Effect of Precision Feeding on Uniformity and Efficiency of Broiler Breeder Pullets

by

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ABSTRACT

Broiler breeders are feed restricted to control growth and increase the production of settable eggs. However, the consecutive need for the deposition and mobilization of nutrients, due the feeding and fasting cycles those birds are submitted to, is not a efficient process. Additionally, the less food is provided within a day, the more competition is observed among birds with the less aggressive ones not having enough chance to eat. This competition decreases the flock BW uniformity. Precision feeding for broiler breeders is a novel technology that feeds birds individually small amounts of feed throughout the day. The primary objective of this thesis was to determine the effect of precision feeding on BW uniformity, efficiency and water intake of Ross 308 pullets in comparison to the commonly used skip-a-day feeding program. Another experiment was ran concurrently to compare five target BW to identify whether that promoted higher flock BW uniformity and feed efficiency. A third experiment was designed to determine how many birds the precision feeding system could feed without compromising efficiency and flock BW uniformity in an attempt to maximize the number of birds per station to minimize cost. The precision feeding treatment was more efficient and uniform with no difference in water intake as compared to the skip-a-day feeding treatment. For the second trial, Low Flush (Ross 708 with high peri-pubertal growth rate) and Low (Ross 708) target BW were the most efficient and had the highest BW uniformity. For the third trial, precision feeding was able to keep the flocks highly uniform without affecting efficiency regardless the stocking pressure employed.

PREFACE

This thesis is an original work by Paulo R. O. Carneiro. Funding for this project was provided by Alberta Livestock and Meat Agency Ltd., Agriculture & Food Council, Danisco Animal Nutrition, Alberta Innovates Bio Solutions, Poultry Industry Council, Alberta Hatching Egg Producers, Canadian Hatching Egg Producers, and Alberta Chicken Producers. In-kind support for this project was provided by Xanantec Technologies Inc. Publication is intended for Chapters 3, 4 and 5 with co-authors M.J. Zuidhof and S.H. Hadinia. The research project, of which this thesis is a part, received research ethics approval from the University of Alberta Research Ethics Board, Precision Broiler Breeder Feeding System, AUP00000121, June 9, 2014.

DEDICATION

To my beloved wife Juliana S. B. Carneiro: Your patience and constant support have brought me here. You are a sparkling of light that shines in my life and gives me reason to keep on going regardless the obstacles I find on the way. Thank you for being there whenever I need it, for loving me that much and for even helping me on some days with my farm duties throughout my studies. You are the most reason why I keep pushing myself to the limit.

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1 INTRODUCTION

Selection for rapid growth and higher meat yield in broilers is associated with increased appetite (Siegel and Wisman, 1966) and has been followed by an unintended increase on feed intake by their parent breeders, leading to excessive BW gain (Renema and Robinson, 2004). Researchers have found that this greater feed intake is negatively related to the performance of birds by decreasing their age at sexual maturity, increasing carcass fat, disrupting the ovary morphology, and decreasing the number of settable eggs (Hocking et al., 1987; Hocking et al., 1993). Therefore, broiler breeders are restricted fed to avoid becoming overweight and to increase persistency and production (Renema and Robinson, 2004). According to Yu et al. (1992b) restricted fed broiler breeders eat approximately a third the amount of feed they would eat if fed ad libitum. A restriction program consists of providing just enough feed for the animals to grow while avoiding overfeeding and obesity. According to de Beer et al. (2007) feeding programs such as skip-a-day, in which pullets don't eat every day, affects their capacity of metabolizing nutrients and is often associated with higher requirements due the consecutive need of storage and mobilization of nutrients. Although skip-a-day is amongst the most used feeding restriction programs used by the industry, because it increases BW uniformity by allowing more timid birds a chance to eat, other programs such as daily (small amount of feed provided once a day every day), 5/2 (the weekly feed allocation split into 5 days of the week), 4/3 (the weekly feed allocation split into 4 days of the week), or 6/1 (the weekly feed allocation split into 6 days of the week) are also used. The decision of which program to apply is the responsibility of the farm manager who analyzes the pros and cons to use each feeding program according to the farm technology and staff available. One problem often associated with feed restricting broiler breeders is the high humidity in the litter due the increased water intake which may lead to foot pad dermatitis (Kaukonen et al., 2016). According to Hocking (1993b) feed restriction in broiler breeders pullets increased water intake by 25% when compared to the ad libitum fed group. Therefore, new methods of feeding management are required to control broiler breeder growth and BW uniformity while keeping the water intake at acceptable levels to avoid wet litter. Precision feeding for broiler breeders may help to solve these problems by allocating feed multiple times daily for individual birds. A literature review on broiler breeders' metabolism and commonly used feed restriction programs used is given in Chapter 2 of this thesis. In Chapter 3 a comparison between precision feeding and skip-a-day feeding is made to identify how these two feed allocation methods affect pullet growth, BW uniformity, efficiency and water intake. In Chapter 4 we evaluate the capability of precision feeding in controlling growth and BW uniformity by using 5 targets BW and assessed the feeding patterns of pullets for each treatment group. In Chapter 5 we tested 4 stocking pressures to identify how many birds a precision feeding station can feed while keeping a high flock BW uniformity. The sixth chapter comprises a synthesis of the three experiments and provides recommendations for the management of broiler breeder pullets using precision feeding.

1.1 OBJECTIVES

The primary objective of this thesis was to determine the effect of precision feeding on pullet BW uniformity and efficiency in comparison with skip-a-day feeding. Within this primary objective, another experiment had the specific objective to evaluate the capacity of precision feeding on keeping birds within a flock under different target BW while controlling BW uniformity. Additionally, we tried to identify how many birds a precision feeding station can feed without compromising pullets' performance. Specific objectives were:

1) Determine the effect of precision feeding on BW uniformity by comparing the BW coefficient of variation of birds reared using skip-a-day feeding program, precision feeding with different target BW or precision feeding with different stocking pressures.

2) Determine the effect of precision feeding on ADFI, ADG and FCR of birds reared using skip-a-day feeding program, precision feeding with different target BW or precision feeding with different stocking pressures.

3) Measure the effects of precision feeding system in water intake by comparing the daily water intake between precision and skip-a-day fed pullets.

4) Identify feeding patterns by comparing the ADFI, ADG, the number of meals per day and the meal size of birds raised using

precision feeding with different target BW or different stocking pressures.

5) Determine the optimal number of birds one station can feed by comparing the BW uniformity and efficiency of pullets raised under different stocking pressures.

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2 LITERATURE REVIEW

2.1 Broiler Breeder Management Practices and Implications on Performance

2.1.1 *Genetic Potential for Growth and Reproduction Problems*

Genetic selection in broilers over the past 50 years has made it possible for the industry to raise, in 2005, birds that were 50% more efficient and expressed over 400% growth compared to 1957 strains (Zuidhof et al., 2014). This selection for rapid growth rate and higher meat yield in broilers has been followed by an unintended increase in feed intake by their parents (Renema and Robinson, 2004). Comparing broiler breeders from 1980 with the ones from 2000 Eitan et al. (2014) observed that the BW at onset of lay increased by 1000 g from 1980 to 2000. Yu et al. (1992b) found that ad libitum fed broiler breeders consumed 37.2% more feed than their restricted counterparts. However, a recent study of broiler breeders during the laying phase showed that ad libitum fed broiler breeders ate double the amount of food as compared to their feed restricted counterparts (Chen et al., 2006). Researchers found that this greater feed intake is negatively related to the performance of birds by decreasing their age at sexual maturity, increasing carcass fat, increasing the occurrence of multiple ovulations, and decreasing the number of settable eggs (Hocking et al., 1987; Hocking et al., 1993; Chen et al., 2006). According to Renema and Robinson (2004), overfeeding broiler breeders increases body weight and fat deposition, which may lower production; therefore, broiler breeders are feed restricted to increase persistency and production. Ovary dysfunction often occurs in response to overfeeding with multiple yellow follicle hierarchies forming in the ovary leading to higher occurrence of double yolk eggs, shelless eggs or eggs with poor shell quality (Hocking et al., 1987).

2.1.2 Egg production physiology

The hypothalamus is the primary gland associated with the ovary development and according to Robinson and Renema (2003), hypothalamus maturity is crucial to hens to respond to the light stimulus between 18 to 23 wk and when birds perceive the day is providing from 11 to 12 hours of light, photoreceptors convert photon energy into biological signal (nerve impulse) which in turn stimulate the release of the gonadotrophin releasing hormone (**GnRH**). There is a network of blood vessels that links the hypothalamus and the adenohypophysis which guarantees the communication between the two glands. The GnRH produced in the hypothalamus further stimulates the anterior pituitary to produce and release the follicle stimulating hormone (**FSH**) and luteinizing hormone (**LH**). The authors state that the FSH and LH stimulate the gonads to produce follicles in females and spermatozoa in males and feedback to the hypothalamus helping the manifestation of secondary sexual characteristics. The release of LH occurs around 6 hours before ovulation and has a short time activity; this period is known as “open period”. According to (Macari et al., 2005), ovulation occurs around 10 hours after the beginning of the night. During the beginning of the night there is the first peak of LH, followed by a progesterone increase, which stimulates a further peak in LH around 6 hours before ovulation. If there is a mature pre-ovulatory follicle it will respond to this burst of LH release and will produce progesterone. This progesterone will stimulate further LH release and so on. Ovulation is the end point, about 6-8 h after the initial LH surge. The same authors highlighted that if a follicle reaches maturity and is functionally producing progesterone outside of the "open period", it will stay in the ovary until the next "open period" occurs. This makes the bird miss a day of laying. As birds age the follicles take longer to mature generating smaller follicle sequences. Therefore, older females miss more laying days which results in fewer eggs laid.

When excessive number of large yellow follicles (**LYF**) forms in the ovary of broiler breeder hens, an oviposition outside the "open period" may occur while the egg is still forming in the oviduct (Macari et al., 2005). This results in premature laying and hence on the formation of a shelless egg or an egg with poor shell quality (Renema and Robinson, 2004). Researchers have demonstrated that follicle growth may be controlled through restricting feed intake (Hocking et al., 1987; Hocking et al., 1993; Eitan et al., 2014). This practice decreases the total amount of yolk deposited in the follicles increasing the egg production and enhancing egg quality. Hocking et al. (1987) conducted a trial to compare the ovarian follicular population of small sized breeders with high reproductive performance fed ad libitum or restricted until the peak of production and found that the ad libitum fed birds produced 18% fewer eggs than the restriction fed group. The researchers concluded that birds fed ad libitum produced more LYF (7-10) than the restricted fed ones (5-8), which resulted in multiple ovulations and lower production of settable eggs, particularly during the onset of lay. Furthermore, they observed that restricting feed intake during rearing limited the production of LYF and the incidence of double ovulations resulting in a 25% increase in the percentage of settable eggs laid from 28 to 30 wk. By feeding 33 wk old Cobb 500 broiler breeders either ad libitum or restricted for 10 d Chen et al. (2006) observed that egg production in ad libitum fed birds dropped from 73.3 to 55.8% and concluded that this was caused by the high lipotoxicity associated with ad libitum feeding that was closely linked to the incidence of ovarian abnormalities. Yu et al. (1992a) showed that feed restricting pullets from 4 to 18 wk resulted in higher egg production. However, according to Bruggeman et al. (1999) restricting feed for birds in the period between 7 and 15 wk of age resulted in improved reproductive performance due an increase on the proportional weights of the ovary and oviduct (1.7 and 1.58% respectively). This may be due the effect of feed restriction on the maturity of the hypothalamus-pituitary axis, being 16 wk of age the period when the reproductive development starts in restricted broiler breeders (Bruggeman et al., 1998). According to Walzem and Chen (2014) overfed hens exhibit excessive LYF and hyperovulation and the need to control the ovulatory rate may be related with the time required to form an egg (25 h). In that regard, a lower egg production may occur when a high number of LYF are present in the ovary due multiple ovulations taking place in the same day (Richards et al., 2003; Chen et al., 2006). Therefore, the number of LYF should be around 5 to 7 so only one egg can be formed per day. Studies conducted by Hocking (1996) showed that feed restricting broiler breeders during the production phase helped to control multiple ovulations with restricted birds displaying 6 LYF in the hierarchy when compared to the ad libitum group that showed 10. Hence, broiler breeders need to spend most of their life under feed restriction to maximize chick production.

2.1.3 Broiler Breeder Metabolism

The negative relationship between growth and reproduction has been studied for more than 50 years in chickens (Maloney et al., 1967; Jaap and Muir, 1968). A similar relationship has also been identified in Japanese quail (Marks, 1985) and turkeys (Nestor et al., 1980). Renema and Robinson (2004) suggested that feed restriction in broiler breeder hens prevents excessive body weight gain and limits the incidence of reproductive disorders. Hocking et al. (1993) observed that the mean proportion of time spent eating by broiler breeders fed ad libitum was 46, 47, 32 and 25% at 3, 8, 12 and 16 wk of age. Broiler breeder hens fed ad libitum from hatch to photostimulation may weigh twice as much and have the double amount of carcass fat when compared to restricted fed birds (Katanbaf et al., 1989c, a). According to Yu et al. (1992b), ad libitum fed birds may have double the carcass fat when compared to restricted fed birds at 33 wk. Robinson et al. (1991) reported that of the 700 g difference in the body weight between the groups fed either ad libitum or restricted until sex maturation, 68% was fat. Katanbaf et al. (1989c) found that the lipid content in the carcass throughout their trial was 24.2% for birds fed ad libitum compared to 16.5% for restricted hens. Sun et al. (2006) found that ad libitum fed broiler breeder hens had 7.9% more carcass fat at 36 wk of age. The higher BW of birds fed ad libitum may also lead to an excessive accumulation of fat in the liver (Renema and Robinson, 2004). Broilers under an ad libitum feeding regimen may saturate the production system of very low density protein (VLDL) responsible for carrying lipids through the blood stream, resulting in triglyceride build up in the liver (Leclercq et al., 1974). The half-life of the plasmatic VLDL in chronically overfed birds is increased resulting in lower "turnover" rate of the increased fat present in the liver (Bacon et al., 1978). The excess of nutrients may have a greater effect on the ovary of lines selected for rapid growth, especially during the process of sexual maturation (Renema and Robinson, 2004). In a review about obesity-induced dysfunctions in females, Walzem and Chen (2014) stated that obese broiler hens had high circulating concentrations of insulin and leptin with changes in lipid and lipoprotein metabolism similar to those of woman with polycystic ovary syndrome. Therefore, overfeeding during rearing, after 4 wk and before 5% production, will result in production of yellow follicles that are more likely to be organized in multi-hierarchies (Hocking et al., 1987; Hocking et al., 1989; Katanbaf et al., 1989b; Yu et al., 1992b; Renema et al., 1999a), which will, in turn, increase the number of unsettable eggs produced (Jaap and Muir, 1968). Multiple follicle hierarchy can be controlled by restricting the hens' feed intake, resulting in a higher production of settable eggs (Hocking et al., 1987; Yu et al., 1992b; Walzem and Chen, 2014). Hocking (1996), showed that the number of yellow follicles is directly related with BW of broiler breeder hens at the onset of lay. Studies on arrhythmic patterns of oviposition in broiler breeder hens done by Jaap and Muir (1968) led to the description of the "Erratic oviposition and defective eggs syndrome" (EODES). Yu et al. (1992b), reported that the restricting broiler breeder hens during rearing, production, or both, resulted in significant reduction in the incidence of erratic oviposition when compared to birds fed ad libitum during the whole period and that. The number of double yolk eggs increased in all groups that involved ad libitum feeding and the erratic oviposition was directly related, both with thin shell or shelless eggs and inversely related to the production of settable eggs. The production of defective eggs due multiple ovulations occurs, primarily, in the first wk of production and a great portion of it disappears during the peak of production, 30 to 32 wk (Renema and Robinson, 2004).

2.1.4 Feed Restriction Programs

Hatching egg producers use different types of feed restriction programs to prevent birds from getting fat, to delay sexual maturity, to avoid reproductive dysfunction and to increase the production of settable eggs. A restriction program consists of providing just enough feed for the animals to achieve desired rates of BW gain. During rearing the daily feed intake is greatly restricted to about 1/3 of what birds from the same age fed ad libitum would eat or half of the intake of birds from the same BW also fed ad libitum (Savory and Kostal, 1996; De Jong and Guémené, 2011). Skip-a-day feeding is among one of the most used feeding restriction programs and consists of feeding birds double the daily feed allocation every other day. The greater amount of feed provided on feed days allows the most timid birds to eat when the most aggressive ones become full or leave the feeder in search for water (Cobb-Vantress, 2008c). The 4/3 feeding program (four days fed and 3 fasting not consecutive) is in between the skip-a-day and daily restriction programs in terms of energy efficiency and it allows farmers to feed the birds on the same days of the week which make this program a good solution to facilitate management during the weekends (Cobb-Vantress, 2008c). The 5/2 feeding program (Five days fed and 2 fasting not consecutive) is also used by the industry and it is particularly advantageous because it allows birds to have access to feed more days. In skip-a-day fed birds, there is a peak on glycogen and lipid present in the liver 24 h after refeeding (de Beer et al., 2007). During refeeding, there is an increase in lipogenesis associated with increased acetyl-coenzyme A carboxylase, malic enzyme and fatty acid synthase gene expression (Richards et al., 2003; Sun et al., 2006; de Beer et al., 2007). Skip-a-day fed birds will often require more feed than daily restricted ones to gain the same amount of weight due the multiple cycles of storage and mobilization of nutrients, which is energetically costly (de Beer and Coon, 2007). According to Zuidhof et al. (2015) skip-a-day fed birds are conditioned to repeated energy shortage and diverge energy from growth of breast muscle towards storage in the abdominal fat pad, which is more efficient for storage and mobilization. de Beer and Coon (2007) compared daily, skip-a-day, 5/2 and 4/3 restriction programs in groups fed with the same amount of feed weekly and observed that BW of the birds submitted to daily restriction was the greatest and the pullets under this treatment had earlier sexual maturation. Birds under the 5/2 restriction program laid heavier eggs than the daily restricted ones, having the 4/3 and skip-a-day programs as intermediates. Apparently, the more days off feed a feed restriction program has, the more unstable is the birds metabolism with pullets having to consecutively store and mobilize nutrients (de Beer et al., 2007). This difference on the metabolic states between birds on the different treatments may help to explain why the daily restricted birds performed better in that experiment. The authors conducted another trial submitting the birds to the same treatments, but controlling the effect of BW by providing different amounts of feed for each treatment aiming to reach the target BW stipulated by the guideline. The researchers observed that the differences in animals' performance were attenuated but not eliminated showing that in spite of adjusting the feed allocation, broiler breeders under different feeding restriction programs have differences in their metabolic status.

The restriction programs described above are considered "quantitative" because they restrict the nutrient intake by directly reducing the total amount of feed the birds have access to within a week. However, "qualitative" restriction programs are also used to control the BW. These programs consist of indirectly reducing the nutrient intake by altering the diet composition which often leads to a dilution of the overall energy level per kg of ration. Zuidhof et al. (2015) conducted a trial comparing different feeding restriction programs having the daily restriction, skip-a-day (quantitative) and high fiber diet (qualitative) as treatments. The researchers found that birds fed the high fiber diet showed higher feed conversion ratio throughout the entire study and were, along the control treatment, the least uniform with the BW CV ranging from 13.9% to 15.8% between 11 and 22 wk. The lower ME per gram of feed (2.2 kcal) in the high fiber diet caused birds to increase their feed intake to achieve the daily ME requirement. The higher feed intake in conventional feeding systems is often associated with longer time eating which may have caused birds to gather around the feeder for longer, causing higher competition for food. Qualitative restriction may have a role in the well-being of the birds since it controls the BW while enabling the animals to eat more often. According to D'Eath et al. (2009), whether or not diet dilution reduces hunger and enhances welfare when compared to quantitative restriction is controversial. Kubikova et al. (2001), found that the behavior of birds under qualitative feed restriction programs was similar to ad libitum ones. However, the plasma corticosterone levels of the qualitative fed birds were higher and lower in comparison with the ad libitum and quantitative treatments, respectively, suggesting that even mild feed restriction programs are stressful. Moradi et al. (2013) tested different qualitative feed restriction methods and found that providing diets with insoluble and soluble fiber sources increased feeding cleanup time by 2.4 and 3.8 times more than the control (daily restriction) group. The researchers also found that the diets with lower bulk density, containing 1% cellulose or 20.47% wheat bran promoted the highest egg production in the early laying period (79.4% and 80.2% respectively). This may be due to reduced stress since the levels of corticosterone were diminished in birds under these treatments. Although the researchers investigated the amount of eggs produced near the peak of production, one should keep in mind that persistency is also a very important trait in broiler breeders. While the peak of production occurs at the first weeks of the laying phase and refers to the highest number of eggs produced in a week; persistency is the rate at which egg production declines after peak. Therefore, higher persistency is also an important aspect of broiler breeder production. In research evaluating the energy restriction in broiler breeders, Sunder et al. (2008) observed that breeders maintained on 20 and 10% less energy than the control group during rearing and production periods, respectively, reached sexual maturity 6 days later and produced 13 more eggs with higher persistency than the control treatment.

2.1.5 Feed Restriction and Water Intake

Managing water intake is detrimental in poultry systems as increased water-to-feed intake ratio increases the moisture content of the excreta, resulting in higher incidence of footpad dermatitis and negatively affecting animal welfare (Jiménez-Moreno et al., 2016). The ability to absorb and release moisture by the litter is important as wet litter may lead to lesion formation (Bilgili et al., 2009). Studies have shown that high litter moisture content is the most important cause of foot pad dermatitis in turkeys and laying hens (Wang et al., 1998; Mayne et al., 2007). According to Wu and Hocking (2011), litter moisture should be below 30% to avoid the occurrence of foot pad lesions. In a study with turkeys, Da Costa et al. (2014) observed that in severe cases, foot pad dermatitis may cause lameness, affecting the wellbeing of birds. Studying the effect of reutilizing litter on the occurrence of food pad lesions in broilers, Martins et al. (2013) observed that birds that were more active had worse foot pad conditions and concluded that it was due the intense contact of foot pads with litter. Because broiler breeders are more active than broilers it is expected that these birds will be more affected by the quality of the litter as it relates to the occurrence of foot pad dermatitis (Kaukonen et al., 2016). When feed restricting broiler breeder flocks, hatching egg producers often observe an increase in litter humidity associated with higher water intake. In that regard Hocking et al. (1993) conducted a trial to compare the water intake of restricted and ad libitum fed broiler breeders and found that feed restricted Ross 308 pullets spent on average 8% more time drinking when compared to those fed ad libitum and concluded that over drinking is an extension of foraging and may act as a dearousal mechanism of hunger. In other research comparing the effects of feeding restriction on water intake Hocking (1993b) found that feed restriction in broiler breeders was associated with 25% increase in water intake. Therefore, managing water intake in broiler breeder flocks is detrimental to maintain litter in dry and in good condition, which is crucial for foot pad health (Kaukonen et al., 2016).

2.1.6 BW uniformity

2.1.6.1 Definition and measurement

There is always natural variation within populations even when birds are day-old. As the animals grow, this variation will increase due to the differential responses of individual birds to factors such as vaccination, disease, or competition for feed (Aviagen, 2013a). At placement, flock body weight should follow a normal distribution with a low variation (± 2 standard deviations). When this criterion is met, we say the flock is uniform for BW. Bennett and Leeson (1989), defined BW uniformity as the percentage of birds in a flock with BW within +/- 15% of the sample mean BW. In a flock that follows a normal distribution, approximately 95% of the individual birds will fall in ± 2 standard deviations either side of the average BW (Cobb-Vantress, 2008b). Flock BW uniformity can also be evaluated indirectly by weighing a sample of birds and calculating the coefficient of variation (**CV**) associated with that particular sample. The CV is expressed as a percentage of the mean and can be calculated by dividing the standard deviation by the average body weight and multiplying the result by 100 (Cobb-Vantress, 2008b). Hatching egg producers aim to raise a flock with the lowest BW CV possible as the lower the BW CV, the lower the BW variation and, hence, the higher the BW uniformity.

2.1.6.2 Importance of flock BW uniformity

BW uniformity is one of the most important aspects when managing broiler breeders. When a flock is uniform, hatching egg producers will match the nutrient requirements of a greater number of individual birds during feeding, which will enable birds to reach sexual maturity at similar ages and support high peak production (Pishnamazi et al., 2008). If a flock is non-uniform during rearing, problems may arise when birds are photostimulated as differences in frame size and BW may cause the hens to respond differently to the light causing birds to enter into lay at different ages. A high uniform flock is directly associated with peak production over 80% and high persistency (Cobb-Vantress, 2008d). On a field study of 6,000 female broiler breeders split into groups with different BW uniformity (from 55 to 80%), Abbas et al. (2015) found that the most uniform group (75 to 80%) had the highest egg production and persistency throughout the entire study with a peak of 85% at 30 wk of age.

2.1.6.3 Feed restriction programs to achieve high flock uniformity

Skip-a-day feeding is one of the feeding restriction programs to provide the best uniformity because it allows the more timid birds, the ones at the lower end of the peck order, more time to eat (Cobb-Vantress, 2008a). However, applying such feeding method sometimes presents a challenge. Because the feed days vary from week to week it becomes more difficult to manage the farm staff schedule, especially during the weekends. The reason for this is that since the birds are fed every other day within two consecutive weeks the feeding days varies. In response to such dilemma the industry has been implementing different methods that, while controlling the BW enable an easier planning in terms of whether or not to feed the birds. Zuidhof et al. (2015) tested the effect of different methods of restricting feed for broiler breeders and grading (separating birds into 4 different categories of BW and feeding each one at daily basis) on uniformity and observed that grading promoted the lowest BW CV (6.2%) and hence the highest uniformity. The main challenge when using a qualitative restriction program is to be able to match the BW with the guideline's target while maintaining uniformity (Savory et al., 1996; Savory and Lariviere, 2000). Lordelo et al. (2004) were able to achieve this by replacing soybean meal (**SBM**) with cotton seed meal (**CSM**) in the diet with the same levels of protein and energy. The researchers found that birds fed CSM had higher feed intake and lower BW CV during the rearing period when compared to SBM fed birds with no negative effect on the reproductive performance. The researchers concluded that birds could eat more CSM without increasing BW gain when compared to the control group because of the very low levels of total and available lysine (58 and 43% respectively) in CSM relative to SBM. Therefore, the higher food intake is what caused the flock BW variation to decrease. Although the effect of feed restriction programs on uniformity is known by the poultry industry, many researchers did not see any difference when comparing different programs (Bennett and Leeson, 1989; Tolkamp et al., 2005; Gibson et al., 2008).

2.2 Fasting and Feasting: Effect of Re-feeding Cycles on Broiler Breeders

2.2.1 Food Deprivation Physiology

Animals use food as a source of nutrients to sustain their basal metabolism, physical activity, growth and reproduction. However, when food is not available there is a need to mobilize nutrients from fat and protein tissues in the body. The ability that animals have to store energy during resource abundance and control its allocation during severe resource limitation is known as starvation resistance (Wang et al., 2006). According to Wang et al. (2006) there are three metabolic phases during food deprivation in animals; each one characterized based on the primary energy source available and its association with the body mass as follows:

- Phase I. It is the initial phase of fasting right after the last meal has been absorbed by the gut. This period normally lasts for hours and the main energy source used during its occurrence is the glycogen present in the liver. Fatty acids are also oxidized from the adipose tissues which allows the skeletal muscles to spare the overall use of glucose.
- Phase II. Once liver glycogen stores are depleted, gluconeogenesis start to fulfil the necessities of glucose-requiring organs such as the brain. The muscle protein is the main source of substrate (amino

acids) for gluconeogenesis. However, once this phase progresses, there is an increase in the oxidation of lipid reserves, which in turn releases glycerol and fatty acids into the blood stream. Glycerol goes to gluconeogenesis and fatty acids are oxidized generating ketone bodies that can also be used as an energy source by the brain.

- Phase III. If the starvation continues after the lipids from the adipose tissues has been used, muscle is greatly degraded for gluconeogenesis. The loss in muscle mass cannot continue for long and eventually the animal dies.

Bertile et al. (2003), studied the hypothalamic gene expression in long term fasted rats and observed that orexigenic gene expressions were greatly increased during the phase III. This explains the enhanced drive for re-feeding during this period. The authors also observed that, as rats entered phase III, the rate of body mass loss and nitrogen excretion increased as a result of protein degradation (Figure 2.1). Researchers studied the physiology of barn owls when fasting during winter and observed that the lipid:protein ratio in the body decreased as birds moved towards phase III, showing that as the state of fasting progressed the amount of lipid stored diminished and the animals started using protein as an energy source (Handrich et al., 1993; Thouzeau et al., 1999). During phase II more than 90% of the energy consumed comes from lipids and only 2.5% from protein (Thouzeau et al., 1999). Differently from rats and owls, Groscolas and Robin (2001) stated that phase I cannot be described in naturally fasting penguins once the level of triglycerides when they arrive on land indicates that these animals are already in a fasting state.

Robin et al. (1998); Groscolas and Robin (2001) observed that long-term fasted penguins spent most of their fasting period in phase II, which was characterized by a steady body weight loss due mainly of fat oxidation. Nevertheless, as birds entered phase III there was a shift toward protein degradation that was observed by a higher uric acid production. Robin et al. (1998), also observed that during phase III penguins increased activity and attempts to escape by 8- and 15-fold, respectively, along higher levels of corticosterol and vocalization and concluded that there is probably a body mass and minimum lipid storage threshold that acts as a re-feeding signal that guarantees the survival of these animals to fasting (Figure 2.2).

2.2.2 Energy Partitioning

The digestive system in animals breaks down food by mechanical and enzymatic action into substances that can be used by the body in a process referred as digestion. The complex carbohydrates and lipids compounds are broken down into simple molecules such as glucose and triacylglycerol that will further provide energy for various cellular functions. During the oxidation process within the cells, the energy present in the chemical bonds of those carbohydrates and lipids are transferred to ADP molecules which will turn into ATP, the animal "battery" that stores energy to be used by the body in different metabolic processes (McKenna et al., 2016). However, this process is not a 100% efficient, resulting in a final available energy for growth lower than the actual amount that was ingested (Figure 2.3). The metabolizable energy for maintenance (MEm) can be calculated by the formula $MEm=aBW^b$, where “a” and “b” are the intercept and the scaling exponent respectively (Hochachka et al., 2003). This equation is based on Kleiber’s law that describes that metabolic rates of organisms follow an allometric relationship with the body mass (Kleiber, 1932). Over the years researchers have been debating about values for b that best describes this relationship (Pinchasov and Galili, 1990; Noblet et al., 1999; Hochachka et al., 2003; Sakomura et al., 2003; Lopez and Leeson, 2005; Sakomura et al., 2005; Lopez and Leeson, 2008). According to Hochachka et al. (2003), the reason behind the discordance is that conventional models assume that a single rate-limiting step is responsible to enforce its scaling behaviour on overall metabolism. Darveau et al. (2002), developed a multi-site allometry model that takes into account the major ATP supply and demand steps in mammalian metabolism and determined a “b” coefficient for each of those steps. These authors stated that the difference between the maximum metabolic rate and basal metabolic rate cannot be predicted accordingly using single scaling methods for “b” such as 2/3 and 3/4 values and concluded that the overall “b” value should take into consideration the interaction among different metabolic steps that occur within the animal’s body. These findings are especially important to take into account when studying broiler breeders, since their energy needs vary according to the restriction program used. According to de Beer et al. (2007) birds under skip-a-day feeding program had a great increase in the gene expression of acetyl-coenzyme A carboxylase, fatty acid synthase and malic enzyme in the liver, resulting in birds with a 2-fold increase in liver glycogen and with 30% more hepatic fat when compared to their everyday fed counterparts. The researchers concluded that hens fed the skip-a-day program had a lower efficiency because of the constant need for deposition and mobilization of nutrients, which resulted in birds being 99g lighter even though both groups ate the same amount of feed. Although the previous research showed results of two contrasting feed restriction programs, varying the daily energy intake in a daily restriction program also promotes differences in efficiency (Savory and Maros, 1993). These studies clarify that the common practice of using the same "b" exponent to represent both broiler and broiler breeder growth is not appropriate due the fact these two types of animals are in different metabolic states, mostly because the effect of feed restriction practices commonly used for the broiler breeders.

Figure 2.4 shows the relationship between metabolic energy for maintenance (MEm) and metabolic energy intake (MEI) for broiler and broiler breeder per gram of body weight. Broiler breeders use on average 79% of the energy intake for maintenance while broilers use on average 61%. This difference reflects on the energy available for growth and shows that, when compared to broilers, broiler breeders only have a fraction of energy available for growth, which explains the daily gains of 10 to 15g normally observed in broiler breeders (Rayan et al., 2015).

On (Figure 2.5) we can further see this difference in the net energy for maintenance (NEm). While broiler breeders require on average 108 kcal of NEm per gram of body weight to sustain basal metabolic activities, broilers require 159 kcal per gram of body weight, showing that broilers needs for maintenance are greater due the vastly different metabolic state of these birds. This is because broilers are fed ad libitum, showing higher plasma levels of glucose and triglycerides which causes these birds to have higher BW, breast muscle and abdominal fat pad when compared to feed restricted birds (Zhan et al., 2007). It is worth of note that in Figure 2.4 the clear distinctions between the two bird lines appear when broiler breeders are weighing 320 g, which occurs around 14 days of age after which the daily intake of broilers increases dramatically and that of broiler breeders decreases due the start of feed restriction.

Webster (2003), studied the physiology and behaviour of hens during molt and observed that in the first 48 hours of food deprivation there was an increase in corticosterone levels and in glycogen mobilization resulting in an increase in activity and aggressiveness. After this period birds would enter the phase II of fasting where an increase in fat mobilization was observed. Considering that broiler breeders don't stay more than 48 hours without feed, we can assume that these birds are kept in the phase I of fasting, which explains the shift in the metabolism that causes these animals to deposit more glycogen and fat during the postprandial period. These differences can be noted in that more aggressive feed restriction programs result in larger livers (de Beer et al., 2007). Therefore, the liver weight is an efficient indirect method to observe the metabolic status of a bird and one should assume that given the same amount of food, the more frequently an animal eats the lighter the liver and so the more stable the metabolism.

2.3 Precision Feeding

2.3.1 Definition

It is common practice to feed animals within a herd based on the average performance of its animals; however, one should keep in mind that every individual has its unique behavior and metabolism, which explains the normal variability among them when fed as a group (van Milgen et al., 2012). Precision feeding relies on applying techniques that allow the right amount of feed with the right composition to be provided at the right time for each animal (Pomar et al., 2009; van Milgen et al., 2012). Wathes et al. (2008), defined the concept of precision livestock farming as the management of livestock using the principles of technology of process engineering. According to these authors, to be considered precision farming a system must have four components:

1. Continuous monitoring of the response or outcome
2. A mathematical model predicting the outcome from inputs
3. A desired outcome of output
4. A mechanism to control inputs

In practical terms, to be considered precision feeding, a farm system must be able to help animals to achieve a target outcome (kg of milk or BW for instance) by constantly monitoring and controlling their FI and the outcome obtained. By feeding animals the exact amount of feed they need at a given time, precision system is thought to decrease feed waste and nutrient excretion which in turn may lead to lower the feed costs (Pomar et al., 2009; Andretta et al., 2014).

2.3.2 Examples

Pomar et al. (2007) studied the effect of raising pigs on a 3 phase (**3P,** three different diets provided over the course of 84 d) or a daily multiphase (**DP**, blend of a low and high concentrate diet adjusted daily to meet individual requirements) system in growth, body composition, and N and P excretion. The mixture of the two diets with different nutrient concentrations in the DP treatment was automated and occurred after the individual pig was identified by the precision feeding system in which they were being fed. The researchers found that pigs from both groups had similar BW at the end of the study. However, the animals under the DP group had reduced N and P excretion by 12% and 1% respectively. There was no significant difference for feed intake between treatments and pigs in the DP group had 8% more lipids in the body, which shows the higher utilization of the nutrients provided. On a similar research, Niemi et al. (2010) evaluated the effect of two phase feeding (**2P**) and multiphase feeding (**MP**) of pigs on the economic returns through application of a stochastic programing model and found that shifting from 2P to MP increased the annual return on the operation by €1.35-€1.88 per pig. Andretta et al. (2014), evaluated the impact of moving from conventional to precision feeding system in growing-finishing pigs on performance, nutrient utilization and body composition. The researchers found that feeding individual pigs on multiple phases (precision feeding) reduced the N and P excretion by 22% and 27% respectively without compromising pig performance or carcass composition. Precision agriculture is also described by Maltz (2000) as a tool to optimize milk production in dairy cows. The automatic milking system has the ability to manipulate milking frequency and increase productivity by feeding each cow the sufficient amount of concentrate to fulfill its production needs. Maltz et al. (2005) used precision feeding in dairy cows during transition time and observed that the animals that were fed individually daily produced 2.7 Kg/d more milk and lost 2% less BW in comparison to the control group. Researchers are also using precision farming techniques to monitor cow behaviour and feed intake (Chizzotti et al., 2015). According to Ghebremichael et al. (2007) the utilization of precision feeding (**PF**) was able to reduce soluble P lost to the environment by 18% and to reduce the overall costs of feed in dairy farming. These authors also tested an integrated farm system model (**IFSM**) to predict the outcome of the farm as a whole and concluded that the combination of both PF and IFSM provided means to use the resources available more efficiently making them a good combination for economic and environmental improvement.

2.3.3 Precision Feeding and Animal Metabolism

The rate at which broiler breeders are restricted seems to directly affect their growth capacity once they are refed. de Beer et al. (2007) compared the effect of every-day feeding (**ED**) with skip-a-day feeding (**SKIP**) and found that livers of birds subjected to SKIP were 12% heavier than ED ones. They also found that feeding caused a dramatic increase in glycogen and lipids in SKIP birds. According to the researchers the SKIP caused the greatest changes in the hepatic lipid synthesis gene expression 12 and 24 h after feeding when compared to ED and concluded that this is indicative of the inconsistent supply of nutrients in SKIP programs. These findings support the research of O'Hea and Leveille

(1969) who found that between 90 and 95% of de novo fatty acid synthesis in chickens takes place in the liver. Because feeding restriction programs such as skip-a-day involve higher feed intake on feeding days and lower efficiency compared to a daily restriction feeding program (de Beer and Coon, 2007; de Beer et al., 2007), one should expect that the more frequent is the feed allocation, the higher will be the broiler breeder efficiency.

On a review about human feeding behaviour, Brunstrom (2011) suggested that satiation might be determined more by the volume of the consumed food rather than by its energy content. Furthermore, the researcher stated that the amount of food we put in our plate is directly related to the intake and that we plan our meal size prior to meal initiation even when we are not the ones making our plates. Holmback et al. (2003) studied the effect of feeding 6 small meals split in 4 h periods against feeding 4 big meals during the day and fasting during the night in males kept awake for 24h. The researchers concluded that, although the people that fasted during the night had lower levels of energy expenditure, blood glucose, triacylglycerol, insulin and glucagon when compared to the other group, there was no clear evidence that it would be more favourable to ingest few larger daytime meals than smaller meals throughout the day and that it seems the body is capable to buffer small differences in meal size and timing when the energy balance is maintained.

Osbourn and Wilson (1960) found that cockerels subjected to severe restriction presented greater relative growth rate after alimentation than the groups that were either mild restricted or fed ad libitum. The authors also found that birds under severe restriction deposited 25% more fat when compared to the ad libitum fed ones while birds under mild restriction were in between these two treatments.

Londero et al. (2016) evaluated the effect of feeding broiler breeders once or twice a day and concluded that hens that were fed two times in a day had a more consistent Ca supply without needing to mobilize this nutrient from the medullary bones.

2.3.4 Precision Feeding for Broiler Breeders

A precision feeding (PF) system for broiler breeders was developed at the University of Alberta and allows broiler breeders to have access of multiple meals per day, according to birds' real time body weight (Figure 2.6). A bird enters the PF system through a door. Once inside, the pullet has her Radio Frequency Identification (RFID) tag read by the system while it is being weighed; if the bird weighs more than or equal to its target BW, it is gently ejected from the station. If the broiler breeder weighs less than its target BW, it is allowed access to approximately 25 g of feed for 1 min (feed bout). At the end of the 1 min period, the broiler breeder is gently ejected from the station. Once the pullet is ejected from the station, the remaining feed is weighed and recorded. The required amount of feed is then added to remaining feed to equal 25 g for the meal of the next pullet. Due to the fact the PF treat birds at an individual level, and the decision whether or not to feed is automatically made, we can consider it part of the precision livestock farming technology described by Wathes et al. (2008). There is little information on the literature on how the frequency of feeding affects broiler breeder metabolism and growth. Furthermore, because broiler breeders are conventionally fed based on the average performance of the flock, little is known about how these birds perform individually. Hence, it is expected that applying precision feeding in broiler breeders would provide a more consistent supply of nutrients for every individual bird which would diminish the need of mobilizing nutrients from body reserves and increase BW uniformity

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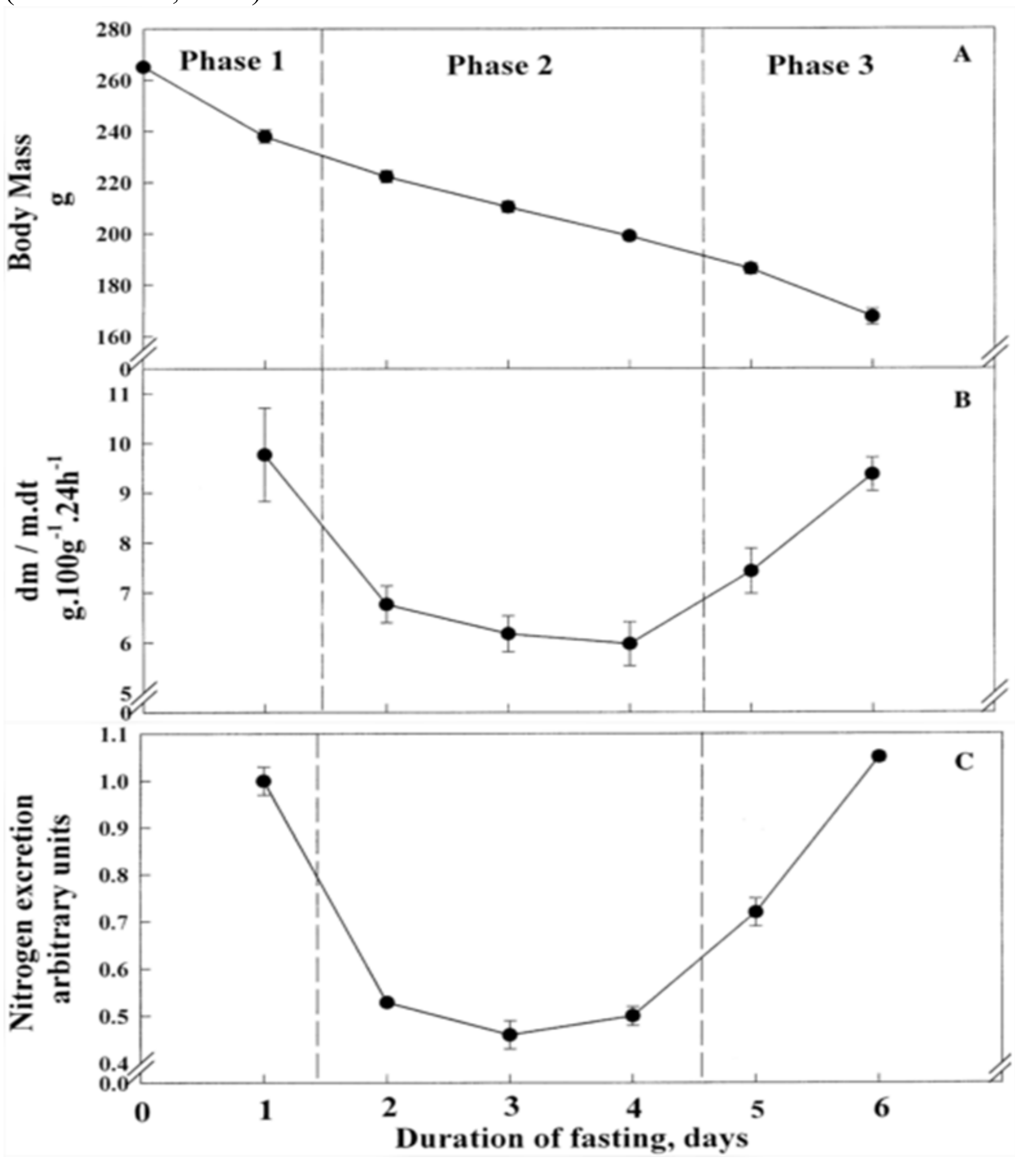
2.5 FIGURES

Figure 2.1 Body mass, specific daily body mass loss (dm/m.dt), and daily nitrogen excretion in fasted rats during three different fasting phases. Adapted from (Bertile et al., 2003)

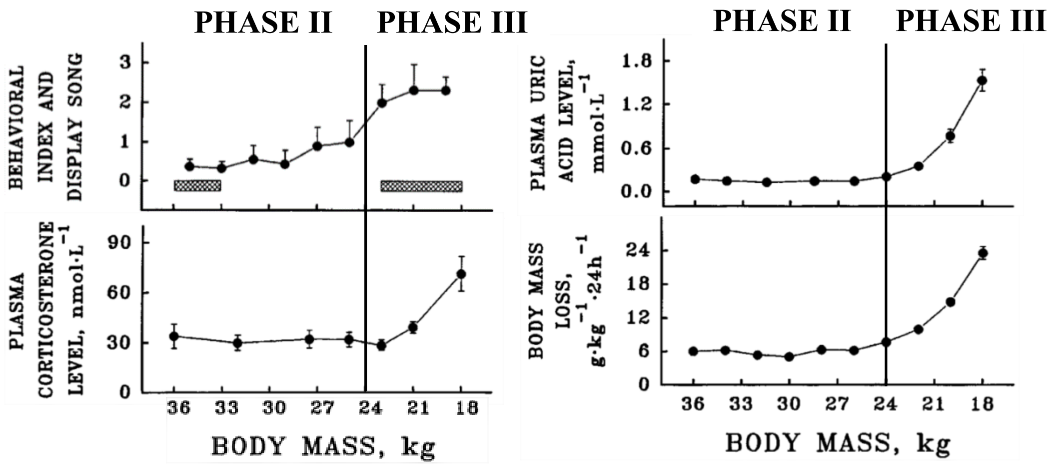


Phase 1: Glycogen is the main source of energy.

Phase 2: Glycogen storage is depleted. Lipid reserves are the main source of energy and protein degradation start to support gluconeogenesis.

Phase 3: Lipid storage is depleted. Intense protein degradation is observed to support gluconeogenesis.

Figure 2.2 Changes in specific daily body mass loss, plasma uric acid, corticosterone and behavior vs. body mass in spontaneously fasting emperor penguins on different phases of fasting. Adapted from Robin et al. (1998).

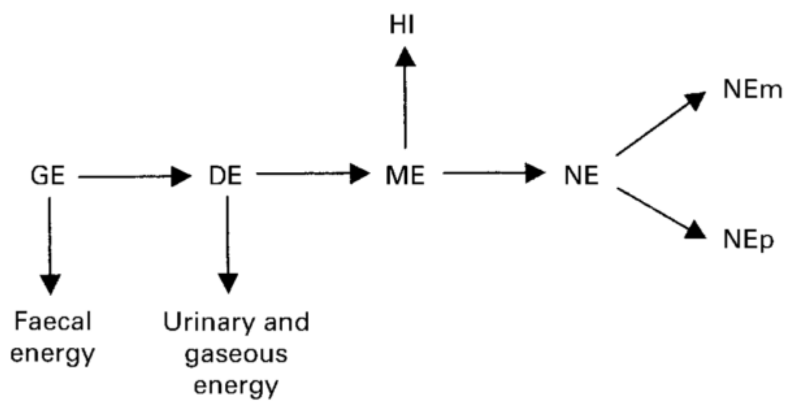


Values are means ± SE (n=6), SE are smaller than symbols when not shown. Crosshatched bars in the top left panel indicate periods when display songs were heard. The behavioral index was calculated as number of days an animal was active during successive periods of fasting corresponding to a 2 kg loss in body mass.

Phase II: Glycogen storage is depleted. Lipid reserves are the main source of energy and protein degradation start to support gluconeogenesis.

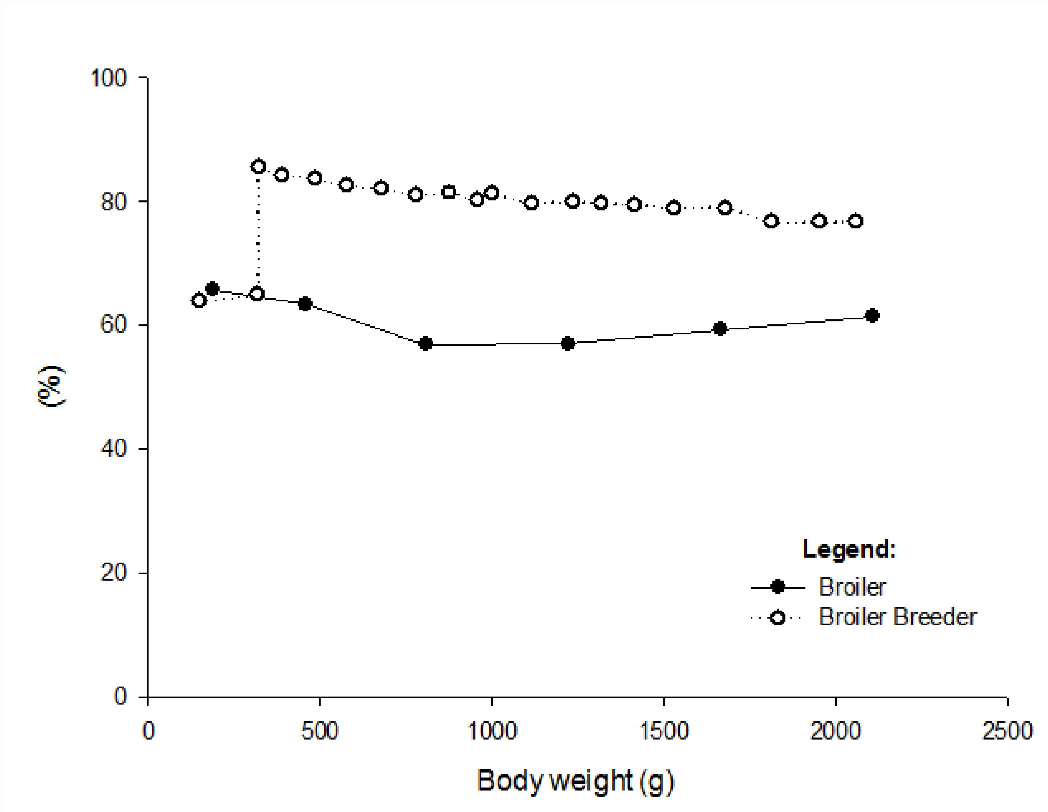
Phase III: Lipid storage is depleted. Intense protein degradation is observed to support gluconeogenesis.

Figure 2.3 Energy hierarchy.



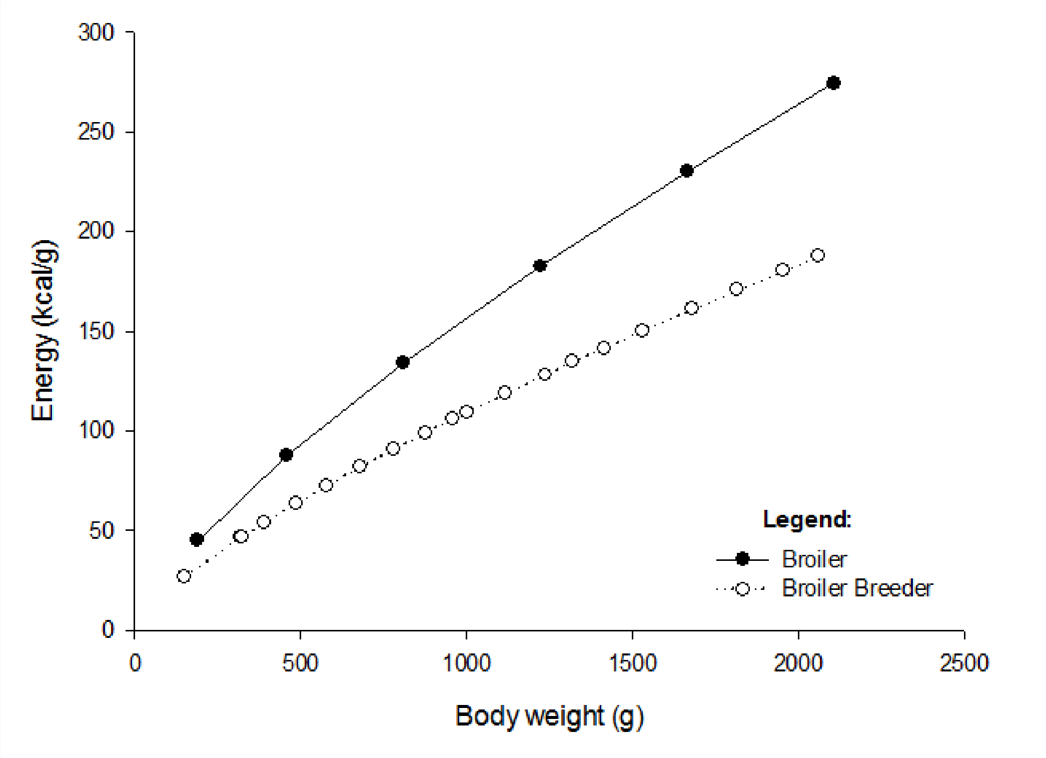
Gross energy (GE) is the energy content of the diet; digestible energy (DE) is gross energy intake (GE) less faecal losses; metabolizable energy (ME) is DE less urinary and gaseous losses; net energy (NE) is ME less heat increment of feeding (HI); NEm and NEp are NE for maintenance NE for production respectively. Adapted from Birkett and de Lange (2001).

Figure 2.4 Relationship between required metabolizable energy for mantenance and metabolizable energy intake (MEm/MEI) for broilers and broiler breeders per gram of body weight.



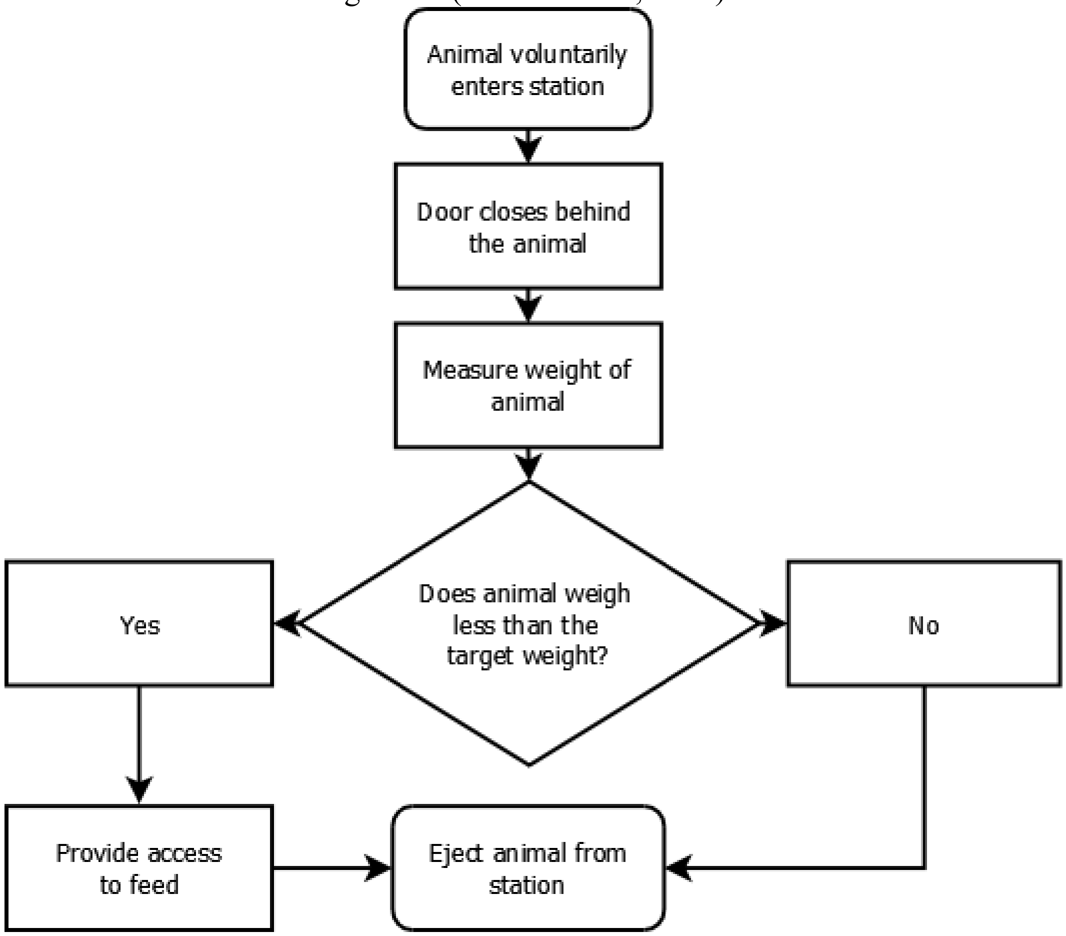
Values for MEm for broilers and broiler breeders were estimated based on experimental data and equations from Pinchasov and Galili (1990), Sakomura et al. (2003), Sakomura et al. (2005) and Lopez and Leeson (2005).

Figure 2.5 Net energy required for maintenance (NEm) for broilers and broiler breeders per gram of body weight.



Values for NEm for broilers and broiler breeders were estimated based on experimental data and equations from Pinchasov and Galili (1990), Sakomura et al. (2003) and Sakomura et al. (2005).

Figure 2.6 Schematic diagram of the precision feeding algorithm. Bird voluatrily entered the station and the decision whether to feed it or not was made comparing its real time BW with a target BW (Zuidhof et al., 2016).



3 Rearing Broiler Breeders with Precision Feeding: A Method to Increase Uniformity and Efficiency

3.1 ABSTRACT

Broiler breeders are feed restricted to keep them close to a desired target BW and optimize chick production. However, low BW uniformity may result from competition for limited feed. The current research compared the effect of precision feeding (PF) during rearing with skip-a-day feeding (SKIP) on uniformity, efficiency, water intake and body development from 10 to 23 wk of age. In a Randomized Complete Block experiment, Ross 308 broiler breeder pullets (N=630) were randomly distributed into 7 environmental chambers, each containing 2 pens. The chambers were complete blocks, with both treatments occurring in every chamber. Weekly, individual BW and pen feed intake were measured. The BW CV and cumulative feed conversion ratio (FCR) were calculated. Water consumption was measured in three randomly selected pens per treatment. At 16 and 23 wk of age, 28 birds per treatment were euthanized and breast muscle, liver and fat pad dissected to access the effect of treatment on body conformation. Body weight CV was significantly lower for PF compared to SKIP birds after 3 weeks of precision feeding, and dropped from 19% at 10 wk to 9% by 23 wk in PF pullets. There was no significant difference in gain between PF and SKIP birds, however PF pullets ate 854 g less and had a cumulative FCR 0.42 lower compared with SKIP pullets by 23 wk of age. Compared to SKIP pullets, PF pullets deposited 7.6% more breast muscle, 28.6% less fat, and had a 9.1% lower relative liver weight. There was no difference in water intake between

treatments. Overall, precision feeding did not affect water intake, but decreased ADFI, FCR, and increased BW uniformity compared to skip-a-day feeding.

Key words: Precision agriculture, feed efficiency, variation, uniformity.

3.2 INTRODUCTION

Selection for rapid growth rate and higher meat yield in broilers has been followed by increased feed intake by the broiler breeders (Renema and Robinson, 2004). The negative relationship between growth and reproduction in chickens has been studied for about 50 years (Maloney et al., 1967; Jaap and Muir, 1968; Hocking et al., 1987). Overfeeding broiler breeders during rearing, after 4 wk and before 5% production, increased production of yellow follicles that were more likely to be organized in multi-hierarchies (Hocking et al., 1987; Hocking et al., 1989; Yu et al., 1992a; Hocking, 1993a; Renema et al., 1999b) which, in turn, increased the number of unsettable eggs produced (Jaap and Muir, 1968). To avoid such problems, broiler breeder pullets are given about a third of what they would normally eat if fed ad libitum (Savory and Kostal, 1996; De Jong and Guémené, 2011). Feed restriction in broiler breeders is often associated with wet litter, which leads some hatching egg producers to also restrict water intake. Hocking (1993b) observed that feed restricted birds drank 25% more water compared to ad libitum fed birds. Feed restriction can be managed in various ways by the industry; a skip-a-day restriction program has been a common management strategy. This feeding method improves the flock uniformity, particularly when feeder space is limited (Cobb-Vantress, 2008c). However, the inefficiency of repeated cycles of nutrient deposition and mobilization is greater with a 48 h feeding cycle than a daily feeding cycle. Skip-a-day fed birds therefore require more feed than birds on a daily restriction feeding program (de Beer and Coon, 2007). These same authors reported that skip-a-day fed broiler breeders deposit more glycogen and fat during the postprandial period, which can double liver weight compared with daily feeding. Webster (2003) studied the physiology and behavior of hens during molt and reported that after the first 48 hours of food deprivation an increase in corticosterone levels, glycogen mobilization, activity, and aggression. In combination with increased activity and aggression, increased hunger is likely to increase the maintenance energy requirement. Although farmers usually feed animals based on average flock or herd performance, every individual has its own unique behavior and metabolism, which contributes to the normal variability among animals when fed as a group (van Milgen et al., 2012). Grading birds into three BW categories and daily feeding each group based on their specific nutrient requirements reduced overall 22 wk flock BW CV to 6.2% from 15.3% in the ungraded control group (Zuidhof et al., 2015). Precision feeding for broiler breeders is a novel technology developed at the University of Alberta that feeds individual birds the right amount of feed at the right time to reach a desirable target BW based on real-time BW measurement. The current study aimed to quantify the effects of precision feeding and skip-a-day feeding on broiler breeder pullet efficiency, uniformity and water intake.

3.3 MATERIAL AND METHODS

3.3.1 Experimental Design

At 9 wk of age, a total of 630 Ross 308 broiler breeder pullets were randomly distributed into 14 pens of 45 birds in a Randomized Complete Block design with two treatments: (**SKIP**, skip-a-day feeding; and **PF**, precision feeding). Each of 7 environmentally controlled chambers (block) held one replicate pen for each treatment. After one week of acclimatization, the experiment was conducted from 10 to 23 wk of age. The experimental protocol was approved by the University of Alberta Animal Care and Use Committee for Livestock and followed Canadian Council on Animal Care Guidelines (CCAC, 2009).

3.3.2 Stocks and Management

Pullets were wing banded with Radio Frequency Identification (RFID) tags prior the start of the trial. Birds had access to the PF system continually. Birds entered the PF station through a door. If more than one bird entered, they were gently ejected. The RFID tag was read and the animal was weighed by the feeding station. The real-time BW of the bird was compared to the target BW, interpolated hourly. If the bird BW was greater than or equal to its target BW, it was gently ejected. If it weighed less than the target BW, the individual bird was provided free access to approximately 25 g of feed for 1 min (a feeding bout). At the end of the feeding bout, the bird was gently ejected. Feed intake was calculated as the difference between the weight of feed at the start and end of the feeding bout. If the BW was 250 g or more below the target BW, the bird was given three consecutive feeding bouts prior to ejection. Each PF pen contained one feeding station. The feeder within the feeding station was 4.8 cm wide, and individual birds ate sequentially, without competition at the feeder itself. In the SKIP treatment, feed (twice the daily recommended feed allocation) was provided once every second day in three tube feeders, providing 10 cm of feeder space per pullet. The pullets competed with each other for their portion of the total allotment.

The environment in each chamber was automatically controlled. The average temperature was 20.8 ± 0.34°C and RH set at 60%, which was maintained using a high pressure misting system. Each pen contained a depth of approximately 5.0 cm of pine shavings and one suspended bell-style nipple drinker. Birds were fed a pelleted broiler breeder grower diet containing 2,900 kcal/kg ME and 15.5% CP (Table 3.1). The photoperiod was maintained at 10L: 14D from 10 to 23 wk of age.

3.3.3 Data Collection

Individual BW and feed intake were measured weekly at a pen level, and BW CV and FCR were calculated. The weight of water consumed was measured weekly in three randomly selected pens per treatment. At 16 and 23 wk of age, 28 birds per treatment were euthanized and dissected to determine the weight of breast muscle, liver and fat pad. These weights were reported as a percentage of live BW.

3.3.4 Statistical Analysis

Analysis of variance was performed using the MIXED procedure of SAS (Version 9.4. SAS Institute Inc., Cary, NC, 2009) with the statistical model being:

$$Y_{ijk} = \mu + T_i + A_j + (TA)_{ij} + P_k + e_{ijk}$$

Where μ = mean, T = treatment effect, A = age effect, TA = interaction treatment x age effect, P = pen effect, e = random error. i= 1, 2, was the target BW curve, j= 10, 11,..., 23, was the age in weeks and k= 1, 2,…, 14 was the pen. 'Pen' was considered as a random variable. Different variances were estimated for each week using the statement: repeated / group=age. The Least Significant Difference test was used to evaluate whether differences existed at $P < 0.05$.

3.4 RESULTS AND DISCUSSION

3.4.1 BW

In this research, calculating the precise amount of feed to allocate to SKIP fed birds based on the average BW of the flock presented a challenge which led us to estimate a lower feed requirement at weeks 15 and 17. Underfeeding pullets at those ages caused a drop on BW (Figure 3.1). The lower feed allocations at 15 and 17 wk and the attempted adjustments made on wk 16 and 18 can be observed on Figure 3.2. Notably, birds responded fast to the adjustments displaying high BW gains at wk 16 and 18 Figure 3.3. Hatching egg producers face similar challenges when allocating feed for broiler breeders with birds often going over the target BW when extra feed is provided in an attempt to correct previous low BW. The PF system helps to prevent over and under feeding as it automatically feeds every bird individually according to BW measured in real time.

3.4.2 Efficiency

Overall, the PF pullets had ADFI 10 g lower than the SKIP with no significant different on ADG (14.5 g on average; Table 3.2). Although there was no significant difference in cumulative gain between PF and SKIP birds, PF pullets ate 854 g less (data not shown, P=0.0005) and had a cumulative FCR 0.42 lower compared with SKIP pullets by 23 wk of age. The effect of the SKIP treatment on pullets' metabolism can be visualized by the trend of ADG (Figure 3.4) and cumulative FCR (Figure 3.4). The last figure shows how the SKIP treatment had higher FCR on most of the wk. Notably, the highest FCR were observed on the 15 and 17 wk, 5.27 and 5.14 respectively, where the biggest feed allocation errors occurred. PF treatment was more efficient with a cumulative FCR 0.42 lower than that of SKIP treatment by 23 wk (Figure 3.4). SKIP fed birds are in a different metabolic state when compared to daily fed birds, this is because those pullets need to storage nutrients when fed and mobilize them during the period of fasting (de Beer et al., 2007). This is an inefficient process which leads SKIP birds to be less efficient and makes them eat more food to achieve the same gains as daily fed birds (de Beer and Coon, 2007). These results corroborate with our finds in which SKIP birds were less efficient than PF ones and displayed higher cumulative feed intake for the same amount of BW weight gain.

3.4.3 Body Components

Birds in the PF treatment deposited 9 and 5% more breast muscle than SKIP pullets at 16 and 23 wk respectively. At 23 wk PF pullets had 33% less fat than SKIP birds (Table 3.3). The higher amount of lean tissue present in PF birds may be related to the more stable nutrient supply this feeding program provides. During refeeding, there is an increase in lipogenesis associated with increased acetyl-coenzyme A carboxylase, malic enzyme and fatty acid synthase gene expression (Richards et al., 2003; Sun et al., 2006; de Beer et al., 2007). The gene expression of those enzymes are increased in SKIP fed birds (Ekmay et al., 2010). Therefore, the higher fat pad content observed in SKIP birds in our study seems to be associated with increased lipogenesis. Comparing different methods of feed restriction Zuidhof et al. (2015) observed that skip-a-day fed birds had the lowest breast muscle and the highest fat pad and liver weights. In our study the liver of SKIP fed hens were 9.1% bigger than that of PF ones at 23 wk. The liver is the primary organ responsible for lipid synthesis in chickens, with 90 to 95% of the lipogenesis from the body taking place in hepatocytes (O'Hea and Leveille, 1969). Navidshad et al. (2016) observed a higher concentration of liver fatty acid-binding protein (L-FABP) in hepatocytes of broilers fed skip-a-day in comparison to the ad libitum group. The authors concluded that skip-a-day feeding induced the expression of L-FABP in liver of broilers. Researchers have found that liver size increased by 2-fold 12 h after feeding in skip-a-day fed birds and concluded that this growth was associated with increased glycogen and lipid synthesis in the liver (de Beer et al., 2007). Hence, the effects that meal size and meal frequency have on pullet metabolism might be indirectly evaluated by analysing the liver weight. Our results show that PF fed pullets deposited more protein and less fat, perhaps due to the more consistent supply of nutrients this feeding system provided.

3.4.4 BW Uniformity

Bennett and Leeson (1989) defined uniformity as the percentage of birds in a sample flock with BW within +/- 15% of the sample mean BW. Flock uniformity can also be evaluated by weighing a sample of birds and calculating the coefficient of variation (**CV**) associated with that particular sample (Cobb-Vantress, 2008b). Although PF treatment started the trial with a higher BW CV (19.3%) when compared to SKIP treatment (14.8%), they experienced a drop of 10% on the BW CV throughout the trial reaching as low as 9.3% on 23 wk. On the other hand, SKIP treatment kept the BW CV between 13.3% to 16.6%, reaching the lowest level of 13.3 at 23 wk. The natural competition for food from more dominant birds upon the less dominant ones generates unequal patterns of feed intake among birds within a flock. This results in some birds not consuming enough feed in a day to support their growth and hence differences in frame size within a flock start to appear. If a flock is non uniform during rearing, problems may arise when birds are photostimulated as the differences in frame size and BW may cause the hens to respond differently to the light causing birds to start laying at different ages. On a field study of 6,000 female broiler breeders split into groups with different BW uniformity (from 55 to 80%), Abbas et al. (2015) found that the most uniform group (75 to 80%) had the highest egg production and persistency throughout the entire study with a peak of 85% at 30 wk of age. Separating the flock into different BW categories and allocating feed differently for each category helps to increase BW uniformity as found by Zuidhof et al. (2015). However, this practice may be unfeasible in some countries due to the high labor cost associated with the technique. Different quantitative restriction programs are also used in an attempt to balance BW control with BW uniformity and skip-a-day is amongst the most common (Cobb-Vantress, 2008c). According (de Beer and Coon, 2007), skip-a-day and daily restricted pullets had similar BW CV (10.7%) at 22 wk of age. Other researchers found that using qualitative restriction methods such as replacing soybean meal with cottonseed meal, maintaining the protein and energy levels the same in the diets, resulted in a drop of 1% in BW CV due the higher feed intake observed by the cottonseed fed group (Lordelo et al., 2004). However, other researchers did not see significant effect of different restriction programs on the flock uniformity (Bennett and Leeson, 1989; Tolkamp et al., 2005; Gibson et al., 2008), which might be associated with the amount of feeder space provided in those trials. The individual access to feed provided by the PF treatment eliminated competition for food. However, the competition to enter the station was intense, with birds displaying more aggressive behavior (Gilmet, 2016). These results suggest that reducing competition for food is detrimental to reach higher BW uniformity, which explains the higher uniformity of precision fed birds in our study.

3.4.5 Water Consumption

Managing water intake is detrimental in poultry systems as increased water-to-feed intake ratio increases the moisture content of the excreta, resulting in higher incidence of footpad dermatitis and negatively affecting animal welfare (Jiménez-Moreno et al., 2016). The relationship between litter moisture content and incidence of foot pad lesions have been extensively studied in poultry production (Wang et al., 1998; Mayne et al., 2007; Bilgili et al., 2009). When severe, foot pad dermatitis may lead to lameness in birds negatively affecting their welfare (Da Costa et al., 2014). Furthermore, Martins et al. (2013) observed that the incidence of foot pad lesions was directed related to the activity of birds and concluded that the most active broilers were the most affected due the intense contact of foot pads with litter. The higher activity and longer life span of broiler breeders compared to broilers may facilitate the occurrence of foot pad dermatitis in those birds (Kaukonen et al., 2016). In that regard, hatching egg producers often restrict water intake in restricted fed birds to diminish the occurrence of wet litter. Comparing the effect of ad libitum and restrict fed broiler breeders, Hocking et al. (1993) found that restricted birds spent 8% more time drinking water when compared to ad libitum fed birds and concluded that over drinking is an extension of foraging and may act as a feeding dearousal mechanism. On another research, Hocking (1993b) observed that restricted fed birds drank 25% more water compared to ad libitum fed birds. This was not observed in our study (Table 3.2), perhaps because both treatments were similarly feed restricted, which possibly diminished the difference that would be noted if there was an ad libitum treatment. Overall, birds drank on average 359 mL of water daily and had on average an ADFI of 71.5 which represents a 5:1 water:feed intake ratio, and is in agreement with Hocking (1993b) who found that feed restricted Ross pullets drank 294.5 mL and ate 59 g of feed per day with a similar water:feed (4.9:1) ratio.

Overall, the precision feeding system decreased feed consumption, increased efficiency and BW uniformity with no effect on water intake.

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3.7 TABLES

Table 3.1 Grower broiler breeder diet fed from 10 to 23 wk of age.

Ingredient	Amount (%)
Ground Corn	25.00
Wheat	47.00
Soybean Meal	5.00
Oats	9.76
Canola Meal	9.00
Ground Limestone	1.80
Dicalcium Phosphate	1.53
Choline chloride premix	0.50
Vitamin premix[1]	0.25
Mineral premix[2]	0.25
NaCl	0.45
Dl-Methionine	0.09
L-Lysine	0.04
Enzyme[3]	0.05
Total	100.00
Calculated content	
ME (kcal/kg)	2,900
Crude protein (%)	15.50
Calcium (%)	0.90
Available phosphorus (%)	0.42
Available Lysine (%)	0.68
Available Methionine (%)	0.37

[1]Premix provided per kilogram of diet: vitamin A (retinyl/ acetate), 10,000 IU; cholecalciferol, 4,000 IU; Vitamin E (DL- α-tocopheryl acetate), 50.0 IU; vitamin K, 4.00 mg; pantothenic acid, 15.0 mg; riboflavin, 10.0 mg; folacin, 2.00 mg; niacin, 65 mg; thiamine, 4.00 mg; pyridoxine, 5.00 mg; vitamin B12, 0.02 mg; biotin, 0.20 mg.
[2]Premix provided per kilogram of diet: iodine, 1.65 mg; Mn, 120 mg; Cu, 20.0 mg; Zn, 100 mg; Se, 0.30 mg; Fe, 80.0 mg.
[3] Avizyme 1302 feed enzyme for use in poultry diets provided per kilogram of complete diet: 5,000 U/g endo-, 4-beta-xylanase EC 3.2.1.8; 1,600 U/g subtilisin (protease) EC 3.4.21.62 (Danisco Animal Nutrition, Marlborough, Wiltshire, UK).

Table 3.2 The effects of precision feeding (PF) and skip-a-day (SKIP) treatments on body weight (BW), body weight coefficient of varitation (CV), average daily feed intake (ADFI), average daily gain (ADG), cumulative feed conversion ratio (FCR) and water intake for broiler breeders from 10 to 23 wk of age.

Age (A)	Treatment (T)	BW	CV	ADFI[1]	ADG[1]	FCR[1]	Water[1]
		—— g ——	—— % ——	—————— g	——————	—— g:g ——	—— mL/d ——
	PF	1,758^{a} ± 6.4	11.0^{b} ± 0.6	65^{b} ± 1.2	14 ± 0.6	4.40^{b} ± 0.09	356 ± 5.5
	SKIP	1,632^{b} ± 6.3	15.0^{a} ± 0.6	75^{a} ± 1.2	15 ± 0.6	4.58^{a} ± 0.09	362 ± 5.5
10 wk		1,096^{l} ± 17.0	16.6^{a} ± 1.0				
11		1,223^{k} ± 11.6	15.6^{ab} ± 1.1	51^{ij} ± 1.8	11^{cd} ± 1.6	3.67^{e} ± 0.16	273^{f} ± 10.5
12		1,282^{j} ± 8.2	13.1^{bc} ± 1.0	55^{hi} ± 0.8	13^{c} ± 0.9	3.72^{e} ± 0.13	289^{ef} ± 11.5
13		1,335^{i} ± 6.8	13.8^{abc} ± 1.5	51^{j} ± 1.6	7^{ef} ± 1.0	4.33^{d} ± 0.17	281^{ef} ± 15.0
14		1,412^{h} ± 8.9	12.8^{bc} ± 1.4	51^{j} ± 1.8	13^{c} ± 1.8	4.28^{d} ± 0.14	307^{e} ± 8.2
15		1,427^{h} ± 7.4	12.6^{bc} ± 1.5	57^{gh} ± 1.3	3^{g} ± 1.0	4.99^{a} ± 0.14	295^{ef} ± 10.0
16		1,582^{g} ± 10.4	13.3^{abc} ± 1.4	67^{f} ± 1.2	22^{b} ± 1.4	4.51^{cd} ± 0.13	316de ± 9.0
17		1,635^{f} ± 12.2	13.4^{abc} ± 1.6	71^{e} ± 1.2	8de ± 1.3	4.91^{ab} ± 0.14	373^{c} ± 13.3
18		1,835^{e} ± 13.0	13.1^{abc} ± 1.9	81^{cd} ± 2.4	28^{a} ± 1.9	4.46^{cd} ± 0.13	379^{c} ± 17.2
19		1,855^{e} ± 10.9	13.8^{abc} ± 1.9	70^{ef} ± 3.5	3^{fg} ± 1.7	4.86^{ab} ± 0.12	406^{bc} ± 11.0
20		2,041^{d} ± 13.2	12.5^{abcd} ± 1.9	90^{bc} ± 4.1	22^{b} ± 1.5	4.71^{abc} ± 0.11	444^{ab} ± 23.4
21		2,176^{c} ± 11.6	11.7^{bcd} ± 1.7	102^{a} ± 3.4	23^{b} ± 1.8	4.69^{bc} ± 0.11	475^{a} ±13.3
22		2,284^{b} ± 12.7	11.3^{cd} ± 1.6	72^{defg} ± 7.3	15^{c} ± 1.7	4.69^{bc} ± 0.11	462^{a} ± 9.0
23		2,542^{a} ± 12.5	8.5^{d} ± 0.5	91^{b} ± 3.7	26^{ab} ± 2.5	4.55^{cd} ± 0.12	370^{cd} ± 21.5
Source of Variation		——————	——————	—— Probability	——————	——————	——————
T		<0.0001	<0.0001	<0.0001	0.0031	0.1006	0.4575
A		<0.0001	<0.0001	<0.0001	<0.0001	0.0014	<0.0001
T x A[2]		<0.0001	0.0007	<0.0001	0.0003	0.0042	0.9498

[1] Means reported for the previous week (i.e. ADFI for week 10 to 11 reported at 11 wk, and so on).
[2] Means for interactions are presented in figures.
[a-l] Means ± SEM within age with no common superscript differ significantly ($P < 0.05$).

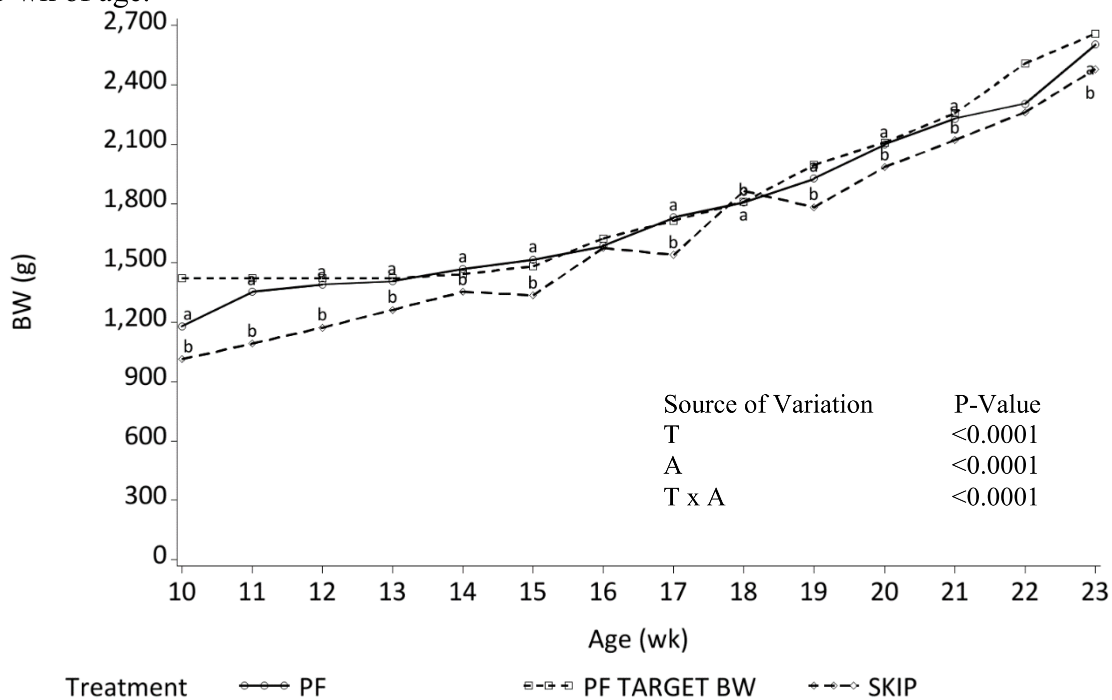
Table 3.3 Effect of precision feeding (PF) and skip-a-day (SKIP) treatments on breast (Breast), fat pad (Fat) and liver (Liver) weight relative to BW at 16 and 23 wk of age.

Age (A)	Treatment (T)	Breast	Fat pad	Liver
		%		
	PF	$18.4^{a} \pm 0.47$	$0.7^{b} \pm 0.06$	$2.2^{b} \pm 0.12$
	SKIP	$17.1^{b} \pm 0.45$	$0.9^{a} \pm 0.06$	$2.4^{a} \pm 0.11$
16 wk		$15.9^{b} \pm 0.47$	$0.2^{b} \pm 0.03$	$2.3^{a} \pm 0.11$
23		$19.6^{a} \pm 0.45$	$1.4^{a} \pm 0.08$	$2.2^{a} \pm 0.11$
16	PF	$16.6^{c} \pm 0.56$	$0.2^{c} \pm 0.04$	$2.3^{a} \pm 0.14$
	SKIP	$15.2^{d} \pm 0.53$	$0.2^{c} \pm 0.04$	$2.3^{a} \pm 0.11$
23	PF	$20.1^{a} \pm 0.50$	$1.2^{b} \pm 0.12$	$2.0^{b} \pm 0.12$
	SKIP	$19.0^{b} \pm 0.47$	$1.6^{a} \pm 0.11$	$2.4^{a} \pm 0.12$
Source of Variation		Probability		
T		0.0004	0.0110	0.0079
A		<0.0001	<0.0001	0.2758
T x A		0.7015	0.0453	0.0128

[a-b] Means ± SEM within column by effect with no common superscript differ significantly ($P < 0.05$).

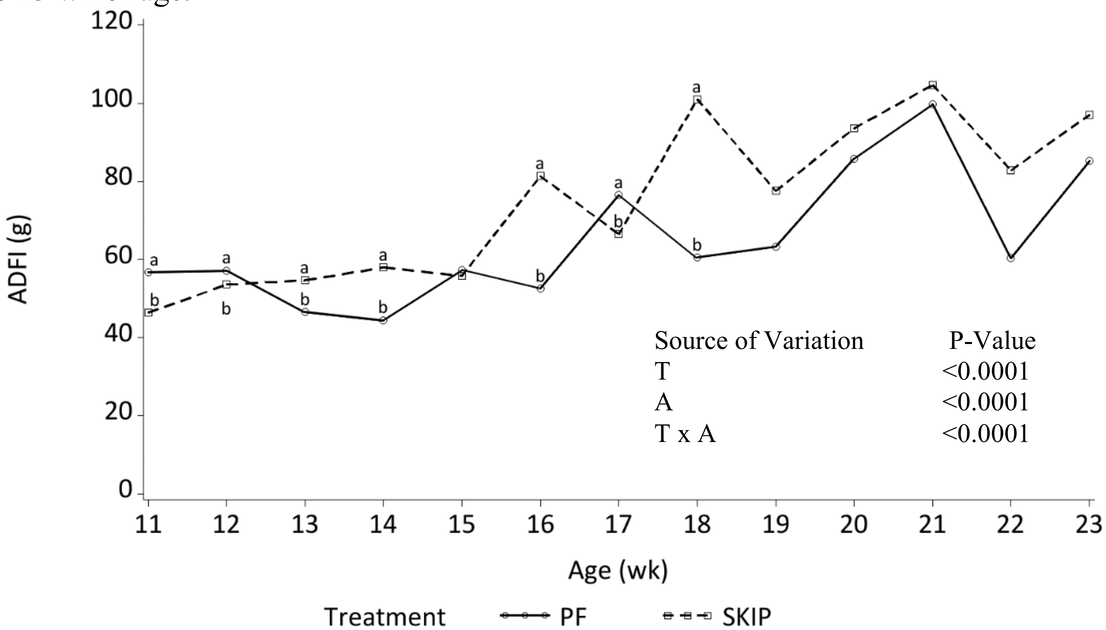
3.8 FIGURES

Figure 3.1 Body weight (BW) of broiler breeder pullets managed using precision feeding (PF) or skip-a-day (SKIP) feeding from 10 to 23 wk of age.



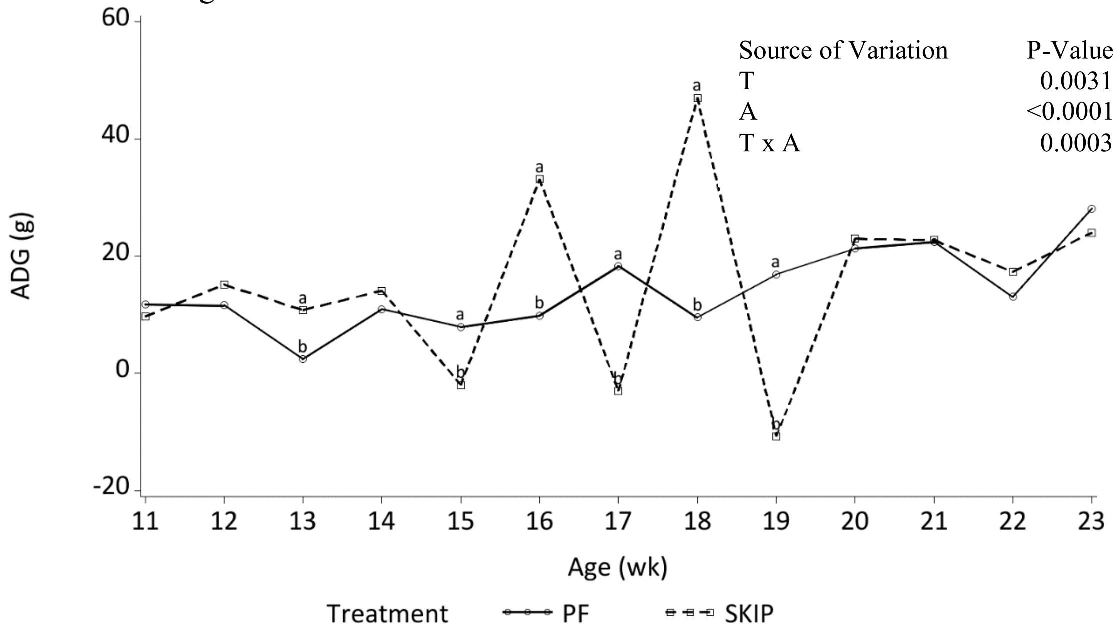
T = treatment effect; A = Age effect; T x A = treatment vs. age interaction effect.
[a-b] Means within age with no common superscript differ significantly (P<0.05).

Figure 3.2 Average daily feed intake (ADFI) of broiler breeder pullets managed using precision feeding (PF) or skip-a-day (SKIP) feeding from 10 to 23 wk of age.



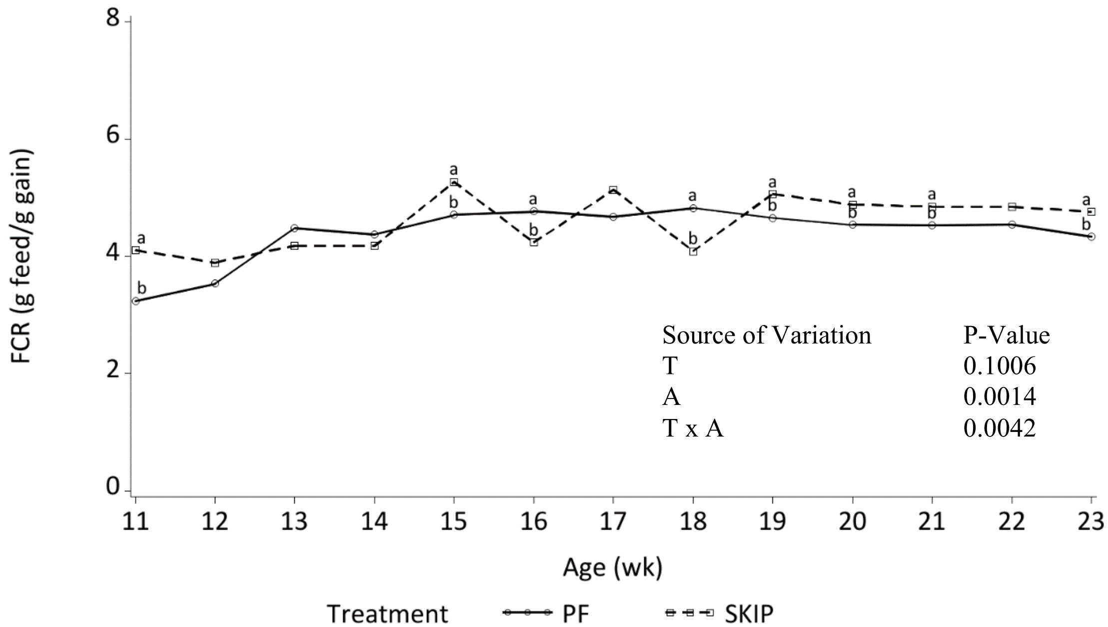
Means are reported for the previous week (i.e. data from week 10 to 11 reported at 11 wk, and so on).
T = treatment effect; A = Age effect; T x A = treatment vs. age interaction effect.
[a-b] Means within age with no common superscript differ significantly (P<0.05).

Figure 3.3 Average daily gain (ADG) of broiler breeder pullets managed using precision feeding (PF) or skip-a-day (SKIP) feeding from 10 to 23 wk of age.



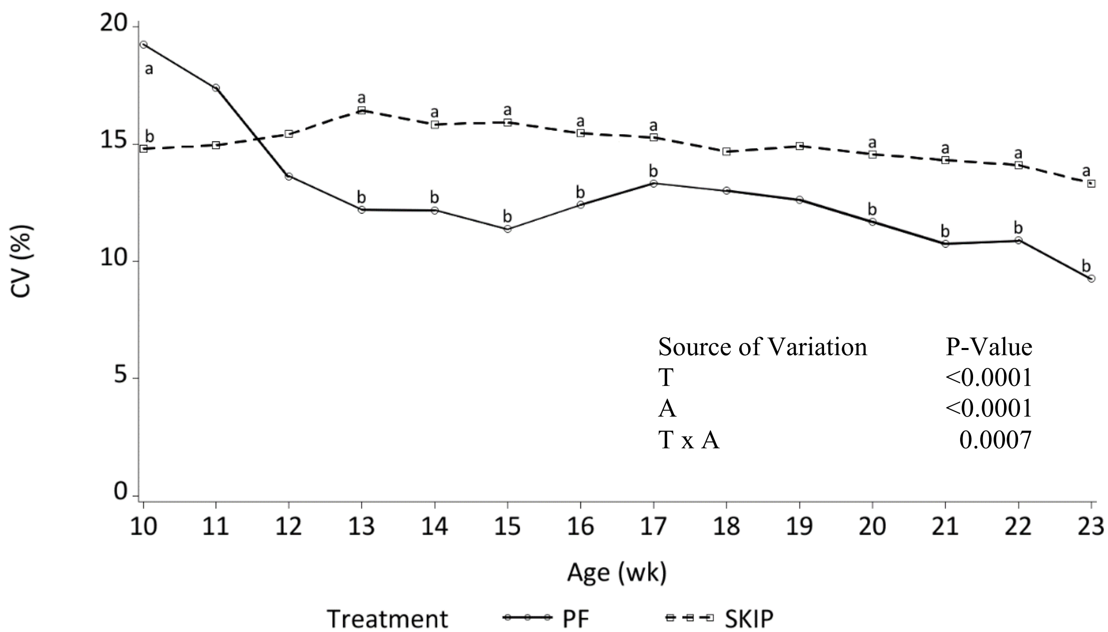
T = treatment effect; A = Age effect; T x A = treatment vs. age interaction effect.
Means are reported for the previous week (i.e. data from week 10 to 11 reported at 11 wk, and so on).
[a-b] Means within age with no common superscript differ significantly (P<0.05).

Figure 3.4 Cumulative feed conversion ratio (FCR) of broiler breeder pullets managed using precision feeding (PF) or skip-a-day (SKIP) feeding from 10 to 23 wk of age.



T = treatment effect; A = Age effect; T x A = treatment vs. age interaction effect.
Means are cumulative (i.e. data from week 10 to 11 reported at 11 wk, from 10 to 12 reported at 12 wk and so on).
[a-b] Means within age with no common superscript differ significantly (P<0.05).

Figure 3.5 Body weight coefficient of variation (CV) of broiler breeder pullets managed using precision feeding (PF) or skip-a-day (SKIP) feeding from 10 to 23 wk of age.



T = treatment effect; A = Age effect; T x A = treatment vs. age interaction effect.
Means are reported for the previous week (i.e. data from week 10 to 11 reported at 11 wk, and so on).
[a-b] Means within age with no common superscript significantly differ from each other (P<0.05).

4 Controlling Body weight and Uniformity of Broiler Breeder Pullets Using Precision Feeding

4.1 ABSTRACT

Feed restriction in the rearing phase is a necessary aspect of broiler breeder management to prevent reproductive problems during laying. A precision feeding system was designed to automatically feed broiler breeders individually according to the individual real time BW, allowing direct control over flock uniformity. The current study was designed to compare the uniformity and efficiency of broiler breeder pullets reared under 5 different target BW treatments. Three hundred sixty 13 wk old Ross 308 broiler breeder pullets were randomly distributed in 8 pens of 45 birds in a completely randomized design, with 5 treatments and 72 replicates (birds). Within each pen, 9 birds were assigned to one of the 5 treatments: Low (Ross 708 target BW), Low flush (Low, with high peri-pubertal growth rate), Standard (Ross 308 target), Standard flush (Standard, with high peri-pubertal growth rate), and Step (BW targets increased stepwise every 3 wk). Birds in the Low Flush treatment had the lowest BW CV (0.8%) while those fed according to the Standard Flush target had the highest BW CV (3.4%, P=0.0001). Peaks in ADFI and ADG were observed for step treatment on wk 17, 20 and 23 as response to the increased target BW. The same occurred for Low Flush and Standard Flush treatments at wk 20. Overall, birds under the Standard Flush target BW treatment had the highest ADFI (97 g) and the Low the lowest (55 g, P<0.0001). Due low ADFI (59 g), birds from Low Flush treatment were probably more competitive displaying less meals per day (N=5) which may have

caused the differences observed in BW CV. The overall ADG of birds raised under the Standard Flush treatment was the highest (22.2 g) and the Low the lowest (16.4 g, $P<0.0001$). Meal size did not differ on a weekly basis between treatments averaging 11 g from 13 to 23 wk. The number of meals per day followed the same trend as the ADFI peaking on wk 17, 20 and 23 for step treatment and on wk 21 for Low Flush and Standard Flush treatment, averaging 7.6 ± 0.21 from 13 to 23 wk. Birds from the Low Flush and Low treatments were the most efficient having the lowest cumulative FCR at 23 wk, 3.4 on average, and the Standard and Step the least efficient having the highest FCR, 5.5 on average. This was probably because the lower BW of Low Flush birds which reflected in a lower MEm. Overall Low and Low Flush groups were the most efficient and uniform.

Key words: Broiler breeder, precision feeding, target BW, uniformity.

4.2 INTRODUCTION

It is common practice to feed broiler breeders within a flock based on their average performance; however, one should keep in mind that every individual has its unique behaviour and metabolism, which explains the normal variability among them when fed as a group (van Milgen et al., 2012). Precision feeding allows the right amount of feed with the right nutrient composition to be provided at the right time for each animal (Pomar et al., 2009; van Milgen et al., 2012). According to Wathes et al. (2008), precision livestock farming (PLF) involves the management of livestock production using the principles of engineering. Regulating FI by monitoring BW in real time is an essential part of this process once it allows the producer to achieve specific goals such as generate compensatory growth or lower nutrient wastage (Tauson, 1991; Andretta et al., 2014). By feeding animals to meet their current requirements, precision systems are thought to decrease feed wastage and to prevent the oversupply of nutrients, leading to lower feed costs. Comparing daily precision feeding with a 3 phase feeding program (3 different diets fed at different ages) in growing pigs, Andretta et al. (2016) observed that feeding pigs to meet 100% of their daily individually lysine requirement reduced digestible lysine intake by 26%, N excretion by 30% and feeding costs by US$7.60/pig. Precision feeding techniques have also being successfully used in dairy calf (Litherland and Hoskins, 2016) and dairy cows (Borchers et al., 2016). The utilization of precision feeding for the rearing of broiler breeders is expected to increase flock uniformity, which is one of the greatest challenges in breeder management. Current management practices aimed at increasing uniformity, such as a skip-a-day feeding program, provide increased feed access for timid birds due to the larger amount of feed allocated per feeding day, however, the constant need to store and mobilize nutrients negatively affects the feed efficiency (de Beer and Coon, 2007; de Beer et al., 2007). Flushing is a technique largely applied in production animals to stimulate ovary development and follicle recruitment to support reproduction (Tauson et al., 2000; Damgaard et al., 2004). Comparing the effect of conventional feeding and flushing in minks, Fink and Tauson (1998) observed a peak in plasma insulin concentration and higher ovulation rates in the animals that were flushed. Broiler breeder hens have a threshold for BW, carcass fat and protein that needs to be met for onset of sexual maturity (de Beer and Coon, 2007; Eitan et al., 2014). Therefore, flushing pullets near photostimulation may help birds to achieve their BW threshold and stimulate ovary development. The utilization of flushing techniques may be necessary for precision fed pullets to stimulate development of the ovary because these birds follow the target BW very closely as opposed to group fed birds that often have individuals that are over the target BW with higher energy intake to support reproduction.

Overall, the current study aimed to assess the effect of using different target BW on the growth rate, efficiency, uniformity, feed intake, number of meals and meal size.

4.3 MATERIAL AND METHODS

4.3.1 Experimental Design

A total of 360 13 wk old Ross 308 broiler breeder pullets were randomly distributed in 8 pens of 45 birds in a completely randomized design with 5 treatments and 72 replicates (birds per treatment). Within each pen, 9 birds were assigned to each of the 5 treatments: **Low** (Ross 708 target BW), **Low Flush** (Low, with high peri-pubertal growth rate), **Standard** (Ross 308 target), **Standard Flush** (Standard, with high peri-pubertal growth rate), and **Step** (Standard BW target increased in a stepwise fashion every 3 wk). The animal use protocol for the study was approved by the University of Alberta Animal Care and Use Committee for Livestock and followed principles established by the Canadian Council on Animal Care Guidelines (CCAC, 2009).

4.3.2 Stocks and Management

Due to development issues with the station prototype, the machines were not fully functional until birds were 10 wk old. This increased the heterogeneity among birds, with some pullets becoming overweight while others were far below the target BW curve. Therefore, to ensure all birds ate at least one meal per day while not becoming overweight and to start the trial with treatments with similar BW, birds were kept at a target BW of 1,400 g 2 wk prior the start of the trial on wk 13. BW targets were updated hourly with the Step treatment changing every 3 wk (Figure 4.1).

After the distribution of pullets at 13 wk of age, each pen had a stocking density of 8.712 kg/m^2. Pens had the environment automatically controlled and temperature and humidity were set to 21°C and 60%, respectively. Each pen contained a depth of approximately 5.0 cm of pine shavings and two suspended bell drinkers equipped with nipples (3.2 pullets per nipple). Each PF pen contained one feeding station equipped with a 4.8 x 4.8 cm feeder. Birds were fed a pelleted grower diet shown in Table 4.1 and provided a 10L:14D photoperiod. Pullets were wing banded with Radio Frequency Identification (RFID) tags prior the start of the trial. Animals had free access to the PF system and the decision whether or not to feed them was made as follows: The pullet entered by a door and was weighed. The BW measured at this step was immediately compared against the target BW previously assigned to the bird (Figure 4.1). If the broiler breeder BW exceeded or was equal to the target BW, the bird was gently ejected from the station. On the other hand, if its BW was below the target BW, the bird was allowed access to approximately 25 g of feed for 1 min (**feed bout**) before being gently ejected from the station. The remaining feed was weighed, recorded and feed intake calculated. If a bird's BW was at least 250 g below the target BW it was given 3 consecutive feed bouts prior to ejection.

4.3.3 Data collection

BW was recorded individually upon every visit to the PS system. The BW used in the statistical analysis, was obtained by taking the median BW of the first day of each week. The CV for BW at a pen level was calculated weekly by dividing the standard deviation of BW by the average BW of birds within each treatment and multiplying the result by 100. The ADFI was obtained by taking the sum of FI from each feeding bout from each bird from the start until the last day of each week and dividing this value by seven. The ADG was obtained by subtracting the BW of each bird at the beginning of a week from its BW at the beginning of the previous week and dividing this value by the number of days. FCR was obtained by dividing the cumulative FI by the cumulative gain on a weekly basis from 13 to 23 wk of age. In addition to the data gathered from the PF system, individual BW was manually determined weekly to check the accuracy of the PF system measurements. To identify birds that were having difficulties learning how to use the PF system, pullets that weighed less than 70% of the Ross (308) target BW were guided to the station entrance every second day to encourage birds to enter the PF system on their own. If the pullet being assisted entered the station by itself more than four times over a period of 48 h or when its

BW increased to 70% or more of the Ross (308) target BW the bird was no longer assisted.

Outliers. Due to development issues with the PF system prototype, the machine would occasionally receive RFID readings from birds not inside the station, making a FI and BW to be erroneously assigned to a different bird that was waiting on the entry door. By observing the daily FI and BW of individual birds using graphs, we were able to detect these ID errors. We developed a methodology to deal with these errors by comparing the pullets FI with the expected FI. The model described by Pishnamazi et al. (2015) was used to calculate the expected metabolizable energy intake (**E[MEI]**) as follows:

$$\mathrm{E[MEI]} = (135.87 - 3.65 \text{ x } 21 + 0.075 \text{ x } 21^2) \text{ x } \mathrm{E[BW]}^{0.84} \text{ x } 1.1 + 0.9 \text{ x } \mathrm{ADG}$$

Where E[BW] was the expected BW in Kg and was calculated by the sum of median BW with gain.

The expected FI (**E[FI]**) was then calculated by dividing the **E[MEI]** by the calculated energy content of the diet (2.900 kcal/kg). Individual data points were eliminated from the data set when E[FI] < 0 or actual FI was less than half or more than double of E[FI]. This step eliminated the data that were erroneously assigned to the wrong bird. When the BW median was below the 75% of the target Ross 308 curve between 20 and 23 wk of age, the bird was deleted from the analysis. This step eliminated 7 birds that did not learn to use the PF system.

4.3.4 Statistical Analysis

An analysis of variance was performed using the MIXED procedure of SAS (Version 9.4. SAS Institute Inc., Cary, NC, 2009) with the statistical model being:

$$Y_{ijk} = \mu + T_i + A_j + (TA)_{ij} + P_k + e_{ijk}$$

Where μ = mean, T = treatment, A = age, TA = interaction treatment x age, P = pen, e=random error. i= 1, 2, 3, 4, 5 were the different target BW treatments, j= 13, 14,..., 23, the age in weeks and k= 1, 2,…, 8 the pens. Due the quantity of data and because it was not possible for SAS to converge a model wherein 'bird' was considered as a random effect, 'pen' was used as a random variable instead. Different variances were estimated for each week using the statement: repeated / group=age*treatment. The Least Significant Difference (LSD) test was used to evaluate whether differences existed at $P < 0.05$.

4.4 RESULTS AND DISCUSSION

4.4.1 BW

BW followed closely the treatment-specific targets input in the PF system (Figure 4.1 and Figure 4.2). Hence, the PF system successfully monitored and controlled the BW at the individual bird level according to specific BW targets. Similarly, Andretta et al. (2014) and Pomar et al. (2009) applied precision feeding technology in growing-finishing pigs and were able to control the pigs' growth by measuring their BW upon every use of the system. At 23, wk birds on the Standard Flush treatment achieved the highest BW (2,878 g) and were 488 g heavier than the Low (2,390 g; $P < 0.0001$) treatment, which had the lightest birds. Pullets on the Low Flush were the second lightest birds (2,529 g); At 23 wk, the Standard and Step treatments had intermediate BW: 2,625 g and 2,663 g, respectively (Figure 4.2). Overall, pullets on the Standard Flush and Low treatments were the heaviest and lightest, respectively, throughout the trial (Table 4.2).

4.4.2 Uniformity

The Step treatment in our trial somewhat resembles what happens in skip-a-day fed pullets and was designed to check if the growth of pullets is affected when the feed allocation is suddenly increased, and to mimic what often occurs in commercial settings when birds are overfed following a feed restriction period. On the other hand, the Standard and Low treatments were designed to evaluate the effect of two commonly used targets (Ross 308 and Ross 708) on pullets growth while the other two flushing treatments aimed to check the effect of increasing the metabolizable energy intake by increasing the ADFI near photostimulation on birds growth. Birds fed under the Low Flush target BW presented the lowest BW CV (0.8%) while those under the Standard Flush had the highest BW CV (3.4%; $P < 0.0001$). It is worth noting that since birds were fed at an individual level, there was no competition among them while feeding, but rather near the PF station entry door. Due lower ADFI, birds from Low Flush treatment were probably more competitive displaying less meals per day (N=5) which probably caused the differences observed in BW CV (Table 4.2). Overall, pullets fed according to Low, Step and Standard had intermediate values for BW CV, ranging from (2.0% to 2.3%; $P<0.0001$; Table 4.2). The current findings are remarkable, since we were able to achieve high levels of uniformity of groups of different birds housed together, reaching a small BW CV of 1.9% ± 0.75% at 23 wk (data not shown, P = 0.8073). Previous research with conventional methods of quantitative restriction reported BW CV in the range of 10.3% ± 3.02% for broiler breeders reared from 4 to 40 wk of age (de Beer and Coon, 2007). In an industrial setting these values tend to be higher, mostly due the higher number of birds raised together which leads to higher competition for feed and more difficult management; it is common for hatching egg producers to consider BW CV less than 10% as a sign of good management (Cobb-Vantress, 2008c).

4.4.3 Feed intake and growth

ADFI (Figure 4.3) was influenced by the target BW treatment and was significantly different between treatments at each age (Figure 4.3). Due to the fact the Low Flush and Standard Flush treatments were derived from Low and Standard targets respectively, it is easy to identify the effect of the increased target BW on the ADFI after the flushing period at 20 wk of age. Overall, birds in the Standard Flush treatment had the highest ADFI (97 g) and the Low the lowest (55 g); the other treatments had intermediate ADFI ranging from 59 g to 88 g (Table 4.2). At 23 wk of age the Standard Flush and Step treatments had the highest ADFI (167 g and 168 g respectively), and Low the lowest (85 g). The Low Flush and Standard were intermediate with values of 102 g and 117 g ($P < 0.0001$; Figure 4.3). These results show how birds rapidly responded to adjustments in the target BW, with the Standard Flush group displaying the highest feed intake. This probably occurred because those pullets had more meals per day (10) when compared to the other groups (from 5 to 9, Table 4.2). The overall ADG of birds raised under the Standard Flush treatment was the highest (22 g) and the Low the lowest (16 g), with other treatments averaging 18 ± 0.5 g; P < 0.0001 (Table 4.2). ADG also varied across the weeks being consistent with achieving the respective treatment target BW (Figure 4.4). Birds in the flush treatments showed an increase in ADG after wk 20 when flushing occurred. Naqvi et al. (2012) used a concentrate diet as a mean to increase the energy intake by ewes during the summer and also observed an increase in BW right after the flushing occurred. In our study, flushing may have caused the plasma insulin levels to rise (Fink and Tauson, 1998) which helps to explain the higher feed efficiency associated with this technique as we will discuss in the next section. At 23 wk of age, birds on the Step treatment had the highest ADG (54 g) and the Low and Standard the lowest (26 g and 28 g respectively). The higher ADG observed for the Step treatment on wk 17, 20 and 23 might be related with other factors than just the increased ADFI on those weeks as we will discuss in the next section. The Low Flush and Standard Flush treatments had intermediate ADG of 34 g and 37 g, respectively (Figure 4.4).

4.4.4 Efficiency

The responses observed for both ADFI and ADG seems to be related to the very close relationship between metabolizable energy required for maintenance (MEm) and metabolizable energy intake (MEI) in our birds. As illustrated in Figure 4.5, broiler breeders use on average 79% of the energy intake for maintenance while broilers use on average 61% (Pinchasov and Galili, 1990;

Sakomura et al., 2003; Lopez and Leeson, 2005; Sakomura et al., 2005). Because the extra energy not used for maintenance is partly lost as heat and a great portion of it will promote growth (Birkett and de Lange, 2001), broiler breeders put on average 21% of the energy intake towards growth while broilers put 39% (Figure 4.5), which explains the small daily gains of 10 to 15 g normally observed in broiler breeders (Rayan et al., 2015). We can further see this difference in the net energy required for maintenance (NEm) shown in Figure 4.5 based on data obtained from Pinchasov and Galili (1990), Sakomura et al. (2003), Sakomura et al. (2005) and Lopez and Leeson (2005); while broiler breeders require on average 108 kcal of NEm per gram of body weight to sustain basal metabolic activities, broilers require 159 kcal per gram of body weight, showing that broilers needs for maintenance are greater due the vastly different metabolic state of these birds. This is because broilers are fed ad libitum, showing higher plasma levels of glucose and triglycerides which causes these birds to have higher BW, breast muscle and abdominal fat pad when compared to feed restricted birds (Zhan et al., 2007). Notably, the clear distinctions between the two bird lines appear when broiler breeders are weighing 320 g, which occurs around 14 days of age after which the daily intake of broilers increases dramatically and that of broiler breeders decreases due the start of feed restriction. Although our study ran from 91 to 161 days of age with birds reaching on average 2,617 g at wk 23, we can assume this relationship between broilers and boiler breeders would still hold if a broiler flock fed ad libitum was compared to a feed restricted broiler breeder flock at these ages. This is because ad libitum fed broilers have higher MEm due their higher BW when compared to feed restricted broiler breeders of the same BW.

In the current study, every time that a sharp change in the target BW occurred, a BW response was observed, indicating the ability of birds to rapidly gain weight when feed allocation increases following a feed restricted period (Figure 4.1 and Figure 4.2). In spite of an increase in the feed intake starting at 20 wk in Low Flush and Standard Flush treatments, pullets in those treatments started to gain weight at higher rates reaching lower cumulative FCR (3.2 and 4.9, respectively) at 23 wk when compared to that observed at wk 20 (3.7 and 5.6, respectively; Figure 4.6) for the same treatments. Also at 23 wk, the Low treatment did not differed from the Low Flush, displaying a cumulative FCR of 3.6. A further effect of increasing the feed allocation for restricted birds on promoting fast growth was observed by the cumulative FCR for the Step treatment. Notably, when the increase in target BW allowed birds to increase ADFI in the STEP treatment at wk 17, 20 and 23 there was a decrease in FCR for those birds, showing an increase in efficiency (Figure 4.6). The lower values observed for FCR on those weeks might have been caused by the reduced maintenance requirement associated with the lower BW (Yu and Robinson, 1992) at wk 16, 19 and 22 when the increase in the target BW took place. However, in the first wk following each sharp increase on ADFI, FCR increased. Suggesting that the higher ADFI may have contributed to an increase in diet induced thermogenesis (Romero et al., 2009). The lower ADG on the same period is probably caused by the increased MEm due the higher BW. In our study, although the Step treatment had consecutive fasting and feeding cycles, it reached the same efficiency as the Standard treatment with a cumulative FCR of 5.5 at 23 wk; $P<0.0001$ (Figure 4.6). de Beer and Coon (2007) observed that broiler breeder hens had higher efficiency when fed small amounts of feed everyday as opposed to larger allocations every other day. The deposition of nutrients after feeding and re-mobilization of those nutrients in a post-absorptive state is an inefficient process and helps to explain the inefficiency of feeding restriction programs such as skip-a-day (de Beer et al., 2007). In this study, however, although the Step treatment was comprised of increases in ADFI to adjust birds to the sudden change in target BW, birds were allowed to eat multiple meals per day which may have diminished the negative effect of multiple fasting and refeeding cycles. The similar BW (Figure 4.2) and the same cumulative feed intake (averaging 7,599 g, data not shown) observed at 23 wk for Step and Standard treatments helps to further validate that those negative effects associated with multiple fasting and refeeding cycles were diminished. The ADG for the Low and Standard birds (Figure 4.4) did not change much regardless of the difference observed in ADFI (Figure 4.3). This, along with the FCR values across the weeks (Figure 4.6), allows us to conclude that although in both treatments the PF system was able to keep birds at desired BW, the use of a lower target BW such as the Low treatment resulted in lower FCR and thus was a more efficient growth curve than the Standard BW target (Figure 4.6). The observed decrease in the FCR of birds raised in the Low treatment might be associated with their lower maintenance requirement due their lighter BW.

4.4.5 Feeding behavior

There was no difference in meal size between birds in the different treatments ($P = 0.9987$) on a weekly basis, not even when sharp changes in ADFI occurred for the Step, Low Flush and Standard Flush treatments (Figure 4.3 and Figure 4.7). This was because the birds were always given access to 25 g of feed for 60 seconds. The number of meals per day varied according to each target BW, mirroring ADFI (Figure 4.8 and Figure 4.3). Therefore, when the target BW increased, PF fed broiler breeders seemed to have increased the amount of feed eaten in a day by having more meals as opposed to increasing the amount of feed eaten per meal. The same trend would not be observed in conventional methods of feed restriction, where birds are given fewer but larger feeding bouts and they have to compete for access to feed over a short period of time. In the current study birds from the Low and Low Flush treatments were the most efficient. Although there were differences among treatments, the PF system was able achieve very low BW CV (1.9% ± 0.75%) when compared to conventional industry practices (10.3% ± 3.02%). This is because the PF system eliminated competition between birds while eating at the feeder (Gilmet, 2016). Overall, the PF system was very effective in controlling BW, showing its potential efficiency and effectiveness to manage a breeder flock.

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4.7 TABLES

Table 4.1. Grower broiler breeder diet fed from 13 to 23 wk.

Ingredient	Amount (%)
Ground Corn	25.00
Wheat	47.00
Soybean Meal	5.00
Oats	9.76
Canola Meal	9.00
Ground Limestone	1.80
Dicalcium Phosphate	1.53
Choline chloride premix	0.50
Vitamin premix[1]	0.25
Mineral premix[2]	0.25
NaCl	0.45
Dl-Methionine	0.09
L-Lysine	0.04
Enzyme[3]	0.05
Total	100.00
Calculated content	
ME (kcal/kg)	2,900
Crude protein (%)	15.50
Calcium (%)	0.90
Available phosphorus (%)	0.42
Available Lysine (%)	0.68
Available Methionine (%)	0.37

[1]Premix provided per kilogram of diet: vitamin A (retinyl/ acetate), 10,000 IU; cholecalciferol, 4,000 IU; Vitamin E (DL- α-tocopheryl acetate), 50.0 IU; vitamin K, 4.00 mg; pantothenic acid, 15.0 mg; riboflavin, 10.0 mg; folacin, 2.00 mg; niacin, 65 mg; thiamine, 4.00 mg; pyridoxine, 5.00 mg; vitamin B12, 0.02 mg; biotin, 0.20 mg.
[2]Premix provided per kilogram of diet: iodine, 1.65 mg; Mn, 120 mg; Cu, 20.0 mg; Zn, 100 mg; Se, 0.30 mg; Fe, 80.0 mg.
[3] Avizyme 1302 feed enzyme for use in poultry diets provided per kilogram of complete diet: 5,000 U/g endo-, 4-beta-xylanase EC 3.2.1.8; 1,600 U/g subtilisin (protease) EC 3.4.21.62 (Danisco Animal Nutrition, Marlborough, Wiltshire, UK).

Table 4.2. The effects of 5 broiler breeder pullet target body weight treatments on average daily feed intake (ADFI), average daily gain (ADG), cumulative feed conversion ratio (FCR), body weight coefficient of variation (CV), number of meals per day (Meals) and meal size from 13 to 23 wk of age.

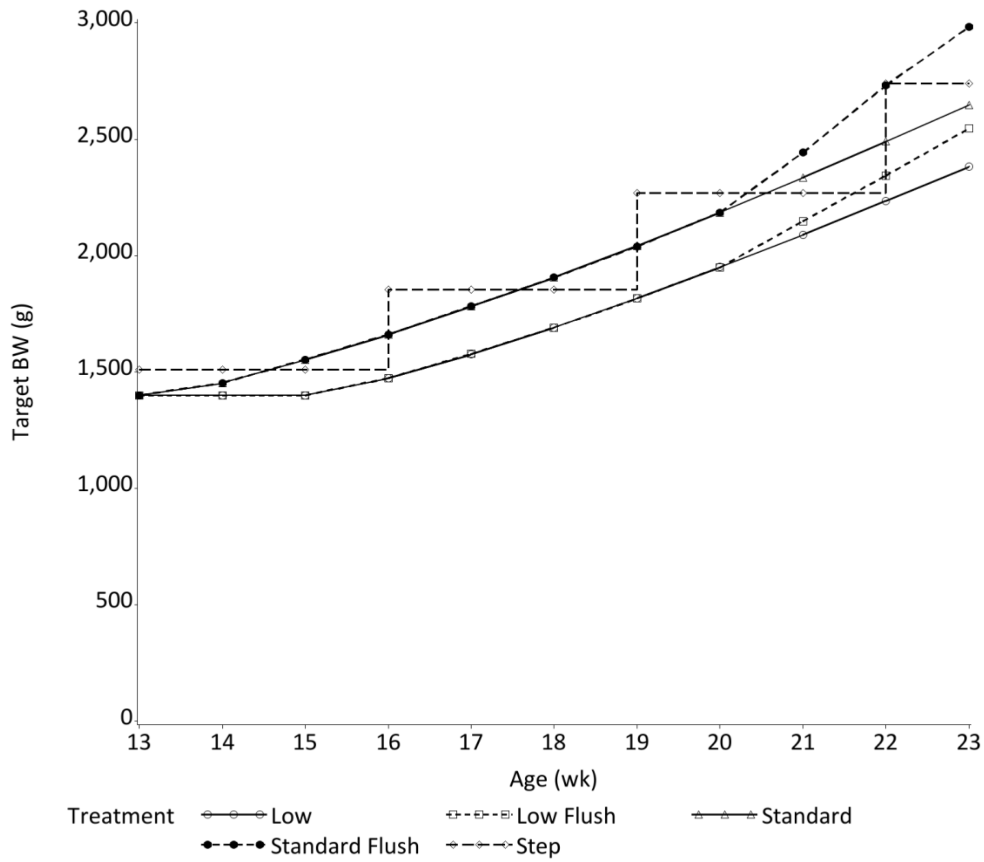
Age (A)	Treatment (T)	BW	CV	ADFI[1]	ADG[1]	FCR[1]	Meals[1]	Meal Size[1]
		g	%	g		g:g	N	g
	Low	1,774^{e} ± 6.6	2.0^{b} ± 0.42	55^{d} ± 1.4	16^{c} ± 0.6	4.4^{c} ± 0.20	5^{c} ± 0.2	10.9^{bc} ± 0.17
	Low Flush	1,800^{d} ± 7.0	0.8^{c} ± 0.33	59^{c} ± 1.5	18^{bc} ± 0.4	4.3^{c} ± 0.20	5^{c} ± 0.2	11.3^{a} ± 0.19
	Standard	1,925^{b} ± 6.1	2.3^{ab} ± 0.40	88^{b} ± 1.5	19^{b} ± 0.4	5.7^{a} ± 0.15	9^{b} ± 0.2	10.7^{bc} ± 0.16
	Standard Flush	1,952^{a} ± 6.3	3.4^{a} ± 0.58	97^{a} ± 1.6	22^{a} ± 0.5	5.3^{b} ± 0.13	10^{a} ± 0.2	11.0^{ab} ± 0.16
	Step	1,885^{c} ± 6.4	2.3^{ab} ± 0.44	86^{b} ± 1.7	19^{b} ± 0.6	6.0^{a} ± 0.15	9^{b} ± 0.2	10.6^{c} ± 0.17
13 wk		1,389^{k} ± 9.9	3.0 ± 0.65					
14		1,444^{j} ± 8.0	2.7 ± 0.76	50^{f} ± 1.7	10^{e} ± 0.7	4.4^{cd} ± 0.25	6^{f} ± 0.3	9.3^{f} ± 0.19
15		1,483^{i} ± 7.7	2.3 ± 0.58	58^{e} ± 1.6	11^{e} ± 0.7	4.8^{bcd} ± 0.26	6^{f} ± 0.2	9.7^{ef} ± 0.21
16		1,556^{h} ± 7.3	1.8 ± 0.45	61^{e} ± 1.6	11^{e} ± 0.5	5.8^{a} ± 0.36	7^{e} ± 0.3	9.4^{ef} ± 0.21
17		1,687^{g} ± 9.9	2.7 ± 0.71	76^{d} ± 2.3	22^{c} ± 1.0	5.6^{a} ± 0.23	8^{bc} ± 0.3	9.6^{ef} ± 0.21
18		1,800^{f} ± 7.6	1.5 ± 0.49	72^{d} ± 2.0	15^{d} ± 0.7	5.8^{a} ± 0.21	8^{cd} ± 0.3	9.9^{e} ± 0.20
19		1,901^{e} ± 7.8	1.9 ± 0.54	73^{d}± 1.8	17^{d} ± 0.7	5.5^{a} ± 0.18	7de ± 0.3	10.4^{d} ± 0.20
20		2,069^{d} ± 8.3	2.3 ± 0.54	94^{b} ± 1.9	24^{b} ± 0.6	5.0^{b} ± 0.15	8^{b} ± 0.2	11.7^{c} ± 0.19
21		2,230^{c} ± 8.6	2.3 ± 0.64	97^{b} ± 1.9	24^{b} ± 0.5	4.8^{bc} ± 0.14	8^{bc} ± 0.3	12.6^{b} ± 0.20
22		2,361^{b} ± 8.4	2.0 ± 0.54	87^{c} ± 1.9	20^{c} ± 0.6	4.9^{bc} ± 0.14	8^{bcd} ± 0.2	11.7^{c} ± 0.24
23		2,617^{a} ± 8.7	1.9 ± 0.40	128^{a} ± 2.3	36^{a} ± 1.0	4.5^{d} ± 0.13	9^{a} ± 0.3	14.7^{a} ± 0.24
Source of Variation		Probability						
T		<0.0001	0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0034
A		<0.0001	0.8890	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
T x A[2]		<0.0001	0.8073	<0.0001	<0.0001	<0.0001	<0.0001	0.9987

[1] Means reported for the previous week (i.e. ADFI for week 13 to 14 reported at 14 wk, and so on).

[2] Means for interactions are presented in figures. ^{a,k} Means ± SEM within age with no common superscript differ significantly (P<0.05).

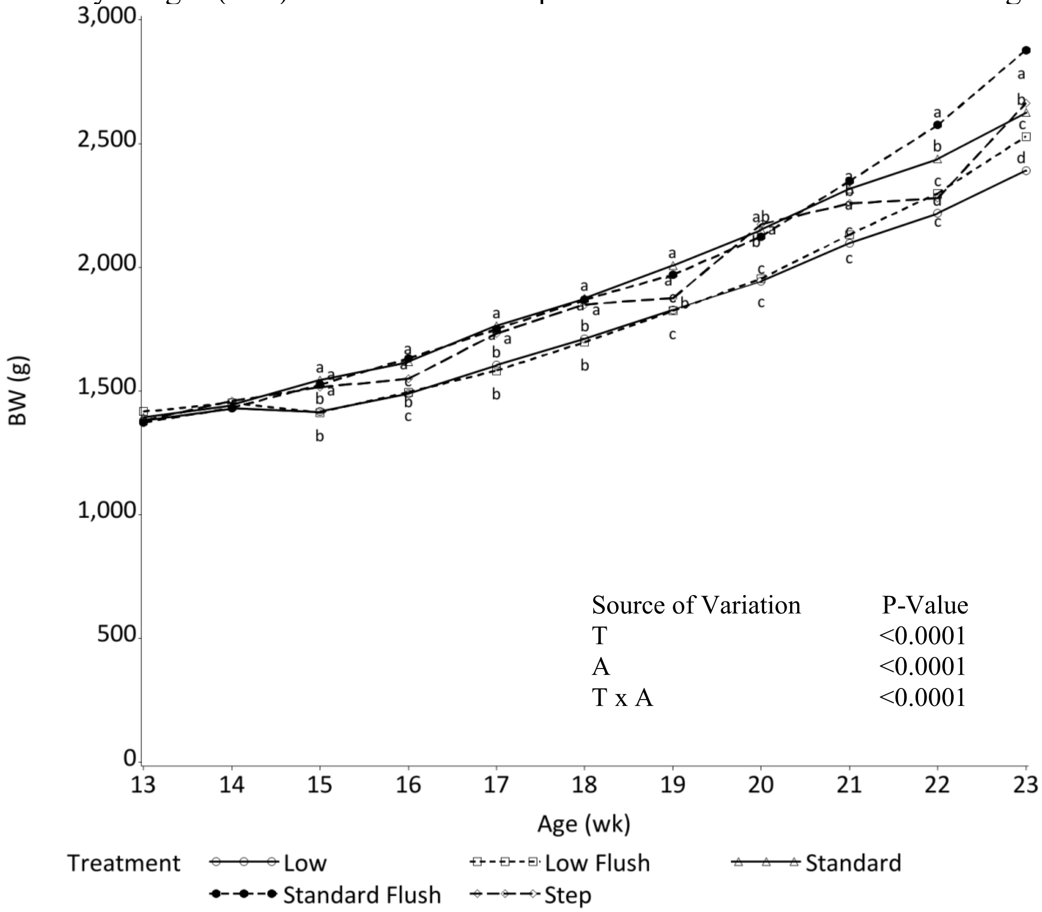
4.8 FIGURES

Figure 4.1 Broiler breeder pullet target body weight curves from 13 to 23 wk of age.



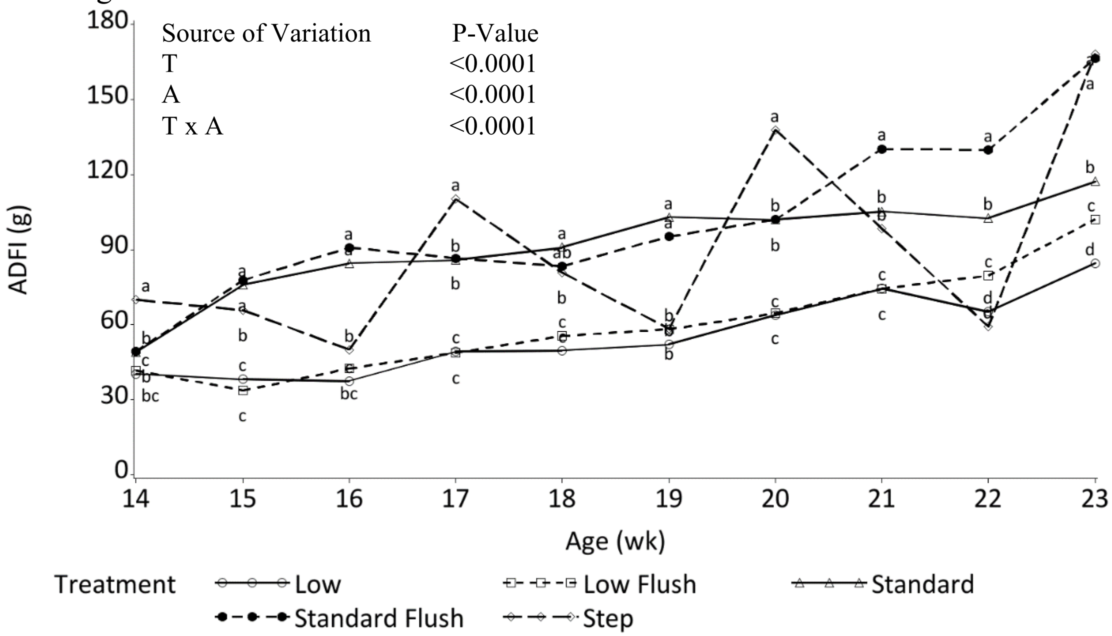
Low (Ross 708 target BW), Low Flush (Low, with higher peri-pubertal growth rate), Standard (Ross 308 target), Standard Flush (Standard, with higher peri-pubertal growth rate), and Step (BW targets increased in stepwise fashion every 3 weeks).

Figure 4.2 Body weight (BW) of broiler breeder pullets raised on 5 different BW targets from 13 to 23



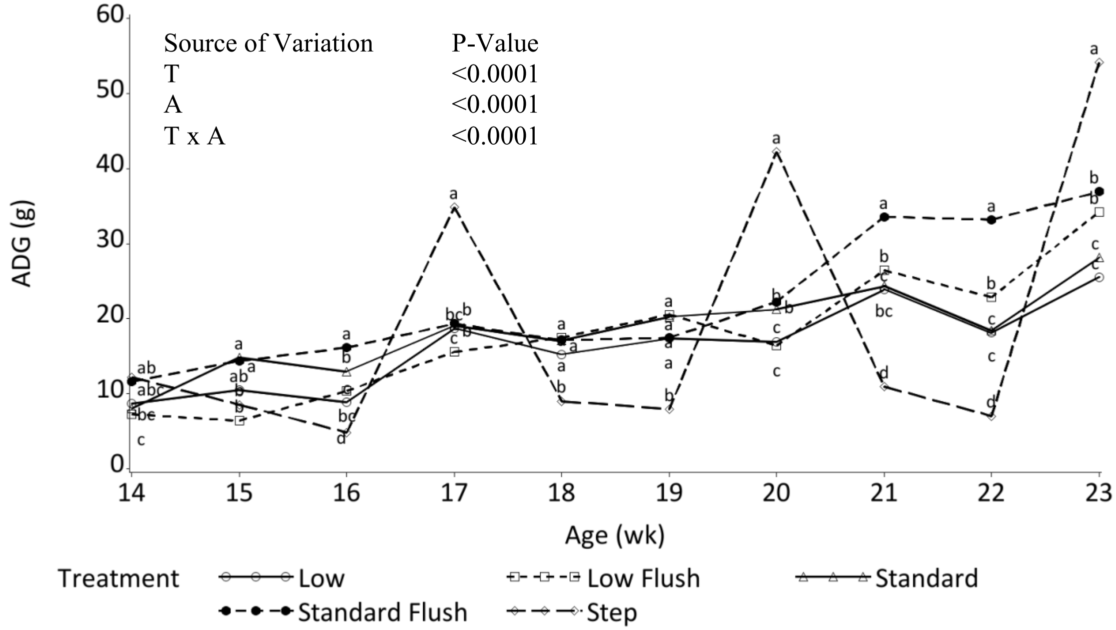
Low (Ross 708 target BW), Low Flush (Low, with higher peri-pubertal growth rate), Standard (Ross 308 target), Standard Flush (Standard, with higher peri-pubertal growth rate), and Step (BW targets increased in stepwise fashion every 3 weeks).
T = treatment effect; A = Age effect; T x A = treatment vs. age interaction effect.
[a-d] Means within age with no common superscript differ significantly ($P < 0.05$).

Figure 4.3. Average daily feed intake (ADFI) of broiler breeder pullets raised on 5 different BW targets from 13 to 23 wk of age.



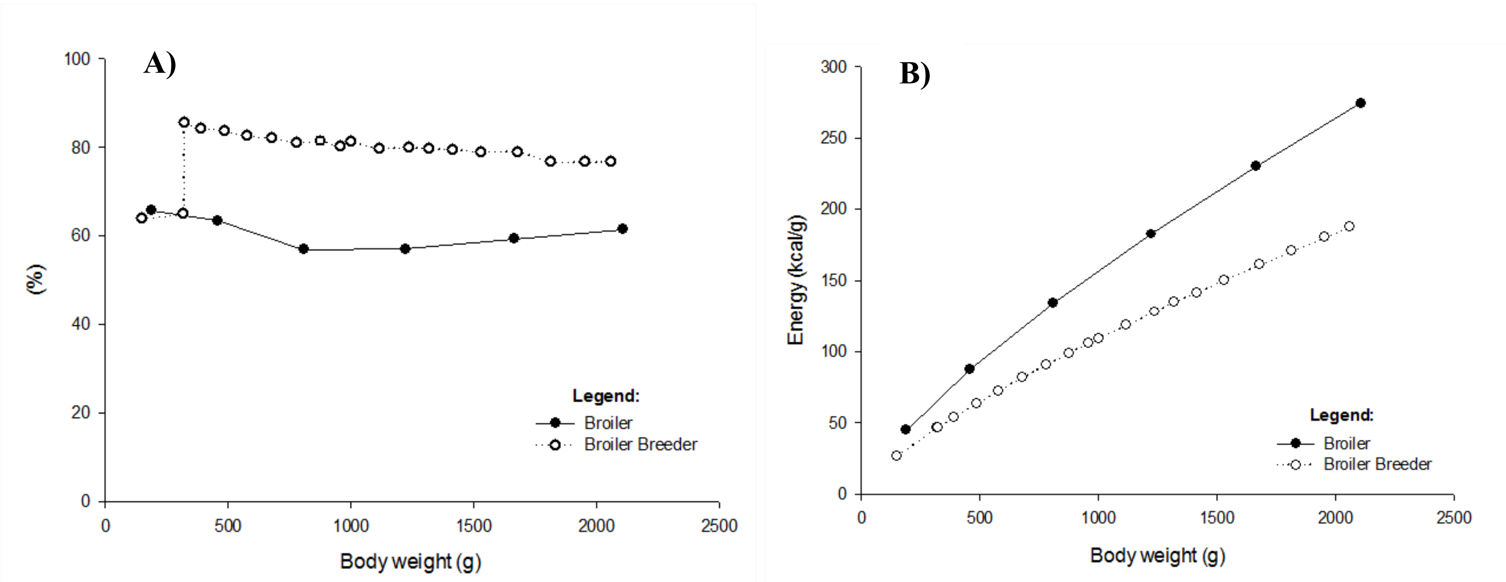
Low (Ross 708 target BW), Low Flush (Low, with higher peri-pubertal growth rate), Standard (Ross 308 target), Standard Flush (Standard, with higher peri-pubertal growth rate), and Step (BW targets increased in stepwise fashion every 3 weeks).
T = treatment effect; A = Age effect; T x A = treatment vs. age interaction effect.
Means reported for the previous week (i.e. ADFI from week 13 to 14 reported at 14 wk, and so on).
[a-d] Means within age with no common superscript differ significantly ($P < 0.05$).

Figure 4.4. Average daily gain (ADG) of broiler breeder pullets raised on 5 different BW targets from 13 to 23 wk of age.



Low (Ross 708 target BW), Low Flush (Low, with higher peri-pubertal growth rate), Standard (Ross 308 target), Standard Flush (Standard, with higher peri-pubertal growth rate), and Step (BW targets increased in stepwise fashion every 3 weeks).
T = treatment effect; A = Age effect; T x A = treatment vs. age interaction effect.
Means reported for the previous week (i.e. ADG from week 13 to 14 reported at 14 wk, and so on).
[a-d] Means within age with no common superscript differ significantly ($P < 0.05$).

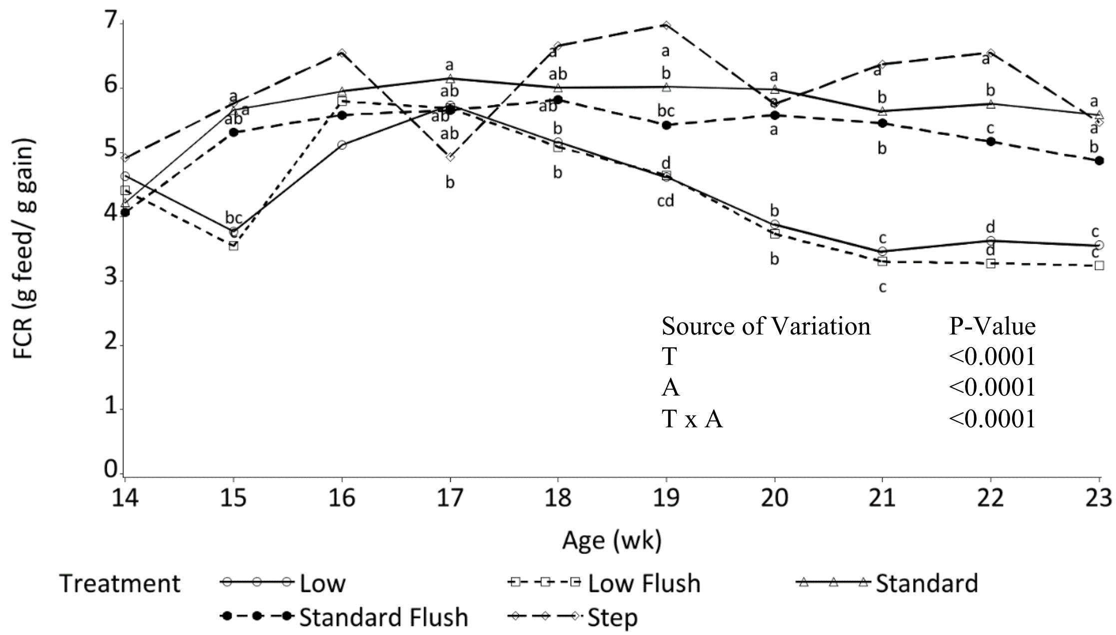
Figure 4.5 Relationship between metabolizable energy required for mantainance and metabolizable energy intake (MEm/MEI) and Net energy required for maintenance (NEm) for broilers and broiler breeders per gram of body weight.



A) Values for MEm for broilers and broiler breeders were estimated based on experimental data and equations from Pinchasov and Galili (1990), Sakomura et al. (2003), Sakomura et al. (2005) and Lopez and Leeson (2005).

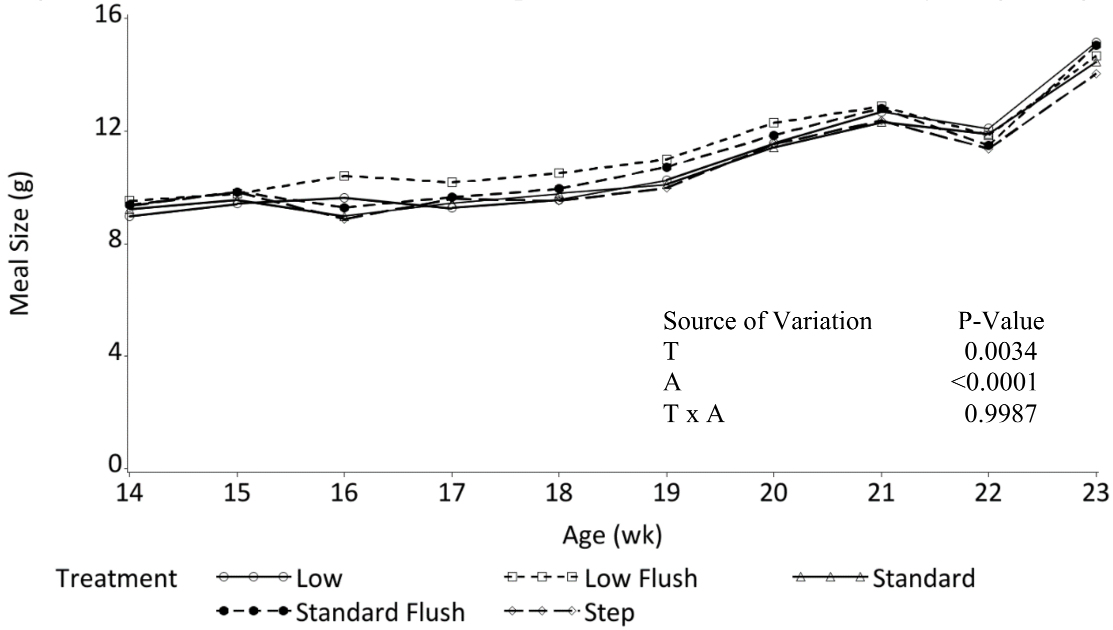
B) Values for NEm for broilers and broiler breeders were estimated based on experimental data and equations from Pinchasov and Galili (1990), Sakomura et al. (2003) and Sakomura et al. (2005).

Figure 4.6. Cumulative feed conversion ratio (FCR) of broiler breeder pullets raised on 5 different BW targets from 13 to 23 wk of age.



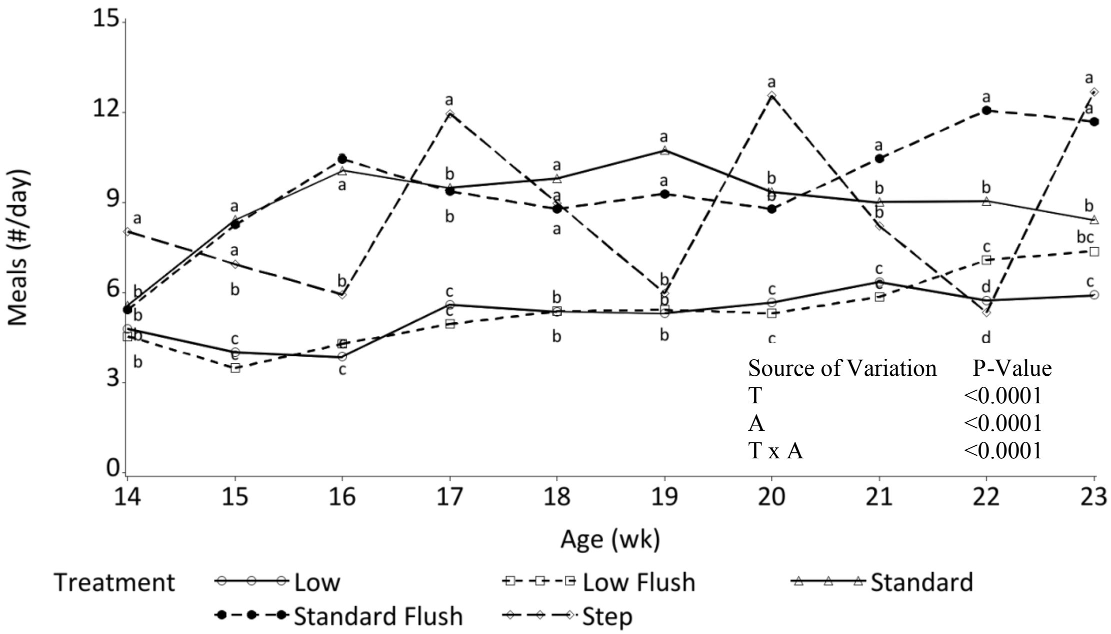
Low (Ross 708 target BW), Low Flush (Low, with higher peri-pubertal growth rate), Standard (Ross 308 target), Standard Flush (Standard, with higher peri-pubertal growth rate), and Step (BW targets increased in stepwise fashion every 3 weeks).
T = treatment effect; A = Age effect; T x A = treatment vs. age interaction effect.
Means are cumulative (i.e. FCR from 13 to 14 reported at 14 wk, from 13 to 15 reported at 15 and so on).
[a-d] Means within age with no common superscript differ significantly ($P < 0.05$).

Figure 4.7 Meal Size of broiler breeder pullets raised on 5 different body weight targets from 13 to 23 wk of age.



Low (Ross 708 target BW), Low Flush (Low, with higher peri-pubertal growth rate), Standard (Ross 308 target), Standard Flush (Standard, with higher peri-pubertal growth rate), and Step (BW targets increased in stepwise fashion every 3 weeks).
T = treatment effect; A = Age effect; T x A = treatment vs. age interaction effect.
Means reported for the previous week (i.e. Meal Size from week 13 to 14 reported at 14 wk, and so on).
No significant differences were detected ($P > 0.05$).

Figure 4.8. Number of Meals of broiler breeder pullets raised on 5 different BW targets from 13 to 23 wk of age.



Low (Ross 708 target BW), Low Flush (Low, with higher peri-pubertal growth rate), Standard (Ross 308 target), Standard Flush (Standard, with higher peri-pubertal growth rate), and Step (BW targets increased in stepwise fashion every 3 weeks).
T = treatment effect; A = Age effect; T x A = treatment vs. age interaction effect.
Means reported for the previous week (i.e. Number of Meals from week 13 to 14 reported at 14 wk, and so on).
[a-d] Means within age with no common superscript differ significantly ($P < 0.05$).

5 Uniformity and Growth of Broiler Breeder Pullets Reared Under Different Precision Feeding Stocking Pressures

5.1 ABSTRACT

Feed restriction is a common practice adopted by hatching egg producers when rearing broiler breeders in an attempt to get a uniform flock with higher rates of lay and increased chick quality during the production phase. However, broiler breeder producers have difficulties to decide what method of feed restriction to apply in their flock as each method may affect flock uniformity and productivity differently. That is because birds are fed as a group which leads to increased competition for food, with less aggressive birds often eating less than they would if the competition was reduced or not present. Precision feeding for broiler breeders is a novel technology that sequentially feeds individual birds several meals throughout the day which may help to control the flock's uniformity as it eliminates the competition at the feeder. In an attempt to identify the maximum feeding capacity of the Precision Feeding system, the current study evaluated the effect that different stocking pressures on the Precision Feeding station have on uniformity and efficiency of broiler breeder pullets from 2 to 21 wk of age. One hundred fifty six day-old Ross 308 broiler breeder pullets were randomly distributed in 4 identical pens in a completely randomized design. The number of birds per station at placement formed the Stocking Pressure treatments: Very Low (24 birds), Low (34 birds), High (44 birds) and Very High (54 birds). Pullets were randomly assigned to replicate groups of 5 or 6 birds each: Very Low had 4 replicates of 6 birds; Low had 4 replicates of 6 birds and 2 replicates of 5

birds; High had 4 replicates of 6 birds and 4 replicates of 5 birds; and Very High had 9 replicates of 6 birds. At wk 2 the Very High stocking pressure treatment showed the highest BW CV (21.8%, $P < 0.0001$).This occurred because prior wk 2 birds had ad libitum access to feed and were allowed to enter the station in groups, which caused competition for food around the small feeder (4.8 x 4.8 cm). Although there was a strong early lack of uniformity associated with high stocking pressures, as soon as the individual feeding stated at wk 2, the BW CV dropped significantly in all treatment groups, reaching as low as 1.8 % ± 0.43% at 21 wk. Changes in ADFI and ADG at wk 10, 15, 17 and 18 observed in the Very Low treatment were associated with some birds misleading the stations to release more food by moving excessively inside the machine, causing low BW readings and improper release of feed. Adjustments made on the precision feeding settings solved this issue by decreasing the amount of feed available to bird from 30 g to 10 g, causing lower BW gains should they deceive the system. The cumulative FCR at 21 wk of age was 3.87 ± 0.04 with no significant difference detected between treatments ($P = 0.4862$, data not shown). The lowest meal size was observed in the Very Low treatment 15 g, with other treatments averaging 16 ± 0.1 g ($P<0.0001$). On the other hand, Very Low treatment displayed the highest number of meals per day (N=5), with other treatments averaging 4 meals per day ($P<000.1$). Apparently, the higher the stocking pressure, the higher the meal to visit ratio displayed by pullets. Indicating that in a high competitive environment to enter the station, birds use the system more efficiently. Overall, precision feeding system resulted in high uniformity from 8 to 21 wk of age regardless the stocking pressure employed. This may justify the utilization of higher stocking pressures to reduce the overall cost of implementing this technology by spreading the cost over more birds.

Key words: Efficiency, BW uniformity, meals, visits, feed allocation.

5.2 INTRODUCTION

Ad libitum feed intake in broiler breeders is associated with obesity and ovarian dysfunction, negatively affecting egg production (Hocking et al., 1987; Hocking et al., 1993). To prevent reproductive problems and to achieve a higher rate of lay and persistency broiler breeder pullets are feed restricted (Renema and Robinson, 2004). Feeding programs such as skip-a-day, in which pullets have access to twice the daily feed allocation every other day, allow more timid birds to eat when the most aggressive ones are full or away for drinking water, having a positive effect on flock uniformity (de Beer and Coon, 2007; Cobb-Vantress, 2008a). Primary breeder guides state that the more birds are competing for food the lower the uniformity tends to be (Cobb-Vantress, 2008e; Aviagen, 2013b). Precision feeding system for broiler breeders is a novel technology that automatically decides whether or not to feed a bird based on its real time BW and a target BW. The system automatically weighs the birds individually and provides feed each time pullets are below their assigned target BW. Because birds are allowed to eat up to 25 g for 60 sec, they visit the stations multiple times a day. Furthermore, one single bird at a time gets assess to the feeding area, which eliminates the competition for food around the feeder that is observed in conventional methods of feed restriction (Renema et al., 2006; Cobb-Vantress, 2008a); having a positive effect on the flock uniformity. The present study aimed to evaluate the effect that different stocking pressures on the precision feeding station have on uniformity and efficiency of broiler breeder pullets from 2 to 21 wk of age.

5.3 MATERIAL AND METHODS

5.3.1 Experimental Design

One hundred fifty six day-old Ross 308 broiler breeder chicks were randomly distributed in 4 identical pens with one precision feeding station each in a completely randomized design. The number of birds per station formed the treatments: **Very Low** (24 birds), **Low** (34 birds), **High** (44 birds) and **Very High** (54 birds). Only 4 precision feeding stations were available due their high cost. Therefore, the total number of birds within each pen was divided into replicates for statistical analysis purpose, having the replicated groups nested within pens. Pullets were randomly assigned to replicate groups of 5 or 6 birds each; Very Low had 4 replicates of 6 birds each, Low had 4 replicates of 6 birds and 2 replicates of 5 birds, High had 4 replicates of 6 birds and 4 replicates of 5 birds, and Very High had 9 replicates of 6 birds. Each replicate group was considered as an experimental unit in order to access flock uniformity. The animal protocol for the study was approved by the University of Alberta Animal Care and Use Committee for Livestock and followed principles established by the Canadian Council on Animal Care Guidelines (CCAC, 2009).

5.3.2 *Stocks and Management*

Upon delivery at 0 days old, the birds were weighed, identified with a neck tag and placed in their respective pens. At 14 days old, all birds were identified with a RFID (radio frequency identification) wing tag. Feed restriction started when pullets reached 16 days of age. Each pen contained pine shavings to a depth of approximately 5.0 cm, one suspended bell drinker and one feeding station (4.8 cm of feeder space per station). The PF station had an RFID reader that allowed us to associate body weights and feed intakes with individual birds using the station, and the time of each event. A feeding bout was defined as the time birds were allowed access to a certain amount of feed prior to being gently ejected from the station. The feeding bout settings (Table 5.1) had to be adjusted throughout the trial to account for specific bird behaviors. Animals had free access to the PF system and the decision whether or not to feed them was made as follows. Each pullet entered by a door and was weighed by a scale integrated into the feeding station. The BW was immediately compared against the Ross 308 target BW. If the broiler breeder BW exceeded or was equal to the target BW, the bird was gently ejected from the station. If its BW was below the target BW, the bird was allowed to have a feeding bout prior to ejection from the station. The remaining feed was weighed, recorded and feed intake calculated by subtraction from the initial feed weight. Temperature in the barn followed the recommendations of the Ross 308 management guide. All birds were fed the same diets as shown in Table 5.2. Pullets were exposed to the photoschedule recommended by the Ross 308 parent stock manual: 23L:1D (0 to 2 day), 19L:5D (day 3), 16L:8D (day 4), 14L:10D (day 5), 12L:12D (day 6), 11L:13D (day 7). Light intensity decreased from 80 lux at day 0 to 30 lux on day 6. On day 9, a photoperiod of 10L:14D with 10 lux was applied to each pen until 21 wk of age.

5.3.3 Training

During the first week, chicks were trained to associate the PF system with food prior to being restricted at 16 days. The training protocol was as follows: four pieces of chick paper were placed in and around each PF station (on each PF platform and outside near the PF entry). Daily, 100 g of feed were put on top of each chick paper. After 48 h the furthest paper from the PF was removed and one per successive day until the sole source of feed was in the feeding trough in each PF station. When birds reached 7 days of age, the PF stations were configured to close and open doors at 5 minutes intervals to accustom the chicks to the sound and movements of the system. During that period, pullets had ad libitum access to the feeding area so they could associate feeding with the feeder inside the system. They were also allowed to enter the PF system in groups so birds could learn from each other how to get to the feed. After the start of feed restriction (16 days), only one bird at a time was able to get access to the feeding area and pullets that did not eat for 36 consecutive hours were placed in a remedial training pen.

5.3.4 Remedial Pen

As pullets in the remedial pen had not eaten for an extended time, a heat lamp was used to create a warm micro-environment. Birds remained in the remedial training pen until they learned to eat from the PF system and had begun to gain weight. Animals that did not eat from the PF for 24 hours inside the remedial pen were manually placed in the PF station. Notably, placing birds into the remedial training pen changed the social hierarchy, and some birds immediately began to use the system. These birds were returned to their home pen. Once the birds displayed PF comprehension by feeding out the station on their own multiple times daily, they were moved back to their original pens.

*5.3.5 **Data Collection***

Using built-in load cells, BW and feed intake were recorded automatically by the precision feeding stations. The number of individual bird visits, bout duration and meal size were summarized daily. Birds were weighed manually once per week throughout the trial to check consistency of the PF scale with another source. Load cells were checked at least weekly and scales calibrated when outside a margin of tolerance of ± 10g for the BW scale and ± 1g for the feeder scale. The number of days birds spent in the remedial pen, and the number of birds that required remedial attention per pen were recorded.

*5.3.6 **Statistical Analysis***

An analysis of variance was performed using the MIXED procedure of SAS (Version 9.4. SAS Institute Inc., Cary, NC, 2009) with the statistical model being:

$$Y_{ijk} = \mu + T_i + A_j + (TA)_{ij} + P_k + e_{ijk}$$

Where μ = mean, T = treatment effect, A = age effect, TA = interaction treatment x age effect, P = pen effect, e= error. i= 1, 2, 3, 4 were the different stocking densities, j= 3, 4,..., 22, where the age in weeks and k= 1, 2,…, 9 were the replicates. Separate variances were estimated for each week. Tukey's test was used to evaluate whether differences existed at $P < 0.05$.

5.4 RESULTS AND DISCUSSION

5.4.1 BW

From 2 to 6 wk of age, the Very Low treatment displayed the highest BW and the Very High the lowest. The Very Low treatment BW were 22, 17, 12, 10 and 6% higher than the Very High treatment in wk 2, 3, 4, 5 and 6 respectively ($P < 0.0001$; Figure 5.1). These results show that l ower stocking pressures resulted in higher BW prior individual feeding began. The reason was that there were fewer birds competing for a very small feeder space prior to the start of individual feeding on those treatments at wk 2. Although not significantly different, the BW diversion that occurred at 16 and 17 wk, with the Very Low birds being 4% heavier than the Very High on both wk (Figure 5.1), was caused by birds that moved excessively or touched the wall of the machine, making themselves appear lighter and causing unstable BW readings. Reducing meal size and duration (Table 5.1) prevented birds from continuing to exceed the target BW by reducing the amount of feed available to be stolen upon every successful feed bout. This caused a significant difference in BW to appear at wk 18 with the Very Low treatment weighing 29 g less than the Very High treatment. At 21 wk all treatments had similar BW (2,465 ± 10 g). These results show that the PF system was able to efficiently control growth regardless of the stocking pressure employed and that we might have not achieved the maximum feeding capacity of the PF system since higher stocking pressures, and hence higher competition, was expected to diminish the capacity of the system to feed birds. Working with precision feeding for growing-finishing pigs, Andretta et al. (2014) and Pomar et al. (2009) also observed that precision fed pigs had similar BW at the end of the trial.

5.4.2 Uniformity

BW uniformity is a very important aspect of managing a broiler breeder flock. When a flock is uniform, hatching egg producers will match the nutrient requirements of a greater number of individual birds during feeding, which will enable birds to reach sexual maturity at similar ages and support high peak production (Pishnamazi et al., 2008). Decreasing the competition for food around the feeder is one of reasons why the industry is applying alternative feed restriction programs such as skip-a-day in their flock (de Beer and Coon, 2007; Cobb-Vantress, 2008a). Zuidhof et al. (2015) tested the effect of daily feeding, scatter feeding (diet spread on the litter daily), skip-a-day feeding and grading (separate flock into 3 BW categories and feeding each category according to the average BW) on BW uniformity and observed that scatter feeding and grading provided the lowest BW CV at 22 wk (10.9% and 6.2% respectively) when compared to daily restriction (15.7 %). Scatter feeding decreased BW CV by 4% because it extended feeding time as pullets had to search for food in the litter. Grading provided the smaller birds with more chances to eat as they were separated from the bigger birds and caused a reduction in BW CV by 7%. In our study, the effect of PF system on BW CV resembles a combination of scatter feeding and grading because the feed intake was spread through the day and smaller birds were separated from the bigger ones during feeding.

At wk 2 the Very High treatment showed the highest CV (21.8%) followed by High (12.3%), Very Low (9.6%) and Low (9.2%), with the three last treatments not being significant different from each other (Figure 5.2). Because birds were ad libitum fed and had free access to the PF station prior to wk 2, the most aggressive birds outperformed the least aggressive ones causing higher BW CV to be associated with higher stocking pressures at the start of the trial. Notably, the BW CV decreased after birds started being individually fed at wk 2 (Figure 5.2). After wk 7 all treatments showed similar BW CV, reaching as low as 1.8 % ± 0.43% at 21 wk. This shows that regardless the stocking pressure employed, the PF system allowed the smaller birds enough opportunities to eat to support growth, and this effect became more prominent once the animals were well acquainted with the PF system. Therefore, reducing the competition around the feeder seems to have played the major role in reducing BW variation in precision fed broiler breeders (Gilmet, 2016). In a study comparing different methods of feed restriction commonly used by the industry, de Beer and Coon (2007) obtained BW CV in the range of 10.3% ± 3.02%. Our findings showed that PF system dramatically increased flock uniformity by reducing BW variation as hatching egg producers consider BW CV less than 10% as a sign of good management (Cobb-Vantress, 2008b). The very low BW CV observed in our study, if successfully obtained in a commercial setting, may lead to higher peak of egg production and persistency in broiler breeders as birds within the flock would mature sexually around the same age due their similar BW (Abbas et al., 2015).

5.4.3 Feed intake and growth

A population of animals has an inherent variation in growth among its individuals. According to van Milgen et al. (2012), precision feeding is capable of managing variation within a population and may contribute to enhance the efficiency of animal production systems. In the present study, the analysis of ADFI and ADG at the bird level may help to identify growth patterns otherwise difficult to find if birds were fed as a group, and helps to understand the reduced variation in BW observed in all treatments. Average daily feed intake (**ADFI**, Figure 5.3) was on average 8 g higher for the Low treatment at 10, 15, 17 and 18 wk, when compared to the High and Very High treatment reaching as high as 88 g at 21 wk. We observed that some birds in the Low treatment were misleading the system to release food by scratching or touching certain parts of the machine, making themselves appear lighter, which helps to explain the higher ADFI observed (Figure 5.4). To reduce the impact of having many incorrect light BW readings, we reduced meal size and duration (Table 5.1). The reduction of feed provided from 20 g to 15 g per bout on wk 17 (Table 5.1) caused a drop of 3 and 12 g on the ADG of Very Low and High treatments, respectively at wk 18 (Figure 5.5, $P < 0.0001$) because it diminished the amount of feed some birds that were deceiving the system were able to steal. Despite the oscillations in ADG and ADFI from week to week, birds were in a consistent positive energy balance as observed by continuous growth (Figure 5.1). At 21 wk the cumulative FCR was on average 3.87 ± 0.04 and did not differ between treatments (Data not shown, P = 0.4862). Showing that a consistent nutrient supply throughout the day is what affects the efficiency (de Beer et al., 2007) of food utilization and not the different stocking pressure employed.

5.4.4 Feeding behavior

During wk 4 and 5, lower stocking densities were associated with higher Meal Size with Very Low and Low averaging 17.5 g of feed consumed per feeding bout when compared to High and Very High that averaged 15.4 g (Figure 5.6, P < 0.0001). The differences observed on the same wk for Number of Meals (Figure 5.7), along with the overall lower Meal/Visit Ratio (Table 5.3) for treatments under lower stocking pressures, suggests that birds under those treatments were less competitive and least efficient in using the PF system as they displayed lower number of meals and higher feed intake per visit. An opposite pattern was observed for the Very High stocking density, suggesting those birds were more competitive and efficient in using the PF station as they regulated the feed intake by visiting the stations more often as opposed to have a higher feed intake per bout. The decreased Meal Size and increased number of meals during wk 7 was due a reduction of 10 g in the amount of feed presented to birds and of 30 s on the feed bout duration at wk 6 (Table 5.1).

During wk 11, there was a drift on the feed scale tare value that caused the system to release approximately 16 g less feed than was programmed to the Very Low treatment (Figure 5.6). Pullets in this treatment responded by increasing the number of meals eaten per day on that wk (Figure 5.7) and managed to maintain

ADFI similar to that of birds in the other treatments (Figure 5.3). A similar response was observed at 17 and 18 wk of age. However, at these ages there was no drift in the feed scale but rather some birds in the Very Low and Low treatment were caught deceiving the system to release more food as previously discussed. The correction made on the feeding bout settings (Table 5.1) resulted on an average reduction in Meal Size of 6 g for the Very Low and 1 g for the Low treatments (Figure 5.6) and on an increase in the Number of Meals of 5 for the Very Low and of 2 for the Low treatments, from 16 to 18 wk (Figure 5.7). Overall, the higher the stocking pressure, the less visits per bird per day to the station were observed with birds on the Very Low and Very High treatments displaying 65 and 28 visits respectively ($P<0.0001$,Table 5.3). This seems because the higher competition was associated with higher stocking pressures. The Meal to Visits Ratio was also affected by the stocking pressure with the Very High treatment displaying 16% of success and the Very low 8% ($P<0.0001$; Table 5.3). Interestingly, birds were able to manage the number of meals and the meal size to consume a certain amount of feed in a day to achieve the target BW; as observed especially at 11, 17 and 18 wk (Figure 5.3; Figure 5.6 and Figure 5.7). In a study about human behavior, Okouchi (2010) explained that a variable ratio reinforcement is an operant conditioning through which a behavior is reinforced after an unpredictable number of attempts to get a reward and it is associated with a fast learning and slow extinction. This might explain the feeding patterns observed in our birds as the reward of feeding could not be predicted by the pullets making them enter the PF system multiple times until they received the reward. On the other hand, when the reward was not given after several attempts, some birds stopped entering the PF system and were put in the remedial pen so they could be reinforced again to try. This was observed during the first weeks of the study (from 2 to 6 wk of age), before the reward was firmly associated with station use (Figure 5.8).

In the present study, all birds had similar BW CV after 7 wk. The Very High (54 birds/station) treatment provided the highest meal to visit ratio and the Very Low (24 birds/station) the lowest. Further research at higher stocking pressures will be needed to identify the maximum number of birds each PF station can feed.

5.5 ACKNOWLEDGEMENTS

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5.7 TABLES

Table 5.1. Precision feeding system software settings used to control the duration of each feeding bout[1] and the quantity of feed presented.

Age	Duration	Quantity
—— wk ——	—— sec ——	—— g ——
3	150	45
6	90	30
12	60	40
13	60	25
16	60	20
17	60	15

[1]Time birds were allowed to eat prior to being gently ejected from the station.

Table 5.2. Starter and grower broiler breeder diets fed from 0 to 21 wk.

Ingredient	Starter (%) 0 to 4 wk	Grower (%) 4 to 21 wk
Ground Corn	15.00	33.45
Wheat	39.41	35.00
Soybean Meal	17.59	6.66
Oats	15.00	6.19
Canola Meal	5.00	8.00
Canola Oil	2.38	1.00
Wheat Bran	0.00	5.00
Ground Limestone	1.58	1.52
Dicalcium Phosphate	1.98	1.50
Vitamin premix1	0.50	0.50
Mineral premix2	0.50	0.50
Salt	0.45	0.39
Dl-Methionine	0.21	0.09
L-Lysine	0.36	0.12
Threonine	0.00	0.03
Enzyme[3]	0.05	0.05
Total	100.00	100.00
Calculated Content		
Crude protein (%)	19.00	15.00
ME (kcal/kg)	2,900	2,865
Crude fiber (%)	2.92	3.81
Calcium (%)	1.10	1.00
Available phosphorus (%)	0.61	0.45
Available Lysine (%)	0.95	0.74
Available Methionine (%)	0.43	0.34

[1] Vitamin premix provided per kilogram of complete diet: vitamin A, 10,000 IU; vitamin D_3, 3,000 IU; vitamin E, 100 IU; vitamin K_3, 3 mg; vitamin B_{12}, 0.03 g; riboflavin, 8 mg; niacin, 60 g; pantothenic acid, 18 mg; folic acid, 1 mg; pyridoxine HCL, 6 mg; thiamine HCL, 3 mg; biotin, 0.2 mg; choline chloride, 80.7mg.

[2] Mineral premix provided per kilogram of complete diet: Cu, 18mg; I, 1.1mg; Fe, 80 mg; Mn, 150 mg; Zn, 125 mg; Se, 0.25 mg.

[3] Avizyme 1302 feed enzyme for use in poultry diets provided per kilogram of complete diet: 5,000 U/g endo-, 4-beta-xylanase EC 3.2.1.8; 1,600 U/g subtilisin (protease) EC 3.4.21.62 (Danisco Animal Nutrition, Marlborough, Wiltshire, UK).

Table 5.3 Average daily number of Total Visits and Meal/Visits Ratio of broiler breeders reared in Precision Feeding System from 2 to 21 wk of age.

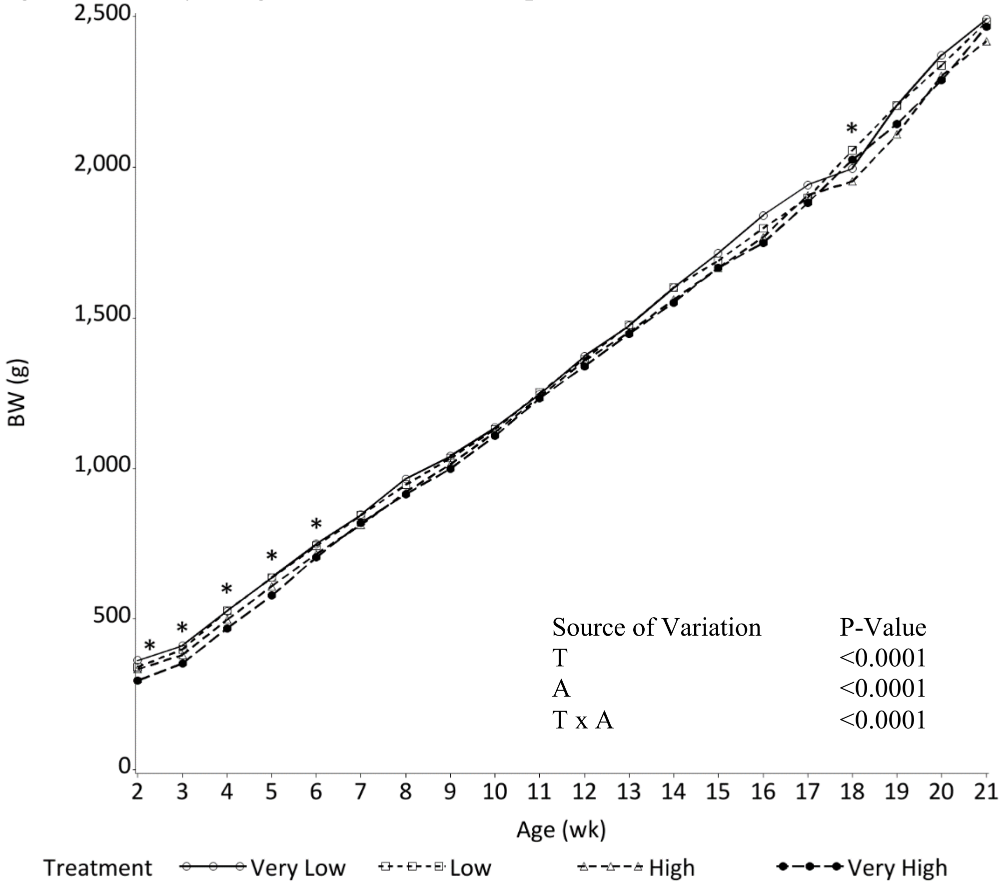
Treatment	Total Visits	Meal to Visits Ratio
	N	%
Very Low	65[a] ± 0.7	8[d] ± 0.3
Low	44[b] ± 0.4	10[c] ± 0.3
High	34[c] ± 0.3	14[b] ± 0.3
Very High	28[d] ± 0.3	16[a] ± 0.4
Probability	<0.0001	<0.0001

Very Low (24 birds per station), Low (34 birds per station), High (44 birds per station), Very High (54 birds per station).

[a-d] Means within column with no common superscript differ significantly ($P < 0.05$).

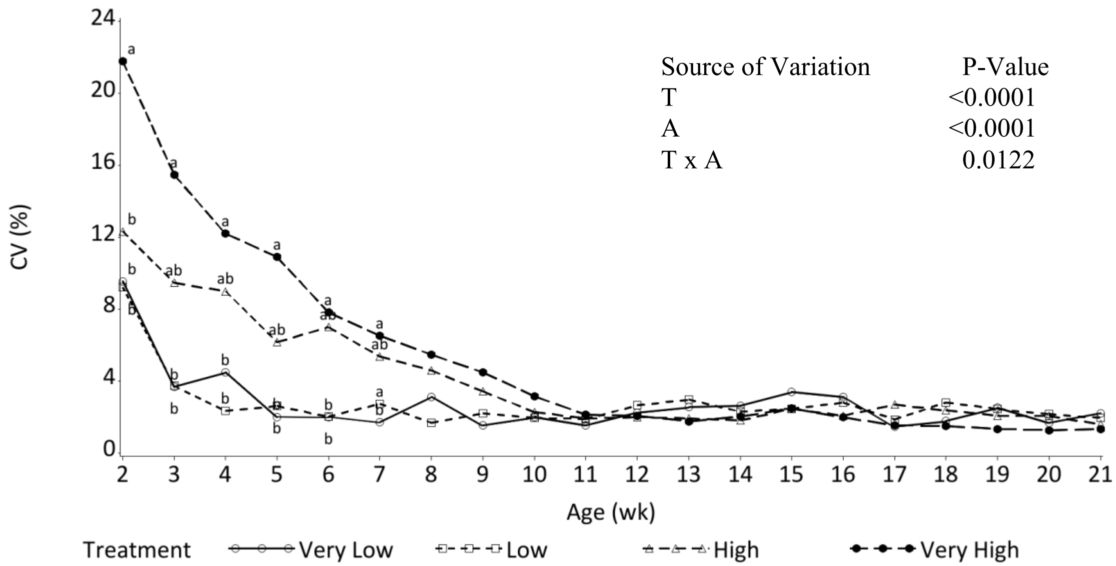
5.8 FIGURES

Figure 5.1 Body weight of broier breeder pullets raised under 4 different stocking pressures from 2 to 21 wk.



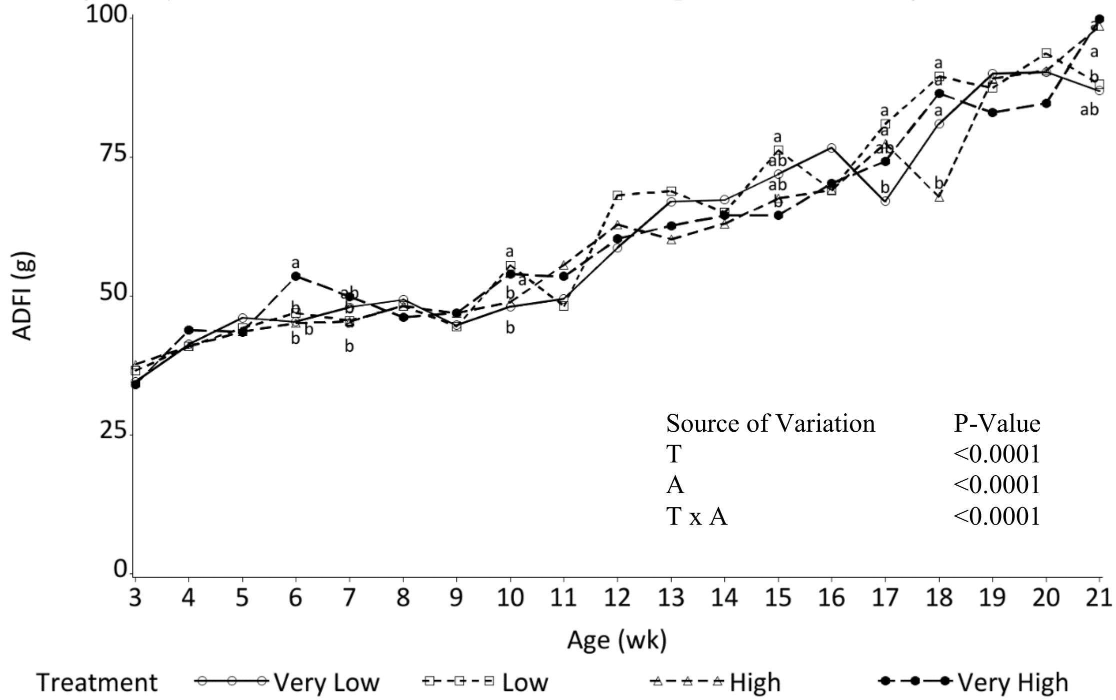
Very low (24 birds / PF station), Low (34 birds / PF station), High (44 birds / PF station), Very high (54 birds / PF station).
T = treatment effect; A = age effect; T x A = treatment vs. age effect.
* Means within age with no common superscript differ significantly ($P < 0.05$).

Figure 5.2 Body weight coefficient of variation (CV) of broiler breeder pullets raised using 4 different stocking pressures from 2 to 21 wk.



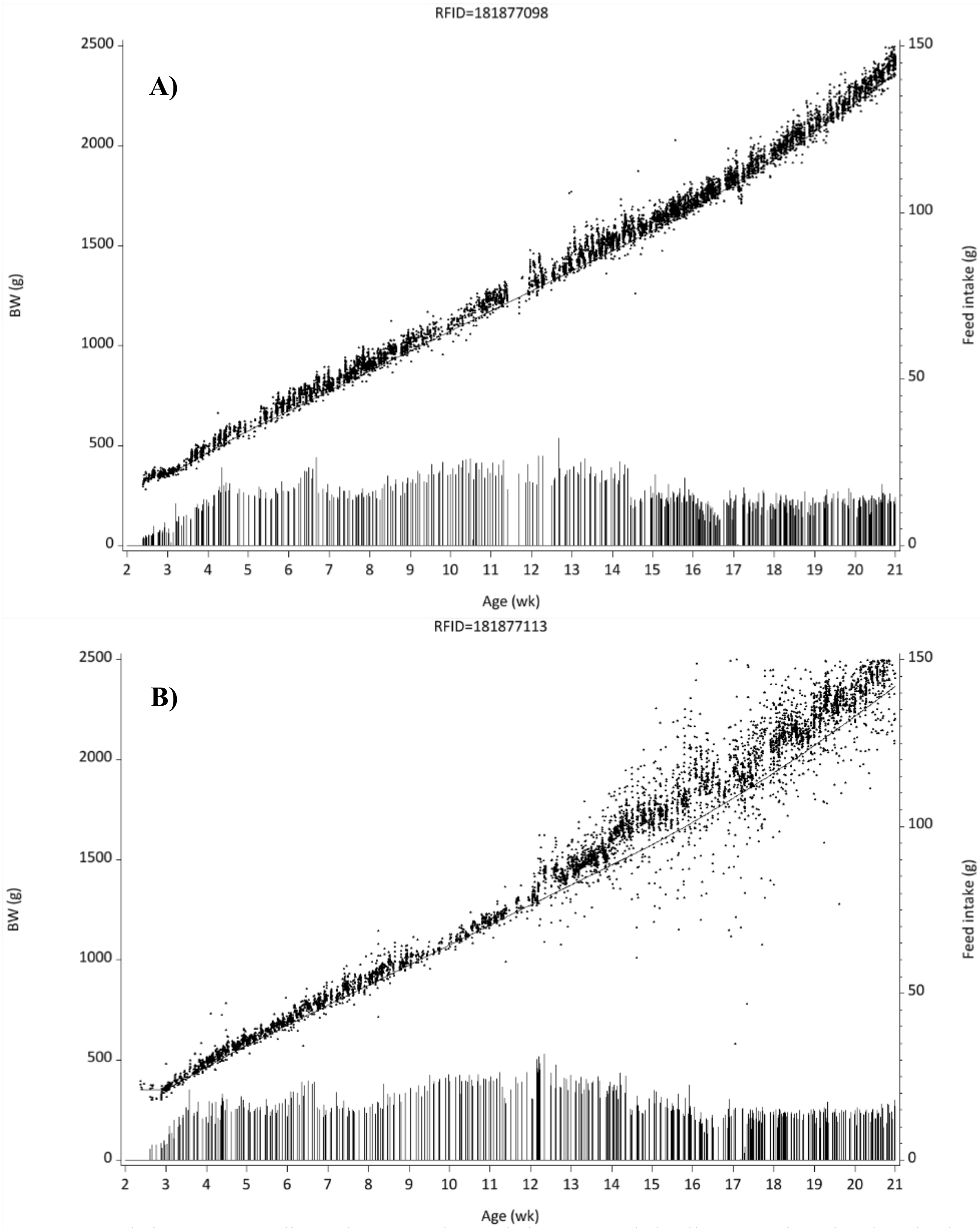
Very low (24 birds / PF station), Low (34 birds / PF station), High (44 birds / PF station), Very high (54 birds / PF station).
T = treatment effect; A = age effect; T x A = treatment vs. age effect.
[a-b] Means within age with no common superscript differ significantly ($P < 0.05$).

Figure 5.3 Average daily feed intake (ADFI) of broiler breeder pullets raised using 4 different stocking pressures from 2 to 21 wk.



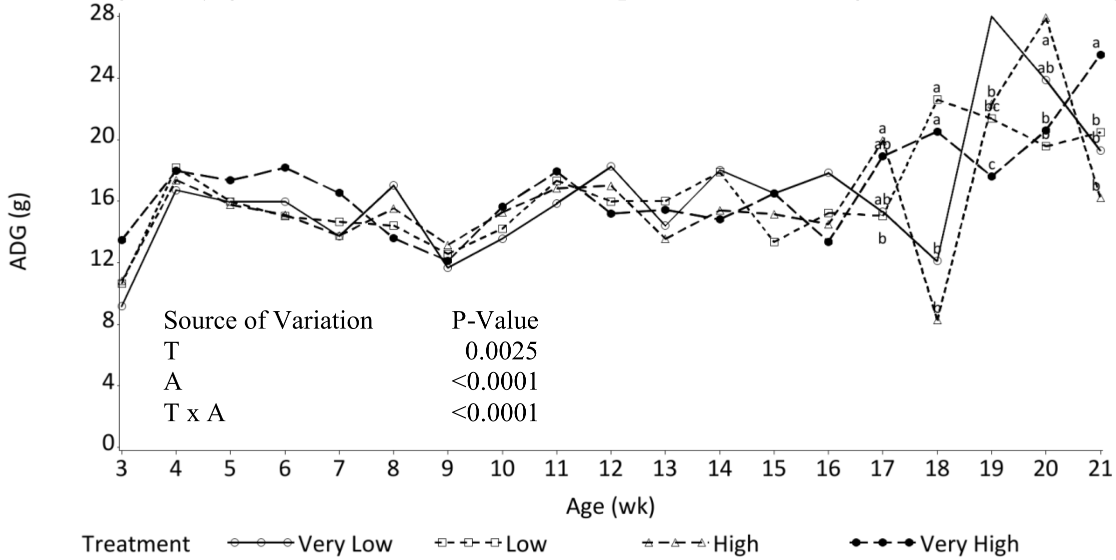
Very low (24 birds / PF station), Low (34 birds / PF station), High (44 birds / PF station), Very high (54 birds / PF station).
T = treatment effect; A = age effect; T x A = treatment vs. age effect.
Means reported for the previous week (i.e. ADFI from week 2 to 3 reported at 3 wk, and so on).
[a-b] Means within age with no common superscript differ significantly ($P < 0.05$).

Figure 5.4 Individual boddy weight (BW) and feed intake (FI) of two birds from the Low (24 birds) treatment from 2 to 21 wk of age.



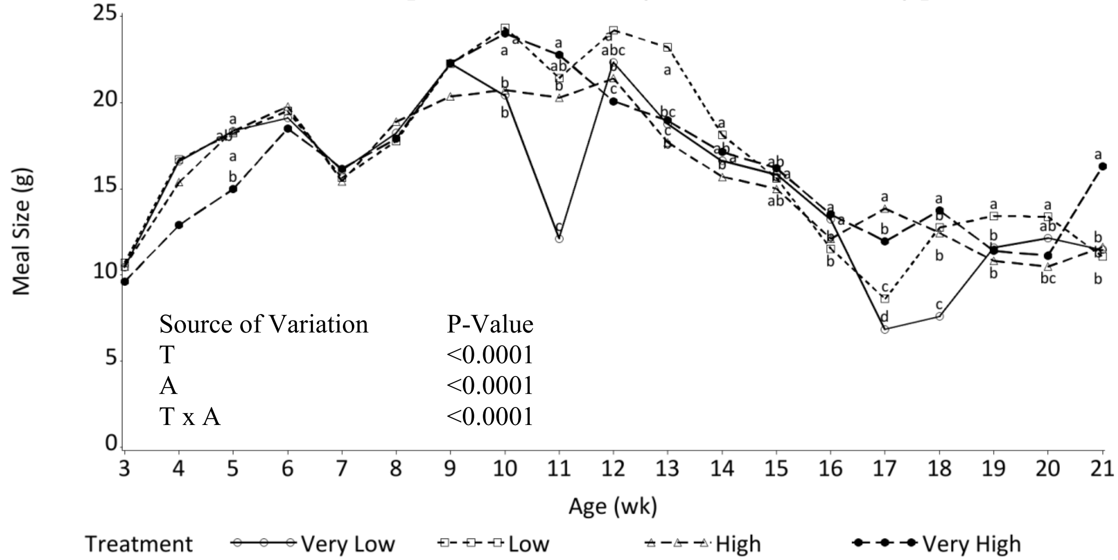
Dots are real time BW readings, bars are the real time FI and the line crossing the dots is the target Ross 308 BW. **A)** Bird with normal behavior shows BW readings more clustered together and closer to the target BW. **B)** Bird that moved excessively or touched the station walls had higher variability in BW. The amount of readings above the target BW is due the excessive consumption of feed in response to a previous erroneous detection of low BW.

Figure 5.5 Average daily gain (ADG) of broiler breeder pullets raised using 4 different stocking pressures from 2 to 21 wk.



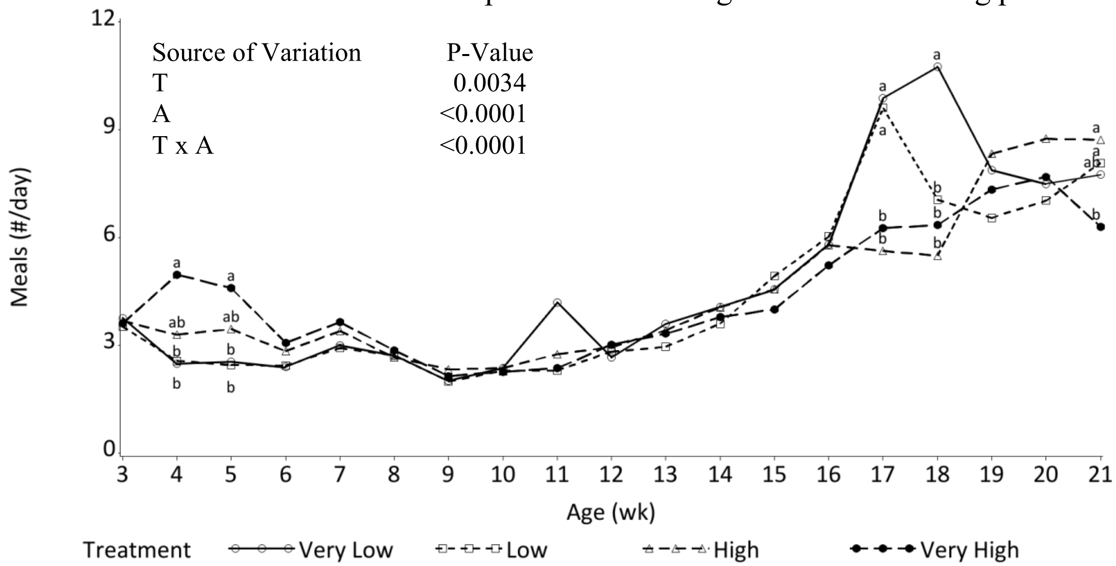
Very low (24 birds / PF station), Low (34 birds / PF station), High (44 birds / PF station), Very high (54 birds / PF station).
T = treatment effect; A = age effect; T x A = treatment vs. age effect.
Means reported for the previous week (i.e. ADG from week 2 to 3 reported at 3 wk, and so on).
[a-c] Means within age with no common superscript differ significantly ($P < 0.05$).

Figure 5.6 Meal Size of broiler breeder pullets raised using 4 different stocking pressures from 2 to 21 wk.



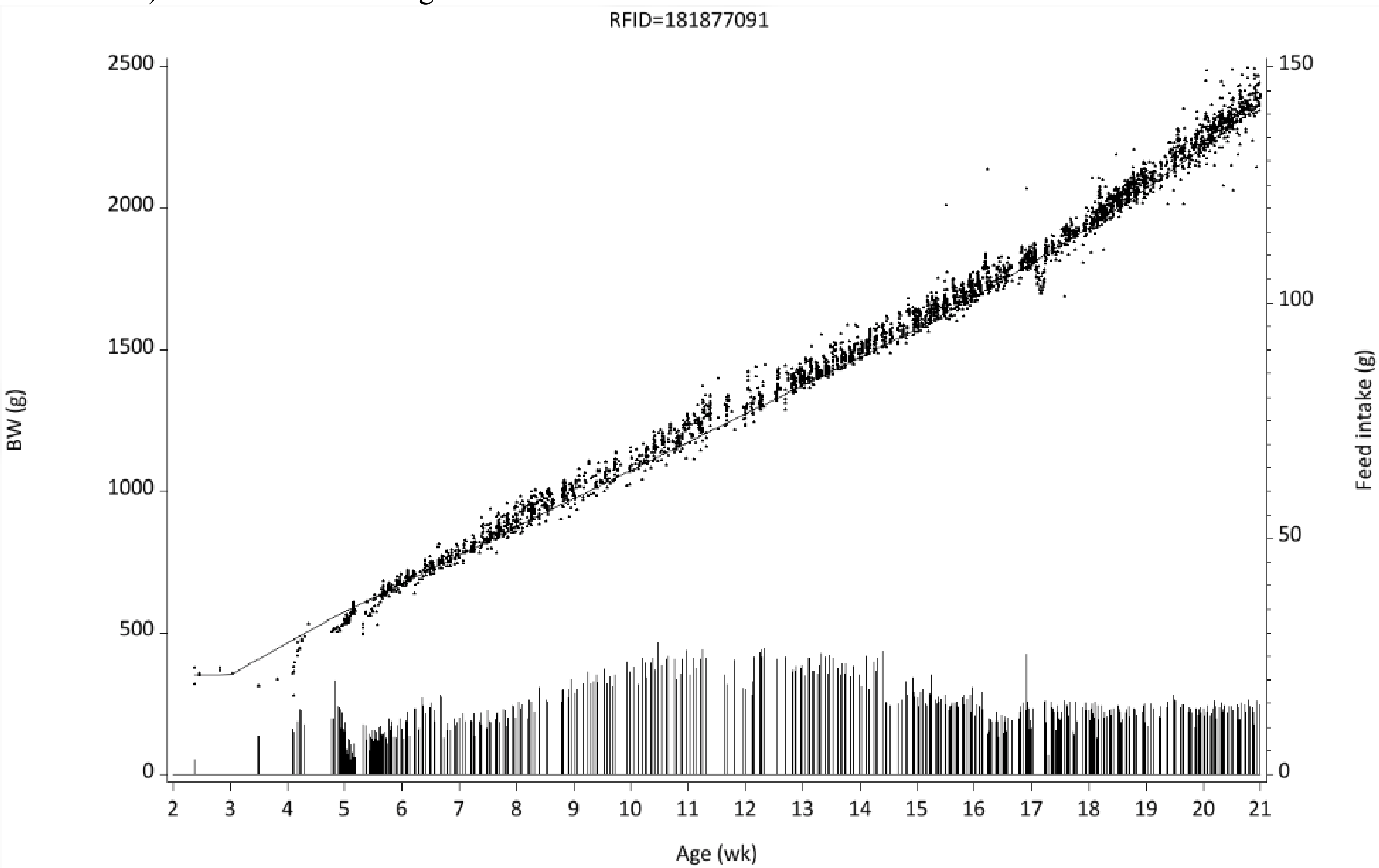
Very low (24 birds / PF station), Low (34 birds / PF station), High (44 birds / PF station), Very high (54 birds / PF station).
T = treatment effect; A = age effect; T x A = treatment vs. age effect.
Means reported for the previous week (i.e. Meal Size from week 2 to 3 reported at 3 wk, and so on).
[a-c] Means within age with no common superscript differ significantly ($P < 0.05$).

Figure 5.7 Number of Meals of broiler breeder pullets raised using 4 different stocking pressures from 2 to 21 wk.



Very low (24 birds / PF station), Low (34 birds / PF station), High (44 birds / PF station), Very high (54 birds / PF station).
T = treatment effect; A = age effect; T x A = treatment vs. age effect.
Means reported for the previous week (i.e. Number of Meals from week 2 to 3 reported at 3 wk, and so on).
[a-b] Means within age with no common superscript differ significantly (*P* < 0.05).

Figure 5.8 Individual body weight (BW) and feed intake (FI) of a bird in need of remedial intervention from the Low treatment (24 birds/station) from 2 to 21 wk of age.



Dots are real time BW readings, bars are the real time FI and the line crossing the dots is the target Ross 308 BW. The gap observed on FI and lack of dots between wk 2 and wk 5 are indications of days which the bird did not attempt to enter the system. After the "station visit" behavior had being reinforced by training on wk 4, the bird returned to enter the system and eat normally on wk 5, and showed consistent increases on BW.

6 SYNTHESIS

Selection for rapid growth rate and higher meat yield in broilers has been followed by an unintended increase in feed intake by their parent breeds (Renema and Robinson, 2004). This higher feed intake is negatively related to the performance of parent stocks due to increased carcass fat and disruption of the ovary morphology which leads to lower production of settable eggs (Hocking et al., 1987; Hocking et al., 1993). Therefore, feed restriction of broiler breeder pullets has become a common practice in an attempt to keep birds close to a target BW that will lead to higher reproductive performance during the production period. The feed allocation during rearing can be detrimental to birds' uniform development. When the amount of feed that is provided to a broiler breeder flock is not enough to match the nutrient requirement of the majority of birds, BW uniformity will decrease due increased competition for food (Pishnamazi et al., 2008). The CV of BW is a standard measure of BW variability and is used to indirectly assess uniformity by the industry. Typically BW CV ranges from 8 to 15% in commercial broiler breeder flocks. A CV of 10% or less is desirable and considered as good uniformity. This thesis focused on determining the effect of precision feeding on flock uniformity and pullet efficiency in comparison to a conventional skip-a-day restriction feeding program. Precision feeding consisted of automatically feeding birds individually multiple meals a day; the number of meals and the need of feeding was based on an automatic decision made by a computer when comparing pullet BW with a target BW input into the system. On the other hand, skip-a-day feeding consisted of group feeding birds a single large meal every other day. Two concurrent studies were run to measure the effect of precision feeding on flock uniformity, efficiency and water intake (Chapters 3 and 4). A third experiment was conducted to evaluate the effect of different stocking pressures on the capacity of the precision feeding system to feed birds individually while keeping the flock at desirable levels of uniformity (Chapter 5).

6.1 OBJECTIVE 1: FLOCK UNIFORMITY

The first objective was to check if precision feeding increased BW uniformity of broiler breeder pullets when compared to the skip-a-day feeding program. Bennett and Leeson (1989), defined BW uniformity as the percentage of birds in a sample flock with BW within +/- 15% of the sample mean BW. We can also determine flock uniformity indirectly by weighing a sample of birds and calculating the coefficient of variation (**CV**) associated with that particular sample (Cobb-Vantress, 2008b). The second approach measures the BW variation of a flock and the lower the CV the lower the BW variation, hence the higher the uniformity. It was reported in Chapter 3 that precision fed pullets reached higher level of uniformity (CV of 9.3% at 23 wk) when compared to skip-a-day fed pullets (CV of 13.3% at 23 wk). The natural competition for food from more dominant birds upon the less dominant ones generates different patterns of feed intake among birds within a flock. This results in some birds not consuming enough feed in a day to support their target growth rate. Hence differences in frame size within a flock start to appear. These type of flocks are considered to be non-uniform and are often associated with birds responding to photostimulation at different ages, which may decrease the production and persistency of production during laying (Abbas et al., 2015). These problems can be diminished by separating the flock into different BW categories and allocating feed differently for each category (grading) as found by Zuidhof et al. (2015). However, this practice may be unfeasible in some countries due to the high labor costs. Therefore, precision feeding might play a great role in such countries where grading becomes unfeasible. Although there is no competition at the feeder itself in the precision feeding system, there is a competition to enter the station. The manipulation of feed intake through the use of different target BW appears to have a direct effect on the flock uniformity as observed on Chapter 4. In that regard, the Low Flush target BW provided the highest uniformity (CV of 0.8%) and the Standard Flush the lowest (CV of 3.4%). Previous research with conventional methods of quantitative restriction reported BW CV in the range of 10.3% ± 3.02% throughout the trial (de Beer and Coon, 2007). In an industrial setting these values tend to be close to the high end of the BW CV range, mostly due the higher number of birds raised together which leads to higher competition for feed and more difficult management; it is common for the hatching egg producers to consider BW CV < 10% as a sign of good management (Cobb-Vantress, 2008c). Therefore, the findings in Chapter 4 are remarkable, since we were able to achieve high levels of uniformity within treatments, even though animals were housed in a single group with birds on other target BW curves, with a small BW CV of 2.1% ± 1.2%. In Chapter 5, the higher the stocking pressure, the lower was the uniformity until 5 wk of age. This happened because the competition for food prior to the start of individual feeding. However, precision feeding corrected the problem of poor uniformity as observed after wk 5 where all treatments were highly uniform showing similar values of CV 2.4% ± 1.03%. This shows that regardless the stocking pressure applied, the PF system seemed to have reduced competition by allowing the least aggressive birds a chance to eat, and this effect became more prominent once the animals were well acquainted to the PF system.

6.2 OBJECTIVE 2: EFFICIENCY

The second objective of this thesis was to check if precision feeding increased the feed efficiency of broiler breeder pullets when compared to skip-a-day feeding. Additionally, we further assessed the effect of different target BW or stocking pressures on pullets' efficiency. Because broiler breeders are in constant state of nutrient scarcity, there is a shift in their metabolism towards maximum post-prandial deposition of nutrients (de Beer et al., 2007). Since skip-a-day fed birds eat once every other day, fat deposition is often intensified which increases the effect of small changes in feed allocation in birds BW. For this reason, finding the right amount of feed to allocate to pullets is often a challenge for hatching egg producers. In Chapter 3, group feeding with the skip-a-day method presented a challenge and when we miscalculated the feed allocation at one point of birds' life, it was difficult to bring them back to their target BW. For this reason, precision feeding proved to be a very good technology as the feed allocation decision ran automatically in the background, in real time, while the system was weighing the bird to be fed. Furthermore, precision feeding demonstrated an reduction of 11% in feed intake when compared to the skip-a-day fed group for the same BW gain displaying a cumulative FCR 0.46 lower than the skip-a-day fed pullets. This may be due to the inefficiency of multiple cycles of nutrient storage and mobilization associated with the every other day feeding schedule (de Beer et al., 2007). Precision fed pullets also displayed an average of 7% higher breast yield and 33% lower fat pad when compared to skip-a-day fed pullets. Considering the feed price of $400.00 per metric ton, and that PF birds consumed 854g less feed throughout the experiment when compared to skip-a-day fed pullets, an economy of $0.34 per bird from 0 to 23 wk of age can be achieved by using the PF system. Additionally, the reduced feed consumption reflects on the reduction of the P and N excretion to the environment (Pomar et al., 2007; Andretta et al., 2014). In Chapter 4 we compared the effect of different target BW on feed efficiency. We observed that fast increases in target BW were associated with sudden increases in feed intake. This might have made birds to consecutively store and mobilize nutrients, resembling what normally occurs in a skip-a-day feeding program (de Beer and Coon, 2007). Because broiler breeders use between 85% to 90% of energy intake for maintenance, they have on average only 12.5% of the MEI available for growth (Chapter 4, Figure 4.5). Therefore, when an increase in the target BW in time of development of the reproductive system was made in a steady manner, as observed in our Flush treatments, birds tended to benefit from the extra energy available for growth such practice provided as shown by lower cumulative FCR associated with those treatments. The fact that no difference in cumulative FCR was observed in our study in Chapter 5 shows that the stocking pressure did not affect this variable. As observed in the previous chapters, the efficiency seemed to be closely associated with the target BW employed. This was probably related with different maintenance requirements associated with the different BW achieved (Yu and Robinson, 1992)

6.3 OBJECTIVE 3: WATER INTAKE

Managing water intake is detrimental in poultry systems as increased water-to-feed intake ratio increases the moisture content of the excreta, resulting in higher incidence of footpad dermatitis and negatively affecting animal welfare (Jiménez-Moreno et al., 2016). Because broiler breeders are more active than broilers it is expected that these birds will be more affected by the quality of the litter as it relates to the occurrence of foot pad dermatitis (Kaukonen et al., 2016). When feed restricting broiler breeder flocks, hatching egg producers often observe an increase in litter humidity associated with higher water intake (Hocking, 1993b). Although in Chapter 3 we did not measure the litter quality, we measured water intake associated with both precision feeding and skip-a-day feeding. Interestingly, we did not find significant difference between the two treatments with birds consuming on average 359 mL per day, which represents a 5:1 water:feed intake ratio, and is in agreement with the findings of Hocking (1993b) who showed that feed restricted Ross pullets drank 294.5 mL and ate 59 g of feed per day reaching similar water:feed ratio. Comparing the effect of ad libitum and restrict fed broiler breeders, Hocking et al. (1993) found that restricted birds spent 8% more time drinking water when compared to ad libitum fed birds and concluded that over drinking is an extension of foraging and may act as a feeding dearousal mechanism. Hocking (1993b) also observed that restricted fed birds drank 25% more water compared to ad libitum fed birds. In our study, the water intake was similar between birds in Skip-a-day and Precision feeding restriction programs, suggesting that regardless the feed restriction employed birds are equally motivated to drink. Therefore, one should expect no difference in litter quality when replacing skip-a-day feeding by precision feeding.

6.4 OBJECTIVE 4: FEEDING PATTERN

In conventional methods of feed restriction such as skip-a-day, because the feed is provided once a day on feeding days, it is almost impossible to observe how often each bird goes to the feeder as they are fed as a group. Precision feeding helps to understand and display patterns of feeding that would not be possible to identify by using conventional restriction programs. In Chapter 4 we observed that higher ADFI were associated with more visits to the precision feeding stations as opposed to increased amount of feed eaten per feeding bout. Although we represent our data as average for the sake of statistical analysis, it was very interesting to observe that some birds displayed unique behaviors. For instance, some birds would repeat the behavior of touching certain parts of the station to make themselves appear lighter and to qualify for a meal. Other birds would visit the system during specific periods of time during the day. Some would visit the station more often during the night. This shows how important it is to treat every animal as an individual and help us to shape new theories on bird behavior and physiology. Because the precision feeding system enables birds to have access to food 24 h a day, we think this technology may bring new light into the welfare of broiler breeders. Being able to eat more often may considerably increase the pullets wellbeing and an analysis of corticosterone levels throughout the day in comparison with other commonly used feeding restriction programs may help to identify if this new technology decreases their stress level. Our studies may lay the ground work for a new line of research through which we can observe different feeding patterns within a flock. This would help us to identify specific feeding behaviors associated with a possible disease outbreak or differences in temperature within the barn. Furthermore, precision feeding would be a good tool for the primary breeders producers as it makes possible the observation of individual growth and feeding patterns on real time basis, which would assist the industry on applying more intricate genetic selection programs in their flocks.

6.5 OBJECTIVE 5: STOCKING PRESSURE

Since the precision feeding system is a novel and expensive technology, we saw the need to determine the optimum number of birds each machine was able to feed to minimize the costs associated with this new technology. In Chapter 5 we were able to observe that once the individual feeding started, the stations were able to feed up to 54 birds with no negative effect on efficiency; the poorer performance observed before the start of the individual feeding was associated with the high competition for food around the feeder and could be easily addressed by putting an extra feed source close to the feeder. However, since no negative effect was observed by the end of the trial, we can assume that we did not use the maximum feeding capacity of the machines. During our first two experiments we observed that some birds were having difficulties of associating the precision feeding system with a reward feeling. Sometimes birds would just not wait while they were being weighed prior to qualify for a meal and jumped out of the machine. Other times, after they reached their target BW and were denied a feeding bout, they would just give up trying after two or three attempts. These birds needed to be trained on how to use the stations in an attempt to bring back the reward feeling they initially had when they were eating from the machines. However, we observed that older birds were more difficult to train as they were often forgetting or not being interested on waiting for the feed. Therefore, we developed a more accurate training protocol that must take place when birds are young (2 wk old) to help birds to identify that "waiting" and "trying" are normal features in precision feeding and that doing that they would eventually qualify for a meal. We observed that when trained at younger ages, broiler breeder pullets were very efficient on using the precision feeding system and often did not give up on waiting for their share of food once they qualified for a meal. The beauty of precision feeding system is that since we collected data in a real time basis, we were able to identify exactly when birds last visited the stations and when they have eaten their last meal.

6.6 NOVELTY OF RESEARCH

Precision feeding in broiler breeders is a novel technology that may help hatching egg producers to achieve higher production rates and uniformity once available commercially. Precision feeding has been applied before in pigs and cows to control BW and optimize production (Maltz et al., 2005; Pomar et al., 2007; Andretta et al., 2014). Although different feed restriction programs have been used in broiler breeders to control growth (de Beer and Coon, 2007; D'Eath et al., 2009; Zuidhof et al., 2015), there is no research that applies precision feeding techniques in these animals. However, it had been suggested that more frequent feeding of broiler breeders may improve welfare (Mench, 2002). According to Gilmet et al. (2016), precision feeding decreased hunger motivation in feed restricted broiler breeder pullets. Additionally, it appears that PF system increased aggressive behavior without affecting the social rank within the flock (Gilmet, 2016). Furthermore, it has been demonstrated that a more consistent feeding allocation method improved flock uniformity (Zuidhof et al., 2015) which may lead to higher performance during laying phase (de Beer and Coon, 2007). This thesis was the first to investigate the effect of precision feeding system on broiler breeder uniformity and efficiency.

6.7 STUDY LIMITATIONS

As the precision feeding system used in our studies was an early prototype, there were some features that could be improved. For instance, the fairly sensitive load cell used on the scales for the experiments on Chapter 3 and 4 caused the scales to eventually record wrong BW and FI values. This sometimes required total replacement of the scale. Furthermore, we observed that the RFID of some birds would sometimes be read when outside the station. In order to filter the data eliminating values where those errors were present, we used the model described by (Pishnamazi et al. (2015)) and median BW in our analysis. This also explains why we started both trials when birds were already 13 wk old, as before this age the stations were not performing in a way to provide reliable data to be analyzed. Although most issues were corrected after wk 13, there were still some data errors shown as outliers in our statistical analysis that had to be eliminated, which might have influenced our results. These issues were fixed on the second prototype that was used on the trial of Chapter 5 making the data more reliable and with no need of correction. In spite of the study limitations, the large amount of data collected helped us to analyze and understand unique characteristics birds have, otherwise impossible to observe when they are fed as a group.

6.8 FUTURE RESERACH

The studies performed in this thesis provided means to understand individual feeding patterns and behaviors of broiler breeders that will help to develop more intricate research. For instance, there is a current prototype being developed that will make possible feeding four different diets for birds which will hopefully provide more means to control the MEI and growth. It would also be interesting to study the economics associated with precision feeding when compared to daily restriction and a qualitative restriction program. As we did not see a negative effect on feeding 54 birds after the individual feeding started on Chapter 5, we can assume that the stations were yet not tested to their maximum capacity. Therefore, more research should be conducted to determine the maximum feeding capacity of the precision feeding system. By using more birds per station we could potentially decrease the cost of operations by dividing the total cost of the PF system among more birds; however, we should keep in mind that by doing so we could also be decreasing the system depreciation time and increasing the competition between birds, which could reduce the flock uniformity. PF system may also help to provide a good understanding of the feeding behavior of broiler breeders by testing different feeding bout settings (time duration and amount of feed provided) in future research. In the near future we expect to use all the data gathered from the stations over the years to build models that will help to explain the growth and reproductive development of broiler breeders reared using different BW targets and fed different diets.

6.9 OVERALL IMPLICATIONS

The availability of precision feeding for the industry may facilitate more intricate genetic selection procedures due the possibility of identifying desirable traits or behaviors at animal level. Since the precision feeding system is capable of acquiring data in real time, it is possible to analyze and graph individual feed intake and body weight gain for any period of a day or week. Furthermore, future models developed by using the data gathered over the years may be used by the hatching egg producers to adjust the feed allocation when using the conventional methods of restriction feeding such as daily, skip-a-day and 4/3. As observed in Chapter 3, we expect that using the precision feeding in a commercial setting will provide considerable feed economy which may increase the profitability in the market. Furthermore, the lower feed intake would diminish the excretion of P and N to the environment (Pomar et al., 2009; Andretta et al., 2014), which is important to prevent the occurrence of eutrophication in aquatic systems (Dodds and Smith, 2016). Also, current changes in the prototype are being made in order to make the machines lighter and more user friendly for hatching egg producers. We also visualize precision feeding working in synchronization with other technologies within a barn that will provide the farmer a direct insight of birds' response to changes in ventilation, air quality and temperature. The association of those traits with number of visits, feed intake and weight gain displayed by birds might help to provide a good quality picture of what is going on within the flock which may help to identify health problems and prevent a disease outbreak. Another important aspect of precision feeding in broiler breeders is that such technology would be perceived by the general public as a good practice and beneficial to the birds because of their ability to eat without being disturbed. The commercialization of such technology would be the next step so the hatching egg producers could benefit from it.

6.10 CONCLUSION

Our results showed that precision feeding was a valuable technology that improved efficiency and flock BW uniformity of broiler breeder pullets. The system was able to effectively keep the BW variation low, and hence maintain high flock BW uniformity even when high stocking pressures were employed.

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