



RODRIGO DE LIMA DOMINGOS

**USE OF A PRECISION FEEDING PROGRAM DURING
GESTATION IMPROVES THE PERFORMANCE OF HIGH-
PRODUCING SOWS**

**LAVRAS-MG
2024**

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Thesis presented to the Federal University of Lavras, as part of the Animal Science Graduate Program requirements, in the area of Non-Ruminant Nutrition and Production, to obtain the Ph.D. title in Animal Science.

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*A Deus por ter me dado forças
E me sustentado até aqui.
Aos meus pais por todo apoio e amor.*

Dedico

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ABSTRACT

Current gestating sow feeding strategies are based on using a single diet regardless of parity or gestation stage. Precision feeding (PF) of the individual sows allows dynamic changes in amino acid and energy requirements throughout gestation. The hypothesis of the study was that meeting the daily predicted amino acid and energy demands of gestating sows using a mathematical model and automatic precision feeder to establish the nutrition programs, would improve reproductive and productive performance compared to conventional feeding programs. Seventy-five mixed-parity sows were distributed among 3 treatments. A treatment managed as flat curve (FLAT: 2.1 kg/d, 1 – 110 d), a high-low-high curve (HLH: 2.2 kg/d, 1 – 49 d; 2.0 kg/d, 50 – 84 d; 2.6 kg/d, 85 – 110 d), where sows received the same diet with 3.2 Mcal/kg of metabolizable energy (ME) and 0.7 g/kg of standardized ileal digestible (SID) lysine. For the PF treatment, feeding level and blend of 2 basal diets (3.0 Mcal/kg of ME; 8.0 and 2.0 g/kg of SID lysine for high and low lysine, respectively) was adjusted daily for each sow to accurately meet estimated amino acid and energy requirements based on live weight, gestation stage and parity. Sows fed PF were heavier on d 110 of gestation ($P = 0.011$) and tended to increase total number of born ($P = 0.092$) and born alive ($P = 0.077$). Sows fed PF showed a higher litter weight ($P = 0.003$) at birth, lower lactation feed intake ($P = 0.010$), higher milk yield ($P = 0.043$) and a larger litter size ($P = 0.050$). Precision feeding sows also presented an improved maternal transformation index ($P = 0.013$) when compared to HLH and FLAT. In conclusion, our results demonstrate that the application of PF strategies based on daily nutrient adjustments is highly beneficial for high-producing sows to support the dynamic needs for nutrient availability for the sow's body growth, mammary gland and fetal development.

Keywords: Lactation; Precision Nutrition; Sow Nutrition.

RESUMO

As estratégias atuais de alimentação de porcas gestantes baseiam-se no uso de uma única dieta para todo o lote, independentemente da ordem de parto ou estágio de gestação. A alimentação de precisão (PF) de fêmeas individuais permite mudanças dinâmicas nas exigências de aminoácidos e energia ao longo da gestação. A hipótese do estudo foi que atender às demandas diárias previstas de aminoácidos e energia de porcas gestantes utilizando um modelo matemático por meio de Alimentador Automático Inteligente de Precisão (AIPF) para estabelecer os programas nutricionais, melhoraria o desempenho reprodutivo e produtivo em comparação com os programas convencionais de alimentação. Setenta e cinco fêmeas de ordem de parto mista foram distribuídas em 3 tratamentos. Um tratamento atribuído como curva de consumo plana (FLAT: 2,1 kg/dia (d), 1 – 110 d), curva high-low-high (HLH: 2,2 kg/d, 1 - 49 d; 2,0 kg/d, 50 – 84 d; 2,6 kg/d, 85 – 110 d), onde as porcas receberam a mesma dieta (3,2 Mcal EM/kg; 0,7 g/kg SID lisina). Para o tratamento PF, o nível de alimentação e a mistura de 2 dietas basais (3,0 Mcal EM/kg; 8,0 e 2,0 g/kg SID Lisina para lisina alta e baixa, respectivamente) foram ajustados diariamente para cada animal com intuito atender com precisão às necessidades estimadas de aminoácidos e energia com base no peso vivo, estágio de gestação e ordem de parto. As porcas alimentadas com FP foram mais pesadas nos 110d da gestação (P=0,011), apresentaram tendência de maior número total de nascidos (P=0,092) e nascidos vivos (P=0,077). As Fêmeas submetidas ao tratamento PF apresentaram menor consumo de ração na lactação (P=0,010), maior produção de leite (P=0,043), maior tamanho de leitegada ao desmame (P=0,050) e, conseqüentemente, maior peso da leitegada (P=0,003) ao nascimento. Os animais submetidos ao PF também apresentaram melhor índice de transformação materna (P=0,013) quando comparadas às HLH e FLAT. Em conclusão, nossos resultados demonstram que a aplicação de estratégias de PF baseadas em ajustes diários de nutrientes ao longo da gestação é altamente benéfica para porcas de alta produção, para apoiar as necessidades dinâmicas de disponibilidade de nutrientes para o desenvolvimento corporal e fetal.

Palavras-chave: Lactação; Nutrição de Precisão; Nutrição de Suínos.

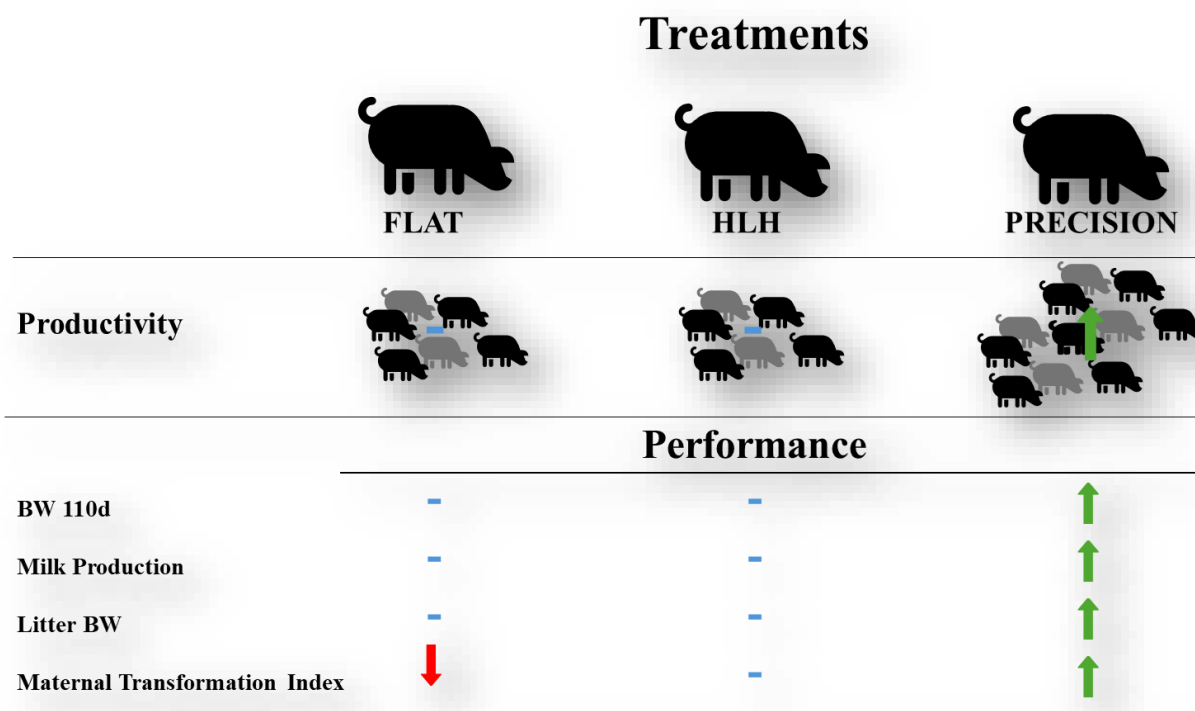
USE OF A PRECISION FEEDING PROGRAM DURING GESTATION IMPROVES THE PERFORMANCE OF HIGH-PRODUCING SOWS

Created by Rodrigo de Lima Domingos and supervised by Márvio Lobão Teixeira de Abreu

The body condition of a gestating sow can directly influence performance during lactation. Excess energy can cause obesity at birth, leading to reduced voluntary intake, resulting in excessive body mobilization during lactation. Normally, sows are fed the same diet during gestation without changes in nutritional levels and even in quantity, although their nutritional requirements vary throughout pregnancy.

The effects of adequate supply based on the daily requirement of the female are not only limited to fetal growth, but also on tissue deposition and milk production that will be used postnatally. Also in the study, it was shown that milk production was higher than the other treatments by approximately 1.2 liters per day, reflecting the more accentuated body mobilization of the tissues deposited during gestation calculated by the deposition and mobilization of fat.

Precision nutrition has become a tool present in the daily life of pig farms in Brazil and in the world, aiming to achieve pig production in a sustainable and efficient way, enhancing economic returns.



The concept of precision nutrition can be seen as an innovative technique in pig research in recent years, with the aim of improving the efficiency of the animal's utilization of essential nutrients.

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CHAPTER 1

1. INTRODUCTION

Advances in pig production have brought many benefits for producers, such as a higher number of piglets per sow per year, higher farrowing rates per year, decreased age at slaughter, increased feed efficiency and higher lean gain (Ball et al., 2008). Nevertheless, negative characteristics, such as within-litter birth weight variation, have developed, resulting in economic losses and lower profits for the producer (Wolf et al., 2008). The establishment of a proper nutrition program for modern sows should consider the genetic material of the farm, nutritional needs, factors that affect these needs, and should understand the various aspects of the metabolic interaction between genotype, nutrition, and reproduction in sows. This understanding is essential so that productivity and longevity can be achieved simultaneously. A gestating sow's energy state can directly influence its performance during lactation. Excessive energy can cause obesity at birth, leading to reduced voluntary intake, resulting in high physical losses during lactation (Sinclair et al., 1998; Kim et al., 2009). The reduction in voluntary intake is an even bigger problem when it comes to gilt and second parity sows in relation to adult sows. Young sows generally have a lower voluntary intake capacity, around 20% lower (Young et al., 2004), compared to adult sows. A severe energy deficiency can result in sows being thin at farrowing, which can lead to problems during lactation with reduced capacity to produce milk and a reduction in litter weight at weaning. To control the energy consumption of pregnant sows more efficiently, restricted and/or controlled feeding is put into practice. Maternal gain should be recognized as the net gain in weight of the sow during the gestation period, disregarding the weight gain attributed to the uterus, placenta, placental fluids, fetuses, and mammary gland. The contribution of maternal gain to the energy requirement of the sow is variable and related to the growth phase, which is higher in primiparous sows. Fetal growth, the uterus, and the mammary gland, representing the energy requirements of reproduction, require a total of 1.59 MJ (or 380 kcal) of ME/day for an equivalent of a 12-fetus litter, regardless of female weight (Noblet et al., 1997). If we consider modern genotypes, where sows are observed with 16+ fetuses, this requirement would be 1.98 MJ (or 473 kcal) ME/day, a 25% increase in energy requirements for reproduction. According to Close (2001), during the

114 days of gestation, about 60% of the energy expenditure through reproduction is due to the uterus and the remaining development of the mammary gland. The total energy demand of the pregnant sow would also depend on the body condition of the animal at the time of insemination. Therefore, sows with lower body fat reserves require more energy to reach the body condition recommended for the time of farrowing. Due to the fact that sows are fed restrictively during gestation, they may become deficient in amino acid intake, especially towards the end of gestation. Thus, when considering a limited supply of feed to restrict energy consumption, it is important to provide a diet that allows high efficiency in the utilization of protein. Amino acids are not only building blocks of protein synthesis but are also used as precursors for nitrogenous substances essential for whole-body homeostasis (Wu et al., 2010). There is strong evidence that the members of the arginine family of amino acids have an important role in placental vascularization and development, especially during the middle of gestation (Wu et al., 2007). This theory is supported by Mateo et al. (2007), who supplemented 1% L-arginine to a corn and soybean meal-based diet after day 30 of gestation to gilts and found that supplementation increased the number of pigs born alive by 22%. There is more information available on lysine requirements than other essential amino acids. However, if apply the ratio that makes ideal use of the proposed need for lysine by Samuel et al. (2008a), the need for methionine would be 40% higher than current recommendations. Methionine plays a key role during pregnancy, including DNA methylation during the development of gestation, which makes it extremely important for the regulation of gene expression. Dourmad and Etienne (2002) concluded that the need for threonine during pregnancy in modern sows is greater than the value proposed by most published references on sow's requirements; the authors attribute this difference to a greater daily nitrogen retention found in modern sows during gestation. These results corroborate the hypothesis that amino acid requirements are larger for modern genotypes due to greater lean tissue deposition and protein turnover capacity. For fetal growth and development of mammary tissue to occur rapidly during the final stage of gestation, amino acid requirements tend to be higher. Therefore, muscle growth must also be considered in younger sows as part of their reproductive needs. While analyzing recent studies with modern genotype sows, particular attention has been given to fetal growth (McPherson et al., 2004) and development of the mammary gland (Ji et al., 2006). The results obtained by these authors indicate an exponential growth of both fetal tissue and the mammary gland mainly after 70 days of gestation. These results are higher than those observed in similar studies in the

'80s and the '90s. Wu et al. (1999) assessed the amino acid composition of pig fetuses during the different stages of gestation and observed that this variable changes significantly during the progress of gestation. The changes in the rate and composition of tissue gain affect the individual needs for amino acids for fetal and mammary gland growth during gestation. From the amino acid composition of various tissues (mammary gland, uterus, fetus, placenta) and the changes that occur during gestation, it is possible to develop models based on the productive profile of modern genotypes, through which we can obtain the real daily nutrient requirements for sows. Based on the results of recent studies, the establishment of nutritional programs using more diets and no longer a single diet throughout the entire gestation period may not only have several benefits for the sows and fetal development (McPherson et al., 2004) but also reduce the excretion of total N and ammonia emissions, which may contribute to higher animal productivity and create a more sustainable environmental system (Clowes et al., 2003a).

The simplest method of meeting the increasing energy and amino acid requirements of sows during late gestation is increasing the level of feed supplied during late gestation. It is proposed that simply increasing feed intake better meets the increasing nutrient demands of the sow. NRC (2012) outlined a 400 g/day (about 20%) feed intake increase after day 90 of gestation based on energy requirements, while this increase should be about 40% based on lysine requirements. A cooperative research study by Cromwell et al. (1989) concluded that additional feed supplied during late gestation improved reproductive performance. The study involved 1,080 litters where multiparous sows in the treatment group were fed 1.82 kg/d of a corn and soybean meal-based diet (3.2 Mcal ME, 14% CP) in addition to the levels received by the control group (summer 1.82, winter 2.27 kg/d) from day 90 of gestation until farrowing. Sows fed extra feed in late gestation farrowed an average of 0.35 more pigs/litter, as well as slightly heavier pigs at birth (1.48 kg vs 1.44 kg) and at weaning (18 days) (Cromwell et al., 1989). A more recent study by Shelton et al. (2003) yielded slightly conflicting results when 0.9 kg/d of extra feed (corn/soybean meal-based diet containing 3.26 Mcal ME, 0.57% SID lysine) was given after day 90 of gestation (2.09 vs 2.95 kg/d). These authors found that increasing feed intake during late gestation led to a decrease in piglet birth weight in multiparous sows, but an increase in piglet birth weight in gilts. Additionally, gilts offered extra feed had an increase in subsequent conception rate compared to the control, whereas sows fed extra feed had a reduced conception rate in subsequent parities. Only in second parity sows did an increased feeding level during late gestation slightly increase litter weight at weaning. We also must consider that extra feed

supplied during late gestation can result in over-conditioning of sows at farrowing, which can compromise sow reproductive performance (Young et al., 1991; NRC, 2012). Research focusing on relating patterns of intake of total feed, energy, or protein (i.e., amino acids) during gestation to sow reproductive performance has yielded varying results. In an extensive review of the scientific literature, Campos et al. (2012) reported that providing extra feed or energy during late gestation only marginally improved piglet birth weight, and effects were not consistent between different studies. Several studies demonstrated no effect, while others indicated improvements in various aspects of production, such as litter size, gestation sow BW gain, lactation sow BW loss, and feed intake during lactation. Differences in results among these studies could be attributed to different levels of energy and nutrients supplied, as well as different durations of time and periods of supplementation. Another important factor to consider is the use of primiparous sows compared to multiparous sows, which are known to have differences in nutrient partitioning. Current commercial gestation sow feeding strategies do not consider the sow as an individual; they are generally based on using a single gestation diet for all sows regardless of parity or stage of gestation. Computer-controlled electronic sow feeders (AIPF) allow precision feeding (PF) of individual, gestating sows according to parity order and gestation stage housed in groups. Based on the above observations, increasing dietary amino acid levels is more beneficial than increasing feed intake, especially during late gestation, as it does not contribute to excess maternal body lipid deposition, which may reduce subsequent sow reproductive performance. While studies have clearly demonstrated that the amino acid demands of gestating sows change throughout gestation, more research is needed to clarify if more closely meeting these changing amino acid requirements will improve sow reproductive performance and ultimately, profitability.

2. LITERATURE REVIEW

2.1 Evolution of nutritional requirements for hyperprolific sows

Global pork production has quadrupled in the last 50 years and continues to grow. The growing demand primarily stems from specialization, automation, market liberation, technological improvements, genetic advancements, and feeding strategies (Gerber, Vellinga, & Steinfeld, 2010; Lassaletta et al., 2019).

Feed composition plays a crucial role in determining the sustainability of swine production. Land usage for animal feed, competition for food between humans and animals, and the amount

of nitrogen excreted into the environment, which can contaminate soils and water, are factors that impact the search for solutions to enhance system productivity (Uwizeye et al., 2016; Schader et al., 2015; Sajeev et al., 2018; Sanchez-Martin et al., 2017). As a result, the growth in production induces a rapid increase in feed demand, including raw materials such as cereals and oils (Foley et al., 2005; Lassaletta et al., 2014; Wang et al., 2018).

The performance and productivity of pregnant sows have also significantly increased in recent decades, leading to higher nutritional requirements for energy and protein during gestation and lactation (Tokach et al., 2019). To support high production levels, animals must be in appropriate body conditions, requiring pregnant sows to receive adequate nutrients to support fetal growth and the numerous metabolic and physiological changes that occur during this period.

According to Dourmad (2019), many commercial farms consider hyperprolific females to be those whose average productivity exceeds 15 piglets at birth and 13 at weaning. Furthermore, numerous studies conducted in recent years, along with the use of mathematical modeling, have contributed to generating estimates for the nutritional requirements of modern sows.

Tokach et al. (2019) illustrated the advancement in the increase of total piglets born from 2006 to 2019. Total live births grew by approximately 0.334 piglets per year, equating to 4.5 animals over a period of 13 years. Consequently, the number of weaners per sow has almost proportionally increased over the years. However, with the increase in live births, a reduction in the birth weight of these animals has also been observed, decreasing by about 120 grams from 2006 to 2013. After a change in selection criteria, a reversal in the trend of birth weight reduction was observed, resulting in an increase of approximately 7% compared to 2013 and 20 grams compared to the beginning of the analysis in 2006 (Tokach et al., 2019).

Given the increase in productivity of modern sows, metabolic and nutritional demands have also risen. Nowadays, genetic lines exhibit higher growth rates and less adipose tissue compared to past genetics (Kim et al., 2015; Thomas et al., 2018). These changes in growth rates, production, and metabolic demands highlight the increased nutritional requirements of gestating or lactating female to enhance performance traits such as fetal growth during late gestation, litter size, mammary gland development, and finally, the milk production during lactation (Tokach et al., 2019).

Dourmad (2019), in evaluating the productive advances of sows over the last 40 years, demonstrated that genetic lines based on Large White and Landrace have been intensively

selected for reproductive performance, particularly in European commercial farms. The improvements were more associated with a growth rate increase (+50%) compared to the number of weaners per litter (+32%) between 1980 and 2016. One of the main factors contributing to the significant growth rate at this stage is the higher milk production.

Various studies have shown the effect of reproductive disorders on animal performance. These problems can affect productivity through early disposal, often resulting from changes in body reserve composition, fat, and energy (Boyd et al., 2000; Dourmad et al., 1994; King, 1987; Whittemore, Franklin, & Pearce, 1980). Ngo et al. (2012) also demonstrated that litter size affects milk production, with production increasing linearly with litter size, but the amount per piglet decreasing.

Over the years, various methods for assessing and determining nutritional requirements have been used, leading to updated research focused on the nutritional needs of animals, thereby contributing to greater accuracy of values. Studies focused on the nutritional requirements of sows at different production stages have been conducted to quantify the effects of energy on reproductive performance, birth and weaning weight, as well as changes in sow weight during lactation (Aherne & Kirkwood, 1985; Dourmad, 2019; Henry & Etienne, 1978).

Amino acids have been studied to meet the nutritional requirements of sows during pregnancy (ARC, 1981). Values found in the literature for lysine, for instance, range from around 24 to 25 grams per day for each kilogram of litter produced (Gourley et al., 2017; Xue et al., 2012).

Numerous research efforts have been undertaken in recent years to develop tools facilitating the prediction of nutritional requirements at various stages. Starting from edition of the NRC in 1998 (NRC, 1998), the biological basis for establishing energy and amino acid requirements shifted towards integrated mathematical equations (mathematical models), marking a significant advancement in pig farming nutrition. According to Noblet et al. (1990), quantifying the requirements of different stages and physiological conditions of animals is crucial for implementing and quantifying animal requirements through factorial methods.

Studies indicate that equations published between 1998 and 2017 already provide adequate predicted values for lysine requirement to optimize progeny growth (Gourley et al., 2017; Sauber et al., 1998; Xue et al., 2012; Yang et al., 2000). These equations stem from regressions, utilizing data from various studies to adjust values.

The regression curve was initially derived from published studies focusing on nutritional lysine requirements from 1972 to 1997. The updated curve incorporates data from published studies

from 1998 to 2017. A updated regression suggests a requirement of 27 grams of digestible lysine per day for every 1 kilogram of litter growth, with sows expected to mobilize 13 grams of lysine per day from body protein stores (Tokach et al., 2019).

Another critical factor in considering the nutritional requirements of sows is the energy content of their diets. Several studies demonstrate that the female's body condition in the final of gestation can influence future performance. An animal with excessive backfat thickness at farrowing may experience reduced feed intake (Dourmad, 1993; Tokach et al., 2019).

Significant advances in animal nutrition for sows during the reproduction have also come from studies focusing on specific amino acids playing crucial roles in the development of productive and reproductive tissues. For instance, Che et al. (2020) evaluated the influence of valine (a branched-chain amino acid) during late gestation in sows (from day 75 until farrowing) and found that birth weight and daily weight gain increased with supplementation. Additionally, supplementation with 0.93% valine/lysine led to increased plasma prolactin concentration, potentially impacting milk production.

Valine, as studied, can activate the mTOR pathway through phosphorylation (Rezaei, 2015). This pathway influences cell growth and proliferation, potentially explaining the improved performance in young animals. Moreover, the mammary gland plays a significant role in the metabolism and uptake of BCAAs (Rezaei et al., 2016), resulting in increased levels of these amino acids in milk and subsequently enhancing the performance of newborn piglets.

As depicted, amino acids serve various metabolic functions. Hence, several studies demonstrate progress in research concerning the effects of amino acids on the performance of pregnant sows (Guoyao et al., 2019; Wu, 2009).

Similarly, energy plays a vital role in an animal's growth and development. Numerous studies have shown that energy intake during pregnancy affects fetal growth and mammary gland development, functions crucial for female performance. However, excessive energy intake during this stage can have negative effects, such as increased weight in females and reduced consumption during lactation, ultimately impacting milk production (Fang et al., 2019; Messias de Bragança et al., 1998).

Long et al. (2010) stated that providing high-energy diets during pregnancy led to increased body weight and adipose reserve loss during lactation. According to NRC (2012), the daily energy requirement for pregnant sows should range between 6,678 and 8,182 Kcal of metabolizable energy (ME) per day.

As discussed earlier, the reproductive performance of female has increased over the years, leading to an increase in nutritional requirements. Energy is no exception. Due to genetic evolution and increased productivity, animals now require higher nutrient and energy amounts. Energy and amino acids serve different functions in the animal's body, but their utilization dynamics change over time, influenced by factors such as physiological stage, production level, weight, and sex. For instance, the requirement for metabolizable energy for maintenance is higher towards the end of gestation than during lactation, as sow weight decreases post-farrowing due to piglet birth (Feyera & Theil, 2017).

Numerous offspring are associated with a high energy requirement due to increased milk demand by piglets. Females often struggle to sustain the high milk production required solely through diet ingestion, leading to maternal reserve mobilization and excessive body weight loss during lactation (Rutherford et al., 2013; Theil, 2015).

When formulating rations for high performance, utilizing nutritional requirement tables is crucial. These tables provide practical levels required by production animals for maximum performance, considering factors such as phase, genetic potential, and production stage. Thus, understanding the animal's characteristics and target phases is essential for effective formulation.

In Brazil, the primary reference is "Tabelas Brasileiras de Aves e Suínos," now in its fourth edition, last published in 2017 (Rostagno et al., 2017). Besides Brazil, the NRC (National Research Council) (NRC, 2012) serves as a worldwide reference for formulating animal diets based on requirements per stage, although its last edition was published in 2012. Additionally, various manuals provide nutritional requirements from genetic companies with a focus on their developed lines.

To enhance the accuracy of animal nutrition, treating each animal individually to meet individual rather than herd requirements is necessary. Another factor impacting animal performance is that consultation tables often assume extended periods for providing the same diet nutritionally. For instance, calculating individual requirements for animals in periods from 0 to 85 days and from 86 to 115 days may result in overestimation or underestimation due to varying nutrient deposition for different tissues.

For example, during the initial third of gestation, multiparous sows require replenishing their energy reserves due to the negative energy balance experienced in the previous lactation. In the middle third, the development of mammary glands and fetal growth initiation could alter the

requirement ratio, prioritizing protein (in the form of amino acids). Precision nutrition through modeling and daily requirements can potentially alleviate such problems, directly impacting economic returns and animal performance.

2.2 Effect of feeding frequency on sows on metabolism

The welfare of farm animals is important for producers, consumers and society (Cornish et al., 2016). Modern hyperprolific females are often fed restrictively for efficient reproduction and to increase longevity (Manu, 2020) and/or are fed only once a day, for reasons such as reduced farm management or the feeding system adopted (example: electronic feeding system).

Pregnant sows that are fed restrictively may experience stress and its impact on their behavior (Bernardino et al., 2016). Increased and sustained stress is associated with impaired well-being. The hypothalamic-pituitary-adrenal (HPA) axis is one of the physiological systems almost always activated by stress. In research carried out, it was observed that the availability of food stimulates the rhythmicity of cortisol in such a way that food restriction or starvation increases the average levels of glucocorticoids in humans and rats (Garcia-Belenguer et al., 1993; Kenny et al., 2014). Cortisol, a steroid hormone secreted by the adrenal gland, has a circadian rhythm with the highest concentration around 8:30 am, gradually decreasing to the lowest levels around midnight (Chan and Debono, 2010; Seth et al., 2016). In studies carried out by Amdi (2013), it was observed that feed restriction in pregnant gilts elicited higher levels of salivary cortisol than gilts used in the control treatment, which had higher feeding levels. When an animal is pregnant, the prolonged stress response, hyperactivation of the HPA axis, and excess glucocorticoids pose risks to normal development, reproduction, emotional balance, physiological health, and the well-being of newborns (Coulon et al., 2013).

Regarding feeding frequency, Verdon et al. (2015) found that increasing feeding frequency allowed the performance of natural behavior to improve welfare compared to less frequently fed sows. However, in studies carried out by Manu (2020), where one, two, or three feedings a day were used, it was found that feeding frequency regimes and sampling protocols did not inhibit the circadian rhythmicity of cortisol in sows. Furthermore, it was speculated that the feed intake of the pregnant females was not prior to peak cortisol concentrations, as all females had peak levels of cortisol before feeding. This confirmed a previous study where the circadian cycle in the adrenal gland defined specific time intervals during which the adrenal gland responds most effectively to adrenocorticotrophic hormones.

According to Meunier-Salaün et al. (2001), pregnant females are fed about 2.5 kg of feed per day, which represents 50% of their ad libitum feed intake. Dividing limited feeding into two or three meals or feeding these animals several times a day did not change basal cortisol concentrations, which is consistent with findings from other studies (Terpstra et al., 1978; Levay et al., 2010).

Terpstra et al. (1978) reported that subjects in a human study who were given a fixed 65% solid carbohydrate diet in a metabolic cage demonstrated basal cortisol levels that did not change with variation in meal frequency. Although baseline glucocorticoid concentrations and caloric restrictions are dose-dependent, the absolute differences in circulating corticosterone between 50% and 25% of caloric restriction are small (Levay et al., 2010).

In view of this, according to Manu (2020), in his study it was not expected to find any difference in basal cortisol levels when all treatment groups had similar energy intake per kilogram of metabolic body weight. However, it was observed that twice-daily feeding reduced the area under the curve (AUC) of cortisol compared to control sows.

Farmer et al. (2002) reported that feeding pregnant sows a concentrate diet twice daily reduced cortisol AUC compared to single-feeding sows. On the other hand, Holt et al. (2006) did not show a feeding frequency response (twice daily at 7:30 am and 2:30 pm) on salivary cortisol concentration in relation to sows fed once daily. According to Manu (2020), the differences in the results are attributable to the sampling length, evaluation method, and cortisol turnover rate. Also, in this same study, females were sampled for these assessments, every 2 hours, from 6:30 am to 6:30 pm, which were evaluated using the AUC. Holt et al. (2006) evaluated their experimental animals using measurements at a single time (1:00 pm). Due to the diurnal rhythmicity of the cortisol secretion pattern, measuring a single point in time may not be informative if the biological reasoning behind the sample is not known (Stewart et al., 2017). It is difficult to interpret saliva or plasma concentrations of any hormone. Cortisol concentration at any given time depends on secretion and clearance rates. Without knowing the turnover rate, cortisol concentrations in blood or saliva are poor indicators of what is happening (Friend, 1980).

Robert et al. (2002) reported that gilts fed two meals a day on a concentrate diet had similar feeding activity compared to gilts fed once a day. However, these researchers assessed sows' feeding behaviors just 5 minutes before the morning feed at 8:00 am. Increasing feeding frequency for pregnant females can improve satiety and their well-being because energy for

stereotyped behaviors can decrease and increase productivity. In support of this theory, in one study it was observed that twice-daily feeding tended to improve bacon thickness gains (Manu et al., 2020).

Sows fed three times a day increased total and feeding activity compared to sows fed twice a day. The increase in activity can be attributed to inadequate intestinal filling due to the lower amount of energy and/or volume of food received in each feeding. In support of this theory, Lawrence et al. (1989) explained that the conventional diet of North American sows is concentrated in nutrients and, although it is sufficient for good health and performance, it may not meet the animal's other needs. In addition, the small amount of food is unlikely to give a feeling of satiety (Verdon et al., 2018).

When the amount of the meal is too small to induce satiety, "non-eating activities" persist (Terlouw et al., 1993; Robert et al., 2002). The behavioral activities that precede feed provision are termed "food anticipatory activity" (FAA) (Johnston, 2014). Sows fed three times a day had higher FAA compared to sows fed once and twice a day. This observation agrees with results found in studies carried out with cats. Cats fed four times a day increased FAA compared to cats fed once a day (De Godoy et al., 2015). Therefore, increasing the daily meal may be a metabolic advantage by distributing the nutrient load throughout the day or improving the welfare of these animals (Manu et al., 2020). However, with the increase in FAA with three meals a day, it is speculated that the diet does not provide adequate bowel filling or distention with the small volume of concentrated diet at each feeding time to induce meal termination.

One mechanism by which meal termination occurs is through activation of gastric mechanoreceptors after stomach distention. Mechanoreceptors carry their signal along the vagus nerve to communicate digestive status to the vagus nerve nucleus, which relays the signal to the brain's feeding centers, such as the hypothalamus, to influence the start or end of a meal (Grill & Hayes, 2012). Furthermore, gastric wall distention and subsequent activation of stretch receptors and mechanoreceptors lead to a lower threshold required for cholecystokinin and leptin to induce decreases in food intake. There are studies demonstrating some alternatives to minimize the feeling of hunger, which involve changing the diet, quantitatively or qualitatively (D'Eath et al., 2009). The use of fiber in the diet is an efficient alternative to reduce abnormal behaviors, arising from the frustration caused by the restriction of access and manipulation of food, before and after feeding (Robert et al., 1997).

A balanced diet guarantees adequate nutrients for each phase, but this is not synonymous with satiety of the sows, and this lack of satiety may reflect on stress and behavior (Meunier-Salaün et al., 2001; De Leeuw et al., 2004). Studies carried out in animals with restricted access to food indicate that food is the most important factor in organizing the rhythm of the HPA axis (Dallman et al., 1993). The fact that females are hungry reflects in abnormal behaviors, arising from the absence of satiety and the presence of motivation to feed. This motivation is represented by behaviors such as rubbing the muzzle on the empty feeder and biting bars in the cell (Douglas, 1998; Jensen, 1980). Furthermore, these changes in motivation can alter the zootechnical performance, the immune function, and also the behavior of these animals, factors of extreme importance in productivity, economic viability, and longevity of the sow (Douglas et al., 1998).

An alternative to reduce such problems is the use of fiber to meet the feed motivation of gestating sows and minimize the feeling of hunger, thus reducing feed motivation and the manifestation of stereotypical behaviors that may reflect on productivity (Lawrence; Meunier-Salaün et al., 2001; De Leeuw et al., 2004). The inclusion of fiber in the diet provides an increase in gastric volume, as fibers retain water in the gastrointestinal tract and have a lower energy density than concentrated food, which can cause greater gastric distention and consequent stimulation of extension receptors and chemoreceptors in the stomach and duodenum (Read et al., 1994; Lepionka, 1997), thus reflecting in the reduction of motivation to eat.

Studies have observed that females fed diets containing high amounts of fiber had the most stable glycemic levels. De Leeuw et al. (2004), in a study, fed a diet with a high value of fermentable non-starch polysaccharides to gilts (beet pulp) and observed a 15% drop in glucose below baseline in animals fed a low fiber diet. It was also verified an increase in the number of piglets born and higher weaning weight for animals from sows that received a high-fiber diet during gestation. Fiber fermentation produces short-chain fatty acids, a good source of energy (De Leeuw et al., 2008), bringing more satiety to these sows, working as a good strategy especially for sows that have reduced feeding frequencies.

Short-chain fatty acids are involved in long-term physiological mechanisms of satiety, preventing blood glucose from decreasing when the amount of glucose available in the small intestine is low (Rérat, 1996). Furthermore, these short-chain fatty acids can contribute with 20 to 30% of the maintenance energy needs in swine (Bergman, 1990).

According to Samuel (2019), there is a trio of "rights" in the precise feeding of modern and hyperprolific sows: the right diet, in the right amount and at the right time. Feeding levels for sows during pregnancy are normally based on maintenance requirements, desired body condition, weight, and litter weight gains (National Research Council, 1998; Spoolder and Vermeer, 2015; Bunter et al., 2018). However, the amount of feed is normally less than the amount that females would voluntarily consume (Van Barneveld et al., 2007).

In electronic feeding systems, pregnant sows are usually fed only once a day, which has been shown to increase the efficiency of energy use; however, it has reduced the efficiency of protein use, and unfortunately, we still observe a scarcity of information recent studies on feeding sows at the right time (Samuel, 2019). Previous research has not shown significant productivity and performance advantages when feeding sows more than once a day. As an example, it was observed that pigs fed a single meal gained weight at a rate similar to that of pigs fed small frequent meals (Allee et al., 1972).

According to Fabry (1969), feeding sows once a day seems to result in greater energy storage efficiency compared to sows fed more than one meal a day. The improvement in energy utilization efficiency was also attributed to reduced energy expenditure related to the consumption of a single meal compared to several meals (Baird, 1970). On the other hand, it was possible to observe that the reduction of feeding frequency influences lipid metabolism. As an adaptive mechanism for storing large energy intakes, lipogenesis is stimulated by infrequent feeding of meals (Leveille and Hanson, 1965). The result of increased lipogenesis is an increase in body fat and plasma lipid concentrations (Fabry, 1969). While animals fed a single meal tend to retain excess energy primarily as fat, animals fed more frequently tend to store excess carbohydrates as glycogen rather than converting them to lipids (Leveille and Hanson, 1965). As a result, we can predict the composition of body weight gain among animals fed more frequently compared to those fed a single meal. Therefore, the effect of feeding on energy metabolism must be considered, mainly due to its impact on dietary needs and body composition of sows (Samuel, 2019).

Animals fed once a day appear to retain more energy in the form of fat compared to animals that consume more frequent meals. However, animals fed once a day tend to oxidize more amino acids due to the inability to handle the large influx of nutrients (Fabry, 1969).

Samuel (2019), when investigating the energy and protein metabolism of pregnant and non-pregnant females (through simultaneous energy measurements using open circuit calorimetry

and protein metabolism as protein turnover), showed that the frequency of feeding had opposite impacts on sow metabolism.

Therefore, while single-feeding improved energy retention efficiency, protein utilization efficiency was reduced (Samuel, 2008). Recently, the University of Minnesota reported that when sows were fed in the afternoon instead of being fed in the morning, changes in energy and nutrient metabolism increased backfat thickness (Manu et al., 2019).

Currently, a very important goal within the swine industry is to achieve precision feeding. One of the objectives in this regard is to reduce the crude protein content of the swine diet. Potential advantages of low crude protein diets include savings on expensive protein ingredients, reducing dietary costs, lowering nitrogen emissions, lowering the impact on the environment, thus improving gut health and production efficiency.

Probably, dietary requirements for amino acids are higher due to single meal feeding, where protein utilization is reduced (Samuel, 2019). In addition, reductions in the crude protein content of the diet will require higher levels and mixtures of synthetic amino acids in the diets. Therefore, the potential for infrequent feeding can negatively impact amino acid utilization due to nutrient asynchrony. Amino acid asynchrony refers to the delayed digestion and absorption of protein-bound amino acids compared to synthetic amino acid sources. However, there may be potential implications for increasing the inclusion of synthetic amino acids, such as in low crude protein and single-meal diets.

Within a gestation cycle, feeding sows more than once a day had no advantages in measures of sow productivity, such as the number of piglets born, born alive, piglet strength, or daily feeding cost per sow (Baird, 1970). Research has shown that feeding frequency affects metabolism and, consequently, dietary nutrient requirements (Le Naou et al., 2014). The effects of feeding frequency and time of day on energy and protein requirements should be considered, especially when using a low-protein diet strategy. In a study developed by Silva et al. (2021), when evaluating the feed intake of lactating sows, through smart feeders, found that feed intake (ad libitum) is predominantly nocturnal. This kinetics of feeding behavior can be explained by the feeding habits of their ancestors and by the ambient temperature, since in this phase (lactation) the animals are very affected by heat stress.

Lactation is a period of the reproductive cycle that can affect the metabolism of sows more than any other physiological state (Cools et al., 2014) due to the increased demand for energy and nutrients for milk production, which can lead to a catabolic state of these animals (Ball et al.,

2008). As reported by Theil et al. (2004), more than half of the metabolizable energy (ME) and nitrogen (N) present in the diet are used for milk synthesis, and sows often do not absorb the amount of energy needed during lactation for several reasons, including limited appetite (Pedersen, Sønderby Bruun, Feyera, Larsen, & Theil, 2016). Researchers (Koketsu, Dial, Pettigrew, & King, 1996; Serenius et al., 2006) reported that low feed intake and excessive loss of fat reserves during lactation directly affect the reproductive performance of sows (Bergsma, Kanis, Verstegen, Van Der Peet-Schering, & Knol, 2009).

In most commercial farms, type of feeding is an effective method to improve female productivity, although other management practices, such as group housing and breeding (Bench, Rioja-Lang, Hayne, & Gonyou, 2013), can also act as effective measures to improve performance (Holt, Johnston, Baidoo & Shurson, 2006).

Therefore, the key parameter to optimize sow nutrition and, consequently, performance is still mainly related to feeding. Another strategy already used by smart feeders is feeding stimuli (during lactation), that is, the release of small amounts of food for females to obtain a higher frequency of presence at the feeder. Wehebrink, Lentföhr, Tölle and Krieter (2006) also found a positive effect on sows' feed intake when the feeding frequency was increased from two to four times a day.

Finally, the feeding of pregnant sows can cause damage mainly in relation to animal welfare, thus reflecting in losses in the production system when applied incorrectly. However, there are strategies to increase well-being and reflect on the performance of animals in the gestation phase. The use of fibers to improve satiety, stimulation through automatic feeders, as well as the improvement of technology through strategies that allow animals to have a greater frequency of feeding are examples of methods to be used to mitigate the effects of feeding once a day.

2.3 Limitations of using precision feeding for sows

When confronted with novel technologies, it becomes imperative to possess requisite knowledge and a proficient workforce for practical implementation. Analogous to the precision nutrition paradigm in swine husbandry, the deployment of such technology may encounter constraints that hinder the attainment of optimal return on investment within the production system. Limitations may manifest in various forms, including the substantial capital outlay for technological investments, the availability of skilled technical personnel, expertise in animal

nutrition, and factors pertaining to animal welfare, such as the acclimatization of gilts and social dynamics within the pen.

The European Commission delineates minimum standards for the protection of swine, with Directive 120 of 2008 (ECC, 2008) amalgamating extant legislation into a singular document. Noteworthy directives pertinent to this legislation concern the welfare of gestating sows, particularly regarding the collective housing of these animals (Maes; Pluym; Peltoniemi, 2016).

The adoption of collective pens facilitates the expression of natural behaviors and activities among animals, albeit not guaranteeing comprehensive animal welfare. Collective housing presents welfare advantages whereby gestating sows are afforded opportunities for locomotion, exploration, and social interactions with conspecifics (Barnett et al., 2001; Brajon et al., 2020). Nonetheless, notwithstanding these advantages, the utilization of collective pens, as implemented in modern husbandry practices involving frequent mixing and regrouping of animals, can engender several potential welfare challenges. Intense conflicts arising from the establishment of social hierarchies may lead to severe injuries and lameness (Brajon et al., 2020; Maes; Pluym; Peltoniemi, 2016), rendering vulnerable animals immobile and thereby diminishing productivity while escalating production costs (Brajon et al., 2020; Maes; Pluym; Peltoniemi, 2016; Verdon et al., 2015).

The occurrence of aggressive behaviors and lameness can significantly impact animal performance and welfare, necessitating heightened vigilance. Consequently, the effective operation of group housing systems is heavily contingent upon technical expertise and skilled labor (Maes; Pluym; Peltoniemi, 2016). It is evident that many of the limitations discussed stem from the utilization of collective pens rather than from precision nutrition itself. Nevertheless, the adoption of collective pen systems for gestating sows is imperative due to the economies of scale, as employing individual housing for each animal could render the system economically unviable.

The integration of technologies commonly associated with such installations may pose constraints owing to the requisite investment, technological proficiency, implementation within the production system, and animal training. The optimal functionality of group housing systems hinges on the synergistic effects of various factors. Management practices should prioritize animal welfare considerations. Moreover, feeding protocols, flooring materials, housing design,

and their interplay are pivotal, as minor adjustments can yield significant impacts on animal welfare (Maes; Pluym; Peltoniemi, 2016; Peltoniemi; Björkman; Maes, 2016).

The proliferation of intelligent and automated feeding systems found a significant avenue for expansion through the adoption of group housing for sows. However, hierarchical structures emerge among cohabitating sows, leading to skirmishes, particularly during the initial phase of group formation (Spoolder et al., 2009; Spoolder; Vermeer, 2015).

The implementation of an automatic feeding system necessitates the utilization of RFID (radio frequency identification) tags for individual identification, primarily aimed at segregating or individually feeding females within collective pens. Individual feeding stations equipped with identification mechanisms ensure complete physical and dietary separation during feeding sessions but do not facilitate simultaneous feeding of multiple animals, as only one station can be allocated per stall housing several animals. Consequently, despite certain models of smart stalls demonstrating significant benefits in animal management and nutrition, a notable limitation persists regarding simultaneous feeding, with aggressions often occurring between sows at the feeder entrances due to hierarchical dynamics (Spoolder; Vermeer, 2015). Dominant animals tend to feed first, disadvantaging lower-ranking sows, and interruptions by dominant sows may occur during feeding sessions (Anil; Anil; Deen, 2005; Bench; Lench, 2013). Furthermore, depending on the feeding station model, each animal may receive its total daily feed allocation only once per day, potentially leading to uneven body condition if uneaten feed is consumed by other animals.

As per Buis (2016), feeding stations integrated within automated systems offer the capability to dispense feed through multiple output lines, accommodating up to four distinct diets. This feature, exclusive to Electronic Sow Feeding (ESF), presents significant opportunities for research into various nutritional levels and additives. However, it necessitates a thorough understanding of the herd, as analytical models must receive the most precise inputs to tailor feeding regimens to individual animal requirements rather than relying on herd averages.

Automated feeding systems for pregnant sows represent a robust solution for group feeding, offering several advantages such as individual consumption monitoring and management, thereby facilitating finer adjustments to feeding programs to meet specific nutritional needs (Vier et al., 2016). Nonetheless, effective implementation requires management strategies,

including the training of young animals to familiarize them with the equipment's noises and unfamiliar structures.

Research suggests that initiating training through the allocation of stations with the same gestation model in facilities housing young animals with ad libitum feeding can be an effective approach (Vier et al., 2016). This early exposure ensures that as animals transition to restricted feeding, the feeder structures are already familiar.

Consequently, training procedures can be segmented into pre-training stages (during growth pen phase), training (in gilt pens), and post-training (when animals are already housed using ESF systems).

In summary, the training of gilts is a critical management practice that requires meticulous execution, often presenting challenges. Apart from the significant time commitment required for training, it is essential that the task be carried out by qualified personnel possessing patience to avoid instilling trauma or fear in the animals towards the new equipment. Instances of animals becoming startled can complicate the training process, leading to increased employee fatigue and time investment (Vier et al., 2016).

Furthermore, the limitations associated with implementing a production system on a commercial farm extend beyond theoretical considerations, encompassing the meticulous handling of animals. Additionally, facility adaptations for system implementation and the procurement of requisite technologies can pose logistical and financial burdens on production operations.

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CHAPTER 2

**ARTICLE 1 - USE OF A PRECISION FEEDING PROGRAM DURING GESTATION
IMPROVES THE PERFORMANCE OF HIGH-PRODUCING SOWS**

**ARTIGO FORMATADO DE ACORDO COM AS NORMAS DA REVISTA
CIENTÍFICA ANIMAL FEED SCIENCE AND TECHNOLOGY**

**[https://www.sciencedirect.com/journal/animal-feed-science-and-
technology/publish/guide-for-aut](https://www.sciencedirect.com/journal/animal-feed-science-and-technology/publish/guide-for-aut)**

1 Use of a precision feeding program during gestation improves the performance of high-
2 producing sows

3

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17

18 *Abbreviations:* AA, amino acids; ADG, average daily gain; BFT, backfat thickness; BW,
19 body weight; CP, crude protein; DM, dry matter; FLAT, flat feeding; HLH, high-low-
20 high feeding; IGF-1, insulin-like growth factor 1; ITmat, Maternal transformation index;
21 ME, metabolizable energy; NEFA, Non-esterified fatty acids; PF, precision feeding; SID,
22 standardized ileal digestible.

23 Abstract

24 Current gestating sow feeding strategies are based on using a single diet regardless of
25 parity or gestation stage. Precision feeding (PF) of the individual sows allows dynamic
26 changes in amino acid and energy requirements throughout gestation. The hypothesis of
27 the study was that meeting the daily predicted amino acid and energy demands of
28 gestating sows using a mathematical model and automatic precision feeder to establish
29 the nutrition programs, would improve reproductive and productive performance
30 compared to conventional feeding programs. Seventy-five mixed-parity sows were
31 distributed among 3 treatments. A treatment managed as flat curve (FLAT: 2.1 kg/d, 1 –
32 110 d), a high-low-high curve (HLH: 2.2 kg/d, 1 – 49 d; 2.0 kg/d, 50 – 84 d; 2.6 kg/d, 85
33 – 110 d), where sows received the same diet with 3.2 Mcal/kg of metabolizable energy
34 (ME) and 0.7 g/kg of standardized ileal digestible (SID) lysine. For the PF treatment,
35 feeding level and blend of 2 basal diets (3.0 Mcal/kg of ME; 8.0 and 2.0 g/kg of SID
36 lysine for high and low lysine, respectively) was adjusted daily for each sow to accurately
37 meet estimated amino acid and energy requirements based on live weight, gestation stage
38 and parity. Sows fed PF were heavier on d 110 of gestation ($P = 0.011$) and tended to
39 increase total number of born ($P = 0.092$) and born alive ($P = 0.077$). Sows fed PF showed
40 a higher litter weight ($P = 0.003$) at birth, lower lactation feed intake ($P = 0.010$), higher
41 milk yield ($P = 0.043$) and a larger litter size ($P = 0.050$). Precision feeding sows also
42 presented an improved maternal transformation index ($P = 0.013$) when compared to
43 HLH and FLAT. In conclusion, our results demonstrate that the application of PF
44 strategies based on daily nutrient adjustments is highly beneficial for high-producing
45 sows to support the dynamic needs for nutrient availability for the sow's body growth,
46 mammary gland and fetal development.

47 **Key words:** Gestation; Lactation; Precision feeding; Sow Nutrition.

48 **1. Introduction**

49 A common practice in commercial pig units is to feed sows the same diet throughout
50 gestation, with no changes in the nutritional levels or even volumes. However, nutritional
51 requirements are dynamic and vary according to the gestational stage, parity, metabolic
52 state and productivity (Dourmad et al., 2008; Gaillard et al., 2020; Gaillard and Dourmad,
53 2022). The sows' body condition during gestation can directly influence performance
54 during lactation, whereas, excessive energy intake can cause obesity at farrowing, leading
55 to a reduced voluntary feed intake during lactation which will result in an excessive
56 catabolism (Kim et al., 2009; Sinclair et al., 1998). Nevertheless, feed restriction imposed
57 during gestation to restrict excessive energy consumption, may also become a limiting
58 factor for protein intake, causing deficiencies, especially during the last phase of
59 gestation. Therefore, the gestation period is subdivided into stages so that feeding
60 strategies can try to focus on the different needs of each stage. One example is the use of
61 *the high-low-high* feeding concept (HLH), where gestation is divided into three stages,
62 which are: body tissue recovery; development of mammary glands and maintenance; and,
63 finally, exponential fetal growth and colostrum production (Kim et al., 2009). Another
64 feeding strategy is the so called *flat feeding* (FLAT) which assumes a different approach
65 in the dynamics of tissue and weight development throughout gestation (Gonçalves et al.,
66 2016; Mallmann et al., 2018). A correct maternal diet is essential to guarantee an adequate
67 sow body development and an optimal physiological, metabolic and endocrine
68 development of the fetuses and the mammary gland (Tuchscherer et al., 2012; Chen et
69 al., 2017; Hansen et al., 2021). The concept of precision feeding (PF) consists of
70 developing feeding systems that estimate and deliver, at the right time, a diet with a
71 quantity and composition of nutrients adapted to the requirements of each animal on a

72 daily basis. The implementation of PF programs depends on the use of automatic
73 intelligent PF systems (AIPF) together with the use of techniques and models that allow
74 a proper understanding of the sow's body weight (BW) development, productivity
75 potential and individual maternal efficiency. There are still opportunities in the
76 development of systems that predict accurately and provide optimized feeding strategies
77 for sows during gestation (Gaillard et al., 2020). Therefore, the present study aimed to
78 evaluate the effects of meeting the predicted daily amino acid (AA) and energy demands
79 of gestating sows using a mathematical model (PF) and an AIPF system compared to two
80 commercial feeding programs (FLAT or HLH).

81

82 **2 Materials and Methods**

83 *2.1. Animals and Experimental Procedure*

84 A total of 75 mixed-parity sows from 9 successive batches of 8 animals were used in a
85 study conducted at the gestation and farrowing facilities of the swine production farm of
86 the Institute of Agricultural Sciences of the Universidade Federal de Minas Gerais
87 between February 2020 and January 2021. The farm herd is based on commercial sows
88 (TN70® Topigs Norsvin) with a standard health status following a regular vaccination
89 program for all animals against *Mycoplasma hyopneumoniae*, parvovirus, erysipelas,
90 and leptospirosis. Within each batch, sows were distributed in a completely randomized
91 experimental design among 3 dietary treatments according to backfat thickness, parity
92 (1st, 2nd, and >3rd parity), and BW after insemination. The sows were selected until d 5
93 post breeding and tagged with reusable radio frequency identification transponder (half-
94 duplex signalling technology; Jyga Technology, Saint-Lambert-de-Lauzon, Canada). The

95 sows were then moved into dynamic group-housed pens with capacity for 20 sows per
96 pen and remained there until d 110 of gestation. After this period (on d 111) sows were
97 transferred to the farrowing facilities. Each gestation pen was fitted with one AIPF station
98 (GESTAL G3 multi, Jyga Technologies, Saint-Lambert-de-Lauzon, Canada). Periodic
99 testing of AIPF feed delivery systems was performed and systems were recalibrated when
100 they exceeded 5% error. The main feed ingredients in the basal diets were corn and
101 soybean meal (Table 1). Each batch of ingredients was analysed for dry matter, energy,
102 crude protein and AA contents via AMINONIR at the Evonik feed analyses laboratory
103 (Evonik Operations GmbH, Hanau-Wolfgang, Germany) for feed analyses. Feed AA
104 contents were analysed using ion-exchange chromatography, except for tryptophan,
105 which was analysed using HPLC and fluorometric detection.

106 For sows on PF, the feeding level was reached according to the blend of two basal diets
107 (Figure 1): *High Lysine* (HL): 3.00 Mcal/kg of metabolizable energy (ME) and 8.0 g/kg
108 of standardized ileal digestible (SID) lysine for high lysine; *Low Lysine* (LL): 3.00
109 Mcal/kg ME 2.0 g/kg SID lysine for low lysine, and the amount of feed offered was
110 adjusted daily for each animal to accurately meet estimated daily ratios for energy and
111 amino acid requirements. Essential and non-essential AA ratios to lysine in each diet were
112 the same and followed the requirements established by the Topigs Norsvin Sow Feeding
113 Manual® (2017). To adjust properly, daily nutritional demands via the model, sows were
114 weighed and backfat thickness measured every week (Sunway, Shenzhen SUNWAY
115 Medical Device Co. Ltd., Model Handscan V7, Shenzhen, China). Thus, the total quantity
116 and blend of HL and LL feed varied on a daily basis throughout gestation based on sow's
117 daily BW, gestation stage and daily requirement ratios (SID Lysine g/ME Mcal)
118 according to the outputs from the sow model developed by Gil Rueda, F. (non-published).
119 The remaining sows, managed as a control flat (FLAT) or a control step-up according to

120 parity and gestation phase (HLH), received the same diet (3.20 Mcal/kg ME; 7.0 g/kg
121 SID lysine). Sows were fed two different feeding curves based on (Gonçalves et al., 2016;
122 Mallmann et al., 2018) for FLAT and based on Topigs Norsvin Sow Feeding Manual®
123 (2017) for the HLH. To establish a standard approach based on the commercial feeding
124 strategies, sows were also grouped according to parity in young (1st and 2nd parities) and
125 adult (>3rd parity) sows. The average feeding scheme of both categories (young and adult)
126 according to the treatment is shown in Figure 2. The PF curves for both young and adult
127 sows were based on the daily requirement ratios of Lysine:ME throughout the entire
128 gestation period.

129 2.2. Measurements and collected parameters

130 The variations in ambient temperature, relative humidity (RH), and photoperiod followed
131 closely the outdoor conditions. Ambient temperature and RH were continuously recorded
132 (1 measurement every 60 s) in the barns, using a datalogger connected to a probe (Didai
133 Tecnologia Ltda., Campinas, Brazil) placed 1 m above the floor. On d 28 after
134 insemination, gestation was verified ultrasonically (Sunway, Shenzhen SUNWAY
135 Medical Device Co. Ltd., Model Handscan V7, Shenzhen, China); empty sows were
136 removed from the pens. Body weight measurements were done weekly using a digital
137 scale (Líder Balanças Ltda., Mod. LD 2000E, Araçatuba, SP, Brazil). After the final BW
138 measure on d 110 gestation, sows were washed and moved to the farrowing room, where
139 they were placed in individual free open farrowing crates. From d 110 to farrowing sows
140 were allowed 2.5 kg/d of the standard lactation feed containing 3.34 Mcal/kg ME; 10.5
141 g/kg SID lysine (Table 1). After farrowing sows were allowed a full access to feed.
142 Individual feeding behaviour was recorded during the *ad libitum* period (between d 1 and
143 23), using an Automated Intelligent Feeder (AIF; Gestal Quattro®, Jyga Technology,

144 Saint-Lambert-de-Lauzon, Canada). Each time that the sow activated a sensor installed
145 in the trough, an amount of 150 g of feed was delivered by the computer. Sows were
146 allowed to repeat this activation every 5 minutes to avoid spillage. After each visit, the
147 time and amount of feed at the beginning and at the end of the visit were recorded. This
148 data was continuously recorded by the system every 15 minutes. In addition to the
149 electronic measurement of feed intake, morning refusals were manually collected and
150 weighed at the same time, between 0730 and 0800 h, and the daily intake was determined
151 as the difference between feed allowance and the refusals collected on the next morning.
152 Periodic testing of AIPF feed delivery systems was performed (in between batches) and
153 systems were recalibrated when they exceeded 5% error. The day prior to weaning (*i.e.*,
154 d 23), sows were allowed 5 kg of feed (*i.e.*, at least 1.5 kg lower than their usual feed
155 intake) to standardize consumption for all sows for determination of sow weight at
156 weaning. The litter size was standardized according to the sow's number of functional
157 teats within 24 h post-farrowing for each sow. Cross-fostering was performed during this
158 study only when a sow farrowed less piglets than its teat capacity and therefore received
159 the surplus piglets from another sow within the same treatment to fill all active teats.
160 When no cross-fostering was necessary, the surplus piglets above the sow's milking
161 capacity were transferred to an artificial rescue milking system on d 1 after litter size
162 standardization. This technique was more used for the PF treatment. Piglets were not
163 allowed creep feed until weaning. At weaning (24 d), sows were again weighed and
164 backfat measured and moved to a breeding facility and presented to a mature boar twice
165 daily to detect onset of standing estrus. During this period all sows were fed 3.5 kg/d of
166 a standard flushing diet. The following litter parameters were collected at farrowing:
167 duration of the farrowing (minutes), total number of piglets born, born alive, stillborn,
168 and mummies. Piglets were individually weighed using a digital scale (Líder Balanças

169 Ltda., Mod. B150, Araçatuba, SP, Brazil) at birth, 24-h post-farrowing, 48-h post-
170 farrowing, d 14 and at weaning to determine litter birth and weaning weights, and daily
171 weight gain during lactation.

172 Blood samples were collected on d 1, 49, 84 and 110 of gestation and 14 of lactation from
173 a pre-determined subsample of 5 sows (20%) per treatment (2 gilts and 3 multiparous).
174 An amount of 10 ml of blood via the jugular arterial 02 hours after feeding (Fei Ji, 2004)
175 was taken for further analyses of plasmatic insulin, urea, insulin-like growth factor 1
176 (IGF-1) and NEFA (Non-esterified fatty acids) during the absorptive phase. Milk samples
177 were collected manually from all the active mammary glands on each sow, from a pre-
178 determined subsample of 12 sows per treatment, after an intravenous injection of 10 UI
179 oxytocin into an ear vein on d 14 of lactation. For that, the following protocol was applied
180 to mimic a suckling event. Piglets were separated from the dam after suckling and 45 to
181 50 min later the sows were milked according to Silva et al., (2009). The amount of milk
182 collected (150 to 200 mL) was close to the estimated milk production during one suckling
183 between farrowing and d 20. Samples were stored at -20°C, immediately after collection.
184 At the end of the experiment, all samples were freeze dried and analysed for amino acid
185 content at the Evonik feed analyses laboratory (Evonik Operations GmbH, Hanau-
186 Wolfgang, Germany).

187

188 *2.3. Calculations and Statistical Analyses*

189 Daily maximum, minimum, mean, and variance of daily ambient temperatures and
190 relative humidities were averaged for each replicate. Body protein, fat, and energy
191 contents during gestation, farrowing and at weaning were estimated according to the
192 equations proposed by Dourmad et al., (1997). Average daily milk production estimation

193 was based on litter growth rate and size during lactation, according to the equations
194 proposed by (Hansen et al., 2012). Maternal transformation index (IT_{mat}) is an indicator
195 of sow efficiency based on conversion of feed to litter weight calculated by kg of lactation
196 feed/kg litter.

197 Initially, each independent variable was analysed separately using the PROC MIXED
198 procedure of SAS (Statistical Analysis System, SAS Institute Inc., Cary, NC, USA.
199 Version 9.4, 2012) with the sow and its litter being the experimental unit for sow and
200 piglet parameters. All performance data was tested for normality using the Univariate
201 procedure of SAS version 9.2 (SAS Inst. Inc., Cary, NC, USA) and was normally
202 distributed. Treatment \times batch interactions were added to all preliminary models but were
203 not significant and were therefore omitted from subsequent analysis. The effect of feeding
204 system (three treatment groups: FLAT, High-Low-High and precision feeding systems)
205 and sow age group (young with parity ≤ 2 and adult with parity > 2) were included as
206 fixed effects in both set of analysis (for sow and piglet parameters). No random effects
207 were considered but PROC MIXED was used because offers several options in the
208 MODEL statement for obtaining approximate degrees of freedom of very unbalanced
209 data (Yang, 2010) like in this case. Additionally, individual piglet growth performance
210 was summarized as average daily gain (ADG) weight gain during the lactation period
211 (from birth to weaning) and birth weight used as covariate; same fixed effects were used
212 (effect of feeding system and age group). A value of $P < 0.050$ was considered statistically
213 significant, whereas probability levels of $0.05 < P < 0.10$ was considered as the tendency.
214 Feed intake data were pooled per sow on a daily basis and were analysed according to
215 linear mixed model variance using the MIXED procedure of SAS/STAT, including the
216 fixed effects of treatment, of lactation, and batch, and their interactions (Silva et al., 2009;
217 2021). The effect of lactation stage on daily feed intake was tested with a mixed linear

218 model (MIXED procedure of SAS) for repeated measurements with treatments and batch
219 as main effects.

220

221 **3. Results**

222 The average minimum and maximum ambient temperatures and RH were 11.0 and
223 39.0°C, and 14 and 98%, respectively. The thermal amplitude observed for both
224 temperatures and humidity were 28°C and 84%, respectively. During the experimental
225 period the sows were exposed to temperatures above 26°C on average 45% of the time.
226 As for temperatures above 30°C sows were exposed 24% of the time.

227 As presented in Table 2, there was no difference of the treatments on initial gestation BW
228 (averaged 206.1 kg). Nevertheless, sow body weight on d 110 was affected by the
229 treatments ($P = 0.011$), whereas sows fed PF, were heavier than HLH and FLAT
230 treatments (281.7, 260.2 and 260.3 kg, respectively). A greater backfat thickness was
231 observed during the final third of gestation of the sows submitted to PF treatment when
232 compared with the others (Figure 3). In the same way, sow BW at 24 h after farrowing
233 tended to increase ($P = 0.093$) for the PF fed sows, compared to the other treatments
234 (258.1, 243.2 and 248.3, respectively for PF, HLH and FLAT). Sow BW at weaning was
235 not affected by the treatments (234.5 kg on average). The live weight variation from 24h
236 before and 24h after farrowing was affected ($P = 0.031$) by the treatments whereas PF
237 sows lost more weight (23.6 kg, 17.0 kg, and 12.0, respectively for PF, HLH and FLAT;
238 Table 2).

239 Treatments tended to influence total number of born ($P = 0.092$) and born alive ($P =$
240 0.077), whereas sows from the PF showed an increased total number of born (+2.04) and

241 born alive (+1.84) in comparison to HLH and FLAT (Table 2). Although there was no
242 difference for individual piglet birth weight, still PF showed heavier litters on d1 (P =
243 0.003; Table 3). The total litter weight on d 1 was +3.41 kg higher for these sows when
244 compared to HLH and FLAT (Table 3). Within-litter birth weight variation was not
245 influenced by treatments.

246 As a consequence of an improved birth performance, PF sows also had a higher litter size
247 on d 1 of lactation (14.79, 13.75 and 13.55, respectively for PF, HLH and FLAT; P =
248 0.078; Table 3). At weaning PF sows also tended to show a higher (P = 0.050) litter size
249 when compared to HLH and FLAT (12.63, 11.35 and 11.10, respectively for PF, HLH
250 and FLAT; Table 3). Still due to the fact that PF sows showed a greater litter size, this
251 also impacted the litter BW on d 1 of lactation (24.27, 21.45 and 20.27 kg, respectively
252 for PF, HLH and FLAT; P = 0.003) and a tendency on d 24 of lactation (92.32, 83.26 and
253 79.94 kg, respectively for PF, HLH and FLAT; P = 0.068; Table 3). Although litter daily
254 gain was not influenced statistically. Sow's voluntary feed intake during lactation was
255 influenced, where FLAT and HLH sows showed a higher voluntary intake when
256 compared to PF sows during lactation (5690, 5502 and 5250 g/d, respectively for FLAT,
257 HLH and PF; P = 0.010). Maternal BW loss was not influenced by the treatments (on
258 average 7.54%). Sow milk production was influenced (P = 0.043) by the treatments,
259 whereas sows from the PF showed a higher milk yield (12.3, 10.9 and 11.0, respectively
260 for PF, HLH and FLAT; Table 3). As the PF sows showed a higher number of weaned
261 and a lower voluntary intake, these animals also presented an improved ITmat (P = 0.013)
262 when compared to the other treatments (1.86, 2.15 and 2.28, respectively for PF, HLH
263 and FLAT). Treatments did not influence either milk AA profile or milk energy on d14
264 of lactation (Table 4). Blood parameters are presented in Figure 4, where no statistical
265 differences were observed between treatments.

266

267 **4. Discussion**

268 Energy and amino acids requirements for gestating sows are dynamic throughout the
269 gestation periods due to metabolic phenomena that occur in this production phase
270 (Sinclair et al., 1998). Different tissues are deposited at different stages of gestation, for
271 example the fetal development undergoes significant changes in the rate of protein
272 deposition, becoming greater after d 70 of gestation (McPherson et al., 2004; NRC, 2012;
273 Dourmad et al., 2018; Hansen et al., 2021). Amino acids are not solely constructing blocks
274 of protein synthesis, but also are additionally used as precursors for nitrogenous elements
275 that are necessary for whole-body homeostasis (Wu, 2009). In example, studies (Mateo
276 et al., 2007; Wu et al., 2007) have indicated that arginine is an important amino acid that
277 plays an essential role in placental vascularization and development, especially in early
278 and mid-gestation between 25 and 45 days of gestation (Feyera and Theil, 2017).
279 Therefore, the establishment of nutritional programs using more diets and no longer a
280 single diet throughout the entire gestation period may have not only several benefits for
281 the sows and fetal development (Wu, 2009; Dourmad et al., 2018; Gaillard and Dourmad,
282 2022), but also reducing lysine and protein ingestion and consequently ammonia
283 emissions (Gaillard and Dourmad, 2022), which may contribute to create a more
284 sustainable environmental system and a higher animal productivity (Wu et al., 2007). For
285 instance, in our study, sows from the PF treatment ingested on average throughout the
286 entire gestation phase 5% less lysine and 7% less nitrogen when compared to the standard
287 feeding programs.

288 As shown in Figure 2, the model predicted a dynamic change in feed intake during
289 gestation for the animals submitted to the PF treatment. This indicates that at certain

290 stages of gestation, the requirements of energy and lysine are greater as well as the
291 dynamics of the deposition of different tissues. For example, increased fetal protein
292 deposition increases the gestating sow's amino acids and energy requirements, such that
293 the estimated lysine and energy requirements of primiparous sows can increase by
294 approximately 200% and 45%, respectively, for late and early gestation (NRC, 2012;
295 Hansen et al., 2021). Attempting to fulfill the nutritional and energy demands for both
296 maternal and pregnancy-associated protein deposition through a static gestation diet, in
297 terms of quantity and nutrient composition, is unfeasible. Therefore, our findings indicate
298 that this could pose negative effects on fetal development.

299 As presented in our findings, the treatments influenced the performance of the gestating
300 sows, especially when analyzing weight gain until farrowing and the amount of tissue
301 mobilized during lactation. The sows submitted to PF presented a higher (+ 21.5 kg of
302 BW for d 110) prepartum weight when compared to the other treatments. The weight gain
303 during gestation of the precision treatment comes in agreement with the supply of
304 nutrients precisely for the growth of the different tissues of the sow, which are mainly
305 derived from fetal growth, as well as from the development of the mammary gland,
306 establishment of energy and protein reserves for mobilization during the lactation period
307 (Feyera and Theil, 2017; Tokach et al., 2019).

308 Based on these findings, one may hypothesize that the weight gained during gestation by
309 the PF sows can be explained not only by a greater mammary gland tissue development
310 and a higher metabolic BW growth rate, but also due to the higher number of total born,
311 which includes the weight of piglets, amniotic fluid and placenta, when compared to the
312 FLAT and HLH treatments. Consequently, the variation in pre-partum weight and 24
313 hours after birth was greater for the PF treatment, followed by HLH and finally FLAT.

314 Nutrients, especially amino acids, can help in the development of tissues in the gestational
315 period. For example, recent studies show that the correct lysine/methionine ratio can
316 impact on the mechanism of angiogenesis of the placenta and consequently the
317 development of the fetuses (Xia et al., 2019; Peng et al., 2020). Not only methionine, but
318 several other amino acids studied such as arginine may have an effect on maternal and
319 fetal development (Tan et al., 2022).

320 Another important variable observed was feed intake during lactation, which was higher
321 in the FLAT and HLH treatments compared to PF. When sows are not fed adequate
322 nutrient amounts, particularly of protein and lipids, skeletal muscle proteins are mobilized
323 to supply milk production needs. Several authors suggest that the nutritional and
324 metabolic changes in lactating sows may have deleterious effects on the sow's biology,
325 with negative impacts on follicle development, and consequently on embryo development
326 and on the number of piglets born in the next litter (Foxcroft et al., 2007; Ashworth et al.,
327 2009; Quesnel et al., 2009; Schenkel et al., 2010; Hoving et al., 2011). Therefore,
328 excessive body mobilization during lactation and a negative catabolic status should be
329 avoided (Costermans et al., 2020a). In our study, body mobilization (Lactation BW loss,
330 %) was higher in the PF treatment, but still within the accepted physiological limits (*i.e.*,
331 9 to 12%; Clowes et al., 2003), where we did not observe negative impacts on
332 performance traits. To the best of our knowledge, these relationships between sow
333 metabolic status and milk production are independent of the voluntary feed intake during
334 lactation. This suggests that not only sows with high feed intake but also sows with low
335 feed intake during lactation can show an increased milk yield if they have more body
336 reserves at the beginning of lactation (Strathe et al., 2017). In fact, PF sows needed less
337 feed to produce milk, indicating that body development during gestation influences

338 lactation intake dynamics. This can be corroborated by the observed ITmat values,
339 whereas FLAT sows, showed the lowest gestational BW development and most likely
340 had to compensate for the lack of body reserves to sustain lactation production and
341 presented a higher voluntary feed intake. The ITmat is an indicator of sow efficiency
342 based on conversion of feed to litter weight. Whereas, sows from the PF treatment
343 presented a lower voluntary feed intake and a higher litter weaning weight, indicating that
344 these animals were more efficient using body reserves and ingested nutrients to sustain
345 productivity. As an overall, our findings indicate that the gestation feeding strategy can
346 impact on lactation feed efficiency. Our statement is corroborated by Strathe et al. (2017),
347 that concluded that modern high-producing sows are not able to fully compensate for
348 increased metabolic demands only through increased voluntary feed intake.

349 Overall, and as expected, sows showed higher concentrations of NEFA during lactation
350 when compared to gestation, since this is a metabolic indicator related to body adipose
351 tissue mobilization. Non-esterified fatty acids in the blood can be transported to the
352 capillaries of the mammary gland, contributing to the synthesis of milk fat (Boyd et al.,
353 1995; Strathe et al., 2017). Therefore, greater mobilization of adipose tissue can increase
354 the fat content of milk by increasing the concentrations of NEFA in the blood, as has been
355 found in dairy cows (Rico et al., 2014; Lerch et al., 2015). The concentration of IGF-1
356 followed the same dynamic trend (Figure 4), this is a protein marker that indicates muscle
357 tissue mobilization in order to provide amino acids for fetal growth and milk production
358 (Hammond et al., 1988). The development of follicles is dependent on the presence of
359 follicular IGF-1. This is because it bonds with follicle-stimulating hormone to activate
360 the phosphatidylinositol 3-kinase signaling pathway, by binding to IGF-1 receptors
361 located in the oocytes and granulosa cells (Law and Hunzicker-Dunn, 2016).

362 No statistical difference was observed on the metabolic parameters measured between
363 treatments. Still according to Costermans et al., (2020b), restricted fed sows during
364 lactation show lower plasma concentrations of IGF-1. The sows of the PF treatment
365 showed a lower daily voluntary feed intake but without difference in blood IGF-1. In
366 addition, it is also known that plasma insulin levels may restrict daily feed intake during
367 lactation (Père and Etienne, 2007).

368 Sows fed the precision treatment had a higher fat deposition in the beginning and also in
369 the end of gestation (Figure 3). The lower backfat reserves at farrowing and higher
370 relative weight loss of the modern sow fed restricted diets during gestation in the current
371 study (*i.e.*, FLAT) may have reduced energy and nutrient availability to the point that the
372 sows were unable to sustain subsequent high milk fat and protein production (Costermans
373 et al., 2020a). Sows have been shown to deplete body reserves to meet milk production
374 needs during lactation; however, there are doubts as to whether a late gestational
375 mobilization of body protein or body fat could reduce subsequent sow lactational
376 performance (Goodband et al., 2013). As mentioned earlier, in our study sows from the
377 PF treatment showed higher body weight at 110 d of gestation, indicating that they stored
378 more tissue in the form of energy reserves and body muscle. Milk fat production in the
379 last week of lactation was positively correlated with BW, loin muscle depth and lactation
380 backfat thickness, which indicates that PF sows had more body reserves during lactation
381 with more energy and metabolites to mobilize.

382 The number of piglets is a determinant factor for estimating litter weight and milk
383 production (Hansen et al., 2012). As PF sows farrowed and weaned a higher number of
384 piglets, it is normal to expect that these sows would express a higher calculated milk yield
385 (12.3, 10.9 and 11.0 kg in the PF, FLAT and HLH, respectively) and a higher litter

386 weaning weight. Nevertheless, sows from the PF were more efficient than FLAT and
387 HLH sows during lactation, as they weaned more piglets with an improved average piglet
388 weaning weight compared to the FLAT and similar to the HLH sows, but at the cost of
389 less feed per kg of milk produced (427, 500 and 522 g of feed/g of milk, respectively for
390 PF, HLH and FLAT) and a similar body weight mobilization. Therefore, one can infer
391 that milk production is not only driven by piglet stimulation during lactation, but also by
392 the previous development of the mammary gland during the late gestational period
393 (Farmer et al., 2022). According to previous studies (Ji et al., 2006; Kim et al., 2009),
394 protein requirements for mammary gland development shows a 24-fold increase from d
395 80 to 114 of gestation in comparison to early stages of gestation. In our study, young and
396 adult sows from the PF ingested on average 21.2 g/d, while the FLAT ingested 15.05 g/d
397 and HLH 18.9 g/d of lysine from d80 to 114. Therefore, we can infer that the nutrient
398 restrictions imposed by conventional feeding programs during the mammary gland later
399 development stages in gestation will limit tissue accretion and could have negative
400 consequences on subsequent lactation milk yield. In this sense, the lower milk yield
401 observed in our study for the conventional feeding treatments can be a direct effect not
402 only of a lower number of weaned piglets, but of an unbalance in nutrient demands
403 between intake and requirements to sustain fetal, body weight and proper mammary gland
404 development all at once.

405 In conclusion, although our study is limited by the number of sows, still the results
406 presented provide important insights into the dynamism of the nutritional requirements
407 throughout gestation and can allow a better understanding of how precision feeding could
408 be a useful tool to improve overall performance. Our results demonstrate that the
409 application of precision feeding strategies based on daily nutrient adjustments throughout

410 gestation is highly beneficial for high-producing sows to support the dynamic needs for
411 nutrient availability for the sow's body growth, fetal and mammary gland development.

412

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421

422 **Declaration of interest**

423 The authors declare no conflict of interest

424

425 **Ethics statement**

426 All methods involving animal handling were realized in accordance with the regulations
427 approved by the Institutional Animal Welfare and Ethics/Protection committee from the
428 Universidade Federal de Minas Gerais (UFMG – CEUA), registered under the protocol
429 n° 189/2019.

430

431 **Software and data repository resources**

432 Data and models used in this study are not applicable for deposition in an official
 433 repository.

434

435

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602 agricultural experiments. *Canadian Journal of Plant Science*. 90, 605–627.
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604 Table 1
605 Composition of the experimental diets

Ingredients	Experimental Diets*			
	CON	HP	LP	LACT
Corn (8% CP ¹)	76.42	54.40	64.93	62.87
Soybean meal (46% CP)	17.24	20.00	-	30.00
Wheat bran (14% CP)	-	13.23	20.00	-
Corn Starch	-	6.00	9.00	-
Soybean oil	-	-	-	1.90
Dicalcium phosphate	1.76	1.64	1.66	1.77
Limestone	0.80	0.87	0.98	1.02
Lignocellulose fiber	2.50	2.50	2.50	1.00
Sodium chloride	0.50	0.50	0.50	0.40
Mineral premix ³	0.15	0.15	0.15	0.15
Vitamin premix ⁴	0.08	0.08	0.08	0.08
Mycotoxin binder ⁵	0.20	0.20	0.20	0.20
Lysine 54.6%	0.26	0.27	-	0.38
L-Threonine 99%	0.06	0.10	-	0.10
L-Tryptophan 99%	0.02	0.02	-	0.05
DL-Methionine 99%	0.01	0.05	-	0.08
Total	100	100	100	100
Analyzed composition, as fed				
Metabolizable Energy, Mcal/kg	3.200	3.000	3.000	3.345
Net Energy, Mcal/ kg	2.43	2.30	2.36	2.50
Lysine dig/NE, (g/1000kcal)	2.87	3.47	0.95	4.20
Crude protein, %	13.95	15.51	8.32	18.82
Crude Fiber, %	4.40	5.30	5.00	4.33
Starch, %	48.63	43.89	55.20	41.16
SID ² Lysine, %	0.700	0.800	0.210	1.050
SID Met+Cys, %	0.460	0.520	0.320	0.630
SID Threonine, %	0.500	0.580	0.250	0.700
SID Tryptophan, %	0.140	0.160	0.060	0.220
SID Valine, %	0.580	0.640	0.350	0.890
SID Arginine, %	0.780	0.930	0.430	1.130
Total Calcium, %	0.850	0.850	0.850	0.950
Total Phosphorous, %	0.630	0.804	0.830	0.681
Digestible Phosphorus, %	0.320	0.320	0.320	0.330
Digestible Ca:P ratio, %	2.70	2.70	2.70	2.90
Sodium, %	0.35	0.350	0.350	0.350

606 *CON: control diet; HP: high protein diet; LP: low protein diet; LACT: lactation diet. ¹CP: Crude protein.
607 ²SID: Standardized ileal digestible. ^{3,4}Provided the following amounts of vitamins and trace elements in
608 units per kg: Copper sulphate (Copper 13.00 g/kg), Iron sulphate (Iron 100.00 g/kg), Manganese monoxide
609 (Manganese 50.00 g/kg), Sodium Selenium (Selenium 184.00 mg/kg), Zinc sulphate (Zinc 95.00 g/kg),
610 Calcium Iodine (Iodine 1000 mg/kg), Vitamin A (22500000 IU/kg), Vitamin D3 (380000 IU/kg), Vitamin
611 E (200000 IU/kg), Vitamin K (10000 mg/kg), Biotin (1000 mg/kg), Folic acid (9000 mg/kg), Niacin
612 (120000 mg/kg), Pantotenic acid (60,000 mg/kg), Vitamin B2 (20000 mg/kg), Vitamin B1 (8000 mg/kg),
613 Vitamin B6 (12000 mg/kg), and Vitamin B12 (100000 mg/kg). ⁵Toxin binder composed by fermentation
614 extracts of *Saccharomyces cerevisiae*, citric acid, lactic acid, phosphoric acid, and propylene glycol.

615 Table 2
616 Effect of feeding strategy and parity on sow performance during gestation.

Variables	Treatment*			Group ⁴		RSD ¹	P-value ²	
	FLAT	HLH	PF	Adult	Young		Treatment	Group
Number of sows	25	25	25	60	15	-	-	-
Initial BW, kg	207.10	202.69	208.64	219.77	188.84	32.2	0.571	<0.001
BW 110 d, kg	260.3 ^b	260.2 ^b	281.7 ^a	278.68	251.08	32.7	0.011	<0.001
Gestation BW gain, kg ³	41.2	40.5	49.4	42.04	44.83	15.16	0.155	0.669
BW 24h after farrowing, kg	248.3	243.2	258.1	261.81	233.67	31.9	0.093	<0.001
BWL ⁴ kg 110 d -1 d postpartum, kg	12.0 ^c	17.0 ^b	23.6 ^a	16.87	17.41	13.16	0.031	0.925
Total born, n	15.75	15.95	17.89	16.50	16.52	3.664	0.092	0.904
Born alive, n	13.40	13.75	15.42	14.00	14.40	3.125	0.077	0.428
Stillborn, n	1.15	1.15	1.10	1.14	1.12	1.245	0.991	0.941
Mummified, n	1.20	1.05	1.37	1.35	1.00	1.362	0.767	0.307
Piglets BW at birth, kg	1.496	1.560	1.641	1.610	1.510	0.244	0.139	0.084
Within-litter birth weight variation, %	22.88	21.66	23.34	22.70	22.50	0.065	0.710	0.873

617 *PF = precision feeding; FLAT = flat feeding; HLH = high-low-high feeding. ¹RSD = residual standard deviation. ² Obtained by analysis of variance (including the effects of parity,
618 treatment, and sow replicate). ³ Weight gain during gestation discounting the weight of conceptuses, placenta and fluid. Weight variation between d1 of gestation and 1d postpartum.
619 ⁴Young = first and second parity; Adult = above three parities. ⁴BWL = Body Weight Loss. ^{a-b-c}Means accompanied by letters within a row differ statistically using the Tukey test
620 (P<0.05)

621 Table 3
622 Effect of feeding strategy and parity on sow lactation performance.

Variables	Treatment*			Group ⁴		RSD ¹	P-value ²	
	FLAT	HLH	PF	Adult	Young		Treatment	Group
Number of sows	25	25	25	60	15	-	-	-
Litter size d 1, n	13.40 ^b	13.75 ^b	14.79 ^a	13.91	14.16	2.14	0.078	0.467
Litter size d 24, n	11.10 ^b	11.35 ^b	12.63 ^a	11.76	11.56	1.73	0.050	0.585
Mortality 1-14 d, %	15.64	12.79	13.04	13.13	14.81	0.13	0.740	0.611
Mortality 1-24 d, %	16.64	15.86	13.75	14.12	17.25	10.40	0.739	0.339
Piglet BW at d 1, kg	1.496	1.560	1.641	1.610	1.510	0.24	0.139	0.084
Piglet weight at d 14, kg	4.734	4.437	4.751	4.910	4.280	0.92	0.392	0.007
Piglet weight at d 24, kg	7.202	7.336	7.310	7.760	6.640	1.32	0.883	0.001
Piglet ADG ⁵ , g/d	236	241	236	253	210	78.00	0.919	0.001
Litter BW ⁶ d 1, kg	20.27 ^b	21.45 ^b	24.27 ^a	22.06	21.04	3.22	0.003	0.200
Litter BW d 24, kg	79.94 ^b	83.26 ^b	92.32 ^a	90.87	76.07	16.79	0.068	0.001
Litter DWG ⁷ , kg	2.49	2.56	2.83	2.87	2.29	0.61	0.200	0.001
Sow ADFI ⁸ (d 1 until weaning), kg/d	5.690 ^a	5.502 ^a	5.250 ^b	6.072	4.724	0.82	0.010	0.012
Sow milk production, kg/d	10.90 ^b	10.99 ^b	12.28 ^a	12.07	10.43	1.83	0.043	0.002
ITmat ³	2.28 ^a	2.15 ^b	1.86 ^c	1.63	1.53	0.26	0.013	0.314
Sow BW at weaning, kg	236.85	231.93	234.69	252.82	211.72	36.27	0.425	0.001
Lactation BW loss, %	6.62	6.19	9.82	6.55	8.16	0.05	0.165	0.010

623 *PF = precision feeding; FLAT = flat feeding; HLH = high-low-high feeding. ¹RSD= residual standard deviation. ² Obtained by analysis of variance (including the effects of
624 parity, treatment, and sow replicate). ³Maternal transformation index = kg of feed/ kg litter. ⁴Young = first and second parity; Adult = above three parities. ⁵ADG: average
625 daily gain. ⁶BW = body weight. ⁷DWG = daily weight gain. ⁸ADFI = average daily feed intake. ^{a-b-c}Means within a row accompanied by letters differ statistically using the
626 Tukey test (P<0.05).

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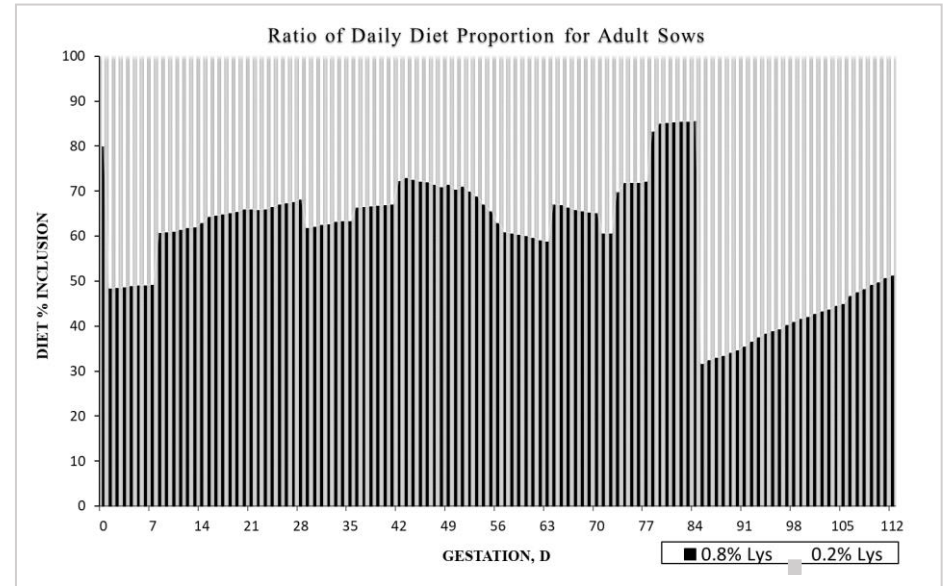
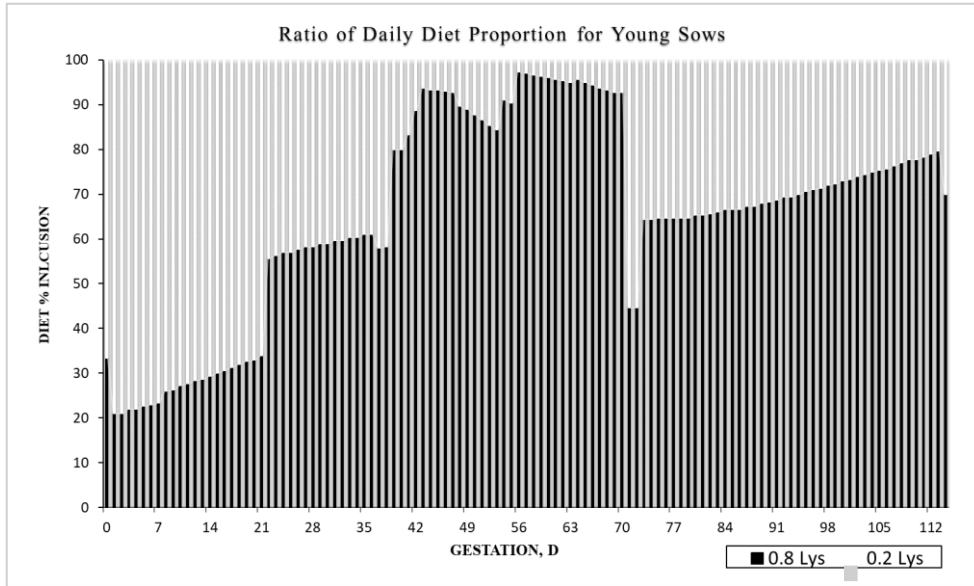
628 Table 4
629 Effect of the feeding strategy and parity on milk amino acids profile and energy on d14 of lactation.

Variables	Treatment*			Group ³		RSD ¹	P-value ²	
	FLAT	HLH	PF	Adult	Young		Treatment	Group
Amino acids, %								
Lys	1.71	1.67	1.78	1.81	1.64	0.31	0.787	0.064
Met	0.50	0.47	0.50	0.50	0.48	0.08	0.744	0.298
Cys	0.36	0.35	0.37	0.37	0.35	0.06	0.750	0.298
Thr	1.06	1.01	1.07	1.06	1.03	0.16	0.695	0.374
Trp	0.34	0.32	0.35	0.35	0.33	0.05	0.521	0.197
Leu	2.16	2.06	2.22	2.19	2.11	0.34	0.616	0.340
Ile	1.06	1.01	1.07	1.06	1.03	0.17	0.714	0.336
Val	1.32	1.25	1.34	1.33	1.28	0.20	0.601	0.327
Arg	1.19	1.13	1.20	1.20	1.15	0.17	0.661	0.320
Glu	5.13	4.92	5.21	5.14	5.04	0.83	0.746	0.402
Pro	2.63	2.47	2.68	2.66	2.53	0.47	0.636	0.225
Asp	2.11	2.00	2.13	2.10	2.06	0.31	0.656	0.506
Ser	1.31	1.25	1.32	1.32	1.28	0.20	0.724	0.320
Phe	1.04	0.98	1.05	1.05	1.00	0.16	0.667	0.243
Ala	0.92	0.87	0.93	0.92	0.90	0.14	0.121	0.013
Gly	0.79	0.74	0.78	0.78	0.76	0.11	0.674	0.441
His	0.67	0.64	0.69	0.69	0.64	0.13	0.711	0.158
Energy								
ME ⁴ Milk, kcal	12216	11631	13290	13527	10961	3463	0.308	0.005
DM ⁵ milk, %	15.60	14.74	14.80	14.62	15.96	0.85	0.271	0.064

630 *PF = precision feeding (n = 12); FLAT = flat feeding; HLH (n = 12) = high-low-high feeding (n = 12). ¹RSD = residual standard deviation. ²Obtained by analysis of variance
631 (including the effects of parity, treatment, and sow replicate). ³Young = first and second parity; Adult = above three parities. ⁴ME: metabolizable energy. ⁵DM: dry matter.

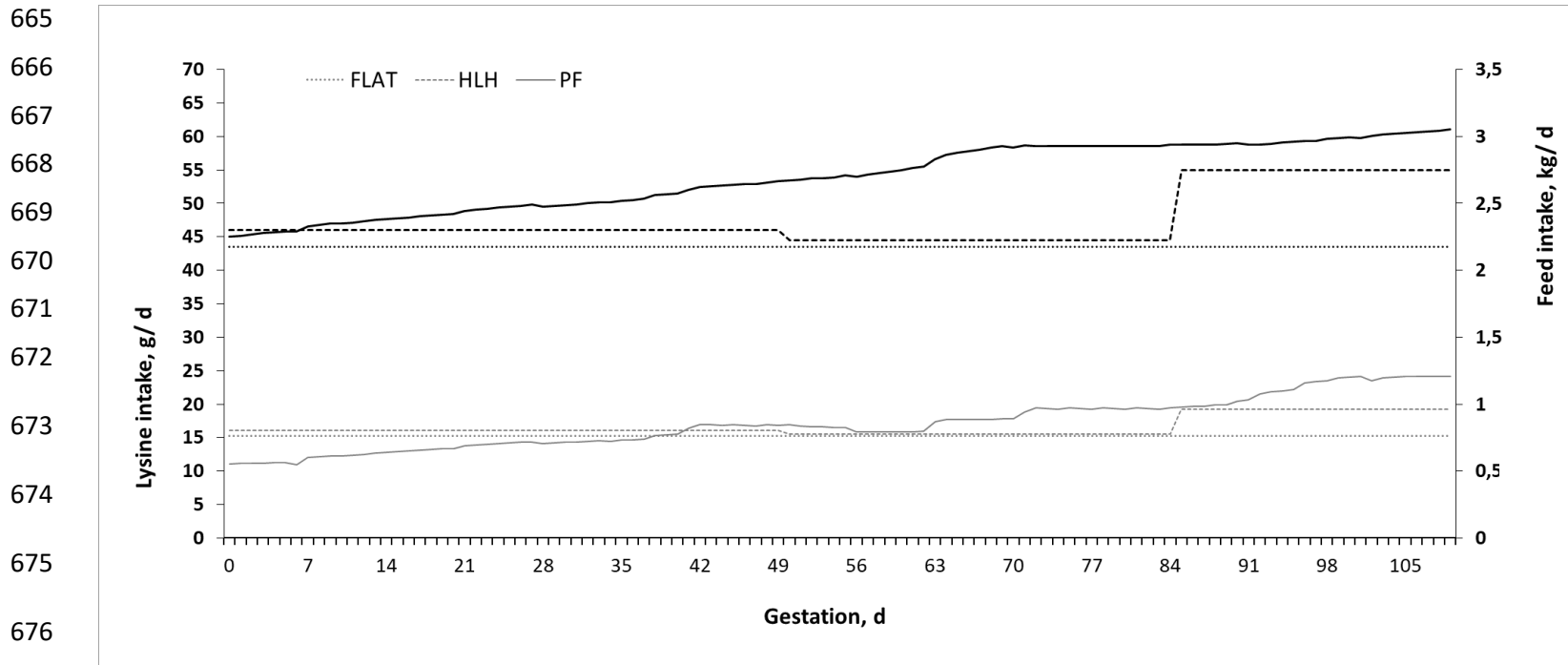
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633 Figure 1
 634 Blending proportion of the 02 diets (high and low lysine) on a daily basis for precision feeding during gestation according to sow category (young and adult).



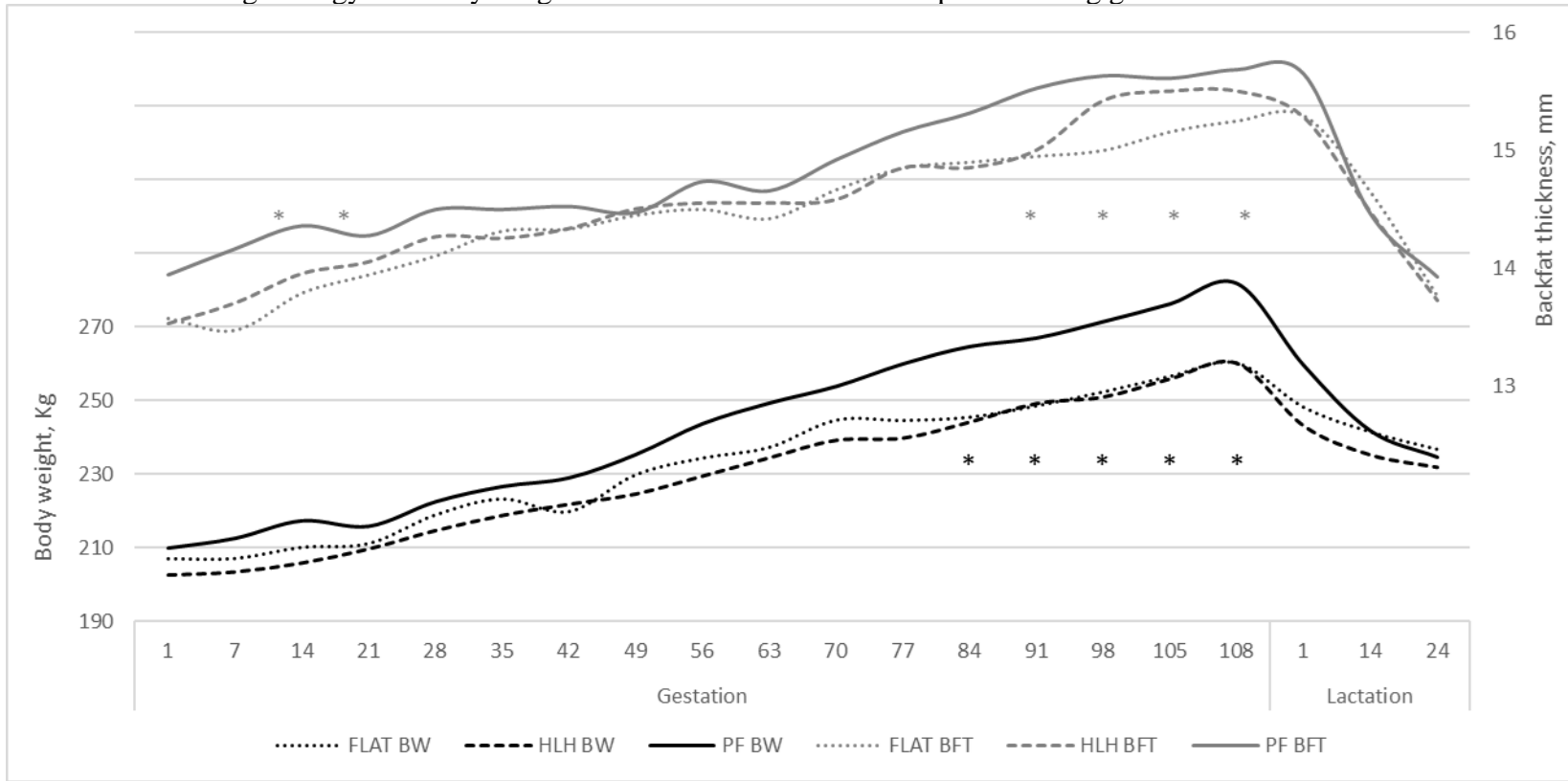
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663 Figure 2
 664 Dynamics of the average daily feed intake and lysine intake according to the different feeding strategies during gestation.



677 PF = precision feeding; FLAT = flat feeding; HLH = high-low-high feeding. Dark black markings represent feed intake and grey markings
 678 represent lysine intake. Curves were calculated based on the average of 15 young and 60 adult sows.

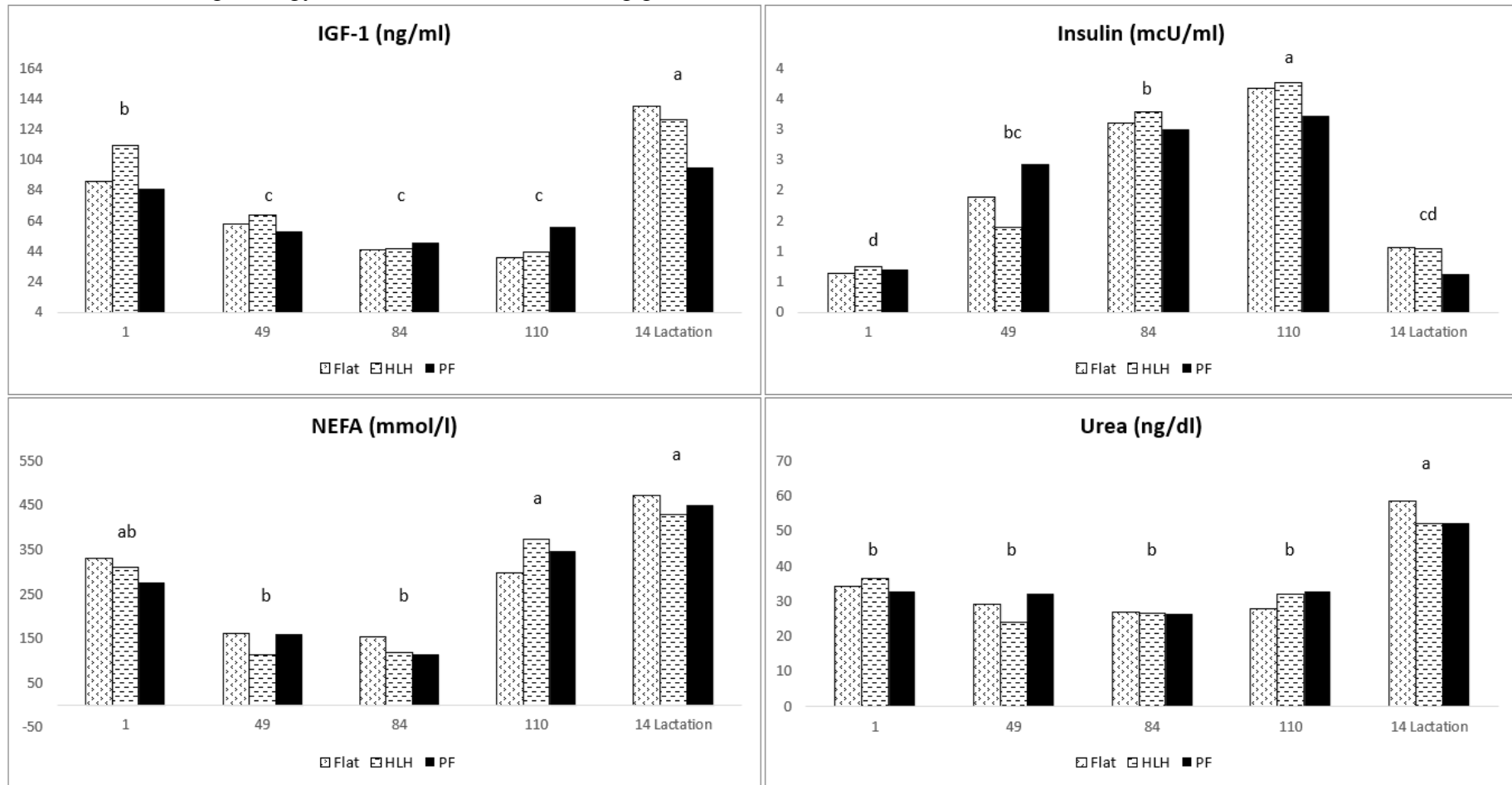
679 Figure 3
 680 Effect of the feeding strategy* on body weight and backfat thickness development during gestation and lactation.



681
 682 *PF = precision feeding; FLAT = flat feeding; HLH = high-low-high feeding; (*; P < 0.05); BFT = Backfat thickness. BW: body weight. Dark black markings
 683 represent body weight development and grey markings represent backfat thickness development. Curves were calculated based on the average of 15 young
 684 and 60 adult sows.

685

686 Figure 4
687 Effect of the feeding strategy* on blood metabolites during gestation and on d 14 of lactation



688 *PF = precision feeding (n = 5); FLAT = flat feeding; HLH (n = 5) = high-low-high feeding (n = 5). IGF-1: insulin-like growth factor 1; NEFA: Non-esterified fatty acids.
689 Curves are calculated based on the average of young and adult sows for each treatment. Letters differ periods statistically using the Tukey test (P < 0.05).
690

CHAPTER 3**ARTICLE 2 - APPLICATION OF A PRECISION FEEDING STRATEGY FOR
GESTATING SOWS AND ITS EFFECTS ON THE KINETICS OF FEED INTAKE
AND FEEDING BEHAVIOUR DURING LACTATION**

**ARTIGO FORMATADO DE ACORDO COM AS NORMAS DA REVISTA
CIENTÍFICA ANIMAL FEED SCIENCE AND TECHNOLOGY**

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1 Application of a Precision Feeding Strategy for Gestating Sows and its Effects on the
2 Kinetics of Feed Intake and Feeding Behaviour During Lactation

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14

15 Running title: Precision Feeding and Kinetics of Feed Intake

16 Abstract

17 Current gestating sow feeding strategies are based on using a single diet. Precision
18 feeding (PF) of the individual sows allows dynamic changes in amino acid and energy
19 requirements throughout gestation. Whereas reduced voluntary feed intake of lactating
20 sows can reflect in the reduction of milk production and consequently weight gain of
21 piglets. Thus, the aim of this study was to evaluate the effect of the Precision Feeding
22 Strategy and the age (Young and Adults) on the kinetics of sow feeding behavior. A total
23 of 70 mixed-parity sows were used. The sows were tagged with radio frequency
24 identification (RFID) transponder and moved into group-housed pens. Each pen was
25 fitted with one AIPF station. For sows on precision feeding (PF), the feeding level was
26 reached according to the blend of two basal diets with high and low protein level (HP:
27 8.0 gr/ kg SID Lys and LP: 2.0 gr/ kg SID Lys for low Lys) with daily adjustments of
28 quantities and proportions based on requirements. The remaining sows, managed as a
29 control flat (FLAT) and control step-up according gestation phase (HLH) received the
30 same diet and were fed two different feeding curves. Effects of diet composition, age, and
31 period of the day were tested according to ANOVA (GLM procedure of SAS). The use
32 of a precision feeding program during gestation did not influence statistically the feeding
33 parameters of the sows during lactation. Average time per visit (ATV), Frequency of
34 visits (FV), average daily feed intake (ADFI), average feed intake per visit (AFIV), total
35 duration of visits (TDV) was not influencing the kinetics of feeding behavior of sows
36 regardless of treatment or age. Although, adult sows showed a higher average feed intake
37 during lactation than young sows. In general, it was observed that the feeding strategy of
38 pregnant sows did not influence the kinetics of feeding behavior of sows in the lactation
39 phase, however, it can be observed that pigs have well-characterized biphasic feed intake
40 habits.

41 **Keywords:** Kinetics of Feed Intake, Lactation, Precision Nutrition.

42

43

44 **1. Introduction**

45

46 Precision nutrition can be an excellent strategy to improve and increase the productive
47 efficiency of breeding females [1]. Precision feeding (PF) of individual sows allows for
48 dynamic changes in amino acid and energy requirements throughout gestation. Extensive
49 research has been conducted to gain insight into the metabolic processes of pigs and
50 determine the optimal conditions and practices, such as feeding, nutrition, and housing,
51 that will maximize pig production in hot climates [2]. The detrimental impacts of elevated
52 environmental temperatures on lactation performance in sows have been extensively
53 documented. In practical terms, an increase in ambient temperature beyond the
54 thermoneutral zone results in a decline in voluntary feed intake, consequently reducing
55 heat production attributed to the thermic effect of feed [3]. The reduction in the voluntary
56 feed intake of lactating sows reflects the reduction of milk production and, consequently,
57 the reduction of piglet weight gain [4]. Young animals have the lowest intake capacity
58 when compared to multiparous sows due to reduced gastric capacity, which may reflect
59 in the reduction of milk quality and production [4]. Thus, different feeding and
60 management strategies in the gestation phase of females are used to maximize the gains
61 and efficiency of the female in the breeding period [6,7]. Excessive body mobilization
62 during lactation, due to low feed intake, may result in reduced longevity and productive
63 performance [8–10] and, consequently, in economic losses. With greater precision, the
64 impact of high ambient temperatures on the performance and feeding behavior of
65 lactating sows has been characterized [2,11,12]. Thus, the aim of this study was to
66 evaluate the effect of the Precision Feeding Strategy [1] and Age (young and adults sows)
67 on the kinetics of sow feeding behavior.

68

69 **2. Material and Methods**

70 *Animals and Experimental Procedure*

71 A total of 70 mixed-parity sows were used in a study conducted at the gestation and
72 farrowing facilities of the swine production farm of the University (UFMG/ ICA). A
73 treatment managed as Flat curve, a High-Low-High curve, where both received the same
74 diet. For sows on precision feeding (PF), the feeding level was reached according to the
75 blend of two basal diets (Diet 1: 3.00 Mcal/kg ME and 8.0 gr/ kg SID Lys for high Lys;
76 Diet 2: 3.00 Mcal/kg ME 2.0 gr/ kg SID Lys for low Lys, respectively; diets HP and LP)
77 and the amount of feed offered was adjusted daily for each animal to accurately meet
78 estimated daily ratios for energy and amino acid requirements. To adjust properly daily
79 nutritional demands via the model, sows were weighed and backfat thickness measured
80 every week. Thus, the total quantity and blend of HP and LP feed varied daily throughout
81 gestation based on sow's body weight, gestation stage and daily requirement ratios (SID
82 Lys g/ ME Mcal) according to the outputs from the sow model validated by [1]. Precision
83 treatment, that feeding level and blend of 2 basal diets was adjusted daily [1].

84 There were 4 periods during the day to evaluate the frequency and quantity of feed per
85 visit, being early morning (00:00-06:00), morning (06:00-12:00), afternoon (12:00 –
86 18:00) and night (18:00-00:00). Individual feeding behaviour was recorded during the ad
87 libitum period on lactation (between d 1 and 24 posts farrowing), using an Automated
88 Intelligent Feeder (AIF; Gestal Solo, Jyga Technology, Canada). Periodic testing of AIPF
89 feed delivery systems was performed (in between batches) and systems were recalibrated
90 when they exceeded 5% error. After each visit, the time and amount of feed at the
91 beginning and at the end of the visit were recorded. This data was continuously recorded
92 by the system every 10 minutes. In addition to the electronic measurement of feed intake,

93 morning refusals were manually collected and weighed at the same time, between 07:30
94 and 08:00h. The daily feed intake was determined as the difference between feed
95 allowance and the refusals collected on the next morning. Periodic testing of AIF feed
96 delivery systems was performed (in between batches) and systems were recalibrated
97 when they exceeded 5% error. The day prior to weaning (i.e., d 24), sows had feed
98 allowance restricted to 5 kg to standardize consumption for all sows for weighing at
99 weaning.

100 The variations in ambient temperature, relative humidity (RH), and photoperiod followed
101 closely the outdoor conditions. Ambient temperature and RH were continuously recorded
102 (1 measurement every 60 s) in the barns, using a datalogger connected to a probe (Didai
103 Tecnologia Ltda., Campinas, Brazil) placed 1 m above the floor. On day 28 after
104 insemination (AI), gestation was verified ultrasonically (Sunway, Shenzhen SUNWAY
105 Medical Device Co. Ltd., Model Handscan V7, Shenzhen, China); empty sows were
106 removed from the pens.

107 Initially, each independent variable was analysed separately using the PROC MIXED
108 procedure of SAS (Statistical Analysis System, SAS Institute Inc., Cary, NC, USA.
109 Version 9.4, 2012) with the sow and its litter being the experimental unit for sow and
110 piglet parameters. All performance data was tested for normality using the Univariate
111 procedure of SAS version 9.2 (SAS Inst. Inc., Cary, NC) and was normally distributed.
112 Treatment \times batch interactions were added to all preliminary models but were not
113 significant and were therefore omitted from subsequent analysis. The effect of feeding
114 system (three treatment groups: FLAT, High-Low-High and precision feeding systems)
115 and sow age group (young with parity ≤ 2 and adult with parity > 2) were included as
116 fixed effects in both set of analysis (for sow and piglet parameters). No random effects
117 were considered but PROC MIXED was used because offers several options in the

118 MODEL statement for obtaining approximate degrees of freedom of very unbalanced
119 data [13] like in this case. A value of $P < 0.05$ was considered statistically significant,
120 whereas probability levels of $0.05 < P < 0.10$ was considered as the tendency. Average
121 time per visit, Frequency of visits, Average Feed Intake, Total duration of visits and
122 Average Daily Feed Intake data were pooled per sow daily and were analysed according
123 to linear mixed model variance using the MIXED procedure of SAS/STAT. These effects
124 were tested with a mixed linear model (MIXED procedure of SAS) for repeated
125 measurements with treatments and batch as main effects.

126

127 **3. Results**

128 The average minimum and maximum ambient temperatures and RH were 11.0 and
129 39.0°C, and 14 and 98%, respectively. The thermal amplitude observed for both
130 temperatures and humidity were 28°C and 84%, respectively. During the experimental
131 period the sows were exposed to temperatures above 26°C on average 45% of the time.
132 As for temperatures above 30°C sows were exposed 24% of the time.

133 In the study, parameters of feeding behaviour kinetics of lactating sows were evaluated
134 (Table 1), were: Average time per visit (ATV), Frequency of visits (FV), average daily
135 feed intake (ADFI), average feed intake per visit (AFIV), total duration of visits (TDV).
136 Feeding strategies did not influence the kinetics of feeding behaviour of sows regardless
137 of treatment or age.

138 The dynamics of daily feed intake during pregnancy among the various treatments and
139 their effects on lactation intake can be seen in figure 3. It was observed that the daily feed
140 intake of sows is higher ($P < 0.05$) than that of young (6.072 vs. 4.724 respectively). The

141 gestation feeding strategy also influenced the lactation daily feed intake where the
142 animals of the Precision treatment obtained a lower daily feed intake ($P < 0.05$) when
143 compared to the other HLH and Flat treatments (5.250 vs 5.502 and 5.690 respectively)
144 (Table 2).

145

146 **4. Discussion**

147 Throughout the experiment, the animals were subjected to high temperatures due to
148 the region and climate of the experimental unit (tropical humid climate). The average
149 temperature during the study was 26°C, where the sows remained 45% of the time.
150 Approximately 24% of the time, the sows remained at temperatures above 30°C. In
151 addition, the relative humidity remained close to 80%, which could potentiate stress and
152 thermal sensation. According to studies, temperatures above 25.5°C can result in a
153 reduction in voluntary feed intake by up to 100g for each degree Celsius elevated [2,13].
154 Thus, it can be assumed that the temperature may have generated heat stress throughout
155 the experiment for the animals regardless of the treatment submitted.

156 Another factor evaluated was the effect of the feeding strategy during pregnancy on
157 the kinetics of feeding behavior in the lactation of sows. No statistical differences were
158 observed for the different variables, as follows: Average time per visit; Frequency of
159 visits, Average feed intake and Total duration of visits (Table 2). On the other hand, for
160 the daily feed intake, the influence of the Precision treatment was observed when
161 compared to the other treatments, data published in the first article [1]. Daily feed intake
162 during gestation and lactation are shown in Figure 3. The age of the sows also
163 significantly influenced the daily feed intake, and the sows (Parity order > 2) had higher
164 feed intake than the young ones (Parity order < 3). This characteristic can be attributed

165 to the lower physical capacity of the gastrointestinal tract of young sows. However, for
166 the treatments, only a numerical reduction in feed intake was observed in the different
167 feeding strategies: Flat, HLH and Precision, respectively. Results shows that precision
168 feeding based on daily nutrient adjustments throughout gestation is highly beneficial for
169 highly prolific sows, supporting nutrient availability for sow body growth [1], fetal
170 development, and mammary gland.

171 Regardless of the treatments, when subdividing the day into 4 different periods
172 (Figure 1), it was observed that the highest feed intake per visit was at night from 18:00
173 to 00:00, where the animals had an approximate intake of 250g/visit. It is important to
174 note that the visit is characterized by the approximation of the earring (RFID) to the sensor
175 inside the feeding stations. On the other hand, for the other periods, no statistical
176 difference was observed, as the consumption curves were similar between the treatments
177 within the same periods.

178 When subjected to thermoneutral conditions and persistent exposure to high
179 temperatures [15] pigs kept in groups demonstrate a biphasic feeding pattern. This pattern
180 is identified by two peaks of feeding activity over a 24-hour period, one at the beginning
181 of the day and the other at the end of the day [2,16], as documented in the current study.

182 Wood-Gush et al. also found that the daily pattern of feeding activity in lactating sows
183 is mainly concentrated during the day, with two distinct feeding periods: one in the
184 morning and one in the afternoon. Observations made in domestic pigs in semi-natural
185 environments indicated that their activity was focused on a few hours in the morning and
186 late afternoon until early evening, with rest intervals during the middle of the day and at
187 night [10,17] corroborating with present study.

188 An interesting fact was that, although the highest frequency of visits was in the
189 morning, the highest consumption per visit was at night (06:00 – 12:00). Similarly, a
190 study showed that there is an increase in feed intake per visit in the afternoon (15:00 and
191 18:00) [15] and a reduction in the number of feeder visits from 20:00 to 04:00 for pigs
192 housed in a group under thermoneutral conditions. This dual eating behavior is mainly
193 attributed to reduced levels of melatonin in the morning and cortisol in the afternoon
194 [16,18].

195 In a model proposed by Boumans et al. [18], which takes into account factors
196 affecting feed intake, it has been observed that the circadian cycle of cortisol and
197 melatonin may explain the feeding pattern in pigs. As in our study, daily feed intake had
198 a characteristic predominance like that of other studies showed before, with two peaks at
199 different times of the day. The author further explains that the timing and amplitude of
200 cortisol peaks affect daytime and nighttime consumption peaks.

201 Fluctuations of melatonin concentrations throughout the day, after the light-dark
202 cycle, reveal a greater nocturnal attraction in both diurnal and nocturnal animals [18–20].
203 Melatonin induces sleep in diurnal mammals, contrasting with its absence of effect in
204 nocturnal mammals. In nocturnal animals, activity is observed when melatonin levels are
205 elevated [20] Melatonin plays a crucial role in regulating energy flow and expenditure,
206 insulin synthesis, coordination, and action, as well as synchronizing metabolic processes
207 in different insulin-sensitive and insulin-resistant phases throughout the day [18,21].

208 In general, it was observed that the feeding strategy of pregnant sows (specifically
209 Flat, HLH and Precision) did not influence the kinetics of feeding behavior of sows in the
210 lactation phase. However, it can be observed that pigs have well-characterized biphasic
211 consumption habits. The mechanisms characterized by such habits are of great

212 importance for understanding consumption cycles, as well as the mechanisms that
213 metabolically affect the use of nutrients and strategies to better manage pig food
214 management.

215 **Declaration of interest**

216 The authors declare no conflict of interest.

217 **Ethics statement**

218 All methods involving animal handling were be realized in accordance with the
219 regulations approved by the Institutional Animal Welfare and Ethics/Protection
220 committee from the Universidade Federal de Minas Gerais (UFMG – CEUA) under the
221 nº 189/2019, Brazil.

222 **Software and data repository resources**

223 Data and models used in this study are not applicable for deposition in an official
224 repository.

225

226

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432 Composition of the experimental diets

Ingredients	Experimental Diets*			
	CON	HP	LP	LACT
Corn (8% CP ¹)	76.42	54.40	64.93	62.87
Soybean meal (46% CP)	17.24	20.00	-	30.00
Wheat bran (14% CP)	-	13.23	20.00	-
Corn Starch	-	6.00	9.00	-
Soybean oil	-	-	-	1.90
Dicalcium phosphate	1.76	1.64	1.66	1.77
Limestone	0.80	0.87	0.98	1.02
Lignocellulose fiber	2.50	2.50	2.50	1.00
Sodium chloride	0.50	0.50	0.50	0.40
Mineral premix ³	0.15	0.15	0.15	0.15
Vitamin premix ⁴	0.08	0.08	0.08	0.08
Mycotoxin binder ⁵	0.20	0.20	0.20	0.20
Lysine 54.6%	0.26	0.27	-	0.38
L-Threonine 99%	0.06	0.10	-	0.10
L-Tryptophan 99%	0.02	0.02	-	0.05
DL-Methionine 99%	0.01	0.05	-	0.08
Total	100	100	100	100
Analyzed composition, as fed				
Metabolizable Energy, Mcal/kg	3.200	3.000	3.000	3.345
Net Energy, Mcal/ kg	2.43	2.30	2.36	2.50
Lysine dig/NE, (g/1000kcal)	2.87	3.47	0.95	4.20
Crude protein, %	13.95	15.51	8.32	18.82
Crude Fiber, %	4.40	5.30	5.00	4.33
Starch, %	48.63	43.89	55.20	41.16
SID ² Lysine, %	0.700	0.800	0.210	1.050
SID Met+Cys, %	0.460	0.520	0.320	0.630
SID Threonine, %	0.500	0.580	0.250	0.700
SID Tryptophan, %	0.140	0.160	0.060	0.220
SID Valine, %	0.580	0.640	0.350	0.890
SID Arginine, %	0.780	0.930	0.430	1.130
Total Calcium, %	0.850	0.850	0.850	0.950
Total Phosphorous, %	0.630	0.804	0.830	0.681
Digestible Phosphorus, %	0.320	0.320	0.320	0.330
Digestible Ca:P ratio, %	2.70	2.70	2.70	2.90
Sodium, %	0.35	0.350	0.350	0.350

433 *CON: control diet; HP: high protein diet; LP: low protein diet; LACT: lactation diet. ¹CP: Crude protein.

434 ²SID: Standardized ileal digestible. ^{3,4}Provided the following amounts of vitamins and trace elements in

435 units per kg: Copper sulphate (Copper 13.00 g/kg), Iron sulphate (Iron 100.00 g/kg), Manganese monoxide

436 (Manganese 50.00 g/kg), Sodium Selenium (Selenium 184.00 mg/kg), Zinc sulphate (Zinc 95.00 g/kg),

437 Calcium Iodine (Iodine 1000 mg/kg), Vitamin A (22500000 IU/kg), Vitamin D3 (380000 IU/kg), Vitamin

438 E (200000 IU/kg), Vitamin K (10000 mg/kg), Biotin (1000 mg/kg), Folic acid (9000 mg/kg), Niacin

439 (120000 mg/kg), Pantotenic acid (60,000 mg/kg), Vitamin B2 (20000 mg/kg), Vitamin B1 (8000 mg/kg),

440 Vitamin B6 (12000 mg/kg), and Vitamin B12 (100000 mg/kg). ⁵Toxin binder composed by fermentation

441 extracts of *Saccharomyces cerevisiae*, citric acid, lactic acid, phosphoric acid, and propylene glycol.

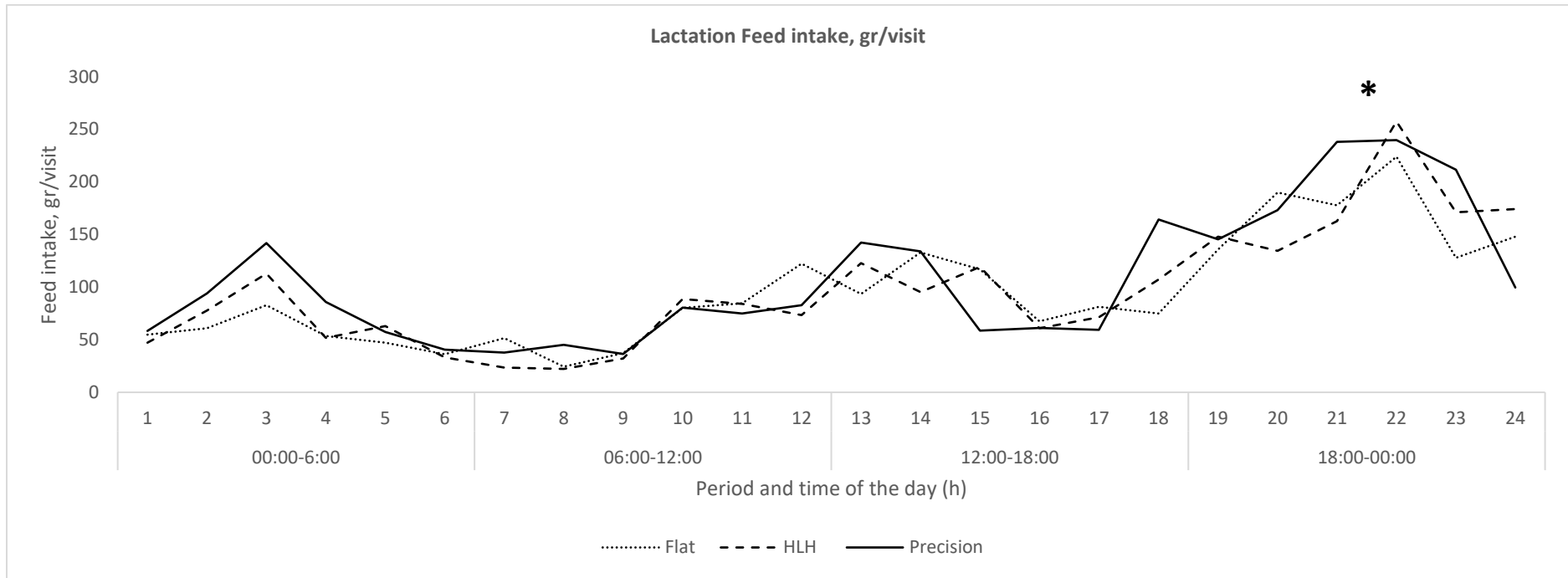
442 **Table2.** Effects of precision feeding strategy and age on kinetics of feed intake and feeding behavior during lactation.

Variable	Feeding strategy			Age		RSD	P-value	
	Flat	HLH	Precision	Adult	Young		Treatment	Age
Average time per visit (min/ visit)	4.580	4.580	4.250	4.181	4.693	0.104	0.705	0.126
Frequency of visits (visit/ day)	11.250	11.170	10.160	10.823	10.844	0.078	0.793	0.914
Average Feed Intake (g/ visit)	96.112	97.275	106.804	98.75	102.59	29.32	0.800	0.336
Total duration of visits (min/ day)	46.510	45.810	40.930	40.254	47.549	0.127	0.454	0.105
Average Daily Feed Intake (kg/ day)	5.690 A	5.502 A	5.250 B	4.724	6.072	0.823	0.010	0.005

443 PF= Precision Feeding; FLAT = Flat Feeding; HLH = High Low High feeding; Young= OP1 and 2; Sow = OP>2.

444

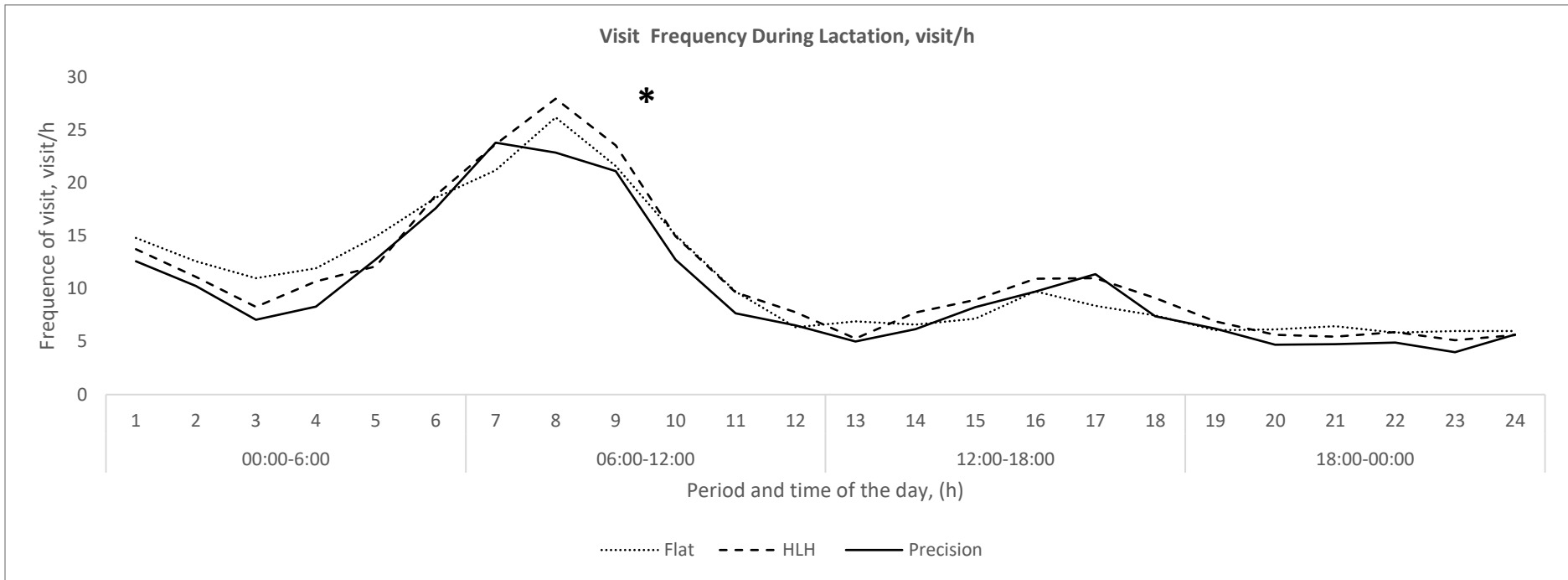
445 **Figure 1.** Dynamics of feed intake during lactation (grams per visit) according to treatment (Flat, HLH and Precision).



446
 447 PF= Precision Feeding; FLAT = Flat Feeding; HLH = High Low High feeding. * Statistical difference from the other treatments using the Tukey test $p < 0.05$.

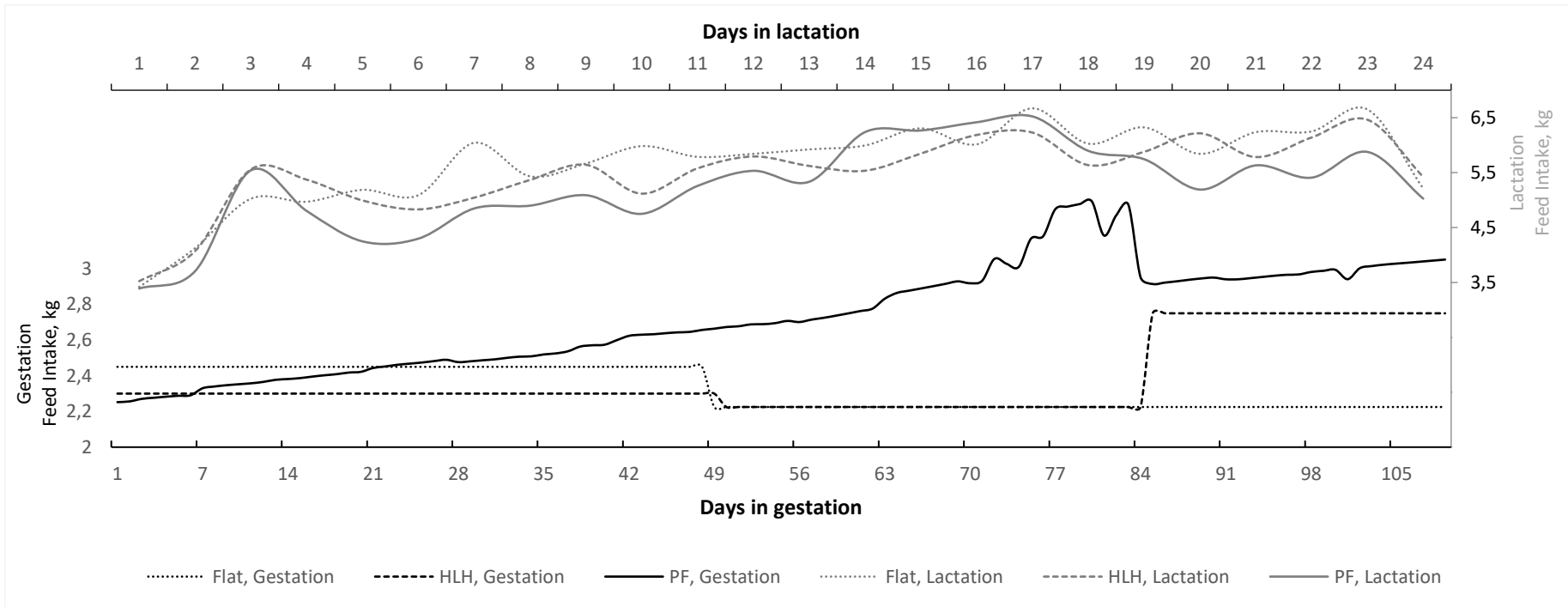
448

449 **Figure 2.** Dynamics of feed intake (visit per hour) during lactation according to treatment (Flat, HLH and Precision).



450
 451 PF= Precision Feeding; FLAT = Flat Feeding; HLH = High Low High feeding. * Statistical difference from the other treatments using the Tukey test $p < 0.05$.
 452

453 **Figure 3.** Dynamics of feed intake during gestation and lactation according to treatment (Flat, HLH and Precision).



454

455 PF= Precision Feeding; FLAT = Flat Feeding; HLH = High Low High feeding.

456