INFLUENCE OF EARLY PHOTOSTIMULATION AND EVERY-DAY-SPIN FEEDING PROGRAMS ON THE REPRODUCTIVE PARAMETERS OF BROILER BREEDER HENS

by

MATTHEW BRUCE HABERSANG

(Under the direction of Andrew P. Benson)

ABSTRACT

The primary objective of broiler breeder management is to create as many fertile hatching eggs of optimal weight and uniformity as possible, while dealing with limited reproductive potential due to genetic selection for fast growth. In order to accomplish this task, the proactive identification of strategic systems which maximize savings in both time and money while improving reproductive parameters must be a priority. This experiment compared the effects of early photostimulation at 15 weeks (15P), and an every-day-spin feeding program (EDS), on the reproductive parameters of broiler breeder hens in a 2x2 factorial arrangement. The results of feeding an every-day-spin program at a standard photostimulation period of 21 weeks (EDS-21P), vs. a skip-a-day program at standard photostimulation (SAD-21P) showed a significant increase of 5% (P= 0.0392) in percent hen-housed egg production (% HHEP) from weeks 44-65, and a significant decrease of 32% in mortality (P=0.041). The early photostimulated 15P treatment did not differ significantly in egg production from the standard 21P treatment due to a 4-week advantage in the onset of lay. The overall conclusions are that an EDS-21P program could be implemented in order to improve egg production and immune function in broiler breeder hens, while a 15P program has potential but needs further research.

KEYWORDS- Broiler breeder, skip-a-day, every-day, early photostimulation.

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Chapter 1

INTRODUCING BROILER BREEDERS

The growth potential of broilers has increased by over 400% during a 50-year time frame (Zuidhof et al., 2014) due to intense genetic selection and improvements in nutrition, but the improvements come with the consequence of reduced reproductive efficiency (Siegel and Dunnington, 1985). For 50 years the adverse effects of accelerated growth on reproductive fitness have been known in the chicken. According to J.E. Schneider and P. Deviche (2017), the conflicting behaviors of reproduction and feeding have been well-studied on a physiological and behavioral level.

The economic and practical objectives that go into the final decision-making processes at the company level are outside the scope of this review, but in short, a good solution in the poultry industry is one that solves a problem without creating another. The ability of producers to predict output and meet market requirements is essential, and promotion of uniformity within the breeder flock helps reduce the variance at the processing plant. As genetic selection for fast growth and increased muscle mass continues, the window for balance in reproductive efficiency narrows, making the development of proactive strategic methods to mitigate the consequences and further define broiler breeder reproductive fitness a primary industry objective.

The importance of context must be noted before going into further detail about the physiological mechanisms that either support or inhibit reproductive behavior and performance, and ultimately define broiler breeder fitness. This is especially true when evaluating livestock bred for a specific purpose, such as broilers bred for meat and white Leghorns bred for optimum egg-laying ability. While both birds are within the species *gallus gallus domesticus,* they are not the same.

Chapter 2

NECESSITY OF FEED RESTRICTION

For many species, including White Leghorns, maturity can be defined as the point in time at which growth ceases and nutrients can be allocated towards maintenance and reproduction. Laying hens currently produce 320 eggs a year, and have a very low incidence of metabolic disorders concerning reproduction or body weight gain (Druvan, 2010; Buzala et al., 2015). For the broiler breeder, the balance between growth and egg production, termed indeterminate growth, occurs throughout the entire life of the hen (Lika and Koojiman, 2003; C. Salas et al., 2016).

The modern broiler is unable to control its own feed intake (De Beer and C.N. Coon, 2007), and due to its fast rate of growth, reaches around 2.5 kg in less than 6 weeks when allowed to feed *ad libitum* (Leeson and Summer, 2000). This 60% reduction in time to market weight when compared to the genetic strains of 50 years ago (Havenstein et al., 2003) has caused a number of metabolic issues that occur along with reduced reproductive performance, including ascites, increased prevalence of sudden death, fatty liver, and obesity (Griffin and Goddard, 1994; McGovern et al., 1999; Julian, 2000). When broiler breeder hens are fed *ad libitum,* they develop systemic inflammation, aberrant leukocyte function, cardiomyopathies, ovarian granulosa cell death, and ovarian follicle regression (Chen et al., 2006; Pan et al., 2012; Xie et al., 2012; Liu et al., 2014; Walzem and Chen, 2014; 2016; Chen et al., 2017).

The ideal body weight for reproduction in broilers is 2.5 kg (same as 6 week *ad libitum* fed market weight*)*, however, 20 weeks of age is when the hypothalamus may fully mature for optimum reproductive performance (Leeson and Summer, 2000). Since an excess in body weight before peak egg production is detrimental to long term performance objectives, (as

reviewed by Robinson et al., 1991b) feed restriction must be used in order to keep birds healthy during both the rearing and laying periods. While not yet studied in broiler and laying chickens, results from an experiment by Boon et al (2000) involving broiler vs. layer lines of Japanese quail showed that with an increased photoperiod of 18L:6D vs 6L:18D, broiler gross energy intake was 37% higher in the 18L group while energy expenditure decreased by 33% in the 6L group. The layer group increased gross energy intake by 22% and decreased energy expenditure by 34%, respectively. These results suggest that energy balance in relation to photoperiod is attained mainly through increased consumption of feed in broiler lines and slowed metabolic function in layers. The inability of the broiler to increase or decrease its metabolism in a controlled environment makes controlling feed intake the most practical method of maintaining a healthy body weight in broiler breeders.

Feed restricted birds are fed approximately 60-80% of the normal rations that a bird fed ad libitum would receive (Renema and Robinson, 2004). Also, feed restricted birds have better flock uniformity (Robbins et al., 1986; Katanbaf et al., 1989; Heck et al., 2004; Bruggeman et al., 2005), and will produce more eggs through the course of their lives (Leeson and Summers, 1985; McDaniel et al., 1981; Yu et al., 1992a; Heck et al., 2004; Bruggeman et al., 2005; Onagsbean et al., 2006) because they are more persistent in lay (Fattori et al., 1991), lay in longer sequences (Robinson et al., 1991a), and lay fewer abnormal eggs (Fattori et al., 1991; Yu et al., 1992a; Heck et al., 2004). In particular, feed restricted birds lay less double-yolked eggs that result when an abnormal amount of large hierarchical follicles are stimulated to develop on the ovary at the same time (Hocking, 1987; Hocking et al., 1989; Heck et al., 2004; Hocking and Robertson, 2005). While feed restriction has widely been accepted as necessary in the poultry industry, the best methods have been up for debate.

The possible methods for feed restriction used in the poultry industry can be categorized as either quantitative or qualitative. In a quantitative feed restriction program, less feed is given per serving, but the nutrient density of the feed remains similar to a control diet. This method is cheaper and more widely used because less bulk in feed is needed. For qualitative, the nutrient density is lowered with a less digestible feed ingredient, and the amount of feed given is increased to make up the nutritional difference. More feed means more cost; however, qualitative restriction may gain more popularity due to increasing animal welfare concerns, and possible other benefits. Research has shown that qualitative restriction with high fiber or appetite suppressants may be better at satiating the appetite of broiler breeders by relieving symptoms of hunger (Morissey et al., 2014). Also, high fiber ingredients are sometimes linked to prebiotic or probiotic function, and evidence that the HPG axis can increase or decrease nutrient uptake by communicating with the gut microbiome to support different stages of reproduction is a new and interesting detail (Schneider & Deviche, 2017). Further research into this arena needs to be conducted to determine the practical significance.

The most commonly used method of feed restriction in the United States is a quantitative skip a day (SAD) program. Using this method, pullets are fed once every other day during the rearing period, and once every day during lay. The implementation of every day feeding at the 21- week photostimulation mark has been shown to increase total egg production by 19 eggs per hen at 65 weeks of age when compared to hens fed on a SAD program until 5% egg production is reached (Gibson et al., 2008). The reduction in feed intake necessary to maintain a healthy body weight in modern broiler breeders has resulted in increased competition for feed when there is inadequate feeder space, which may result is poor uniformity through the growth curve if some birds do not get a chance to eat. While the same total amount of feed is given on either the SAD

or ED feed program, the volume of feed given at feed time is doubled when feeding every 48 hours (SAD) vs. 24 (ED), which helps to increase feed clean-up time and gives every bird an opportunity to eat (Zuidhof et al., 2015). A uniform flock has more synchrony in age at sexual maturity, good peaks in egg production, and allows the company to better predict and maintain nutrient requirements (De Beer and C.N. Coon, 2007).

Variations in feed programs between SAD or ED can also affect uniformity. Scatter, or spin feeding, can be used with either an ED or SAD (not normally used with SAD) and is a program that spreads out feed particles evenly on the ground in order to eliminate feeder space competition. Birds are forced to learn foraging skills, feed clean up time is increased, and due to the increased spatial and temporal feed availability, uniformity can be increased (Zuidhof et al., 2015). Research by Zuidhof et al. (2015) showed lower CV by week 22 in SAD fed pullets vs. ED fed (12.7% vs 15.2%) pullets, but the difference was mitigated by an every-day scatter (EDS) program (10.9%).

In addition to improving flock uniformity, EDS feeding has also been shown to improve recovery from *Salmonella* and *Campylobacter* infections (Wilson et al.,2018), which can be introduced into a poultry house through feed, equipment, rodents, insects, pets, and people, and affect the growth of chicks (Hoover et al., 1997; Davies and Breslin, 2003; Jones and Richardson, 2004; Arsenault et al.,2007; Roche et al., 2009; Dewaele et al., 2012; Lapuz et al., 2012; Wilson et al., 2018). Alimentary tract emptying during the off-feed day in SAD, similar to feed withdrawal before slaughter, may allow for continued colonization in the pullet flock, and SAD was the only treatment to have detectable cecal *Salmonella* through 20 weeks when compared to ED and EDS (Wilson et al., 2018).

There are also several methods of SAD feeding, including 5-2, 4-3, and simple skip (SK). The 5-2 method is most commonly used, and involves feeding 5 days every week while skipping 2 (F-F-S-F-F-S), a 4-3 schedule involves feeding 4 and skipping 3 (F-S-F-S-F-S-F), and an SK skips every other day with a non-resetting schedule. While all methods feed the same amount, birds get fed 71.4% of the time for 5-2, 57.1% of the time for 4-3, and 50% of the time for SK. Meal sizes on feed day, including ED, from smallest to largest are: ED, 5-2, 4-3, and SK. Performance objectives improved by ED programs compared to SK include FCR (10%; De Beer and C.N. Coon, 2007), age at sexual maturity (Wilson et al., 1989), percent hen housed egg production (10 day lead), and earlier egg peaks (Katanbaf et al., 1989). According to De Beer and Coon (2007), the feed conversion differences are the result of inefficient repeated cycles of fasting and mobilization of nutrients associated with SK. The advantage of using the skip methods, particularly with 5-2, were significantly larger egg weights relative to BW when compared to ED hens (De Beer & Coon, 2007).

There are also ways to vary the feeding program after photostimulation. In a study done by Spradley et al (2018), pullets were put on a once vs twice daily feeding program at photostimulation, while still given equal amounts of feed overall. The total egg production improved in the twice a day group by 5 eggs per hen through week 41, and hen day egg production improved by 2 percent through week 59. This gain was countered, however, by a higher mortality rate of hens in lay in the twice a day group (63% vs. 25%), and financial gains were lost on a hen housed basis (Spradley et al., 2018).

Photoperiod is the term used to describe the ratio of light hours to dark hours per day, and shorter photoperiods during the rearing period have been shown to accelerate the dissipation of the photorefractory state and synchronize the onset of lay at photostimulation (van der Klein et

al., 2018b). In a study with Japanese quail that tested different photoperiods against feed availability by Boon et al. (2000), there was a discontinuous growth curve when the photoperiod decreased to 12L:12D or less. The birds then relied on body reserves for energy during the postabsorptive state and showed BW increase during light and dark phase, and subsequent cessation of gain or BW loss when the respiratory quotient (RQ) fell below 1. Access to feed was also a determining factor in overall body weight gain where birds with access to feed for 6 hours during an 18-hour light period showed a body weight gain pattern similar to the treatment group who had access to feed for 6 hours during a 6 hour total light period (Boon et al., 2000). Photorefractoriness occurs naturally when exposure to long photoperiods of 13 hours or more during the same year as a chick is hatched delays sexual maturity in the chick, avoiding suboptimal conditions for reproduction (Lewis, 2006; van der Klein et al., 2018b). In a study by van der Klein et al. (2018b) using a precision feeding system that compared different photoschedules and high vs low BW at photostimulation, cumulative feed intake (CFI) was lower in hens on the high BW treatment that were reared on the 8L:16D compared to 10L:14D and 12L:12D.

Another way to control reproduction in broiler breeders is by altering time at photo-stimulation. The minimum age at which broiler breeders can be photosensitive is 10 weeks (Lewis, 2007), but the industry standard for photostimulation is at 21 weeks. An economic benefit could be derived if earlier photostimulation resulted in earlier age at sexual maturity, and no other negative impacts on reproductive traits were discovered. This would also lengthen the productive period per flock by eliminating weeks of non-productive time in rearing (van der Klein et al., 2018).

During the rearing stage, broiler breeders will typically have an 8 to 10-hour lighting program, and at 21 weeks, a 12 to 14- hour photoperiod is implemented. Weekly increases are then made to reach a maximum of 15-16 hours by week 25-30. The broiler breeder's response to photostimulation depends on the dissolution of juvenile photorefractoriness, which is defined as the inability to respond positively to a stimulatory photoperiod (Lewis et al. 2003). Reproduction can be delayed when photorefractory birds are not given short days during rearing, or when transfer to long days happens too early, and the dissipation of photorefractoriness also depends on the amount that growth is restricted.

Chapter 3

PHYSIOLOGY OF FEED INTAKE & REPRODUCTION

3.1 Introduction

The relationship between feeding and reproduction in poultry is complex and elaborate, and the signaling pathways include hormones, neurotransmitters, secreted factors, and cytokines (Richards et al., 2010). The importance of regulated pathways when correctly identified, are that they can be used as critical control points and manipulated in order to better maintain whole body energy balance and accomplish a given objective (Richards et al., 2010). As the mechanisms of energy utilization and retention efficiency change as a function of internal and external cues, energy partitioned for egg production is altered (Romero et al., 2009; Salas et al., 2016).

Taken practically, broiler breeder hens must: 1) be of an adequate BW with sufficient energy reserves, 2) receive an adequate nutritional allotment to support reproduction on a regularly scheduled basis, and 3) be photostimulated (greater than 12 hours) at the onset of reproduction to promote the hormonal cascade of the HPG axis. The basic components of HPG axis function are gonadotropin-releasing hormone (GnRH), follicle stimulating hormone (FSH), and luteinizing hormone (LH), and understanding the details of HPG axis stimulation first requires a review of these basic components.

3.2 GnRH, FSH, & LH

Gonadotropin-releasing hormone is produced and released from the hypothalamus in response to environmental and physiological cues (Contijoch et al., 1992; Advis and Contijoch, 1993). GnRH is a 10 AA neuropeptide, and production occurs in the preoptic area of the hypothalamus (Matsuo et al., 1971; Burgus et al., 1972). From there, fibers extend into the

hypothalamic-hypophyseal portal system where GnRH is released into the circulation. It then goes to the anterior pituitary gland where it stimulates the production and release of FSH and LH in the gonadotrope cells. FSH and LH enter systemic circulation and end up in the gonads where they regulate follicular maturation and ovulation by binding with FSH and LH receptors in the ovary. The functions of FSH are to promote the maturation and proliferation of granulosa cells (Davis et al., 2000, 2001), help in maintaining the follicular hierarchy through the prevention of atresia (Palmer and Bahr, 1992; Johnson et al., 1996a, 1999), induction of the LH receptor, steroidogenic acute regulatory protein, and P450 cholesterol side cleavage enzyme in granulosa cells for further steroid production (Li and Johnson, 1993; Johnson and Bridgham, 2001; Johnson et al., 2004), and stimulation of progesterone production (Calvo and Bahr, 1983; Robinson et al., 1988; Davis et al., 1999, 2001; Johnson et al., 2004). FSH receptivity is the determining factor in the recruitment of a pre-hierarchical follicle into the hierarchy, thus avoiding apoptotic cell death.

In the next phase of follicular maturation, FSH receptivity goes down while LH receptivity gets stronger (Calvo and Bahr, 1983), and thecal LH to LH-R interactions promote steroidogenesis within the prehierarchical follicles (Robinson et al., 1988; Kowalski et al., 1991) while m-RNA expression of LH-R does not vary significantly depending on follicular development (Johnson et al., 1996b). LH induction of granulosa cell proliferation (Davis et al., 2000) and progesterone production (Davis et al., 1999; Johnson et al., 2004) eventually leads to the ovulation of the F1 follicle, which peaks 4-6 hours prior to ovulation (Etches, 1990).

3.3 Leptin, Ghrelin, & Visfatin

Before stimulating the HPG axis into an active reproductive state, the body must evaluate itself for reproductive readiness. Some of the intrinsic mechanisms that communicate this

information come in the form of adipokines, or hormones derived from fat. Three notable adipokine hormones are leptin, ghrelin, and visfatin. Leptin has been shown to regulate food intake, energy balance, body weight, and reproduction (Zieba et al., 2005). Its receptors which mediate reproductive cues have been located in the pituitary gland, hypothalamus, and the gonads (Cioffi et al., 1997; Karlsson et al., 1997; Spicer et al., 1997, 1998; Ruiz Cortes et al., 2000; Donato et al., 2011). The message communicated through leptin is that the body is energetically ready, through sufficient adipose amounts, to assume a reproductive state. Specific signals include beginning puberty, maintaining normal sexual maturation, and initiation of fertility (Friedman and Halaas, 1998; Baldelli et al., 2002). Decreases in plasma leptin during feed restriction or starvation have been shown to decrease GnRH and LH from the hypothalamus and anterior pituitary gland. Conversely, intraperitoneal and intracerebroventricular injection of leptin has been shown reverse the effects, restoring GnRH and LH levels (Henry et al., 2001; Farooqi et al., 2002). Normal reproduction is inhibited when there is an over-abundance of leptin, such as in conditions of obesity (reviewed by Hausman et al., 2012; Perez-Perez et al., 2015), and the inhibition is the result of leptin receptor activation within the gonadal tissues and subsequent steroidogenic depression (Spicer et al., 1997, 1998, 2000; Zachow et al., 1997; Agarwal et al., 1999; Brannian et al., 1999; Ruiz-Cortes et al., 2003; Hausman et al., 2012; Perez-Perez et al., 2015). While most research into the effects of leptin has been conducted in mammals, leptin has been identified in hepatic and adipose tissues in avian species (Taouis et al., 1998; Ashwell et al., 1999; Serroussi et al., 2014), and expression of the leptin receptor has been found in the ovary of the hen (Ohkubo et al., 2000; Paczoska-Eliasiewicz et al., 2003). It should be noted that there is debate on whether leptin serves the same role in chickens as it does in mammals.

Ghrelin is an adipokine hormone that is 28 amino acids long, acts as the endogenous ligand of the growth hormone (GH) secretogue receptor (GHS-R) (Kojima et al., 1999), and stimulates GH secretion. In mammalian species ghrelin communicates energetic insufficiency to regulate reproduction and metabolism (Elmquist and Zigman, 2003; van der Lely et al., 2004), and an ICV injection decreases pulse frequency of LH in both male and female rats, female ewes and monkeys, and human males, regardless of whether the gonads are intact (Faruta et al., 2001; Vulliemoz et al., 2004; Fernandez-Fernandez et al., 2005; Iqbal et al., 2006; Garcia et al., 2007; Kluge et al., 2007). In broiler breeder hens, the receptor for ghrelin has been detected in theca and granulosa cells from both nonhierarchical and hierarchical follicles, expression of the ghrelin receptor is down-regulated in cultured granulosa cells after adding FSH and LH, and ghrelin levels increase in the plasma of hens that are fasted (Freeman and Davis, 2008).

Visfatin is an adipokine shown to play a role in insulin resistance, cardiovascular disease, inflammation, apoptosis, and tumor formation (Li et al., 2018). Visfatin is up-regulated in several immune system cells, such as monocytes, macrophages, dendritic cells, and lymphocytes (Santina et al., 2009; Bergh et al., 2012). It may reduce blood glucose and promote the differentiation of adipocytes, playing a role in regulating glucolipid metabolism (Wang et al., 2016; Fukuhara et al., 2005; Xiao et al., 2015; Ons et al., 2010). In an experiment using Roman brown layer chicks and comparative transcriptome analysis by Li., et al (2018), ICV injection of 400ng visfatin significantly reduced endogenous insulin secretion through negative feedback in the high treatment. Both treatments caused a significant increase in appetite (Cline et al., 2008; Li et al., 2018). In turkeys, visfatin expression has been identified in plasma, peripheral tissues, and ovarian cells (Diot et al., 2015), and in broilers, expression is higher in muscles than in fat tissues (Krzysik-Walker et al., 2008; K-W et al., 2011). The results also showed decreased

tyrosine hydroxylase, dopamine, and corticotropin releasing hormone, which were hypothesized to promote chick feeding through an increase in the release of opioids. In the layer chicks, GnIH went up in the low, 40ng treatment of visfatin, but dropped in the high, 400ng treatment. GnRH-I went up in the low, but leveled off in the high (Li et al., 2018).

Highlighting the importance of context in physiological systems, visfatin is shown to decrease tyrosine hydroxylase and dopamine in layers, and dopamine has been shown to inhibit prolactin in the hypophyseal-portal system (Grattan, 2015). Serotonin is known to inhibit reproduction directly through decreased GnRH-I synthesis (el Halawani et al., 1995) and LH secretion (Hall et al., 1986) in turkey hens (el Halawani et al., 1995; Rozenboim et al., 1993; el Halawani et al., 1988) and broiler breeder hens (Mobarkey et al., 2013), and inhibit indirectly through vasoactive intestinal peptide (VIP; el Halawani et al., 1995; Moore et al., 1978; Opel and Proudman, 1988; Palkovitz et al., 1977) which is the major avian prolactin releasing factor (Chaiseha et al., 1998; Youngren et al., 1996). High prolactin levels can induce testicular regression in roosters (Lofts and Marshall, 1956; Mazzi et al., 1967), and inhibit GnRH-I and LH secretion (Rozenboim et al., 1993; Weick and Stobie, 1995; Avital-Cohen et al., 2015). In aging White Leghorn roosters, immunization against cVIP causes mRNA gene expression of prolactin, GnRH-I, LH, and FSH to decrease, and leads to a decrease in sperm concentration, ejaculation grade, percent testis weight, and semen volume (Avital Cohen et al., 2015). Giving ovine prolactin (oPRL) restores the function. Conversely, in aging broiler breeder roosters, a higher expression of prolactin leads to decreased reproductive function, and immunization against cVIP improves sperm concentration, ejaculation grade, percent testis weight, and semen volume (Avital-Cohen et al., 2015). Furthermore, administration of oPRL decreases function when given to previously cVIP immunized broiler breeder roosters. In summary, visfatin decreases tyrosine

hydroxylase thus decreasing dopamine and CRH, promoting chick feeding through stimulation of opioid neuropeptides neuropeptide Y (NPY) and agouti-related protein (AgRP). Dopamine decreases prolactin, and prolactin decreases GnRH-I in broiler breeder roosters, thus visfatin has an indirect effect of decreasing GnRH-I by increasing prolactin. This should not be taken out of context and applied to layer roosters, where an increase in prolactin for an aging rooster leads to an increase in reproductive parameters (Avital-Cohen et al., 2015).

3.4 GnIH & Melatonin

Another important neuropeptide in birds is gonadotropin-inhibitory hormone (GnIH). It has been shown to regulate both reproduction and feeding behavior (Tachibana et al., 2005, 2008), and is synthesized in the paraventricular nucleus (PVN) of the avian brain (Tsutsui et al., 2000). Its expression is controlled through photoperiod in avian species (Chowdhury et al., 2010), and it functions to inhibit LH and FSH secretion from gonadotrope cells in the anterior pituitary gland (Tsutsui et al., 2000). Its concentration in the brains of Japanese quail and chickens is highest in the thalamus, hypothalamus, subthalamus, and epithalamus (Tsutsui, et al., 2000; Satake et al., 2001; Ikemoto and Park, 2005; Bentley et al., 2008). Due to the close proximity of GnIH fibres to GnRH neurons in the preoptic area of birds, there is a suggested direct regulation of GnRH by GnIH (Ubuka et al., 2008; Son et al., 2012; Sethi and Chaturvedi, 2016). There is also evidence that GnIH is released into the hypophyseal portal system due to the prescence of GnIH in the external median eminence (ME), and that it inhibits release of LH, but not prolactin (Tsutsui et al., 2000). GnIH precursor mRNA has been found in the ovary, testis, epididymis, and vas deferens of Japanese quail (Bentley et al., 2008), however, it was not detected in the ovaries of the Leghorn (Maddineni et al., 2008b). In an experiment with male Japanese quail by Ubuka et al. (2006a), a dose dependent decrease in testosterone,

gonadotropins, and spermatogenesis was detected in mature birds after chronic treatment of GnIH through an osmotic pump. The treatment also caused induction of testicular apoptosis.

GnIH has been researched for its connections with melatonin, a hormone known to inhibit reproduction during seasonal changes in avian species (Ohta et al., 1989; Bentley & Ball, 2000; Guyomarc'h et al., 2001; Rozenboim et al., 2002). Melatonin comes from the pineal gland and eyes, regulates the gonadal system through the Mel1b and Mel1c receptors, and has been shown to induce GnIH expression in the PVN by acting directly on GnIH receptors (Sethi & Chaturvedi, 2016). It displays a cyclic expression pattern based on enzymatic activity of N-acetyltransferase (Binkley, 1981; Underwood et al., 1984) which is most active in darkness vs. light. This means that during longer spring and summer days, when most birds are in the breeding season, blood levels of melatonin will be low (Blinkley, 1981). An experiment by Ubuka et al. (2005) in Japanese quail using pinealectomy (Px) and orbital enucleation (Ex) to remove the sites of melatonin synthesis and evaluate its impact on GnIH showed decreased melatonin levels, and dose dependent decreased hypothalamic expression of GnIH mRNA precursor polypeptide and GnIH peptide. Subsequent supplementation of melatonin to the Px plus Ex quail increased GnIH and GnIH precursor polypeptide mRNA expression (Ubuka et al., 2005). Melatonin was concluded to act directly through binding with GnIH receptors. Melatonin has been shown to exert inhibitory HPA axis control in chickens by indirectly suppressing ACTH release and thus corticosterone (CORT) (Decuypere et al., 1989; Rasmussen et al., 2003; as reviewed by Hassanzadeh et al., 2019), the hormone which guides the stress response in birds.

The inhibitory reproductive effect of the GnIH system in broilers and other avian species may be partially mediated by stress. GnIH expression is stimulated in ovarian and testicular tissue, and in the testicular tissue, GnIH expression is also stimulated by CORT (McGuire et al.,

2013). Metabolic stress in the form of high ambient temperatures was shown to result in decreased food intake and increased GnIH hypothalamic mRNA expression in broiler chicks (Chowdhury et al., 2012), and in Pekin ducks, 48 hour fasting periods resulted in activation of GnIH neurons and decreased LH levels (Fraley et al., 2013).

CORT activation is partly controlled by its respective receptor, the glucocorticoid receptor (GC). In Japanese quail, GC receptor mRNA on GnIH neurons in the PVN responds to 24-hour CORT treatment by showing increased GnIH mRNA expression (Son et al.,2014). *In ovo* high-dose CORT injections in chickens decreased GnRH-I and increased GnIH in post-hatch chicken hypothalamic tissues, and after sexual maturity, the treatment resulted in a reduction in ovary and oviduct weight along with poor egg production and quality (Ahmed et al., 2014).

Chapter 4

THE EXPERIMENT

4.1 Introduction

In order to maintain the health and increase the productive cycle of broiler breeders, feed restriction is the most widely accepted method. The best means of administering the program, however, is still up for debate. During the rearing period and throughout the laying cycle, maintenance of a uniform growth curve is a strong determinant of overall flock performance. Skip-a day (SK) programs have been shown to produce larger eggs than every-day-spin (EDS) programs, but EDS programs are generally ahead overall with an earlier peak in hen day egg production. Furthermore, ED fed programs are viewed more positively from an animal welfare perspective because they may reduce negative behaviors associated with long periods of fasting while promoting more positively associated behaviors. Negative behaviors include spot- or feather-pecking and cannibalism, while positive behaviors include dust-bathing. The first objective of this study is to compare the effectiveness of EDS and SK programs by measuring BW CV during rearing and after photostimulation, and commonly measured parameters of egg production after photostimulation. The parameters include hen-day-egg and hen-housed lay rates, egg weight, fertility, hatchability, and mortality.

The most effective industry management strategy saves both time and money. A shorter rearing period for a pullet flock would cut production costs in heating and cooling by several weeks, and also free up time and facilities for repairs or continued production. Pullets early photostimulated at 15 weeks versus the conventional 21 weeks would consume more feed daily in order to reach a recommended target BW. This may also improve issues of animal welfare by reducing negative behaviors seen in severely feed-restricted birds and may increase production

through reduced stress. The second objective of this study is to examine the potential of an early 15-week photostimulation treatment with a conventional 21-week treatment. The measured parameters are the same as previously listed for both the rearing and production periods.

4.2 Materials & Methods

This study was a 2X2 factorial design experiment which compared effects of a) two growth curves/photostimulation ages (15 or 21 weeks) and b) two different feeding programs, spin feeding vs. skip-a-day (SK), on broiler breeder production parameters from rearing through 65 weeks of age.

In October 2017, 2400 female and 360 male Cobb broiler breeder chicks were obtained at one day of age, and brought to the University of Georgia Poultry Research Center. Females were placed in 12 total pens, 2 pens per 24 x 30 ft room. Males were housed separately, in one room with 6 pens. Both sexes were grown on pine shavings in rooms with heat and evaporative cooling. Birds were fed *ad libitum* a standard corn/soybean meal starter mash diet through 2 weeks of age, and then switched to a pelleted breeder developer diet on either a skip-a-day (SK) schedule using chain-feeders, or an every-day-spin (EDS) schedule using spin-feeders from 2-20 weeks of age. Rearing pens were separated by treatment to reduce variation incurred through SAD birds either hearing or seeing the EDS birds eat on the SAD off-feed day. Water was provided *ad libitum* from nipple drinkers. Chicks were provided with decreasing day length from 24L:0D to 8L:16D from 2-7 days of age, and remained on 8L:16D until photostimulated at 15 or 21 weeks. Photostimulation day length was 14L:10D. Pullets were wing-banded at 2 weeks of age, weighed bi-weekly, and feed allotments were adjusted to maintain target growth curves. The objective weight of 2.1 kg. at photostimulation was reached at either 15 or 21 weeks depending

on treatment. All procedures were approved through the University of Georgia animal care and use committee.

At either 14 or 20 weeks of age, birds were selected based on uniform weight distribution, and placed into 36 total pens with 36 pullets and 4 roosters per pen the following week. Placement was based on rearing treatment and fell into one of the following four categories; EDS-15P; EDS-21P; SK-15P; SK-21P, with 18 pens per category. All 36 pens, regardless of rearing treatment, were fed every day from hen or rooster feeders, and were fed in order to maintain egg production and the breeder recommended BW growth curve. Feed was allocated when the lights went on at 6:30 a.m. every morning, and feed type was switched from developer pellets to layer pellets upon onset of photostimulation. Breeding pens measured 12 ft x 9 ft, and in each pen there were slats that covered 2/3 of floor space while the other 1/3 was pine shavings. The slats contained 10 nipple drinkers, a six-hole nesting box, and 4 hen feeders with rooster exclusion grills. A rooster feeder was hung over the pine shavings and kept elevated enough during feeding time to restrict access to hens. Feeder space was adequate for both hens and roosters. Ratio of males to females was held constant at 10% by replacing male mortality with extra males from an outside pool, and after depletion of the pool, males were rotated to maintain fertility. Mortality was recorded and necropsies were performed if necessary. A sample of 12 pens, 6 from each treatment, were weighed weekly from week 20-65. The separation of weigh groups allowed all 36 pens to be weighed every 3 weeks.

Eggs were collected 3 times and weights were recorded for 12 out of 36 pens daily (6 from each treatment). All 36 pens were weighed once every three days. Hen-housed and hen-day egg production was calculated weekly using daily egg counts. The numbers of good, floor, abnormally shaped, cracked, double-yolked, dirty, and total eggs were recorded from each pen.

A maximum of 90 good eggs were collected from each pen every three weeks and incubated in Natureform incubators. Eggs were candled on day 12 of incubation and transferred into the hatcher on day 19. Eggs were categorized as infertile, cracked, contaminated, or containing dead embryos during candling, transfer, and after hatching. Storage of eggs was at the UGA Poultry Research Center where they were kept at 18.3-19.9 deg C in an egg storage cooler 7 days prior to incubation. Temperature settings for incubation were 37.8 deg C from 0-18 days and 37.2 deg C from 19-21 days. Relative humidity settings were 53% from 0-19 days and 70% on day 20 and 21. Following candling, infertile and early dead (>7 days) eggs were removed. At hatch, the unhatched eggs were examined and categorized as early dead (>7 days), mid dead (7-14 days), late dead (15-21 days), or pipped. Eggs that cracked due to transfer were removed from data set. Total hatchability as well as hatchability of fertile eggs was calculated after each incubation. Closely monitored parameters include egg production, egg weight, egg quality, fertility, hatchability, and mortality.

Statistics

Statistics were analyzed using SPSS and MINITAB. Each of the 4 treatments in the 2X2 factorial arrangement were replicated 9 times, with 38 hens in each replicate pen. Treatment was source of variation, and a statistic was considered significant if it was below P=0.05. Percentage data is displayed for relevance but was transformed using arc sine in order to draw conclusions from the experiment

4.3 Results

During rearing the EDS pullets had lower body weights than the SK treatment as they approached the end of rearing, at 11 and 14 week in the 15-P growth curve (Table 2) and weeks 18 and 20 in the 21-P growth curve (Table 3). The SK treatement improved uniformity at the end of rearing for the 15-P growth curve (Table 4) and at 11, 18 and 20 weeks of age in the 21-P growth curve (Table 5).

Significant differences were found in mean body weight (BW) for the EDS vs SK treatments at the pre-experiment 15 week mark with values of 2022 g vs 2095 g (Table 6), and at the 21 week mark with values of 2029 g vs 2114 g (Table 7), respectively ($P < 0.05$). After this intial difference at the first week photostimulation, the BW between the treatements did not differ throughout the production period of the experiment.

Within the 15-P treatment, significant differences ($P<0.05$) were found between the EDS and SK treatment in HHEP at weeks 21, 22, and 23, and HDEP during weeks 21 and 22, with EDS outperforming SK during early production. Values for HHEP were 24.79 ± 1.64 vs 18.14 ± 1.00, 51.83 ± 2.41 vs 38.49 ± 1.99, and 59.67 ± 2.36 vs 53.48 ± 1.7, respectively, and for HDEP were 24.87 ± 1.65 vs 18.24 ± 1.00 and 52.02 ± 2.53 vs 38.96 ± 1.92 (Table 8). A significant difference was found in HHEP between EDS and SK within the 21-P treatment during week 56 (Table 9; 41.60 ± 1.96 vs 35.99 ± 1.68), with EDS outperforming SK.

Differences were seen in settable egg production, with EDS having higher amounts of cracked eggs vs SK (6.71 ± 0.39 vs 5.56 ± 0.23) within the 15-P treatment, and EDS having higher amounts of total floor egg production vs SK (6.79 ± 0.46 vs 4.63 ±0.49) within the 21-P treatment (Table 10). At week 31 a significant difference was seen in egg weight within the 21-P between EDS and SK with values of 58.73 ± 0.28g vs 57.75 ± 0.26g, respectively (Table 12),

while no differences were noted for egg weight between EDS and SK within the 15-P (Table 11). Results from specific gravity testing showed differences between EDS and SK within 15-P (Table 13) at week 35 (1.079 ± 0.0004 vs 1.080 ± 0.0004; $P < 0.05$), while showing no differences within 21-P (Table 14).

Differences within the 15-P treatment were seen in fertility and hatchability (Table 15) at the 26 week mark, with EDS having lower percentage of in-shell dead embryos (0.53 ± 0.26) vs SK (1.40 ± 0.26). Within the 21P treatment, differences were seen in multiple areas of fertility and hatchability. Differences were seen in percent fertility at the 44-week mark between EDS and SK (91.13 ± 1.42 vs 84.05 ± 2.63), hatchability at the 44-week mark (88.41 ± 2.02 vs 80.00 ± 2.30), hatch of fertile at week 35 (97.30 ± 0.49 vs 95.06 ± 0.78) and week 50 (91.50 ± 1.41 vs 96.29 ± 0.80), early dead embryos at week 32 (2.10 ± 0.39 vs 0.37 ± 0.19), late dead embryos at week 44 (0.49 ± 0.27 vs 1.68 ± 0.35), and in shell-dead at weeks 41 (0.00 ± 0 vs 0.50 ± 0.20) and 59 (3.25 ± 0.53 ± 6.98 ± 1.09).

4.4 Discussion

This experiment primarily shows that several methods of rearing can be used with similar end results in production, however, certain advantages may exist. The more uniform body weight in the EDS could be due to both an increased time spent naturally foraging and the removal of competition for feeder space which allowed a more uniform distribution of feed to the flock. It should be noted that the improved uniformity improved at the end of the rearing period when feed allotment was increased to obtain target body weight for photostimulation. EDS is a good alternative to SAD and has the advantage of encouraging more natural behavior, a feature modern consumers value. This increased activity as a result of EDS, as compared to SK, may

have contributed to the lower body weight toward the end of the rearing phase for both growth curves, 15-P and 21-P. Flock uniformity during the lay period was not dependent on treatment which is different from previous literature results by Zuidhof et al. (2005), that showed increased uniformity with EDS feeding.

The trend in the EDS-21P treatment to lay more floor eggs (6.79 ± 0.46 vs 4.63 ±0.49) then the SK-21P group is not well understood, but it may be due to inadequate nest box availability, especially during peak production. More nest boxes may help solve the problem, as hens who initially lay floor eggs may be more likely to continue the behavior out of habit and convenience. Other potential explanations are that an increased awareness of the surrounding environment could develop in parallel to learning how to forage during rearing, or an overall increased level of comfort results from not having to compete for limited feeder space.

The significant differences seen in fertility and hatchabilty between EDS and SK may show the potential positive effects of EDS programs on the overall health of broiler breeders vs a SK program. While hatch of fertile during week 50 was significantly higher in SK birds, EDS outperformed SK in several other parameters, such as fertility and hatchability during week 44, and hatch of fertile at week 32. Overall the results indicate that both SK and EDS programs can be used with similar results during both an experimental advanced growth curve for photostimulation at 15 weeks as well as the tradtional growth curve for photostimulation at 21 weeks of age.

Although direct comparions between the 15-P and 21-P birds are diffiuclt to directly compare due to different production curves, the overall data shows that an accerelated growth curve during rearing for early photostimulation shows potential ans should studied with future expeirments. During production the BW during the first week of lay was significantly higher in

the 15-P birds (3.2 kg at 20 weeks of age) than in the 21-P birds (2.8 kg at 24 weeks of age). The 15-P birds were fed as if they were at target body weight at 21 weeks, and this may have resulted in significantly higher body weights during the onset of lay, as well as during the first 5 weeks of egg production. Following 30 weeks of age and peak production, there were no significant differences in the BW between 21-P and 15-P.

As expected, the birds brought to target body weight and photostimulated at 15 weeks (15-P) came into lay earlier (20 weeks of age) than the control treatment (21-P) who began laying at 24 weeks of age. This is in contrast to van der Klein et al. (2018) where there was no difference in age at first egg between birds photostimulated following attainment of threshold body weight at either 18 weeks and 21 weeks of age. The 15-P group took 5 weeks to lay the first egg and 21-P only 3, yet both treatments reached overall peak production 6 weeks after the first egg. The increased weight during early production may have led to the significant difference in average weekly double yolk (DY) eggs during the 21 weeks after the first egg was laid for each treatment in the 21-P and 15-P treatment groups (Table 6). This significant increase in DY egg quantity has been previously reported with feed restricted vs. ad libitum fed birds and early sexual maturation, with *ad libitum* and early maturing birds laying a significantly larger quantity of DY eggs (Heck et al., 2004; Hocking and Robertson, 2005). Renema et al (1999) showed elevated LH and FSH levels following photostimulation in ad libitum fed birds, indicating a modulation of reproductive hormone concentrations during sexual maturation by feeding level in conjunction with a sensitivity of the ovary to nutritional effects. This study shows broiler breeders can be fed on an advanced growth curve to reach target body weight and attain the metabolic set point to trigger the hypothalamic switch and allow the ovarian follicular pool to respond to gonadotropins as early as 15 weeks of age.

This trial demonstrated that age at sexual maturity in broiler breeder pullets can be significantly advanced with the use of an less restrictive growth curve during rearing to reach target body weight, and surpass the metabolic trigger for sexual maturation, as early as 15 weeks of age. Furthermore, it showed that there are production advantages to using every day spin feeding during rearing that could also benefit consumer perception of poultry production by utilizing a feeding method that allows for birds to utilize their natural foraging behavior. Although the advancement of age for sexual maturation and egg production didn't result in a greater number of eggs produced, it does show proof of concept and a feeding strategy could be optimized for these birds to improve egg production that could match or surpass standard rearing and photostimulation practices. Unfortunately, the 15-P birds were at a heavier weight upon age at first egg and this setback likely contributed to the numerically lower egg production numbers and may have potentiated a slight increase in mortality in the 15-P hens (Data not shown). Interestingly, there was no impact on fertility when both pullets and cockerels were brought to sexual maturity 6 weeks earlier than standard commercial conditions. A better understanding of the underlying mechanisms behind the metabolic trigger for the onset of sexual maturation or the development of, as mentioned above, an optimized feeding strategy for early photostimulation would improve egg production in these 15-P hens while allowing for a relaxed feed restriction program during rearing. With an optimized feeding strategy, the shortening of the rearing period would be economically beneficial as it would shorten the period of no return and lengthen the productive period for hatching egg production. Furthermore, from a welfare perspective, it would lessen the severity of feed restriction during this shortened rearing period. These results indicate that there is potential with this alternative strategy to rearing broiler breeders that could improve consumer perception of bird welfare.

Table 1. Composition of the experimental broiler breeder diets.

Ingredient	Diet[1]	Diet[2]
		%
Corn	59.750	62.050
Wheat middlings	21.000	7.71
Soybean meal (48%CP)	14.000	16.3
Soybean oil	0.540	2.62
Limestone	1.000	7.37
Defluorinated Phosphate	1.770	0.000
Dicalcium Phosphate	0.000	0.1.73
Salt	0.160	0.190
L-Lysine, HCl 78.8%	0.070	0.260
DL- Methionine 99%	0.500	0.300
L-Threonine 98%	0.080	0.260
Vitamin mix[3]	0.800	0.800
Mineral mix[4]	0.080	0.160
Solka-Floc[5]	0.250	0.250
Calculated analysis		
AME (kcal/kg)	2836	2864
Crude protein (%)	14.483	13.920
Calcium (%)	1.076	3.432
Available phosphorus (%)	0.448	0.420
Digestible total sulfur amino acids (%)	0.869	0.669
Digestible lysine (%)	0.642	0.780
Digestible threonine (%)	0.517	0.683

[1]Developer diet was fed until 20 weeks of age for the birds photsimulated at 15 weeks of age and until 24 weeks of age for the birds photostimulated at 21 weeks of age

[2]Layer diet was fed from 20 through 65 weeks of age for the birds photostimulated at 15 weeks of age, and from 24 through 65 weeks of age for the birds photostimualted at 21 weeks of age.

[3]Vitamin premix (DSM custom vitamin premix. DSM Nutritional Products, Inc. Parsippany, NJ) provides the following per kilogram of diet: vitamin A, 5,510 IU; vitamin D_3, 1,100 IU; vitamin E, 11 IU; vitamin B_{12}, 0.001mg; riboflavin, 4.4 mg; niacin, 44 mg; d-panthotenic acid, 12 mg; choline chloride, 220 mg; menadione sodium bisulfate, 3.34 mg; folic acid, 5.5 mg; pyridoxine HCl, 4.7 mg; thiamin mononitrate, 2.2 mg; d-biotin, 0.11 mg; and ethoxyquin, 125 mg.

[4]Trace mineral premix (Southeastern Minerals custom trace mineral mix. Southeastern Minerals Inc. Bainbridge, GA) provides the following in milligrams per kilogram of diet: manganese, 60; zinc, 50; iron, 30; copper, 5; iodine, 1.5; selenium, 0.5. Trace mineral forms were manganese sulfate, zinc sulfate, ferrous sulfate, copper sulfate, calcium iodate, and sodium selenite.

[5]AZOMITE (Azomite Mineral Products, Nephi, UT) was added at the expense of Solka-Floc (International Fiber Corporation, North Tonawanda, NY).

Table 2. Body weight of broiler breeder pullets reared for attainment of target body weight (2.1 kg) at 15 wk of age being fed once a day with spin feeding or fed every other day with a chain feeder[1].

	Rearing treatment	
Age	Chain feeding every other day	Spin feeding every day
wk	g	
3	419 ± 4	417 ± 4
5	702 ± 7	703 ± 8
8	1105 ± 11	1047 ± 11
11	1418 ± 12	1348 ± 11*
14	2080 ± 16	2013 ± 19*

[1]The values are the means ± SEM of 3 replicate pens of 200 pullets per treatment. *Differs from corresponding chain-reared value, ($P < 0.05$).

Table 3. Body weight of broiler breeder pullets reared for attainment of target body weight (2.1 kg) at 21 wk of age being fed once a day with spin feeding or fed every other day with a chain feeder[1].

	Rearing treatment	
Age	Chain feeding every other day	Spin feeding every day
wk	g	
3	419 ± 4	417 ± 4
5	624 ± 7	635 ± 6
8	892 ± 8	847 ± 8
11	1072 ± 10	1082 ± 9
14	1450 ± 14	1416 ± 12
18	1750 ± 16	1690 ± 13*
20	2111 ± 19	2050 ± 15*

[1]The values are the means ± SEM of 3 replicate pens of 200 pullets per treatment. *Differs from corresponding chain-reared value, ($P < 0.05$).

Table 4. The coefficient of variation of body weight (%) of broiler breeder pullets reared for attainment of target body weight (2.1 kg) at 15 wk of age being fed once a day with spin feeding or fed every other day with a chain feeder[1].

	Rearing treatment	
Age	Chain feeding every other day	Spin feeding every day
wk	%	
3	13	13.3
5	13.7	13.5
8	12.4	11.7
11	11.9	11.8
14	12.4	10.9*

[1]The values are the means of 3 replicate pens of 200 pullets per treatment. *Differs from corresponding chain-reared value, ($P < 0.05$).

Table 5. The coefficient of variation of body weight (%) of broiler breeder pullets reared for attainment of target body weight (2.1 kg) at 21 wk of age being fed once a day with spin feeding or fed every other day with a chain feeder[1].

	Rearing treatment	
Age	Chain feeding every other day	Spin feeding every day
wk	%	
3	13	13.9
5	14.5	14.2
8	13.7	13.4
11	13.4	11.9
14	13.1	11.9
18	13.8	11.8*
20	12.7	11.2*

[1]The values are the means of 3 replicate pens of 200 pullets per treatment. *Differs from corresponding chain-reared value, ($P < 0.05$).

Table 6. Body weight of broiler breeder hens from 15 (onset of photostimulation) through 65 wk of age that had been reared being fed once a day with spin feeding or fed every other day with a chain feeder[1].

	Rearing treatment	
Age	Chain feeding every other day	Spin feeding every day
wk	g	
15 (pre-experiment)	2095 ± 0	2022 ± 0*
20	3173 ± 17	3148 ± 27
24	3625 ± 43	3520 ± 35
30	4228 ± 48	4175 ± 20
36	4558 ± 39	4572 ± 24
41	4580 ± 26	4576 ± 27
50	4738 ± 65	4755 ± 39
55	4872 ± 116	4869 ± 113
61	4822 ± 110	4741 ± 90
65	4822 ± 74	4743 ± 36

[1]The values are the means ± SEM of 9 replicate pens of 38 hens per treatment. *Differs from corresponding chain-reared value, ($P < 0.05$).

Table 7. Body weight of broiler breeder hens from 21 (onset of photostimulation) through 65 wk of age that had been reared being fed once a day with spin feeding or fed every other day with a chain feeder[1].

	Rearing treatment	
Age	Chain feeding every other day	Spin feeding every day
wk	g	
21 (pre-experiment)	2114 ± 0	2029 ± 0*
26	3334 ± 23	3327 ± 13
30	3860 ± 30	3812 ± 39
35	4378 ± 27	4295 ± 30
43	4681 ± 34	4653 ± 36
51	4749 ± 117	4738 ± 70
61	4816 ± 109	4776 ± 68

[1]The values are the means ± SEM of 9 replicate pens of 38 hens per treatment. *Differs from corresponding chain-reared value, ($P < 0.05$).

Table 8. Weekly hen housed egg production (HHEP) and hen day egg production (HDEP) of broiler breeder hens from 15 (onset of photostimulation) through 65 wk of age that had been reared being fed once a day with spin feeding or fed every other day with a chain feeder[1].

	Rearing treatment			
	Chain feeding every other day		Spin feeding every day	
Hen age	HHEP	HDEP	HHEP	HDEP
(week)			(%)	
20	2.05 ± 0.46	2.05 ± 0.46	3.10 ± 0.71	3.10 ± 0.71
21	18.14 ± 1.00	18.24 ± 1.00	24.79 ± 1.64*	24.87 ± 1.65*
22	38.49 ± 1.99	38.96 ± 1.92	51.83 ± 2.41*	52.02 ± 2.53*
23	53.48 ± 1.70	54.44 ± 1.75	59.67 ± 2.36*	60.34 ± 2.23
24	63.34 ± 1.74	64.47 ± 1.76	67.36 ± 1.85	69.21 ± 1.86
25	65.28 ± 1.91	66.63 ± 1.84	68.54 ± 1.65	70.43 ± 1.72
26	72.31 ± 1.50	73.81 ± 1.42	74.08 ± 1.51	76.12 ± 1.47
27	71.43 ± 2.31	73.13 ± 2.30	72.61 ± 2.16	74.54 ± 1.84
28	70.72 ± 2.22	72.62 ± 2.18	70.75 ± 1.31	72.68 ± 1.21
29	67.54 ± 1.98	69.75 ± 1.85	67.69 ± 1.86	70.30 ± 1.25
30	63.58 ± 2.18	65.87 ± 2.14	65.71 ± 1.30	68.30 ± 0.90
31	59.83 ± 2.81	62.59 ± 2.98	62.13 ± 2.14	64.70 ± 1.74
32	59.66 ± 2.13	62.73 ± 1.99	61.43 ± 2.11	65.21 ± 1.79
33	56.97 ± 2.12	60.13 ± 2.14	60.47 ± 2.46	64.15 ± 2.11
34	57.85 ± 2.70	61.42 ± 2.69	59.40 ± 2.13	63.46 ± 1.76
35	59.99 ± 3.16	63.61 ± 3.04	59.01 ± 2.89	63.25 ± 2.82
36	58.62 ± 2.46	62.41 ± 2.34	57.23 ± 2.75	61.49 ± 2.45
37	55.57 ± 2.59	59.13 ± 2.41	58.26 ± 2.51	62.61 ± 2.13
38	57.94 ± 2.34	61.70 ± 2.23	56.62 ± 2.52	61.12 ± 2.47
39	56.77 ± 2.04	60.46 ± 1.91	55.90 ± 2.68	60.55 ± 2.01
40	57.26 ± 2.78	61.47 ± 3.08	54.93 ± 2.56	59.76 ± 2.07
41	54.11 ± 3.06	58.68 ± 3.45	54.64 ± 2.37	59.69 ± 1.97
42	51.61 ± 2.37	55.86 ± 2.43	53.97 ± 1.92	59.03 ± 1.74
43	49.96 ± 2.55	54.36 ± 2.44	53.07 ± 2.36	58.06 ± 1.66
44	48.41 ± 2.40	52.91 ± 2.48	48.95 ± 2.52	53.68 ± 1.85
45	47.19 ± 2.55	52.23 ± 2.65	47.97 ± 3.00	52.46 ± 2.13
46	48.74 ± 2.81	53.95 ± 2.94	46.46 ± 3.12	51.08 ± 2.66
47	48.90 ± 3.09	54.30 ± 3.28	50.56 ± 2.53	55.87 ± 2.59
48	46.93 ± 2.97	52.80 ± 3.14	49.25 ± 2.47	54.65 ± 2.64
49	45.92 ± 2.68	51.83 ± 2.39	46.44 ± 2.74	52.15 ± 2.78
50	39.39 ± 3.25	44.86 ± 3.34	40.01 ± 3.24	45.16 ± 3.09
51	37.92 ± 3.16	43.55 ± 3.09	36.81 ± 3.53	41.66 ± 3.30
52	37.78 ± 3.40	44.27 ± 3.37	37.19 ± 2.05	42.87 ± 1.91
53	34.89 ± 3.34	41.14 ± 3.26	34.87 ± 2.90	40.32 ± 2.75
54	32.30 ± 3.29	38.39 ± 3.31	34.10 ± 3.32	39.68 ± 3.10
55	31.38 ± 3.48	37.58 ± 3.67	32.05 ± 3.20	37.72 ± 2.93
56	27.87 ± 2.51	34.42 ± 3.04	29.25 ± 2.57	35.37 ± 2.36
57	27.68 ± 3.85	34.38 ± 4.73	26.92 ± 3.51	32.42 ± 3.63
58	29.12 ± 3.92	36.43 ± 4.54	29.78 ± 3.54	36.28 ± 3.72

59	30.02 ± 3.53	37.23 ± 3.99	29.32 ± 3.05	35.79 ± 3.02
60	28.60 ± 3.62	35.42 ± 4.06	32.76 ± 3.20	40.46 ± 2.93
61	28.52 ± 3.32	35.43 ± 3.75	31.29 ± 3.33	39.17 ± 3.15
62	27.90 ± 2.86	34.95 ± 3.20	32.38 ± 2.84	39.19 ± 2.87
63	31.37 ± 2.68	39.38 ± 2.74	32.99 ± 3.34	40.09 ± 3.64
64	32.19 ± 2.21	40.82 ± 2.13	31.34 ± 2.90	38.37 ± 2.99
65	29.74 ± 3.00	37.74 ± 3.20	30.56 ± 2.86	37.55 ± 2.93

[1]Values are the mean ± SEM of 9 replicate pens of 38 hens per treatment. *Spin feeding rearing value for a given parameter differs from the chain feeding rearing value, ($P < 0.05$).

Table 9. Weekly hen housed egg production (HHEP) and hen day egg production (HDEP) of broiler breeder hens from 21 (onset of photostimulation) through 65 wk of age that had been reared being fed once a day with spin feeding or fed every other day with a chain feeder[1].

	Rearing treatment			
	Chain feeding every other day		Spin feeding every day	
Hen age	HHEP	HDEP	HHEP	HDEP
(week)	(%)			
24	1.17 ± 0.36	1.17 ± 0.36	1.38 ± 0.45	1.38 ± 0.45
25	17.57 ± 2.00	17.70 ± 2.03	13.20 ± 1.29	13.24 ± 1.29
26	53.82 ± 2.73	54.36 ± 2.90	48.70 ± 2.16	48.99 ± 2.15
27	76.09 ± 2.14	76.81 ± 2.31	76.44 ± 1.67	77.15 ± 1.86
28	82.20 ± 1.57	83.19 ± 1.64	84.54 ± 1.68	85.62 ± 2.06
29	83.22 ± 1.71	84.74 ± 1.86	82.87 ± 1.27	84.14 ± 1.43
30	80.81 ± 0.98	83.29 ± 1.07	82.25 ± 1.04	83.73 ± 1.00
31	80.41 ± 1.40	83.60 ± 1.24	81.54 ± 1.34	83.25 ± 1.47
32	79.44 ± 1.58	82.88 ± 1.61	79.57 ± 1.77	81.23 ± 1.66
33	75.54 ± 1.91	78.79 ± 1.85	78.24 ± 1.62	79.86 ± 1.49
34	73.70 ± 2.15	77.76 ± 1.95	75.27 ± 1.90	77.04 ± 1.61
35	70.26 ± 2.88	74.37 ± 2.79	73.64 ± 1.90	75.35 ± 1.50
36	69.30 ± 2.90	73.32 ± 2.73	72.81 ± 1.93	75.37 ± 1.26
37	69.80 ± 3.36	73.88 ± 3.40	71.14 ± 2.72	73.88 ± 3.40
38	69.75 ± 2.73	73.81 ± 2.57	72.35 ± 2.61	74.86 ± 2.14
39	68.20 ± 2.47	72.16 ± 2.26	71.09 ± 2.31	74.24 ± 1.62
40	65.23 ± 2.93	69.47 ± 2.94	66.12 ± 2.51	69.43 ± 1.88
41	65.71 ± 2.38	70.24 ± 2.45	65.25 ± 2.93	68.48 ± 2.44
42	61.75 ± 2.46	66.18 ± 2.44	60.94 ± 3.06	64.11 ± 2.56
43	60.40 ± 2.78	64.71 ± 2.78	60.61 ± 3.06	63.74 ± 2.54
44	55.79 ± 2.41	60.36 ± 2.38	59.65 ± 3.49	63.23 ± 2.94
45	55.54 ± 3.61	60.96 ± 3.65	57.35 ± 3.27	60.97 ± 2.64
46	52.73 ± 2.91	58.05 ± 2.78	56.10 ± 3.18	59.62 ± 2.47
47	53.59 ± 3.47	59.36 ± 3.38	59.23 ± 3.30	63.19 ± 2.70
48	53.63 ± 3.63	59.57 ± 3.54	59.86 ± 3.49	64.06 ± 3.00
49	50.28 ± 3.25	56.64 ± 3.23	55.39 ± 2.86	59.88 ± 2.21
50	45.92 ± 2.94	52.16 ± 2.80	50.50 ± 2.75	54.68 ± 1.97
51	42.95 ± 2.93	48.83 ± 2.94	48.87 ± 2.81	53.55 ± 1.94
52	41.49 ± 3.18	47.30 ± 3.26	47.49 ± 2.43	52.31 ± 1.65
53	39.28 ± 2.48	45.22 ± 2.68	44.57 ± 2.73	49.17 ± 2.04
54	39.43 ± 1.93	45.48± 2.24	45.15 ± 2.64	49.81 ± 1.92
55	38.72 ± 2.55	44.84 ± 2.80	45.11 ± 2.21	50.08 ± 1.53
56	35.99 ± 1.68	42.17 ± 1.89	41.60 ± 1.96*	46.37 ± 1.36
57	32.01 ± 2.04	38.16 ± 2.37	36.93 ± 2.01	41.16 ± 1.68
58	33.27 ± 2.27	39.96 ± 2.74	37.93 ± 1.90	42.34 ± 1.71
59	35.56 ± 2.46	43.02 ± 2.87	39.26 ± 1.79	44.11 ± 1.47
60	36.90 ± 2.59	44.90 ± 2.98	42.11 ± 2.18	47.14 ± 1.52
61	35.59 ± 2.78	43.44 ± 3.20	40.18 ± 2.28	45.10 ± 2.04

62	36.42 ± 2.82	44.33 ± 3.05	40.89 ± 2.47	46.07 ± 1.97
63	39.70 ± 2.89	48.80 ± 3.26	41.77 ± 2.62	47.00 ± 2.08
64	37.10 ± 2.89	45.59 ± 3.33	39.72 ± 2.36	44.86 ± 1.74
65	38.20 ± 3.09	47.19 ± 3.65	40.06 ± 3.05	45.11 ± 2.56

[1]Values are the mean ± SEM of 9 replicate pens of 38 hens per treatment. *Spin feeding rearing value for a given parameter differs from the chain feeding rearing value, ($P < 0.05$).

Table 10. Total egg and settable egg production per hen housed of broiler breeder hens through 65 wk of age that had been reared being fed once a day with spin feeding or fed every other day with a chain feeder[1].

	15 week of age photostimulation		21-week of age photostimulation	
	Rearing treatment			
	Chain feeding every other day	Spin feeding every day	Chain feeding every other day	Spin feeding every day
	eggs/hen			
Total egg production	148.89 ± 6.84	153.29 ± 6.45	156.41 ± 5.95	164.34 ± 5.59
Total settable egg production	123.41 ± 6.41	124.72 ± 6.51	132.95 ± 5.91	136.75 ± 5.22
Total cracked egg production	5.56 ± 0.23	6.71 ± 0.39*	5.14 ± 0.26	5.75 ± 0.38
Total misshaped egg production	2.33 ± 0.15	2.22 ± 0.25	2.03 ± 0.14	1.87 ± 0.15
Total double-yolked egg production	2.06 ± 0.10	2.15 ± 0.14	0.79 ± 0.12	0.90 ± 0.11
Total dirty egg production	11.89 ± 0.55	12.63 ± 1.12	10.87 ± 0.48	12.28 ± 0.83
Total floor egg production	3.65 ± 0.87	4.87 ± 0.46	4.63 ± 0.49	6.79 ± 0.46*

[1]The values are means ± SEM of 6 replicate groups of hens with each group containing 8 individually caged hens. *Spin feeding rearing value for a given parameter differs from the chain feeding rearing value, for a given photostimulation time ($P < 0.05$).

Table 11. Egg weight of eggs produced from broiler breeder hens from 15 (onset of photostimulation) through 65 wk of age that had been reared being fed once a day with spin feeding or fed every other day with a chain feeder[1].

	Rearing treatment	
Age	Chain feeding every other day	Spin feeding every day
wk	g	
23	48.84 ± 0.43	48.71 ± 0.46
25	50.47 ± 0.30	51.36 ± 0.30
27	53.52 ± 0.40	53.45 ± 0.20
29	54.64 ± 0.49	55.72 ± 0.65
31	58.20 ± 0.21	58.38 ± 0.23
33	59.63 ± 0.30	59.68 ± 0.40
35	61.05 ± 0.28	60.98 ± 0.27
37	62.80 ± 0.23	62.92 ± 0.41
39	63.65 ± 0.55	63.88 ± 0.26
41	65.10 ± 0.47	65.33 ± 0.45
43	66.38 ± 0.54	66.31 ± 0.33
45	67.23 ± 0.50	67.66 ± 0.21
47	68.97 ± 0.48	68.82 ± 0.36
49	69.38 ± 0.49	70.74 ± 0.63
51	70.54 ± 0.80	71.55 ± 0.44
53	71.10 ± 0.52	71.52 ± 0.39
55	71.98 ± 0.68	71.97 ± 0.56
57	72.01 ± 0.46	72.40 ± 0.46
59	72.72 ± 0.48	72.67 ± 0.48
61	72.91 ± 0.38	73.70 ± 0.68
63	72.35 ± 0.46	72.72 ± 0.68
65	72.54 ± 0.53	72.24 ± 0.53

[1]Values are the mean ± SEM of 9 replicate pens of 38 hens per treatment.

Table 12. Egg weight of eggs produced from broiler breeder hens from 21 (onset of photostimulation) through 65 wk of age that had been reared being fed once a day with spin feeding or fed every other day with a chain feeder[1].

	Rearing treatment	
Age	Chain feeding every other day	Spin feeding every day
wk	g	
27	50.57 ± 0.63	50.47 ± 0.33
29	54.22 ± 0.30	53.80 ± 0.33
31	57.75 ± 0.26	58.73 ± 0.28*
33	60.78 ± 0.14	61.22 ± 0.36
35	61.63 ± 0.18	62.05 ± 0.33
37	62.65 ± 0.30	63.22 ± 0.35
39	63.24 ± 0.37	63.76 ± 0.29
41	64.70 ± 0.53	65.91 ± 0.29
43	66.08 ± 0.53	66.66 ± 0.50
45	67.54 ± 0.82	68.35 ± 0.44
47	67.90 ± 0.64	68.78 ± 0.41
49	68.17 ± 0.62	69.35 ± 0.43
51	69.65 ± 0.49	70.49 ± 0.29
53	70.57 ± 0.45	70.95 ± 0.36
55	71.61 ± 0.37	71.34 ± 0.32
57	71.83 ± 0.33	71.27 ± 0.32
59	72.33 ± 0.38	72.40 ± 0.34
61	72.08 ± 0.47	72.57 ± 0.39
63	71.22 ± 0.14	71.19 ± 0.16
65	71.68 ± 0.36	72.01 ± 0.27

[1]Values are the mean ± SEM of 9 replicate pens of 38 hens per treatment. *Differs from corresponding chain-reared value, ($P < 0.05$).

Table 13. Specific gravity of eggs from broiler breeder hens from 15 (onset of photostimulation) through 65 wk of age that had been reared being fed once a day with spin feeding or fed every other day with a chain feeder[1].

	Rearing treatment	
Age	Chain feeding every other day	Spin feeding every day
wk		
30	1.081 ± 0.0003	1.081 ± 0.0004
35	1.080 ± 0.0004	1.079 ± 0.0004*
39	1.080 ± 0.0003	1.079 ± 0.0005
44	1.081 ± 0.0003	1.080 ± 0.0004
48	1.077 ± 0.0004	1.077 ± 0.0004
53	1.071 ± 0.0006	1.072 ± 0.0003
58	1.072 ± 0.0005	1.071 ± 0.0004
65	1.077 ± 0.0004	1.076 ± 0.0006

[1]Values are the mean ± SEM of 9 replicate pens of 38 hens per treatment. *Differs from corresponding chain-reared value, ($P < 0.05$).

Table 14. Specific gravity of eggs from broiler breeder hens from 21 (onset of photostimulation) through 65 wk of age that had been reared being fed once a day with spin feeding or fed every other day with a chain feeder[1].

	Rearing treatment	
Age	Chain feeding every other day	Spin feeding every day
wk		
30	1.081 ± 0.0003	1.081 ± 0.0003
35	1.079 ± 0.0005	1.080 ± 0.0004
39	1.080 ± 0.0006	1.081 ± 0.0003
44	1.079 ± 0.0007	1.078 ± 0.0011
48	1.077 ± 0.0006	1.078 ± 0.0005
53	1.075 ± 0.0005	1.074 ± 0.0005
58	1.072 ± 0.0005	1.071 ± 0.0005
65	1.076 ± 0.0006	1.076 ± 0.0005

[1]Values are the mean ± SEM of 9 replicate pens of 38 hens per treatment.

Table 15. Fertility and hatchability of eggs produced by broiler breeder hens from 15 (onset of photostimulation) through 65 wk of age that had been reared being fed once a day with spin feeding or fed every other day with a chain feeder[1].

Hen age and treatment	Fertility	Hatchability[2]	Hatch of fertile	Early dead embryos[3,4]	Late dead embryos[3,4]	In-shell[3,4]
				%		
23 weeks						
Chain	80.01 ± 2.68	73.15 ± 2.62	91.47 ± 1.25	1.97 ± 0.64	1.23 ± 0.35	3.65 ± 0.61
Spin	82.44 ± 1.66	75.69 ± 1.54	91.84 ± 0.86	2.31 ± 059	1.38 ± 0.53	3.07 ± 0.48
26 weeks						
Chain	90.22 ± 1.62	82.92 ± 2.06	91.88 ± 1.22	3.62 ± 0.99	2.27 ± 0.51	1.40 ± 0.26
Spin	89.69 ± 2.04	82.98 ± 2.06	92.52 ± 0.95	3.75 ± 073	2.44 ± 0.38	0.53 ± 0.28*
29 weeks						
Chain	93.21 ± 0.54	89.01 ± 1.05	95.48 ± 0.81	0.25 ± 0.25	2.84 ± 0.42	1.11 ± 0.49
Spin	92.96 ± 2.28	88.40 ± 2.92	94.92 ± 1.01	0.49 ± 0.33	2.08 ± 0.69	1.11 ± 0.26
32 weeks						
Chain	90.74 ± 0.64	88.27 ± 0.64	97.31 ± 0.84	0.37 ± 0.26	1.85 ± 0.77	0.25 ± 0.16
Spin	89.88 ± 1.80	87.65 ± 2.32	97.45 ± 1.00	0.74 ± 0.37	0.98 ± 0.45	0.49 ± 0.27
35 weeks						
Chain	92.08 ± 1.00	88.18 ± 1.09	95.77 ± 0.76	2.54 ± 0.55	0.74 ± 0.41	0.62 ± 0.33
Spin	91.18 ± 1.32	87.19 ± 1.54	95.60 ± 0.62	1.87 ± 0.26	1.25 ± 0.30	0.88 ± 0.32
38 weeks						
Chain	90.00 ± 1.57	89.24 ± 1.43	99.19 ± 0.44	0.00 ± 0.00	0.51 ± 0.38	0.25 ± 0.25
Spin	89.61 ± 1.47	87.84 ± 1.44	98.03 ± 0.49	0.12 ± 0.12	1.15 ± 0.42	0.51 ± 0.20
41 weeks						
Chain	90.49 ± 1.26	87.42 ± 1.45	95.59 ± 0.42	1.86 ± 0.38	1.20 ± 0.33	0.00 ± 0.00
Spin	88.90 ± 1.93	86.51 ± 2.29	97.23 ± 0.68	1.01 ± 0.63	1.23 ± 0.51	0.14 ± 0.14
44 weeks						
Chain	84.62 ± 4.84	82.34 ± 5.10	97.07 ± 0.78	1.31 ± 0.49	0.97 ± 0.26	0.00 ± 0.00
Spin	87.19 ± 2.78	83.20 ± 2.87	95.38 ± 0.95	2.17 ± 0.66	1.66 ± 0.49	0.16 ± 0.16
47 weeks						
Chain	76.72 ± 4.82	74.27 ± 4.99	96.49 ± 1.12	0.25 ± 0.25	0.79 ± 0.44	1.41 ± 0.31
Spin	74.21 ± 5.52	70.68 ± 5.02	95.55 ± 0.90	1.14 ± 0.38	1.10 ± 0.47	1.30 ± 0.61
50 weeks						
Chain	79.40 ± 3.51	73.38 ± 3.45	92.34 ± 1.11	2.09 ± 0.48	2.99 ± 0.59	0.95 ± 0.55
Spin	70.25 ± 4.64	66.14 ± 4.38	94.16 ± 0.87	1.31 ± 0.42	1.90 ± 0.65	0.89 ± 0.37
53 weeks						
Chain	69.68 ± 5.38	65.63 ± 5.29	93.84 ± 1.07	2.28 ± 0.63	1.12 ± 0.41	0.65 ± 0.44
Spin	72.06 ± 4.26	66.59 ± 3.92	92.53 ± 1.54	1.85 ± 0.64	2.38 ± 1.13	1.23 ± 0.97
56 weeks						
Chain	74.16 ± 5.18	67.81 ± 4.35	91.73 ± 1.29	0.48 ± 0.22	2.47 ± 0.55	3.41 ± 1.25
Spin	69.61 ± 3.97	64.18 ± 4.02	92.08 ± 1.58	0.14 ± 0.14	1.77 ± 0.62	3.52 ± 0.93
59 weeks						
Chain	68.49 ± 8.01	61.60 ± 6.87	90.98 ± 1.68	0.88 ± 0.49	2.68 ± 0.69	3.32 ± 1.17
Spin	66.68 ± 4.00	60.05 ± 3.94	89.89 ± 2.09	2.14 ± 1.08	1.19 ± 0.62	3.30 ± 0.98

Overall						
Chain	83.54 ± 1.73	79.40 ± 1.56	95.07 ± 0.27	1.32 ± 0.12	1.10 ± 0.11	1.20 ± 0.19
Spin	82.52 ± 1.75	78.19 ± 1.76	94.74 ± 0.42	1.44 ± 0.13	1.09 ± 0.19	1.26 ± 0.13

[1]Values are the mean ± SEM of 9 replicate pens of 38 hens per treatment. Ninety eggs from each replicate pen were incubated and hatched at 26, 29, 32, 35, 38, 41, 44, 47, 50, 53, 56 and 59 wk of age. *Spin feeding rearing value for a given parameter differs from the chain feeding rearing value, ($P < 0.05$).

[2]Hatch of eggs set

[3]Embryo mortality was classified as early dead (less than 14 d) or late dead (15-21 d of incubation) embryos. In shell included both live and dead –in-shell at the time of hatch.

[4]Calculated as a percentage of fertile eggs.

Table 16. Fertility and hatchability of eggs produced by broiler breeder hens from 21 (onset of photostimulation) through 65 wk of age that had been reared being fed once a day with spin feeding or fed every other day with a chain feeder[1].

Hen age and treatment	Fertility	Hatchability[2]	Hatch of fertile	Early dead embryos[3,4]	Late dead embryos[3,4]	In-shell[3,4]
26 weeks				%		
Chain	87.15 ± 3.09	80.64 ± 3.11	92.50 ± 1.26	1.10 ± 0.57	2.84 ± 0.72	2.57 ± 0.73
Spin	86.83 ± 2.05	80.84 ± 1.90	93.19 ± 1.32	1.44 ± 0.48	2.12 ± 0.60	2.43 ± 0.82
29 weeks						
Chain	94.07 ± 1.08	90.00 ± 1.20	95.65 ± 0.69	0.12 ± 0.12	2.47 ± 0.61	1.48 ± 0.26
Spin	93.95 ± 1.26	90.00 ± 1.58	95.76 ± 0.53	0.74 ± 0.32	2.10 ± 0.34	1.11 ± 0.32
32 weeks						
Chain	88.27 ± 3.12	84.81 ± 3.45	95.95 ± 0.89	0.37 ± 0 19	2.59 ± 0.49	0.49 ± 0.38
Spin	92.59 ± 1.10	85.19 ± 2.10	92.78 ± 1.85	2.10 ± 0.39*	3.58 ± 1.01	0.99 ± 0.34
35 weeks						
Chain	90.00 ± 1.61	85.56 ± 1.69	95.06 ± 0.78	2.72 ± 0.46	0.86 ± 0.31	0.86 ± 0.36
Spin	91.36 ± 1.48	88.89 ± 1.50	97.30 ± 0.49*	1.98 ± 0.36	0.25 ± 0.16	0.25 ± 0.16
38 weeks						
Chain	86.79 ± 2.63	84.69 ± 2.54	97.61 ± 0.61	0.49 ± 0.38	1.11 ± 0.37	0.49 ± 0.20
Spin	92.59 ± 1.28	90.49 ± 1.42	97.72 ± 0.44	0.12 ± 0.12	1.11 ± 0.37	0.86 ± 0.31
41 weeks						
Chain	85.82 ± 2.34	82.15 ± 2.13	95.77 ± 0.64	1.14 ± 0.42	2.03 ± 0.50	0.50 ± 0.20
Spin	89.88 ± 1.45	87.04 ± 1.28	96.88 ± 0.65	1.36 ± 0.36	1.47 ± 0.57	0.00 ± 0.00*
44 weeks						
Chain	84.05 ± 2.63	80.00 ± 2.30	95.25 ± 0.77	1.89 ± 0.31	1.68 ± 0.35	0.49 ± 0.27
Spin	91.13 ± 1.42*	88.41 ± 2.02*	96.97 ± 1.16	1.48 ± 0.61	0.49 ± 0.27*	0.74 ± 0.52
47 weeks						
Chain	78.27 ± 3.34	74.66 ± 3.58	95.26 ± 1.11	1.24 ± 0.34	1.75 ± 0.51	0.62 ± 0.42
Spin	84.88 ± 3.24	80.87 ± 3.10	95.31 ± 1.11	0.83 ± 0.45	1.85 ± 0.40	1.32 ± 0.49
50 weeks						
Chain	73.97 ± 4.80	71.17 ± 4.56	96.29 ± 0.80	1.44 ± 0.57	1.12 ± 0.54	0.25 ± 0.16
Spin	80.62 ± 4.19	74.02 ± 4.60	91.50 ± 1.41*	2.98 ± 0.46	2.94 ± 0.70	0.68 ± 0.29
53 weeks						
Chain	70.92 ± 3.17	58.74 ± 2.94	82.88 ± 1.82	6.39 ± 1.08	1.55 ± 0.47	4.25 ± 1.58
Spin	74.76 ± 3.23	61.45 ± 2.96	82.23 ± 2.00	5.75 ± 0.97	1.43 ± 0.49	6.12 ± 1.49
56 weeks						
Chain	77.62 ± 2.17	69.37 ± 2.77	89.26 ± 1.78	0.16 ± 0.16	1.90 ± 0.63	6.19 ± 0.93
Spin	74.20 ± 4.04	67.16 ± 4.19	90.29 ± 1.12	0.00 ± 0.00	2.96 ± 0.69	4.07 ± 0.64
59 weeks						
Chain	67.49 ± 4.58	58.33 ± 5.65	84.71 ± 3.49	0.12 ± 0.12	2.06 ± 0.61	6.98 ± 1.09
Spin	72.61 ± 4.00	65.51 ± 3.92	90.13 ± 1.05	1.22 ± 0.76	2.63 ± 0.61	3.25 ± 0.53*
Overall						
Chain	80.99 ± 1.62	75.03 ± 1.64	92.62 ± 0.46	2.00 ± 0.19	1.43 ± 0.21	2.20 ± 0.25
Spin	84.25 ± 1.84	78.00 ± 1.94	92.54 ± 0.40	2.11 ± 0.24	1.58 ± 0.23	2.29 ± 0.31

[1]Values are the mean ± SEM of 9 replicate pens of 38 hens per treatment. Ninety eggs from each replicate pen were incubated and hatched at 26, 29, 32, 35, 38, 41, 44, 47, 50, 53, 56 and 59 wk of age. *Spin feeding rearing value for a given parameter differs from the chain feeding rearing value, ($P < 0.05$).
[2]Hatch of eggs set
[3]Embryo mortality was classified as early dead (less than 14 d) or late dead (15-21 d of incubation) embryos. In shell included both live and dead –in-shell at the time of hatch.
[4]Calculated as a percentage of fertile eggs.

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