al., 2006).

Not only fatty acids but also greater levels of plasma creatinine and urea before farrowing are associated with greater CY (Loisel et al., 2014). Yet, the mobilized protein can be used by mammary glands as a source of amino acids or glucogenic substrates (Theil et al., 2012). Thus, we infer that a greater protein mobilization around parturition may be associated with an increased CY.

Performance During the Lactation Period

As previously reported (Amdi et al., 2013; Ren et al., 2017; Mallmann et al., 2018), the performance of piglets until weaning was not affected by feed intake during late gestation, even with a greater colostrum intake by piglets of gilts fed 1.8 kg/d. Voluntary feed intake was lower for females with greater feed intake during late gestation, as already reported (Shelton et al., 2009; Mallmann et al., 2018). Voluntary feed intake is mainly controlled by the metabolic condition before farrowing and driven by the central nervous system (Eissen et al., 2000). Thus, heavier females with more BF are prone to have a lower feed intake, and consequently more body reserve loss during the lactation period. The capacity to compensate the lower feed intake during gestation by the mobilization of the body reserves during lactation (King and Dunking, 1986; Mallmann et al., 2018) was indeed expressed by greater loss of BW and BF between the post-farrowing and weaning periods. Furthermore, only a severe reduction in the daily feed intake affects the performance of piglets (King and Dunking, 1986; Sulabo et al., 2010). Therefore, it is likely that the difference of 0.3 kg in daily feed intake (4.2 and 3.9 kg for 1.8 and 3.3 kg/d treatments, respectively) between the two extreme feed intakes during late gestation was easily counteracted by the greater mobilization of body reserves in gilts fed 3.3 kg/d.

Subsequent Performance

The increase in WEI observed in females of lower feed intake during late gestation (1.8 and 2.3 kg/d) was too small and not enough to reduce the farrowing rate and subsequent litter size. In recent studies, no negative effects on subsequent performance were observed with bump feeding during late gestation (Gonçalves et al., 2016b; Mallmann et al., 2018) or with different feed intake levels during different gestational periods (Ren et al., 2017). In a previous study, the subsequent litter size decreased when the BW loss was greater than 10% (Schenkel et al., 2010). However, although gilts fed 2.8 and 3.3 kg/d lost more than 10 % of BW during lactation, their subsequent litter size was not reduced. Taken together, these findings confirm that contemporary females can have less adverse effects driven by metabolic changes during lactation (Patterson et al., 2011).

CONCLUSION

In gilts with suitable body condition, the BW, BCS, and BF gains increased as the feed intake during the last third of the gestational period increased from 1.8 to 3.3 kg/d; however, only a marginal increase in piglet birth weight was achieved. Increased feed intake during late gestation increased the stillborn rate, whereas CY and voluntary feed intake during lactation were reduced. The litter growth and subsequent female reproductive performance were not affected by feed intake during late gestation.

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Table 1. Composition of the experimental diets (as-fed basis)

Ingredient	Gestation[1]	Lactation[2]
Corn	82.69	58.56
Soybean meal	12.87	33.66
Vitamin and mineral premix[3]	1.00	1.00
Dicalcium phosphate	1.00	0.86
Limestone	1.31	1.39
Salt	0.50	0.50
L-Lys	0.18	0.33
DL-Met	0.04	0.10
L-Thr	0.09	0.14
Soybean oil	–	3.00
Phytase	0.01	–
Others	0.31	0.46
Total	100.00	100.00
Calculated Analysis		
SID[4] Lys, %	0.64	1.27
SID Met: Lys, %	38	31
SID Met and Cys: Lys, %	70	54
SID Thr: Lys, %	74	64
SID Trp: Lys, %	18	18
SID Val: Lys, %	80	67
CP, %	13.39	21.68
Ca, %	0.82	0.89
STTD P[5], %	0.50	0.56
Na, %	0.23	0.24
Cl, %	0.46	0.60
ME, Mcal/kg	3,288	3,429
NE, Mcal/kg	2,521	2,550

[1]Diet was fed from day 90 of gestation to farrowing.
[2]Diet was fed during the lactation period.
[3]Vitamin composition per kg of diet – Gestation: Vitamin A: 13,800 IU/kg; vitamin D_3: 2,760 IU/kg; vitamin E: 92 IU/kg; vitamin K_3: 3,082 ppm; vitamin B_1: 2,300 ppm; riboflavin (B_2): 5,060 ppm; pyridoxine (B_6): 2,760 ppm; vitamin B_{12}: 30.82 ppb; niacin: 30.82 ppm; pantothenic acid: 13.800 ppm; folic acid: 1.932 ppm; biotin: 0.97 mg/kg; choline: 1.800 ppm. Mineral composition – Gestation: Selenium: 0.480 ppm; iron: 135.945 ppm; copper: 75.0 ppm; manganese: 49.765 ppm; zinc: 158.073 ppm; iodine: 1.520 ppm; fluorine: 34.855 ppm; cobalt: 0.600 ppm.
Vitamin composition per kg of diet – Lactation: Vitamin A: 12,000 IU/kg; vitamin D_3: 2,400 IU/kg; vitamin E: 80 UI/kg; vitamin K_3: 2.680 ppm; vitamin B_1: 2.00 ppm; riboflavin (B_2): 4.4 ppm; pyridoxine (B_6): 2.4 ppm; vitamin B_{12}: 26.8 ppb; niacin: 26.8 ppm; pantothenic acid: 12.0 ppm; folic acid: 1.680 ppm; biotin: 0.970 mg/kg; choline: 1.800 ppm. Mineral composition – Lactation: Selenium: 0.400 ppm; iron: 113.416 ppm; copper: 50.0 ppm; manganese: 42.371 ppm; zinc: 131.672 ppm; iodine: 1.260 ppm; fluorine: 28.125 ppm; cobalt: 0.500 ppm.
[4]SID = standardized ileal digestible.
[5]STTD = standardized total tract digestible.

Table 2. Chemical analysis of the diets (as-fed basis)[1]

Ingredient	Gestation	Lactation
Proximate analysis, %		
DM	89.10 (88.87)	89.50 (86.58)
CP	12.79 (13.39)	20.20 (21.68)
Crude Fiber	1.89 (2.17)	2.56 (2.51)
Fat	3.42 (3.11)	7.55 (5.54)
Ash	5.31 (1.91)	5.64 (2.91)
Ca	1.02 (0.82)	1.20 (0.89)
P	0.51 (0.50)	0.65 (0.56)
Total AA, %		
Lys	0.72 (0.74)	1.27 (1.42)
Ile	0.55 (0.51)	0.85 (0.90)
Leu	1.36 (1.28)	1.66 (1.81)
Met	0.28 (0.28)	0.28 (0.43)
Met and Cys	0.44 (0.58)	0.49 (0.75)
Thr	0.60 (0.57)	0.90 (0.94)
Trp	0.12 (0.14)	0.22 (0.26)
Val	0.71 (0.61)	0.97 (0.99)
His	0.36 (0.37)	0.46 (0.58)
Phe	0.69 (0.64)	1.03 (1.05)

[1]Values in parentheses indicate those calculated from diet formulation and are based on the values from the NRC (2012).

Table 3. Effects of feed intake in the last third of gestation on maternal body weight, farrowing performance, and characteristics related to the offspring of gilts under commercial conditions[1]

	Feed intake, kg[2]					Probability, *P* <	
	1.8	**2.3**	**2.8**	**3.3**			
Item	***n* = 244**	***n* = 242**	***n* = 241**	***n* = 250**	**SEM**	**Linear**	**Quadratic**
Body Weight (BW), kg							
day 90	186.6	187.3	187.1	187.2	2.79	0.668	0.714
day 112	200.7	204.6	210.0	213.1	0.58	<0.001	0.200
Weaning	167.8	170.7	171.6	173.9	3.45	<0.001	0.748
Body condition score (BCS)							
day 90	3.6	3.5	3.5	3.5	0.27	0.140	0.352
day 112	3.5	3.5	3.6	3.7	0.03	<0.001	0.385
Weaning	3.0	3.0	3.0	3.1	0.03	<0.001	0.615
Backfat (BF), mm							
day 90	13.4	13.4	13.5	13.4	0.58	0.772	0.768
day 112	13.2	13.6	14.3	14.6	0.12	<0.001	0.381
Weaning	11.8	12.2	12.7	12.9	0.72	<0.001	0.776
Caliper unit							
day 90	15.0	14.8	14.9	14.8	0.79	0.280	0.988
day 112	14.2	14.6	15.2	15.8	0.22	<0.001	0.470
Weaning	11.2	11.4	11.9	12.1	0.84	0.002	0.331
Changes in Period 1, day 90 to 112							
BW, kg	15.0	18.8	24.2	27.4	0.58	<0.001	0.200
BW, %	8.1	10.1	13.1	14.7	0.49	<0.001	0.230
BCS	-0.1	0.0	0.1	0.2	0.02	<0.001	0.707
BF, mm	-0.1	0.4	1.1	1.4	0.12	<0.001	0.381

Caliper unit	-0.8	-0.4	0.3	0.8	0.22	<0.001	0.470
Changes in Period 2, day 112 to Weaning							
BW, kg	-33.4	-35.1	-39.2	-40.2	1.87	<0.001	0.596
BW, %	-16.7	-17.2	-18.7	-18.9	0.88	<0.001	0.625
BCS	-0.5	-0.5	-0.6	-0.6	0.02	<0.001	0.480
BF, mm	-1.5	-1.5	-1.8	-1.9	0.33	0.008	0.988
Caliper unit	-3.1	-3.4	-3.6	-3.7	0.32	0.001	0.672
Overall changes, day 90 to Weaning							
BW, kg	-18.7	-16.7	-15.4	-13.3	1.44	<0.001	0.991
BW, %	-10.0	-8.9	-8.1	-7.0	0.83	<0.001	0.923
BCS	-0.6	-0.5	-0.5	-0.4	0.04	<.0001	0.484
BF, mm	-1.6	-1.2	-0.8	-0.5	0.27	<.0001	0.553
Caliper unit	-4	-3.7	-3.3	-2.9	0.36	<.0001	0.577
Litter size							
Total born, *n*	14.5	14.1	14.3	14.3	0.29	0.600	0.333
Born alive, *n*	13.8	13.2	13.3	13.4	0.23	0.208	0.079
Born alive + stillborn, *n*	14.2	13.8	14.0	14.0	0.27	0.590	0.277
Stillborn, %[3]	3.4[a]	4.6[b]	5.5[b]	4.2[b]	0.52	-	-
Mummified fetuses, %[3]	2.0	2.1	1.8	1.9	0.33	-	-
Piglet weight							
Average piglet birth weight, g[4]	1300	1327	1298	1289	14.15	0.193	0.083
Total litter weight, kg[4]	18.0	18.3	18.0	17.8	0.20	0.109	0.059
Birth weight CV, %	18.7	18.7	18.8	19.3	0.39	0.256	0.621
Piglets weighing <1,000 g, %[3]	16.6a	14.2b	17.1a	17.9a	1.06	-	-
Subsequent Performance							

Weaning-to-estrus interval, d[5]	4.9	4.9	4.8	4.7	0.09	0.082	0.228
Bred up to 7 d after weaning, %	85.7	84.2	86.4	87.5	2.3	0.462	0.584
Farrowing rate, %	91.7	93.2	94.1	95.2	1.6	0.135	0.993
Retention rate, %	88.2	86.0	88.2	89.3	2.1	0.565	0.442
Total piglets born, *n*	13.9	13.8	13.7	13.4	0.26	0.163	0.682
Born alive, *n*	13.0	12.9	13.0	12.6	0.25	0.379	0.523

[1]A total of 977 females (Landrace × Large White) were used, with 244, 242, 241, and 250 females for the treatments 1.8, 2.3, 2.8, and 3.3 kg/d, respectively.

[2]Feed intake: 1.8, 2.3, 2.8, and 3.3 kg/d from day 90 of gestation until farrowing.

[3]Submitted to a non-parametric analysis.

[4]Calculated considering the number of born alive + stillborn.

[5]Analyzed considering females in estrus until day 10 after weaning.

[a-b]: means in the row with one letter in common are not significantly different ($P > 0.05$).

Table 4. Effects of feed intake in the last third of gestation on the performance of sows and piglets during the lactation period[1].

Item	**Feed intake, kg[2]**				**SEM**	**Probability, *P* <**	
	1.8 ***n* = 61**	**2.3** ***n* = 66**	**2.8** ***n* = 55**	**3.3** ***n* = 63**		**Linear**	**Quadratic**
Colostrum yield, kg	3.6	3.5	3.3	3.2	0.26	0.016	0.703
Post-farrowing weight, kg	176.8	180.8	185.3	188.5	1.32	<0.001	0.668
Voluntary feed intake, kg	4.2	4.1	3.8	3.9	0.23	0.001	0.165
Lactation weight change, kg	-14.3	-16.8	-20.8	-19.2	1.31	<0.001	0.058
Lactation weight change, %	-8.1	-9.3	-11.3	-10.4	0.75	<0.001	0.169
Litter size after cross-fostering, *n*	13.6	13.7	13.5	13.6	0.20	0.815	0.818
Piglets weight after cross-fostering, g	1411	1450	1411	1388	26.86	0.339	0.225
Litter weight after cross-fostering, kg	19.2	19.7	19.1	18.9	0.37	0.332	0.292
Weaned piglets, %	87.9	86.8	87.5	86.9	1.18	0.677	0.854
Litter weight on d 19 d, kg	59.2	58.2	59.2	59.9	2.08	0.494	0.401
Individual weaning weight on d 19, kg	4.9	4.9	5.0	5.1	0.16	0.196	0.489

[1]A total of 245 females (Landrace × Large White) were used, with 61, 66, 55, and 63 females for the treatments 1.8, 2.3, 2.8, and 3.3 kg/d, respectively.

[2]Feed intake: 1.8, 2.3, 2.8, and 3.3 kg/d from day 90 of gestation until farrowing.

4 CAPÍTULO 3 – SEGUNDO ARTIGO CIENTÍFICO

ARTIGO PUBLICADO NA REVISTA
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Maternal nutrition during early and late gestation in gilts and sows under commercial conditions: impacts on maternal growth and litter traits

André L Mallmann, Deivison P Fagundes, Carlos E Vier, Gabriela S Oliveira, Ana P G Mellagi, Rafael R Ulguim, Mari L Bernardi, Uislei A D Orlando, Ricardo J Cogo, Fernando P Bortolozzo ✉

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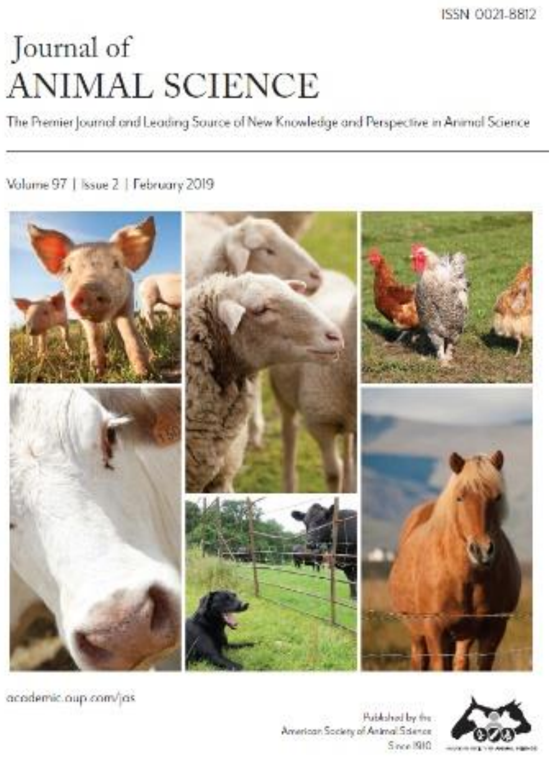

Running head: Gestation nutrition and piglet birth weight

Maternal nutrition during early and late gestation in gilts and sows under commercial conditions: impacts on maternal growth and litter traits

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ABSTRACT

The effects of two different feeding levels, offered in two phases during gestation, on body measurements and litter traits were evaluated in 152 gilts and 551 sows. The treatments consisted of the combination of two gestation phases (Phase 1 - d 22 to 42; Phase 2 - d 90 to 110) and two feed amounts (1.8 or 3.5 kg/d). Females were weighed on days 22, 42, 90, and 110 of gestation. Born alive and stillborn piglets were weighed within 12 h of birth. Total placental efficiency (ratio between litter weight and total placental weight) was measured in 518 females. Variables concerning body measurements at days 42 and 90 of gestation were analyzed considering the effects of feed amount, parity order (**PO**) and its interaction as a 2 × 2 factorial arrangement. Body measurements at day 110 of gestation and litter traits were analyzed considering the effects of feed amounts in Phase 1, feed amounts in Phase 2, PO and their interactions, as a 2 × 2 × 2 factorial arrangement. As expected, body weight, backfat and caliper units were greater at days 42, 90 and 110 ($P \leq 0.006$) for females fed 3.5 kg/d during the previous phase than those fed 1.8 kg. No differences were observed among feed levels in total number of piglets born, mummified fetuses, sum of born alive and stillborn piglets, and within-litter birth weight CV ($P \geq 0.118$). The percentage of stillborn piglets was affected by a 3-way interaction (feed level at Phase 1 × feed level at Phase 2 × PO). Gilts fed 1.8 kg/d at Phase 1 and 3.5 kg/d at Phase 2 had fewer stillborn piglets than the other females ($P \leq 0.004$). Birth weight was not affected by feed levels ($P \geq 0.153$); however, sows had heavier piglets than gilts ($P < 0.001$). Females fed 3.5 kg/d during Phase 2 tended to have heavier litters ($P = 0.054$) than those fed 1.8 kg/d. Feeding a high level at Phase 2 reduced the occurrence of lightweight piglets in gilts, but not in sows (feed level Phase 2 × PO; $P = 0.031$). Total placental weight, average placental weight and total placental efficiency were not affected by feed level at Phase 1, feed level at phase 2 or interactions ($P > 0.14$). Sows had total placental weight and average placental weight greater ($P \leq 0.003$) than gilts. In conclusion, increasing feed intake during Phase 1, Phase 2, or both phases resulted in increased maternal body weight gain, without expressive effects on litter traits. Feeding 3.5 kg/d to gilts during Phase 2 reduced the occurrence of lightweight piglets.

Keywords: birth weight, feeding, gilts, reproduction, sows

INTRODUCTION

Over the last decades, genetic improvements concerning pig litter size have created a problem due to the concomitant reduction in birth weight. Different efforts regarding nutritional strategies have been made to improve the birth weight of piglets or to compensate for the birth weight reduction resultant from larger litter sizes (De Vos et al., 2014; Gonçalves et al., 2016a).

Fetuses grow at an exponential rate during late gestation (McPherson et al., 2004), and the negative impacts of reduced intrauterine growth can persist during the lifetime of lightweight piglets. A common strategy to improve the birth weight of piglets is to feed females with higher feed amounts - bump feeding - in late gestation. However, our recent studies (Mallmann et al., 2018; 2019) and others presented in the literature (Gonçalves et al., 2016a) have not shown any benefits of the bump feeding practice, irrespective of the litter size (Mallmann et al., 2018).

One of the reasons for low piglet birth weight can be found earlier in gestation. In modern hyper-prolific females, high ovulation rates and a consequently greater number of embryos on day 30 of gestation can compromise embryo development (Foxcroft et al., 2009; Da Silva et al., 2016). The availability of nutrients in utero can alter the expression of some genes during the peri-implantation period, with consequences for the growth of conceptuses. Among intrauterine environmental factors, nutrition affects the rapid placental development during the first trimester of gestation, playing a critical role in ensuring adequate uteroplacental blood flow and fetal growth (Wu et al., 2004). In this sense, the occurrence of conceptus losses between days 22-42 of gestation is likely due to the nutritional failures caused by insufficient placental development (Wright et al., 2016). The epitheliochorial placenta is established around days 26-30 of gestation (Dantzer, 1985) and is responsible for transporting nutrients, gases, and wastes between maternal and fetus systems (Reynolds and Redmer, 1995). In a molecular basis approach, higher energy levels throughout gestation have improved placental efficiency and reduced piglet birth weight variation (Che et al., 2017). Moreover, females fed lower energy amounts, based on the daily maintenance level, in different short time points during gestation (27 to 34, 55 to 62, and 83 to 90 d of gestation) had lighter piglets at birth (Ren et al., 2017).

The mentioned approaches are part of the current challenge, which is based on the following question: how can piglet birth weight be improved if females submitted to bump feeding do not transfer the extra energy ingested to fetal growth? It has been suggested that earlier placental development is necessary to support higher blood flow and, consequently, later greater energy exchange between maternal uterus and fetuses (Meschia, 1983; Reynolds and Redmer, 1995). We hypothesize that higher amounts of feed during the exponential placental development period (days 22 to 42) may improve placental efficiency, allowing a better nutrient exchange later in gestation in females submitted to bump feeding. Our objective is therefore to evaluate the bump feeding effects on maternal growth and litter traits using two feed amounts (1.8 or 3.5 kg) and two different phases (days 22 to 42 and 90 to 110 d) during gestation of gilts and sows under commercial conditions.

MATERIALS AND METHODS

The protocol used in the present study was approved by the Ethics Committee of Animal Utilization (CEUA) of the Federal University of Rio Grande do Sul (UFRGS), under the process no. 36267.

Location

The study was conducted in a pig farm with 5,500 females, located in the Midwest of Paraná State, Brazil (24°55'04'' S, 50°05'50'' W), between January and April (average, minimum, and maximum temperatures were 23.5, 16.1, and 34.0ºC, respectively, with an average relative humidity of 86.7%, corresponding to summer and early autumn in the southern hemisphere.

Housing and Feeding

Females were moved to gestation pens after the last insemination (1.8 ± 0.8 d later) and were housed in static groups during gestation (around 70 females per pen), which means with no movements of newly bred sows into the pen until the entire group reached 110 d of gestation. Pens with 140 m^2 provided 2.0 m^2 per animal, for both gilts and sows, and were equipped with one electronic feeding station (**ESF**; SowComp, WEDA Dammann & Westerkamp GmbH, Germany), allowing space for up to 70 females. All females were fed by ESF and could enter the equipment as often as they wished. The ESF system recorded daily feed intake during the experimental period. The amount of feed recorded by the system was assumed to be consumed by the females before they left the feed station. Nipples provided *ad libitum* access to water.

Feed content was calculated monthly based on the analysis of ingredients. Dietary samples were collected every 2 weeks for 4 months and analyzed in triplicates for crude protein **(CP)**, total AA, and dry matter (methods described in CBAA, 2017, based on **AOAC** – Official Methods of Analysis of AOAC International Methodologies, 19th edition, 2012). Samples were also analyzed for crude fiber, ash, ether extract, calcium, and phosphorus (AOAC Int., 2012; CBAA, 2017).

Experimental and Treatment Design

From d 0 to d 21 and from d 43 to d 89 of gestation, all females were fed 1.8 kg/d of a corn-soybean-based meal with 3.15 Mcal ME/kg, 15.0% CP, and 0.68% SID Lysine (Table 1). The analyzed diet was considered consistent with the formulated values based on analytic variability (Table 1). During the other gestational periods, females were fed according to the groups cited below.

On day 20 of gestation, a total of 152 gilts and 551 sows, with parity (**PO**) 0 to 5 (PIC Camborough®, Hendersonville, TN, Landrace × Large White crossbred) were selected according to the general health status and a body condition score between 2.5 and 4.5 (1-5 scale; Young et al., 2004). Females were individually weighed and assigned to two treatments, in a completely randomized design, to be fed a corn-soybean-based diet: 1.8 kg/d (5.7 Mcal ME and 12.2 g/d SID Lys) and 3.5 kg/d (11.0 Mcal ME and 23.8 g/d SID Lys). On day 89 of gestation, females of each group were again randomly assigned to receive two different feed levels: 1.8 or 3.5 kg/d. From that moment onwards, the treatments consisted of the combination of two feed amounts (1.8 or 3.5 kg/d) offered in two gestation phases (Phase 1 - d 22 to 42; Phase 2 - d 90 to 110) for both gilts and sows. Females were moved to farrowing rooms on day 110 of gestation and fed 1.8 kg/d of a corn-soybean-based meal (3.30 Mcal ME/kg, 20.0% CP, and 1.20% SID Lysine) until farrowing.

All females were weighed and submitted to backfat (**BF**) and caliper evaluations at the beginning and the end of each phase (22, 42, 90, and 110 d of gestation). All weight measurements were performed with a 500-g precision scale (EW6, Tru Test, Auckland, New Zealand). Backfat measurements were performed at the P2 point (6.5 cm away from the midline of the vertebral column at the last rib level) with A-mode ultrasonography (Renco Lean Meter – Renco Corporation, Minneapolis, MN) within a range of 2 mm. Caliper unit was taken on the same backfat point with the caliper equipment in a unit range from 1 to 25 (Knauer and Baitinger, 2015). The birth weight of the piglets born alive and stillborn was recorded within 12 h of birth, using a 1-g resolution scale. Mummified fetuses were not weighed; however, the number was recorded and included in the total number of piglets born.

Placental Efficiency

The total weight of placentas was recorded after farrowing in 518 females. The average placental weight was calculated dividing the total weight of placentas by the sum of piglets born alive and stillborn piglets. According to Wilson et al. (1999), placental efficiency is determined as a ratio between individual piglet birth weight and respective placental weight. In the present study, a total placental efficiency was obtained as a ratio between the litter weight and the respective total placental weight, as reported by Dallanora et al. (2017).

Statistical Analysis

Statistical analysis was performed using the Statistical Analysis System software, version 9.3 (SAS® Inst. Inc., Cary, NC). The models for analysis of variables concerning the responses of Phase 1 included PO (gilts or sows), feed amounts (1.8 or 3.5 kg/d), and their interaction as fixed effects, in a 2 × 2 factorial arrangement. From Phase 2 onwards, the analysis considered a 2 × 2 × 2 factorial arrangement, including PO, feed amounts of Phase 1, feed amounts of Phase 2, and their interactions as fixed effects.

The following variables were analyzed using the GLIMMIX procedure fitted assuming a normal distribution: BW, BF, and caliper unit at different time points and their respective gains and losses, total number of piglets born, born alive piglets, sum of born alive and stillborn piglets, litter weight, piglet weight at birth, total placental weight, average placental weight, and placental efficiency. The sum of born alive and stillborn piglets was used as a covariate for the analysis of litter weight, piglet weight at birth, total placental weight, average placental weight, and total placental efficiency. The results of differences in body measurements (i.e., gain or loss) are presented in intervals during gestation: days 22 to 42, days 42 to 90, days 90 to 110, and for the overall period (days 22 to 110).

The percentages of stillborn piglets, mummified fetuses, and piglets weighing less than 1000 g were analyzed using the GLIMMIX procedure fitted assuming a binomial distribution. The total number of piglets born was significant as a covariate in the analysis of stillborn piglets and mummified fetuses. The within-litter birth weight CV was analyzed as a beta distribution using the GLIMMIX procedure.

Week of treatment onset and pen nested within PO were included as random effects. Differences were considered significant at $P \leq 0.05$, and P-values between 0.05 and 0.10 were designated as a tendency. Each female was considered as an experimental unit.

RESULTS

Body Measurements

No differences were observed between the feed levels for BW, BF, and caliper units on day 22 (Table 2; $P > 0.458$). However, gilts and sows differed ($P < 0.006$) in BW (153.5 ± 4.7 and 213.8 ± 3.1 kg) and caliper unit (14.2 ± 0.2 and 13.5 ± 0.1), respectively, with no difference in BF (12.4 ± 0.3 and 12.6 ± 0.2 mm; $P = 0.501$). The BW, BF, and caliper units were greater on days 42 and 90 in females fed 3.5 kg/d ($P \leq 0.006$; Table 2). Only BW was different between gilts and sows on days 42 and 90 ($P < 0.001$).

The gains of BW and BF from day 22 to 42 were affected by the interaction between feed amount and PO ($P < 0.04$; Table 2). Within females fed 1.8 kg/d, gilts gained 4.4 kg more weight than multiparous sows ($P < 0.001$); however, no differences were observed between gilts and sows fed 3.5 kg/d. The BF gain was greater in gilts fed 3.5 kg/d than in multiparous sows fed 1.8 kg/d ($P = 0.032$). Both gilts and sows fed 3.5 kg/d showed greater BF gain than those fed 1.8 kg/d, with no difference between parities within the feed levels ($P \geq 0.722$). Females fed 3.5 kg/d in Phase 1 gained more caliper units between day 22 and 42 than those fed 1.8 kg/d ($P < 0.001$).

The BW gain between 42 and 90 d of gestation was affected by the interaction between feed intake in Phase 1 and PO. Gilts fed 3.5 kg/d and sows fed 1.8 kg/d had similar BW gain ($P > 0.05$; Table 2), whereas gilts fed 1.8 kg/d gained more BW than sows fed 3.5 kg (P < 0.001). Within each feed level, gilts gained more BW than sows ($P < 0.001$), and both gilts and sows fed 1.8 kg/d had greater BW gain from day 42 to 90 than those fed 3.5 kg/d between 22 to 42 d ($P < 0.001$). The change in BF from day 42 to 90 was not affected by feed intake, PO, and their interaction ($P \geq 0.280$; Table 2). The females fed 3.5 kg/d between 22 to 42 d showed greater caliper loss from 42 to 90 d of gestation than those fed 1.8 kg/d ($P < 0.001$).

The mean and SEM values concerning the effects of feed levels offered at both phases are presented in Table 3, while the probabilities values are shown in Table 4. High feed intake during Phase 1 or Phase 2 resulted in greater BW, BF, and caliper unit levels on day 110 ($P \leq 0.006$). Sows were 50.6 kg heavier than gilts on day 110 (258.9 *vs.* 208.3 kg; $P < 0.001$), respectively. An interaction between feed intake in Phase 2 and PO was observed for changes in BW and BF between 90 and 110 d ($P \leq 0.016$). Within the 3.5 kg/d feed level, sows gained 4.0 kg more than gilts ($P = 0.029$), with no difference when fed 1.8 kg/d ($P = 0.938$). The interaction for BF change showed that gilts fed 3.5 kg/d during Phase 2 gained more BF from day 90 to 110 than sows fed 1.8 kg/d ($P < 0.001$). Both gilts and sows fed 3.5 kg/d during Phase 2 gained more BF from day 90 to 110 than gilts and sows fed 1.8 kg/d, respectively ($P < 0.001$). Within each feed level in Phase 2, no effect of PO was observed for BF changes ($P \geq 0.291$). Although the change in caliper unit was affected by feed intake in Phase 1 ($P = 0.026$), it was more significantly affected by feed intake in Phase 2 ($P < 0.001$). The females fed 3.5 kg/d lost 0.14 and gained 0.53 units, whereas females fed 1.8 kg/d gained 0.06 and lost 0.60 units when considering feed levels at Phase 1 and Phase 2, respectively.

Considering the overall changes (days 22 to 110; Tables 3 and 4), the interactions between feed level in Phase 1 and PO and between feed level in Phase 2 and PO ($P \leq 0.012$) affected the overall BW. Within both gilts and sows, 3.5 kg/d in Phase 1 or Phase 2 resulted in a greater BW gain than 1.8 kg/d. Within 3.5 kg/d, gilts and sows did not differ ($P > 0.065$), whereas a greater BW gain was observed in gilts than in sows fed 1.8 kg/d ($P < 0.001$). The changes in BF and caliper unit were affected by feed intake offered in both Phase 1 and Phase 2 ($P < 0.001$). Females fed 3.5 kg/d had greater BF and caliper gain than those fed 1.8 kg/d. Overall, caliper changes were also affected by PO (P = 0.002), with gilts losing (-0.36) and sows gaining (0.29) caliper units.

Litter Traits

The mean and SEM values concerning the effects of feed levels offered at both phases are presented in Table 3, while the probabilities values are shown in Table 4. The number of total piglets born, born alive, the sum of piglets born and born alive, and the percentage of mummified fetuses were not affected by feed levels, PO or their interactions ($P \geq 0.135$). The 3-way interaction (feed level at Phase 1 × feed level at Phase 2 × PO) affected the percentage of stillborn piglets ($P = 0.008$). Gilts fed 1.8 kg/d at Phase 1 and 3.5 kg/d at Phase 2 had fewer stillborn piglets than the other females ($P \leq 0.007$). The sows fed 3.5 kg/d at Phase 1 and 1.8 kg/d at Phase 2 had a greater percentage of stillborn piglets than either gilts fed the same feed levels and sows fed 1.8 kg/d at Phase 1 and 3.5 kg/d at Phase 2 ($P \leq 0.043$).

Sows had heavier piglets ($P < 0.001$; 1367.5 *vs.* 1503.0 g) and heavier litters ($P <$ 0.001; 20.8 *vs.* 19.2 kg) than gilts. Although birth weight was not affected by feed amount in any phase ($P > 0.150$), total litter weight was marginally greater in females fed 3.5 kg/d (20.2 *vs*. 19.7 kg) during late gestation ($P = 0.054$). Even though the within-litter birth weight CV was not affected by feed level or PO ($P \geq 0.118$), the percentage of piglets weighing < 1,000 g was affected by the interaction between the feed level at Phase 2 and PO ($P = 0.031$). Gilts fed 3.5 kg/d had a lower percentage of lightweight piglets than those fed 1.8 kg/d ($P = 0.006$; 13.4 *vs.* 18.8%, respectively), with no difference in sows (P = 0.419; 13.5 *vs.* 14.7%, respectively).

Total placental weight, average placental weight and total placental efficiency were not affected by feed level at Phase 1, feed level at phase 2 or interactions ($P > 0.14$). Although sows had total placental weight and average placental weight greater ($P \leq$ 0.003) than gilts (3.3 *vs.* 3.0 kg and 232.2 *vs.* 209.6 g, respectively), the total placental efficiency was not different ($P = 0.604$) between sows and gilts (6.9 *vs.* 7.0).

DISCUSSION

Effects on Body Measurements

We demonstrated that increasing the feed amount in one or two different phases during gestation significantly increased BW, BF, and caliper units. Conventional gestating feeding programs are established to fulfill the requirements for maintenance, maternal growth, and fetal and mammary gland growth, in addition to the development of the uterus and the placenta (NRC, 2012). Early-mid gestation is the best opportunity to recover the body reserves lost in the previous lactation phase, whereas in late gestation, the objective is to provide adequate nutrients for fetal and mammary gland growth (Goodband et al., 2013; Menegat et al., 2017). Assuming the equation proposed by the NRC (2012) to calculate the energy necessary for maintenance under thermoneutral conditions (100 kcal × $BW^{0.75}$), gilt and sow requirements on day 20 were 4.4 and 5.6 Mcal/d, increasing to 5.2 and 6.1 Mcal/d on day 90, respectively. Similar results have been reported by Thomas et al. (2018a), who showed increases of 20 and 14% in the maintenance of gilts and sows as gestation progressed. The lysine requirements increase in a greater proportion, from 6.8 to 15.3 g/d, as gestation progresses (Kim et al., 2009), based on fetal tissue gain (Mc Pherson et al., 2004) and mammary gland development (Ji et al., 2005). Considering the feeding levels used in the present study, females fed 1.8 kg/d ingested 5.7 Mcal/d and 12.2 g/d SID Lys, while the 3.5 kg/d treatment provided 11.0 Mcal/d and 23.8 g/d SID Lys. When fed 1.8 kg/d, sows had their maintenance energy requirements fulfilled on day 20 of gestation. Even though the energy provided by 1.8 kg/d was 0.4 Mcal below the level recommended for maintenance on day 90 of gestation, the sows had an overall BW gain.

However, it is necessary to consider that slight losses in caliper units occurred in gilts and sows, mostly during late gestation, when 1.8 kg/d was provided in both phases or only in Phase 2, indicating that fat and protein were mobilized. Knauer and Baitinger (2015) observed that caliper measurement is correlated with loin depth (i.e., protein reserves; r = 0.51) and backfat (r = 0.62), which agrees with the correlation of 0.61 with BF (data not shown) observed in the present study. Mallmann et al. (2019) also observed losses of BF (- 0.1 mm) and caliper unit (-0.8) when gilts were fed 1.8 kg/d during late gestation, even though they had whole BW gain (15.0 kg). If the BW gain in females fed 1.8 kg/d during late gestation (~9 kg) and their litter weight at farrowing (~19 kg) are considered, we can attribute the BW increase to whole BW gain instead of gain in maternal weight. In general, sows will only lose BW when a severe restriction is applied; however, they will use fat and protein reserves to meet the energy requirements for fetal growth (Goodband et al., 2013). In a recent study performed in sows, BW losses were observed when the feed level was set at 50% of the maintenance level in three different short gestational periods, whereas females fed the maintenance level during the entire gestation gained 24 kg between 27 and 109 d (Ren et al., 2017).

In the present study, gilts gained 54.8 kg in BW during the overall gestation, which is close to the recommendation of 55 kg reported previously (Ji et al., 2005; NRC, 2012). Thomas et al. (2018b) reported no BF gain during gestation in gilts, whereas we observed a BF gain of 2.5 mm. It should, however, be noted that our gilts were thinner at the onset of the experimental period when compared to the gilts in their study (12.4 *vs.* 18.2 mm).

Effects on Litter Traits and Birth Weight

Bump feeding is a common and controversial feeding strategy used in breeding herds and consists of increasing the feed amount after day 90 of gestation to meet the requirements of females and to increase piglet birth weight (Gonçalves et al., 2016a). Based on recent studies that used this strategy, our attempt was to verify the effects of bump feeding late in gestation in females that received a greater feed amount between 22 and 42 d of gestation, which includes the period of placental establishment (Dantzer, 1985) and is also considered a critical phase for embryo survival and development (Geisert and Schmitt, 2002). Furthermore, if the intention is to have a greater maternal-fetal exchange during late gestation, an adequate vascular bed development earlier in gestation is necessary (Meschia, 1983). In our earlier studies (Mallmann et al., 2018; 2019), we inferred that one of the reasons why the birth weight was not increased in bump-fed females might be the metabolic state earlier in gestation, as suggested by Foxcroft (2009). However, even though a better metabolic state was provided by increasing the feed amount during the placenta establishment, placental efficiency and birth weight were not improved in the present study. Some studies tried to improve placental efficiency (Dallanora et al., 2017) or angiogenesis (Mateo et al., 2007) by changing the amino acid profile. Individual placental weight was increased when the amino acid profile was changed in different moments during gestation, although no effects were found on placental efficiency and piglet birth weight (Dallanora et al., 2017). Krombeen et al. (2018) studied the different factors that contribute to placental efficiency variation and reported 6.73 as the most efficient placental unit and 4.85 as the least efficient one; the associated fetuses differed in placental weight by 24.95%, contrasting with a difference of only 4.15% in body weight (Krombeen et al., 2018). This indicates that there are compensatory mechanisms that ensure adequate fetal growth when the placenta size is restricted, and these are not only restricted to the placenta (Vallet et al., 2013).

In the present study, there were no improvements in litter traits in females with a greater feeding level in both phases. Musser et al. (2006) reported that piglet birth weight was not statistically improved when the feed level was increased from 1.81 to 3.61 kg/d, between 30 and 50 d of gestation, even with piglets from females fed 3.61 kg/d being numerically 50 g heavier. However, birth weight was significantly increased when the energy level was increased (from 0.5 to 1, 1.5, and 2 × maintenance) in three different short periods, at 27-34, 55-62, and 83-90 d of gestation (Ren et al., 2017). Using 14 gilts per group, Che et al. (2017) increased the energy level in 0.4 Mcal DE/d during the entire gestation, which resulted in an increase in birth weight by 150 g, with a reduction from 20.9 to 12.0% in within-litter variation. In the present study, although the treatments did not affect within-litter variation, there was a reduction by 5.3% in lightweight piglets when gilts ingested more feed during late gestation. In a previous study, the occurrence of lightweight piglets reduced by 2.4% following the increase in feed amount from 1.8 to 2.3 kg/d in late gestating gilts, with no improvements when the feed amount increased to 2.8 and 3.3 kg/d (Mallmann et al., 2019).

The total numbers of piglets born or born alive piglets were not affected by changing the amount of feed in any of the gestational phases. In agreement, litter size was not affected when different feeding levels were provided during specific (days 25 to 50, 25 to 70, 45 to 85) phases (Nissen et al., 2003; Cerisuelo et al., 2008). Based on the maintenance requirements, Ren et al. (2017) changed the feeding levels, in three different periods of 7 d during gestation, and no effects were observed in total piglets born, born alive piglets, and stillborn piglets. However, in females with fewer piglets born (10.5 piglets per litter) than in the current study, a greater amount of feed (1.81 *vs.* 3.63 kg/d), provided between 30 and 50 d of gestation, resulted in a reduction by 1.2 piglets (Musser et al., 2006). In recent studies, bump feeding has been associated with more stillborn piglets. For example, Gonçalves et al. (2016b) reported an increased stillborn rate in sows fed a high energy level. In another study, gilts fed 1.8 kg/d had a lower percentage of stillborn piglets than gilts fed 2.3, 2.8, or 3.3 kg/d late in gestation (Mallmann et al., 2019). In the present study, however, gilts that received 1.8 kg/d from 22 to 42 d and 3.5 kg/d in late gestation had a stillborn rate unexpectedly lower than the other groups, with unexplained underlying reasons.

Against this background, it is necessary to better understand the placental functions and to develop economically viable strategies to improve its development and functions in order to increase litter uniformity and piglet birth weight (Vallet et al., 2013).

Based on our findings and on those of other studies performed in a commercial perspective, providing greater feed levels (Mallmann et al., 2018; 2019) or greater energy or lysine levels (Gonçalves et al., 2016b) is not justified because productive returns do not compensate them. In general, the benefits obtained with different feeding strategies are not substantial, and in our understanding, the way to solve this issue is to change the traits considered in selection programs. Including new traits in breeding selection indices will provide an excellent opportunity to mitigate some antagonisms (Amer et al., 2014), such as the relationship between litter size and piglet birth weight.

CONCLUSIONS

In gilts and sows with a suitable body condition, the BW and BF gains during gestation increased as the feed amount increased in Phase 1 (days 22 to 42), Phase 2 (days 90 to 110), or in both phases. Piglet birth weight was not increased with greater feed amounts; however, a lower occurrence of lightweight piglets was found when gilts ingested greater feeding levels during late gestation. Placental efficiency was not affected by feed amounts.

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Table 1. Composition of the experimental gestation[1] diet (as-fed basis).

Item	Gestation
Ingredient, %	
Corn	49.6
Oats	14.0
Soybean meal, 46% CP	11.1
Wheat, 14.5% CP	10.0
Rice bran defatted, 17% CP	5.0
Corn DDGS, 6% fat	5.0
Molasses	1.2
Vitamin and mineral premix[2]	0.2
Monocalcium phosphate	0.35
Limestone	1.02
Salt	0.25
Sodium bicarbonate	0.30
L-Lys	0.29
DL-Met	0.02
L-Thr	0.09
Soybean oil	1.2
Phytase[3]	0.02
Others	0.36
Total	100.00
Calculated analysis	
SID[4] Lys, %	0.68
SID Met: Lys, %	37
SID Met and Cys: Lys, %	78
SID Thr: Lys, %	81
SID Trp: Lys, %	23
SID Val: Lys, %	110
CP, %	15.03
Ca, %	0.73
STTD P[5], %	0.40
Na, %	0.25
Cl, %	0.20
ME, Mcal/kg	3.15
Proximate analysis, %	
DM	88.55 (87.78)
CP	14.89 (15.03)
Crude fiber	5.23 (3.85)
Fat	3.38 (4.38)
Ash	5.87 (4.87)
Ca	0.99 (0.73)
P	0.64 (0.40)

Total AA, %[6]	
Lys	0.77 (0.78)
Ile	0.71 (0.58)
Leu	1.29 (1.37)
Met	0.26 (0.28)
Met and Cys	0.56 (0.57)
Thr	0.64 (0.63)
Trp	0.15 (0.16)
Val	0.67 (0.75)
His	0.29 (0.40)
Phe	0.82 (0.64)

[1]Diet was fed during the entire gestation.
[2]*Vitamin composition per kg of diet*: Vitamin A: 12,500 IU; vitamin D_3: 2,500 IU; vitamin E: 125.0 IU; vitamin K_3: 4.5 mg; vitamin B_1: 2.5 mg; riboflavin (B_2): 7.5 mg; pyridoxine (B_6): 3.5 mg; vitamin B_{12}: 33.8 µg; niacin: 50.0 mg; pantothenic acid: 25.0 mg; folic acid: 2.4 mg; biotin: 0.26 mg; choline: 1.25 g. *Mineral composition:* Selenium: 0.64 mg; iron: 75.0 mg; copper: 21.7 mg; manganese: 61.4 mg; zinc: 183.4 mg; iodine: 1.5 mg.
[3]Aela (Auster Animal Nutrition, São Paulo, Brazil) provided 1,000 phytase units per kilogram of diet, with a release of 0.19% STTD P.
[4]SID = standardized ileal digestible.
[5]STTD = standardized total tract digestible.
[6]Values in parentheses indicate those calculated from the diet formulation and are based on the values from the NRC (2012).

Table 2. Effects of feed intake (FI; 1.8 or 3.5 kg/d) during Phase 1 (days 22 to 42) on maternal body measurements in gilts and sows under commercial conditions.

	Gilts			Sows			P-values		
	1.8 kg	3.5 kg		1.8 kg	3.5 kg				
Item	*n* = 74	*n* = 78	SEM	*n* = 280	*n* = 271	SEM	FI	PO[1]	FI × PO[1]
Body weight (BW), kg									
Day 22	153.0	153.9	5.2	213.4	214.3	3.4	0.730	<0.001	0.978
Day 42	164.1	174.8	4.9	220.2	237.2	3.1	<0.001	<0.001	0.209
Day 90	189.0	194.6	4.8	236.3	245.2	3.1	0.002	<0.001	0.488
Backfat (BF), mm									
Day 22	12.5	12.2	0.4	12.6	12.6	0.2	0.592	0.501	0.698
Day 42	13.3	13.9	0.5	13.1	14.4	0.3	0.001	0.739	0.224
Day 90	13.4	13.9	0.5	13.9	15.1	0.3	0.006	0.135	0.198
Caliper unit									
Day 22	14.1	14.4	0.2	13.5	13.5	0.1	0.458	0.006	0.333
Day 42	13.8	15.5	0.3	13.5	14.7	0.2	<0.001	0.192	0.171
Day 90	13.4	14.4	0.3	13.5	14.3	0.2	<0.001	0.902	0.710
Changes, days 22 to 42									
BW, kg	11.1	20.9	0.9	6.7	22.9	0.5	<0.001	0.218	<0.001
BF, mm	0.9	1.7	0.5	0.3	1.7	0.3	<0.001	0.642	0.038
Caliper unit	-0.2	1.2	0.3	-0.02	1.2	0.2	<0.001	0.689	0.470
Changes, days 42 to 90									
BW, kg	24.9	19.8	1.2	16.2	8.0	0.8	<0.001	<0.001	0.020
BF, mm	0.1	0.1	0.5	0.7	0.7	0.4	0.343	0.280	0.670
Caliper unit	-0.4	-1.1	0.3	0.0	-0.5	0.3	<0.001	0.118	0.120

[1]PO = parity order.

Table 3. Effects of feed intake during Phase 1 (days 22 to 42) and Phase 2 (days 90 to 110) of gestation on maternal body measurements, farrowing performance, and characteristics related to the offspring in gilts and sows under commercial conditions[1].

	Gilts					Sows				
	Phase 1 (days 22 to 42)					Phase 1 (days 22 to 42)				
	1.8 kg		3.5 kg			1.8 kg		3.5 kg		
	Phase 2 (days 90 to 110)					Phase 2 (days 90 to 110)				
	1.8 kg	3.5 kg	1.8 kg	3.5 kg		1.8 kg	3.5 kg	1.8 kg	3.5 kg	
Item	*n* = 37	*n* = 37	*n* = 37	*n* = 41	SEM	*n* = 137	*n* = 143	*n* = 135	*n* = 136	SEM
Body weight (BW), kg										
Day 90	189.3	188.7	193.8	195.3	5.7	237.6	235.1	245.0	245.4	3.5
Day 110	199.8	212.1	202.4	219.0	6.1	246.5	262.9	253.5	272.5	3.9
Backfat (BF), mm										
Day 90	13.6	13.2	13.6	14.1	0.7	13.9	13.9	14.7	15.5	0.4
Day 110	13.7	15.1	13.8	16.3	0.6	13.7	15.1	14.9	16.6	0.4
Caliper unit										
Day 90	13.4	13.5	14.4	14.3	0.3	13.4	13.6	14.3	14.2	0.2
Day 110	13.0	14.2	13.7	14.6	0.3	12.8	14.1	13.6	14.7	0.2
Changes (days 90 to 110)										
BW, kg	10.5	23.4	8.6	23.7	1.3	9.0	27.9	8.5	27.2	0.9
BF, mm	0.0	1.9	0.1	2.1	0.5	-0.1	1.2	0.2	1.1	0.3
Caliper unit	-0.4	0.7	-0.7	0.3	0.2	-0.6	0.6	-0.7	0.5	0.1
Overall changes (days 22 to 110)										
BW, kg	52.0	65.2	54.9	70.0	2.8	32.4	51.3	40.1	59.4	1.2
BF, mm	1.3	3.0	1.9	3.7	0.6	1.1	2.6	2.3	4.1	0.3
Caliper unit	-1.2	0.2	-0.6	0.2	0.3	-0.7	0.5	0.1	1.3	0.1
Farrowing performance										
Total born piglets, *n*	14.8	14.6	14.7	14.4	0.6	14.6	15.3	14.9	14.6	0.4
Born alive piglets, *n*	13.5	13.7	13.4	13.2	0.6	13.3	13.8	13.3	13.1	0.3
Born alive + stillborn piglets, *n*	14.6	13.9	14.0	14.0	0.6	14.2	14.7	14.3	14.1	0.3
Stillborn piglets, %	5.3	1.8	4.8	5.4	1.0	5.9	5.6	7.4	6.5	0.6
Mummified fetuses, %	3.1	3.8	2.6	2.3	1.0	2.0	2.5	2.0	2.3	0.4

Litter traits										
Average birth weight, g	1,370.5	1,381.1	1,359.1	1,359.1	35.0	1,487.4	1,509.0	1,473.7	1,542.0	19.2
Litter weight, kg	19.2	19.5	18.9	19.3	0.5	20.4	20.9	20.5	21.2	0.3
Piglets weighing <1,000 g, %	18.4	12.3	19.1	14.6	2.3	14.9	14.5	14.5	12.6	1.2
Birth weight CV, %	21.1	18.6	20.5	19.8	1.3	21.6	21.9	22.0	20.9	0.8
Total placental weight[2], kg	3.1	3.1	3.1	2.9	0.2	3.4	3.2	3.3	3.4	0.9
Average placental weight[2], g	214.6	216.3	209.9	197.5	13.3	235.0	226.0	227.6	240.4	6.6
Total placental efficiency[2,3], g/g	6.7	6.8	7.1	7.4	0.4	6.7	7.1	6.8	6.8	0.2

[1]Probability values are presented in Table 4.

[2]A subsample of 518 females (24 to 32 gilts and 98 to 105 sows per treatment) were used for this analysis.

[3]Calculated as a ratio between litter weight and total placental weight.

Table 4. Probability values corresponding to main effects and interactions among feed intake (1.8 or 3.5 kg) in Phase 1 (FI1 – days 22 to 42), feed intake in Phase 2 (FI2 – days 90 to 110), and parity order (PO) of high-performing gilts and sows on maternal body measurements, piglet birth weight, and farrowing performance under commercial conditions[1].

	Interactions						
Item	FI1 × FI2 × PO	FI1 × PO	FI2 × PO	FI1 × FI2	FI1	FI2	PO
Body weight (BW) day 90, kg	0.945	0.488	0.749	0.593	0.002	0.907	<0.001
BW day 110, kg	0.847	0.461	0.481	0.460	0.006	<0.001	<0.001
Backfat (BF) day 90, mm	0.858	0.192	0.512	0.167	0.006	0.506	0.135
BF day 110, mm	0.606	0.366	0.555	0.311	0.004	<0.001	0.427
Caliper unit day 90	0.702	0.714	0.943	0.510	<0.001	0.948	0.902
Caliper unit day 110	0.947	0.534	0.685	0.449	<0.001	<0.001	0.757
Changes (days 90 to 110)							
BW, kg	0.156	0.802	<0.001	0.289	0.107	<0.001	0.270
BF, mm	0.462	0.750	0.016	0.618	0.400	<0.001	0.343
Caliper unit	0.569	0.078	0.548	0.870	0.026	<0.001	0.964
Overall changes (days 22 to 110)							
BW, kg	0.636	0.012	0.002	0.432	<0.001	<0.001	0.002
BF, mm	0.862	0.140	0.723	0.677	<0.001	<0.001	0.957
Caliper unit	0.332	0.053	0.660	0.163	<0.001	<0.001	0.002
Farrowing performance							
Total born, *n*	0.525	0.916	0.499	0.466	0.597	0.848	0.656
Born alive, *n*	0.798	0.845	0.802	0.364	0.359	0.836	0.813
Born alive + stillborn piglets, *n*	0.330	0.958	0.476	0.945	0.468	0.740	0.657
Stillborn piglets, %	0.008	0.188	0.103	0.020	0.004	0.016	0.002
Mummified fetuses, %	0.645	0.264	0.544	0.425	0.135	0.405	0.281
Litter traits							
Average birth weight, g	0.416	0.455	0.261	0.609	0.842	0.153	<0.001
Litter weight, kg	0.829	0.378	0.562	0.715	0.920	0.054	0.001
Piglets weighing <1,000 g, %	0.309	0.123	0.031	0.951	0.849	0.003	0.315

Birth weight CV, %	0.223	0.679	0.311	0.849	0.993	0.118	0.131
Total placental weight[2], kg	0.198	0.357	0.586	0.742	0.685	0.566	0.003
Average placental weight[2], g	0.197	0.271	0.603	0.780	0.551	0.800	0.001
Total placental efficiency[2,3], g/g	0.487	0.148	0.835	0.904	0.320	0.389	0.604

[1]A total of 703 females were used, with 37 to 41 gilts and 135 to 143 sows per treatment.

[2]A subsample of 518 females (24 to 32 gilts and 98 to 105 sows per treatment) were used for this analysis.

[3]Calculated as a ratio between litter weight and total placental weight.

5 CAPÍTULO 4 – TERCEIRO ARTIGO CIENTÍFICO

ARTIGO PUBLICADO NA REVISTA
“JOURNAL OF ANIMAL SCIENCE”
(De acordo com as normas da revista)

Impact of feed intake in early gestation on maternal growth and litter size according to body reserves at weaning of young parity sows

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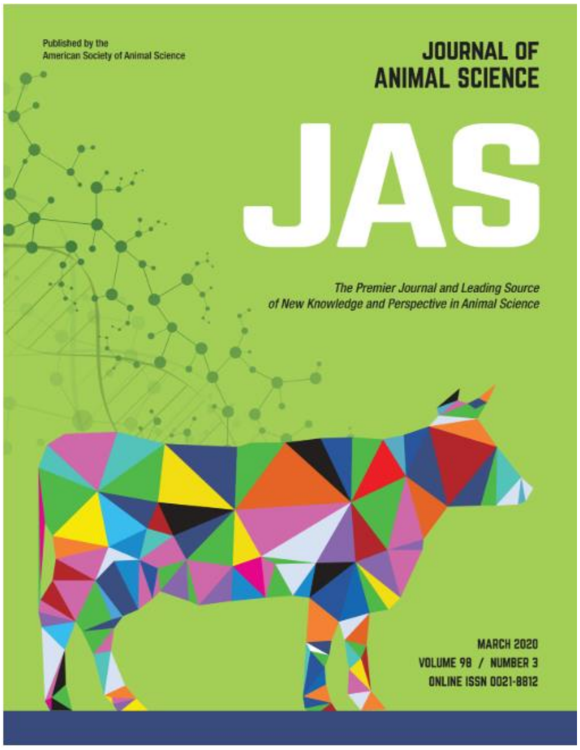

Running head: Feeding strategy early in gestation

Impact of feed intake in early gestation on maternal growth and litter size according to body reserves at weaning of young parity sows

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ABSTRACT

The effect of increasing the feed level (1.8, 2.5, and 3.2 kg/d) during early gestation in parity 1 **(PO1)** and parity 2 **(PO2)** sows on maternal growth and litter size was evaluated. A total of 361 sows were group-housed and fed a diet based on a corn-soybean meal (3.15 Mcal ME per kg and 0.68% SID lysine) from day 6 of gestation until day 30. Sows were weighed at weaning and on day 30 of gestation. Farrowing rate, number of total piglets born, piglets born alive, stillborn piglets, and mummified fetuses were recorded at farrowing. The effect of feed level on the total number of piglets born were also evaluated according to classes of body weight **(BW)**, body condition score **(BCS)**, backfat **(BF)**, and caliper unit at weaning for each parity order. There was no evidence for significant effect of the interaction between feed level × parity on the variables related to maternal growth and reproductive performance ($P \geq 0.128$). Greater feed levels linearly increased the gains in body condition (i.e., BW, BCS, BF, and caliper unit) between weaning and day 30 of gestation ($P < 0.001$). Farrowing rate was not influenced by the feed level ($P \geq 0.200$) and parity ($P \geq 0.209$). The number of total piglets born decreased linearly as the feed level increased ($P = 0.041$); whereas, no evidences for differences were observed on piglets born alive among treatments ($P \geq 0.317$), neither between parities ($P \geq 0.904$). For PO1 sows, the total piglets born on BW classes (≤ 183 kg *vs.* > 183 kg) and on classes of BF (≤ 11.5 mm *vs.* > 11.5 mm) were quadratically affected by the feed levels ($P \leq 0.041$). In contrast, the number of total piglets born was marginally affected (linear; $P \leq 0.094$) by the feed level in the different classes of BW, BCS, and caliper unit in PO2 sows. There was no evidence for differences for the interaction of feed level and classes of body condition ($P \geq 0.199$), for PO2 sows. Similarly, no interactions between feed level and classes of BW, BCS and BF at weaning were observed ($P \geq 0.233$) for PO1 sows, however, the total piglets born were affected by an interaction between feed level and caliper unit class ($P = 0.042$). In conclusion, increased feed intake from day 6 of gestation until day 30 resulted in increased maternal BW gain but reduced the number of total piglets born. Furthermore, lighter and in a poor BCS PO1 sows at weaning produced fewer total born piglets with no benefits from greater amounts of feed.

Keywords: earlier gestation, feeding, reproduction, total born, young sows.

INTRODUCTION

Young parity sows are sensitive to body weight changes during lactation and more prone to subsequent reproductive impairments. The period of early and mid-gestation is commonly used to recover body reserves, especially for young parity sows (NRC, 2012). Lactation performance, and mostly the voluntary feed intake, are affected by body condition at farrowing (Kim et al., 2013; Mallmann et al., 2019). The subsequent reproductive performance may be affected by body losses during lactation and body condition at weaning (Schenkel et al., 2010).

Feeding strategies post-insemination have been discussed over the years, mostly due to their potential impact on reproductive performance (Leal et al., 2019). Early gestation is a critical period for embryo development (Geisert and Schmitt, 2002) because nutritional management and metabolic changes can affect embryo survival and litter size (Langendijk et al., 2017). In a study performed by Jindal et al. (1996), embryo survival in gilts was negatively affected (84.7 *vs*. 64.5%) by increasing the feed allowance (1.9 *vs.* 2.6 kg/d) soon after insemination and up to day 15 of gestation. Conversely, Quesnel et al. (2010) reported that increasing feed allowance (2.0 *vs.* 4.0 kg/d) for gilts, between insemination and day 7 of gestation, did not affect embryo survival (87 *vs.* 84%). Consistent with these latter results, the litter size in parity 1 and 2 sows increased by two embryos when the feed amount was increased from 2.5 to 3.25 kg/d between days 3 and 32 of gestation (Hoving et al., 2011).

It has been reported that feed restriction after insemination should not be recommended in gilts, whereas higher feed amounts appear to benefit young parity sows of contemporary genotypes (Leal et al., 2019). However, most of the studies were performed with gilts under experimental conditions that used a limited number of females per group. Young weaned sows experience lactation catabolism, and thus different approaches are necessary to recover their body condition and maintain the pregnancy. However, how the interaction between feeding strategy used after breeding and the recovery of body reserves affects the subsequent performance of swine females remains unclear. Therefore, understanding the female response according to its body condition at weaning will be necessary to extrapolate the results for practical use in swine systems.

The hypothesis of the present study is that greater amounts of feed earlier in gestation may benefit young parity sows or sows with a poor body condition at weaning. This study aimed to evaluate the effect of three different feed levels (1.8, 2.5 and 3.2 kg/d), offered between days 6 and 30 of gestation, on maternal growth, farrowing rate, and litter size of first and second parity sows.

MATERIALS AND METHODS

The protocol used in the present study was approved by the Ethics Committee of Animal Utilization (CEUA) of the Federal University of Rio Grande do Sul (UFRGS), under Process no. 32657.

Location

The study was conducted in a herd with 5,500 swine females, located in the Midwest of Paraná State (24°55'04" S, 50°05'50" W), Brazil, between January and April (average, minimum, and maximum temperature were 23.5, 16.1 and 34.0ºC, respectively, with 85.3% relative humidity). The two periods correspond to summer and early autumn, respectively, in the southern hemisphere.

Housing and Feeding

The sows were individually housed in stalls (2.2 × 0.7 m) during the lactation period and weaning-to-estrus interval (**WEI**). During both phases, the sows were fed a corn-soybean meal diet with 3.45 Mcal ME/kg, 20.0% crude protein (**CP**), and 1.10%

standardized ileal digestible lysine (**SID Lys**). Feed was provided *ad libitum* during lactation; during the WEI, a total amount of 3.5 kg/d was provided in four meals. The sows were moved to gestation pens at 0.8 ± 0.1 d (0 to 3 d) after the last insemination and housed in static groups during gestation (around 70 females per pen). Pens with 140 m^2 provided 2.0 m^2 per sow and were equipped with one electronic feeding station (**ESF**; SowComp, WEDA Dammann & Westerkamp GmbH, Germany). Feed intake during the treatment period was recorded daily by the ESF system. *Ad libitum* access to water was provided throughout the experiment.

Feed content was calculated monthly based on analyses of ingredients. Dietary samples were collected every 2 weeks for 4 months and analyzed in triplicate for CP, total AA and dry matter (AOAC International, 2012). Samples were also analyzed for crude fiber, ash, ether extract, calcium, and phosphorus (AOAC International, 2012; CBAA, 2017).

Experimental and Treatment Design

A total of 361 sows (parities 1 - **PO1** and 2 - **PO2**; PIC Camborough®, Hendersonville, TN, Landrace × Large White crossbred) were selected at weaning according to general health status and body condition score (**BCS**) between 2.0 and 4.5 (1-5 scale; Young et al., 2004). After weaning, the sows were checked for estrus once a day (09:00 h) by the back-pressure test in the presence of a mature boar. The first insemination was performed at estrous onset and repeated at 24-h intervals during estrus. Each female received 2.2 ± 0.1 semen doses (1.5×10^9 sperm cells; total volume 50 mL).

The day of the first insemination was considered day 0 of gestation. From day 0 until day 5, and from day 31 to farrowing, all sows were fed 1.8 kg/d of a corn-soybean meal diet with 3.15 Mcal ME/kg, 15.0% CP, and 0.68% SID Lys (Table 1). The analyzed diet was considered consistent with formulated values based on analytic variability (Table 2). The selected sows were uniformly distributed, according to body weight (**BW**) at weaning, number of piglets born in previous farrowing, weaned piglets, and days of WEI, into the following treatments: 1) 1.8 kg/d (5.7 Mcal ME and 12.2 g/d SID Lys; 2) 2.5 kg/d (7.9 Mcal ME/d and 17.0 g/d SID Lys); 3) 3.2 kg/d (10.1 Mcal/kg and 21.8 g/d SID Lys). The different feed levels were provided between days 6 and 30 of gestation. The sows were moved to farrowing rooms on day 110 of gestation.

Measurements

All sows were weighed and evaluated for BCS, backfat **(BF)**, and caliper unit on the first day after weaning and at day 30 of gestation. The weight was measured with a 500 g precision scale (EW6, Tru Test, Auckland, New Zealand). The BF measurement was performed on the P2 point (6.5 cm away from the midline of the vertebral column at the last rib level) with an A-mode ultrasound (Renco Lean Meter – Renco Corporation, Minneapolis, MN) within a range of 2 mm. Caliper unit was measured on the same BF point with the caliper equipment in a unit range from 1 to 25 (Knauer and Baitinger, 2015). Reproductive performance criteria were recorded using Agriness S2 software (Agriness, Santa Catarina, Brazil). The following reproductive responses were collected: farrowing rate, number of total piglets born, piglets born alive, stillborn piglets, and mummified fetuses.

Statistical Analysis

Statistical Analysis System (SAS) software, version 9.3 (SAS Inst. Inc., Cary, NC), was used to perform the statistical analysis. All models included feed level as a fixed effect. The week of feed treatment onset was included as a random effect. Polynomial contrasts were used to evaluate the linear and quadratic effects of the dose-response (different feed levels offered daily), parity and their interactions.

The following variables were analyzed using the GLIMMIX procedure, fitted assuming a normal distribution: BW, BF, caliper unit at different periods, and the respective gains and losses; the number of total piglets born and piglets born alive. Body condition score and respective gains or losses were evaluated as a multinomial distribution using the GLIMMIX procedure. The farrowing rate was analyzed as a binary distribution using the GLIMMIX procedure. The total number of piglets born alive, percentage of stillborn, mummified fetuses and the sum of piglets born alive and stillborn piglets were analyzed as binomial distribution using the GLIMMIX procedure.

The effects of the different feed levels on the number of total piglets born and farrowing rate were also evaluated considering different classes of BW, BCS, BF, and caliper unit at weaning, based on the median of these variables. For PO1 sows, classes of body measures at weaning were as follows: BW ($\leq$ 183 and > 183 kg), BCS ($\leq$ 3 and > 3), BF ($\leq$ 11.5 and > 11.5 mm), and caliper unit ($\leq$ 11 and > 11). For PO2 sows, classes of body measures at weaning were as follows: BW ($\leq$ 208 and > 208 kg), BCS ($\leq$ 3 and > 3), BF ($\leq$ 11 and > 11 mm), and caliper unit ($\leq$ 10 and > 10). These analyses were performed mainly to investigate whether feed levels used after breeding and body reserves at weaning would interact to affect the subsequent performance of swine females. Polynomial contrasts were used to evaluate the linear and quadratic effects of the dose-response (different amounts of feed offered daily), the different classes of body condition and their interactions.

Each female was considered to be an experimental unit in all the analyses. The results were considered significant at $P \leq 0.05$; a tendency was considered when $0.05 < P \leq 0.10$. The means were compared using the Tukey-Kramer test.

RESULTS

There was no evidence for differences among treatments at the beginning of the experiment ($P \geq 0.570$) for the total number of piglets born from previous farrowing (13.4 ± 0.2), number of weaned piglets (12.3 ± 0.1), and WEI (4.7 ± 0.1 d), respectively.

Influence of Feed Levels and Parity on Maternal Growth

Body weight, BCS, BF, and caliper unit at weaning were not different among feed levels (Table 3; $P \geq 0.488$), and no evidence for significance was observed for the interaction feed level × parity ($P \geq 0.161$). However, there was an expected effect of parity ($P < 0.001$) on BW at weaning, where PO2 sows were 24.9 kg heavier than PO1. Parity was not evidenced to influence ($P \geq 0.137$) the other variables of body condition at weaning (BCS, BF, and Caliper).

On day 30 of gestation, BW, BCS, BF, and caliper unit increased linearly as the feed level increased (Table 3; $P \leq 0.003$). No evidence for differences in the BCS, and caliper unit ($P \geq 0.158$) between parities were observed; however, the PO2 sows were 19.9 kg heavier ($P < 0.001$) and showed a slightly lower BF ($P = 0.058$) at day 30 of gestation, compared to PO1 sows. There was no evidence for the interaction feed level × parity and for BW, BCS, BF, and caliper unit at day 30 ($P \geq 0.385$). Greater feed levels linearly increased body gains (i.e., BW, BCS, BF, and caliper unit gains) between weaning and day 30 of gestation ($P < 0.001$). Parity 1 sows gained 4.9 kg more weight than PO2 sows ($P < 0.001$) but no evidence for differences were observed ($P \geq 0.223$) in changes of BCS, BF and caliper unit between weaning and day 30 of gestation. The body gains were not affected by the interaction feed level × parity ($P \geq 0.143$).

Influence of Feed Levels and Parity on Farrowing Rate and Litter Size

Farrowing rate did not differ with the feed level (Table 3; $P \geq 0.200$) and between parities ($P = 0.209$). The number of total piglets born decreased linearly as the feed level increased ($P = 0.041$). Parity 2 sows had 1.7 more total piglets born ($P = 0.001$) compared to PO1 sows (Table 3). Piglets born alive, sum of piglets born alive and stillborn piglets, stillborn piglets, and mummified fetuses were not affected by the feed levels ($P \geq 0.106$), neither by the parity order ($P \geq 0.404$). No evidences for significant effect of interaction feed level × parity was observed for all reproductive responses ($P \geq 0.128$).

Influence of Body Condition at Weaning and their Interaction with Feed Levels on Total Piglets Born

For PO1 sows, there was a significant feed level × Caliper class interaction ($P = 0.042$; Table 4) for the number of total piglets born. For females with ≤ 11 caliper units, the total piglets born were quadratically affected, with the highest value observed in 2.5 kg/d level; while for females with > 11 caliper units, no evidence for difference was observed. Regarding the others body condition classes, the 2-way interactions were not evidenced to be significant ($P \geq 0.233$). However, feed level had quadratic effect in the models considering BW class ($P = 0.033$) and BF class ($P = 0.041$); whereas in the model considering BCS class, only a marginally effect of feed level was observed ($P = 0.062$; Table 4). The total number of piglets born was affected by the classes of BW and BCS at weaning in PO1 sows ($P \leq 0.023$). Lighter PO1 sows (≤ 183 kg) and in a poor BCS (≤ 3 kg) at weaning has produced 1.6 and 1.5 less piglets than heavier sows (> 183 kg) or in a better BCS (> 3), respectively. A similar response was observed for females with > 11.5 mm of BF, which tended to produce 0.8 more piglets than those with ≤ 11.5 mm of BF ($P = 0.075$).

In parity 2 sows there was no evidence for significant interaction of feed level × classes of body condition ($P \geq 0.199$; Table 5), neither for the isolated effect of classes of body condition ($P \geq 0.417$) on the number of total piglets born. However, the number of total piglets born was marginally affected (linear; $P \leq 0.094$) by the feed level in the different models considering the classes of BW, BCS, and caliper unit (Table 5). No evidences for differences of the feed levels were observed in models with backfat class ($P = 0.108$).

DISCUSSION

The main objective of this study was to evaluate the effects of different feed levels provided during early gestation on reproductive performance and the capacity to replenish the body reserves in first and second parity sows. Furthermore, the intention was to evaluate whether the effects of feed levels were dependent on the body condition of sows at weaning. This subject has been a focus of discussion in production systems because feeding restriction of gilts and sows immediately after insemination has been recommended. However, as recently reviewed, 75% of the experiments indicated that there is no detrimental effect of high energy levels post-breeding (above maintenance) on embryo survival (Leal et al., 2019). Contrarily, in the remaining experiments, a lower embryo survival was reported in swine females that received a higher feed amount during gestation (Leal et al., 2019). However, those trials were usually performed under experimental conditions that used only two feed levels for comparison and mostly with gilts. The focus of the present study was on young weaned sows, which are more sensitive to body changes during lactation. Young parity sows (PO1 and PO2) were subjected to a dose-response study with three different feed levels (1.8, 2.5, and 3.2 kg/d).

Effects of Feed Levels and Parity on Maternal Growth

The first month of gestation aims to maintain the pregnancy and ensure embryo survival. For early parity, however, these goals become a challenge because sows do not reach their mature body until the fourth or fifth parity (Thomas et al., 2018). Additionally, PO1 and PO2 sows are more prone to have body lactation losses, being necessary to increase the feed intake to recover their body reserves. As expected, using high feed levels earlier in gestation increased the body reserves, regardless the parity. However, even if the feed levels provided approximately 1, 1.5, and 2 times the estimated energy requirements for maintenance, based on their average metabolic BW (100 kcal × BW^$^{0.75}$; NRC, 2012), sows gained less weight than expected. Sows were weighed at weaning, but treatments commenced on gestational day 6. Thus, it is necessary to consider the body losses during WEI (Koutsotheodoros et al., 1998; Werlang et al., 2011). In the present study, BW loss between weaning and gestation housing (~7 d later) was around 4.5% (approximately 9 kg; data not shown), comparable to BW losses between 3.8 and 4.2% previously reported by Koutsotheodoros et al. (1998) and Werlang et al. (2011), respectively. It means that at the beginning of the experiment (day 6 of gestation), females where at least 9 kg lighter than at weaning. So, the real BW gains during the treatment period were, therefore, close to 5, 12, and 18 kg for sows fed 1.8, 2.5, and 3.2 kg/d, respectively. Hoving et al. (2011) reported BW gains of 15.5 and 24.4 kg for females fed 2.5 and 3.25 kg/d between days 3 and 32 of gestation; however, those females were genetically different and lighter than those of the present study. Despite being lighter, their females had more BF at weaning and gained less BF than those in the present study. Similarly, another study reported greater BW gains (15.2 and 20.2 kg) and lower BF gains (1.2 and 1.6 mm) for PO1 sows fed 2.5 and 3.25 kg/d respectively, between days 3 and 35 of gestation (Hoving et al., 2012a).

Regarding parity, PO1 sows gained more weight than PO2 sows during the treatment period, as also reported by Thomas et al. (2018), who attributed it to the greater requirements for maintenance in PO2 sows until day 74 of gestation. Considering the BW at weaning and the feed levels performed, PO1 sows had more energy available to grow because more energy above maintenance was provided (NRC, 2012). It is important to mention that PO1 sows were 24.9 kg lighter than PO2 sows at the beginning of the experiment; so, fewer nutrients and energy for maintenance were needed. Hoving et al. (2011) reported similar BW gain between PO1 and PO2 sows; however, the difference in BW between parities was lower at the beginning of the experiment, compared to our study.

Effects of Feed Levels and Parity on Litter Size and Farrowing Rate

In a recent systematic review, while gilts had no detrimental effects on embryo survival when the energy level of diet in early pregnancy is provided above the maintenance, a positive effect on embryo survival is observed in PO1 sows (Leal et al., 2019). Nevertheless, the negative effect of the increased feed level on total piglets born contrasts with results of other studies that reported no evidences of differences (Virolainen et al., 2005a; Quesnel et al., 2010; Hoving et al., 2012a) or reported an increased embryonic survival or piglets born (Hoving et al., 2011; Athorn et al., 2013). The increase in feed amount from 1.8 to 3.6 kg/d did not affect the litter size in gilts (Virolainen et al., 2005a). Embryo survival and development on day 27 of gestation were not affected by a high feed level (2 *vs.* 4 kg/d) offered during the first 7 d of gestation in gilts (Quesnel et al., 2010). There was greater embryo survival on day 10 after insemination in gilts that received 2.8 compared to 1.5 kg/d (Athorn et al., 2013). Hoving et al. (2011) observed that sows that received extra feed (+ 0.75 kg) had fewer litters with ≤ 13 piglets and more litters with ≥ 17 piglets compared to a control group. In that study, the litter size increased from 13.2 to 15.2 piglets in PO1 and PO2 when the amount of feed was increased from 2.5 to 3.25 kg/d, between days 3 and 32 of gestation. However, in a second study, Hoving et al. (2012a) were unable to increase the litter size in primiparous sows fed 3.25 compared to 2.5 kg/d. In the present study, the finding that 30.9% of sows fed 3.2 kg/d had < 11 piglets, whereas these percentages were only 18.7% and 17.9 % in the 1.8 and 2.5 kg/d groups, respectively (P = 0.055; data not shown), indicates a detrimental impact on litter size of overfed young sows. Consistently, Virolainen et al. (2005b) observed that embryo recovery was lower in multiparous sows fed 4 kg/d than sows fed 2 kg/d.

The reduction in piglets born by the higher-fed sows in the present study may be explained by a higher metabolic clearance of progesterone and its impact on embryo survival (Prime and Symons, 1993). Jindal et al. (1996) reported that a high feed level reduced systemic progesterone and embryo survival in gilts. The effect of feed level on progesterone concentration has been controversial because there are differences in the progesterone profile according to the site of blood collection (caudal vena cava *vs.* systemic circulation). It has been reported that progesterone concentration from the caudal vena cava is higher compared to the jugular vein (Virolainen et al., 2005a; Athorn et al., 2013). The vena cava drains the blood flow from the uterus and ovaries, the sites of local production of progesterone, before hepatic metabolism (Virolainen et al., 2005a). The nutritional regime significantly affected the progesterone concentration in the jugular vein (i.e., systemic measure), with no effect in the caudal vena cava (Virolainen et al., 2005a). These authors also observed a lower post- compared to pre-prandial progesterone concentration in the jugular vein in gilts. This finding provides support of the increased metabolism on portal blood flow. Athorn et al. (2013) observed that greater feed intake increased the number of progesterone pulses on day 9 of gestation. Furthermore, the vena cava progesterone concentration tended to be greater on day 6 (before embryo implantation) in high-fed gilts, but there was no difference in the jugular vein. The embryo survival was 15% higher on day 10 post-insemination in high-fed compared to low-fed gilts. Thus, Athorn et al. (2013) speculated that embryo survival benefits by the local production of progesterone, ensured by the counter-current flow and lymphatic pathways in high-fed gilts. In primiparous sows, Hoving et al. (2012a) reported no difference in progesterone concentration (jugular vein) between the animals offered 2.5 or 3.25 kg/d between days 3 and 35 of gestation. However, the progesterone concentration tended to be lower during the first 15 days of pregnancy in multiparous sows (PO 2 to 11) fed 4 compared to 2 kg/d (Virolainen et al., 2005b). Hoving et al. (2011) hypothesized that embryonic survival may be affected, and even cause failed maternal recognition of the pregnancy, if the progesterone concentration is reduced in the pre-attachment period. Although we did not perform hormonal evaluations, the fact that litter size was reduced with high feed levels allows us to speculate that the progesterone concentration was affected. However, this variable should be better explored in further studies.

It is worth mentioning that most of the studies that used multiparous sows were performed with a reduced number of sows. Furthermore, the feed levels did not consider the extremes, i.e., below and above the requirements for maintenance in the same experimental design. Even though Leal et al. (2019) reported that embryo survival was compromised only when the energy levels were greater than 12.9 Mcal/d, the reduced litter size observed with the highest feed level of the present study (10.1 Mcal/d; 3.2 kg) indicate that providing 7.9 Mcal/d (2.5 kg/d), between days 6 and 30 of gestation, ensured better results for total piglets born by PO1 and PO2 sows. Even though considering that the number of total piglets born observed for PO2 was higher compared with PO1 sows, no evidence for interaction with feed level was observed on the main reproductive variables. However, it is important to consider this response within parity taking account the body condition of the females at weaning.

Influence of Body Condition at Weaning and their Interaction with Feed Levels on Total Piglets Born

Better results for litter size were expected when sows with poor body condition at weaning received higher feed levels. However, the lack of interaction between feed level and classes of BW, BCS and BF demonstrated that sows with lower body reserves did not benefit from a greater feed amount. This result indicates that current strategies for increasing the feed level post-insemination for body recovery should be reviewed because they implicate in losing potential on performance of young weaned sows. The reductions of 1.6, 1.5, 1.2, and 1.3 piglets born in PO1 sows with lower BW, BCS, BF and caliper units at weaning, respectively, regardless of the feed level, is consistent with reduced litter sizes in PO1 sows with a BW less than 177.9 kg or with a poor BCS, as reported by Schenkel et al. (2010). Young sows still need to grow to achieve a target weight at first farrowing; if the feed level is not adequate, growth might be prioritized instead of reproduction (Hoving et al., 2010). In contrast to PO1 sows, whose body reserves are more affected by nutritional level, the litter size was not affected in PO2 sows with lower body reserves. Schenkel et al. (2010) attributed the reduction in subsequent litter size of primiparous sows to both body reserves at weaning and body losses during the previous lactation. Prunier et al. (2003) suggested that subsequent poor reproductive performance is more related to lactational events rather than post-weaning events. In fact, reproductive performance (i.e., total embryos, embryo survival, pregnancy rate) was negatively affected in PO1 sows that experienced high weight losses during lactation (Hoving et al., 2012b). Unfortunately, changes in body reserves and the metabolic profile during lactation were not evaluated in the present study. However, lighter sows at weaning are suggestive of poor body condition management during lactation, or even during the previous gestation. Hoving et al. (2010) observed that for each 10 kg higher BW gain between the first insemination and first weaning, the total number of piglets born was increased by 0.42 piglets.

In the current study, the total number of piglets born was also reduced when PO1 sows were fed 1.8 kg/d in comparison to those fed 2.5 kg/d. Insulin and insulin-like growth factor 1 (IGF-1) are hormones that respond, to some extent, to nutritional changes (De et al., 2009); they may act directly on the ovary or systematically on the hypothalamus and interfere with luteinizing hormone (LH) release (Quesnel et al. 2009). Increases in insulin and IGF-1 concentrations were reported in gilts fed 2-times the maintenance diet compared to those fed 1.2- and 0.6-times the maintenance (De et al., 2009). Furthermore, LH pulsatility was negatively affected in pregnant gilts that underwent feed restriction (1.8 *vs.* 3.6 kg/d; Peltoniemi et al., 1997). Notably, gilts do not experience lactational catabolism, and distinct metabolism should be considered for weaned sows. Indeed, no differences between 2.5 and 3.25 kg/d offered feed during early gestation were reported for progesterone, LH, and IGF-1 concentrations in PO1 sows (Hoving et al., 2012a). However, even considering the absence of interaction of feed level with class of BW, BCS and BF, the fact that litter size was compromised in PO1 sows (quadratic effect) indicates that nutrients slightly above the maintenance, provided by 1.8 kg/d in the present study, were perhaps insufficient for sows that experience lactational catabolism and are still growing. This effect was ensured for PO1 sows with lower caliper unit ($\leq$ 11), where a quadratic effect of feed level was observed for total piglets born; with no effect in sows with higher caliper unit (> 11). The trend for linear reduction in total born piglets observed in PO2 sows (as the feed level increased) indicates that 3.2 kg/d is also an excessive feed amount to offer in early pregnancy for this category of females.

CONCLUSION

In young parity sows (PO1 and PO2) with suitable body condition, the gain in body measurements (BW, BCS, BF, and caliper units) increased as the feed intake during the first month of gestation increased from 1.8 to 3.2 kg/d. However, increasing feed allowance negatively impacted the total number of piglets born in PO1 and PO2 sows. Moreover, even considering sows with lower body reserves at weaning, the greater feed intake (3.2 kg/d) during early gestation did not increase the number of piglets born, especially for PO1 sows.

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Table 1. Composition of the experimental diets (as-fed basis).

Ingredient	Gestation[1]
Corn	49.6
Oats	14.0
Soybean meal, 46 % CP	11.1
Wheat, 14.5% CP	10.0
Rice bran defatted, 16% CP	5.0
Corn DDGS, 6% fat	5.0
Molasses	1.2
Vitamin and mineral premix[2]	0.2
Monocalcium phosphate	0.35
Limestone	1.02
Salt	0.25
Sodium bicarbonate	0.30
L-Lys	0.29
DL-Met	0.02
L-Thr	0.09
Soybean oil	1.2
Phytase[3]	0.02
Others	0.36
Total	100.00
Calculated Analysis	
SID[4] Lys, %	0.68
SID Met: Lys, %	37
SID Met and Cys: Lys, %	78
SID Thr: Lys, %	81
SID Trp: Lys, %	23
SID Val: Lys, %	110
CP, %	15.03
Ca, %	0.73
STTD P[5], %	0.40
Na, %	0.25
Cl, %	0.20
ME, Mcal/kg	3,151

[1]Diet was fed from day 6 to 30 of gestation.

[2]*Vitamin composition per kg of diet*: vitamin A: 12,500 IU; vitamin D_3: 2,500 IU; vitamin E: 125.0 IU; vitamin K_3: 4.5 mg; vitamin B_1: 2.5 mg; riboflavin (B_2): 7.5 mg; pyridoxine (B_6): 3.5 mg; vitamin B_{12}: 33.8 µg; niacin: 50.0 mg; pantothenic acid: 25.0 mg; folic acid: 2.4 mg; biotin: 0.26 mg; choline: 1.25 g. *Mineral composition:* selenium: 0.64 mg; iron: 75.0 mg; copper: 21.7 mg; manganese: 61.4 mg; zinc: 183.4 mg; iodine: 1.5 mg.

[3]Aela (Auster Animal Nutrition, São Paulo, Brazil) provided 1000 phytase units per kg of diet with release of 0.19% STTD P.

[4]SID = standardized ileal digestible.

[5]STTD = standardized total tract digestible.

Table 2. Chemical analysis of the diets (as-fed basis). Values in parentheses indicate those calculated from diet formulation and are based on the values from NRC (2012).

Ingredient	Gestation
Proximate analysis, %	
DM	88.55 (87.78)
CP	14.89 (15.03)
Crude Fiber	5.23 (3.85)
Fat	3.38 (4.38)
Ash	5.87 (4.87)
Ca	0.99 (0.73)
P	0.64 (0.40)
Total AA, %	
Lys	0.77 (0.78)
Ile	0.71 (0.58)
Leu	1.29 (1.37)
Met	0.26 (0.28)
Met and Cys	0.56 (0.57)
Thr	0.64 (0.63)
Trp	0.15 (0.16)
Val	0.67 (0.75)
His	0.29 (0.40)
Phe	0.82 (0.64)

Table 3. Least square means estimates and probability values of the effects of feed levels from day 6 to 30 of gestation on maternal body weight and reproductive performance of parity (PO) 1 and 2 sows under commercial conditions[1]

Item	Feed level, kg/d[2]			SEM	Parity		Probability, *P*<[3]				
	1.8	2.5	3.2				L	Q	PO	L×PO	Q×PO
	n **= 122**	***n*** **= 122**	***n*** **= 117**		1	2					
Body Weight (BW), kg											
Weaning	197.2	197.4	197.1	2.2	184.8	209.7	0.983	0.902	<0.001	0.713	0.715
Day 30	192.8	200.4	206.0	2.0	189.8	209.7	<0.001	0.584	<0.001	0.583	0.563
Weight change, kg	-4.3	2.8	9.4	1.6	5.1	0.2	<0.001	0.775	<0.001	0.818	0.753
Body condition score (BCS)											
Weaning	3.1	3.1	3.1	0.03	3.2	3.1	0.665	0.854	0.228	0.859	0.161
Day 30	3.3	3.3	3.5	0.04	3.4	3.3	<0.001	0.381	0.644	0.385	0.542
BCS change	0.1	0.2	0.3	0.03	0.2	0.2	<0.001	0.354	0.589	0.502	0.603
Backfat (BF), mm											
Weaning	11.4	11.3	11.2	0.3	11.6	11.2	0.652	0.510	0.137	0.739	0.439
Day 30	13.0	13.1	14.3	0.5	13.8	13.1	0.003	0.109	0.058	0.739	0.507
BF change, mm	1.2	1.4	2.3	0.4	1.8	1.5	<0.001	0.099	0.223	0.668	0.962
Caliper unit											
Weaning	11.0	10.8	10.8	0.3	10.9	10.9	0.488	0.918	0.992	0.471	0.472
Day 30	12.4	13.0	13.6	0.2	13.1	12.9	<0.001	0.977	0.158	0.747	0.790
Caliper unit change	1.3	2.1	2.8	0.3	2.1	2.0	<0.001	0.967	0.389	0.143	0.502
Reproductive performance[4]											
Farrowing rate, %	87.6	88.4	81.4	3.0	83.5	88.3	0.200	0.389	0.209	0.365	0.368
Total piglets born, *n*	14.6	14.6	13.5	0.5	13.4	15.1	0.041	0.215	0.001	0.780	0.128
Total piglets born alive, *% (n)*	92.0 (13.4)	91.5 (13.4)	92.8 (12.5)	1.0	92.0 (12.3)	92.1 (13.9)	0.467	0.317	0.904	0.864	0.640
Born alive + stillborn, % (*n)*	97.6 (14.2)	97.1 (14.2)	97.0 (13.1)	0.5	97.0 (13.0)	97.4 (14.7)	0.349	0.730	0.404	0.512	0.634
Stillborn, %	5.6	5.6	4.3	0.8	5.0	5.2	0.106	0.343	0.681	0.776	0.302
Mummified fetuses, %	2.4	3.0	3.0	0.5	3.0	2.6	0.349	0.730	0.404	0.511	0.634

[1]A total of 361 females (Landrace × Large White) were used, with 122, 122, and 117 females for the treatments 1.8, 2.5, and 3.2 kg/d, respectively

[2]Feed levels: 1.8, 2.5, and 3.2 kg/d from day 6 to day 30 of gestation.

[3]*P*-values for linear (L) and quadratic (Q) effect of feed level, parity (PO) and their interactions.

[4]Reproductive performance is related to the farrowing of the same cycle that the treatments were performed.

Table 4. Total piglets born for parity 1 (PO1) sows submitted to different feed levels from day 6 to 30 of gestation according to body condition (BC) classes at weaning[1]

Class variables at weaning	*n*	Feed level, kg/d[2]			SEM	BC Class	Probability, *P* <				
		1.8	2.5	3.2			L	Q	BC Class[3]	L × BC Class	Q × BC Class
Body condition classes											
Body Weight, kg							0.190	0.033	0.017	0.774	0.779
≤ 183	84	12.7	13.4	11.5	0.9	12.5 ± 0.6					
> 183	91	14.0	15.2	13.2	0.9	14.1 ± 0.6					
Body condition score							0.224	0.062	0.023	0.963	0.325
≤ 3	85	12.4	14.0	11.5	0.9	12.6 ± 0.6					
> 3	90	14.4	14.5	13.4	0.9	14.1 ± 0.6					
Backfat, mm							0.150	0.041	0.075	0.233	0.236
≤ 11.5	87	13.0	14.2	10.9	0.9	12.7 ± 0.6					
> 11.5	88	13.8	14.3	13.6	0.9	13.9 ± 0.5					
Caliper							0.244	0.070	0.053	0.578	0.042
≤ 11	93	12.2	14.5	11.7	0.8	12.8 ± 0.5					
> 11	82	14.8	13.9	13.4	0.9	14.1 ± 0.6					

[1]A total of 175 PO1 females (Landrace × Large White) were used, divided into different body classes at weaning to be fed on 1.8, 2.5, and 3.2 kg/d from day 6 to 30 of gestation.

[2]Feed level: 1.8, 2.5, and 3.2 kg/d from day 6 to day 30 of gestation.

[3]Different classes for body condition (BC; body weight, body condition score, backfat and caliper unit)

Table 5. Total piglets born for parity 2 (PO2) sows submitted to different feed levels from day 6 do 30 of gestation according to body condition (BC) classes at weaning[1]

Class variables at weaning	*n*	Feed level, kg/d[2]			SEM	BC Class of	Probability, *P* <				
		1.8	2.5	3.2			L	Q	ClassBC[3]	L × BC Class	Q × BC Class
Body condition classes											
Body Weight, kg							0.087	0.955	0.922	0.469	0.498
≤ 208	64	15.4	15.4	14.7	0.7	15.2 ± 0.4					
> 208	68	16.1	14.8	14.4	0.7	15.1 ± 0.4					
Body condition score							0.094	0.935	0.530	0.929	0.990
≤ 3	56	15.6	15.0	14.5	0.7	15. 0 ± 0.4					
> 3	76	16.0	15.3	14.8	0.8	15.4 ± 0.4					
Backfat, mm							0.108	0.831	0.860	0.659	0.199
≤ 11	59	16.0	14.7	15.1	0.8	15.2 ± 0.4					
> 11	73	15.7	15.6	14.2	0.7	15.1 ± 0.4					
Caliper unit							0.081	0.867	0.417	0.757	0.986
≤ 10	54	15.8	16.0	14.6	0.9	15.5 ± 0.4					
> 10	78	15.8	14.5	14.5	0.7	14.9 ± 0.4					

[1]A total of 150 PO2 females (Landrace × Large White) were used, divided into different body classes at weaning to be fed on 1.8, 2.5, and 3.2 kg/d from day 6 to 30 of gestation.

[2]Feed levels: 1.8, 2.5, and 3.2 kg/d from day 6 to day 30 of gestation.

[3]Different classes for body condition (BC; body weight, body condition score, backfat and caliper unit)

6 CAPÍTULO 5 – QUARTO ARTIGO CIENTÍFICO

ARTIGO A SER PUBLICADO

(De acordo com as normas da revista)

Running head: Flush feeding gilts and reproduction

Effects of flush feeding strategy before breeding on reproductive performance of modern replacement gilts: impacts on ovulation rate and litter traits

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ABSTRACT

The effects of two feed levels offered during two estrous cycles before insemination were evaluated on the reproductive performance of gilts. A total of 102 gilts (PIC Hendersonville, TN) weighing 120.9 ± 9.1 kg were individually housed, and manually fed twice a day with 2.1 or 3.6 kg/d of a diet based on a corn-soybean meal (3.15 Mcal ME per kg and 0.64% standardized ileal digestible lysine) during two estrous cycles before breeding (Cycle 1 – between 1st and 2nd estrus; Cycle 2 – between 2nd and 3rd estrus). Gilts were weighed at the beginning of the experiment, at second and third estrus, and at slaughter (30.2 ± 1.6 d of gestation). Follicles were counted at 2nd estrus, and the embryo-placental units and the corpora lutea were individually counted, measured, and weighed at slaughter. Gilts fed 3.6 kg/d had greater body weight and backfat gain during cycle 1 (*P* < 0.001; + 9.9 kg and + 1.0 mm, respectively) and cycle 2 (*P* < 0.001; + 10.0 kg and + 0.8 mm, respectively) becoming heavier at 2nd and 3rd estrus (*P* < 0.001). At 2nd estrus, gilts fed 3.6 kg/d had 1.9 more medium-large follicles (*P* = 0.032) but no difference in follicle size (*P* = 0.49) was observed. Gilts fed 3.6 kg/d in cycle 1 or cycle 2 had a greater ovulation rate (*P* < 0.009) than those receiving 2.1 kg/d. Also, 3.6 kg/d in cycle 2 increased early embryo mortality (*P* = 0.006; 2.4 *vs.*1.1 dead embryos) and consequently reduced total embryo survival (*P* = 0.026; 84.5 *vs.* 90.1%). Gilts fed 3.6 kg/d during cycle 1 had almost two more total embryos (*P* = 0.001; 17.1 *vs.*

15.2) and two more vital embryos on Day 30 (P = 0.001; 16.7 *vs.* 14.7) in comparison with gilts fed 2.1 kg/d. The coefficient of variation for placental length was greater for gilts fed 3.6 kg/d during cycle 1 (P = 0.006). No further significant effects of feeding levels were observed on embryo and placental traits (P > 0.091). These results suggest that the feeding level during the first cycle after pubertal estrus is crucial to set ovulation rate and potential litter size for breeding at next estrus. However, flush feeding gilts before insemination can negatively impact litter size by reducing embryo survival when breeding at third estrus.

Keywords: embryo survival, feeding, flushing, gilts, ovulation rate.

INTRODUCTION

The modern genotype gilt likely has a dramatically different metabolic profile during the final stages of growth and breeding when compared to genotypes of 15-30 years ago. Over time, body composition at puberty has changed from a lighter and fatter (Beltranena et al., 1991) to a heavier and leaner phenotype (Kummer et al., 2009; van Wettere et al., 2011). Different than in the past, when gilts were feed restricted to avoid over body conditioning, gilts are nowadays *ad libitum* fed during the growth phase. Nevertheless, nutritional flushing is still commonly performed before breeding, even though results with the use of this strategy are uncertain in modern females.

Flush feeding is a term used to describe a nutritional strategy employed before breeding to improve ovulation rate (Cox et al., 1987; Beltranena et al., 1991), consisting of an increase in the amount of feed, energy or by changing the energy source (Cox et al., 1987; Beltranena et al., 1991; Almeida et al., 2014). Short-term increases in feed intake will stimulate GnRH release (Ashworth and Antipatis, 1999) and ovarian activity by increasing nutrient uptake and utilization, as well as mitogenesis and growth when acting directly on the ovary (Prunier and Quesnel, 2000). Beltranena et al. (1991) showed that gilts fed an additional 0.8 kg/day (flushed) between the first and second estrus had an increase in the number of follicles ovulated compared to control gilts (14.0 vs. 12.0, respectively). Different breeds, such as the prolific Chinese Meishan, also showed an improvement in ovulation rate when flushed with 3.5 kg/d of feed compared with the feed maintenance level of 1.15 kg/d (Ashworth et al., 1999).

Recent reports show that the number of vital embryos and ovulation rate are negatively and quadratically related instead of linearly, mainly due to embryo mortality

(Da Silva et al., 2017a). Langendijk et al. (2016) demonstrated that increased mortality may also be due to a reduction in uterine capacity on day 35 of gestation. Although a negative relationship between uterine capacity and embryo mortality exists, increasing ovulation rate and, consequently, litter size is essential in gilts since it is a good predictor for subsequent lifetime performance (Iida and Koketsu, 2015). Together, these facts suggest that the increase in litter size due to improvement in ovulation rate might be dependent on changes in the uterine capacity as well as in follicle and embryo quality.

The flush feeding strategy has also been used over the years during the weaning-to-estrus interval in sows, to influence follicle development and ovulation rate similar to that used in gilts. However, when using this approach, no advantage in reproductive performance was observed for weaned sows (Graham et al., 2015; Gianluppi et al., 2020). Although the flushing strategy before breeding is still in use based on recommendations from more than two decades ago, there is a lack of current information regarding the effect of this nutritional strategy on the performance of the modern genotype replacement gilt. The objective of the present study was to evaluate the impact of the flush feeding strategy on ovulation rate and traits of the embryo, placenta, and *corpora lutea*. Using an experimental design consisting of a 2 × 2 factorial arrangement with two feeding levels (2.1 and 3.6 kg) provided during two estrous cycles before breeding, we hypothesized that flush feeding gilts before breeding would improve follicle and *corpora lutea* quality that would be reflected in positive effects on litter size and embryo traits.

MATERIAL AND METHODS

The use of animals for this experiment was approved by the University of Illinois Institutional Animal Care and Use Committee (IACUC #18196).

Animals and Housing

The experiment was performed at the University of Illinois Swine Research Center, a farrow-to-finish unit that maintains a 220-sow inventory. Prepubertal gilts (n = 102; 58 PIC Terminal line gilts and 44 PIC Camborough, Hendersonville, TN) were used in two replicates housed in stalls with *ad libitum* access to water and fed twice a day according to the treatments cited below.

Experimental Design

A total of 102 gilts were selected according to health status and body weight **(BW)** (>100 kg). They were housed in a breeding and gestation building with 164.4 ± 6.6 d (157 to 170 d) of age. One day after selection, a combination of 400 IU equine chorionic gonadotrophin **(eCG)** + 200 IU human chorionic gonadotrophin **(hCG)** was given by an intramuscular route (5 mL; PG600, Merck Animal Health, Madison, NJ). Estrous detection started on the next day using twice daily (0700 and 1600 h) fenceline exposure to a sexually mature boar and with the back-pressure test. From those gilts initially treated with PG600, 93/102 (91.2%) were in estrus in 3.8 ± 0.8 d after the PG600 injection. However, regardless of estrous expression, this moment was considered as the first estrus for all the gilts used in the experiment. Starting 10 d after PG600 administration, gilts were synchronized using oral administration of 15 mg of altrenogest (Matrix, 2.2 mg/mL, Merck Animal Health, Madison, NJ) once a day (0700 h) for 14 consecutive days. After the last altrenogest administration, gilts were exposed twice a day to a mature boar for detection of the second estrus. Similarly, boar exposure and the back-pressure test were also performed in the subsequent cycle to detect the third estrus of the gilts. Thus, the interval between the first and second estrus was considered as cycle 1 and the interval between the second and the third estrus was defined as cycle 2.

Gilts were *ad libitum* fed before the beginning of treatments (grow-finish phase) with a feed intake on average of 3.5 kg/d. On day 10 after PG600, all the gilts were individually weighed and randomly assigned to a different feeding amount (treatment) during cycle 1: 2.1 kg/d (6.7 Mcal metabolisible energy – **ME**, and 13.2 g/d standardized ileal digestible lysine - **SID Lys**) or 3.6 kg/d (11.4 Mcal ME and 22.7 g/d SID Lys). At the second estrus, gilts in each treatment were again randomly assigned to receive two different feed levels during cycle 2: 2.1 or 3.6 kg/d. A schematic view of the experimental design is presented in Fig. 1. Diets used during the experiment consisted of a corn-soybean-based meal with 3.18 Mcal ME/kg, 13.6% crude protein **(CP)**, and 0.63% SID Lysine (Table 1).

One gilt from each treatment became sick during the experimental period (cycle 1) and were removed from the study. During cycle 1, a total of 15 and 11 gilts that were fed 2.1 and 3.6 kg/d, respectively, were removed from the experiment because no estrus was detected within 10 d after altrenogest withdrawal, leaving a total of 74 gilts to be assigned and fed the treatment diets during cycle 2. Treatments for cycle 2 were applied starting on the first day of the second estrus and finished at expression of the third estrus. At the detection of third estrus, gilts were artificially inseminated once a day on each day of standing estrus (1600 h) using pooled semen doses (ejaculates from two PIC commercial boars) each containing 3×10^9 sperm cells. On the days following first breeding, all gilts were fed 2.1 kg/d until slaughter. The first insemination was considered as day zero of gestation.

Body Measurements

All gilts were individually weighed at the beginning of the experiment, at the second and third estrus, and one day before slaughter. At each of these moments, backfat (**BF**) was measured at the P2 point (6.5 cm away from the midline of the vertebral column at the last rib level) with A-mode ultrasonography (Renco Lean Meter–Renco Corporation, Minneapolis, MN) with a measured accuracy of ±2 mm. Body weight (**BW**) and BF were used to calculate the body weight and backfat gains during cycle 1 and cycle 2. Body weight and age were also used to estimate the lifetime growth rate **(GR)**.

Reproductive Parameters at Slaughter

Gilts were slaughtered at 30.2 ± 1.6 d (27 to 33 d) of gestation and the reproductive tracts recovered. The uterine horn was longitudinally cut along the antimesometrial side starting at the uterine-ovarian junction. Embryo-placental units were individually removed, and the distance between two necrotic tips measured (placental length). Embryos were classified according to their vitality status as vital, based on morphology and color, or nonvital, with the presence of strongly hemolyzed amniotic fluid, reabsorbed fetal membranes, or both (van der Waaij et al., 2010). Early embryo mortality was defined by the difference between the number of *corpora lutea* and the number of total embryos, whereas late embryo mortality was determined by the difference between the total number of embryos and the total number of vital embryos. Crown-rump length and weight were measured for each individual embryo. The uterus weight was obtained after removal of all embryo-placental units and all liquid expelled.

Ovaries were removed from the reproductive tract and stored at 4 ºC until processing within 1 to 3 d after slaughter. Individual corpora lutea (**CL**) from both ovaries were counted to calculate ovulation rate after being carefully dissected and having connective tissue trimmed off. Because the CL shape is irregular, the diameter was obtained by the average of measurements in two directions using a caliper (1 mm of precision). Each CL was also individually weighed with a scale (0.05 g of precision) to calculate the average CL weight and CL weight variation. Total luteal mass was calculated by the sum of all individual CL weights for both ovaries.

Real-time Transrectal Ultrasonic Evaluation of Follicles

On the afternoon of the day of second and third estrus, transrectal ultrasonography was performed in all gilts using a Prosound Aloka 500 V with a 7.5 MHz linear array transducer using a continuous digital recording. The number and size of all medium-large follicles (> 5.5 mm) in both ovaries were determined at a later time using the playback function for measures from the digital recordings.

Statistical Analysis

Statistical analysis was performed using the Statistical Analysis System software, version 9.3 (SAS® Inst. Inc., Cary, NC). The models for analysis of variables concerning the responses during cycle 1 included the feed treatment levels (2.1 and 3.6 kg/d), as fixed effects. From cycle 2 onwards, the analysis considered a 2 × 2 factorial design, including feed treatment level during cycle 1, feed treatment level during cycle 2 and their interaction as fixed effects. Replicate was included in all models as a random effect. Differences were considered significant at $P \leq 0.05$, and *P*-values between 0.05 and 0.10 were designated as a tendency.

The percentage of gilts in estrus after PG600, percentage of gilts in estrus after altrenogest, and pregnancy rate were analyzed as binary distributions using the GLIMMIX procedure. A binomial distribution was used to analyze embryo survival. The coefficient of variation of the following variables were analyzed with models fitted for a beta distribution: follicle size, CL size and weight, placental length and weight, and embryo length and weight. All the other variables were analyzed using the GLIMMIX procedure with models assuming a normal distribution. The body weight of gilts at the beginning of the experiment was used as a covariate in all models when significant. All models for reproductive measures at slaughter included the interval between insemination and the day of slaughter as a covariate, when significant.

RESULTS

Body Weight and Backfat Measurements

There were no differences ($P > 0.890$) in lifetime GR (680.0 *vs.* 678.0 g/d), BW (121.0 *vs.* 120.7 kg), and BF (9.6 *vs.* 9.6 mm) between treatments at the beginning of the experiment. Gilts fed 3.6 kg/d had greater average daily gain (*P* < 0.001) and BF gain (*P* < 0.001) during cycle 1, becoming 9.9 kg heavier and 1 mm fatter at their second estrus (Table 2; *P* ≤ 0.001).

Body weight gain during cycle 2, BW, and lifetime GR at the third estrus were greater for gilts fed 3.6 kg/d during cycle 1 or cycle 2 (Table 3; *P* ≤ 0.042). Even though BF at the third estrus was greater for gilts fed 3.6 kg/d during either cycle 1 or cycle 2 (*P* ≤ 0.009), BF gain was increased only when 3.6 kg/d was provided during cycle 2 (*P* = 0.001). Furthermore, on day 30 of gestation, BW increased when gilts received 3.6 kg/d in cycle 1 or cycle 2 (Table 4; *P* < 0.001) although gilts that received 3.6 kg/d in cycle 2 had a lower BW gain from mating to slaughter (*P* < 0.001). The gain in BF during 30 d of gestation was not affected by feed level, but gilts fed 3.6 kg/d during cycle 2 had greater BF than those fed 2.1 kg/d (*P* < 0.001).

Reproductive Parameters

The proportion of gilts expressing a second estrus after altrenogest withdrawal did not differ (*P* = 0.350) between 2.1 kg/d (74.3%; *n* = 35) and 3.6 kg/d (82.3%; *n* = 39). The second estrus lasted 51.0 ± 2.5 h, with no difference between treatments (*P* = 0.250). Gilts fed 3.6 kg/d tended to show estrus 0.3 d earlier after altrenogest withdrawal (Table 2; *P* = 0.089), resulting in a shorter interestrus interval (*P* = 0.022) compared with gilts fed 2.1 kg/d during cycle 1. Gilts fed 3.6 kg/d in cycle 1 had 1.9 more follicles (Table 2; *P* = 0.032) than gilts fed 2.1 kg/d. Although no differences were observed in medium-large follicle size (*P* = 0.489), gilts fed 3.6 kg/d during cycle 1 tended to have a lower CV in follicle size (Table 2; *P* = 0.065) than those receiving 2.1 kg of feed.

The length of the second estrous cycle and duration of the third standing estrus were not affected by feed treatment levels offered during cycle 1 or cycle 2 (Table 3; *P* ≥ 0.251). Gilts fed 3.6 kg/d during cycle 2 had larger follicles (7.6 *vs.* 7.2 mm; *P* = 0.032), whereas the CV of follicle size was not affected by feed levels offered in cycle 1 or cycle 2 (Table 3; *P* ≥ 0.107).

Gilts inseminated at third estrus were 213.4 ± 6.4 d of age with no differences between feed levels (*P* ≥ 0.801). The pregnancy rate averaged 97.1 ± 2.8 % and uterine weight was 1.7 ± 0.1 kg, with no effects of feed levels (*P* ≥ 0.547). Ovulation rate was greater in gilts fed 3.6 than 2.1 kg/d in cycle 1 or cycle 2 (Fig. 2; *P* ≤ 0.009). Even though no effect of feed level was observed on individual CL weight (Table 4; *P* ≥ 0.158), gilts fed 3.6 kg/d during cycle 1 (*P* = 0.021) had a greater total luteal weight and greater variation in CL weight (*P* = 0.033) than those fed 2.1 kg/d. Individual CL size and CL size variation were not affected by feed levels offered in any of the cycles (Table 4; $P \geq 0.205$).

Gilts fed 3.6 kg/d during cycle 1 had almost two more total embryos (Fig. 2; *P* = 0.001; 17.1 *vs* 15.2) and two more vital embryos (*P* = 0.001; 16.7 *vs.* 14.7) compared to those receiving 2.1 kg/d. Gilts fed 3.6 kg/d in cycle 2 had 1.2 more early dead embryos compared to gilts fed 2.1 kg/d (Table 4; *P* = 0.006; 2.4 *vs.* 1.2). Late embryo mortality was not affected by feed levels (Table 4; $P \geq 0.112$). Embryo survival was negatively affected by greater feed levels provided during cycle 2 (Fig. 2; *P* = 0.026; 84.5 *vs.* 90.1%). Embryo weight was not influenced by feed levels offered in any cycle ($P \geq 0.470$). However, gilts fed 3.6 kg/d during cycle 1 tended to have longer embryos (*P* = 0.091; 27.0 *vs.* 26.5 mm) than those fed 2.1 kg/d. The variation in embryo weight and embryo length were not affected by feed levels ($P \geq 0.591$).

Placental weight and placental length were not affected by feed levels offered in cycle 1 or cycle 2 ($P \geq 0.287$). However, gilts fed 3.6 kg/d during cycle 1 showed a marginal increase in placental weight variation (*P* = 0.098) and greater variation in placental length (*P* = 0.006) than gilts fed 2.1 kg/d.

DISCUSSION

The results of the present study indicated that flush feeding modern replacement gilts after pubertal estrus is still important to improve ovulation rate. Flush feeding gilts with 3.6 kg/d during the first cycle after puberty resulted in an increase of two follicles and a trend for more uniform follicles at second estrus. Most studies performed 2 to 3 decades ago reported increases in the range of 1 to 4 more CL with increments in the feed intake ranging from 0.8 to 2.7 kg per day before insemination (Ashworth, 1991; Beltranena et al., 1991; Rhodes et al., 1991). Beltranena et al. (1991) improved ovulation rate from 12 to 14 CL with an increase of 0.8 kg/d of feed in gilts that were feed restricted during the developmental phase (from 47.2 kg until puberty), and from 12.0 to 14.7 CL when gilts were fed *ad libitum* during development and for one cycle before insemination. At the third estrus, the greatest difference in ovulation rate (16.2 *vs.*19.2 CL) was observed between gilts receiving extreme feed levels in both cycles, 2.1 kg/d and 3.6 kg/d, respectively. However, the average ovulation rate of ~18.0 CL observed in gilts fed 3.6 kg/d, in at least one of the cycles before insemination, reveals their capacity to respond to increased feed intake and influence the number of follicles capable of ovulation. As suggested by Beltranena et al. (1991), flushing does not stimulate superovulation but increases ovulation rate approximating that for gilts fed *ad libitum* throughout the entire period before breeding. Feeding gilts *ad libitum* (5.0 kg/d) instead of restricted (2.3 kg/d), for 14 d before insemination, improved ovulation rate by 4.2 CL at third estrus (Ashworth, 1991). Similarly, increased numbers of follicles were observed (14.8 *vs.* 17.8) when the feed amount was increased from 1.4 to 3.4 kg/d for 19 d, between the second and third estrus (Ferguson et al., 2003).

A short-term increase in feed intake has been reported to enlarge the liver and intensify blood flow, resulting in increased clearance of progesterone (Ashworth and Antipatis, 1999). Consequently, this would reduce the negative feedback effect on the hypothalamic-pituitary axis and increase the gonadotropin-releasing hormone **(GnRH)** release. Gilts receiving high feed levels for 19 d before ovulation had more luteinizing hormone **(LH)** pulses, and greater plasma concentrations of insulin like growth factor **(IGF-1)** and insulin (Ferguson et al., 2003). Similar results for IGF-1 and insulin in gilts receiving *ad libitum* access to feed before insemination were reported previously (Beltranena et al., 1991). Insulin and IGF-1 are probably the most important mediators between nutritional status and reproductive performance, interacting metabolically on GnRH release or acting directly on the ovary (Beltranena et al., 1991; Prunier and Quesnel, 2000; Ferguson et al., 2003). Although no hormonal evaluations were performed during the estrous cycle in the present study, we can infer based on previous studies, that for gilts fed 3.6 kg/d, it is likely that greater levels of insulin and IGF-1 increased LH pulses, and this resulted in improved ovarian activity through increased nutrient uptake and utilization, mitogenesis and growth (Prunier and Quesnel, 2000). The fact that gilts fed 3.6 kg in cycle 1 and those fed 2.1 kg/d in cycle 2, or vice versa, achieved similar ovulation rate at the third estrus, suggests that the hormonal mediation to increase ovulation rate occurs soon after the feed increase. However, its effect on ovarian follicles is longer lasting, and can still influence ovulation rate into the next estrous cycle. The effect of feed intake is likely at the level of follicle populations on the ovary. After ovulation, a cohort of small follicles (< 2 mm) rapidly appears on the ovary surface with selection for ovulation at the next estrus originating from this recruited pool (Knox, 2005). Since small follicles respond to levels of IGF-1, whereas medium and large follicles are dependent on follicle-stimulating hormone **(FSH)** and LH stimulation (Knox, 2005), the effects of nutrients are likely impacting the health and growth of the small antral follicles early in the cycle. Thus, we speculate that gilts fed 3.6 kg/d in cycle 1 had more follicles recruited at the beginning of cycle 2, and subsequent feeding level had minimal further effects on the ovulation potential for this pool of follicles.

The synergistic or independent actions of insulin, IGF-1, and gonadotropins may explain the increase in follicle size observed at third estrus in the gilts fed 3.6 kg/d during the previous cycle. The quality of follicles has been reported to be increased by increasing the amount of feed before breeding in pubertal gilts (Ashworth et al., 1999; Ferguson et al., 2003) and primiparous sows (Zak et al., 1997). According to Ferguson et al. (2003), more oocytes reached metaphase II, an indicator for better and more mature oocytes, after feed level was increased from maintenance to a high nutrition plane for 19 d (1.35 kg/d *vs.* 3.5 kg/d). Similarly, Zak et al. (1997) recovered more oocytes at the metaphase II stage of maturation after feeding primiparous to appetite during the last week of lactation when compared to the sows maintained under feed restriction. Even though an *in vitro* model was used to assess oocyte maturation and embryo development in those studies (Zak et al., 1997; Ferguson et al., 2003), the authors reported that oocyte quality was likely the key determinant for greater embryo survival.

Currently, most pig breeding farms are using a protocol by which gilts are stimulated to show first estrus around 190 to 200 d of age, and these gilts are then inseminated at the second estrus when they are 210 to 220 d of age. Our experimental model used an approach to achieve the same breeding age, but for experimental practicality, gilts were hormonally induced into puberty at ~170 d of age to allow for synchronized treatment cycles and breeding at third estrus at optimal age and weight. Although feeding gilts 3.6 kg/d in cycle 1 or cycle 2 improved ovulation rate, embryo mortality was increased, and embryo survival decreased when flushing was performed during the cycle immediately preceding insemination. Previously published research indicated that early embryonic mortality could be associated with greater diversity in the sizes of the pre-ovulatory follicles (Pope et al., 1990) and, more recently, with reduced follicular and oocyte quality (Da Silva et al., 2017a). Yet, as aforementioned, those gilts in the present study, that were fed 3.6 kg/d, had larger follicles at estrus, compared to those fed the lower amount, a result that could associate with improved follicle and oocyte quality. Although data are limited, a weak positive correlation (r = 0.28; P = 0.001) between follicle volume and CL weight was reported in sows by Soede et al. (1998). However, in the present experiment, although larger CL would be expected in the gilts fed 3.6 kg/d before breeding, because they had larger sized pre-ovulatory follicles, this correlation was not confirmed (r = 0.15; P = 0.250). The reduced embryo survival in gilts fed 3.6 kg before breeding could be explained by the correlation of early embryo mortality and ovulation rate observed in both gilts (van der Waij et al., 2010; Da Silva et al., 2017a) and sows (Da Silva et al., 2016). However, this assumption when applied to the feed levels over two consecutive cycles may not be as clear, since the increased ovulation rate observed in gilts receiving 3.6 kg/d in one or both of cycles, did not negatively impact embryo survival when fed 2.1 kg/d in cycle 2.

In some studies, the feeding regime performed before breeding had carry-over effects on post-mating luteal function (Ashworth et al., 1999; Almeida et al., 2000). However, most of the reports associated the impairment of reproductive function with low feed intake instead of high feed levels, which is the opposite of the findings of the present study. For example, embryo survival was greater in Meishan gilts at day 12 of gestation when fed higher amounts (1.15 *vs.* 3.5 kg/d) before breeding (Ashworth et al., 1999). Similarly, embryo survival was reduced in gilts feed-restricted for one week before insemination. However, in this case, the authors suggested the reduced survival might have been due to lower amounts of plasma progesterone during early pregnancy (Almeida et al., 2000). In our model, all gilts were fed 2.1 kg/d after the first insemination to exclude any potential adverse effects of high feed intake levels during early pregnancy on embryo survival (Jindal et al., 1996; Jindal et al., 1997; Xu et al., 2010). Langendijk and Peltoniemi (2013) suggested that progesterone metabolization by the liver in the first few days of pregnancy can have a significant impact on fertility since progesterone secretion by the ovaries is still low and still increasing. Despite all of the gilts receiving 2.1 kg/d of feed in gestation, it is possible that the metabolic rate of gilts previously fed 3.6 kg/d was still high after insemination, and allowed greater progesterone clearance, and negatively affected embryo survival. However, some studies have also reported that low feed levels after mating are detrimental to embryonic survival. Athorn et al. (2013) reported that embryo survival at day 10 of gestation was lower in gilts receiving 1.5 kg/d compared to those receiving 2.8 kg/d after mating. Condous et al. (2014) reported that gilts inseminated at third estrus, following ad libitum feeding for approximately 6 d, had decreased embryonic survival when fed a lower amount (maintenance) post-mating. The effect of the post-mating feed level on progesterone concentration has been controversial and inconsistent (Leal et al., 2019). Indeed, gilts fed 1.5 kg/d had fewer progesterone pulses on day 9 of gestation than gilts fed 2.8 kg/d (Athorn et al., 2013). Furthermore, gilts that were fasted on day 10 and 11 of gestation had lower systemic progesterone from day 12 through day 15 after conception and fewer born piglets than fully fed gilts

(Langendijk et al., 2017). Although progesterone was not evaluated in the present study, we can speculate that the level of post-mating feed restriction (from 3.6 to 2.1 kg) imposed a reduction of 1 × maintenance energy requirements (from approximately 2.4 to 1.4 × maintenance), was perceived as a nutritional stress and may have affected the progesterone concentration in females that received the high feed level before breeding. In support of this concept, these females gained less weight during the 30 d of gestation compared with those fed 2.1 kg/d before breeding (13.9 × 17.9 kg). Data from a study where a more severe feed restriction was applied after mating (Condous et al., 2014), the decreased embryo survival was associated with the loss of weight during the first 25 d of gestation in gilts fed 1 × maintenance compared with 1.5 × maintenance.

While the individual CL measurements were not affected by feed levels, the total luteal weight increased in gilts fed 3.6 kg/d during the first cycle after puberty. In the present study, each extra ovulation increased the total luteal mass by 0.18 g (r = 0.32; *P* = 0.005; *data not shown*), lower than the 0.32 g increase reported by Da Silva et al. (2017a) in gilts slaughtered at 35 d of gestation. In that study, gilts with 20.9 ovulated follicles had a decrease in individual CL size as the ovulation rate increased (Da Silva et al., 2017a). Overall, in the present study, ovulation rate and CL size had a moderately negative correlation (r = -0.41), and each extra ovulation decreased individual CL size by 0.11 mm (*P* = 0.003). Despite this relationship and the increase in ovulation rate with increasing feed level, mean CL weight and size were not decreased in females fed 3.6 kg/d, possibly because at this feed level, nutritional support was adequate for the cellular development of additional CL in both weight and size.

Contrary to our initial hypotheses, we observed limited effects of greater feed level on embryo and placental traits, even though gilts fed 3.6 kg/d before breeding had larger follicles and heavier total luteal mass. Da Silva et al. (2017b) did not evaluate different feeding strategies but reported a positive relationship between the average in CL diameter and piglet birth weight. In their study, piglet birth weight was 37.6 g heavier for each mm increase in average CL diameter, whereas in our study the embryos were only 0.29 g heavier for each mm increase in CL size (r = 0.27; *P* = 0.022; *data not shown*). As CL size was not affected by feed levels, the lack of increase in embryo weight in females fed 3.6 kg/d is, therefore, not surprising. However, the correlation between CL size and embryo weight was weak, and feed levels could have affected embryo weight independently of CL size, but this effect was not observed in the present study.

The most common scenario in the industry is to breed gilts at the second estrus, but it is important to consider that for some genetic lines the recommendation is for breeding at an older age, which could also involve breeding gilts at third estrus or more or at lighter or heavier weights, depending upon growth and maturational rate. In this case, results obtained in the present study indicate that the feed level provided during the first cycle after pubertal estrus is important to establish the ovulation rate and the potential litter size, whereas the feed level in the estrous cycle before insemination affects embryo survival. The potential litter size following the first mating becomes a challenging issue considering that ovulation rate is improved while embryo survival may be impaired at the same high feed level. The increase in the number of medium-large follicles at second estrus was evident in gilts receiving 3.6 kg/d. However, it is difficult to extrapolate this result to the number of piglets born in scenarios where gilts are commonly flushed after puberty and bred at the second estrus. More studies are needed using gilts from modern genotypes, considering nutritional flushing strategy after puberty and breeding at the second estrus, mainly to ensure that we are not missing potential in ovulation rate and subsequent reproductive performance.

CONCLUSIONS

Flush feeding gilts (2.1 *vs.* 3.6 kg/d) increased the BW and BF in both cycle 1 (between first and second estrus) and cycle 2 (between second and third estrus) before breeding. Increasing the feeding level during cycle 1 or cycle 2 increased the number of medium-large follicles. Total luteal mass was increased in gilts fed 3.6 kg/d in cycle 1. However, the embryo survival was reduced when gilts were fed 3.6 kg/d during the cycle before breeding. Characteristics (weight and length) of embryos or placentae at 30 d of gestation were not affected by feed levels before insemination.

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Conflict of interest statement

All the authors involved in conducting this research declare there are no conflicts of interest.

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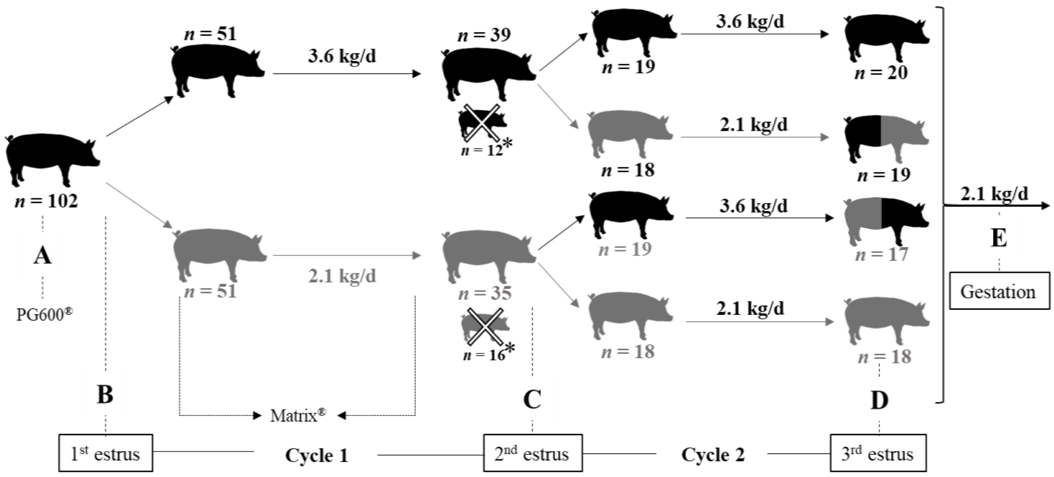


Figure 1. Schematic view of the experimental design. **A**- Total of 102 gilts were selected and induced with PG600 at 164 days of age; **B**- Gilts were randomly assigned to two feed levels (2.1 kg/d or 3.6 kg/d) to be fed and synchronized with Matrix (altrenogest) during cycle 1 (between 1st and 2nd estrus); **C**- Each group of gilts was randomly divided at 2nd estrus to be fed 2.1 or 3.6 kg/d during cycle 2 (between 2nd and 3rd estrus); **D**- Gilts that expressed a 2nd estrus remained in the experiment and were inseminated at 3rd estrus. **E**- After insemination up to day 30 of gestation (gestation period), all gilts were fed 2.1 kg/day *Gilts removed for anestrus or health problems.

Table 1. Composition of the experimental diet (as-fed basis).

Ingredient	Gestation[1]
Corn	77.5
Soybean meal, 47%	11.6
Sugar beet pulp	7.0
Choice white grease	1.0
Limestone	0.8
Dicalcium phosphate	1.3
Salt	0.4
Vitamin and mineral premix[2]	0.2
L-Lys	0.1
Others	0.1
Total	100.0
Calculated Analysis	
SID[4] Lys, %	0.68
SID Met: Lys, %	37
SID Met and Cys: Lys, %	78
SID Thr: Lys, %	81
SID Trp: Lys, %	23
SID Val: Lys, %	110
CP, %	15.03
Ca, %	0.73
STTD P[5], %	0.40
Na, %	0.25
Cl, %	0.20
ME, Mcal/kg	3,151

[1]Gestation diet was fed to developing gilts during cycle 1, cycle 2 and gestation.
[2]*Vitamin composition per kg of diet*: Vitamin A: 12,500 IU; vitamin D_3: 2,500 IU; vitamin E: 125.0 IU; vitamin K_3: 4.5 mg; vitamin B_1: 2.5 mg; riboflavin (B_2): 7.5 mg; pyridoxine (B_6): 3.5 mg; vitamin B_{12}: 33.8 µg; niacin: 50.0 mg; pantothenic acid: 25.0 mg; folic acid: 2.4 mg; biotin: 0.26 mg; choline: 1.25 g. *Mineral composition:* Selenium: 0.64 mg; iron: 75.0 mg; copper: 21.7 mg; manganese: 61.4 mg; zinc: 183.4 mg; iodine: 1.5 mg.
[3]Aela (Auster Animal Nutrition, São Paulo, Brazil) provided 1000 phytase units per kilogram of diet with release of 0.19% STTD P.
[4]SID = standardized ileal digestible.
[5]STTD = standardized total tract digestible.

Table 2. Effects of feed level provided between 1st and 2nd estrus (cycle 1) to high-performing gilts on maternal body measurements, and reproductive parameters at 2nd estrus

Item	Feed level, kg/d 2.1 n = 35	Feed level, kg/d 3.6 n = 39	SEM	Probability, P <
Body measurements				
Body weight, kg	133.6	143.5	1.1	<0.001
Body weight gain, kg	9.8	19.7	1.1	<0.001
Backfat, mm	10.6	11.6	0.4	<0.001
Backfat gain, mm	0.7	1.7	0.4	<0.001
Reproductive parameters				
Estrus after altrenogest, d	6.5	6.2	0.1	0.089
Interestrus interval[1], d	25.5	25.0	0.4	0.022
Total medium-large follicles[2], n	14.3	16.2	0.6	0.032
Follicle size, mm	7.8	7.9	0.1	0.489
Follicle size CV, mm	30.2	27.1	1.2	0.065

[1]Considering the altrenogest treatment for 14 d.

[2]Considering follicles > 5.5 mm.

Table 3. Effects of feed level provided to high-performing gilts between 1st and 2nd estrus (Cycle 1; **FLC1**), feed level provided between 2nd and 3rd estrus (Cycle 2; **FLC2**), and their interactions on body measurements, and reproductive parameters at 3rd estrus

Item	Feed level, kg/d					Probability, *P* <		
	Cycle 1							
	2.1		3.6					
	Cycle 2							
	2.1	3.6	2.1	3.6		FLC1	FLC2	FLC1*FLC2
	n = 18	*n* = 17	*n* = 19	*n* = 20	SEM			
Body measurements, 3rd estrus								
Body weight, kg	146.1	156.7	152.8	163.0	1.2	<0.001	<0.001	0.778
Body weight gain[1], kg	12.5	23.0	9.5	19.1	1.5	<0.001	<0.001	0.475
Backfat, mm	11.0	11.9	11.5	12.9	0.3	0.009	<0.001	0.376
Backfat gain[1], mm	0.6	1.4	0.3	1.1	0.3	0.228	0.001	0.950
Lifetime growth rate, g/d	675.8	714.0	695.6	741.9	25.0	0.042	0.005	0.722
Reproductive parameters								
Cycle length, d	20.8	20.6	20.9	20.8	0.4	0.349	0.534	0.798
Estrous duration, h	49.6	50.9	45.8	52.8	4.7	0.801	0.251	0.427
Follicle size, mm	7.2	7.8	7.3	7.5	0.2	0.630	0.032	0.255
Follicle size CV, %	22.2	20.6	27.5	24.5	4.6	0.107	0.408	0.843

[1] Gains observed during cycle 2.

Table 4. Effects of feed level provided to high-performing gilts between 1st and 2nd estrus (Cycle 1; **FLC1**), feed level provided between 2nd and 3rd estrus (Cycle 2; **FLC2**), and their interactions on body measurements and reproductive performance at slaughter[1]

	Feed level, kg/d					Probability, $P <$		
	Cycle 1							
	2.1		3.6					
	Cycle 2							
	2.1	3.6	2.1	3.6		FLC1	FLC2	FLC1*FLC2
Item	n = 18	n = 17	n = 19	n = 20	SEM			
Body measurements, slaughter								
Body weight, kg	163.5	170.0	170.7	177.1	2.6	<0.001	<0.001	0.945
Body weight gain, kg	17.6	13.5	18.1	14.3	1.7	0.418	<0.001	0.843
Backfat, mm	12.2	13.1	12.2	14.0	0.6	0.467	<0.001	0.574
Backfat gain, mm	1.2	1.1	0.7	1.0	0.4	0.276	0.542	0.435
Corpora Lutea (CL) traits								
Total CL weight, g	7.9	8.1	8.5	8.7	0.5	0.021	0.340	0.980
CL individual weight, g	0.5	0.5	0.5	0.5	0.04	0.553	0.309	0.158
CL weight CV, %	10.4	10.8	13.2	12.4	1.5	0.033	0.872	0.551
CL individual size, mm	10.1	9.9	9.9	9.9	0.3	0.578	0.364	0.323
CL size CV, %	5.9	5.7	5.9	6.4	0.4	0.205	0.694	0.265
Embryo traits								
Early embryo mortality, n	1.3	2.5	1.0	2.3	0.5	0.601	0.006	0.885

Late embryo mortality, *n*	0.5	0.7	0.7	0.4	0.3	0.743	0.775	0.112
Embryo weight, g	2.1	2.0	2.0	2.1	0.1	0.693	0.998	0.470
Embryo weight CV, %	11.9	12.5	12.5	12.1	1.2	0.913	0.928	0.670
Embryo length, mm	26.6	26.3	27.3	26.6	0.3	0.091	0.112	0.574
Embryo length CV, %	8.6	8.5	8.9	9.2	1.4	0.591	0.937	0.821
Placental traits								
Placental weight, g	28.6	29.9	28.1	29.2	2.2	0.688	0.471	0.963
Placental weight CV, %	25.1	24.1	27.5	28.1	2.0	0.098	0.905	0.661
Placental length, cm	45.5	44.8	46.1	44.4	1.2	0.948	0.287	0.645
Placental length CV, %	16.3	16.4	20.7	18.7	1.2	0.006	0.430	0.401

[1]Gilts were slaughtered at 30.2 ± 1.6 d (27 to 33 d) of gestation.

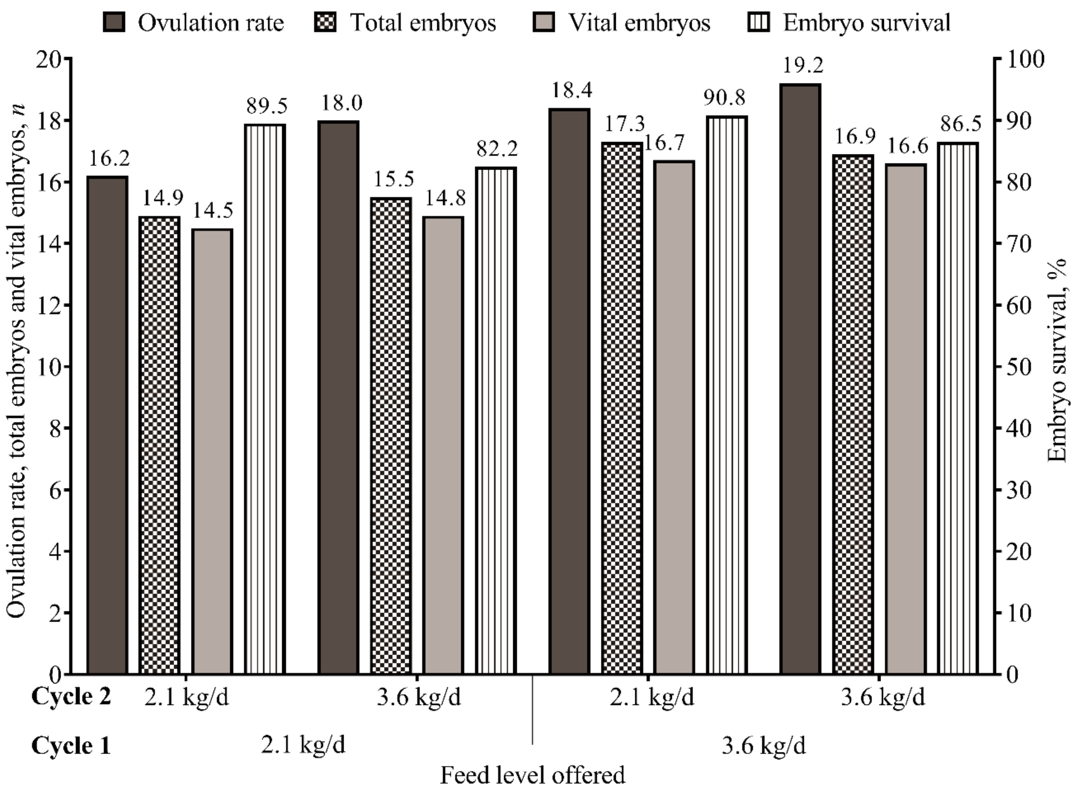


Figure 2. Ovulation rate, total embryos, vital embryos and embryo survival for gilts submitted to 2.1 or 3.6 kg/d during cycle 1 (between 1st and 2nd estrus) and during cycle 2 (between 1st and 2nd estrus) and slaughtered at 30.2 ± 1.6 d of gestation. Effects: Ovulation rate, feed level provided during cycle 1 or cycle 2 ($P \leq 0.009$); total embryos and vital embryos, feed level provided during cycle 1 ($P \leq 0.001$), and embryo survival, feed level provided during cycle 2 ($P = 0.026$)

7 CONSIDERAÇÕES FINAIS

A seleção genética em conjunto com a melhoria nas condições sanitárias, de ambiência, de manejo e nas condições nutricionais elevaram a suinocultura a patamares excelentes de produção. Sobretudo a seleção genética, que com foco no aumento no número de leitões nascidos totais, foi a grande responsável por aumentar o número de leitões produzidos do sistema. Por outro lado, os esforços no âmbito do manejo nutricional foram realizados com diferentes objetivos. Um deles foi tentar amenizar o impacto negativo sobre o peso ao nascer proporcionado pelo acréscimo de leitões na leitegada. Um outro foi verificar a efetividade de manejos consagrados sobre a eficiência produtiva e da sua necessidade, pensando também nos custos produtivos do sistema.

Um desses manejos amplamente utilizados na suinocultura é o aumento na quantidade de ração na fase final de gestação – *bump feeding*. Os dois trabalhos realizados com o uso dessa estratégia demonstraram que o impacto sobre o peso ao nascer é modesto. Além disso, os impactos sobre o desempenho da fêmea de um modo geral são muito mais negativos do que positivos e sobre o desempenho da leitegada, os reflexos são inexistentes. Inclusive quando consideramos o desempenho reprodutivo por ciclos subsequentes e a taxa de retenção no plantel (material suplementar). Em contrapartida, o uso desse manejo implica diretamente no aumento dos custos produtivos, estimados em 50 reais por fêmea por ano, variando de acordo com a quantidade fornecida em cada sistema produtivo. Através destes resultados e de outros presentes na literatura, hoje não temos suporte técnico que justifique o uso dessa estratégia, embora seja necessário ponderar que pode haver variabilidade entre sistemas e linhagens genéticas.

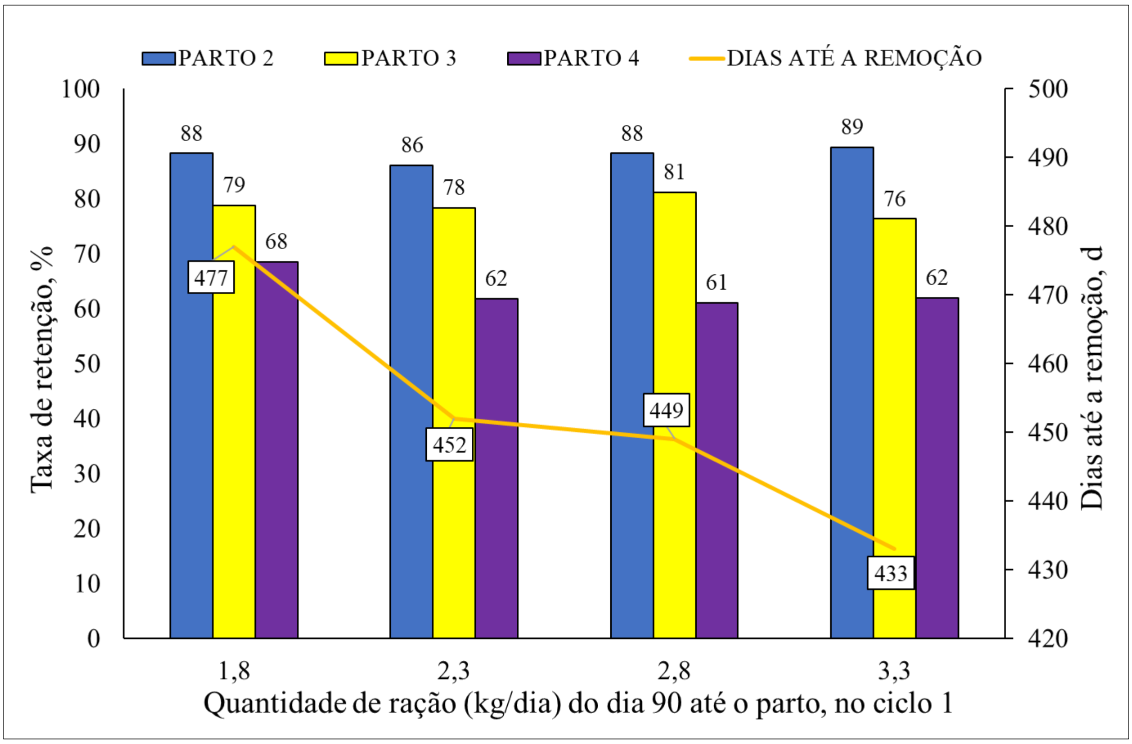
Quando testamos diferentes quantidades de ração na fase inicial de gestação em fêmeas OP1 e OP2, fêmeas OP1 atingiram o seu máximo desempenho ao parto quando alimentadas com a quantidade intermediária de ração (2,5 kg/d). Já as fêmeas OP2 tiveram o seu desempenho reprodutivo prejudicado à medida que a quantidade de ração fornecida foi aumentada. Isso nos demonstra que há um desafio envolvido nessa fase inicial da gestação, especialmente na fêmea OP1, categoria extremamente vulnerável ao catabolismo lactacional. E, vale considerar que de um modo geral, o desempenho mostrou-se pior quando as fêmeas foram alimentadas com 3,2 kg/d. Baseado nisso, o questionamento que fica é sobre a estratégia a ser utilizada para recuperar o escore corporal, uma vez que hoje recomenda-se o fornecimento de quantidades superiores a 3 kg/d, e a partir dos resultados do presente estudo sabemos que possivelmente estejamos perdendo potencial produtivo com o fornecimento desse volume.

Apesar de as fêmeas modernas possuírem características diferentes das fêmeas do passado, o uso do *flushing* pré-inseminação em leitoas mostrou-se como uma estratégia ainda necessária para aumentar o número de ovulações. No entanto, o fato de a sobrevivência embrionária ter sido impactada negativamente quando esse manejo fora realizado no ciclo prévio a inseminação faz com que mais trabalhos sejam necessários. A grande reflexão que fica é se estamos conseguindo aproveitar esse potencial aumento no número de ovulações no formato em que esse manejo está sendo conduzido nas granjas, uma vez que a maioria dos sistemas produtivos utiliza o *flushing* no ciclo imediatamente anterior a inseminação.

Especificamente no manejo nutricional aplicado nas granjas brasileiras, os trabalhos realizados nessa Tese dão suporte de alguma forma para as decisões estratégicas. Todos os experimentos envolvendo a gestação tiveram como quantidade mínima o fornecimento de 1,8 kg/d e os resultados foram semelhantes ou melhores aos demais grupos. Isso demonstra que a fêmea moderna é muito mais resiliente que a fêmea do passado e que possivelmente estejamos superestimando os seus requerimentos. Considerando apenas o não uso do *bump feeding*, há um potencial de redução próximo a 50 kg de ração/fêmea/ano e agregando isso a um fornecimento constante de 1,8 kg/d para a fêmea com escore corporal ideal, o potencial de redução nas quantidades ultrapassam os 100 - 150 kg de ração/fêmea/ano. No entanto, há de se considerar que o sistema produtivo é muito dinâmico, fato que torna necessário e fundamental a constante atualização em todos os processos envolvidos para cada sistema. Além disso, os resultados aqui apresentados podem e devem servir de embasamento técnico, mas a adoção de uma ou outra estratégia é dependente do grau de ousadia e inovação que cada sistema possui.

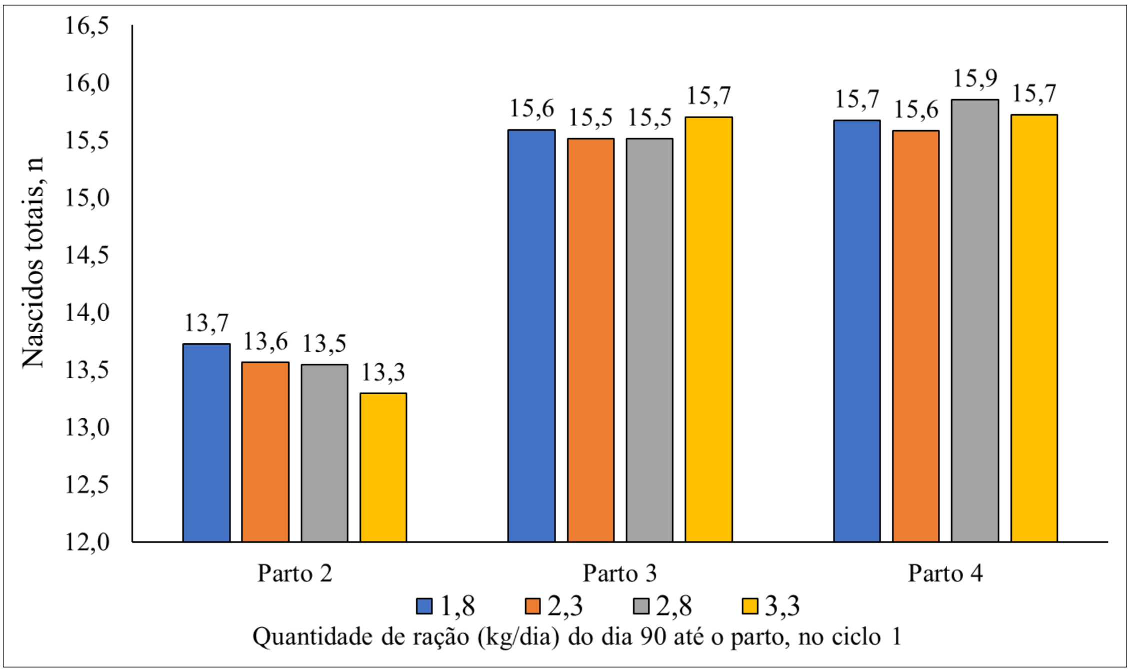
8 MATERIAL SUPLEMENTAR

Anexo 1. Taxa de retenção até o terceiro parto e dias até a remoção do plantel de fêmeas submetidas ao manejo do *bump feeding* enquanto leitoas – primeiro ciclo de vida.



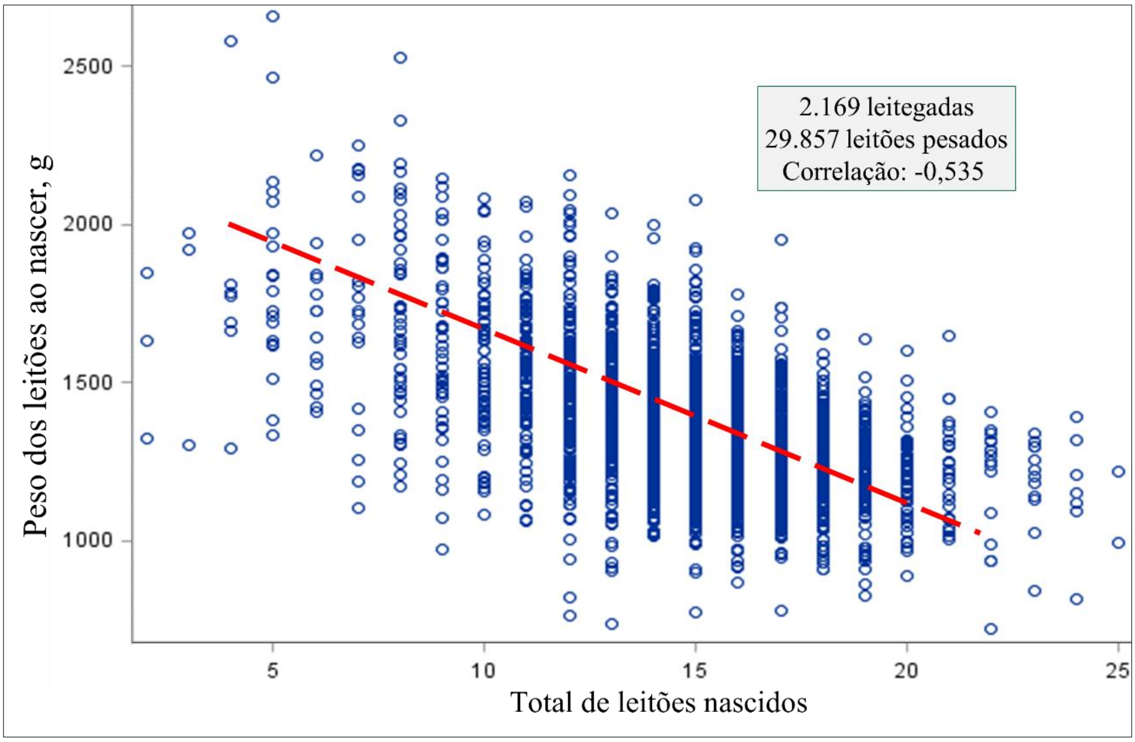
O manejo alimentar de *bump feeding* foi realizado apenas durante o ciclo de vida. No segundo e terceiro ciclos, para as fêmeas desmamadas em escore ideal foi fornecido 1,8 kg/d durante todo o período gestacional. Para as demais fêmeas, foi realizado a adequação do escore corporal e após isso, a quantidade de ração foi mantida em 1,8 kg/d. Não foram encontradas diferenças estatísticas entre os tratamentos para a taxa de retenção (linear, P = 0,140) e para os dias de retenção no plantel (P = 0,120).

Anexo 2. Produção de leitões de fêmeas ao longo de três partos submetidas ao manejo do *bump feeding* enquanto leitoas – primeiro ciclo de vida.



O manejo alimentar de *bump feeding* foi realizado apenas durante o ciclo de vida. No segundo e terceiro ciclos, para as fêmeas desmamadas em escore ideal foi fornecido 1,8 kg/d durante todo o período gestacional. Para as demais fêmeas, foi realizado a adequação do escore corporal e após isso, a quantidade de ração foi mantida em 1,8 kg/d. Não foram encontradas diferenças estatísticas entre os tratamentos nos diferentes partos ($P \geq 0{,}028$).

Anexo 3. Correlação entre o tamanho da leitegada e o peso dos leitões ao nascimento.



O gráfico acima é composto pelo peso de 29.857 leitões pesados ao nascimento, de 2.169 leitegadas, correspondentes aos experimentos descritos no primeiro e segundo artigo científicos. O tamanho médio da leitegada foi de 14,7 leitões e o peso médio dos leitões foi de 1.372 g. A correlação entre o tamanho da leitegada e o peso dos leitões ao nascimento foi de r=-0,535, o que implicou em uma redução de 37g no peso ao nascer a cada leitão que foi acrescido na leitegada.

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