ABSTRACT

EUSEBIO BALCAZAR, PAMELA ELIANA. Effect of Breeder Nutrition and Feeding Program during Rearing and Production on Broiler Leg Health. (Under the direction of Dr. Edgar O. Oviedo-Rondón).

Effects of breeder feeding practices and diet types, which differ between geographic regions of the world, were evaluated on leg health of Cobb 500 broiler progeny. Breeders and their progeny were fed either corn or wheat based diets. At photostimulation, pullet breeders were moved to a floor pen house equipped with either similar (S) or more (M), 6.5 vs 8.4 cm/hen, feeder space than in rearing (6.3 cm/pullet). Two feed allocation programs, late slow (LS) or late fast (LF), were applied from 14 to 29 wk of age. Progeny experiments were conducted when breeders were 32 and 44 wk of age. Considering that effects of treatments on leg physical inspection and locomotion evaluation results were similar in both broiler experiments, data were combined. Breeders fed wheat laid eggs with greater albumen height at 31 wk. At hatching, progeny of breeders fed wheat diets had lighter femurs and shanks only when they were given M. Progeny whose parents were also fed wheat had more chances to display crooked toes at 6 wk compared to corn group only when breeders were restricted to LS and given S. The only egg characteristic affected by feeder space was G at 33 wk indicating higher values for breeders provided with M. At hatching, progeny had longer tibias and shanks only when breeders were fed corn diets following LS. Onwards, M progeny were more likely to suffer walking impairment at 6 wk than broilers from S breeders only when corn diets were used, and LS was applied to breeders.

In a parallel experiment, breeders from strains A and B were raised under the same conditions during the growing phase, and placed in cages during the laying phase for pedigree purposes. In each cage either 1 or 2 hens were placed to provide more (MR) or less (L) feeder space, respectively. Feed allocation programs, LS or LF, were applied from 14 wk to photostimulation. Broiler progeny evaluations were conducted when breeders were 32 and 44 wk. Strain A eggs had greater albumen height, higher eggshell percentage, and thicker eggshell membrane resulting in a reduction of G at 46 wk. Progeny of strain A were twice

more likely to display worsened walking ability than strain B broilers at 4 wk. Strain B breeders restricted to LS and given MR had progeny with less severe angular deformations and locomotion problems at 6 wk compared to strain B breeders allocated to LF and given MR. Strain A broilers only had less severe angular deformities when breeders were fed according to LS but given L. Indeed, the highest G was observed when LS program was applied to strain B breeders. MR in combination with corn diets worsened walking ability in progeny at 4 wk compared to L; however, no effects of feeder space were observed on G even though eggshell thickness was lower in MR breeders. Broilers having more leg problems had longer bones, and greater BMD and BMC measured at 7 wk.

In conclusion, eggshell conductance was the most consistent egg variable related to progeny leg health. These two breeder strains seemed to respond differently to feeder space changes from rearing to production. Strain A broilers had less leg problems when breeders were provided with similar or less feeder space. In contrast, the beneficial effect of the LS breeder feeding program on progeny walking ability and several leg abnormalities of strain B broilers were only observed when breeders were given more feeder space.

Effect of Breeder Nutrition and Feeding Program during Rearing and Production on Broiler Leg Health

by
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DEDICATION

To my family for the unconditional love and support

(*Para mi familia por el amor y el soporte incondicional)*

BIBLIOGRAPHY

Pamela Eliana Eusebio Balcazar was born on October 4th, 1983 in Lima, Peru. She is the oldest daughter of Florencio Eusebio and Juana Balcazar. She attended a Peruvian-Chinese School called “Diez de Octubre” in Lima, Peru. Since she was a child, her family owned a poultry farm where she spent most of her childhood and developed her interest in animals. Because of her childhood background, she decided to persue a Bachelor of Science in Animal Science at The Molina National Agrarian University (UNALM) in Lima, Peru. While she was studying in UNALM, she worked as an intern in some of the most well known Peruvian companies in the poultry meat industry. Then, she moved to the United States to continue her academic education in 2007. Her participation in previous internship programs motivated her to pursue a Masters of Science degree in Poultry Science at North Carolina State University. While she was studying in NC State, she had the opportunity to conduct and present several experiments in Scientific Meetings where she won Graduate Student Awards in the International Poultry Scientific Forum in 2009 and in the Poultry Science Association Meeting in 2010. Ultimately, she is planning to keep working in investigation and extension programs in the Poultry Industry.

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CHAPTER I: LITERATURE REVIEW

ABSTRACT

Leg health is a worldwide concern due to welfare issues and high economic losses in the poultry industry. Skeletal disorders are relevant welfare problems due to locomotion impairment and bone fragility during handling of birds. In addition, leg health negatively impacts feed efficiency, growth performance, and increases late mortality in broilers. At the processing plants, speed of automatic processing lines and meat quality could be adversely affected by a high prevalence of leg problems. The most common leg problems are the developmental disorders including valgus and varus deformities, tibial dyschondroplasia, crooked toes, spondylolisthesis, and rotated tibia. Lameness is also a predominant leg health issue, which is measured by scoring willingness of the birds to stand and walk. Bone formation starts very early in life during incubation and is affected by nutrient bioavailability in the egg and gas exchanges through the eggshell. Genetics is still a major component of leg health issue in broilers. However, some management or nutrition factors of breeders may affect leg health in the progeny. The two major diets formulated in the poultry industry worldwide, corn or wheat-barley based diets, have differences in some nutrient contents including non-starch polysaccharides, macro and trace minerals, intrinsic phytase, vitamins, carotenoids, and fatty acids. The type of extension of feed restriction in broiler breeders during rearing to production can also impact broiler progeny performance by changing proportionality of oviduct segments. In addition, feeder space change at photostimulation has an impact on breeder reproductive efficiency and broiler progeny performance. In conclusion, leg problems are common multifactorial disorders which are influenced not only by broiler management but also by breeder management and egg characteristics that impact incubation conditions for embryos.

INTRODUCTION

There is a worldwide concern in the poultry industry concerning leg abnormalities and walking ability of broilers due to welfare issues and high economic losses. Skeletal disorders are one of the most prevalent welfare problems in the poultry industry; especially those that cause impair movement and bone breakage during catching, transportation, and deboning (Julian, 2004; Mench, 2004). These disorders are not only welfare concerns but also production problems. Leg health has a detrimental effect on feed efficiency and growth performance (Oviedo-Rondón, 2007). In addition, it is a very frequent cause of culling and late mortality during the grow-out in broilers.

Leg problems also impact processing plant practices. The number of broilers dead during transportation to processing plants could increase due to leg abnormalities. Around one third of broilers that died during transportation to processing plants were found to have died from hemorrhaging associated with femur dislocation (Gregory and Wilkins, 1992). In addition, skeletal deformities slow down automatic processing lines and increase the requirement of manual trimming during deboning (Oviedo-Rondón, 2007). Another concern that arises from leg disorders at the processing plant is food quality. Bone fragility and porosity are correlated with the incidence of bone fragments in deboned meat products and discoloration of meat adjacent to bone due to the leaching of blood (Gregory and Wilkins, 1992). In fact, tibia ash is highly correlated to bloody breast meat and broken bones (Driver, 2006). Moreover, lame broilers that spend more time lying in the litter (Oviedo-Rondón et al., 2009a) have more breast blisters, scratches, inflammatory processes, and muscle atrophy (Julian 1998; Vaillancourt and Martinez, 2002). A secondary consequence of poor leg health is the increment of contaminants carried by lame broilers into the processing plant which threatens food safety (Oviedo-Rondón, 2007). All these carcass quality defects plus emaciation originates when broilers cannot walk to feeders and drinkers, which results in increased meat losses due to condemnations of carcasses (Pattison, 1992; Yogaratnam, 1995; Julian, 2004).

Several surveys have been performed to evaluate the prevalence of leg problems in different regions, especially in Europe. A recent study of over 50% of UK broiler production indicated that 28% of chickens suffered locomotion problems and 3% were almost unable to walk (Knowles et al., 2008). Previous European surveys of walking impairment resulted in a range from 26 to 30% (Kestin et al., 1992; Sanotra et al., 2001). Estimation of the total culled birds due to lameness was 2.6% relative to the total UK annual broiler production that was about 750 million birds (Pattison, 1992; Yogaratnam, 1995). The high prevalence of leg problems motivated the European Commission to declare leg problems a serious welfare issue in broiler production in 1992 (Jensen, 2000). In contrast, there have been nationwide surveys that determine prevalence of leg problems in the United States. The main concern has been the economic losses due to leg abnormalities. Lame broilers have poor growth performance (Kestin et al., 1999; Kestin et al., 2001) and are likely to be downgraded at slaughter. The most recent large scale survey of leg health in broilers in the U.S. indicated that leg problems accounted for 1.1% of mortality and 2.1% of carcass condemnations and downgrades annually (Morris, 1993). The annual cost of leg problems to the U.S. poultry industry has been estimated to be $80 to $120 million for broilers, and $32 to $40 million for turkeys (Sullivan, 1994). These findings confirm the worldwide importance of doing research to reduce leg health issues, and suggest that there is a higher awareness of leg problems in Europe compared with the USA.

Therefore, adequate internal structure of bones, morphological and biomechanical properties of legs should be in optimal conditions to enable locomotion and ameliorate welfare issues that also can cause reductions in growth performance.

SKELETAL DISORDERS OF BROILERS

Leg abnormalities can be categorized as infectious and non-infectious (Oviedo-Rondón et al., 2006). The non-infectious type is the most relevant disorder in terms of economic importance according to reports from the MAFF working Party (UK) and the AAAP Symposiums (U.S.) in 1981 and 1991 (Pattison, 1992). The three most predominant leg problems detected in those reports are generally considered developmental disorders. Riddell (1992) classified non-infectious skeletal disorders by their developmental, degenerative, and metabolic pathogenesis. Developmental disorders are often considered to have a genetic basis but could be influenced by environment or nutritional factors. Degenerative disorders imply the breakdown or death of tissue. Finally, metabolic disorders occur when there is failure in the production of cartilage or bone matrix, or in bone mineralization or remodeling. The main focus of this review will be on developmental disorders.

Valgus and Varus Deformities

Valgus and varus deformities are the most frequent causes of lameness and skeletal deformity in broiler and turkey flocks (Julian, 1984). The prevalence of valgus and varus deformities in broilers varies from 0.5 to 2.0%, but occasionally it reaches 5 to 25% in problem flocks (Riddell, 1992). Valgus is defined as a lateral, and varus as a medial angulation of the distal tibiotarsus resulting in deviation of the lower part of the leg (Julian, 1984). The major angulation occurs at the distal end of the tibiotarsus but lesser angulation may also occur in the proximal tarsometatarsus (Riddell, 1992). Valgus deformation is more common than varus deformation (Leterrier and Nys, 1992). Valgus and varus deformities are observed in all animal species. Doige (1988) suggested that possible causative factors for these defects are excessive joint laxity, hypothyroidism, trauma, poor conformation, and defective endochondral ossification.

Additionally, Riddell (1992) proposed that the irregularity of vascular morphology of the growth plate characteristic in broiler chickens may predispose the bird to valgus and varus deformities. Angular deformations have been associated with flattening of the tibial condyles and displacement of gastrocnemius tendon (Cruickshank and Sim, 1986). Abnormal alignments of the tension and compression forces applied to long bones in growing animals resulted in the development of this bone torsion (Lanyon and Bourn, 1979). Remodeling and correction of malalignments of bones that may have started to grow out of line is hindered by a rapid rate of growth (Whitehead et al., 2003). Birds with severe angulations will walk on their hock joints causing ulceration of the overlying skin and sometimes secondary infection. When the deviation becomes so severe that the bird is unable to rise, particularly in the case of valgus deformity this is called 'twisted legs' (Thorp, 1992).

Tibial Dyschondroplasia

Tibial dyschondroplasia (TD) was first described by Leach and Nesheim (1965). TD lesion is an unmineralized, unvascularized plug of cartilage that extends from the growth plate into the metaphysis (Leach and Gay, 1987). Dyschondroplasias are most commonly found in the proximal tibiotarsus, but has been reported to occur in most long bones (Farquharson and Jefferies, 2000). Tibial dyschondroplasia is most specifically related to rapid growth as it is common in meat-type poultry and rare or absent in other birds (Julian, 1998). Genetic effects concerning TD were demonstrated after the divergent selection for TD prevalence during 7 years that showed low and high TD-line chickens had 0 and 0.3 TD prevalences, respectively (Leach and Nesheim, 1972). The prevalence of TD in commercial broiler chicken flocks is greater than 30%, but most TD lesions are subclinical (Riddell, 1992).

The precise cellular defect that occurs in TD is not completely clear, but it is generally accepted that TD is a consequence of an inability of maturing chondrocytes to undergo terminal differentiation, which normally leads to vascularization and mineralization (Farquharson and Jefferies, 2000). Regulators of chondrocyte differentiation involved in the pathogenesis of TD are growth factors such as transforming growth factor-β, insulin-like growth factor, and fibroblast growth factor (Loveridge et al., 1993; Thorp et al., 1995; Farquharson and Jefferies, 2000), nuclear receptors for 1,25-dihydroxy-cholecalciferol

(Berry et al., 1996), ascorbic acid (Whitehead, 1997) and c-myc proto-oncogene protein (Loveridge et al., 1992).

Dietary manipulation and deficiency of nutrients influence the prevalence of TD in broilers. Feeding high levels of phosphorus relative to calcium increases the prevalence of TD (Edwards and Velmann, 1983; Riddell and Pass, 1987). Additionally, marginal levels of dietary calcium can increase the prevalence and severity of TD (Leach, 1982). On the other hand, high levels of pyridoxine and folic acid may reduce the incidence and severity of TD (Edward, 1990). The addition of chloride to the diet without balancing sodium and potassium increased the TD incidence (Leach and Nesheim, 1972; Oviedo-Rondón et al., 2001; Murakami et al., 2001). Altered biomechanical forces seen in spontaneous unilateral weight bearing birds can induce dyschondroplasic defects in the femur and the proximal tibiotarsus of the load bearing limb (Thorp and Duff, 1988). However, experimental induction of unilateral weight bearing had little effect on the incidence and severity of TD (Riddell, 1975).

TD has been recognized to reduce rate of longitudinal bone growth at the site of the lesion (Thorp, 1988), and increased local bone distortion and bowing (Lynch et al., 1992), loss of symmetry in the proximal femur (Duff, 1979), and fractured fibulas (Riddell, 1992). For instance, Lynch et al. (1992) demonstrated that 80% of chickens that were detected with TD had abnormal tibia bowing characterized by a tibial plateau angle higher than 25°. Moreover, the severity of TD has been positively related to fluctuating asymmetry, consequently, higher fluctuating asymmetries resulted in worsened walking impairment (Møller et al., 1999).

Crooked Toes

Crooked toes are very common leg abnormalities in meat-type broilers. The pathogenesis of crooked toes is not well understood, but it could be explained by the shortening of digital flexor tendons (Crespo and Shivaprasad, 2003) resulting in laterally or medially crooked toes (Herenda and Franco, 1996). Hick and Lerner (1949) indicated that deviated toes were highly heritable in White Leghorns. Furthermore, the selection over three generations reduced the prevalence of crooked toes from 30% to less than 15% in a commercial broiler strain (Sørensen et al., 1980). The increment of homozygosity due to artificial selection and inbreeding increased toe malformation prevalence linked to poor developmental homeostasis (Learner, 1954). On the other hand, Mercer and Hill (1984) reported low (+0.22) genetic correlation between BW and prevalence of crooked toes indicating that there are other factors that influence crooked toes to a greater magnitude.

Incubation and post-hatch conditions affect the prevalence of crooked toes in the broiler at market age. The use of different temperature profiles during incubation (Oviedo-Rondón et al., 2009a), high late incubation temperatures, and transportation stress from hatchery to farm (Oviedo-Rondón, 2009b) increased the prevalence of crooked toes at marketing age. Deficiencies of riboflavin and folic acid also increase prevalence of this toe malformation (Summers et al., 1984). Broilers that exhibited crooked toes also had a greater heterophil:lymphocyte ratio indicating that crooked toes prevalence could be associated with increased stress in broilers (Campo and Prieto, 2009).

Spondylolisthesis

Spondylolisthesis, also called "kinky back", is characterized by posterior paralysis due to deformation and displacement of the sixth thoracic vertebra, resulting in a pinched nerve in the spinal cord (Riddell, 1981). The posterior end of spine rotates upward and affected birds sit on their tail with their legs extended (Julian, 1984). The highest incidence of this disorder observed was 2% (Riddell, 1992). The condition is restricted to broiler chickens (Riddell, 1992) and is the only rapid growth-associated skeletal deformity that is more frequent in females (Julian, 1984).

Rotated Tibia

Rotated tibia is described as rotation of the metaphysis of the tibiotarsus (Riddell, 1981). The incidence is generally 0.2% but a higher incidence has been observed in some flocks. The abnormal rotation of the tibiotarsus is commonly 90° and the tarsometatarsus is directly laterally when the tibiotarsal-tarsometatarsal joint is flexed (Riddell, 1982). Droual et al. (1991) found an association between rotational and bending deformities of the distal tibiotarsus and scoliosis, a neural axis problem, in chickens.

LOCOMOTION PROBLEMS

Rapid growth increases the requirements for oxygen, nutrients, enzymes, hormones, inductive agents and growth factors (Whitehead et al., 2003). Thus, the supportive systems are challenged to maintain structure, function and satisfy demands of tissues during growth (Dibner et al., 2007). One of the most affected supportive systems is the skeletal system that consists of bones, cartilage, ligaments, and tendons. Lameness is currently measured on-farm by scoring walking ability or willingness of the birds to stand (Mench, 2004). Kestin et al. (1992) proposed a 6 point-gait scoring-system in which score 0 indicated normal walking and score 5 indicated that birds are unable to walk. Recently, Webster et al. (2008) validated a correspondence between the Kestin gait-scoring system and a simpler three-point gait-scoring system for field assessments. However, there is a low correlation between gait score and specific leg problems, such as TD, varus and valgus deformities, and crooked toes that suggests other factors are also involved in walking ability (Kestin et al., 1999; Sanotra et al., 2001). Lynch et al. (1992) reported that only 50% of chickens exhibiting dyschondroplasic defects had walking impairment. Other factors that influence walking ability are body conformation (Abourachid, 1991), hypothyroidism (Gonzales et al., 1999), tendon development (Robert and Scales, 2004), spinal cord injuries and vertebra deviations (Muir et al., 1998), exercise (Bessei, 2006), bacteria joint infection, pain due to degenerative joint diseases (Buckwalder et al., 2004), and several management factors (Febrer et al., 2006).

BONE DEVELOPMENT

Morphogenesis of the avian skeleton involves the developmental cascade of pattern formation, establishment of mirror-image bilateral symmetry, initiation and promotion of endochondral bone differentiation, and growth culminating in functional weight bearing governed by the bone morphogenetic proteins in the limb bud in the chick embryo (Reddi and Anderson, 1976; Reddi, 1981). The key steps in the bone morphogenesis are chemotaxis, mitosis of progenitor stem cells, differentiation of cartilage, and replacement by bone (Reddi, 2000). After chemotaxis, progenitor cells adher to the matrix as mediated by fibronectin (Weiss and Reddi, 1980). On day 3 of embryo development, the attached cells proliferate, and the daughter cells emerge as chondrocytes around 7 d of incubation. On day 9 the hyperthophic chondrocytes and associated matrix mineralize (Johnston and Comar, 1955). Bone formation is maximal around 11 days of incubation, as indicated by a major increase in alkaline phosphatase that is intimately associated with bone formation and osteoblast differentiation. The newly formed ossicle is the site of hematopoietic marrow differentiation at 21 d of incubation (Reddi and Anderson, 1976).

Then, phosvitin and lipovitellin, important nutrients for bone development, aggregate in the yolk spheres (Moran, 2007). Phosvitin has a large amount of phosphate, containing about 90% of the yolk protein phosphorus (Burley & Cook, 1961; Perlmann, 1973). Calcium is transferred through yolk sac villi from the vascular system to adhere to the surface of yolk spheres. Calcified granules are not absorbed but accumulate within the yolk sac until piping (Moran, 2007). Dissolution of mammillary knobs adjacent to the chorioallantois-shell membrane interface represents the dominant source of blood calcium (Abdel-Salam et al., 2006). Thus, endochondral ossification begins in-ovo but primarily occurs inmediately after hatching (Bain and Watkins, 1993). In fact, Everaert et al. (2008) demonstrated that the shell becomes weaker during embryonic development, due to calcium mobilization (Vanderstoep and Richards, 1970), which results in the loosening of the shell membranes from the eggshell around day 18 of incubation (Vanderstoep and Richards, 1970; Johansson et al., 1996).

Yolk and its lipid content also affect embryo bone development. Different maternal dietary lipids modify the concentrations of n-3, n-6, and other polyunsaturated fatty acids in tibia as well as ex-vivo prostaglandin E_2 production in bone organ culture of newly hatched quail (Liu and Denbow, 2001). In growing animals, dietary lipids varying in the amounts of n-3, n-6, and saturated fatty acids modulate bone fatty acid composition, production of local regulatory factors, bone formation rate, (Alam et al., 1993; Kokkinos et al., 1993; Watkins et al., 1997), bone calcium and pyridinium cross-links (Claassen et al., 1995; Kruger et al., 1997). The primary source of energy and the basis for embryo development is the use of fatty acids of the yolk (Moran, 2007). The complete combustion of fatty acids is supported by respiratory gas exchange when the chorioallantois starts to be formed around 4 days of incubation (Ribatti et al., 2000). It has been estimated that yolk supplies 90% of the total caloric needs of a chicken embryo (Freeman and Vince, 1974). Eventually, a large proportion of lipids (2 g) are transferred to the chick embryo from 19 to 21 d of incubation (Ding and Lilburn, 1996).

Skeletal development problems observed in the post natal period is likely an indication of distress during late-term incubation, deficiency in nutrients deposited into the egg by the hen (Moran, 2007), or impaired bone morphogenetic proteins signaling mechanisms governing endochondral bone formation in the embryo development (Reddi, 2000). Under commercial conditions, the most frequent stressors that embryos may encounter occurs when the incubator conditions such as temperature, humidity, and ventilation are suboptimal (Hulet, 2007; Meijerhof, 2002)

Incubation conditions can affect the incidence of tibial dyschondroplasia and early bone development in poultry (Yalçin et al., 2007). Moreover, Oviedo-Rondón et al. (2008a,b; 2009a,b) indicated that elevated temperatures (> 37°C) coupled with hypoxia (< 19% oxygen) conditions, during the last 4 d of incubation reduced bone development, collagen type X, and transforming growth factor β expression, and increased relative bone asymmetry in broilers.

MATERNAL EFFECTS ON PROGENY LEG HEALTH

Genetics

The major poultry breeding companies have increased the intensity of selection against skeletal deformities (Pattison, 1992). Although reductions in leg problems were achieved, leg problems are still related to genetic effects. Some leg health evaluations have indicated that Cobb broilers had significantly higher prevalence of walking impairment (≥ gait score 2) and tibial dyschondroplasia than Ross chickens (Sanotra et al., 2003).

Leg disorders for broiler progeny have a moderate heritability. The heritability for twisted legs ranges from 0.2 to 0.5 (Mercer and Hill, 1984; Le Bihan-Duval et al., 1996), for tibial dyschondroplasia from 0.3 to 0.4 (Zhang et al., 1998; Ducro and Sørensen, 1992), and for locomotor activity from 0.05 to 0.20 (Whitehead et al., 2003). Several studies have detected a genetic component for broiler locomotor activity. Bizeray et al. (2000) reported that fast-growing birds had reduced walking duration, standing, and number of steps than slow-growing chicks at 1 and 4 d of age. This suggests there was a genetic effect because slow-growing chicks were actually heavier at hatch.

Selection for fast growth and improved feed efficiency has also resulted in commercial poultry strains having lower thyroid activity compared to non-selected birds (Gonzales et al., 1999). Hypothyroid animals exhibit lower physical activity, weakness of limbs, and leg trembling during walking (Zoeller and Rovet, 2004). In addition, an induced mutation in the unliganded thyroid hormone receptor α1 in neuronal tissues produced locomotion dysfunction (Venero et al., 2005).

Nutritional Implications of the Utilization of Wheat or Corn as a Major Source of Energy

Corn and wheat are two major cereal sources of energy for poultry feed. The usage of both grains is concentrated in specific geographic regions. Wheat is mostly used in Europe, Australia, Canada (Bird, 1997; International Grains Council, 2004), whereas corn is widely used in the U.S. and Brazil. Europe appears to report a higher prevalence of leg problems as compared with the U.S. (Morris, 1993; Pattison, 1992; Yogaratnam, 1995). Thus, the evaluation of the effects of the major cereals used in the poultry industry could be important to elucidate effects of maternal diet type on progeny leg health. Besides the well documented differences in metabolizable energy, protein, fat, and fiber between corn and wheat (Bird, 1997) (Table I-1), there may be other important nutritional factors that affect growth performance and prevalence of leg problems.

Table I-1. Nutrients in corn and wheat ingredients

Nutrients	Corn	Wheat
Metabolizable energy[1] (Kcal/g)	3,350	3,120
Chemical composition (%)		
Crude protein[1]	8.50	11.50-14.00
Ether extract[2]	3.20	2.10
Neutral detergent fiber[2]	21.59	35.07
Acid detergent fiber[2]	2.55	2.21
Ash[2]	1.06	1.04
Amino acid profile[1] (%)		
Lysine	0.25	0.31
Methionine	0.18	0.17
Methionine + Cysteine	0.37	0.42
Threonine	0.30	0.32
Tryptophan	0.06	0.40
Arginine	0.39	0.51

Adapted from [1]Bird et al. (1997) and [2]Godoy et al. (2005).

Non-Starch Polysaccharides. Corn contains very low levels of non-starch polysaccharides (NSP), whereas wheat contains substantial amounts of both soluble and insoluble NSP. The main soluble NSP in these grains are arabinoxylans (Choct, 1997).

Arabinoxylan content in wheat grain ranges from 6 to 8% of DM from which 1.8% DM is soluble (Guitérrez-Alamo et al., 2008). The water-soluble NSP forms viscous solutions due to their capacity to absorb water up to ten times their weight (Choct, 1997). This soluble portion of NSP is mainly responsible for the decreased digestibility and absorption of nutrients (Choct and Annison, 1992; Van Der Klis et al., 1993).

The mechanisms that cause this detrimental effect are increased digesta viscosity (Schutte et al., 1995), retardation of passage of feed throughout the intestinal tract (Edwards et al., 1992), changes in physiology and morphology of the digestive tract, and interaction with the microflora of the gut (Carré et al., 1995). Moreover, Fischer (2003) reported that feeding wheat based diets to broilers increased the viscosity in the jejunum and ileum, and increased gastrointestinal tract size compared to corn utilization. These changes were attributed to differences in dietary NSP content and caecal fermentation. Another study demonstrated that wheat based diets reduced apparent metabolizable energy, lipid and crude carbohydrate digestibility as well as nitrogen retention in broiler chickens (Shakouri and Kermanshashi, 2003). Therefore, NSP would reduce the availability of essential nutrients needed for reproductive and growth purposes.

Macro and Trace Minerals. Corn and wheat are different in macro and trace mineral content (Godoy et al., 2005). Wheat contains more total calcium, phosphorus, and magnesium than corn. Also, wheat doubles the concentration of copper and zinc compared to corn, whereas corn contains about four times more manganese than wheat (Table I-2). All egg constituents derive from the hen's metabolism, thus variations in feeding hens may affect embryo development (Viera, 2007). The hen deposits minerals selectively in the egg. Calcium carbonate is the largest eggshell component that accounts for 95% of its weight (Romanoff and Romanoff, 1949).

Magnesium and phosphorus are mainly deposited in albumen and yolk, respectively (Cook and Briggs, 1986; Angel, 2007). The yolk is the primary storage site of trace minerals, except for copper that is mostly present in the eggshell and corresponding membranes (Richards, 1997).

Thus, differences in copper, manganese, and zinc concentrations between the two cereal types might affect available nutrients in the yolk and eggshell resulting in the disturbance of normal bone development. Copper prevents premature crystallization in the amorphous mineral deposits of the bone matrix vesicles (Sauer et al., 1997), and also plays an important role in the cross-linking of collagen and elastin (Carlton and Henderson, 1964). Copper deficiency with less than 1 ppm decreases collagen cross-links formation and lowers mineralization in chicks (Osphal et al., 1982). Zinc is involved in the chondrocytes proliferation and differentiation (Oviedo et al., 2006), regulation of hydroxyapatite crystallization (Sauer et al, 1997; Starcher, 1980), collagen synthesis, and the cellular invasion of the cartilage matrix by the osteoblast (Dibner et al., 2007). Zinc is a component of the two fingers of the vitamin D receptors (Zhongjian et al., 2000). Kidd et al. (1992) reported that the progeny from breeder hens fed diets supplemented with zinc-methionine had greater tibial bone ash content.

Finally, manganese is essential for the formation of mucopolysaccharides that form the ground substance of the cartilage model (Gilbert, 1997). In fact, supplementation of 20 and 40 ppm of zinc and manganese as methionine chelate forms significantly reduced the incidence of shaky leg and angular deformations by half in comparison to the inorganic sulfate form (Ferket et al., 1992).

Table I-2. Differences in macro and trace mineral contents between corn and wheat

Feed ingredients	Macro-minerals			Trace minerals		
	Ca	P	Mg	Cu	Mn	Zn
	----------------- (%) -----------------			----------------- (ppm) -----------------		
Corn	0.01	0.25	0.14	6.25	3.75	47.50
Wheat	0.06	0.33	0.26	13.00	1.00	108.00

Adapted from Godoy et al. (2005).

Intrinsic Phytase. Corn and wheat contain similar phytate P levels (Nelson, 1967; Choct, 1997); however, bioavailability of phosphorus differs between these two cereals. Phosphorous bioavailability estimated for wheat was five-fold higher than soft winter wheat (12 versus 58%) in chickens (Hayes et al., 1979) and growing pigs (Miracle et al., 1997).

The greater phosphorus availability in wheat is apparently due to elevated endogenous phytase (Pointillart, 1994; Eeckhout and De Paepe, 1994) and acid phosphatase activities (Viveros et al., 2000) as compared to corn (Table I-3).

According to Eeeckhout and De Paepe (1994), feed ingredients should be considered to have phytase activity when this is higher than 100 U/Kg. Thus, wheat, but not corn, has intrinsic phytase activity.

Endogenous wheat phytases were more resistant to proteolysis in the stomach (Jongbloed et al., 1992) and more active at low gastric pH than extrinsic phytases (Ranhotra and Loewe, 1975). Moreover, in a laying hen experiment, wheat-soybean meal and corn-soybean meal diets were analyzed for phytase activity and found to contain 20 and 267 U/Kg, respectively. Hens fed wheat based diets had higher tibia ash compared to those fed corn based diets indicating the importance of the elevated activity of native phytase (Liebert et al., 2005).

In addition, there is evidence that phytate can be utilized from poultry fed diets containing grains with high levels of intrinsic phytase (Leytem et al., 2007). In contrast, the use of corn-soybean meal diets including 15% wheat middlings increased phosphorus utilization and reduced fecal phosphorus; however, average daily gain, FCR and crude protein utilization were reduced by supplementation of intrinsic phytase coming from wheat middlings (Gong et al., 2006). This suggests that the positive response from endogenous wheat phytase might depend on the NSP content and other antinutritional factors in wheat.

Table I-3. Total phosphorus, phytate phosphorus, phytase, and acid phosphatase activities of corn and wheat

Feed ingredients	Total P (%)	Phytate P (%)	Phytate P (% of total P)	Endogenous phytase[1] (U/Kg)	Acid phosphatase (U/g)
Corn	0.23	0.18	78	70	1,640
Wheat	0.29	0.23	79	1637	10,252

Adapted from Viveros et al. (2000)

Vitamins. Vitamin E acts as an antioxidant by inhibiting lipid peroxidation in biological membranes (Panfili et al., 2003). It is more concentrated in corn than wheat (15.3 vs. 8.7 mg/Kg) (Herting and Drury, 1969). Panfili et al. (2003) reported similar results for α-tocopherols and identified other differences in vitamin E activity and the tocotrienols/tocopherols ratio (T3/T) between these two cereal types as shown in Table I-4. The T3/T ratio was calculated because it has been proven that α-tocotrienol was at least 3-fold more efficient as a scavenger of peroxyl radicals than α-tocopherol (Packet, 1995). Thus, it seems that wheat has a more efficient antioxidant action as compared to corn. Deficiency of vitamin E caused higher prevalence of leg abnormalities, especially lateral or medial deviation of the distal tibia or proximal metatarsus (Summers et al., 1984). Furthermore, vitamin E depletion may lead to muscular dystrophy manifested in walking impairment (Austic and Scott, 1991).

With regards to B vitamins, corn has much less thiamine, riboflavin (Copping, 1936), pyridoxine, and niacin (Ruiz et al., 1990) than wheat (Lebiedzinska and Szefer, 2006) (Table I-4). Deficiency of a number of B vitamins has been reported to increase leg abnormalities (Waldenstedt et al., 2006). Particularly, pyridioxine deficiency has been related to stunted longitudinal bone growth (Massé et al., 1996), hyperhomocysteinemia, and reduced activity of lysyl oxidase that is fundamental for elastin and collagen cross linking (Oviedo-Rondón et al., 2006). Riboflavin deficiency is mostly associated with curled-toe paralysis caused by peripheral nerve degeneration (Jortner et al., 1987). Niacin deficiency is predominantly related to angular deviations of the hock joint (Summers et al., 1984).

The bioavailability of biotin in wheat was equal or less than 12%, in contrast to almost 100% in corn (Bryden et al., 2006). Similar results were reported by Baker et al. (1978) and Frigg (1976) in chick growth assays. Bryden et al. (2006) suggested that the low digestibility of biotin might result from the bird's inability to liberate biotin from wheat in a form suitable for absorption, because biotin digestibility was not associated with the biotin concentration or any other characteristics of the wheat grain. Biotin is involved in the formation of malonyl-CoA, which is essential for de novo fatty acid synthesis and elongation of long-chain polyunsaturated fatty acids (Watkins, 1989). Thus, biotin can modulate prostaglandin E_2 and obtain the desired effect on bone development (Watkins, 2002; Farquharson, 2003). Watkins et al. (1988) reported that biotin-deficient chicks had lower prostaglandin precursors such as dihomo-γ-linolenate (20:3ω6), arachidonate (20:4ω6), and eicosapentaenoate (20:5ω3) compared to chicks that received an adequate biotin level (500μg/Kg). As a consequence, periosteal bone appositional and bone formation rates, and percentage new bone formation were reduced in the tibiotarsus of biotin-deficient chicks. Marginal nutritional deficiencies of biotin in practical diets have been associated with foot pad lesions in broilers (Harms and Simpson, 1975) and turkeys (Mayne, 2005). On the other hand, supplementation of biotin at doses of 200, 300, and 400 μg/Kg improved growth rate and increased bone mineral content (Quarantelli et al., 2006). Furthermore, biotin supplementation of breeder hens results in an increase in biotin level in eggs and a decrease of foot pad dermatitis in the progeny (Harms et al., 1979). Therefore, deposition of biotin in the egg is important for embryo development (Kjaer et al., 2006) and broiler growth performance.

Carotenoids. Wheat has fewer carotenoids than corn (Bird, 1997; Blair and Paulson, 1997). In avian species, the primary carotenoids of economical and ecological interest are the oxygenated carotenoids, including lutein, and its isomers zeaxanthin and canthaxanthin (Goodwin, 1984). Carotenoids are considered the second level of antioxidant defense after vitamin E, and the water-soluble antioxidants, ascorbic acid and glutathione. This antioxidant system is necessary for the prevention and minimization of lipid peroxidation (Niki, 1996). Surai and Sparks (2001) evaluated two diet types with different natural antioxidant components originated from the use of corn or wheat based diets. Lutein and zeaxanthin were the major carotenoids in the diets, compromising 80 to 82% of total carotenoids. The concentration of carotenoids for corn and wheat based diets was 11.8 mg/kg and 5.6 mg/kg, respectively. Breeders feed corn based diets laid eggs containing higher concentrations of total carotenoids, lutein, and zeaxanthin and the progeny at hatching was characterized by increased concentrations of total carotenoids and zeaxanthin in all tissues.

In addition, Koutsos et al. (2005) demonstrated that lack of carotenoid exposure, either in the egg or in the diet, resulted in enhanced systemic inflammation in chicks. The effectiveness of carotenoids as antioxidants is also dependent upon their interaction with other coantioxidants, especially alpha-tocopherol and vitamin C (Young and Lowe, 2001).

Fatty Acids. Wheat based diets formulated to meet poultry nutritional requirements generally contain more fat in order to increase the caloric concentration of the diet. Thus, the type of dietary fat would affect the fatty acid profile of poultry feed. Cornstarch lipids contain a higher percentage of polyunsaturated fatty acids compared to wheat starch (Baszckak et al., 2003).

Supplementation of maternal diet with fish oil increased the concentration of long chain n-3 poliunsaturated fatty acid (PUFA), like docosahexaenoic acid (DHA), relative to total fatty acids in the yolk (Pappas et al., 2005). The n-6/n-3 ratio for fish oil, soybean oil, and poultry fat is 2, 12 (Pappas et al., 2006), and 27 (Hutchison et al., 2004), respectively. In animals, a higher ratio of n-6 to n-3 fatty acids is associated with detrimental effects on bone health, and a lower ratio is associated with healthy bone properties (Watkins et al., 2001).

Table I-4. Differences in E and B vitamins between corn and wheat

Vitamins	Corn	Wheat
Vitamin E[1]		
α-tocopherol, mg/kg	3.7	15.9
α- tocotrienols, mg/kg	0.2	9.5
Vitamin E activity, tocopherol equivalents	9.8	23.8
T3/T ratio	0.3	1.9
Vitamin B[2], mg/Kg		
Thiamine (Vit B_1)	0.6	3.9
Riboflavin (Vit B_2)	0.5	1.3
Pyridoxine (Vit B_6)	1.5	4.5
Niacin	12	45

Adapted from [1]Panfili et al. (2003) and [2]Lebiedzinska and Szefer (2006). For vitamin E determination, corn and soft wheat were used. For vitamin B, corn and buckwheat groats for human consumption were used.

Other Factors. Breeder diet type during genetic selection may affect nutrient utilization. During the genetic selection of two commercial broiler lines, one line was fed corn-soybean meal diets with lower relative amino acid concentration, and the other line was fed wheat-soybean meal diets with 15 to 20% higher amino acid concentration than those fed corn based diets. It was found that the genetic line that received wheat based diets expressed approximately two-fold higher levels of mRNA abundance for peptide transport than the other line. This suggested that the genetic line fed wheat based diets had a greater capacity to assimilate amino acids in the form of di- and tripepetides (Gilbert et al., 2007).

Nutrient Accumulative Nutrition during Rearing Pullet Phase and to Peak of Program

Optimization of reproductive performance and progeny growth performance is based on management of sexual maturation timing and nutrient allocation throughout both rearing and laying periods (Robinson et al., 2007). Before sexual maturation, nutrients are deposited in the carcass or used for metabolic functions. The use of different pullet feeding programs can affect how nutrients are distributed in the body during sexual maturation (Renema et al., 2007). For instance, a sigmoid feeding program during pullet rearing phase resulted in an increased number of eggs per hen-housed and an improvement of hatch of fertile compared with a linear rearing feeding program, whereas the feed increase rate from photostimulation to peak of egg production did not have any effects on egg production and hatchability (Leksrisompong et al., 2006). In contrast, the use of a slow feeding regime, providing smaller incremental changes in shorter intervals based on body weights from photostimulation to 26 wk of age, improved egg production by means of limiting follicle recruitment (Renema et al., 2003).

Equally important is the cumulative nutrition before onset of lay to obtain an acceptable reproductive performance (Brake, 2006). Brake (2004) observed a positive dose-related response between early egg production and cumulative energy and protein attained during pullet rearing phase. Protein and energy intake during the pullet rearing phase and eggshell quality are also associated with low fertility in broiler breeders (McDaniel, 1981; Wilson and Harms, 1984; Morris, 1988).

During the early laying period, broiler breeder pullets are still in a sexual maturiting phase in which nutrients are diverted to liver and body fat storage as well as follicle development (Schneider et al., 2005). Robbins et al. (1986) reported that an abrupt rather than a gradual increase in feeding level during the pullet-layer transition of broiler breeders might hasten sexual maturity.

Broiler breeders feeding programs may affect progeny growth performance. Broilers from broiler breeders allocated to a lower feeder space (5.3 vs. 7.1 cm/female) during the pullet-rearing phase and fed a slow feeding program to peak program produced the heaviest broilers at 42 d (Leksrisompong et al., 2009). Further studies on the oviduct demonstrated that oviduct segments did not always develop in a synchronous manner. The use of the slow feeding program from photostimulation to the peak of egg production induced the oviduct segments to develop with similar rates (Leskrisompong and Brake, 2008).

Feeder Space during each Breeder Phase and Feeder Space Change at Photostimulation

Not only feed allocation affects reproductive efficiency of broiler breeder flocks, but also the availability of feeder space has an impact on average breeder performance during rearing and production. Limited feeder space for feed-restricted hens could increase aggression incidence and diminish egg production caused by feeder space competition or frustrated attempts to eat (Cunningham and Van Tienhoven, 1983; Rosales, 1994). However, aggression seems to be a function of the crowding level, this means that stocking density was confounded with group size. Lower crowding levels increased aggression occurrence in broiler chickens (Estévez et al., 1997; Pettit-Riley et al., 2002) and laying hens (Hughes and Wood-Gush, 1997; Nicol et al., 1999). On the other hand, a study with Hy-Line W-36 hens demonstrated that the reduction of feeder space did not impact the aggression level, but instead decreased feeding time, desynchronized feeding bouts to a lesser extent, and shared the feeder less (Thogerson et al., 2009). Leksrisompong et al. (2008) reported that an increase of feeder space from 7.0 to 10.3 cm/female at photostimulation increased female breeder mortality compared with no change of feeder space (10.4 to 10.3 cm/female) at photostimulation. In addition, no change in feeder space at photostimulation (10.4 to 10.3 cm/female) improved hen-housed egg production compared to treatment combinations in which there was change of feeder space (7.0-10.3 or 10.4-6.2 cm/female).

As there are several literature reports that suggest the importance of maternal effects of feeding program and feeder space change at photostimulation on broiler progeny growth performance, it was important to evaluate these maternal effects on bone development and leg health of progeny fed diet types containing the two cereals most used in the poultry industry.

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CHAPTER II: EFFECTS OF DIET TYPE, FEEDING PROGRAM TO 29 WK OF AGE, AND FEEDER SPACE CHANGE ON BREEDER GROWTH AND REPRODUCTIVE EFFICIENCY

ABSTRACT

This study aimed to examine the effects of diet type, feeding program to 29 wk of age, and feeder space change on breeder hen reproductive efficiency. Cobb-500 breeders were housed in 16 pens of 81 females each, and fed either corn (C) or wheat (W) based diets, formulated to have similar nutrient composition during the entire experiment. Two feeding programs, late fast (LF) or late slow (LS), were used from 14 to 29 wk of age. At 22 wk, 69 females that represented the BW distribution from each pen were placed in a layer house where feeder space either remained the same (6.3-6.5 cm/female) or was increased (6.3-8.4 cm/female). Breeder growth performance, reproductive efficiency, and egg characteristics were evaluated. Data was analyzed as a 2x2x2 factorial design with diet type, feeding program, and feeder space change as main factors. Breeders fed W were consistently heavier than breeders fed C from 10 to 52 wk of age. Additionally, breeders fed W had higher hen mortality during layer phase only. The use of LF feeding program increased BW only during the layer phase and induced more hen mortality only during the pullet rearing phase compared to the utilization of LS feeding program. Breeders fed W improved egg production laying eggs with greater Y:A ratio compared to C group. Breeders fed according to the LS feeding program had better fertility, and laid eggs with smaller eggshell percentage that might be associated to the lower early embryonic mortality compared to hens restricted to the LF feeding program. Even though feeder space did not influence hen BW or internal egg characteristics, increasing feeder space at photostimulation induced breeders to mature earlier and produced more eggs than no change in feeder space. It was concluded that the feeding of W, the use of the LS feeding program, and feeder space change improved to some degree hen productivity.

INTRODUCTION

The nutrition and feeding practices of broiler breeders has been the subject of research for many years pursuing ways to improve egg production and progeny growth performance (Hocking, 2009). Adequate nutrition and feeding practices for broiler breeders are promising areas to research in the poultry industry due to the minimal impact on the overall feed cost of broiler production, accounting for less than 7% of the total feed consumed by the chicken during growth (Calini and Sirri, 2007). Normal embryonic growth and progeny development depends on the efficacy of nutrient deposition into the eggs (Wilson, 1997) and the changes in egg component size (Angel, 2007).

The author did not find any report comparing the effects of corn and wheat as main sources of energy in diets for broiler breeders. However, the inclusion of corn or wheat in egg-layer diets has been evaluated. The use of either one of these cereals did not affect performance, hen productivity, or egg characteristics of laying hens (Liebert et al., 2005; Lázaro et al., 2003; Safaa et al., 2009). In contrast, Frikha et al. (2009) reported higher BW gain for egg-laying pullets fed corn diets, but similar feed conversion ratio as pullets fed wheat diets.

Optimization of reproductive performance is based on management of sexual maturation timing and nutrient allocation throughout both rearing and laying periods (Robinson et al., 2007). Before sexual maturation, nutrients are deposited in the carcass or used for metabolic functions. The use of different pullet feeding programs can affect how nutrients are distributed in the body during sexual maturation (Renema et al., 2007). For instance, sigmoid feeding program during pullet rearing phase resulted in an increased number of eggs per hen-housed and an improved of fertile hatchability compared with a lineal rearing feeding program, whereas the feed increase treatments from photostimulation to peak of production did not have any effects on egg production and hatchability (Leksrisompong et al., 2006). In contrast, the use of a slow feeding regime, providing smaller incremental changes in shorter intervals based on body weights from photostimulation to 26 wk of age, improved egg production by means of limiting follicle recruitment compared to a fast feeding regime (Renema et al., 2003). Equally important is the cumulative nutrition before onset of lay to obtain an acceptable reproductive performance (Brake, 2001). Brake (2004) observed a positive dose-related response between early egg production and cumulative energy and protein attained during the pullet rearing phase.

Not only feed allocation affects broiler breeder reproductive efficiency, but also the availability of feeder space has an impact on breeder performance during rearing and production. Limited feeder space for feed-restricted hens could increase aggression incidence and diminish egg production caused by feeder space competition or frustrated attempts to eat (Cunningham and Van Tienhoven, 1983; Rosales, 1994). However, aggression seems to be a function of the crowding level that includes stocking density confounded with group size. Lower crowding levels produced more aggression in broiler chickens (Estevez et al., 1997; Pettit-Riley et al., 2002) and laying hens (Hughes and Wood-Gush, 1997; Nicol et al., 1999). On the other hand, a study with Hy-Line W-36 hens demonstrated that the reduction of feeder space did not impact the aggression level, but instead desynchronized feeding behavior (Thogerson et al., 2009).

Leksrisompong et al. (2008) reported that the increase of feeder space from 7.0 to 10.3 cm/female at photostimulation increased female breeder mortality compared with no change of feeder space (10.4 to 10.3 cm/female) at photostimulation. In addition, no change in feeder space at photostimulation (10.4 to 10.3 cm/female) improved hen-housed egg production compared to treatment combinations in which there was change of feeder space (7.0-10.3, 10.4-6.2 cm/female).

Thus, this experiment was carried out to determine the effects on reproductive performance and egg traits of broiler breeders being reared on either corn or wheat based diets, formulated to have similar nutrient composition, during rearing and production. A second objective was to determine the effects of the two rates of increasing feed amounts during rearing until peak of production following a late fast or late slow feeding program. The third objective was to evaluate the effects of changing feeder space at photostimulation**.** The ultimate purpose of this study was to provide a better understanding of the combined effects of diet type, feed allocation, and feeder space and how these effects could impact reproductive performance and egg characteristics.

MATERIALS AND METHODS

Broiler Breeder Husbandry

A total of 1296 Cobb 500 non-feather sexable broiler breeder females and 288 broiler breeder males were grown sex-separate in a black-out house on an 8-h photoperiod after 23 h light per day for one week. Breeder pullets were randomly assigned to sixteen floor pens containing 81 pullets each. Each female growing pen had 5 tube feeders and 2 automatic bell drinkers. Each feeder pan was 37 cm in diameter with a circumference of 116 cm, providing 6.3 cm per pullet. Breeders were fed either corn or wheat based diets, formulated to have similar nutrient composition, during rearing and production. Nutritional recommendations took in consideration guide lines of breeding companies and average of values by commercial companies in the US and Europe. Supplemental biotin was added to both diets to meet the recommended nutritional requirements (Cobb-Vantress, 2008). The composition of the diets utilized throughout the trial is shown in Table II-1. The starter diet was fed in crumbles from 0 to 4 wk of age, the grower diet was in mash form and fed from 5 to 25 wk, and production diets were fed as mash from 26 to 52 wk. A pre-lay diet was fed from 18 to 25 wk of age only to breeders provided wheat based diets. Two feeding programs, late fast (LF) and late slow (LS) were applied from 14 to 29 wk (Figure II-1). Breeders were fed in a 4/3 feed restriction program from 3 to 22 wk of age.

Pullets were weighed in groups at 1d, 4 wk, and 10 wk of age. At 20 wk, pullets and cockerels were individually weighed to select birds representing the BW distribution of each rearing pen. A total of 69 pullets and 7 cockerels from each pen were moved to a two-thirds slat one-third litter pen located in a curtain-sided layer house at 22 wk of age. Pullets were immediately photostimulated with 14 h of light. Pen size was 16 m^2 (159” x 156”) given a stocking density of 4.3 female breeders per m^2. Each breeder pen was equipped by one 8-hole galvanized nest box, two automatic bell drinkers and either 4 or 5 female tube feeders to provide similar (6.5 cm/hen) or more (8.4 cm/hen) feeder space compared with the pullet-rearing phase (6.3 cm/female). In addition, one male tube feeders in each pen. To improve fertility in the entire flock, intraspiking was performed at 37 wk of age.

To ensure sex separate feeding, 48 x 58 mm feeder grills were installed around each female tube feeders. A random group of 20 breeders per pen were selected and weighed in groups of 5 birds each at 24, 28, 33, 37, 40, 48, and 52 wk of age. Mortality was recorded on a daily basis throughout the experimental period.

Reproductive Performance

Egg production was recorded daily. Average age at sexual maturity was considered to be when the breeders of each pen reached 50% egg production (Lewis et al., 2007). Peak egg production was determined as a 5 d rolling average (De Beer and Coon, 2007). Sixty normal non-dirty eggs were collected and incubated on a weekly basis from 34 to 52 wk of age to determinate hatchability and fertility.

Eggs were set in Jamesway 252B machines (Butler Manufacturing Co., Ft. Atkinson, WI) for incubation and hatching following an egg set tray. All unhatched eggs were broken out to record fertile, contaminated, cracked, and pipped eggs (with a poked hole in the eggshell from the beak). Early embryonic mortality (1 to 12 days of incubation) and late embryonic mortality (13 to 20 days of incubation) were recorded and distinguished by the appearance of feathers. Fertility was calculated as the number of fertile eggs per 100 eggs set. Hatchability was calculated as the number of chicks hatched per 100 eggs set, and hatchability of fertile eggs was calculated as the number of chicks hatched per 100 fertile eggs set.

Egg Analyses

Eggs were evaluated at 31, 37, and 46 wk of breeder hen age. In each pen, only nest eggs that were not dirty, cracked, or double-yolked were collected for analysis twice daily at 1000 and at 1500 h. All eggs were numbered and weighed. Length and width of each egg were measured with a digital caliper to the nearest 0.01 mm to determine volume, surface area (Altuntaş and Şekeroğlu, 2008), and shape index (Anderson et al., 2004) using the following equations:

$V = (\pi/6) \times W^2$; $SA = \pi D_g^2$, $D_g = (LW^2)^{1/3}$; $ESI = W/L \times 100$

Where: L = length, W = width, D_g = geometric mean diameter, V = volume, and SA = Surface area, ESI = Shape index

After measuring external egg characteristics, eggs were broken and the yolk was separated from the albumen. The yolk and the shell were weighed and the wet albumen weight was calculated by subtracting the yolk and the eggshell weight from the egg weight. All egg components were expressed as a percentage of initial egg weight. In addition, yolk:albumen ratio (Y:A ratio) was calculated.

Statistical Analyses

In the growing phase, sixteen pen experimental units were assigned to combinations of levels of the experimental factors diet type and feed allocation according to a 2×2 completely randomized design. In the production phase, pens were randomized to two levels of a third experimental factor, feeder space change, according to a 2 × 2 × 2 experimental design, so that each of the eight treatment combinations was observed in two pens.

Breeders were fed either corn or wheat based diets throughout the experiment. The amount of feed provided was the same until 14 wk of age, at this time two restriction feeding programs, either LF or LS were used until 29 wk of age (Figure II-1). Data analysis was performed using JMP 8 (SAS Inst. Inc., Cary, NC) statistical analysis software. Only for egg analyses, each egg was considered as an experimental unit, and pens were included as random effects and nested within treatment combinations. Percentage of hen mortality, egg production, and egg components was transformed to Arc sine prior to analyses. All pairwise comparisons among treatments means were carried out using Tukey's studentized range test at an experimentwise type I error rate of $\alpha = 0.05$.

Statistical model during the production phase for egg analyses:

$Y_{ijklm} = \mu + \alpha_i + \beta_j + \delta_k + \alpha\beta_{ij} + \alpha\delta_{ik} + \beta\delta_{jk} + \alpha\beta\delta_{ijk} + \lambda_{l(ijkm)} + \varepsilon_{ijklm}$

Where:

Y_{ijklm} : Variable response

μ : Overall mean

α_i : Effect of i[th] diet type (i = 1,2)

β_j : Effect of j[th] feeding program (j = 1,2)

δ_k : Effect of k[th] feeder space change (k= 1,2)

$\alpha\beta_{ij}$: Effect of the first order interaction between diet type i and feeding program j

$\alpha\delta_{ik}$: Effect of the first order interaction between diet type i and feeder space change k

$\beta\delta_{jk}$: Effect of the first order interaction between feeding program j and feeder space change k

$\alpha\beta\delta_{ijk}$: Effect of the second order interaction among diet type i, feeding program j and, feeder space change k

$\lambda_{l(ijkm)}$: Random effect of breeder pen nested within treatments. (l = effect of pen, m= effect of hen or egg)

ε_{ijklm} : The experimental error associated to each observation.

Table II-1. Composition of broiler breeder diets (%) and formulated nutrient contents

INGREDIENTS	Starter (0-4 wk)		Grower (5-25 wk)		Pre-lay (18-25 wk)	Production (26-52 wk)	
	Corn	Wheat	Corn	Wheat	Wheat	Corn	Wheat
	------------------- (%) -------------------						
Corn	60.56	10.00	57.65	15.00	15.00	56.48	15.00
Soft wheat grain	0.00	59.76	0.00	52.25	52.82	0.00	59.66
Soybean meal, 48%	26.12	20.24	14.15	8.05	8.18	18.75	12.35
Wheat bran	6.00	2.00	19.40	16.90	15.92	11.77	0.00
Poultry fat	1.02	2.07	0.51	1.25	1.14	3.16	2.69
Dicalcium phos., 18.5%	2.36	2.27	1.87	1.77	1.79	2.02	2.10
Limestone fine	1.05	1.13	1.17	1.25	2.69	6.52	6.55
Sodium bicarbonate	0.14	0.24	0.16	0.37	0.37	0.06	0.11
Salt	0.55	0.38	0.44	0.32	0.32	0.46	0.37
Mineral premix [1]	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Vitamin premix [2]	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Lysine, 78.8%	0.05	0.19	0.04	0.20	0.20	0.00	0.21
Methionine, 99%	0.11	0.12	0.03	0.08	0.08	0.10	0.15
L-Threonine, 98%	0.03	0.08	0.00	0.10	0.10	0.00	0.11
Coccidiostat	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Filler (Vermiculite)	1.30	0.81	3.87	1.77	0.70	0.00	0.00
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0
NUTRIENT COMPOSITION							
ME, Kcal/Kg	2,900	2,900	2,750	2,750	2,750	2,850	2,850
Gross energy, Kcal/Kg [3]	3,855	3,893	3,762	3,791	-	3,645	3,682
Crude protein,%	19.21	19.21	15.00	15.00	15.00	15.60	15.60
Crude protein , % [A]	20.40	20.34	16.10	16.72	-	16.23	15.51
Calcium,%	1.00	1.00	0.95	0.95	1.50	3.00	3.00
Available phosphorus,%	0.50	0.50	0.45	0.45	0.45	0.45	0.45
Lysine, %	1.05	1.05	0.75	0.75	0.75	0.81	0.81
TSAA, %	0.78	0.78	0.60	0.60	0.60	0.65	0.65
Threonine, %	0.72	0.72	0.54	0.54	0.54	0.55	0.55
Tryptophan, %	0.20	0.24	0.15	0.18	0.18	0.18	0.19
Arginine, %	1.25	1.18	0.94	0.88	0.88	1.02	0.91
Sodium, %	0.26	0.22	0.22	0.23	0.23	0.22	0.22
Potassium, %	0.82	0.74	0.69	0.61	0.61	0.75	0.63
Chloride, %	0.37	0.31	0.31	0.28	0.28	0.30	0.30
DEB (mEq/100g)	218	198	187	179	177	202	180

[1] Trace minerals from premix provided per kilogram of diet: manganese ($MnSO_4$), 120 mg; zinc ($ZnSO_4$) 120 mg, iron ($FeSO_4$), 80 mg; cooper ($CuSO_4$), 10 mg; iodine ($Ca(IO_3)_2$), 2.5 mg and cobalt ($CoSO_4$), 1 mg. Additional selenium was provided by a selenium premix (0.02 %) in all diets at 0.10 %. [2] Vitamins from premix provided per kilogram of diet: vitamin A, 13,228 IU; vitamin D_3, 3,968 IU; vitamin E, 66 IU; vitamin B_{12}, 40 mg; riboflavin, 13 mg; niacin, 110 mg; d-pantothenic acid, 22 mg; menadione, 4 mg; folic acid, 2 mg; vitamin B_6, 8 mg; thiamine, 4 mg; biotin, 250 mg. Choline chloride (60%) and biotin were included in all diets at 0.20 and 0.05 %, respectively.[3] Gross energy was determined by oxygen bomb calorimeter C 2000 Basic (IKA®, Staufen, Germany). [A] Determined by proximate analysis.

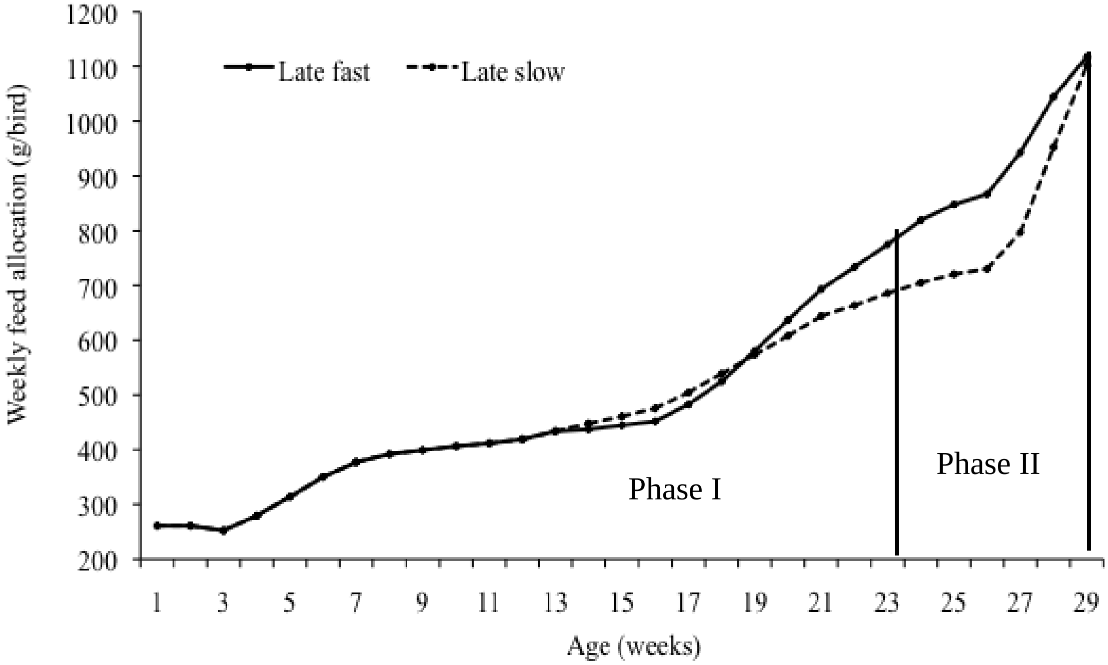

Figure II-1. Weekly feed allocation (g/bird) from 1 to 29 wk of age. In phase I, the cumulative nutrition from placement to prior to photostimulation, was 26,397 kcal of ME and 1,476 g of crude protein (CP) for the late fast feeding program, and 26,209 kcal of ME and 1,465 g of CP for the late slow feeding program. In phase II, the cumulative nutrition from photostimulation to 29 wk was 18,035 cal of ME and 986 g of CP for the late fast feeding program and 16,014 cal of ME and 875 g of CP for the late slow feeding program. Cumulative nutrition was determined based on calculated values.

RESULTS

Body Weights and Cumulative Mortality

Body weights at placement were similar among treatments (Table II-2). In the growing phase, there were no (P > 0.05) interaction effects for diet type and feeding program. Breeders fed wheat based diets were consistently 3% heavier (P < 0.05) than those fed corn based diets in the rearing phase after 10 wk of age. On the other hand, feeding program did not influence BW (P > 0.05). In the production phase, no interaction effects were observed among the three factors evaluated for BW. Breeders fed wheat based diets were still 4 to 5%

heavier ($P < 0.05$) compared with those fed corn based diets until the end of the experiment (Figure II-2). Feeding program had significant effects on BW only at 24, 28, 33, and 40 wk of age ($P < 0.05$). Breeders exposed to the LF feeding program during rearing until 28 wk of age were heavier compared with those fed according to the LS feeding program. The difference in breeder BW between these two feeding programs was greater at 33 wk of age (3360 vs. 3096 g) with smaller differences (~110 g) observed at 24, 28, and 40 wk of age. This effect of feeding programs on BW was not significant ($P > 0.05$) after 40 wk.

Cumulative mortality during the pullet-rearing phase demostrated no significant interaction effects of diet type and feeding program, but there were significant effects of feeding program as a main factor. Female broiler breeders fed according to the LF feeding program had higher ($P < 0.05$) mortality (4.63 vs. 1.54 %) compared with those breeders applied to the LS feeding program (Figure II-3). Mortality during the pullet-rearing phase was more frequent between 17 to 19 wk of age (Figure II-4). In the production phase, no significant interaction effects were observed ($P > 0.05$) among diet type, feeding program, and feeder space. However, higher ($P < 0.05$) mortality (4.53 vs. 2.36 %) was observed with breeders fed wheat based diets compared with those fed corn based diets (Figure II-5). Seventy percent of the mortality during the layer phase occurred from 37 to 52 wk of age.

Reproductive Performance

There were no interaction effects ($P > 0.05$) among treatments for overall reproductive performance (Table II-3). Breeders fed corn based diets took longer ($P < 0.01$) to reach sexual maturity and they had lower ($P < 0.05$) hen housed-egg production and hen-day egg production ($P < 0.01$) compared with breeders fed wheat based diets. The use of LS feeding program delayed ($P < 0.05$) sexual maturity, but breeders fed according to that program laid heavier ($P < 0.05$) eggs at peak of egg production. Breeders fed according to the LF feeding program had lower overall fertility ($P < 0.05$) and higher overall early embryonic mortality compared to breeders in the LS program.

Table II-2. Effects of broiler breeder diet type and feeding program on Cobb 500 female BW at 4, 10, and 20 wk during the pullet-rearing period.

Diet	Feeding program	Age			
		1d	4 wk	10 wk	20 wk
		(g)			
Corn		40.2	623	1232[b]	2061[b]
Wheat		40.5	627	1267[a]	2126[a]
	Late fast	40.3	623	1250	2087
	Last slow	40.4	626	1249	2101
Corn	Late fast	40.3	620	1232	2045
	Late slow	40.1	625	1233	2078
Wheat	Late fast	40.3	626	1269	2130
	Late slow	40.7	627	1266	2124
Pooled SEM		0.22	3.01	5.85	9.85
CV (%)		1.55	1.31	1.32	1.33
Source of variation		(*P*-values)			
Diet		0.314	0.417	0.001	0.001
Feeding program		0.767	0.483	0.906	0.356
Diet x feeding program		0.394	0.634	0.768	0.184

[a,b] Means within a column without a common superscript differ significantly ($P < 0.05$).

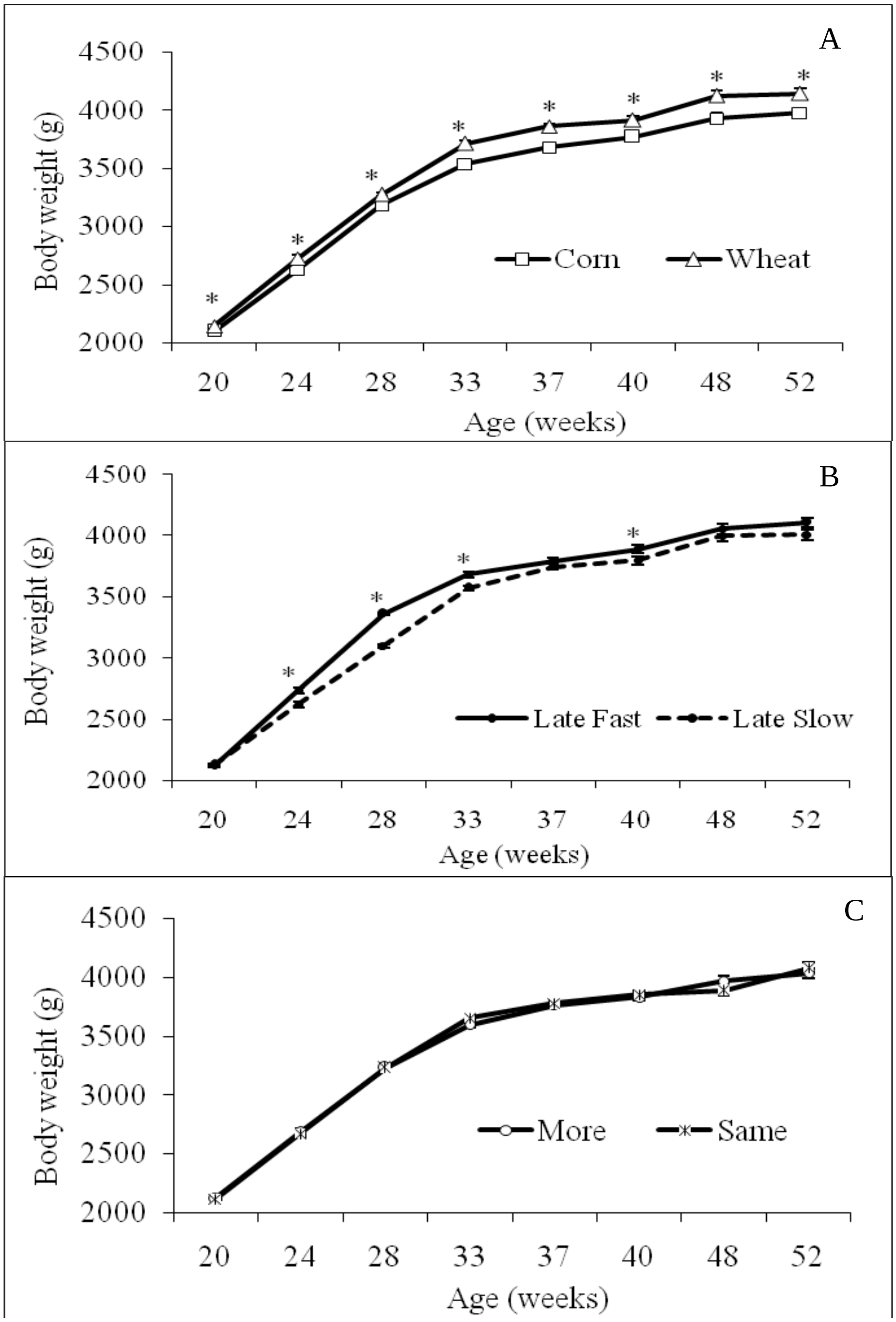

Figure II-2. Effects of diet type (A), feeding program (B), and feeder space (C) on Cobb 500 broiler breeder female BW at 20, 24, 28, 33, 37, 40, 48, and 52 wk of age. Data are means of 8 observations at each time point. Bars represent SEM. An asterisk (*) indicates time points for which a significant ($P < 0.05$) difference was found.

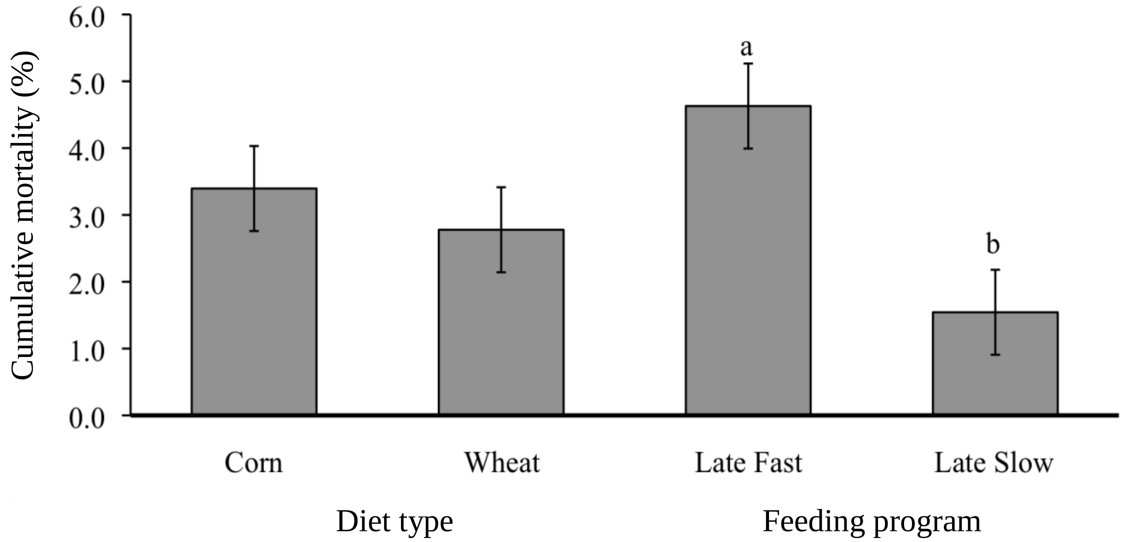

Figure II-3. Effects of diet type and feeding program as main factors on cumulative mortality of Cobb 500 broiler breeders during pullet-rearing phase from 1 to 22 wk of age. Data are means of 8 replicate pens. Bars represent SEM. Means without common superscripts differ significantly ($P < 0.05$).

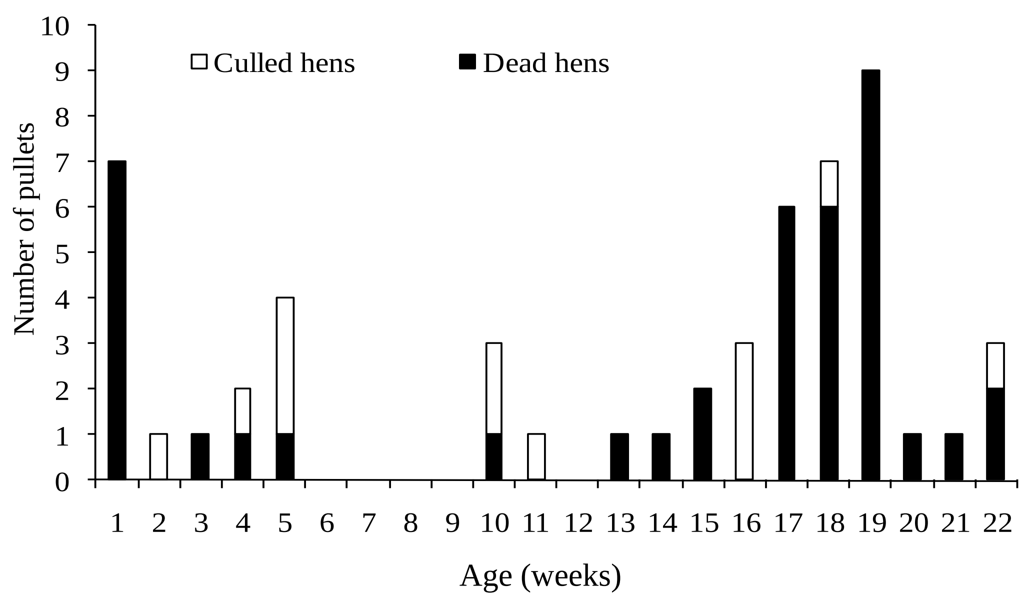

Figure II-4. Distribution of pullet mortality during the rearing phase from 1 to 22 wk.

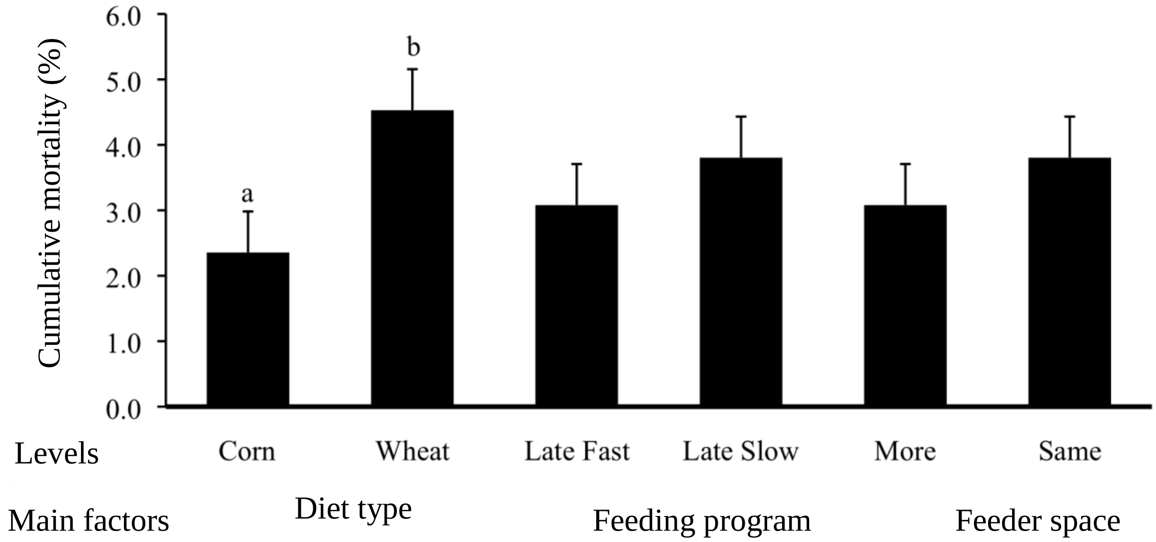

Figure II-5. Effects of diet type, feeding program, and feeder space as main factors on cumulative mortality of Cobb 500 broiler breeders during the production phase from 23 to 52 wk of age. Data are means of 8 pen replicates. Bars represent SEM. Means without common superscripts differ significantly ($P < 0.05$).

The increase in feeder space from rearing to production (6.3 to 8.4 cm/hen) accelerated ($P < 0.05$) sexual maturation, increased ($P < 0.05$) peak egg production, but lessened egg weight at 31 wk of age. In addition, increasing feeder space at housing improved ($P < 0.05$) egg production up to 52 wk of age.

When evaluating hatch of fertile weekly from 32 to 52 wk, an interaction ($P < 0.05$) effect between diet type and feeder space was observed only at 41 wk of age. This interaction indicated that breeders fed corn based diets had higher hatch of fertile than those fed wheat based diets when feeder space was increased in production. Diet type as a main factor had significant effect ($P < 0.05$) on hatch of fertile only at 39 wk, showing that breeders fed corn based diets had 6.5 % more hatch of fertile than hens fed wheat based diets. Related to feeding program, broiler breeders fed according to the LF feeding program exhibited greater ($P < 0.05$) hatch of fertile compared with those fed according to the LS program at 40, 41, and 47 wk of age (Figure II-6A). In the other weeks, hatch of fertile followed a similar numerical tendency ($P > 0.05$) independent of feeding program. There were no significant ($P > 0.05$) effects of feeder space change on hatch of fertile. The weekly evaluation of early embryonic mortality indicated that diet type did not have significant ($P > 0.05$) effects at any age. In contrast, feeding program affected early embryonic mortality ($P < 0.05$) at 40, 41, 50, and 52 wk of age, indicating that breeders allocated to the LS feeding program had less ($P < 0.05$) early embryonic mortality than those fed according to the LF program (Figure II-6B). Additionally, feeder space had significant effects at 49 and 52 wk of age. Increased feeder space from rearing to production reduced ($P < 0.05$) early embryonic mortality at both age.

Analyzing the weekly evaluation of late embryonic mortality, no interaction effects ($P > 0.05$) among treatments were observed. Diet type only affected late embryonic mortality at 41 wk. Breeders fed wheat based diets had higher ($P < 0.05$) late embryonic mortality compared with those fed corn based diets. At 38 wk, breeders fed according to the LS feeding program had higher ($P < 0.05$) late embryonic mortality compared with those on the LF program. At 35 wk, breeders that had similar feeder space from rearing to production had lower late ($P < 0.05$) embryonic mortality than breeders with increased feeder space in production.

The weekly analysis of hen-day egg production (%) from 26 to 52 wk of age (Figure II-7) showed that breeders fed wheat based diets had higher ($P < 0.05$) egg production from 27 wk of age to peak of production, thereafter the difference was not significant ($P > 0.05$) until 51 wk when again broiler breeders fed wheat based diets had better egg production. Feeding program also affected egg production from 27 to 29 wk of age, in which breeders fed according to the LF program had higher ($P < 0.05$) egg production. In contrast, increasing feeder space in production improved egg production ($P < 0.05$) mostly after peak of egg production at 26, 32, 35, 36, 37, and 39 wk of age.

Table II-3. Effects of diet type, feeding program, and feeder space change as main factors on reproductive performance of Cobb 500 broiler breeder hens from 26 to 52 wk of age

Variables	Diet		Feeding program		Feeder space		SEM
	Corn	Wheat	Late fast	Late slow	Same	More	
Age at sexual maturity[1], d	198.0[a]	195.4[b]	195.8[b]	197.6[a]	197.8[a]	195.6[b]	0.6
Age at peak egg production[2], d	221.4	219.1	219.9	220.6	222.9	217.6	3.1
Peak egg production[2], %	84.53	86.20	85.48	85.24	83.70[b]	87.00[a]	0.83
Egg weight[3] at peak, g	57.95	57.72	58.11[a]	57.57[b]	58.27[a]	57.40[b]	0.23
Hen-housed egg production[5], n	131.9[b]	136.6[a]	134.9	133.6	131.7[b]	136.8[a]	1.4
Hen-day egg production[5], %	61.61[b]	64.16[a]	63.29	62.47	61.88[b]	63.88[a]	0.50
Fertility[6], %	94.25	92.50	91.39[b]	95.38[a]	93.58	93.18	1.21
Hatch of fertile[6], %	92.59	91.69	91.56	92.72	91.54	92.74	0.68
Early embryonic mortality[6], %	4.37	4.65	5.41[a]	3.61[b]	5.06	3.96	0.51
Late embryonic mortality[6], %	1.90	2.31	1.80	2.41	2.23	1.99	0.21

[a-b] Means within a column without a common superscript differ significantly (*P* < 0.05).
[1] Average age of sexual maturity was considered to be when breeders laid 50% egg production.
[2] Peak of egg production was determined as a 5-d rolling average.
[3] Egg weight measured at the peak of production at 31 wk of age.
[5] Variables measured from 26 to 52 wk of age.
[6] Eggs were incubated weekly from 34 to 52 wk of age.

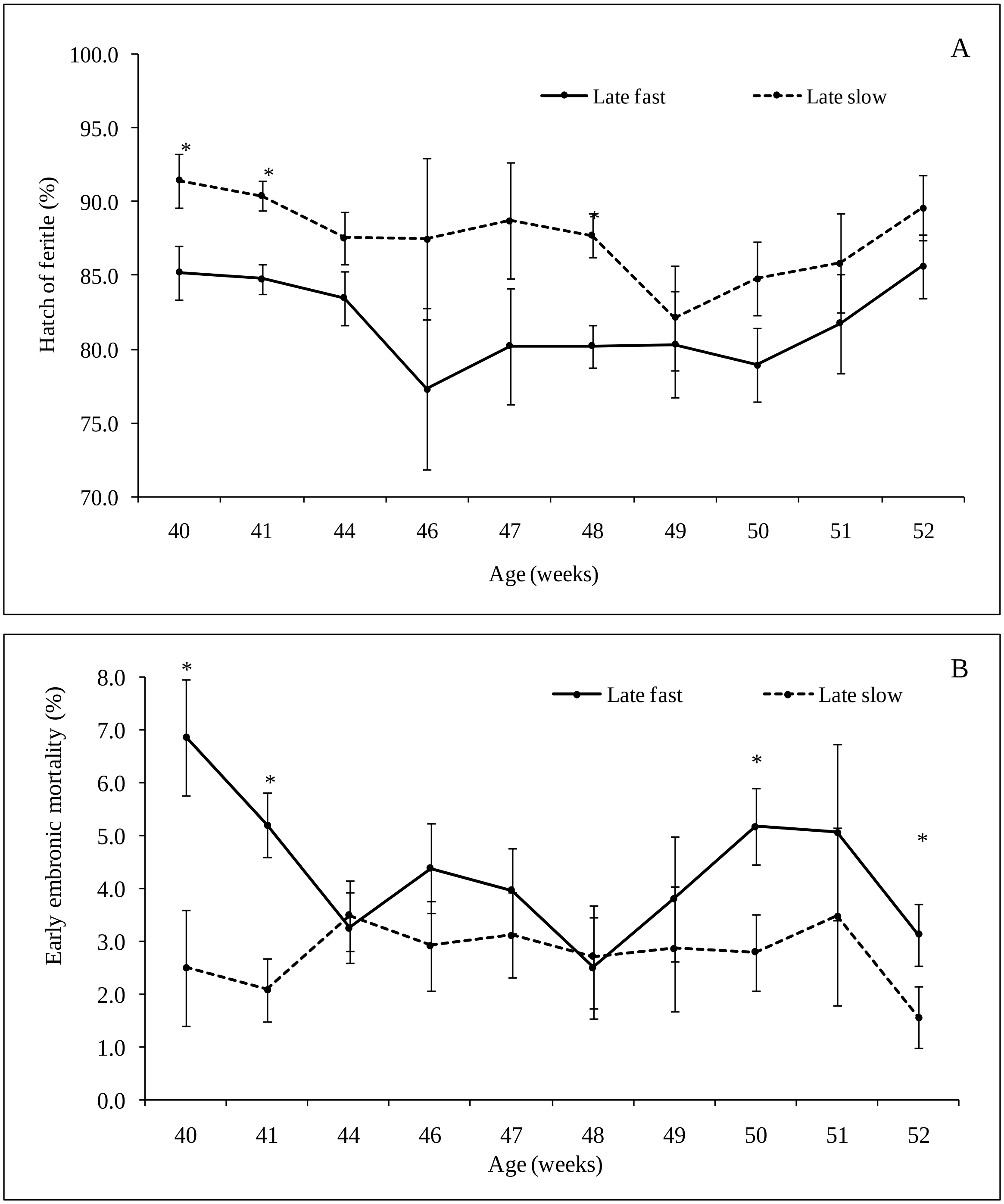

Figure II-6. Effects of feeding program on hatchability of fertile eggs (A) and early embryonic mortality (B) of Cobb 500 broiler breeders from 40 to 52 wk of age. Data are means of 8 pen replicates. Bars represent SEM. An asterisk (*) indicates time points for which a significant ($P < 0.05$) difference was found.

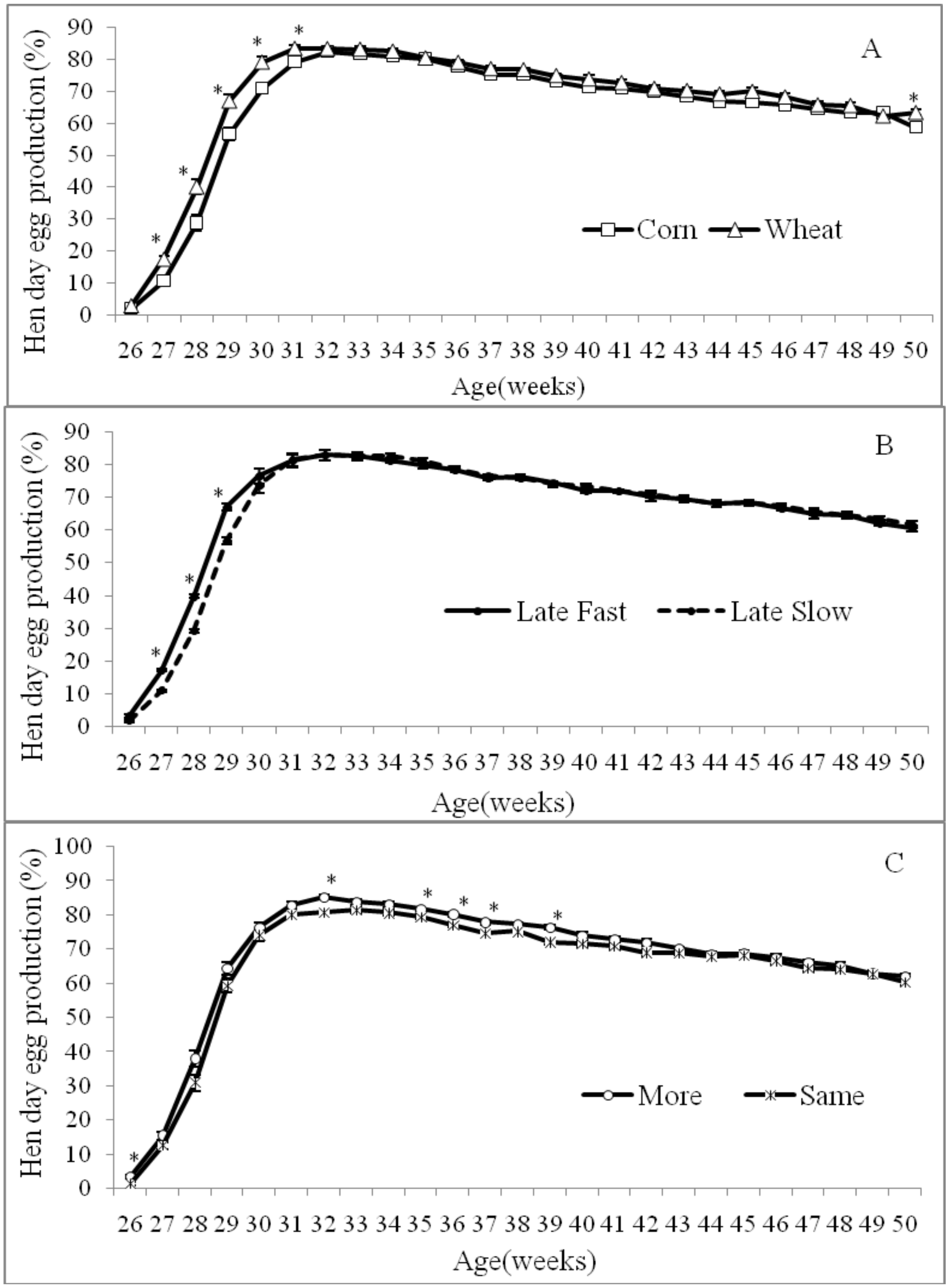

Figure II-7. Effects of diet type (A), feeding program (B), and feeder space change (C) on hen-day egg production (%) of Cobb 500 broiler breeders from 26 to 50 wk of age. Data are means of 8 observations at each time point. Bars represent SEM. An asterisk (*) indicates time points for which a significant ($P < 0.05$) difference was found.

Egg Characteristics

Egg traits were evaluated during three periods at 31, 37, and 46 wk of age. There were three-way interaction effects among diet type, feeding program, and feeder space for egg weight at 46 wk of age (Table II-4). Breeders fed corn based diets and under the LS feeding program with more feeder space from rearing to production produced smaller ($P < 0.001$) eggs compared with hens fed the same diet type, using the same feeding program, but raised with similar feeder space in production as rearing (Table II-4).

There were two-way interactions between feeding program and feeder space for egg surface area at 31 wk and for egg weight at 37 wk of age. This indicated that breeders laid eggs with the smallest surface area at 31 wk and the lowest egg weight at 37 wk when they were fed according to the LS feeding program and when more ($P < 0.05$) feeder space was given in the production house, compared to all the other treatment combinations.

The only external egg characteristic influenced ($P < 0.05$) by diet was shape index at 46 wk of age. Eggs laid by breeders fed wheat based diets were more rounded than eggs laid by breeders fed corn based diets (Table II-5). Feeder space affected egg weight, egg shape index, and egg volume only at 31 wk of age. Increasing feeder space in production influenced broiler breeders to produce a greater ($P < 0.05$) quantity of smaller and rounded eggs with lower ($P < 0.01$) volume. Diet type influenced albumen height ($P < 0.05$) only at 31 wk of age (Table II-7). Eggs laid by breeders fed corn based diets had thinner albumen. In addition, there was a consistent effect of diet type on the relative weights of egg components. Breeders fed wheat based diets laid eggs with less ($P < 0.01$) albumen, and larger ($P < 0.001$) yolks resulting in higher ($P < 0.001$) Y:A ratio compared with eggs laid by breeders fed corn based diets at 31, 37 and 46 wk of age. The only internal egg trait influenced by feeding program was percentage shell at 31 and 46 wk of age. Breeders allocated to the LF feeding program laid eggs with heavier ($P < 0.01$) eggshell at both ages. Feed space change as a main factor did not have any significant ($P > 0.05$) effects on internal egg characteristics.

Table II-4. *P*-values for the effects of diet type, feeding program, and feeder space change on external egg traits in Cobb 500 broiler breeders

External egg traits	Age (wk)	Diet[1] (D)	Feeding program [2] (FP)	Feeder space [3] (FS)	D*FP	D*FS	FP*FS	D*FP*FS
		----------------------------------	----------------------------------	(*P*-values)	----------------------------------			
Weight								
	31	0.256	0.050	0.003	0.124	0.484	0.607	0.263
	37	0.211	0.106	0.025	0.692	0.099	0.019	0.269
	46	0.961	0.555	0.116	0.908	0.753	0.084	0.001
Shape index								
	31	0.538	0.245	0.034	0.458	0.179	0.987	0.326
	37	0.235	0.929	0.445	0.896	0.578	0.686	0.699
	46	0.027	0.577	0.975	0.579	0.677	0.110	0.270
Surface area								
	31	0.883	0.213	0.051	0.726	0.461	0.047	0.598
	37	0.407	0.796	0.447	0.402	0.895	0.166	0.179
	46	0.981	0.431	0.513	0.533	0.485	0.206	0.400
Volume								
	31	0.306	0.003	0.007	0.010	0.799	0.900	0.201
	37	0.652	0.244	0.271	0.304	0.445	0.052	0.866
	46	0.200	0.764	0.074	0.678	0.795	0.401	0.069

[1] Broiler breeders either received corn or wheat based diets throughout their life.
[2] Two feeding program were allocated following either a late fast or late slow feeding program from 14 to 29 wk of age (Figure II-1).
[3] At photostimulation (22 wk), broiler breeders were transferred to a layer house equipped with either similar or more feeder space as during pullet-rearing phase.

Table II-5. Effect of broiler breeder diet type, feeding program and feeder space change on mean egg weight, shape index, surface area, and volume at 31, 37, and 46 wk of age

External egg traits	Age (wk)	Diet[1]		Feeding program[2]		Feeder space[3]		CV[4] (%)	SEM
		Corn	Wheat	Late fast	Late slow	Same	More		
Weight, g									
	31	57.72	57.54	57.91[a]	57.36[b]	58.06[a]	57.21[b]	5.87	0.19
	37	63.76	64.25	64.32	63.69	64.45[a]	63.56[b]	5.56	0.27
	46	68.18	68.16	68.07	68.28	68.46	67.89	6.39	0.26
Shape index									
	31	77.70	77.83	77.88	77.64	77.53[b]	77.99[a]	2.09	0.15
	37	77.72	78.11	77.94	77.89	77.79	78.04	3.29	0.23
	46	75.63[b]	76.26[a]	75.87	76.01	75.94	75.94	3.65	0.20
Surface area, mm^2									
	31	6,890	6,868	6,899	6,859	6,841	6,918	2.69	18.6
	37	7,420	7,414	7,415	7,418	7,416	7,419	1.20	11.6
	46	7,673	7,673	7,676	7,669	7,678	7,670	1.64	8.7
Volume, mm^3									
	31	973	969	976[a]	966[b]	975[a]	966[b]	3.00	2.32
	37	1,044	1,046	1,048	1,042	1,048	1,042	4.38	3.55
	46	1,061	1,066	1,063	1,064	1,067	1,060	4.76	3.09

[a,b] Means within a column without a common superscript differ significantly ($P < 0.05$).
Data are means of eighty, forty and seventy eggs for each breeder treatment evaluated at 31, 37, and 46 wk of age, respectively. Egg was considered as experimental unit and broiler breeder pen was nested within treatments.
[1] Broiler breeders either received corn or wheat based diets throughout their life.
[2] Fed amounts were allocated following either a late fast or late slow feeding program from 14 to 29 wk of age (Figure II-1).
[3] At photostimulation (22 wk), broiler breeders were transferred to a layer house equipped with either similar or more feeder space as during the pullet-rearing house.
[4] Coefficient of variation.

Table II-6. *P*-values for the effects of diet type, feeding program and feeder space change on internal egg traits in Cobb 500 broiler breeders

Egg internal traits	Age (wk)	Diet[1] (D)	Feeding program[2] (FP)	Feed space [3] (FS)	D*FP	D*FS	FP*FS	D*FP*FS
		---------------------------------- (*P*-values)	----------------------------------					
Albumen height, mm								
	31	0.0081	0.361	0.255	0.173	0.133	0.152	0.240
	37	0.4480	0.939	0.357	0.136	0.602	0.232	0.777
	46	0.0787	0.169	0.634	0.916	0.227	0.191	0.363
Shell, %								
	31	0.0558	0.014	0.382	0.358	0.638	0.594	0.088
	37	0.8499	0.803	0.262	0.731	0.930	0.670	0.189
	46	0.8566	0.011	0.707	0.473	0.711	0.525	0.320
Yolk, %								
	31	0.0001	0.621	0.103	0.550	0.929	0.142	0.283
	37	0.0009	0.716	0.819	0.096	0.055	0.797	0.313
	46	0.0001	0.736	0.879	0.100	0.666	0.179	0.493
Albumen, %								
	31	0.0040	0.811	0.179	0.914	0.777	0.196	0.587
	37	0.0069	0.906	0.700	0.098	0.067	0.992	0.564
	46	0.0001	0.512	0.660	0.465	0.217	0.731	0.512
Y:A ratio								
	31	0.0001	0.933	0.088	0.810	0.902	0.165	0.370
	37	0.0009	0.767	0.860	0.110	0.090	0.773	0.371
	46	0.0001	0.241	0.349	0.099	0.523	0.929	0.981

[1] Broiler breeders either received corn or wheat based diets throughout their life.
[2] Two feeding program were allocated following either a late fast or late slow feeding program from 14 to 29 wk of age (Figure II-1).
[3] At photostimulation (22 wk), broiler breeders were transferred to a layer house equipped with either similar or more feeder space as during the pullet-rearing phase.

Table II-7. Effect of broiler breeder diet type, feeding program, and feeder space change on albumen height, Haugh units, shell, albumen and yolk percentage, and yolk albumen ratio

Egg internal traits	Age (wk)	Diet		Feeding program		Feeder space		CV[4] (%)	SEM
		Corn	Wheat	Late fast	Late slow	Same	More		
Albumen height, mm									
	31	7.50[b]	7.70[a]	7.56	7.63	7.64	7.55	12.18	0.18
	37	7.80	7.94	7.88	7.87	7.99	7.79	12.99	0.19
	46	7.45	7.26	7.28	7.43	7.38	7.33	17.77	0.18
Haugh units									
	31	86.94[b]	88.21[a]	87.23	87.93	87.70	87.45	6.08	0.31
	37	87.15	87.89	87.28	87.76	87.77	87.26	6.76	0.46
	46	83.32	82.11	82.23	83.17	82.63	82.81	10.01	0.49
Shell, %									
	31	9.36	9.27	9.38[a]	9.26[b]	9.30	9.34	1.57	0.03
	37	9.16	9.15	9.14	9.16	9.12	9.19	3.26	0.04
	46	9.15	9.16	9.21[a]	9.10[b]	9.15	9.17	3.27	0.03
Albumen, %									
	31	63.04[a]	62.58[b]	62.79	62.83	62.70	62.92	2.14	0.10
	37	61.60[a]	61.03[b]	61.33	61.30	61.36	61.27	2.18	0.14
	46	60.05[a]	59.19[b]	59.56	59.68	59.66	59.58	2.32	0.13
Yolk, %									
	31	27.56[b]	28.14[a]	27.81	27.89	27.97	27.73	3.53	0.11
	37	29.22[b]	29.86[a]	29.50	29.57	29.52	29.56	3.3	0.15
	46	30.91[b]	31.72[a]	31.34	31.28	31.29	31.33	3.8	0.12
Y:A ratio									
	31	0.437[b]	0.450[a]	0.440	0.440	0.450	0.440	8.91	0.002
	37	0.475[b]	0.491[a]	0.480	0.480	0.480	0.480	8.74	0.003
	46	0.513[b]	0.534[a]	0.530	0.520	0.520	0.530	8.96	0.003

[a,b] Means within a column without a common superscript differ significantly ($P < 0.05$).
Data are means of eighty, forty, and seventy eggs for each breeder treatment combination evaluated at 31, 37, and 46 wk of age respectively. Egg was considered as experimental unit and broiler breeder pen was nested within treatments. [1] Broiler breeders either received corn or wheat based diets throughout their life. [2] Feed amounts were allocated following either a late fast or late slow feeding program from 14 to 29 wk of age (Figure II-1). [3] At photostimulation (22 wk), broiler breeders were transferred to a layer house equipped with either similar or more feeder space as in the pullet-rearing phase. [4] Coefficient of variation.

DISCUSSION

Body Weights and Cumulative Mortality

In this experiment, corn and wheat based diets were formulated to have the same nutrient contents for energy, protein, calcium, available phosphorous and essential amino acids in each period. Laboratory analyses of both diets demonstrated that this goal was only partially achieved. It is important to indicate that wheat based diets included approximately 1% more poultry fat in broiler breeder pullet diets to adjust the metabolizable energy content to corn based diets. In addition, wheat based diets contained 30 kcal more gross energy than corn based diets on pullet and layer diets. It is possible that modification of fatty acid profile may have influenced our results. According to Brake (1990) and Peebles et al. (2000), the inclusion of poultry fat used as a vehicle for increasing ME intake in broiler breeder diets boosted BW in a positively dose-related manner. Studies in broiler and Japanese Quail breeders have shown that the dietary fat type modifying fatty acid composition in feed did not affect adult BW; even though, egg characteristics and progeny performance were influenced (Bozkrut et al., 2008). Therefore, this suggests that the slightly higher (3-5%) BW observed from 10 to 52 wk of age in breeders fed wheat diets might be due to an additional amount of fat that produced a modest increment of dietary metabolizable energy. Wheat has higher non-starch polysaccharides concentrations (Choct, 1997), as well as lower bioavailability of biotin (Bryden et al., 2006) and lessened carotenoid contents (Surai and Sparks, 2001) in comparison to corn; however, these factors did not seem to affect broiler breeder growth performance in this experiment.

In relation to feeding program, breeders allocated to the LS feeding program tend to be lighter compared with those exposed to the LF feeding program during the early lay period from 24 to 33 wk of age, while BW were similar during the entire pullet-rearing phase. The LS feeding program presented smaller feed amount increments than the LF program from 19 to 29 wk of age. The different rates of feed additions applied to broiler breeders generated a lower cumulative nutrition on the LS program causing a reduction in 188 kcal of ME energy and 11 g of crude protein until photostimulation (22 wk) or 2,208 kcal of ME energy and 121g of crude protein until 29 wk compared to the used for the LF program. This low plane of nutrition caused by the use of the LS program might have limited BW gain during the early laying period. However, there was a compensatory growth exhibited by breeders fed according to the LS program during the late laying period from 34 to 52 wk of age. It is reasonable that the effect of the low plane nutrition produced by the LS program was more noticeable during the early laying period because broiler breeder pullets were still in a sexual maturity phase in which nutrients are diverted to liver and body fat storage as well as follicle development (Schneider et al., 2005).

The increment of feeder space from 6.3 to 8.4 cm/female broiler breeder at photostimulation did not cause a significant increase in BW at any age. Higher mortality was also observed for breeders fed wheat based diets compared to corn based diets (4.6 vs. 1.5%) only during layer phase that could be related to the marginal elevation on BW throughout the breeders' life. Hocking (1990) reported much higher mortality in heavier female broiler breeders fed *ad-libitum* vs. restricted-regime (46 vs. 4%) largely related to cardiovascular failure. In the current experiment, most hen mortality occurred from 37 to 52 wk of age. Broiler breeders assigned to the LF feeding program presented higher mortality only during the pullet rearing phase. This might be a result of the low plane of nutrition in the LF feeding program producing a reduction in 87 kcal of ME and 13 g of crude protein on the cumulative nutrition until 18 wk of age. This was congruent with results showing more concentrated mortality from 17 to 19 wk of age (42% of total mortality during pullet-rearing phase).

In this experiment no effects of feeder space change from rearing to production (6.3 to 8.4 cm/female) were observed on female mortality. This contradicts previous reports demonstrating that the change in feeder space at photostimulation (7.1 to 10 cm/female) increased mortality in broiler breeders (Leksrisompong et al., 2008).

Reproductive Performance

Reproductive performance was influenced by diet, feeding program and feeder space change. Breeders fed wheat-based diets were heavier throughout the experiment and took less time to reach sexual maturity. Hocking (2004) reported that as BW increased, the age of sexual maturity decreased in a curvilinear fashion. Also, breeders fed wheat-based diets had better egg production compared with the group fed corn based diets.

In relation to feeding programs; breeders fed according to the LF feeding program were forced into lay; thus, they had earlier sexual maturity, even though they had similar BW before photostimulation, compared to hens exposed to the LS feeding program. This was in accordance with Robbins et al. (1986), who reported that an abrupt rather than a gradual increase in feeding level during the pullet-layer transition of broiler breeders might hasten sexual maturity. Feeding program also affected egg weight measured at peak production.

In addition, breeders allocated to the LF feeding program presented a reduced fertility and higher early embryo mortality. Fertility has been reported to be affected primarily by male performance (McGary et al., 2002); nevertheless, the female contributes to fertility greatly through cumulative nutrition. In addition, the female can influence fertility through mating receptivity and spermatozoal storage in special sperm host glands in the oviduct (Brake, 2006). Protein and energy intake during the pullet rearing phase and eggshell quality are also associated with low fertility in broiler breeders (Wilson and Harms, 1984; Morris, 1988). Therefore, the lower fertility observed in broiler breeders fed according to the LF feeding program might be related to the elevated cumulative energy and protein from photostimulation until 29 wk of age. The difference within that period between the two feeding programs was 2,021 kcal of ME and 110 g of CP in favor of the LF feeding program. On the other hand, the higher early embryo mortality presented in eggs laid by breeders allocated to the LF feeding program can be associated with higher percentage eggshell observed at 31 and 46 wk of age. The increment in eggshell percentage could adversely affect gaseous exchange during the first weeks of incubation (Peebles and Brake, 1985; Roque and Soares, 1994).

Increasing feeder space at photostimulation (6.3 to 8.4 cm/female) reduced time to reach sexual maturity and resulted in higher peak of egg production. These two factors could influence positively hen productivity. In fact, breeders that received more feeder space at photostimulation had better hen-day egg production during the first 8 weeks after peak of production compared to those that remained with the similar feeder space. However, the overall hen-housed and hen-day egg production was not affected by changing feeder space at 22 wk of age. In contrast, Leksrisompong et al. (2008) reported better hen productivity and lower hen mortality when breeders had no change in feeder space at photostimulation (10.4-10.10.3 cm/female) compared to increase or reduction of feeder space at photostimulation. In addition, breeders that were allocated to more feeder space at photostimulation laid smaller eggs at 31 wk. It is interesting that the increase in feeder space at photostimulation improved egg production after peak production and influenced external egg characteristics, but BW was similar throughout the experiment. A possible explanation of these results could the changes in BW uniformity resulted from feeder space competition. Furthermore, Thogerson et al. (2009) reported that feeder space could also desynchronize feeding behavior.

Egg Characteristics

Egg characteristics were affected by all the factors evaluated in different degrees. Diet type influenced egg shape index showing more rounded eggs laid by breeders fed wheat based diets, but egg weight, surface area, and volume were not affected. Egg shape index can vary from sharp to normal, and round if they have an ESI value of <72, 72 to 76, and >76, respectively (Sarica and Erensayin, 2004). In the present experiment, an ESI average of 77 was very close to the normal range. On the other hand, internal characteristics were strongly and consistently influenced by diet type. Breeders fed wheat based diets laid eggs with higher

Y:A ratio due to higher yolk percentage and lower albumen percentage persistently observed during the breeders' life. Yolk supplies 90% of the total caloric needs of a chicken embryo by means of the combustion of fatty acids (Freeman and Vince, 1974; Moran 2007). These larger yolks could be due to the positive effects of poultry fat with more polyunsaturated fatty acids than corn based diets. Thus, a higher Y:A ratio indicated more available nutrients for the embryo development. Additionally, breeders fed wheat based diets laid eggs with greater albumen height compared with eggs laid by breeders fed corn based diets at 31 wk of age. Feeding program influenced egg weight, egg volume at 31 wk of age and eggshell percentage at 31 and 46 wk of age. Feeder space impacted egg weight at 31 and 37 wk of age and shape index and egg volume only at 31 wk of age; however it did not affect any internal egg characteristics measured in this experiment.

CONCLUSIONS

Breeders fed-wheat based diets were slightly and consistanly heavier than breeders fed corn-based diets from 10 to 52 wk of age. Differences in BW caused by the diet type maybe a response of the larger amount of poultry fat (~1%) in wheat-based diets to balance both diet types for ME. Mortality was similar during pullet rearing phase, but breeders fed wheat-based diets had higher hen mortality during the layer phase. Feeding program influenced BW only during the layer phase in which breeders fed according to the LF feeding program exhibited higher BW compared to those fed restricted to the LS feeding program. In addition, breeders fed following the LF feeding program had higher hen mortality only during the pullet rearing phase compared to those fed according to the LS feeding program. Higher mortality was observed in hens fed according to LF feeding program between 17 to 19 wk of age that might be a result from the smaller increments of feed amounts from 14 to 16 wk of age.

Regarding reproductive performance, breeders fed wheat-based diets increased egg production and laid eggs with higher Y:A ratio compared to those fed corn-based diets. Breeders fed according to the LS feeding program had better fertility, and laid eggs with smaller percentage eggshell that might be related to the lower early embryonic mortality compared to hens fed restricted to LF feeding program. Even though feeder space did not influence hen BW or internal egg characteristics, increasing feeder space at photostimulation induced breeders to mature earlier and produced more eggs than no change in feeder space.

According to these results it was concluded that the feeding of wheat based diets, the use of the LS feeding program, and feeder space change improved in some degree hen productivity; however, effects of these factors on growth performance and leg health of broiler progeny needs to be taken into consideration to evaluate the effectiveness of these broiler breeder treatments in the poultry industry.

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CHAPTER III: THE EFFECT OF MATERNAL FEEDING PROGRAM TO 29 WK, AND BREEDER FEEDER SPACE CHANGE AT PHOTOSTIMULATION ON BROILER PROGENY BONE DEVELOPMENT USING CORN OR WHEAT BASED DIETS

ABSTRACT

This study evaluated the effects of breeder nutrition and feeding practices on broiler progeny bone development. Cobb 500 breeders were housed in 16 pens with 81 females/pen and fed either corn (C) or wheat (W) based diets during rearing and production using either late fast (LF) or late slow (LS) feed allocation programs from 14 to 29 wk of age. At 22 wk, 69 females that represented the BW distribution from each pen were placed in a layer house where feeder space either remained the same (6.3 – 6.5 cm/female) (S) or was increased (6.3 - 8.4 cm/female) (M). Eggs produced at 33 wk of age were incubated to determine eggshell conductance and a sample of seven chicks from each breeder treatment taken to obtain leg bone traits at hatching. Data was analyzed as a 2x2x2 factorial design considering diet type, feeding program, and feeder space as main factors. Breeders fed W produced progeny with lower weight of femurs and shorter shanks at hatching compared to those fed C only when breeders were given M at photostimulation. However, diet type did not influence eggshell conductance, hatchling BW without yolk, residual relative yolk weight, or any RA of bilateral leg bones at hatching. Broiler breeders fed restricted according to the LS feeding program laid eggs with greater eggshell conductance compared to those managed with the LF feeding program. However, the maternal feeding program did not affect any progeny bone morphological traits or the RA of leg bones at hatching. Eggs from breeders given M at photostimulation had higher eggshell conductance than those from breeders provided with S. Maternal feeder space change did not influence BW without yolk; however, M breeders produced progeny with heavier femurs and longer shanks compared to those provided S, but only when breeders were fed W. Moreover, the increased maternal feeder space at photostimulation was associated with an increased RA of femur length in the progeny. It was

concluded that maternal diet type and feeder space change influenced bone development of broiler progeny.

INTRODUCTION

Bone growth and growth plate differentiation starts early during embryo development (Ballock and O'Keefe, 2003). At 11 days of incubation, alkaline phosphatase is at its maximum, which has been intimately associated to bone formation and osteoblast proliferation (Reddi and Anderson, 1976). Afterwards, the highest growth rate of bone mass occurs in the days prior to hatch and a few days post-hatch (Church and Johnson, 1964; Van der Eerden et al., 2003). Thus, it is possible that bone developmental disorders could arise from maternal effects during early and late incubation periods. During the last 4 days of incubation, the embryonic demand for oxygen exceeds the oxygen diffusion capacity of the eggshell pore system and choriallantoic membrane resulting in a relative respiratory acidosis (Tazawa, 1980; Rahn, 1981). Oviedo-Rondón et al. (2008a) suggested that one mechanism by which oxygen concentration during incubation could affect bone development was the high susceptibility of osteoclasts to acidosis conditions.

The primary source of energy and the basis for embryo development has been shown to be the combustion of fatty acids of the yolk (Moran, 2007). The complete combustion of fatty acids is supported by the gas exchange that occurs when the chorioallantosis starts to be formed around 4 days of incubation (Ribatti et al., 2000). Specific lipids, trace minerals, and vitamins deposited in the yolk are involved in bone modeling and remodeling (Oviedo-Rondón et al., 2006). Thus, maternal nutrition could influence bone development. Recent research on the effect of maternal nutrition on progeny leg health has been conducted. The supplementation of organic trace minerals in maternal diets enhanced symmetry of shank lengths at hatching and consequently improved walking ability at 49 d of age in broiler chickens (Oviedo et al., 2008b).

In addition, high levels of vitamin D_3 in maternal diets increased tibia ash that reduced leg and bone disorders (Atencio et al., 2005). Furthermore, fats added to hen diets may alter yolk fatty acid composition (Hargis and Van Elswyk, 1993; Liu and Denbow, 2001), and subsequently, bone formation and resorption (Watkins, 1991). Cruickshank (1934) reported that the ingestion of unsaturated fatty acids considerably modified the degree of saturation and the proportion of fatty acids in the yolk, whereas saturated dietary fatty acids had little effect on the proportion of mixed fatty acids. Moreover, saturation of fatty acids might have an impact on embryo development and subsequent broiler growth because avian embryos preserved polyunsaturated fatty acids for cell membrane synthesis while saturated fatty acids were consumed to sustain the increasing caloric need of formed tissues (Maldjian et al., 1995; Speake et al., 2003; Speake and Deans, 2004).

Major poultry diet formulations differ across the world. Commercial diets in the USA and Europe are corn and wheat-barley (Hocking and Bernard, 1997) based diets, respectively. Although wheat has lower metabolizable energy and higher protein content than corn (Rogel et al., 1987; Guiterrez-Alamo et al., 2008), certain nutritional factors that differ could be closely linked to progeny growth performance and bone development, even after diets have been balanced to have similar nutrient composition. Wheat contains greater concentrations of vitamin E (Panfili et al., 2003), B_1, B_2, and B_6 (Lebiedzinska and Szefer, 2006), as well as, available phosphorus (Miracle et al., 1977; Stober et al., 1979; Hayes et al., 1979) than corn. The concentration of biotin is similar between corn and wheat; however, biotin bioavailability in chickens is much lower from wheat (Frigg, 1976; Anderson et al., 1978; Baker, 1978; Bryden et al., 2006). One of the major anti-nutritional factors in wheat is the elevated non-starch polysaccharide concentration (Choct, 1997). On the other hand, corn has a higher carotenoid content, which works as an antioxidant to prevent and limit lipid peroxidation (Niki, 1996; Surai and Sparks, 2001).

The feeding program of female broiler breeders has been reported to affect progeny growth performance. Broilers from broiler breeders allocated on a lower feeder space (5.3 vs. 7.1 cm/female) during the pullet-rearing phase and fed a slow feeding program to peak of egg production produced the heaviest broilers at 42 d of age (Leksrisompong et al., 2009). Further studies on the oviduct tract portions demonstrated that oviduct segments did not always develop in a synchronous manner. The use of the slow feeding program from photostimulation to the peak of egg production induced the oviduct segments to develop with similar rates as the whole oviduct (Leksrisompong and Brake, 2008).

Thus, this experiment was carried out to determine maternal effects on progeny bone development during incubation. The first objective was to evaluate the effects of diet type either corn or wheat based diets in broiler breeders, formulated to have similar nutrient composition, during rearing and production. A second objective was to determine the effects of two rates of increasing feed amounts, late fast or late slow feeding program applied to female broiler breeders from 14 to 29 wk. The third objective was to evaluate the effects of changing feeder space at photostimulation**.** The ultimate purpose of this study was to provide a better understanding of the combined effects of diet type, feed allocation, and feeder space change and how these effects could impact eggshell properties and chick bone traits at hatching.

MATERIAL AND METHODS

Broiler Breeder Husbandry

A total of 1296 Cobb 500 non-feather sexable broiler breeder females and 288 broiler breeder males were grown sex-separate in a black-out house on an 8-h photoperiod after 23 h light per day for one week. Breeder pullets were randomly assigned to sixteen floor pens containing 81 pullets each. Each female growing pen had 5 tube feeders and 2 automatic bell drinkers. Each feeder pan was 37 cm in diameter with a circumference of 116 cm, providing

6.3 cm per pullet. Breeders were fed either corn or wheat based diets, formulated to have similar nutrient composition, during rearing and production. Nutrient concentrations followed both guidelines from the parent stock breeder companies and average values reported by companies in the US and Europe. Supplemental biotin was added to both diets to meet recommended nutritional requirements (Cobb-Vantress, 2008). The composition of the diets utilized throughout the trial is shown in Table II-1. The starter diet was fed in crumbles from 0 to 4 wk of age, the grower diet was in mash form and fed from 5 to 25 wk, and production diets were fed as mash from 26 to 52 wk. A pre-lay diet was fed from 18 to 25 wk of age only to breeders provided wheat based diets. Two feeding programs, late fast (LF) and late slow (LS) were applied from 14 to 29 wk (Figure II-1). Breeders were fed in a 4/3 feed restriction program from 3 to 22 wk of age.

Pullets were weighed in groups at 1d, 4 wk, and 10 wk of age. At 20 wk, pullets and cockerels were individually weighed to select birds representing the BW distribution of each rearing pen. A total of 69 pullets and 7 cockerels from each pen were moved to a two-thirds slat one-third litter pen located in a curtain-sided layer house at 22 wk of age. Pullets were immediately photostimulated with 14 h of light. Pen size was 16 m^2 (159” x 156”) given a stocking density of 4.3 female breeders per m^2. Each breeder pen was equipped by one 8-hole galvanized nest box, two automatic bell drinkers and either 4 or 5 female tube feeders to provide similar (6.5 cm/hen) or more (8.4 cm/hen) feeder space compared with the pullet-rearing phase (6.3 cm/female). In addition, one male tube feeders in each pen. To improve fertility in the entire flock, intraspiking was performed at 37 wk of age.

To ensure sex separate feeding, 48 x 58 mm feeder grills were installed around each female tube feeders. A random group of 20 breeders per pen were selected and weighed in groups of 5 birds each at 24, 28, 33, 37, 40, 48, and 52 wk of age. Mortality was recorded on a daily basis throughout the experimental period.

Hatching Experiment

All the egg production of one day, around 60 eggs from each broiler breeder pen, was collected from 33-wk-old broiler breeders. Then, eggs were weighed and set in a ChickMaster incubator. At 18 days of incubation, eggs were again weighed to determine the amount of moisture loss from those eggs. The eggshell conductance (G) was calculated using the formula provided by Ar et al. (1974):

$$G_{H2O} = M_{H2O}/\Delta P_{H2O}$$

Where G_{H2O} was water vapor conductance or eggshell conductance (mg/d per mmHg), M_{H2O} is the rate of water loss from egg (mg/d), and ΔP_{H2O} was the water vapor pressure difference across the shell (mmHg) obtained by the difference between P_{H2O} and P_O. P_{H2O} was water vapor pressure of the egg contents and P_O was water vapor pressure in the environment surrounding the outside of the egg. Temperature and relative humidity in the incubator and the barometric pressure in the room was recorded to determine P_{H2O} and P_O.

After weighing, eggs were transferred to individual hatching bags. At hatch on day 21 of incubation, a random sample of 7 chicks from each breeder treatment was collected to obtain BW and residual yolk weights (0.01 g). Afterwards, legs were dissected and divided into drums, thighs, and shanks. Muscles were removed and bones were cleaned and weighed (0.001 g). Length of each leg bone was measured (0.01 mm) with an electronic caliper (ProMax Fred V. Fowler Co., Inc. 66 Rowe Street Newton, MA 02466). Shank length was measured between the bottom of the foot pad and the top of the bent hock joint. Shank width was measured from side to side below the dew claw. Relative asymmetry (RA) of bilateral traits was determined as described by Møller et al. (1999):

$$RA = (|R-L|/[R+L]/2) \times 100$$; Where: R= right traits, and L = left traits

Statistical Analyses

A completely randomized design with 16 pens assigned to a 2 x 2 x 2 factorial combination was used. A linear mixed effects model with fixed factorial effects of diet type, maternal feeding program, breeder feeder space change, and all interactions, were fit to the data using JMP 8 (SAS Inst. Inc., Cary, NC). Each egg and embryo bone characteristic was considered as an experimental unit, and pens were included as random effects, and nested within treatment combinations. A Pearson correlation analysis was performed on eggshell conductance, residual yolk at hatching, bone size traits, and relative asymmetries of bilateral bones (Steel et al., 1997). Sample correlation coefficients from 0.00 to 0.29, 0.30 to 0.69 and, 0.70 to 1.00 indicated none or weak, moderate, and strong linear relationships (Jackson, 2008). Percentage of moisture loss and each leg bone was transformed to Arc sine prior to analyses. All pairwise comparisons among means were conducted using Tukey's studentized range test at an experimentwise type I error rate of $\alpha = 0.05$.

Statistical model:

$Y_{ijklm} = \mu + \alpha_i + \beta_j + \delta_k + \alpha\beta_{ij} + \alpha\delta_{ik} + \beta\delta_{jk} + \alpha\beta\delta_{ijk} + \lambda_{l(ijkm)} + \varepsilon_{ijklm}$

Where:

Y_{ijkl} : Variable response

μ : Overall mean

α_i : Effect of i^{th} diet type (i = 1,2)

β_j : Effect of j^{th} feeding program (j = 1,2)

δ_k : Effect of k^{th} feeder space change (k= 1,2)

$\alpha\beta_{ij}$: Effect of the first order interaction between diet type i and feeding program j

$\alpha\delta_{ik}$: Effect of the first order interaction between diet type i and feeder space change k

$\beta\delta_{jk}$: Effect of the first order interaction between feeding program j and feeder space change k

$\alpha\beta\delta_{ijk}$: Effect of the second order interaction among diet type i, feeding program j and, feeder space change k

$\lambda_{l(ijkm)}$: Random effect of breeder pen nested within treatment combinations ijk (l = effect of breeder pen, m= effect of egg or bone trait)

ε_{ijklm} : The experimental error associated to each observation.

RESULTS

Egg Weight, Eggshell Properties, Chick BW, and Relative Yolk Sac Weight

At 33 wk of age, no interaction ($P > 0.05$) effects were detected for egg weight, moisture loss and eggshell conductance. In addition, no effect of diet type was detected ($P > 0.05$) on eggshell conductance. However, eggshell conductance was greater when broiler breeders were fed restricted with the LS feeding program ($P < 0.05$) or when they received a feeder space increase from rearing to production ($P < 0.05$) (Table III-1).

Diet type and maternal feeding program did not affect ($P > 0.05$) broiler BW at hatching. However, progeny of broiler breeders that received more feeder space at photostimulation were smaller ($P < 0.05$) than broilers from breeders with similar feeder space as during rearing (Table III-2). The BW without yolks was not influenced ($P > 0.05$) by diet type and breeder feeder space change from rearing to production. On the other hand, breeder feeding program affected ($P < 0.05$) progeny BW without yolks. Newly-hatched chicks from broiler breeders fed according to the LF feeding program had higher BW without yolks compared to those receiving the LS feeding program. Residual yolk was reduced ($P < 0.01$) in broiler progeny that originated from breeders fed corn based diets, and restricted with the LS feeding program, and provided more feeder space at photostimulation compared to the same group of chickens but with no change in maternal feeder space at photostimulation.

Results of correlation analyses included relationships between egg weight before incubation, eggshell conductance, BW, BW without yolk, and relative weights of dissected yolks (Table III-3). There was a very strong positive relationship ($r = 0.92$, $P < 0.001$) between egg weight before incubation and yolk-free body weights at hatching. No significant ($P > 0.05$) correlation was observed between egg weight and eggshell conductance. Also, egg weight was not significantly ($P > 0.05$) correlated with relative weights of dissected yolks at hatching. Eggshell conductance was positively correlated to BW without yolk ($r = 0.23$, $P < 0.05$), but was not significantly ($P > 0.05$) related to BW at hatching. Eggshell conductance was negatively correlated to relative yolk weights ($r = -0.44$, $P < 0.001$). In addition, residual relative yolk weights were moderately related to BW at hatching ($r = 0.43$, $P < 0.001$), but was not significantly ($P > 0.05$) related to BWY.

Bone Morphological Traits and Relative Asymmetry

There was a significant interaction effect of breeder diet type and feeder space change at 22 wk of age on relative femur ($P < 0.05$) and shank ($P < 0.001$) weights, and femur length ($P < 0.05$) of broiler progeny (Table III-4). Femurs and shanks of progeny produced by broiler breeders given more feeder space at photostimulation and fed wheat-based diets were less than chick bones from breeders that received the same feeder space allocation but were fed corn-based diets. In addition, heavier shanks and longer femurs were observed in progeny from breeders fed corn-based diets and given more feeder space at photostimulation as compared to breeders fed the same diet type but with no change in feeder space at 22 wk of age.

There was a significant ($P < 0.05$) interaction effect of breeder diet type, maternal feeding program, and breeder feeder space change at photostimulation on tibia and shank lengths of broiler progeny. Tibias and femurs of progeny from hens fed corn-based diets following the LS feeding program and given more feeder space at photostimulation were longer than broiler bones from breeders fed the same diet type and allocated to the identical feeding program, and the same feeder space at photostimulation. No change in breeder feeder space at photostimulation resulted in tibias that weighed less, and thicker (*P* < 0.01) shanks in the progeny compared to the increment of maternal feeder space from rearing to production.

No interaction effects were (*P* > 0.05) detected for RA of broiler progeny bone traits at hatching. Breeder diet type and maternal feeding program did not affect (*P* < 0.05) RA of any leg bone. However, broilers whose parents received more feeder space at photostimulation had more (*P* < 0.05) asymmetric femurs in terms of length compared to progeny form breeders with no change in feeder space from rearing to production (Figure III-1).

Additionally, the relationship between eggshell conductance and yolk relative weights with bone morphological traits (Table III-5) and their RA was examined. Eggshell conductance was positively but weakly correlated to all bone size traits (r = 0.16-0.28, *P* < 0.05), except for femur length and shank width. On the other hand, residual relative yolk weight was negatively related to all bone size characteristics (r = -0.29 to -0.46, *P* < 0.01) except for relative weight and width of shanks. Furthermore, a negative correlation was observed between eggshell conductance and RA of femur length (r = -0.23, *P* = 0.02) and shank width (r = -0.21, *P* = 0.03). No other significant (*P* > 0.05) correlations were detected between eggshell conductance and RA of leg bone measurements. Residual relative yolk weights were not significantly (*P* > 0.05) correlated to any RA of leg bone morphological traits except for shank weight (r = 0.23, *P* < 0.01) indicating that as yolks at hatching were larger, shanks were more asymmetric in terms of weights.

Table III-1. Effect of breeder diet, maternal feeding program, and breeder feeder space change on egg weight, moisture loss, and eggshell conductance of eggs laid by 33-wk-old broiler breeders

Diet type[2]	Feeding program[3]	Feeder space change[4]	Egg weight and eggshell properties		
			Egg weight[1]	Moisture loss[1]	Eggshell conductance[1]
			(g)	(%)	(mg of H_2O/mmHg)
Corn			59.70	8.91	13.73
Wheat			59.51	8.85	13.53
	Late fast		59.81[a]	8.80[b]	13.50[b]
	Late slow		59.40[b]	8.96[a]	13.75[a]
		More	59.37[b]	9.00[a]	13.78[a]
		Same	59.84[a]	8.76[b]	13.48[b]
Corn	Late fast		59.82	8.83	13.59
	Late slow		59.58	8.98	13.86
Wheat	Late fast		59.80	8.77	13.42
	Late slow		59.22	8.94	13.65
Corn		More	59.45	9.04	13.88
		Same	59.95	8.78	13.57
Wheat		More	59.28	8.97	13.67
		Same	59.74	8.74	13.39
	Late fast	More	59.69	8.85	13.60
		Same	59.93	8.75	13.41
	Late slow	More	59.05	9.16	13.95
		Same	59.76	8.76	13.56
Corn	Late Fast	More	59.71	8.91	13.74
		Same	59.93	8.75	13.45
	Late slow	More	59.20	9.17	14.02
		Same	59.96	8.80	13.70
Wheat	Late fast	More	59.67	8.78	13.46
		Same	59.93	8.75	13.37
	Late slow	More	58.89	9.15	13.88
		Same	59.55	8.72	13.42
Pooled SEM			0.18	0.08	0.13
CV (%)			5.64	13.09	13.12
Sources of variation			--------------------------------	(*P*-values)	--------------------------------
Diet			0.297	0.440	0.109
Feeding program			0.044	0.054	0.039
Feeder space change			0.024	0.002	0.017
Diet*feeding program			0.353	0.863	0.883
Diet*feeder space change			0.928	0.811	0.897
Feeding program*feeder space change			0.207	0.055	0.403
Diet*feeding program*feeder space change			0.862	0.514	0.467

[1] Data are means of 110 observations for each breeder treatment. [2] Broiler breeders were fed corn or wheat based diets their entire life. [3] Two feeding programs, late slow or late fast program, were applied to female breeders from 14 wk to 29 wk. [4] At photostimulation, female breeders were given more or less feeder space. [a,b] Means within a column without a common superscript differ significantly ($P < 0.05$).

Table III-2. Effect of breeder diet, maternal feeding program, and breeder feeder space change on body weight, body weight without yolk, and residual yolk of broiler progeny at hatching from 33-wk-old Cobb 500 broiler breeders

Diet type[2]	Feeding program[3]	Feeder space change[4]	BW[1]	BW without yolk[1]	Residual yolk[1]
			------------ (g)	-------------	---- (%) ----
Corn			43.9	38.0	13.8
Wheat			44.2	37.7	14.1
	Late fast		44.2	38.2[a]	13.7
	Late slow		43.9	37.4[b]	14.2
		More	43.5[b]	37.6	13.7
		Same	44.6[a]	38.0	14.2
Corn	Late fast		43.8	38.1	13.4
	Late slow		44.0	37.8	14.2
Wheat	Late fast		44.6	38.3	14.0
	Late slow		43.8	37.0	14.2
Corn	More		43.6	37.9	13.4
	Same		44.2	38.0	14.2
Wheat	More		43.4	37.3	14.0
	Same		44.9	38.0	14.2
	Late fast	More	43.8	38.9	13.5
		Same	44.5	38.3	13.9
	Late slow	More	43.1	37.1	13.9
		Same	44.6	37.7	14.4
Corn	Late fast	More	44.2	38.6	13.6[ab]
		Same	43.4	37.6	13.3[b]
	Late slow	More	42.9	37.2	13.2[b]
		Same	45.0	38.4	15.2[a]
Wheat	Late fast	More	43.5	37.6	13.4[b]
		Same	45.7	39.0	14.6[ab]
	Late slow	More	43.3	36.9	14.7[ab]
		Same	44.2	37.1	13.7[ab]
Pooled SEM			0.51	0.40	0.44
CV (%)			5.77	5.29	15.81
Sources of variation			----------------	(P-values)	----------------
Diet			0.579	0.418	0.486
Feeding program			0.509	0.036	0.246
Feeder space change			0.024	0.248	0.225
Diet*feeding program			0.316	0.186	0.550
Diet*feeder space change			0.346	0.353	0.370
Feeding program*feeder space change			0.406	0.590	0.957
Diet*feeding program*feeder space change			0.026	0.025	0.008

[1] Data are means of 110 observations for each breeder treatment. [2] Broiler breeders were fed corn or wheat based diets their entire life. [3] Two feeding programs, late slow or late fast program, were applied to female breeders from 14 wk to 29 wk. [4] At photostimulation, female breeders were given more or less feeder space. Broiler sex was used as a covariate. [a,b] Means within a column without a common superscript differ significantly ($P < 0.05$).

Table III-3. Correlation coefficients among egg weight before incubation, eggshell conductance, body weight (BW), BW without yolk, and relative weights of dissected yolks at hatch

Trait[1]	Eggshell conductance	BW at hatching	BW without yolk at hatching	Yolk relative weights
Egg Weight	0.07	0.92***	0.92***	0.18
Eggshell conductance		-0.02	0.23*	-0.44***
BW at hatching			0.89***	0.43***
BW without yolk at hatching				-0.04

*The correlation coefficients are significant at $P < 0.05$.
**The correlation coefficients are significant at $P < 0.01$.
***The correlation coefficients are significant at $P < 0.001$.
[1]A total of 110 observations were used for correlation analyses.

Table III-4. Effect of breeder/broiler diet, maternal feeding program, and breeder feeder space change on bone size traits[1] of broiler progeny from 33-wk-old Cobb 500 broiler breeders at hatching

Diet[2]	Feeding program[3]	Feeder Space[4]	Weight relative to BW without yolk			Lengths			Width
			Tibia	Femur	Shank	Tibia	Femur	Shank	Shank
			----------- (%) -----------			------------------- (mm) -------------------			
Corn			0.89	0.54[a]	3.05	30.36	21.83	23.84	3.59
Wheat			0.87	0.52[b]	3.02	30.43	21.77	23.81	3.66
	Late fast		0.89	0.53	3.02	30.44	21.87	23.82	3.61
	Late slow		0.86	0.52	3.05	30.36	21.73	23.84	3.63
		More	0.89[a]	0.53	3.05	30.56[a]	21.91[a]	23.95[a]	3.57[b]
		Same	0.86[b]	0.53	3.01	30.24[b]	21.69[b]	23.70[b]	3.68[a]
Corn	Late fast		0.90	0.55	3.01	30.34	21.86	23.78	3.55
	Late slow		0.87	0.53	3.08	30.39	21.81	23.90	3.62
Wheat	Late fast		0.88	0.52	3.02	30.54	21.88	23.85	3.67
	Late slow		0.86	0.51	3.02	30.33	21.66	23.78	3.65
Corn		More	0.90	0.55[a]	3.11[a]	30.64	22.05[a]	24.06	3.53
		Same	0.87	0.53[ab]	2.98[b]	30.09	21.61[b]	23.62	3.64
Wheat		More	0.88	0.51[b]	3.00[b]	30.48	21.78[ab]	23.84	3.60
		Same	0.86	0.52[ab]	3.04[ab]	30.39	21.76[ab]	23.78	3.71
	Late fast	More	0.91	0.54	3.04	30.59	22.00	23.89	3.57
		Same	0.87	0.53	2.99	30.29	21.74	23.74	3.65
	Late slow	More	0.87	0.53	3.07	30.53	21.83	24.02	3.57
		Same	0.86	0.52	3.03	30.18	21.64	23.66	3.70
Corn	Late fast	More	0.92	0.55	3.10	30.47[ab]	21.99	23.82[ab]	3.53
		Same	0.87	0.54	2.93	30.21[ab]	21.73	23.75[ab]	3.57
	Late slow	More	0.89	0.55	3.12	30.80[a]	22.12	24.30[a]	3.53
		Same	0.86	0.52	3.04	29.97[b]	21.49	23.49[b]	3.71
Wheat	Late fast	More	0.90	0.52	2.99	30.71[a]	22.01	23.95[ab]	3.61
		Same	0.87	0.53	3.05	30.37[ab]	21.75	23.74[ab]	3.73
	Late slow	More	0.86	0.51	3.01	30.25[ab]	21.54	23.74[ab]	3.60
		Same	0.85	0.52	3.03	30.40[ab]	21.78	23.82[ab]	3.70
Pooled SEM			0.01	0.01	0.02	0.11	0.10	0.11	0.03
CV (%)			7.92	9.04	3.73	2.03	2.68	2.64	5.46
Sources of variation			------------------------------------- (*P* – values) -------------------------------------						
Diet (D)			0.250	0.017	0.253	0.545	0.578	0.817	0.056
Feeding program (FP)			0.057	0.210	0.100	0.463	0.218	0.840	0.510
Feeder space (FS)			0.045	0.441	0.083	0.006	0.039	0.035	0.004
D*FP			0.868	0.884	0.177	0.270	0.437	0.446	0.234
D*FS			0.400	0.050	0.001	0.051	0.050	0.106	0.993
FP*FS			0.395	0.640	0.773	0.842	0.744	0.346	0.473
D*FP*FS			0.935	0.978	0.190	0.029	0.056	0.034	0.354

[1] Data are means of 15 observations for each breeder treatment. [2] Broiler breeders were fed corn or wheat based diets their entire life. [3] Two feeding programs, late slow or late fast program, were applied to female breeders from 14 wk to 29 wk. [4] At photostimulation, female breeders were given more or less feeder space. [a,b] Means within a column without a common superscript differ significantly ($P < 0.05$).

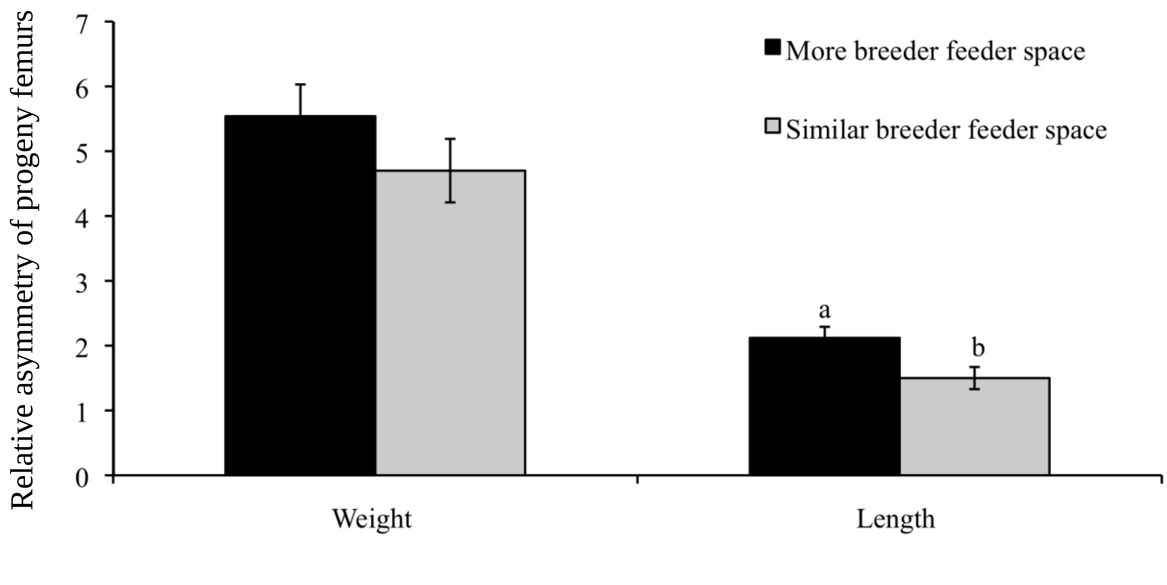

Figure III-1. Effect of broiler breeder feeder space change from rearing to production phases (6.3-6.5 vs. 6.3-8.4 cm/female) on relative asymmetry of femur weight and length at hatching of broiler progeny from 33-wk-old Cobb 500 broiler breeders. Data are means of 15 observations for each breeder treatment. Bars represent SEM. Means without common superscripts differ significantly ($P < 0.05$).

Table III-5. Correlation coefficients and probabilities among residual yolk at hatching, eggshell conductance and leg characteristics measured at hatching

Incubation variables	Leg characteristics at hatching		r[1]	*P*- values
Eggshell conductance	Relative weights	Femur	0.27	0.005
		Tibia	0.24	0.012
		Shank	0.22	0.025
	Lengths	Femur	0.16	0.108
		Tibia	0.28	0.003
		Shank	0.18	0.057
Residual yolk % at hatch	Relative weights	Femur	-0.37	<.0001
		Tibia	-0.46	<.0001
		Shank	-0.05	0.594
	Lengths	Femur	-0.29	0.002
		Tibia	-0.33	0.000
		Shank	-0.30	0.001

[1]A total of 110 observations were used for correlation analyses.

DISCUSSION

Egg Weight, Eggshell Properties, Chick BW, and Residual Yolk

Diet type did not influence egg weight at time evaluation. Yuan et al. (1994) reported that BW snd hen age were the primary factors that influenced egg weight of broiler breeders. Contrarily, in the present experiment, broiler breeders fed wheat based diets exhibited higher BW during the pullet rearing and layer phases, but no changes in egg weight were observed. This suggested that differences in breeder BW of 4 to 5% throughout the experiment were not sufficient to impact egg weight.

In addition, diet type did not influence moisture loss, eggshell conductance, chick BW at hatching, and relative yolk sac weight. A previous evaluation of egg characteristics on the same parent flock at 31 wk of age demonstrated that the utilization of wheat as the main source of energy increased yolk:albumen ratio and decreased albumen thickness, but percentage shell was not affected (Chapter II). Yolk:albumen ratio was taken to be an indicator of the amount of nutrients ready to be used by the embryo (Veira, 2007). Besides, thicker albumen has been related to detrimental effects on vital gas exchange (Brake et al., 1997) and nutrient availability to the embryo (Benton and Brake, 1996). Furthermore, the effective utilization of yolk nutrients during embryo development depends on an adequate gas exchange. Thus, it was expected to obtain improvements on BW at hatch of progeny from breeders fed wheat based diets because of the persistant higher yolk:albumen ration. However, there were no effects of diet type on hatchling BW. These results could be a result from differences in nutrient composition or nutrient bioavailability in the egg, especially in the yolk, between the use of corn or wheat based diets.

Feeding program applied to broiler breeders from 14 wk to age at sexual maturity (28 wk) influenced moisture loss and eggshell conductance. Breeders fed according to the LS feeding program exhibited greater moisture loss and eggshell conductance, and their broiler progeny exhibited less BW without yolk (37.4 vs. 38.2 g) than those hatched from breeders allocated to the LF program. Eggshell water vapor conductance has been reputed to be an accurate measure of the eggshell's functional ability to resist water vapor passage (Paganelli et al., 1978). Eggshell conductance has been linked to percentage shell, porosity, and the eggshell cuticle (Peebles and Brake, 1986). Furthermore, a pronounced detrimental effect caused by high temperature during incubation on intestinal maturation in broiler chicks was observed when eggs had low conductance (Wineland et al., 2006a). Thus, eggshell conductance might be an important variable to take into consideration during incubation because of its impact on yolk nutrient utilization and bone development during incubation. In the current study, breeders fed following the late slow feeding program produced higher eggshell conductance also laid eggs with lower percent shell measured at 31 wk of age in agreement to previous findings.

In the egg evaluation at 31 wk of hen age, the increased feeder space at photostimulation did not alter any proportion of egg components, but it induced changes in mass, shape index, and volume of eggs. In the current study, increasing feeder space from rearing to production increased moisture loss and eggshell conductance, and reduced egg weight and hatchling BW. Egg weight has been reported to be influenced by BW, age at sexual maturity, and photoperiod (Ciacciariello and Gous, 2005; Lewis and Gous, 2006). In the present experiment, maternal feeder space change did not affect breeder BW at any time point. However, breeders that received more feeder space at photostimuation matured earlier than those given the same feeder space. This reduction in egg weight could be a result from the earlier sexual maturation in breeders with more feeder space at photostimulation.

The implementation of more feeder space at photostimulation increased eggshell conductance; however, we did not observe any differences in percentage eggshell at 31 wk. Other variables that have been related to eggshell conductance are eggshell porosity (Tullett et al., 2003), eggshell cuticle (Peebles et al., 1987), and eggshell membrane. These variables that were not measured in this experiment could be influenced during the development of the reproductive tract. Melnychuk et al. (1997) reported that during sexual maturation, the growth and development of the oviduct is typically seen before growth of the ovary. Indeed, the broiler breeder oviducts have a dramatic weight increase from photostimulation at 22 wk to 24 wk of age (0.5 to 15 g) (Robinson et al., 2007). Therefore, the change in feeder space that affected age of sexual maturity might have also altered in some degree the development of specific oviduct segments, modifying nutritional composition of the egg.

Although there were differences in BW at hatching between the two feeder space treatments, BW without yolk was unaffected by feeder space change. BW without yolk is a more accurate variable to estimate improvements in embryogenesis because changes in yolk weights are suppressed. In fact, in the current study, hatchlings from breeders given the same feeder space from rearing to production were heavier and they also possessed a larger amount of yolk relative to BW without yolk (14.2 vs. 13.7 %) than progeny from breeders given more feeder space. This difference in relative yolk weight was only observed when breeders were fed corn based diets following a LS feeding program.

Bone Morphological Traits and Relative Asymmetry

The utilization of maternal corn-based diets increased relative weight of the femur at hatching in broiler progeny only when broiler breeders were given more feeder space at photostimulation. Surprisingly, the same breeder flock fed wheat-based diets laid eggs with greater yolk:albumen ratio at 31, 37 and 46 wk of age. Yolk:albumen ratio is general indicator of availability of nutrients for the embryo development (Veira, 2007). Although yolk was greater in relation to albumen, nutrients deposition in the yolk might be different between breeders fed corn and wheat as major source of energy. No other morphological leg bone characteristics were affected by diet type. Similar to our observations, previous studies demonstrated that the femur, but not the tibias, was more sensitive to dietary changes (Itoh and Hatano, 1964; Dilworth and Day, 1965; Moran and Todd, 1994).

Maternal feeding programs did not alter bone morphological traits or RA of broiler progeny even though there were significant differences in eggshell conductance (13.5 vs. 13.8 mg of H_2O/mmHg). In contrast, it has been reported that broiler strains with low eggshell conductance (17.45 mg of H_2O/day/mmHg) displayed less symmetry between shank weights at hatching compared to a broiler strain with high eggshell conductance (19.5 mg of H_2O/day/mmHg) (Wineland et al., 2006b; Oviedo-Rondón et al., 2008a).

The increased maternal feeder space from the pullet rearing to the production phase caused broiler progeny to have longer and heavier tibias, and longer femurs and shanks at hatching. An interaction indicated equivalent maternal feeder space effect on progeny relative shank weight, but only when breeders were fed corn based diets. In contrast, maintaining similar maternal feeder space at photostimulation increased the shank width of broiler progeny. In general, the change in feeder space increased bone size and mass at hatching.

In the current study, breeders that were transferred to a layer house equipped with more feeder space than in rearing (6.3-8.4 cm/female) produced hatchlings that displaying more asymmetric femurs in terms of length. Relative asymmetry between limbs is a measurement that indicates the ability of individuals to confront with stressful conditions during ontogeny (Parsons, 1990; Møller and Swaddle, 1997; Møller et al., 1999). As intensive directional selection for fast-growing chickens has been performed in the poultry industry, the overall level of developmental instability has likely increased (Møller and Pomiankowski, 1993; Satterlee et al., 2000). Furthermore, stressors during incubation impair embryonic development and increase relative asymmetry in chickens (Eriksen et al., 2003)

CONCLUSIONS

It was concluded that breeders fed wheat-based diets produced progeny with lower weight of femurs and shorter shanks at hatching compared to those fed corn-based diets only when breeders were given more feeder space at photostimulation. However, diet type did not influenced eggshell conductance, hatchling BW without yolk, residual relative yolk weight, or any RA of bilateral leg bones at hatching. Broiler breeders fed restricted according to the LS feeding program laid eggs with greater eggshell conductance compared to those managed with the LF feeding program. However, the maternal feeding program did not affect any progeny bone morphological traits or the RA of leg bones at hatching. Eggs from breeders given more feeder space at photostimulation had higher eggshell conductance than those from breeders provided with similar feeder space. Maternal feeder space change did not influence BW without yolk; however, breeders given more feeder space produced progeny with heavier femurs and longer shanks compared to those provided similar feeder space but only when breeders were fed corn-based diets. Moreover, the increased maternal feeder space at photostimulation was associated with an increased RA of femur length in the progeny.

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CHAPTER IV: THE EFFECT OF MATERNAL FEEDING PROGRAM TO 29 WK AND BREEDER FEEDER SPACE CHANGE AT PHOTOSTIMULATION ON BROILER PROGENY GROWTH PERFORMANCE AND LEG HEALTH USING CORN OR WHEAT-BASED DIETS

ABSTRACT

The objective of this study was to evaluate the effects of diet type, maternal feeding program to 29 wk of age, and breeder feeder space change on broiler leg health at 6 wk of age. Cobb-500 breeders were housed in 16 pens of 81 females each, and fed either corn (C) or wheat (W) based diets, formulated to have similar nutrient composition during growing and layer phase. Two feeding programs, late fast (LF) or late slow (LS), were used from 14 to 29 wk of age. At 22 wk, 69 females that represented the BW distribution from each pen were placed in a layer house where feeder space either stay the same (6.3-6.5 cm/female) (S) or was increased (6.3-8.4 cm/female) (M). Eggs produced at 32 and 44 wk were collected and incubated for two broiler experiments. Sixteen male and sixteen female day-old chicks were placed in floor pens. Six and four replicates pens were used for experiment 1 and 2, respectively. Broiler gait scores and leg problem incidence were evaluated at 6 wk of age. Data was analyzed as a 2x2x2 factorial design with diet type, feeding program, and feeder space as main factors. The utilization of W increased the probability of observing crooked toes in broiler progeny at 6 wk compared to the use of C, only when breeders were fed according to the LF feeding program and given S. In addition, breeders given M produced progeny with more locomotion problems as compared to those from breeders provided S, but only when C was used, and the LS feeding program was applied to the breeders. Finally, the maternal feeding program interacted with other factors to influence leg health but it did not solely influence walking ability or leg problems of progeny. In conclusion, higher probability of observing walking impairment of broiler progeny was detected when breeders were given more feeder space change at photostimulation instead of no change, fed according to the LS feeding program using C diets.

INTRODUCTION

Bone development starts early during embryo incubation (Ballock and O'Keefe, 2003). Bone formation is at its maximum around 11 days of incubation indicated by an upswing of alkaline phosphatase (Reddi and Anderson, 1976). Afterwards, the highest growth rate of bone mass occurs between days prior to hatch and a few days post-hatch (Church and Johnson, 1964; Van der Eerden et al., 2003). Avian embryos develop and grow from energy and nutrients stored in the egg by the hen (Veira, 2007). In addition, specific incubation conditions could affect bone development. For instance, high temperatures and oxygen concentration during late incubation affect bone development (Oviedo-Rondón et al., 2008a). As a consequence, maternal physiological and nutritional status can influence bone development during incubation and subsequent prevalence of bone developmental disorders in their progeny at marketing age.

Adequate maternal nutrition could affect bone development of the progeny (Oviedo-Rondón et al., 2006). Recent researches have demonstrated that the supplementation of organic trace minerals (Oviedo et al., 2008b), vitamin D_3 (Atencio et al., 2005), or specific dietary fats (Liu and Denbow, 2001) in maternal diets influenced bone development and prevalence of leg problems in the progeny. Corn and wheat-barley based diets are the two major poultry diets formulated worldwide (Hocking and Bernard, 1997). Wheat and corn differ in metabolizable energy, protein and some first limiting amino acid contents, but these differences can be balanced by diet formulation to accomplish nutrient requirements of poultry (Roger et al., 1987; Guiterrez-Alamo et al., 2008). However, other nutritional factors inherent to these two types of diets are not feasible balanced and could be more closely linked to progeny growth performance and their bone development. Wheat contains a greater concentration of vitamin E (Panfili et al., 2003), B_1, B_2, and B_6 (Lebiedzinska and Szefer, 2006), and available phosphorus (Miracle et al., 1977; Stober et al., 1979; Hayes et al., 1979) than corn. Concentration of biotin is similar between corn and wheat; however, biotin bioavailability in chickens is much lower in wheat (Frigg, 1976; Anderson et al., 1978;

Baker, 1978; Bryden et al., 2006). One of the major anti-nutritional factors of wheat is the elevated non-starch polysaccharide concentration (Choct, 1997). On the other hand, corn has higher carotenoid contents which work as antioxidants to prevent and restrict lipid peroxidation (Niki, 1996; Surai and Sparks, 2001).

Progeny growth performance has been proved to be influenced by maternal feeding programs. Leksrisompong et al. (2009) reported that breeders allocated to a lower feeder space (5.3 vs. 7.1 cm/female) during the pullet rearing phase and fed a slow feeding program to peak program produced the heaviest broilers at 42 d. Further studies on the oviduct tract portions demonstrated that oviduct segments did not always develop synchronously. In fact, the use of the slow feeding program from photostimulation to the peak of egg production induced the oviduct segments to develop with similar rates (Leksrisompong and Brake, 2008).

Thus, this experiment was carried out to determine maternal effects on progeny bone development during incubation from breeders being reared on either corn or wheat based diets formulated to have similar nutrient composition during rearing and production. A second objective was to determine the effects of the two rates of increasing feed amounts during rearing until age to 29 wk of age following a late fast or late slow feeding program. The third objective was to evaluate the effects of changing feeder space at photostimulation**.** The ultimate purpose of this study was to provide a better understanding of the combined effects of maternal feed allocation, breeder feeder space change, and how these effects could impact broiler progeny growth performance and prevalence of leg problems using corn or wheat based diets.

MATERIAL AND METHODS

Broiler Breeder Husbandry

A total of 1,296 Cobb 500 non-feather sexable broiler breeder females and 288 broiler breeder males were grown sex-separate in a black-out house on an 8-h photoperiod after 23-h light per day for one week. Breeder pullets were randomly assigned to 16 floor pens containing 81 pullets each. Each female growing pen had 5 tube feeders and 2 automatic bell drinkers. Each feeder pan was 37 cm in diameter with a circumference of 116 cm, providing 6.3 cm of feeder space per pullet. Breeders were fed either corn or wheat based diets, formulated to have similar nutrient composition, during rearing and production. Nutrient specifications were used considering parent stock recommendations and companies in Europe and US. Supplemental biotin was added to both diets to meet the recommended nutritional requirements (Cobb-Vantress, 2008). The composition of the broiler breeder diets used throughout the trial is shown in Table II-1. The starter diet was fed from 0 to 4 wk of age, grower diet from 5 to 25 wk, and production diets from 26 to 52 wk. A pre-lay diet was fed from 18 to 25 wk of age only to breeders provided wheat-based diets. All breeder diets were offered in mash form. Two feeding programs, late fast (LF) and late slow (LS) were applied until age at which sexual maturity was reached (28 wk of age) (Figure II-1). Breeders followed a 4/3 feed restriction program from 3 to 22 wk of age. Pullets were weighed in groups at 1 d, 4 wk and 10 wk of age.

At 20 wk, pullets were individually weighed to select hens representing the body weight (BW) distribution of each pen. A total of 69 pullets from each rearing pen were moved to a two-thirds slat one-third litter pen located in a curtain-sided layer house at 22 wk of age. Pullets were immediately photostimulated to 14 h of light for photostimulation. Pen size was 16 m^2 (4 x 4 m) given a stocking density of 4.3 female breeders per m^2. Each breeder pen was equipped by one set of 8 nest boxes, 2 automatic bell drinkers and either 4 or 5 tube-type feeders to provide similar (6.5 cm/hen) or more (8.4 cm/hen) feeder space comparable with pullet-rearing phase. Seven males that represented the BW pen distribution from the same diet type treatment were housed in each breeder pen. To ensure feed separation of sexes, 48x58 mm feeder grills were installed around each female tube feeder.

Broiler Experiment 1

This experiment was conducted between January and February of 2009 and chickens were reared at the Poultry Educational unit at the Lake Wheeler Road Field Laboratory. Eggs were collected during a four-day period from 32-wk-old broiler breeders. Eggs were stored at 15.0^{o}C (64.4^{o}F) and 65% RH for 5 days. One hundred eighty eggs from each broiler breeder pen were allocated in individual trays. Afterwards, 8 trays were set in each of two Jamesway model 252B incubators (Butler Manufacturing Co., Ft. Atkinson, WI 53538). The incubator was initially operated at 37.8 ^{o}C (100.5 ^{o}F). After the 3 d of incubation, the temperature was decreased to 37.5^{o}C (99.5 ^{o}F). At 19 d of incubation, eggs were transferred from the setter trays to metal hatching baskets and returned to their respective machines. At 21 d of incubation the chickens were removed from the trays and sexed by cloacal inspection and identified with neck tags. Eight male and 8 female chickens were randomly taken from each of the two breeder broiler pens in each 2x2x2 interaction cell. Thus, 16 male and 16 female chickens from each broiler breeder treatment were assigned to each of 48 pens generating 6 replicate pens per broiler breeder interaction cell. Each litter pen had two tube-type feeders and one bell-type drinker to provide feed and water for *ad libitum* consumption. During the first 5 d there was also a gallon chick drinker used for supplemental water and two plastic trays used for supplemental feed. Stocking density was 9.5 chickens per m^2. Chicks were fed either corn or wheat based diets as were their parents. Broiler diet composition is shown in Table IV-1. Both, corn and wheat based diets were formulated on a digestible amino acid basis to have similar nutrient composition. Nutrient specifications were used considering parent stock recommendations and companies in Europe and US. Starter diets were fed as crumbles and grower and finisher diets as pellets.

Chickens were group weighed at placement and again at 7, 14, 35, and 48 d of age. Feed consumption was determined at the end of each feeding period to calculate feed conversion ratio adjusted by mortality adding BW gain of dead birds to the total BW gain of each pen.

Broiler Experiment 2

In order to evaluate the previously mentioned maternal factors when the broiler breeders were 44-wk-old an additional broiler experiment was executed. This experiment was conducted between April and May of 2009 and chickens were reared at Poultry Educational unit at the Lake Wheeler Road Field Laboratory. Eggs were stored, incubated and hatched in the same facility and under identical conditions as Experiment 1. At 21 d of incubation the chickens were removed from the trays and sexed by cloacal inspection and identified with neck tags.

Eight male and 8 female chickens were randomly taken from each of the two broiler breeder pens per 3-way interaction cell. Hatchlings were placed in the same broiler house with litter pens as used in Experiment 1. Thus, 16 male and 16 female chicks from each broiler breeder 3-way interaction cell were assigned to one of 32 pens generating 4 replicate pens per broiler breeder 3-way interaction cell. The equipment distribution, stocking density, and husbandry were equivalent to Experiment 1. Chicks were fed either corn or wheat based diets as were their parents in the same feed form as in Experiment 1. Also, diets were formulated on a digestible amino acid basis similarly to diets in experiment 1, but there were minor differences in crude protein in the starter and grower diets (Table IV-2).

Chicks were group weighed at placement and at 7, 14, 35, and 48 d of age. Feed consumption was determined at the end of each feeding period to calculate feed conversion ratio adjusted for mortality, adding BW gain of dead birds to the total BW gain of each pen.

Leg Health Evaluation of broiler Progeny

Chickens were individuallty visually inspected for crooked toes, twisted legs, valgus, and varus deformities at 41 and 46 d of age, in broiler experiment 1 and 2, respectively. Angular deformities were reported including valgus combined with varus malaligments because of the low prevalence of varus in the broiler flock. Walking ability was evaluated following the six-point gait-scoring system of Kestin et al. (1992) ranging from completely normal (score 0) to immobile (score 5). To simplify discussion of results, we extrapolated our data to the three-point gait-scoring system as defined by Webster et al. (2008) due to a strong correspondence found between these two systems by the same author. The gait scores (GS) from the three-point system are explained below:

GS 0: Birds can walk at least 1.5 m with a balanced gait. Birds may appear ungainly but with little effect on function.

GS 1: Birds can walk at least 1.5 m but with a clear limp or decidedly awkward gait.

GS2: Birds will not walk 1.5 m May shuffle on shanks or hocks with assistance of wings.

Statistical Analyses

A complete randomized block design with a 2 x 2 x 2 arrangement of treatments was used for broiler progeny data of experiments 1 and 2. Broiler house was divided into 4 blocks to correct for house environmental effects. There were 4 and 6 broiler pen replicates experiment 1 and 2, respectively. In both experiments, pen was treated as an experimental unit to examine broiler growth performance such as BW gain, feed intake, mortality, and mortality-adjusted FCR using JMP 8 (SAS Inst. Inc., Cary, NC) statistical analysis software. To analyze leg problem and gait score data, we used a generalized linear mixed effects model with fixed factorial effects of diet type, maternal feeding program, breeder feeder space change, and all interactions using Proc GLIMMIX (SAS Inst. Inc., Cary, NC). Leg problem and locomotion ability was analyzed as binomial data from each broiler in both experiments.

Pens were included as random effects, nested within treatment combinations. Log odds of a certain leg abnormality were modeled within factorial effects to obtain the probability of observing each leg problem or gait score. There were not significant interactions between breeder age, broiler sex, and any treatment effects. Consequently, these interactions were not included in the model, and breeder age and broiler sex were considered as explanatory variables. Percentage of broiler mortality was transformed to Arc sine prior to analyses. All pairwise comparisons among means were conducted using Tukey's studentized range test at an experimentwise type I error rate of $\alpha = 0.05$.

Statistical model for leg inspection:

$\log(\pi_{ijklm}/(1-\pi_{ijklm})) = \mu + \alpha_i + \beta_j + \delta_k + \alpha\beta_{ij} + \alpha\delta_{ik} + \beta\delta_{jk} + \alpha\beta\delta_{ijk} + \lambda_{l(ijkm)} + \tau_a + \omega_s + \varepsilon_{ijklm}$

Where:

$\log(\pi_{ijklm}/ 1-\pi_{ijklm})$: log odds of observing leg problems

μ : Overall mean

α_i : Effect of i^{th} diet type (i = 1,2)

β_j : Effect of j^{th} feeding program (j = 1,2)

δ_k : Effect of k^{th} feeder space change (k= 1,2)

$\alpha\beta_{ij}$: Effect of the first order interaction between diet type i and feeding program j

$\alpha\delta_{ik}$: Effect of the first order interaction between diet type i and feeder space change k

$\beta\delta_{jk}$: Effect of the first order interaction between feeding program j and feeder space change k

$\alpha\beta\delta_{ijk}$: Effect of the second order interaction among diet type i, feeding program j and, feeder space change k

$\lambda_{l(ijklm)}$: Random effect of broiler pen nested within treatment combinations ijk (l = effect of broiler pen, m= effect of each broiler chicken)

τ_a : Effect of broiler breeder age

ω_s: Effect of broiler sex

ε_{ijklm} : The experimental error associated to each observation.

Table IV-1. Composition of broiler diets (%) and formulated nutrient contents for experiment 1

INGREDIENTS	Starter (0-14 d)		Grower (15-35 d)		Finisher (36-48 d)	
	Corn	Wheat	Corn	Wheat	Corn	Wheat
	---------------------------------- (%) ----------------------------------					
Corn	57.44	20.00	59.89	20.00	64.50	20.00
Soft wheat grain	0.00	43.19	0.00	47.06	0.00	50.26
Soybean meal, 48%	28.07	19.19	25.26	13.92	20.17	14.68
Poultry fat	2.70	3.70	3.89	4.73	3.78	5.54
Distiller's dried grain with solubles	5.00	4.95	5.00	5.00	5.00	2.50
Poultry by product meal	1.91	4.00	1.50	4.78	2.74	3.02
Dicalcium phosphate, 18.5%	1.67	1.59	1.45	1.38	1.25	1.17
Limestone fine	1.28	1.18	1.24	1.05	1.07	1.10
Sodium bicarbonate	0.18	0.24	0.11	0.20	0.09	0.16
Salt	0.37	0.28	0.39	0.26	0.37	0.29
Mineral premix [1]	0.20	0.20	0.20	0.20	0.20	0.20
Vitamin premix [2]	0.15	0.15	0.10	0.10	0.10	0.10
Choline Chloride 60	0.20	0.20	0.20	0.20	0.20	0.20
Lysine, 78.8%	0.26	0.45	0.21	0.44	0.15	0.29
Methionine, 99%	0.29	0.32	0.26	0.30	0.18	0.21
L-Threonine, 98%	0.17	0.24	0.17	0.26	0.10	0.16
Coban®	0.05	0.05	0.05	0.05	0.05	0.05
BMD®	0.05	0.05	0.05	0.05	0.05	0.05
Phytase (Ronozyme® P)	0.02	0.02	0.02	0.02	0.02	0.02
Total	100.00	100.00	100.00	100.00	100.00	100.00
NUTRIENT COMPOSITION						
ME, kcal/kg	3050	3050	3,150	3,150	3,200	3,200
Crude protein, %	21.75	21.75	20.25	20.25	18.85	18.85
Calcium, %	0.98	0.98	0.90	0.90	0.82	0.82
Available phos.*, %	0.49	0.49	0.45	0.45	0.41	0.41
Dig. lysine, %	1.20	1.20	1.08	1.08	0.93	0.93
Dig. methionine, %	0.60	0.59	0.55	0.55	0.46	0.45
Dig. cystine, %	0.31	0.31	0.29	0.29	0.27	0.28
Dig. TSAA, %	0.90	0.90	0.84	0.84	0.73	0.73
Dig. threonine, %	0.81	0.81	0.77	0.77	0.64	0.64
Dig. tryptophan, %	0.20	0.21	0.19	0.19	0.16	0.19
Dig. isoleucine, %	0.81	0.73	0.75	0.65	0.68	0.62
Dig. valine, %	0.94	0.86	0.88	0.78	0.82	0.74
Dig. arginine, %	1.27	1.16	1.17	1.04	1.05	1.00
Sodium, %	0.23	0.23	0.22	0.22	0.21	0.21
Potassium, %	0.89	0.78	0.83	0.69	0.74	0.69
Chloride, %	0.30	0.30	0.31	0.30	0.29	0.28
DEB, mEq/100g	254	234	231	205	206	200

[1] Trace minerals from premix provided per kilogram of diet: manganese ($MnSO_4$), 120 mg; zinc ($ZnSO_4$) 120 mg, iron ($FeSO_4$), 80 mg; cooper ($CuSO_4$), 10 mg; iodine ($Ca(IO_3)2$), 2.5 mg and cobalt ($CoSO_4$), 1 mg.[2] Vitamins from premix provided per kilogram of diet: vitamin A, 13,228 IU; vitamin D_3, 3,968 IU; vitamin E, 66 IU; vitamin B_{12}, 40 mg; riboflavin, 13 mg; niacin, 110 mg; d-pantothenic acid, 22 mg; menadione, 4 mg; folic acid, 2 mg; vitamin B_6, 8 mg; thiamine, 4 mg; biotin, 250 mg. *Phytase was used as an additive to release 0.1 % available phosphorous only.

Table IV-2. Composition of broiler diets (%) and formulated nutrient contents for experiment 2

INGREDIENTS	Starter (0-14 d)		Grower (15-35 d)		Finisher (36-48 d)	
	Corn	Wheat	Corn	Wheat	Corn	Wheat
	---------- (%) ----------					
Corn	56.08	20.00	59.76	20.00	64.50	20.00
Soft wheat	0.00	41.31	0.00	46.17	0.00	50.26
Soybean meal, 48 %	28.88	20.67	24.84	14.79	20.17	14.69
Poultry fat	2.80	3.80	3.83	4.81	3.78	5.54
Distiller's dried grain with solubles	4.83	4.91	5.00	5.00	5.00	2.50
Poultry by product meal	2.71	4.50	2.22	4.78	2.74	3.01
Dicalcium phosphate, 18.5%	1.67	1.59	1.45	1.38	1.25	1.17
Limestone fine	1.21	1.14	1.18	1.05	1.07	1.10
Sodium bicarbonate	0.17	0.24	0.11	0.19	0.09	0.16
Salt	0.37	0.28	0.39	0.27	0.37	0.29
Mineral premix [1]	0.20	0.20	0.20	0.20	0.20	0.20
Vitamin premix [2]	0.10	0.10	0.10	0.10	0.10	0.10
Choline Chloride 60	0.20	0.20	0.20	0.20	0.20	0.20
Lysine 78.8%	0.24	0.42	0.21	0.42	0.15	0.29
Methionine 99%	0.27	0.30	0.25	0.29	0.18	0.21
L-Threonine, 98%	0.16	0.23	0.14	0.23	0.10	0.16
Coban®	0.05	0.05	0.05	0.05	0.05	0.05
Bacitraxin methylene disalicylate	0.05	0.05	0.05	0.05	0.05	0.05
Phytase (Ronozyme® P)	0.02	0.02	0.02	0.02	0.02	0.02
Total	100.00	100.00	100.00	100.00	100.00	100.00
NUTRIENT COMPOSITION						
ME, Kcal/Kg	3050	3050	3150	3150	3,200	3,200
Crude protein, %	22.50	22.50	20.50	20.50	18.85	18.85
Calcium, %	0.98	0.98	0.90	0.90	0.85	0.85
Available phos.*, %	0.49	0.49	0.45	0.45	0.41	0.41
Dig. lysine, %	1.22	1.22	1.08	1.08	0.93	0.93
Dig. methionine, %	0.59	0.58	0.55	0.55	0.46	0.45
Dig. cystine, %	0.32	0.32	0.29	0.29	0.27	0.28
Dig. TSAA, %	0.90	0.90	0.84	0.84	0.73	0.73
Dig. threonine, %	0.83	0.83	0.75	0.75	0.64	0.64
Dig. tryptophan, %	0.21	0.22	0.19	0.19	0.16	0.19
Dig. isoleucine, %	0.83	0.76	0.75	0.67	0.68	0.62
Dig. valine,%	0.98	0.90	0.89	0.80	0.82	0.74
Dig. arginine, %	1.32	1.22	1.18	1.06	1.05	1.00
Sodium, %	0.23	0.24	0.22	0.22	0.21	0.21
Potassium, %	0.90	0.81	0.83	0.70	0.74	0.69
Chloride, %	0.30	0.30	0.31	0.30	0.29	0.28
DEB, mEq/100g	257	241	229	208	206	200

[1] Trace minerals from premix provided per kilogram of diet: manganese ($MnSO_4$), 120 mg; zinc ($ZnSO_4$) 120 mg, iron ($FeSO_4$), 80 mg; cooper ($CuSO_4$), 10 mg; iodine ($Ca(IO_3)2$), 2.5 mg and cobalt ($CoSO_4$), 1 mg.

[2] Vitamins from premix provided per kilogram of diet: vitamin A, 13,228 IU; vitamin D_3, 3,968 IU; vitamin E, 66 IU; vitamin B_{12}, 40 mg; riboflavin, 13 mg; niacin, 110 mg; d-pantothenic acid, 22 mg; menadione, 4 mg; folic acid, 2 mg; vitamin B_6, 8 mg; thiamine, 4 mg; biotin, 250 mg. *Phytase was used as an additive to release 0.1 % available phosphorous only.

RESULTS

Progeny Growth Performance and Mortality

Broiler Progeny Initial BW and BW Gain. In Experiment 1, no significant ($P > 0.05$) effects of diet type were observed for initial progeny BW. However, there was an interaction effect among diet type, feeding program, and feeder space change from rearing to production for progeny BW at hatch from 32-wk-old broiler breeders ($P < 0.01$) (Table IV-3 and Table IV-4). When breeders were fed wheat-based diets following the LF feeding program but given more feeder space at photostimulation, broiler progeny was smaller at hatching. In addition, the interaction indicated that newly hatched chicks whose parents were fed wheat based diets following the LF feeding program with similar feeder space from rearing to production were heavier than progeny from breeders that received the same diet type and equal feeder space allocation, but fed according to the LS feeding program.

There was an interaction effect of diet type and feeding program for BW gain to 14 d indicating that progeny from breeders fed corn based diets and allocated the LS program gained less ($P < 0.001$) BW than those hatched from breeders restricted with the same feeding program but fed wheat based diets. Additionally, the interaction showed that breeders fed wheat based diets following the LF program produced progeny with more BW gain to 14 d compared to broilers from hens fed according to the LS program, whereas no differences produced by maternal feeding program were observed for progeny fed corn based diets. No significant ($P > 0.05$) effects were detected for BW gain to 14 d due to maternal feeder space change.

An interaction effect among diet type, feeding program, and feeder space change from rearing to production was observed for cumulative BW gain to 35 d ($P < 0.05$), and overall cumulative BW gain to 48 d ($P < 0.01$) of broiler progeny. When hens were fed according to the LS feeding program and given more feeder space at photostimulation, the use of breeder corn-based diets produced progeny that exhibited higher BW gain to 35 d and to 48 d of age compared to broilers from breeders fed wheat based diets. Regardless of the breeder feeder space change at photostimulation, hens fed wheat based diets on the LF feeding program produced broilers that gained more BW in both feed periods than progeny from breeders that received the same diet type but fed according to the LS feeding program. Also, BW gain of the progeny up to 48 d of age was influenced by feeder space change only when breeders were fed corn based diets following the LS program. Thus, increasing feeder space to breeders generated broiler progeny that gained more BW at 48 d than those broilers from breeders whose feeder space remained the same from rearing to production.

In experiment 2, there was an interaction ($P < 0.001$) effect between diet type and feeding program for initial BW of progeny from 44-wk-old broiler breeders (Table IV-3, IV-5). Hens fed corn based diets following the LF feeding program produced smaller hatchlings compared to those consuming wheat based diets and restricted to the same rate of feed allocation, whereas no effects of diet type were observed when breeders were allocated to the LS program. Similarly to experiment 1, newly-hatched chicks whose parents were fed according to the LS program and given more feeder space at photostimulation were smaller ($P < 0.001$) than progeny hatched from hens fed the same feeding program, but transferred to a layer house with equal feeder space as rearing.

BW gain to 14 d showed an interaction ($P < 0.05$) effect among diet type, feeding program, and feeder space change from rearing to production. Breeders fed corn based diets following the LF program and provided more feeder space at photostimulation produced broilers that exhibited higher BW gain than broilers produced by hens fed wheat base diets following the LS feeding program and given similar feeder space; other treatment combinations were intermediate. Similarly to experiment 1, breeders fed wheat based diets produced progeny that gained less ($P < 0.01$) BW to 35 d compared to broilers from hens consuming corn based diets.

Overall BW gain to 48 d showed an interaction (*P* < 0.01) effect between diet type and breeder feeder space change at photostimulation. In the same manner as experiment 1, broiler progeny whose parents were fed corn based diets and provided with more feeder space gained more BW than chickens from breeders that received the same feeder space allocation but were fed wheat based diets, whereas no effects were observed when breeder feeder space remained equal to rearing.

Broiler Progeny Feed Consumption. Cumulative feed consumption of broiler progeny from experiments 1 and 2 is shown in Tables IV-6 and IV-7. No significant (*P* > 0.05) effects of any maternal treatments were detected on cumulative feed consumption up to 14 d of age when breeders were 32-wk-old. However, progeny produced by 44-wk-old breeders whose diets included corn as a major source of energy ingested more (*P* < 0.01) feed than broilers fed wheat based diets. A significant (*P* < 0.05) interaction of diet type, feeding program, and breeder feeder space change from rearing to production was detected for cumulative feed intake to 35 and 48 d of progeny from 32-wk-old broiler breeders. Progeny from hens fed wheat diets following the LS program and given more feeder space at photostimulation ate less feed for both feeding periods than chickens from breeders feed according to the identical feeding program with equal feeder space allocation fed corn based diets instead.

In addition, breeders fed wheat based diets restricted to the LS program and provided with more feeder space produced progeny that had lower cumulative feed consumption to 35 and 48 d compared to broilers whose parents were fed the same diet type, managed with equal feeder space allocation but fed according to the LF program. The three-way interaction also indicated that the feed intake was greater to 35 and to 48 d of age for broiler progeny from breeders fed corn based diets following the LS program and given more feeder space than broilers produced by hens whose diets and rate of feed allocation was the same, but feeder space did not change. No significant (*P* > 0.05) effects of maternal treatments were observed on cumulative feed intake of 35 and 48-d-old chickens produced by 44-wk-old broiler breeders.

Feed Conversion Ratio Adjusted for Mortality. Cumulative progeny feed conversion ratio adjusted for mortality (AdjFCR) from experiment 1 and 2 is shown in Table IV-6 and TableIV-8.

An interaction among diet type, feeding program, and breeder feeder space change at photostimulation was observed (P < 0.01) for cumulative AdjFCR of broiler progeny produced by 32-wk-old breeders in the second feed period from 1 to 35 d. Progeny from breeders fed wheat based diets restricted with the LS program and given more feeder space at photostimulation exhibited improvements in AdjFCR compared to chickens from hens subjected to equal conditions but fed corn based diets. The utilization of corn based diets and in combination with more breeder feeder space as well as the utilization of wheat based diets and no change in breeder feeder space combined with the LF feeding program improved progeny AdjFCR compared to feed allocation with the LS program (1.550 vs. 1.613, 1.546 vs. 1.591). The three-way interaction also indicated that when corn based diets were used progeny from breeders restricted to the LS program with no change in feeder space at photostimulation had better AdjFCR than chickens from hens reared equally but given more feeder space from rearing to production (1.557 vs. 1.613).

Overall AdjFCR of progeny from 32-wk-old broiler breeders showed an interaction (P < 0.0001) between diet type and feeder space change at photostimulation. Breeders fed wheat based diets and given more feeder space produced chickens that had better AdjFCR compared to progeny from parents whose diets included corn as a major source of energy (1.728 vs. 1.773); however, an opposite response was observed when breeders had the same feeder space as during rearing (1.725 vs. 1.759). The interaction also demonstrated that breeders fed wheat based diets and given more feeder space at photostimulation produced progeny that utilized feed more effectively than chickens from hens whose feeder space remained the same at photostimulation (1.728 vs. 1.759); however, an inverse response was observed when breeders were fed corn based diets (1.773 vs. 1.725).

Table IV-3. *P*-values for the effects of diet type, maternal feeding program, breeder feeder space change, and all possible interactions on body weight gain of broiler progeny in experiments 1 and 2

Sources of variation	Experiment 1				Experiment 2			
	BW at 1 d	Body weight gain			BW at 1 d	Body weight gain		
		1-14 d	1-35 d	1-48 d		1-14 d	1-35 d	1-48 d
	(*P*-values)							
Diet[1] (D)	0.082	0.250	0.141	0.369	0.0896	0.7340	0.0074	0.0002
Feeding program[2] (FP)	0.007	0.107	<.0001	<.0001	0.9758	0.0246	0.7410	0.3076
Feeder space[3] (FS)	0.005	0.644	0.039	0.007	0.0002	0.0167	0.3271	0.8801
D*FP	0.638	0.001	<.0001	<.0001	0.0015	0.7785	0.9175	0.4309
D*FS	0.704	0.122	0.027	0.042	0.3533	0.0235	0.1330	0.0056
FP*FS	0.969	0.137	0.020	0.587	0.0007	0.6544	0.8102	0.8943
Diet*FP*FS	0.002	0.115	0.018	0.007	0.8315	0.0422	0.5496	0.6477
Sex	0.005	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001

[1] Broiler breeders received either corn or wheat based diets throughout their life (Table II-1)
[2] Feed was allocated following either a late fast or late slow feeding program from 14 to 28 wk of age (Figure II-1)
[3] At photostimulation (22 wk), broiler breeders were transferred to a layer house equipped with either similar or more feeder space as pullet-rearing phase.

Table IV-4. Effects of diet type, maternal feeding program, and breeder feeder space change on initial body weight and body weight gain of broiler progeny in experiment 1

Diet[2]	Feeding program[3]	Feeder space[4]	BW[1] at 1 d	Body weight gain[1] 1-14 d	1-35 d	1-48 d
			----------------------------	(g)	----------------------------	
Corn			41.9	443	2286	3436
Wheat			42.2	440	2268	3419
	Late fast		42.3[a]	443	2306[a]	3470[a]
	Late slow		41.9[b]	439	2248[b]	3383[b]
		More	41.8[b]	442	2290[a]	3453[a]
		Same	42.3[a]	441	2265[b]	3401[b]
Corn	Late fast		42.1	441[ab]	2281[b]	3431
	Late slow		41.8	445[a]	2291[ab]	3440
Wheat	Late fast		42.4	444[a]	2331[a]	3510
	Late slow		42.0	434[b]	2206[c]	3328
Corn		More	41.7	445	2312[a]	3481[a]
		Same	42.1	440	2260[b]	3390[b]
Wheat		More	41.9	439	2267[b]	3425[ab]
		Same	42.4	441	2269[ab]	3412[ab]
	Late fast	More	42.0	446	2333[a]	3501
		Same	42.5	441	2279[b]	3440
	Late slow	More	41.7	438	2247[b]	3405
		Same	42.1	441	2250[b]	3363
Corn	Late fast	More	42.1[ab]	443	2307[abc]	3456[abcd]
		Same	42.0[ab]	438	2255[bc]	3407[bcde]
	Late slow	More	41.4[b]	447	2318[ab]	3506[ab]
		Same	42.2[ab]	442	2264[bc]	3374[cde]
Wheat	Late fast	More	42.0[b]	448	2358[a]	3547[a]
		Same	42.9[a]	444	2303[abc]	3473[abc]
	Late slow	More	41.9[b]	429	2176[d]	3303[de]
		Same	42.0[b]	439	2235[cd]	3352[e]
Pooled SEM			0.2	2.5	12.5	19.3
CV (%)			1.69	2.66	2.57	2.65

[1] Data are means of 12 observations for each breeder treatment using broiler sex as covariate. [a-d] Means within a column without a common superscript differ significantly (P < 0.05). [2] Broiler breeders received either corn or wheat based diets throughout their life (Table II-1). [3] Feed was allocated following either a late fast or late slow feeding program from 14 to 28 wk of age (Figure II-1). [4] At photostimulation (22 wk), broiler breeders were transferred to a layer house equipped with either similar or more feeder space as pullet-rearing phase.

Table IV-5. Effects of diet type, maternal feeding program, and breeder feeder space change on initial body weight and body weight gain of broiler progeny in experiment 2

Diet[2]	Feeding program[3]	Feeder space[4]	BW[1] at 1 d	Body weight gain[1]		
				1-14 d	1-35 d	1-48 d
			------------------------- (g)	--------------------------		
Corn			44.6	462	2177[a]	3200[a]
Wheat			44.8	463	2136[b]	3115[b]
	Late fast		44.7	466[a]	2159	3169
	Late slow		44.7	459[b]	2154	3147
		More	44.4[b]	466[a]	2163	3156
		Same	45.0[a]	458[b]	2149	3159
Corn	Late fast		44.3[b]	466	2180	3203
	Late slow		44.8[ab]	458	2174	3198
Wheat	Late fast		45.1[a]	466	2137	3134
	Late slow		45.0[ab]	460	2134	3096
Corn		More	44.1	470[a]	2195	3229[a]
		Same	45.0	454[b]	2158	3171[ab]
Wheat		More	44.6	463[ab]	2132	3083[c]
		Same	45.1	463[ab]	2140	3147[bc]
	Late fast	More	44.7[bc]	469	2168	3168
		Same	44.7[ab]	463	2150	3169
	Late slow	More	44.1[c]	463	2159	3144
		Same	45.3[a]	454	2148	3150
Corn	Late fast	More	44.2	476[a]	2205	3238
		Same	44.4	456[ab]	2155	3168
	Late slow	More	44.1	463[ab]	2186	3221
		Same	45.5	453[ab]	2161	3175
Wheat	Late fast	More	45.1	462[ab]	2131	3099
		Same	45.2	470[ab]	2144	3170
	Late slow	More	44.0	464[ab]	2133	3067
		Same	45.1	455[b]	2135	3125
Pooled SEM			0.2	3.3	15.2	21.9
CV (%)			1.42	2.61	2.70	2.66

[1] Data are means of 8 observations for each breeder treatment using broiler sex as covariate. [a-c] Means within a column without a common superscript differ significantly (P < 0.05). [2] Broiler breeders received either corn or wheat based diets throughout their life (Table II-1). [3] Feed was allocated following either a late fast or late slow feeding program from 14 to 28 wk of age (Figure II-1). [4] At photostimulation (22 wk), broiler breeders were transferred to a layer house equipped with either similar or more feeder space as pullet-rearing phase.

Maternal feeding programs alone affected cumulative AdjFCR during the entire experiment 1 with progeny from 32-wk-old breeders. Greater increments of maternal feed amount from 14 to 28 wk of age, late fast feeding program, and generated improvements in progeny Adj FCR compared to smaller feed increments.

Diet type fed to breeders and broilers affected progeny cumulative AdjFCR to 14 ($P < 0.05$) and 48 d of age ($P < 0.001$) in experiment 2 when breeders were 44-wk-old (Table IV-6 and Table IV-8) Broilers fed corn based diets had better AdjFCR throughout their life compared to broilers fed diets that contained wheat as a major source of energy. In addition, an equivalent effect of diet type was observed ($P < 0.05$) on cumulative AdjFCR to 35-d of progeny from 44-wk-old breeders, regardless of the maternal feeding program and breeder feeder space change at photostimulation. No significant ($P > 0.05$) effects of feeding program applied to 44-wk-old breeders were observed for progeny cumulative AdjFCR at any feeding phase. A significant effect of diet type was detected on progeny cumulative AdjFCR only in the first feeding period indicating better ($P < 0.01$) broiler progeny feed utilization when 44-wk-old breeders were fed corn based diets compared to those from hens fed wheat based diets.

Table IV-6. Probabilities of the effects of diet type, maternal feeding program, breeder feeder space change, and all possible interactions on cumulative feed intake and cumulative feed conversion ratio (FCR) adjusted by mortality of broiler progeny in experiment 1 and 2

Sources of variation	Feed intake						Mortality-Adjusted FCR					
	Experiment 1			Experiment 2			Experiment 1			Experiment 2		
	1-14 d	1-35 d	1-47 d	1-14 d	1-35 d	1-48 d	1-14 d	1-35 d	1-47 d	1-14 d	1-35 d	1-48 d
	------------------------------ (*P*-values) ------------------------------											
Diet[1] (D)	0.6078	0.1207	0.5138	0.004	0.206	0.234	0.3992	0.1755	0.4325	0.0227	<.0001	0.0002
Feeding program[2] (FP)	0.8193	0.1305	0.0457	0.122	0.548	0.816	0.0019	0.0001	0.0001	0.6768	0.6858	0.2649
Feeder space[3] (FS)	0.1994	0.0205	0.0073	0.249	0.690	0.921	0.3568	0.2705	0.2735	0.0099	0.4473	0.8142
D*FP	0.0048	0.0001	0.0008	0.459	0.871	0.392	0.1788	0.5716	0.4979	0.6768	0.9032	0.4830
D*FS	0.0223	0.0001	0.0002	0.151	0.031	0.134	0.5349	0.0001	0.0001	0.9867	0.0702	0.7969
FP*FS	0.9641	0.5251	0.8285	0.556	0.267	0.867	0.0944	0.2952	0.4732	0.5382	0.0640	0.8491
D*FP*FS	0.1033	0.0048	0.0248	0.239	0.208	0.861	0.2405	0.0075	0.243	0.1650	0.0230	0.8666

[1] Broiler breeders received either corn or wheat based diets throughout their life (Table II-1)
[2] Feed was allocated following either a late fast or late slow feeding program from 14 to 28 wk of age (Figure II-1)
[3] At photostimulation (22 wk), broiler breeders were transferred to a layer house equipped with either similar or more feeder space as pullet-rearing phase.

Table IV-7. Effects of diet type, maternal feeding program, and breeder feeder space change on feed intake of broiler progeny in experiment 1 and 2

Diet[3]	Feeding program[4]	Feeder space Change[5]	Experiment 1[1]			Experiment 2[2]		
			1-14 d	1-35 d	1-48 d	1-14 d	1-35 d	1-48 d
			(g)					
Corn			597	3603	6029	631[b]	3539	5925
Wheat			594	3559	5998	655[a]	3579	6020
	Late fast		595	3603	6062[a]	649	3568	5963
	Late slow		596	3560	5965[b]	637	3550	5981
		More	598	3615[a]	6080[a]	639	3565	5976
		Same	592	3548[b]	5947[b]	647	3553	5968
Corn	Late fast		589	3560[ab]	5991[ab]	634	3546	5881
	Late slow		604	3646[a]	6066[a]	628	3533	5968
Wheat	Late fast		601	3645[a]	6133[a]	664	3590	6045
	Late slow		587	3474[b]	5863[b]	646	3567	5995
Corn		More	605	3701[a]	6194[a]	632	3580	5989
		Same	588	3505[b]	5864[b]	630	3499	5860
Wheat		More	592	3528[b]	5967[b]	645	3550	5963
		Same	597	3591[b]	6029[ab]	665	3607	6077
	Late fast	More	598	3645	6134	642	3557	5960
		Same	592	3560	5990	655	3579	5966
	Late slow	More	599	3585	6027	635	3573	5992
		Same	593	3535	5903	639	3527	5971
Corn	Late fast	More	594	3626[ab]	6107[abc]	629	3550	5932
		Same	584	3495[bc]	5877[bcd]	639	3542	5830
	Late slow	More	617	3777[a]	6281[a]	636	3611	6046
		Same	591	3515[bc]	5851[cd]	620	3455	5890
Wheat	Late fast	More	602	3664[ab]	6162[ab]	656	3564	5989
		Same	599	3626[ab]	6104[abc]	671	3617	6102
	Late slow	More	581	3392[c]	5772[d]	634	3536	5938
		Same	594	3555[bc]	5954[bcd]	658	3598	6052
Pooled SEM			4.5	25.8	55.6	6.9	28.1	72.8
CV (%)			2.73	2.61	2.65	3.10	2.30	3.55

[1]Data are means of 6 pen observations for each breeder treatment. [2] Data are means of 4 pen observations for each breeder treatment. [a-d] Means within a column without a common superscript differ significantly ($P < 0.05$). [3] Broiler breeders received either corn or wheat based diets throughout their life (Table II-1). [4] Feed was allocated following either a late fast or late slow feeding program from 14 to 28 wk of age (Figure II-1). [5] At photostimulation (22 wk), broiler breeders were transferred to a layer house equipped with either similar or more feeder space as pullet-rearing phase.

Table IV-8. Effects of diet type, maternal feeding program, and breeder feeder space on feed conversion ratio adjusted for mortality (AdjFCR) adjusted by mortality of broiler progeny in experiment 1 and 2

Diet[3]	Feeding Program[4]	Feeder space Change[5]	Experiment 1[1]			Experiment 2[2]		
			1-14 d	1-35 d	1-48 d	1-14 d	1-35 d	1-48 d
			---------------------------- (g:g) ----------------------------					
Corn			1.341	1.564	1.749	1.383^{b}	1.611^{b}	1.848^{b}
Wheat			1.347	1.557	1.743	1.413^{a}	1.676^{a}	1.931^{a}
	Late fast		1.334^{b}	1.541^{b}	1.725^{b}	1.400	1.644	1.879
	Late slow		1.354^{a}	1.580^{a}	1.767^{a}	1.395	1.642	1.900
		More	1.347	1.563	1.750	1.380^{b}	1.641	1.892
		Same	1.341	1.557	1.742	1.415^{a}	1.645	1.888
Corn	Late fast		1.327	1.543	1.726	1.383	1.611	1.831
	Late slow		1.355	1.585	1.772	1.383	1.610	1.865
Wheat	Late fast		1.341	1.539	1.725	1.418	1.677	1.927
	Late slow		1.352	1.575	1.762	1.408	1.674	1.935
Corn		More	1.346	1.582^{a}	1.773^{a}	1.365	1.614	1.853
		Same	1.337	1.547^{b}	1.725^{b}	1.400	1.608	1.844
Wheat		More	1.347	1.545^{b}	1.728^{b}	1.395	1.669	1.931
		Same	1.346	1.568^{a}	1.759^{a}	1.430	1.683	1.931
	Late fast	More	1.332	1.541	1.727	1.387	1.637	1.880
		Same	1.336	1.541	1.724	1.414	1.651	1.879
	Late slow	More	1.362	1.586	1.774	1.374	1.645	1.904
		Same	1.346	1.574	1.761	1.416	1.639	1.896
Corn	Late fast	More	1.323	1.550^{c}	1.743	1.360	1.603^{a}	1.833
		Same	1.332	1.536^{c}	1.709	1.405	1.620^{a}	1.830
	Late slow	More	1.369	1.613^{a}	1.803	1.370	1.625^{a}	1.873
		Same	1.342	1.557^{bc}	1.742	1.395	1.595^{a}	1.858
Wheat	Late fast	More	1.340	1.532^{c}	1.711	1.413	1.671^{b}	1.927
		Same	1.341	1.546^{c}	1.739	1.423	1.683^{b}	1.928
	Late slow	More	1.355	1.558^{bc}	1.745	1.378	1.666^{b}	1.935
		Same	1.350	1.591^{ab}	1.779	1.438	1.683^{b}	1.935
Pooled SEM			0.005	0.006	0.005	0.011	0.006	0.017
CV (%)			1.49	1.17	1.37	2.40	1.06	2.65

[1]Data are means of 6 pen observations for each breeder treatment. [2] Data are means of 4 pen observations for each breeder treatment. [a-c] Means within a column without a common superscript differ significantly ($P < 0.05$). [3] Broiler breeders received either corn or wheat based diets throughout their life (Table II-1). [4] Feed was allocated following either a late fast or late slow feeding program from 14 to 28 wk of age (Figure II-1). [5] At photostimulation (22 wk), broiler breeders were transferred to a layer house equipped with either similar or more feeder space as pullet-rearing phase.

Progeny Mortality. No significant ($P > 0.05$) effects of any maternal treatments were detected on cumulative mortality of broiler progeny originated from 32-wk-old breeders in Experiment 1 (Table IV-9). However, an interaction between maternal feeding program and breeder feeder space change at photostimulation was observed ($P < 0.01$) for progeny cumulative mortality when breeders were 44-wk-old in Experiment 2. The use of the LS maternal feeding program and the implementation of more breeder feeder space at photostimulation increased broiler progeny mortality compared to the allocation of the same feeding program combined with the same breeder feeder space as rearing, whereas this response was not observed when breeders were fed according to the LF feeding program.

Gait Scores and Leg Problems

After leg features visually inspected on 6-wk-old broiler progeny from 32 and 44-wk-old breeders were combined, no significant interaction effects of maternal treatments were observed on any leg traits except for the probability of observing gait score 0, gait score 1 (Figure IV-1) and crooked toes (Figure IV-2) on broiler progeny. Main effects of maternal treatments along with covariate effects such as breeder age and broiler sex are showed in Table IV-10 and Table IV-11.

Six-wk-old broiler progeny from 44-wk-old breeders were more ($P < 0.05$) likely to exhibit locomotion problems indicated by lower gait score 0 and higher gait score 1 and 2 compared to broilers from 32-wk-old breeders. However, broilers from 32-wk-old breeders had more ($P < 0.001$) chances to suffer crooked toes than progeny from 44-wk-old breeders. No significant ($P > 0.05$) effects of breeder age were observed on the probability of observing any angular deformations and twisted legs on broiler progeny.

Table IV-9. Overall mortality of broiler progeny produced at 32 and 44 wk of hen age.

Diet type[3]	Feeding program4	Feeder space5	Mortality of progeny	
			32 wk of hen age[1]	44 wk of hen age[2]
			---------------------- (%) ----------------------	
Corn			4.72	2.88
Wheat			3.17	2.50
	Late fast		4.57	2.81
	Late slow		3.32	2.56
		More	4.58	3.06
		Same	3.30	2.31
Corn	Late fast		5.84	3.13
	Late slow		3.59	2.63
Wheat	Late fast		3.30	2.50
	Late slow		3.04	2.50
Corn		More	7.00	3.25
		Same	2.43	2.50
Wheat		More	2.17	2.88
		Same	4.17	2.13
	Late fast	More	4.36	2.38[ab]
		Same	4.78	3.25[ab]
	Late slow	More	4.81	3.75[a]
		Same	1.83	1.38[b]
Corn	Late fast	More	7.59	3.00
		Same	4.09	3.25
	Late slow	More	6.41	3.50
		Same	0.78	1.75
Wheat	Late fast	More	1.13	1.75
		Same	5.47	3.25
	Late slow	More	3.21	4.00
		Same	2.87	1.00
Sources of variation			-------------- (*P*-values) ----------	
Diet			0.468	0.190
Feeding program			0.412	0.222
Feeder space			0.339	0.090
Diet*Feeding program			0.456	0.843
Diet*Feeder space			0.012	0.791
Feeding program*Feeder space			0.112	0.002
Diet*Feeding program*Feeder space			0.420	0.146

[1]Data are means of 6 pen observations for each breeder treatment; [2] Data are means of 4 pen observations for each breeder treatment; [a-d] Means within a column without a common superscript differ significantly ($P < 0.05$). [3] Broiler breeders received either corn or wheat based diets throughout their life (Table II-1). [4] Feed was allocated following either a late fast or late slow feeding program from 14 to 28 wk of age (Figure II-1). [5] At photostimulation (22 wk), broiler breeders were transferred to a layer house equipped with either similar or more feeder space as pullet-rearing phase.

Six-wk-old male chickens from 32 and 44- wk-old breeders combined were more likely to present walking impairment ($P < 0.01$) and physical leg defects such as crooked toes ($P < 0.0001$), twisted legs ($P < 0.05$), and total ($P < 0.0001$) and severe ($P < 0.0001$) angular deformations compared to female chickens. In contrast, male broilers showed lower ($P < 0.01$) probabilities to display mild angular deformations compared to female broilers.

An interaction effect among diet type, feeding program and breeder feeder space change at photostimulation was detected ($P<0.01$) for the probability of observing gait score 1 on 6-wk-old broiler progeny. Progeny from breeders fed corn based diets following the LS feeding program and moved to a layer house with more feeder space as rearing had more chances to exhibit worsen walking ability than broilers from hens fed according to identical program and given equal feeder space allocation, but both breeders and broilers consumed wheat based diets. In contrast, progeny from breeders fed corn based diets following the LF feeding program and moved to a layer house with similar feeder space as rearing were less ($P < 0.01$) likely to display crooked toes than broilers from hens fed according to identical program and given equal feeder space allocation but fed wheat based diets.

Table IV-10. *P*-values for the effects of diet type, maternal feeding program, breeder feeder space change and all possible interactions on the probability of observing specific gait scores and leg problems of broiler progeny using breeder age and broiler sex as predictable variables

Sources of variation	Gait scores[6,7]			Leg problems[6]				
				Angular deformations[8]			Twisted legs	Crooked Toes
	0	1	2	Mild	Severe	Total		
	---------- (*P*-values) ----------							
Breeder Age[1]	0.003	0.017	0.009	0.482	0.496	0.229	0.134	0.001
Broiler sex[2]	<.0001	<.0001	0.013	0.003	<.0001	<.0001	0.050	<.0001
Diet[3] (D)	0.136	0.090	0.731	0.703	0.431	0.724	0.765	0.384
Feed program[4] (FP)	0.838	0.871	0.227	0.303	0.959	0.292	0.503	0.374
Feeder space[5] (FS)	0.025	0.015	0.873	0.386	0.114	0.618	0.653	0.600
D*FP	0.058	0.060	0.951	0.956	0.457	0.561	0.834	0.047
D*FS	0.015	0.037	0.187	0.188	0.051	0.861	0.374	0.017
FP*FS	0.893	0.670	0.417	0.536	0.907	0.543	0.061	0.788
D*FP*FS	0.005	0.002	0.835	0.378	0.200	0.692	0.418	0.009

[1] Progeny from 32- and 44-wk-old broiler breeders were analyzed together.
[2] Six-wk-old male and female broiler chickens were inspected individually.
[3] Broiler breeders either received corn or wheat based diets throughout their life. Broilers received diets based on the same cereal as their parents.
[2] Feed was allocated following either a late fast or late slow feeding program from 14 to 28 wk of age.
[5] At photostimulation (22 wk), broiler breeders were transferred to a layer house equipped with either similar or more feeder space (6.3-6.5 vs. 6.3-8.4 cm/female) as pullet-rearing phase.
[6] Data correspond to 192 individual chicken observations in experiment 1 along with 128 chicken observations in experiment 2 for each treatment.
[7] Gait scores were evaluated according to Webster et al. (2008)
[8] Angular deformations include valgus and varus malalignments

Table IV-11. Effects of diet type, maternal feeding program, and breeder feeder space change on the probability of observing specific gait scores and leg problems of broiler progeny using breeder age and broiler sex as predictable variables

Main factors	Levels	Gait scores[6,7]			Leg problems[6]				
					Angular deformations[8]			Twisted legs	Crooked toes
		0	1	2	Mild	Severe	Total		
		----------------- (Probability of observing each leg feature) -----------------							
Breeder age[1]									
	32 wk	0.74[a]	0.24[b]	0.016[b]	0.43	0.22	0.71	0.008	0.060[a]
	44 wk	0.65[b]	0.31[a]	0.034[a]	0.40	0.20	0.66	0.015	0.029[b]
Broiler sex[2]									
	Female	0.82[a]	0.16[b]	0.017[b]	0.45[a]	0.12[b]	0.59[b]	0.008[b]	0.025[b]
	Male	0.53[b]	0.43[a]	0.032[a]	0.39[b]	0.35[a]	0.77[a]	0.016[a]	0.070[a]
Diet type[3]									
	Corn	0.68	0.30	0.022	0.41	0.22	0.70	0.011	0.038
	Wheat	0.72	0.25	0.025	0.42	0.20	0.68	0.012	0.046
Feeding program[4]									
	LF	0.69	0.27	0.028	0.40	0.21	0.66	0.013	0.038
	LS	0.70	0.28	0.020	0.43	0.21	0.71	0.010	0.046
Feeder space[5]									
	More	0.66[b]	0.31[a]	0.023	0.40	0.23	0.70	0.012	0.040
	Same	0.73[a]	0.24[b]	0.024	0.43	0.19	0.68	0.010	0.044
Pooled SEM		0.02	0.02	0.005	0.03	0.03	0.03	0.003	0.006

[a-b] Means within a column without a common superscript differ significantly ($P < 0.05$).
[1] Progeny from 32-and 44-wk-old broiler breeders were analyzed together.
[2] Six-wk-old male and female broiler chickens were inspected individually.
[3] Broiler breeders either received corn or wheat based diets throughout their life.
[2] Feed was allocated following either a late fast or late slow feeding program from 14 to 28 wk of age.
[5] At photostimulation (22 wk), broiler breeders were transferred to a layer house equipped with either similar or more feeder space (6.3-6.5 vs. 6.3-8.4 cm/female) as pullet-rearing phase.
[6] Data corresponds to around 192 chicken observations in experiment 1 along with 128 chicken observations in experiment 2 for each treatment.
[7] Gait scores were evaluated according to Webster et al. (2008).
[8] Angular deformations include valgus and varus malalignments.

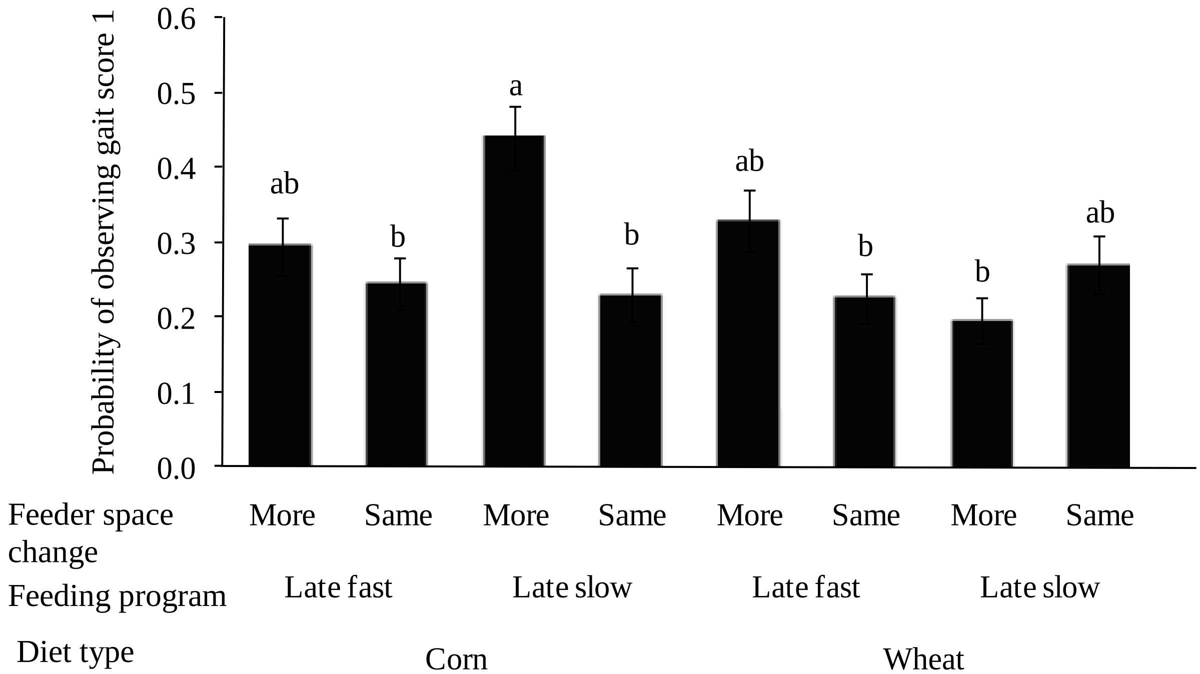

Figure IV-1. Interaction effect among diet type, maternal feeding program, and breeder feeder space change with regards to the probability of observing gait score 1 in 6-wk-old broiler progeny. Broiler breeders either received corn or wheat based diets throughout their life following a late fast or a late slow feeding program from 14 to 28 wk of age. At photostimulation (22 wk), broiler breeders were transferred to a layer house equipped with either similar or more feeder space (6.3-6.5 vs. 6.3-8.4 cm/female) as during pullet-rearing phase. A three-point gait-scoring system was used to report walking ability ranking from 0 to 2 (Webster et al., 2008). Bars represent SEM. Data are means of approximately 192 chicken observations in experiment 1 combinated with 128 observations in experiment 2. Means without common superscripts differ significantly ($P < 0.01$).

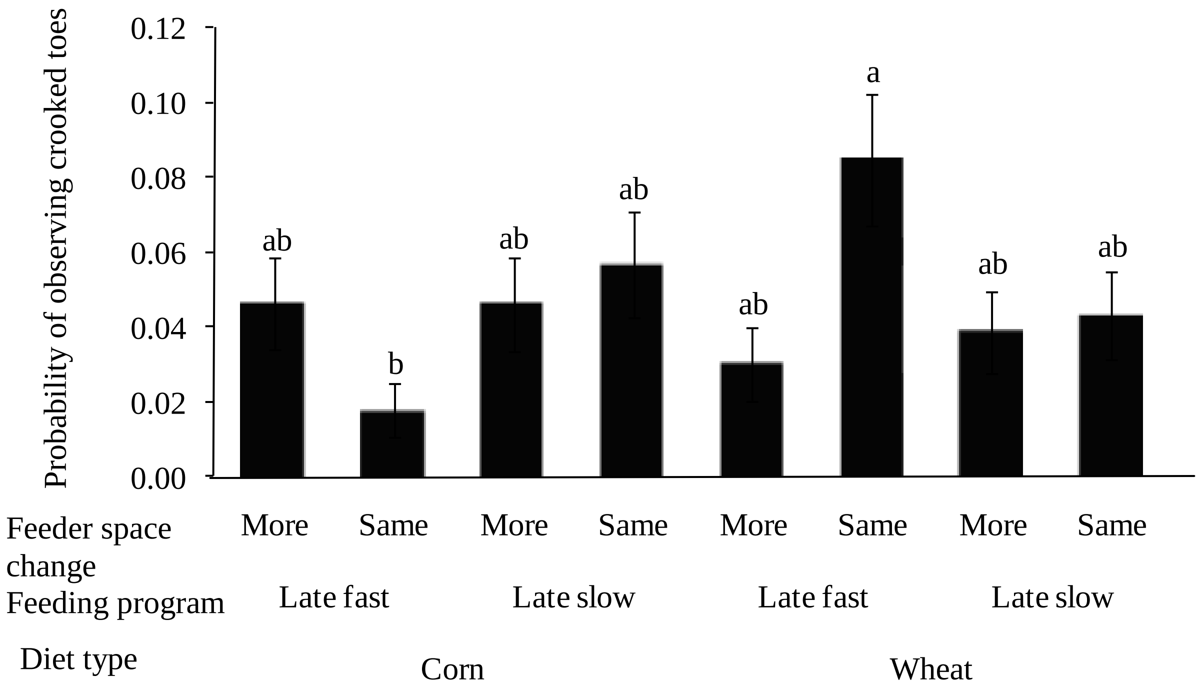

Figure IV-2. Interaction effect among diet type, maternal feeding program, and breeder feeder space change for the probability of observing crooked toes in 6-wk-old broiler progeny. Broiler breeders received either corn or wheat based diets throughout their life following a late fast or a late slow feeding program from 14 to 28 wk of age. At photostimulation (22 wk), broiler breeders were transferred to a layer house equipped with either similar or more feeder space (6.3-6.5 vs. 6.3-8.4 cm/female) as during the pullet-rearing phase. Bars represent SEM. Data are means of approximately 192 chicken observations in experiment 1 combinated with 128 observations in experiment 2 for each treatment. Means without common superscripts differ significantly ($P < 0.01$).

DISCUSSION

Progeny Growth Performance and Cumulative Mortality

Broiler and breeders were fed the same type of diet in the two broiler experiments. Seven-wk-old progeny from 44-wk-old broiler breeders (Experiment 2) were smaller (200 g) than those hatched from 32-wk-old breeders (Experiment 1). Peebles et al. (2001) indicated that older breeders tend to have bigger yolks and less albumen compared to young breeders, consequently, their progeny may have better growth performance. However, in our experiment, progeny from 44-wk-old were reared during summer conditions with high temperatures that could have reduced feed intake and caused heat stress that would lower growth performance.

The use of corn in breeder and progeny diets produced a consistent improvement at all time periods in AdjFCR of progeny from 44-wk-old breeders, but no effects were observed when breeders were 32-wk-old. This result might reflect the comparative nutritional benefits of corn over wheat. Breeders that consumed corn based diets might have deposited higher levels of biotin (Anderson et al. 1978; Baker, 1978; Bryden et al., 2006) and antioxidants (Surai and Sparks, 2001) in the yolk. Perhaps we did not observe significant differences in feed conversation of broiler progeny from 32-wk-old breeders because they were reared during winter with optimal temperatures.

Breeders at 32 wk of age that had been fed following the LF feeding program produced broilers that had higher BW at 48d compared to those from hens fed according to the LS program only when wheat based diets were used, regardless of feeder space. In contrast, Leksrisompong et al. (2009) reported that broilers from broiler breeders provided a lower feeder space (5.3 vs. 7.1 cm/female) during the pullet-rearing phase and fed a slow feeding program to peak program produced the heaviest broilers at 42 d. No effects of maternal feeding program were observed when breeders were 44 wk. The breeders fed according to the LF program consumed a great amount of feed from 18 to 22 wk of age, the period during which the oviduct became fully functional. Therefore, breeders fed according to the LF might have a better plane of nutrition and a enhanced oviduct development that may help with larger yolks, and other egg traits that help to improve development of chickens.

At both breeder ages evaluated, progeny from breeders given more feeder space at photostimulation had lower initial BW compared to those from hens provided with the same feeder space as rearing; however, broilers had greater BW gain in subsequent feeding periods. This suggested that progeny from breeders that received more feeder space had a faster growth rate than their counterparts. Lower mortality was perceived from progeny produced by breeders fed according to the LS feeding program and given more feeder space at photostimulation. This group of chickens also had lower BW indicating a slow growth rate. Progeny mortality was more frequent during the late growing period due to heat stress and also associated to a fast growth rate in the Experiment 2.

Gait Scores and Leg Problems

Data from both experiments combined indicated that male chickens were two times more likely to display walking impairment, crooked toes, twisted legs, and severe angular deformations than female chickens. A large scale experiment conducted by Oviedo et al. (2009) demonstrated similar results with regards to the effect of broiler sex on locomotion and leg abnormalities. Males also had consistently higher BW gain, indicating a higher growth rate. Higher growth rate has been related to a higher prevalence of skeletal problems, regardless of gender (Kestin et al., 1992; Sanotra et al., 2001; Sanotra et al., 2003; Mench, 2004)

Progeny produced at 44 wk of breeder age had more chances to have worsened walking ability but a lower probability to display crooked toes as compared to progeny produced at 32 wk. Walking ability and crooked toes have different etiology. Besides disturbance of bone formation, walking ability has been associated with modifications of tendon development, pain, spinal cord injuries, and vertebra deviations (Oviedo-Rondón, 2007).

The interaction among all maternal effects indicated progeny from breeders fed corn based diets following the LS program and given more feeder space at photostimulation had more chances to display walking impairment compared to broilers from hens under identical conditions but fed wheat based diets. However, breeders fed wheat based diets with the LF program but given no change in feeder space produced progeny more likely to present crooked toes compared to chickens under equivalent conditions but fed corn based diets.

The utilization of wheat in breeder and broiler diets under specific conditions increased the probability to display crooked toes in progeny at 6 wk of age. Toe deformation that resulted from the utilization of wheat based diets might be related to the higher concentration of non-starch polysaccharides (Choct, 1997) and lower bioavailability of biotin in wheat (Frigg, 1976; Anderson et al., 1978; Baker, 1978; Bryden et al., 2006). On the other hand, the use of corn in breeder and broiler diets under specific conditions increased walking ability impairment of 6-wk-old-progeny that could be related to faster growth rate observed in this group of chicken.

The increase in maternal feeder space at photostimulation worsened walking ability in broiler progeny compared to chickens whose parents did not receive any change in feeder space from rearing to production. This group of chickens exhibited a faster growth observed in lower hatch BW but greater growth rates later in life. In addition, progeny produced at 33 wk of age had shanks thatwere more asymmetric at hatching (Chapter III).

CONCLUSIONS

In conclusion, the utilization of wheat based diets increased the probability of observing crooked toes in broiler progeny at 6 wk compared to the use of corn based diets, only when breeders were fed according to the LF feeding program and given similar feeder space at photostimulation. However, the use of corn based diets worsened the walking ability of progeny more than the utilization of wheat based diets, but only when breeders were fed according to the LS feeding program and provided with more feeder space at photostimulation. It seems that the walking ability of broilers fed corn based diets was influenced by the faster growth rate observed in those chickens. In addition, breeders given more feeder space at photostimulation produced progeny with more locomotion problems as compared to those from breeders provided with similar feeder space but only when corn based diets were used and the LS feeding program was applied to the breeders. This result appears to be related to a higher relative asymmetry of femur weights observed at hatching from 33-wk-old breeders given more feeder space at photostimulation. Finally, the maternal feeding program interacted with other factors to influence leg health but it did not influence by itself walking ability or leg problems of progeny.

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CHAPTER V: EFFECT OF BREEDER FEEDING PROGRAM TO PHOTOSTIMULATION AND FEEDER SPACE AVAILABILITY ON EGG CHARACTERISTICS AND BROILER PROGENY LEG HEALTH OF TWO GENETIC LINES USING CORN OR WHEAT-BASED DIETS

ABSTRACT

This study was conducted to evaluate the effects of breeder nutrition and management on broiler leg health issues at 4 and 6 wk of age and bone traits at 7 wk of age. Broiler breeders of two strains (A or B) were housed in 16 pens and fed either corn (C) or wheat (W) based diets during rearing. Late fast (LF) and late slow (LS) feed restriction programs were used during rearing. At 22 wk, hens and roosters representing the BW distribution from each treatment were moved to a cage breeder house and the hens were placed at either 1 or 2 hens/cage simulating more or less feeder space. At 32 and 44 wk, eggs were collected and incubated. All progeny were pedigreed to track individual breeder hen effects when broilers were placed in floor pens. Broilers were fed the same diet (C or W) as their parents. At 4 and 6 wk of age, leg health was evaluated. Data was analyzed as a 2x2x2x2 factorial design with strain, diet type, feeding program, and cage space as main factors using GLIMMIX of SAS. The use of the LS maternal feeding program along with the supplementation of more maternal feeder space during the layer phase reduced the chances to observe locomotion problems at 6 wk of age in B broilers. On the other hand, probabilities of observing crooked toes and locomotion issues in A broilers were not influenced by diet type, maternal feeding program, or maternal feeder space. However, the chances to observe angular deformations on A broilers were greater when breeders were fed according to the LS feeding program and given less feeder space. It appeared that A and B response similarly to breeder feeding program; however, B strain was more sensitive to effects of diet type and availability of feeder space during lay. Ultimately, broilers having more leg problems had longer bones, and greater BMD and BMC measured at 7 wk.

INTRODUCTION

Bone formation starts early during embryo development (Ballock and O'Keefe, 2003) and is clearly observed at 11 days of incubation (Reddi and Anderson, 1976). Furthermore, days prior to hatch and a few days post-hatch, bone growth rate is at its highest (Church and Johnson, 1964; Van der Eerden et al., 2003). Simultaneously, during the last three to four days of incubation, the demand for oxygen exceeds the oxygen diffusion capacity of the eggshell pore system (Tazawa, 1980; Rahn, 1981). Therefore, it has been suggested that changes in nutrient yolk deposition and gas exchange capacity influenced by nutritional and physiological status of the hen might impact bone development, and the prevalence of subsequent leg problems in broilers.

Access to oxygen supports the complete combustion of fatty acids which is used as the primary source of energy for embryo development (Moran, 2007). Specific lipids, trace minerals, and vitamins deposited in the yolk have been reported to be involved in bone development (Oviedo-Rondón et al., 2006). Thus, adequate maternal nutrition could improve bone development. For instance, the supplementation of organic trace minerals in maternal diets improved symmetry of shank lengths at hatch, and consequently improved the walking ability of 49-d-old broiler chickens (Oviedo-Rondón et al., 2008b). Furthermore, different dietary fats added to hen diets may alter yolk fatty acid composition (Hargis and Van Elswyk, 1993; Liu and Denbow, 2001), and subsequently, bone formation and resorption.

Egg characteristics, especially eggshell properties, influence gas diffusion capacity (Seymour and Visschedijk, 1988), and consequently embryo development (Stock and Metcalfe, 1984; Asson-Batres et al., 1989; Lourens et al., 2007). Oviedo-Rondón et al. (2008c,d; 2009a,b) indicated that elevated temperatures (>37°C) coupled with hypoxia (<19% oxygen) conditions, during the last 4 d of incubation reduced bone development, collagen type X, and transforming growth factor β expression, and increased relative bone asymmetry in broilers.

Several previous investigations have demonstrated that genetic background influences walking ability (Kestin et al., 1992; Kestin et al., 1999), bone structure (Venalainen et al., 2006) and prevalence of leg problems. Furthermore, differences in relative weights of albumen and eggshell have been found between Cobb and Ross broiler breeder strains (Fisher and Gous, 2009). This suggests that genetic line could also affect broiler progeny bone development due not only to specific genes related to bone, but also by changes in egg properties that may affect embryo development. To our knowledge, there has not been any investigation that links egg characteristics to prevalence of leg problems in their broiler progeny.

Poultry diet formulations differ across the world. Commercial diets in the USA and Europe are corn and wheat-barley based diets (Hocking and Bernard, 1997), respectively. Although wheat has lower metabolizable energy and higher protein content than corn (Rogel et al., 1987, Guiterrez-Alamo et al., 2008), other nutritional factors could be more closely linked to progeny growth performance and their bone development, even after both diets have been balanced to have similar nutrient composition. Wheat contains greater concentration of vitamin E (Panfili et al., 2003), B_1, B_2, and B_6 (Lebiedzinska and Szefer, 2006), and available phosphorus (Miracle et al., 1977, Stober et al., 1979; Hayes et al., 1979) than corn; however it contains an elevated non-starch polysaccharide concentration (Choct, 1997) that is known to reduce digestibility of nutrients. Concentration of biotin is similar between corn and wheat; however, biotin bioavailability in chickens is much lower in wheat (Frigg, 1976; Baker, 1978; Bryden et al., 2006). On the other hand, corn has a higher carotenoid content, which works as an antioxidant to prevent and restrict lipid peroxidation during incubation (Niki, 1996; Surai and Sparks, 2001).

Feeding program affects progeny growth performance in broiler breeders. Broilers from broiler breeders allocated to a lower feeder space (5.3 vs. 7.1 cm/female) during the pullet-rearing phase and fed a slow feeding program from photostimulation to peak of egg production produced the heaviest broilers at 42 d (Leksrisompong et al., 2009). Further studies on the oviduct tract portions demonstrated that oviduct segments did not always develop in a synchronous manner. The use of the slow feeding program from photostimulation to the peak of egg production induced the oviduct segments to develop with similar rates as the whole oviduct (Leksrisompong and Brake, 2008). Leksrisompong et al. (2008) reported that feeder space change at photostimulation in broiler breeders increased hen mortality and reduced egg production. There is little information about the effects of feeder space on broiler progeny growth performance and leg problem prevalence.

Thus, the objective of this experiment was to evaluate the effects of the maternal feeding program from 14 wk to photostimulation at 22 wk and feeder space availability during layer phase on leg disorder prevalence, walking ability, bone mineral density, and content of broiler progeny from two strains using corn or wheat based diets. Effects of strain, diet type, maternal factors, and interaction among them were evaluated in broiler progeny from a broiler breeder flock at 32 and 44 wk of age. Special emphasis was given to egg characteristics linked to broiler progeny leg health.

MATERIALS AND METHODS

Broiler Breeder Husbandry

Broiler breeders of two strains labeled as A and B were grown sex-separate in the same pens in a black-out house on an 8-h photoperiod after 23-h light per day for one week. Pullets were identified with neck tags and randomly assigned to 16 floor pens. Each female growing pen had 5 tube feeders and 2 automatic bell drinkers. Males were randomly assigned to 16 floor pens. Each female feeder pan was 37 cm in diameter with a circumference of 116 cm, providing 6.3 cm of feeder space per pullet. Breeders were fed either corn or wheat based diets, formulated to have similar nutrient composition, during rearing and production. Supplemental biotin was added to both diets to meet recommended nutritional requirements (Cobb-Vantress, 2008). The composition of the broiler breeder diets used throughout the trial is shown in Table II-1. The starter diet was fed from 0 to 4 wk of age, grower diet from 5 to 25 wk, and production diets from 26 to 52 wk. A pre-lay diet was fed from 18 to 25 wk of age to only breeders that were provided wheat based diets. Starter diets were offered in crumbles form, grower diets were offered in mash form, and layer diets were offered as pellets. Two feeding programs, late fast (LF) or late slow (LS), were applied until photostimulation (Figure V-1). Breeders followed a skip 4/3 restriction program from 3 to 22 wk of age.

At 20 wk, pullets and male breeders were individually weighed to select breeders representing the BW distribution of each pen. At 22 wk of age, 135 strain A and 100 strain B pullets were moved to cages containing one or two hens each in a curtain-sided layer house. Pullets were immediately photostimulated to 14 h of light for photostimulation. Neck tags were used to track breeders within each treatment combination. Breeders received the same diet type as during the pullet-rearing phase. Cage size was 1350 m^2 (30x 45 x 42 cm) providing 30 cm (1 hen/cage) or 15 cm with 2 hens per cage. Two nipple drinkers in each cage allowed the hens to consume water *ad libitum*.

For pedigree purposes, hens were artificially inseminated with fresh pooled semen from roosters of the same strain and diet type at 32 wk and 45 wk of age. Each sample of pooled semen was composed of semen from 3 or 4 roosters and inseminated to breeder groups of approximately 12 broiler breeders within the same treatment. Thus, paternal genotype was equally distributed within each breeder treatment. Hens were inseminated using 0.05 ml of each sample of pooled semen.

Egg Analyses

At 31 and 47 wk, two consecutive eggs from each breeder hen were collected to measure internal and external egg characteristics. Only eggs that were not dirty, cracked, or double-yolked were used for this analysis. All eggs were numbered and weighed. Length and width of each egg were measured with a digital caliper (ProMax, Fred V. Fowler Co., Inc., Auburndale, MA 02466) to the nearest 0.01 mm to calculate surface area with an algorithm (Altuntaş and Şekeroğlu, 2008), and shape index with another algorithm (Anderson et al., 2004) using the following equations:

$SA = \pi D_g^2$………...$D_g = (LW^2)^{1/3}$

ESI = W/L x 100

Where: SA = Surface area, Dg = geometric mean diameter, L = length, and W = width, EI = egg shape index.

After measuring external egg traits, eggs were broken onto a flat surface to measure albumen height with an electronic tripod micrometer. Then, the yolk was separated from the albumen and weighed. Albumen was rinsed from the shell with water and the shell with membrane intact was air dried. The wet albumen weight was calculated by subtracting the yolk weight and the air-dried shell weight from the egg weight. All the egg components were expressed as a percentage of initial egg weight, and yolk:albumen ratio (Y:A ratio) was calculated.

For the egg evaluation at 47 wk, the eggshell membrane thickness was measured with a piston micrometer (Ames, Amherst, MA) at 6 points at the equator of each egg (Christensen et al., 2006). Eggshell membranes were removed according to Christensen (1983), and eggshell thickness without membrane was measured at the exact 6 points used previously. Eggshell membrane thickness was calculated by subtracting the eggshell thickness before and after removing the eggshell membranes. To determine density of pores, pieces from blunted, equator, and pointed end of each eggshell were selected. The pieces were treated to make visible pores according to Rahn et al. (1981). The pores were counted in three different areas in each of the three regions of the eggshell (Christensen, 1983). Eggshell thickness and eggshell membrane thickness was the mean of the 6 points measured at the egg equator. Concentrations of pores on the blunted, equator, and pointed end on each eggshell were the means of three areas counted on each region.

At 46 wk, all eggs produced during six days were collected, weighed, and set in a ChickMaster incubator model G18. At 18 days of incubation, eggs were again weighed to determine the amount of moisture loss from those eggs. The eggshell conductance (G) was calculated using the formula provided by Ar et al. (1974):

$$G_{H2O} = M_{H2O}/\Delta P_{H2O}$$

Where G_{H2O} was water vapor conductance or eggshell conductance (mg/d per mmHg), M_{H2O} is the rate of water loss from egg (mg/d), and ΔP_{H2O} was the water vapor pressure difference across the shell (mmHg) obtained by the difference between P_{H2O} and P_O. P_{H2O} was water vapor pressure of the egg contents and P_O is water vapor pressure in the environment surrounding the outside of the egg. Temperature and relative humidity in the incubator and the barometric pressure in the room was recorded to determine P_{H2O} and P_O.

Broiler Progeny Management

The first broiler experiment was conducted between January and February of 2009 and chickens were reared at Chicken Educational Unit at the Lake Wheeler Road Field Laboratory. Eggs were collected during an 8-d period from 32-wk-old broiler breeders. They were stored at 15.0^{o}C (64.4^{o}F) and 65% RH for 5 days. Eggs were set into two Natureform Model NOM-45 incubators (Natureform International, Jacksonville, FL 32218). The incubator was initially operated at 37.8^{o}C (100.5^{o}F). After 3 d of incubation, the temperature was decreased to 37.5^{o}C (99.5^{o}F). At 19 d of incubation, eggs were transferred from the setter trays to individual plastic hatching bags and returned to their respective machines. At 21 d of incubation chickens were removed from the trays, sexed, and identified with neck tags. Male and female broilers were identified by different color neck tags. Then, chickens from the same strain and maternal diet type were clustered into four broiler groups. Each broiler group was equally distributed among 8 floor pens. Maternal feeding program and breeder feeder space availability effects were represented in each of the 8 replicate pens, and tracked by individual chicken. Each litter pen had two tube-type feeders and one bell-type drinker to provide feed and water for *ad libitum* consumption. During the first 5 d there was also a gallon chick drinker used for supplemental water and two plastic trays used for supplemental feed. Chicks were fed either the same corn or wheat based diets had been their parents. Broiler diet composition is shown in Table IV-1. Both corn and wheat based diets were formulated on a digestible amino acid basis to have similar nutrient composition. Starter diets were fed as crumbles, and grower and finisher diets were fed as pellets.

The second broiler experiment was conducted between April and May of 2009 and chickens were reared in the same broiler house as in the first experiment. Eggs were collected during an 8-d period from 44-wk-old broiler breeder hens. Eggs were stored, incubated, and hatched in the same facility and under identical conditions as for experiment 1. At 21 days of incubation chickens were removed from plastic hatching bags, sexed, and identified with neck tags. Male and female broilers were identified by different color neck tags. Then, chickens from the same strain, maternal diet type, and sex were clustered into four broiler groups. Each broiler group was equally distributed among 4 floor pens. Maternal feeding program and breeder feeder space availability effects were represented in each one of the 4 replicate pens, and tracked by individual chickens. The equipment distribution and husbandry was equivalent to Experiment 1. Chicks were fed either the same corn or wheat based diets as were their parents in the same feed form as in Experiment 1. Also, diets were formulated on a digestible amino acid basis similar to diets in Experiment 1, but there were minor differences in crude protein of the starter and grower broiler diets (Table IV-2).

For both broiler experiments, all chickens from each broiler group were weighed at placement and again at 14, 35, and 48 d of age. Individual BW was recorded from 10 broilers of each of the sixteen treatments at 49 d to confirm group BW and to examine effects of maternal feeding program and breeder feeder space availability.

Leg Health Evaluation

At 4 and 6 wk of age, chickens were visually inspected for crooked toes, twisted legs, as well as, valgus, and varus deformities. Angular deformities were reported by combining valgus with varus malaligments because of the low prevalence of varus in both broiler flocks. Walking ability was evaluated following the six-point gait-scoring system of Kestin et al. (1992) ranging from completely normal (score 0) to immobile (score 5). To simplify discussion of results, we extrapolated our data to the three-point gait-scoring system defined by Webster et al. (2008) due to a strong correspondence found between these two systems found by the same author. The gait scores (GS) from the three-point system were:

GS 0: Birds can walk at least 1.5 m with a balanced gait. Birds may appear ungainly but with little effect on function.

GS 1: Birds can walk at least 1.5 m but with a clear limp or decidedly awkward gait.

GS 2: Birds will not walk 1.5 m May shuffle on shanks or hocks with assistance of wings.

At 49 d, a random sample of 10 male broilers from each treatment was killed by cervical dislocation. Legs were dissected into drums, thighs, and shanks. Muscles were removed and bones were cleaned and weighed to the nearest 0.001 g. Length from each leg bone was measured in mm with an electronic caliper (ProMax Fred V. Fowler Co., Inc. 66 Rowe Street Newton, MA 02466). Shank length was measured between the bottom of the foot pad and the top of the bent hock joint, whereas shank width was measured from side to side below the dew claw. Afterwards, bones were wrapped with cheese cloth to prevent moisture loss. Bone mineral density (BMD) and bone mineral content (BMC) were determined by Dual energy X-ray absorptiometry (Prodigy, G. E. Lunar, Madison, WI). Relative asymmetry (RA) of bone morphological traits, BMD, and BMC was defined as indicated by Møller et al. (1999):

$RA = (|R-L|/[R+L]/2) \times 100$; Where: R= right traits, and L = left traits

Statistical Analyses

A completely randomized design with 262 hens assigned to the 2 x 2 x 2 x 2 treatment combinations was used. Strain, diet type, maternal feeding program, and breeder feeder space availability were considered as main factors. To evaluate egg characteristics, only eggs from breeders that produced progeny reared in each of the two broiler experiments were included in the statistical analysis. This enabled us to associate egg trait response with probabilities of observing leg problems in broiler progeny. At hatch, chicks were randomly clustered into 4 broiler groups with the same diet type and genetic line in the broiler experiment 1. In the broiler experiment 2, there were 8 broiler groups clustered according to previous criteria plus broiler sex. There were 6 and 4 broiler pen replicates of each broiler group in experiments 1 and 2, respectively. Individual tags were used to track maternal feeding program and breeder feeder space availability effects. Pen was used as experimental unit for statistical analysis of broiler live performance.

A linear mixed effects model with fixed factorial effects of diet type, maternal feeding program, breeder feeder space change, and all interactions were used for leg health, bone morphology, BMD, and BMC variables. Broilers representing each pen were used as experimental units, and pen was included as random effect and nested within treatment combinations. BW was used as a covariate for statistical analysis of all bone measures (Jepsen et al., 2003; Schreiweis et al., 2004; Talaty et al., 2010). Data was analyzed using JMP 8 (SAS Inst. Inc., Cary, NC) statistical analysis software. To analyze leg problem and gait score data, the generalized mixed linear models procedure, GLIMMIX (SAS Inst. Inc., Cary, NC) was utilized. Leg problem and locomotion ability were analyzed as binomial variables for broiler experiments 1 and 2. Considering that results were very similar between the two broiler experiments, broiler progeny data were combined using breeder age and broiler sex as explanatory variables. Log odds of an event were modeled within diet type, maternal feeding program, feeder space availability, genetic line, and treatment combinations to obtain the probability of observing each leg problem or gait score. Female broiler breeder identification was used as random effect to correct for variable number of broiler chickens ranging from 1 to 7 produced by each hen in each experiment. All percentage data were transformed to Arc sine prior to analyses. All pairwise comparisons among means were conducted using Tukey's studentized range test at an experimentwise type I error rate of $\alpha = 0.05$.

Statistical model:

$$\log(\pi_{ijklmn}/(1-\pi_{ijklmn})) = \mu + \alpha_i + \beta_j + \delta_k + \gamma_l + (\alpha\beta)_{ij} + (\alpha\delta)_{ik} + (\alpha\gamma)_{il} + (\beta\delta)_{jk} + (\beta\gamma)_{jl} + (\delta\gamma)_{kl} + (\alpha\beta\delta)_{ijk} + (\alpha\beta\gamma)_{ijl} + (\alpha\delta\gamma)_{ikl} + (\beta\delta\gamma)_{klj} + (\alpha\beta\delta\gamma)_{ijkl} + \lambda_n + \lambda_{l(ijklm)} + \tau_a + \omega_s + \varepsilon_{ijklmn}$$

Where:

$\log(\pi_{ijklmn}/(1-\pi_{ijklmn}))$: log odds of observing leg problems

μ : overall mean

α_i : Effect of i_{th} genetic line (l = 1, 2)

β_j : Effect of j^{th} diet type (i = 1, 2)

δ_k : Effect of k^{th} feeding program (j = 1, 2)

γ_l : Effect of l^{th} feeder space availability (k= 1, 2)

$\alpha\beta_{ij}$: Effect of the interaction between i^{th} strain and j^{th} diet type

$\alpha\delta_{ik}$: Effect of the interaction between i^{th} strain and k^{th} feeding program.

$\alpha\gamma_{il}$: Effect of the interaction between i^{th} strain and l^{th} feeder space availability.

$\beta\delta_{jk}$: Effect of the interaction between j^{th} diet type and k^{th} feeding program.

$\beta\gamma_{jl}$: Effect of the interaction between j^{th} diet type and l^{th} feeder space availability.

$\delta\gamma_{kl}$: Effect of the interaction between k^{th} feeding program and l^{th} feeder space availability

$\alpha\beta\delta_{ijk}$: Effect of the interaction among i^{th} strain j^{th} diet type, and k^{th} feeding program.

$\alpha\beta\gamma_{ijl}$: Effect of the interaction among i^{th} strain, j^{th} diet type, and l^{th} feeder space availability

$\alpha\delta\gamma_{ikl}$: Effect of the interaction among i^{th} strain, k^{th} feeding program, and l^{th} feeder space availability

$\beta\delta\gamma_{jkl}$: Effect of the interaction among j^{th} diet type, k^{th} feeding program, and l^{th} feeder space availability

$\alpha\beta\delta\gamma_{ijkl}$: Effect of the interaction among i[th] strain, j[th] diet type, k[th] feeding program, and l[th] feeder space availability

$\lambda_{l(ijklm)}$: Random effect of broiler pen nested within treatment combinations ijk (l = effect of broiler pen, m= effect of each broiler chicken)

λ_{n}: Random effect of female broiler breeder identification

τ_a : Effect of broiler breeder age

ω_s: Effect of broiler sex

ε_{ijklmn} : The experimental error associated to each observation.

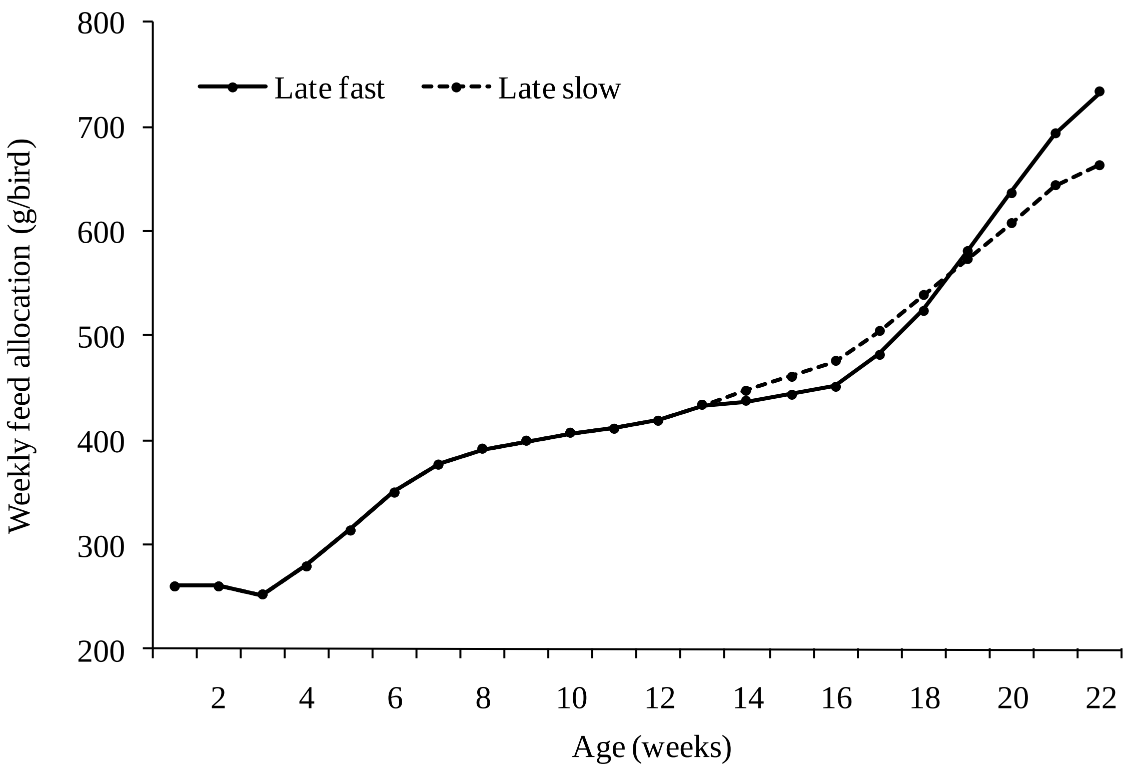


Figure V-1. Weekly feed allocation (g/bird) from placement to photostimulation (22 wk). The cumulative nutrition until photostimulation was 26,397 Kcal of ME and 1,476 g of crude protein (CP) for the late fast feeding program, and 26,209 Kcal of ME and 1,465 g of CP for the late slow feeding program. Differences between the slow and fast feeding programs were 181 Kcal of ME and 15 g of CP to provide virtually the same cumulative nutrition to 22 wk when birds were photostimulated. After photostimulation, all breeders were allocated to a standard feeding program.

RESULTS

Egg Characteristics

At 31 wk, no significant ($P > 0.05$) differences due to treatments were observed for egg shape index, % shell, % albumen, and % yolk, and Y:A ratio. No interaction ($P > 0.05$) effects were detected for egg weight or egg surface area at 31 wk. Eggs from breeders fed corn based diets were heavier ($P < 0.01$) and had greater surface area ($P < 0.01$) than those from hens fed wheat based diets (Table V-1) An interaction effect between strain and diet type on albumen height indicated that strain A breeders laid eggs with thicker ($P < 0.01$) albumen than strain B breeders only when they were fed wheat based diets at 31 wk. At 47 wk, there were no significant ($P > 0.05$) effects on egg weight, egg surface area, percentage yolk and albumen, and Y:A ratio. No interaction ($P > 0.05$) effects were observed for any egg characteristics evaluated at 47 wk. Eggs from broiler breeders fed corn based diets were more rounded ($P < 0.05$) than those from breeders fed wheat based diets. Eggs from strain B breeders had thinner ($P < 0.05$) albumen than eggs from strain A.

Eggshell analyses were also performed at 47 wk (Table V-2). There were no interaction ($P > 0.05$) effects on percentage eggshell and eggshell membrane thickness at 47 wk. Strain A eggs had heavier ($P < 0.0001$) eggshells and thicker ($P < 0.0001$) eggshell membranes compared to strain B eggs. In addition, broilers fed corn based diets laid eggs with thicker ($P < 0.05$) eggshell membrane compared to those fed wheat based diets. There was an interaction effect of diet type, feeding program, and feeder space availability on eggshell thickness. Eggs laid by breeders given more feeder space availability (1 hen/cage) were thinner ($P < 0.05$) than eggs from breeders provided with less feeder space availability (2 hens/cage) only when breeders were fed wheat based diets following the LS feeding program. For eggshell porosity, there was an interaction effect of diet type and feeder space availability indicating that breeders fed corn based diets and given more feeder space availability (1 hen/cage) laid eggs with the highest ($P < 0.01$) number of pores compared to all other combinations. Additionally, an interaction effect between strain and feeding program indicated that strain B broiler breeders fed according to the LS feeding program had the highest ($P < 0.0001$) eggshell conductance. The interaction between diet type and feeder space availability indicated that breeders fed corn based diets and given more feeder space availability had higher ($P < 0.05$) eggshell conductance compared to those fed wheat based diets provided with the same feeder space allotment.

Group BW and Individual BW at 49 d of age

Group BW was recorded from each pen to evaluate strain, diet type, and interaction between these factors during both broiler experiments. No significant ($P > 0.05$) interactions were observed for any variable except for BW gain between 36 and 48 d in the first broiler experiment. The interaction ($P < 0.01$) between strain and diet type indicated that the feeding of corn based diets to strain A broilers increased BW gain compared to both corn or wheat based diets for strain B broilers, but it was not different from the feeding of wheat based diets to strain A broilers. In the first broiler experiment, strain A broilers gained more ($P < 0.01$) BW in the entire grow out than strain B broilers (Table V-3). No differences ($P > 0.05$) were observed for diet type on initial BW or BW gain at any feeding period. In the second broiler experiment, strain B broilers gained less BW ($P < 0.01$) than strain A chickens between 1 and 14 d and 15 to 35 d; however, this difference was not detectable for the BW gain to 48 d. Broilers fed corn based diets had higher BW gain than those fed wheat based diets between 15 and 35 d ($P < 0.01$) and 36 to 48 d ($P < 0.05$).

The progeny from 32-wk-old breeders (Experiment 1) were heavier in the A strain ($P < 0.05$) than in the B strain (3,828 vs. 3,744 g) at 49 d. An interaction effect of diet type, maternal feeding program for BW of broilers at 49 d ($P < 0.01$) is shown in Figure V-2. Broiler progeny from 32-wk old broiler breeders provided with less feeder space availability (2 hens/cage) weighed less than those from breeders given more feeder space availability (1 hen/cage) only when broilers and breeders were fed corn based diets and breeders were restricted to the LS feeding program. In the progeny from 44-wk-old breeders, broilers from LS feeding program were smaller ($P < 0.05$) than chickens from the LF program (3,509 vs. 3,606 g). No significant ($P > 0.05$) effects of strain, diet type, and feeder space availability were detected for 49-d BW of progeny from 44-wk-old broiler breeders.

Leg Problems and Walking Ability of Broiler Progeny

Broiler progeny were individually inspected to evaluate leg problems and gait scores at 28 and 42 d of age in both broiler experiments. As similar results were observed in both experiments, progeny from 32 and 44-wk-old breeders were combined using breeder age and broiler sex as predictable variables. There was an interaction effect ($P < 0.01$) between strain and maternal feeding program for the probability of observing crooked toes in 4-wk-old broiler progeny (Figure V-3). The use of maternal LF feeding program increased the chances of producing crooked toes in strain B broiler progeny as compared to the maternal LS feeding program in strain B and strain A chickens, whereas it was not different from the use of LF feeding program in strain A broilers. An interaction effect of strain, diet type, and maternal feeder space availability was detected ($P < 0.05$) for the probability of observing crooked toes in broiler progeny at both evaluations (Figure V-4). Strain B broilers whose parents were given less feeder space availability (2 hens/cage) were more likely to have toe malformations with the use of wheat based diets compared to the utilization of corn based diets (0.07 vs. 0.02) at 28 d of age, whereas other combinations were intermediate. At 42 d, the utilization of corn in diets for strain B breeders and broilers coupled with the implementation of less breeder feeder space availability (2 hens/cage) reduced the probability of observing chickens with toe malformations compared to the use of wheat in diets for strain B breeders and broilers along with the provision of less maternal feeder space availability, and to the use of corn diets for strain A breeders and broilers independently of the maternal feeder space availability allotment.

No significant ($P > 0.05$) effects of treatments were detectable for twisted legs at any evaluation. Angular deformations were not ($P > 0.05$) affected by any treatment at 28 d of age.

At 42 d of age, severe angular deformations were significantly (*P* < 0.0001) influenced by the interaction effects of strain, maternal feeding program, and breeder feeder space availability (Figure V-5). Strain B broilers whose parents were restricted with the LS feeding program and given more feeder space availability (1 hen/cage) were less likely to suffer severe angular deformations compared to strain B chickens whose parents were allocated to the LF program and given more feeder space availability (1 hen/cage), and to strain A broilers whose parents were fed following the LS program and given more feeder space availability (1 hen/cage), as well as, strain A broilers whose parents were allocated to LF program regardless of feeder space availability. In addition, strain A broilers whose parents were restricted to a LF program regardless of feeder space availability along with strain A broilers whose parents were allocated only to the LS program and given more feeder space availability (1 hen/cage) had higher a probability of displaying severe angular deformities compared to all strain B broilers, except for strain B broilers from hens that had used the LF program and were provided with more feeder space availability (1 hen/cage).

No significant effects of strain, diet type, and maternal effects were observed for gait score 2 at any broiler progeny leg inspection. Thus, walking impairment reported in this current study includes only gait score 1. In the leg inspection at 28 d of age, broiler breeders given less feeder space availability (2 hens/cage) produced broilers that were less (*P* < 0.05) likely to have locomotion problems compared to progeny from hens provided with more feeder space availability (0.04 vs. 0.07), only when corn based diets were fed to breeder and broilers (Figure V-6). Additionally, strain A broilers were twice as likely (*P* < 0.0001) of exhibiting walking impairment than strain B broilers (0.08 vs. 0.04) at 4 wk of age. At 6 wk, feeding wheat based diets along with the implementation of more feeder space availability (1 hen/cage) in the B strain produced a lower (*P* < 0.01) probability of exhibiting locomotion issues than the A strain independently of diet type and maternal feeder space availability, and feeding corn based diets coupled with the implementation of more feeder space availability (1 hen/cage) in the B strain (Figure V-7). In addition, the maternal LS feeding program along with the provision of more feeder space availability (1 hen/cage) in the B strain improved (*P* < 0.001) walking ability of progeny compared to A strain broilers regardless of maternal feeding program and feeder space availability, and to the use of the maternal LF feeding program along with the implementation of more feeder space availability in the B strain (Figure V-8).

Table V-1. Main effects of strain, diet, feeding program, and cage space on egg characteristics of 31 and 47-wk-old broiler breeders

Egg traits	Age (wk)	Strain[1]		Diet[2]		Feeding program[3]		Hens/cage[4]		CV %
		A	B	Corn	Wheat	Late fast	Late Slow	1	2	
Egg weight, g										
	31	58.47	58.04	58.92[a]	57.59[b]	58.19	58.32	58.29	58.22	5.91
	47	69.40	68.88	69.07	69.21	69.42	68.87	68.84	69.44	5.82
Shape index										
	31	77.73	77.56	77.61	77.68	77.73	77.56	77.58	77.71	3.65
	47	75.97	75.80	76.24[a]	75.54[b]	75.96	75.82	75.94	75.83	3.11
Albumen height, mm										
	31	8.19	8.07	8.12	8.13	8.17	8.09	8.07	8.18	12.71
	47	8.03[a]	7.72[b]	7.88	7.86	7.89	7.86	7.81	7.94	12.85
Albumen, %[5]										
	31	63.41	63.14	63.45	63.10	63.19	63.36	63.23	63.32	3.00
	47	59.64	59.47	59.60	59.51	59.53	59.57	59.48	59.63	3.39
Yolk, %[5]										
	31	27.55	27.90	27.54	27.90	27.77	27.68	27.87	27.58	8.81
	47	31.59	31.99	31.71	31.87	31.83	31.75	31.98	31.60	9.41
Yolk:Albumen ratio										
	31	0.435	0.443	0.434	0.443	0.441	0.437	0.441	0.437	6.02
	47	0.530	0.539	0.533	0.536	0.536	0.534	0.538	0.531	6.05

[a-b] Means within a column without a common superscript differ significantly ($P < 0.05$).
[1] Strain A vs. strain B broiler breeders. [2] Broiler breeders received either corn or wheat based diets throughout their life (Table II-1). [3] Feed was allocated following either a late fast or late slow feeding program from 14 to 28 wk of age (Figure V-1). [4] At photostimulation (22 wk), broiler breeders were transferred to cages containing 1 or 2 hens per cage. [5] Weight of egg components relative to entire egg weight.

Table V-2. Main effects of strain, diet type, feeding program, and feeder space availability on eggshell properties

Items[1]	Eggshell (%)	Eggshell thickness (mm)	Eggshell membrane thickness (mm)	Eggshell porosity (Number/cm^2)	Eggshell conductance (mg of H_2O/mmHg)
Strain[2]					
A	8.88[a]	0.351	0.094[a]	110	16.5[b]
B	8.54[b]	0.354	0.083[b]	113	17.2[a]
Diet type[3]					
Corn	8.73	0.351	0.092[a]	116[a]	16.9
Wheat	8.69	0.354	0.086[b]	106[b]	16.8
Feeding program[4]					
Late fast	8.67	0.351	0.087	109	16.8
Late slow	8.74	0.353	0.091	114	16.9
Hens/cage[5]					
1	8.60[b]	0.344[b]	0.091	113	16.8
2	8.82[a]	0.360[a]	0.087	110	16.9
CV (%)	7.1	7.0	11.8	11.9	17.7

[a-b] Means within a column without a common superscript differ significantly ($P < 0.05$).

[1] Eggs from 47-wk-old broiler breeders were evaluated for all eggshell properties except for eggshell conductance which was examined in 46-wk-old broiler breeders. [2] Strain A vs. strain B broiler breeders. [3] Broiler breeders received either corn or wheat based diets throughout their life (Table II-1). [4] Feed was allocated following either a late fast or late slow feeding program from 14 to 28 wk of age (Figure V-1). [5] At photostimulation (22 wk), broiler breeders were transferred to cages containing 1 or 2 hens per cage.

Bone Traits and Bone Mineral Density

Broiler Progeny from Breeders at 32 wk of age. Relative weights and lengths of each leg bone were measured in 49-d old broiler progeny. No significant ($P > 0.05$) differences caused by any maternal effects or diet type were observed for percentage tibia and femur length of progeny. The utilization of corn in breeder and broiler diets increased ($P < 0.01$) shank length (102 vs. 100 mm) compared to the consumption of wheat based diets. There was an interaction effect ($P < 0.05$) between diet type and strain on the relative weight of tibia, tibia length, and shank width of progeny (Table V-4). The inclusion of corn as major grain source in diets fed to strain A breeders and broilers resulted in progeny with heavier ($P < 0.01$) and thicker ($P < 0.05$) shanks, and longer ($P < 0.05$) tibias compared to the utilization of wheat based diets, whereas no differences were observed for strain B chickens. Only strain A broilers whose parents were fed according to the LF feeding program had heavier ($P < 0.001$) femurs compared to strain A chickens from hens fed following the LS feeding program (0.64 vs. 0.57 %). Breeder feeder space availability did not ($P > 0.05$) influence any bone morphological trait.

Relative asymmetry of each bilateral bone trait was calculated. There were no significant ($P > 0.05$) effects of any maternal treatment on RA of tibia weight, femur, tibia, and shank lengths, and width shank. An interaction ($P < 0.01$) effect of maternal feeding program and breeder feeder space availability were detected for RA of femur weight.

Table V-3. Main effects of stain and diet type on BW of broiler progeny groups

Main Factors	Levels	BW 1d	Body weight gain 1-14 d	Body weight gain 15-35 d	Body weight gain 36 - 48d	Body weight gain 1 - 48 d
		------------------------------ (g)	------------------------------			
Broiler experiment 1[1]						
Strain[3]						
	A	38.1[b]	425[a]	1752[a]	1093[b]	3275[a]
	B	38.9[a]	401[b]	1673[b]	1133[a]	3209[b]
Diet[4]						
	Corn	38.6	410	1719	1116	3244
	Wheat	38.4	416	1706	1110	3240
Pooled SEM		0.22	2.2	8.1	8.2	15.2
Broiler experiment 2[2]						
Strain[3]						
	A	45.1	451[a]	1665[a]	947[b]	3062
	B	45.2	434[b]	1607[b]	1005[a]	3035
Diet[4]						
	Corn	45.3	439	1666[a]	1000[a]	3094[a]
	Wheat	45.0	445	1606[b]	952[b]	3004[b]
Pooled SEM		0.17	4.0	12.8	15.4	22.1

[a-b] Means within a column without a common superscript differ significantly ($P < 0.05$).
[1] Broiler progeny from 32-wk-old broiler breeders. Data are means of 8 replicates considering broiler sex as covariate. [2] Broiler progeny from 44-wk-old broiler breeders. Data are means of 12 replicates considering broiler sex as covariate. [3] Strain A vs. strain B broiler breeders. [4] Broiler breeders received either corn or wheat based diets throughout their life (Table II-1).

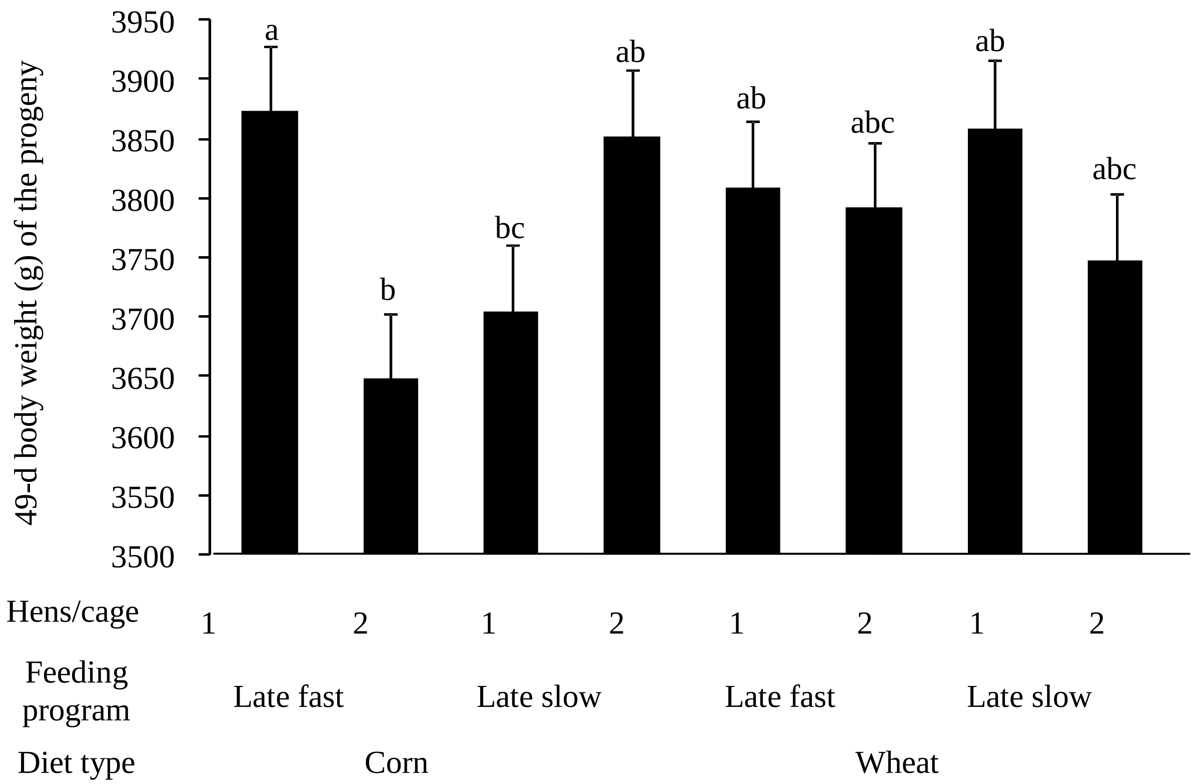


Figure V-2. Interaction effects among diet type, feeding program, and feeder space availability (hens/cage) on 49-d BW of broilers from 32-wk-old breeders. Bars represent SEM. Means without a common superscript differ significantly ($P < 0.05$).

Progeny from breeders fed according to the LS feeding program produced broiler progeny that had more asymmetric (4.4 vs. 2.6) femurs in terms of relative weight compared to chickens from hens restricted to the LF feeding program only when breeders were given less feeder space availability (2 hens/cage). Another interaction ($P < 0.05$) effect of maternal feeding program and breeder feeder space availability was observed for RA of progeny shank weight. The use of LS feeding program along with the implementation of more feeder space availability (1 hen/cage) originated broiler progeny that had lower RA (1.5 vs. 2.5) of shank weights compared to the use of less feeder space availability (2 hens/cage), whereas no differences were observed for breeders fed according to the LF feeding program.

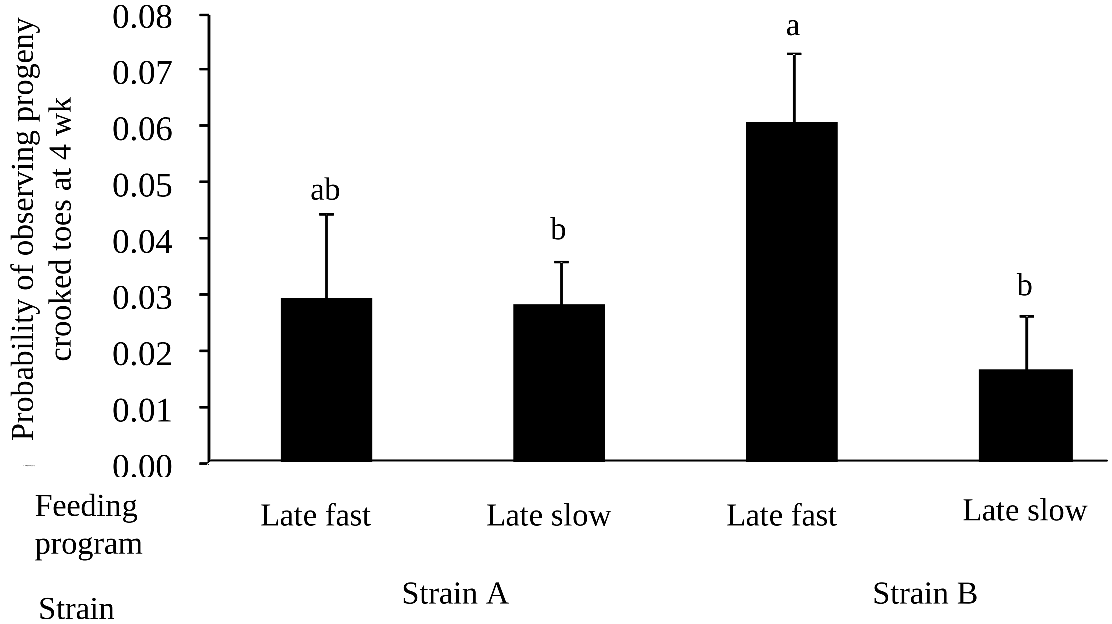


Figure V-3. Interaction effects between strain and feeding program on probability of observing crooked toes at 28 d of age. Bars represent SEM. Means without a common superscript differ significantly ($P < 0.05$).

In addition, the interaction between strain and feeder space availability indicated that the implementation of less feeder space availability (2 hen/cage) worsened ($P < 0.05$) RA of shank weights compared to the use of more feeder space availability (1 hen/cage) only on strain A broilers (2.6 vs. 1.5), but not in strain B broilers. Diet type did not significantly influence ($P > 0.05$) the RA of bone morphological traits.

The BMD and BMC were determined for each leg bone of 49-d broiler progeny. No significant ($P > 0.05$) interaction effects were detected for any BMD and BMC. No significant ($P > 0.05$) effects of treatments were observed for femur BMC. The broiler and breeder consumption of corn based diets increased shank BMD 2% ($P < 0.05$) and shank BMC 5% ($P < 0.01$) of progeny compared to the utilization of wheat based diets. There was a consistent effect of breeder space availability on progeny BMD for tibia, femur, and shank bones (Figure V-9).

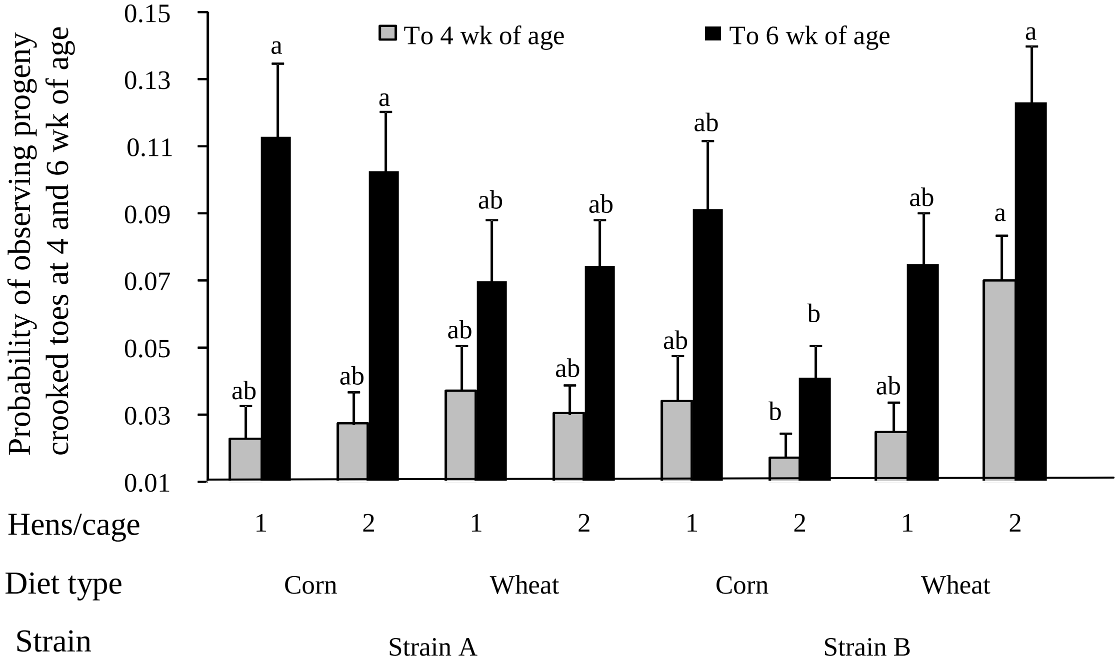


Figure V-4. Interaction effects of strain, diet type, and feeder space availability on probability of observing crooked toes at 4 wk. Bars represent SEM. Means without a common superscript differ significantly ($P < 0.05$).

Progeny BMD were higher when breeders were given more feeder space availability (1 hen/cage) compared to less feeder space availability in cages containing 2 hens. Additionally, tibia BMD of progeny was increased ($P < 0.05$) by 3 % when breeders were provided with more feeder space availability (1 hen/cage). Strain and maternal feeding program did not ($P > 0.05$) affect BMD and BMC in progeny from breeders at 32 wk of age. Differences between left and right BMD and BMC of each leg bone were calculated. No significant ($P > 0.05$) differences were observed for RA of shank BMD and femur BMC. The utilization of wheat in broiler and breeder diets aggravated ($P < 0.05$) RA of progeny femur BMD compared to the inclusion of corn based diets (3.2 vs. 2.4). The use of the LS maternal feeding program increased ($P < 0.05$) RA of progeny tibia BMC compared to the utilization of the LF feeding program.

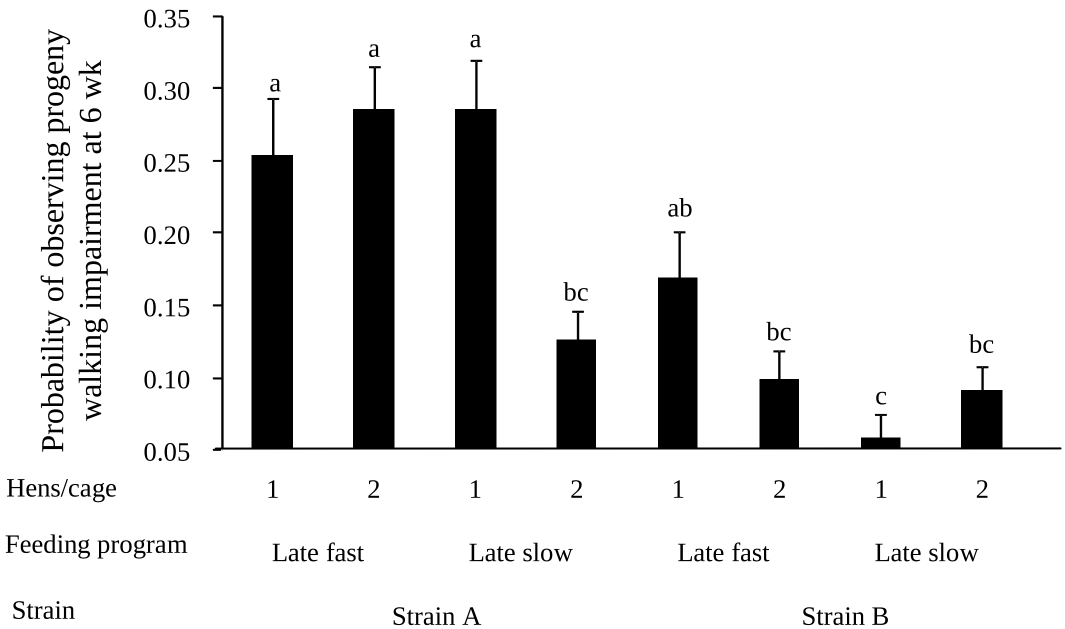


Figure V-5. Interaction effects of strain, feeding program and feeder space availability on probability of observing severe angular deformations at 42 d of age. Bars represent SEM. Means without a common superscript differ significantly ($P < 0.05$).

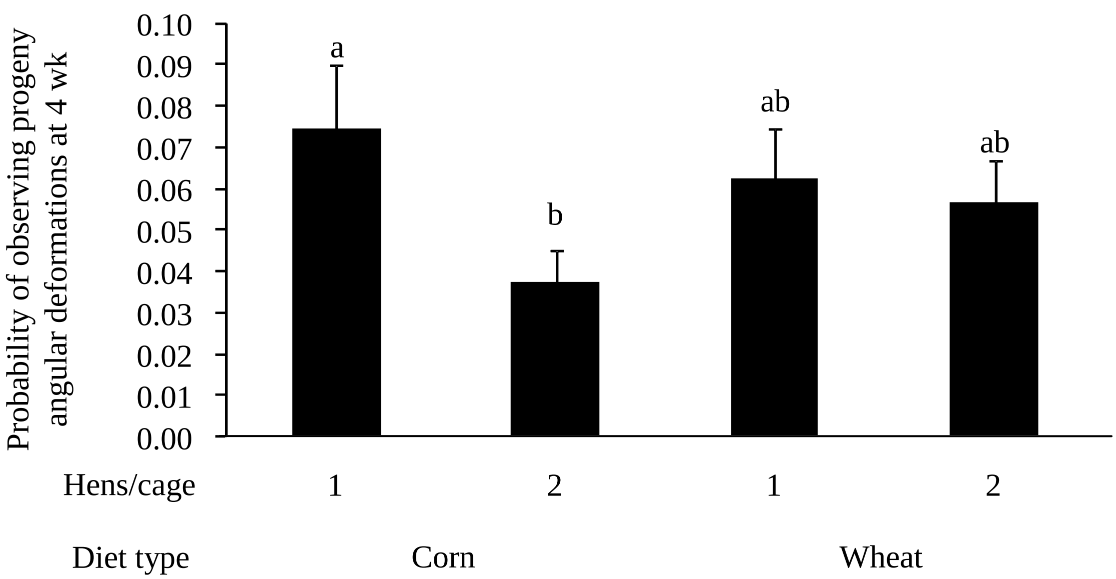


Figure V-6. Interaction effects of strain, feeding program and feeder space availability on probability of observing overall and severe angular deformations of 28 d-old broiler progeny. Bars represent SEM. Means without a common superscript differ significantly ($P < 0.05$).

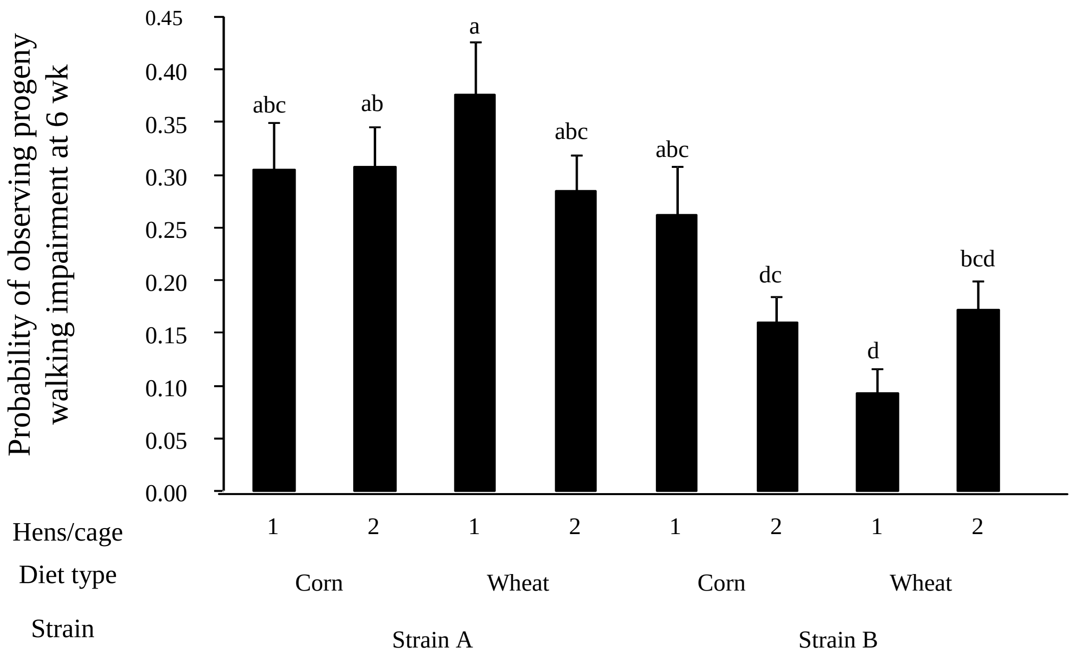


Figure V-7. Interaction effects of strain, diet type, and feeder space availability on probability of observing walking impairment in 6-wk broiler progeny. Bars represent SEM. Means without a common superscript differ significantly ($P < 0.05$).

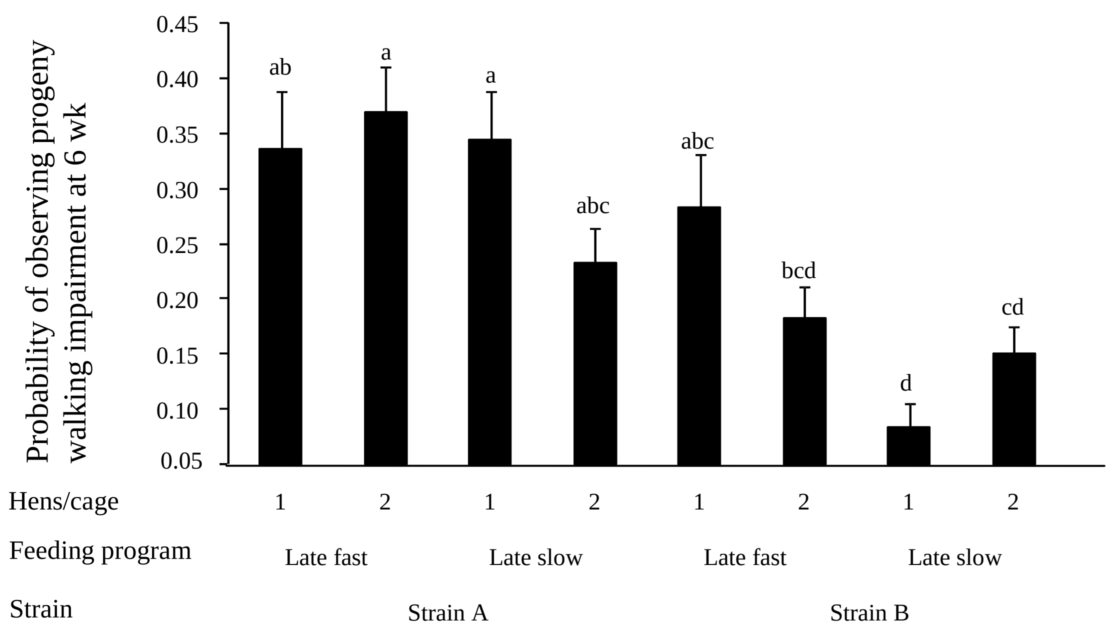


Figure V-8. Interaction effects of strain, feeding program, and feeder space availability on probability of observing walking impairment in 6-wk-old broiler progeny. Bars represent SEM. Means without a common superscript differ significantly ($P < 0.05$).

Table V-4. Interaction effect between strain and diet type for shank relative weight, shank width and tibia length of broiler progeny from 32-wk-old broiler breeders

Strain	Diet	Shank		Tibia
		Relative weight (%)	Width (mm)	Length (mm)
A	Corn	1.64[a]	16.3[a]	118.9[a]
	Wheat	1.53[c]	15.5[b]	116.6[b]
B	Corn	1.59[ab]	15.7[ab]	117.7[ab]
	Wheat	1.56[bc]	15.7[ab]	118.2[ab]
Pooled SEM		0.02	0.17	0.58

[a-b] Means within a column without a common superscript differ significantly ($P < 0.05$).

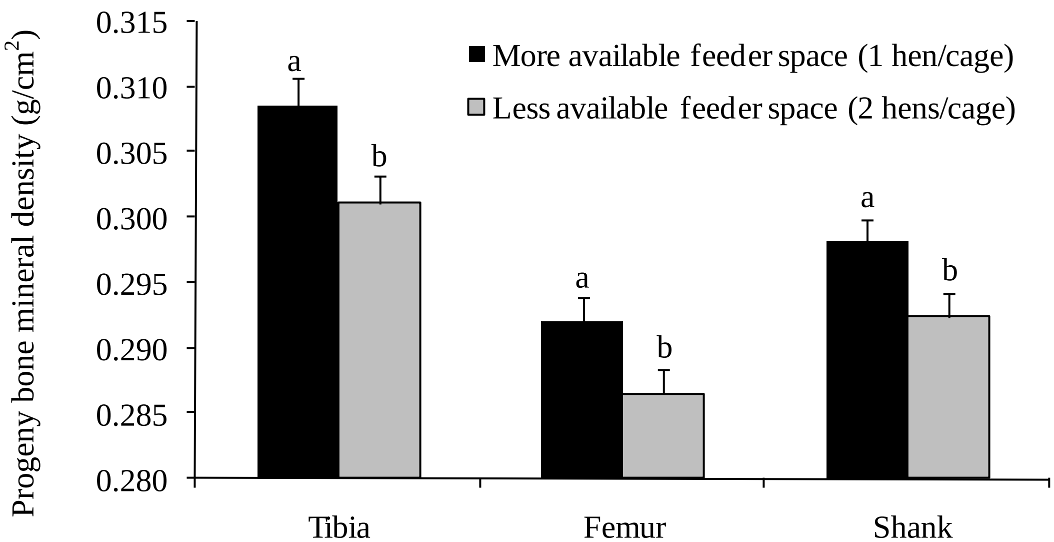
The interaction ($P < 0.01$) effect of strain and feeding program indicated that breeders fed according to the LS feeding program caused higher RA (3.0 vs. 1.9) of tibia BMD in the progeny compared to hens fed following the LF feeding program only in strain B chickens, but not in strain A broilers.

In addition, an interaction ($P < 0.05$) effect of strain, diet type, and maternal feeder space availability was detected for RA of shank BMC. Higher RA of shank BMC was observed in strain A broiler progeny from breeders given less feeder space availability (2 hens/cage) using wheat based diets compared to strain B chickens from breeders provided with more feeder space availability (1 hen/cage) using corn based diets (6.6 vs. 3.0), whereas no significant differences were detected among the other treatment combinations.

Broiler Progeny from Breeders at 44 wk of age. Similar bone morphological traits, BMD, and BMC were observed in progeny at 44 wk than in progeny at 32 wk of age. No significant ($P > 0.05$) effects were observed for shank width. Strain A broilers exhibited higher ($P < 0.05$) shank relative weights compared to strain B broilers (1.64 vs. 1.61 %). Additionally, the intake of corn in breeder and broiler diets increased ($P < 0.001$) progeny shank length (101 vs. 99 mm) and relative weights (1.65 vs. 1.60%) as well as tibia length (117 vs. 115 mm) and relative weights (0.87 vs. 0.84%) compared to feeding wheat based diets. An interaction effect ($P < 0.01$)

was observed for femur length indicating that consumption of corn based diets incremented progeny femur length (84 vs. 80 mm) compared to wheat based diets only when female parent flock was given less feeder space availability (2 hens/cage). There was an interaction effect (*P* < 0.05) of the four main factors for relative weights of progeny femur.

Strain B breeders fed corn based diets following the LF feeding program and given more feeder space availability (1 hen/cage) produced broiler progeny that had heavier femurs (0.60 vs. 0.54%) than chickens from strain A breeders fed wheat based diets following the same feeding program and provided with less feeder space availability (2 hens/cage), whereas no differences were observed for other treatment combinations.



FigureV-9. Effect of maternal feeder space availability on tibia, femur, and shank BMD of 49-d broiler progeny from 32-wk-old broiler breeders. Bars represent SEM. Means without a common superscript differ significantly (*P* < 0.05).

No significant (*P* > 0.05) effects were detected for RA of femur and tibia weights, and shank length. Strain A broilers had exacerbated (*P* < 0.01) RA of shank weight compared to strain B broilers (2.09 vs. 1.45). However, the interaction effect between strain and maternal feeder space availability indicated that strain B broilers had worsened (P < 0.05) symmetry of femur length compared to strain A chickens only when breeders were given less feeder space availability (1.34 vs. 0.81). The use of maternal LS feeding program improved (P < 0.01) RA of progeny tibia length compared to the use of maternal LF feeding program (0.72 vs. 1.24) only strain B broilers. However, the interaction between diet type and maternal feeding program indicated that the use of the LS program worsened (P < 0.05) RA of progeny femur length compared the use of LS program only when wheat based diets were used for breeder and broilers (1.36 vs. 0.80).

No significant interaction (P > 0.05) effects were detected for the BMC of any leg bone. The main effects of strain and diet type on BMC of all leg bones evaluated in the current study are shown in Figure V-10. At 49 d, strain A broilers had higher BMC in shanks (P < 0.01) and tibias (P < 0.0001) than strain B chickens, whereas no significant (P > 0.05) differences were observed for femur BMC. On the other hand, the utilization of corn based diets in broiler and breeder diets increased (P < 0.001) progeny BMC in all leg bones compared to the use of wheat based diets.

The interaction between strain and breeder feeder space availability indicated that strain A broilers had higher (P < 0.05) shank BMD than strain B broilers (0.291 vs. 0.275 g/cm^2) only when they were produced by breeders given less feeder space availability (2 hens/cage). The interaction between strain and maternal feeding program demonstrated that strain A tibias had more (P < 0.05) BMD than strain B tibias only when they came from breeders fed according to LS feeding program, whereas no differences were observed in progeny fed following LF feeding program. The implementation of more feeder space availability (1 hen/cage) increased (P < 0.01) femur progeny BMD (0.284 vs. 0.280 g/cm^2) compared to the provision of less available breeder feeder space (2 hens/cage).

No significant (P > 0.05) interactions were detected for RA of BMD and BMC of progeny shanks and tibias. Strain A tibias had higher RA of BMD and BMC compared to strain B tibias. On the other hand, the implementation of more maternal feeder space availability at photostimulation increased (P < 0.05) RA of BMC (P < 0.05; 5.7 vs. 4.5) and BMD (P < 0.01; 3.5 vs. 2.7) of progeny shanks. No significant effects (P > 0.05) were observed in regards to diet type and maternal feeding program on progeny RA of BMD and BMC.

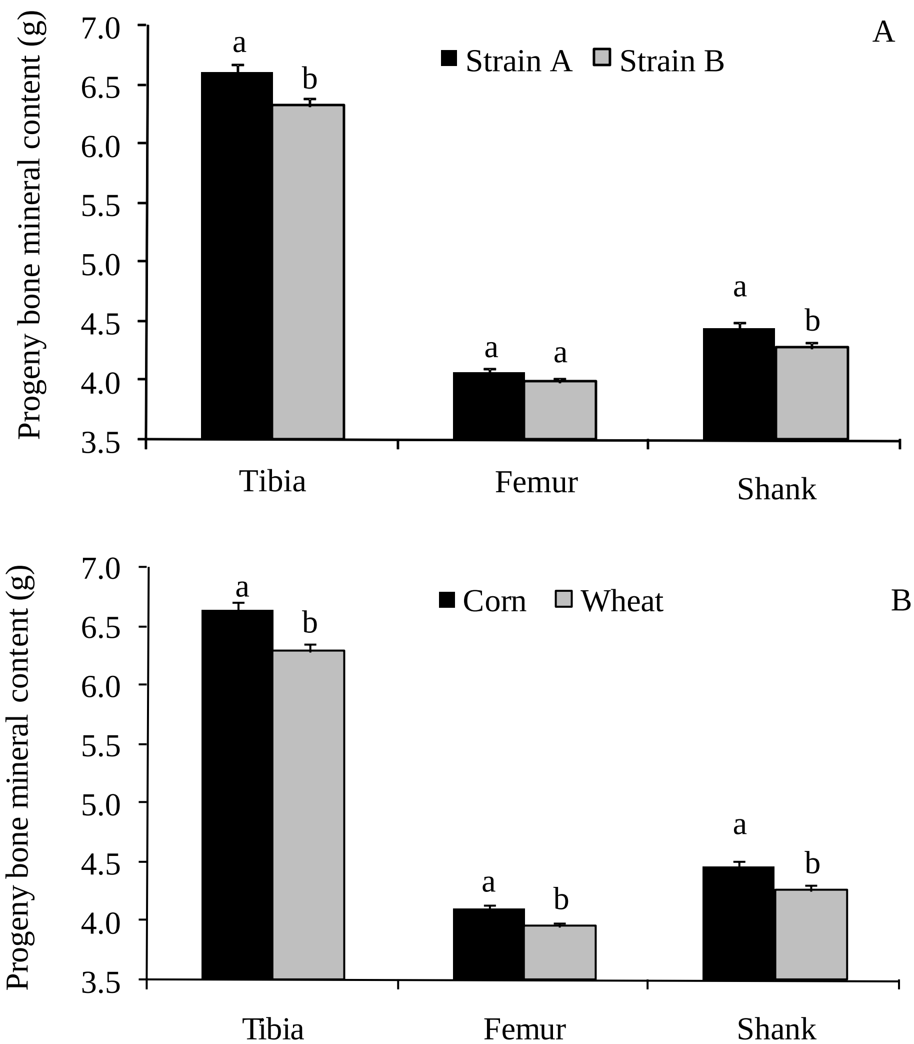


Figure V-10. Main effects of strain (A) and diet type (B) on tibia, femur, and shank mineral content of 49-d broiler progeny from 44-wk-old broiler breeders. Bars represent SEM. Means without a common superscript differ significantly (P < 0.05).

DISCUSSION

The purpose of this study was to evaluate the effects of maternal feeding programs and breeder feeder space availability on broiler progeny leg health of two major genetic lines in combination with the utilization of corn or wheat based diets. It was hypothesized that strain, diet type, and the previously mentioned maternal factors or the interactions among them would modify egg characteristics that eventually would impact embryogenesis, bone development, and prevalence of broiler leg problem. In fact, these factors influenced to some degree egg traits and prevalence of leg disorders in the current study.

Egg Characteristics

Strain, feeding program, and feeder space availability did not influence egg weight at 31 and 47 wk of age. On the other hand, broiler breeders fed wheat based diets had smaller eggs than breeders given corn based diets at 31 wk of age, but not at 47 wk. Egg weight is highly correlated to chick weight at hatching (Pinchasov, 1991; Narushin and Romanov, 2002) and subsequent marketing broiler BW. In this experiment the consumption of corn or wheat based diets did not significantly affect 49-d old BW of broiler progeny. In addition, the utilization of wheat as a major source of energy in breeder and broiler diets seemed to improve egg shape by reducing the egg roundness which has been related to higher early embryonic mortality in quails (Khurshid et al., 2004). In contrast, other reports have shown that egg shape index was not correlated to hatchling weight (Poyraz, 1989), hatchability (Contreras, 2008), and quality of hatching eggs (Esen and Ozcelik, 2002). If there was any effect of egg shape on embryo development it could be due to more mistakes on the proper positing of eggs with the air chamber facing upwards.

No significant effects of any treatment were observed for relative weights of albumen and yolk, nor Y:A ratio. On the contrary, diet type consistently influenced these egg traits in breeders reared under the same conditions during the pullet-rearing phase and fed identical diet types as this study, but moved to a floor pen layer house at photostimulation (Chapter II). In the present experiment, breeders were placed in cages at photostimulation that allowed tracking individual breeder effects on breeders that produced broiler progeny in each experiment. Only the data from these breeders with progeny were used for statistical analyses in order to improve the interpretation of the effects of egg characteristics on this pedigree evaluation.

Strain A breeders laid eggs with thicker albumen at 31 wk of age when given wheat based diets, and at 47 wk regardless of diet type. A recent study conducted with strains A and B breeders from 25 to 60 wk of age with evaluations every 5 wk demonstrated that both strains laid eggs with similar yolk weights, but that strain A eggs had more albumen and slightly heavier shells (Fisher and Gous, 2009). Poggenpoel (1986) found that the heritability of albumen height was 0.48 in a strain of White Leghorns selected for egg production. Several investigations have shown that albumen height differed between strains (Toussant et al., 1995; Silversides and Scott, 2001). It has been reported that thicker albumen imposed a barrier to gas diffusion (Meuer and Baumann, 1988; Brake et al., 1993; Vick et al., 1993), that has been shown to be a limiting factor for tissue embryo development (Shafey, 2002). Moreover, Benton and Brake (1996) suggested that thicker albumen may limit nutrient availability to the embryo.

On the other hand, Peebles et al. (2000) found that Arbor Acres broiler breeders that laid eggs having greater albumen height also exhibited higher availability of total unsaturated versus saturated fatty acids, particularly linoleic acids in the yolk on the second day of incubation. It was suggested that this finding was associated with different depositional rates of certain yolk fatty acids in hens laying eggs of different albumen height rather than a consequence of the effects of albumen height on embryonic metabolism. Linoleic acid is a precursor of arachidonic acid, and consequently of a variety of oxygenated compounds, called eicosanoids, that have established biological actions in chickens including stimulation of myoblast, chondrocyte, and bone cell differentiation (Watkins, 1991). Specifically, prostaglandin E_2 (PGE_2) was reported to regulate chondrogenesis and stimulate bone formation in chick calvaria bone, and PGE_2 along with prostaglandin $F_{2\alpha}$ stimulated collagen synthesis in embryonic chick tibia (Chyun and Raisz, 1994). Thus, albumen height might be an indicator of other egg factors indirectly affecting bone development during incubation.

All breeder treatments evaluated somewhat influenced eggshell characteristics. Strain A eggs had heavier eggshells, as previously reported by Fisher and Gous (2009), and the eggshell membrane was thicker in comparison to strain B eggs. In the present experiment, eggshell membrane thickness seemed to be a major factor contributing to improvement of eggshell conductance, according to our results that showed that strain B breeders allocated to the LS feeding program had the highest eggshell conductance in comparison to all other combinations. Additionally, no significant differences were observed for eggshell thickness and porosity between the two broiler breeder strains. It was important that egg weights were equivalent between the two strains even though strain B breeder hens were slightly heavier (4-7%) than strain A breeder hens throughout the layer phase. In contrast, Hamidu et al. (2007) reported no differences in eggshell conductance between eggs of two commercial lines of broilers. In the current study, strain B broiler breeders were used. This line is genetically selected for slower initial growth rate and higher breast meat yield, while the other strains have been selected for faster early growth which meets broader marketing requirements.

The eggshell membrane functions to help to retain fluid of albumen and to resist bacterial invasion (Burley and Valdhra, 1989). Furthermore, it appears to enhance the permeability of eggs to oxygen during the late stages of incubation when demand for oxygen exceeds the diffusion capacity of the eggshell (Kayar et al. 1981). The oxygen permeability of the avian eggshell and shell membrane was initially low but increased about 10-fold after the first seven days of incubation (Lomholt, 2005). This increment correlated with a decline in water content and an increment of gas within eggshell membranes controlled by the colloid osmotic effect of the albumen early during incubation (Kutchai and Steen, 1971; Seymour and Pipper, 1988;

Brake et al., 1997). Therefore, the low albumen height, relative weight of eggshell, and eggshell membrane thickness observed in strain B eggs might interact to enhance eggshell conductance that indicated better gas exchange of O_2 and CO_2 between the embryo and surrounding environment of the egg.

Bone formation starts early during incubation and can be visible around 11 days of incubation (Johnston and Comar, 1955; Reddi and Anderson, 1976). A few days prior to hatch and first days post-hatch, bone growth rate is the highest (Applegate and Lilburn, 2002). Van Golde et al. (1998) showed that O_2 availability can be a limiting factor for embryo development even in the middle of incubation period. Moreover, other literature reports demonstrate that embryo development was better in the presence of more oxygen availability late in incubation (Stock and Metcalfe, 1984; Asson-Batres et al., 1989; Lourens et al., 2007). Notably, higher concentrations of O_2 during the last four days of incubation increased bone development and reduced average RA of limbs (Oviedo-Rondón et al., 2008a, b).

The utilization of wheat based diets reduced the eggshell membrane thickness compared to corn based diets. This was in agreement with Roberts et al. (1998), and Roberts and Choct (2006), who found that grains containing high amounts of NSP influence eggshell characteristics. Wheat contains high concentrations of non-starch polysaccharides (NSP), whereas corn contains almost none (Choct, 1997). NSP has been reputed to reduce bioavailability of nutrients (Shakouri and Kermanshashi, 2003) including trace minerals (Debon and Tester, 2001). For instance, Seal and Mathers (1989) reported that rats fed different NSP sources had greater accumulations of zinc in all intestinal tissues, but only a small amount of Zn was transfered to the serosal surface that was the major site for control of trace mineral absorption (Ellert, 1998). In addition, changes in the metabolic activity of the intestine induced copper and Zn deficiencies (Bremner and Mills, 1981). Thus, it was suggested that NSP affected the intestinal capacity to absorb trace minerals.

The shell membranes have been shown to consist of a mixture of protein and glycoprotein (Burley and Vadehra, 1989). Chicken eggshell membrane contains type I, V, and X collagens (Wong et al., 1984) and cross-linking amino acids such as desmosine and isodesmosine (Leach et al., 1981). Uronic and sialic acids have also been found in the chicken eggshell membranes that constituent sugars of proteoglycans (Nakano, 2003). In addition, Arias et al. (1992) detected keratan sulfate proteoglycan in eggshell membranes. Therefore, trace minerals regulating the formation of eggshell membrane chemical components might affect its structure. For instance, Mn activates the glycosyl transferases involved in the formation of mucopolysaccharides, which are components of proteoglycans (Leach, 1976). The enzyme lysyl oxidase is a cuproenzyme involved in conversion of lysine to cross-linked desmosine and isodesmosine (Chowdury, 1990). Moreover, Cu deficiency in hens caused abnormal distribution of the shell membrane fibers due to alterations in lysine-derived cross-links, which subsequently resulted in egg shape deformation and abnormal mechanical properties (Baumgartner et al., 1978). Thus, availability of trace minerals in broiler breeder diets that partially depend upon the amount of NSP in cereals might affect formation of eggshell membranes.

It was believed that thinner eggshell membrane caused by the use of wheat based diets might increase water vapor eggshell conductance. However, higher eggshell conductance was observed in eggs from breeders fed corn based diets compared to wheat based diets, but only when hens were given more feeder space availability (1 hen/cage). This might be explained by the highest pore concentration of eggs laid by breeders fed corn based diets and also provided with more feeder space availability (1 hen/cage). Eggshell pore concentration is an indicator of overall eggshell porosity (Peebles et al., 2004). Porosity is one of the major limiting factors of gas exchange during incubation that affects the conductance of O_2 available for embryo growth (Christensen et al., 1995). The total functional pore area and the metabolic rate of the embryo determine the air-cell gas tensions (Paganelli, 1978). Morita et al. (2009) reported that higher eggshell porosity in older breeders resulted from the higher volume and surface area of their eggshells. In the present experiment, egg weight and surface area were similar among treatments that discard physical egg effects on egg pore concentration. Non-starch polysaccharides from wheat based diets might have also slightly reduced availability of calcium carbonate that accounts for about 98% of eggshell (Viera et al., 2007). Thus, egg pore concentration could be affected by the rate of calcium carbonate crystallization. However, other mechanisms by which egg pore formation could be influenced by the present treatments evaluated in this project are changes in the regulation of secreting cells in the isthmus or uterus (Bebout and Hempleman, 1994), and number and distribution of secretory vesicles (Tullett, 1975).

The interaction between strain and feeding program indicated that strain B breeders fed according to the LS feeding program had the highest eggshell conductance. No significant differences caused by feeding program were observed in relative weight of eggshell, thickness, eggshell membrane thickness, and average egg pore concentration. However, breeders restricted with the LS feeding program tended to lay eggs with greater pore density measured at three equidistant points along the egg's long axis. Particularly, the number of equator pores was significantly higher in eggs laid by breeders allocated to the LS feeding program. Pores are not evenly distributed over the shell surface (Li-Chan et al., 1994) and they decline from the blunt end to the pointed end of the egg causing differences in local shell conductance (Rokitka and Rahn, 1987). Although surface-specific gas conductance is higher at the poles, the pores at the equator also contribute to gas exchange (Seymour and Visschedijk, 1988). Therefore, higher pore density observed only at the equator might contribute in some degree to the enhancement of gas exchange observed in eggs from breeders fed according to the LS feeding program.

Feeding program might have impacted pore density by changing the proportions of oviduct segments. Leksrisompong et al. (2008) reported that the utilization of a slow rate of feed increments from photostimulation to 29 wk of age increased relative weights of oviduct, infundibulum, magnum, and isthmus in comparison to the use of a fast feed allocation. In addition, Leksrisompong et al. (2008) suggested that the slow feeding program induced the oviduct segments to developing in a synchronous manner.

Breeders given more feeder space availability (1 hen/cage) at photostimulation laid eggs with lower relative weight of eggshell than hens provided with less feeder space availability (2 hens/cage). This observation might be related to the higher pore concentration observed in eggs laid by breeders fed corn based diets and given more feeder availability (1 hen/cage). In addition, the implementation of more feeder space availability at photostimulation reduced eggshell thickness only in eggs from breeders fed wheat based diets and fed according to the LS feeding program. Although changes in eggshell structure produced by feeder space availability were expected to influence eggshell conductance, we did not observe any differences in that variable. Air-cell gas tensions depend on the total functional pore area and the metabolic rate of the embryo (Paganelli, 1978). Thus, possible changes in embryo metabolic rates associated with the availability of feeder space might hinder effects of eggshell properties on eggshell conductance. The higher eggshell relative weight in eggs from breeders given less feeder space might indicate that the embryo has more available minerals for tissue development and metabolic processes. The major mineral component of eggshell is calcium, but there are other important minerals in smaller concentrations such as magnesium, phosphorous (Viera, 2007), copper, zinc, manganese, and iron (Richards, 1997).

Group Body Weight and Individual Body Weight at 49 d of age

Individual BW was only recorded at 49 d for both broiler experiments. Results of progeny from 32-wk old broiler breeders showed that strain A broilers were heavier than strain B broilers. Other investigations have also concluded that there are significant differences in growth rates between commercial strains of broilers (Bonnet et al., 1997; Hacina et al., 1996). In addition, Lewis et al. (2009) reported that Ross broilers had significantly greater feed intake but poorer feed conversion efficiencies than Cobb broilers; however, no differences in growth and overall mortality were observed between the two strains evaluated in the present experiment. Thus, it was clear that genetic line influenced growth performance, but other factors such as management practices and environmental conditions should be considered. There were no differences between strains for BW at 49 d of progeny from 44-wk old breeders.

There was a greater difference in 49-d BW between progeny produced by breeders from either more (1 hen/cage) or less feeder space availability (2 hens/cage) treatments only when corn based diets were used and the LF feeding program was applied to broiler breeders. The higher final BW observed in progeny from breeders given more feeder space availability did not seem to be related to eggs or eggshell characteristics. Therefore, a possible explanation of this finding would be a manipulation of nutrient deposition in the egg, or changes in the chemical nutrient composition and bioavailability of nutrients from the yolk.

In addition, progeny from 44-wk-old breeders allocated to the LF feeding program were heavier than broilers from breeders fed according to LS feeding program. Leksrisompong et al. (2009) reported that the use of the a slow feeding program applied to broiler breeders from photostimulation to peak of egg production along with the use of lower feeder space allotment (5.3 vs. 7.1 cm) during the growing produced the highest BW broiler progeny at 42 d. It was suggested that greater albumen height and percentage eggshell of eggs laid by breeders fed according to the fast feeding program were related to broiler BW. In the current study, the feeding programs reflected sigmoidal curves in which there was an either greater or lower increment of feed amounts from 14 to 18 wk, and 19 to 22 wk of age. Therefore, these experiments cannot be entirely comparable; however, they both indicated that maternal feed allocation could influence progeny broiler growth performance.

Leg problems, Walking Ability, and Bone Mineral Density

Prevalence of leg problems and walking ability were evaluated at 4 and 6 wk of age in broiler progeny obtained from the same breeders at 32 and 44 wk of age. To simplify presentation of data, observations from broilers of both experiments were combined using broiler breeder age and broiler sex as covariate. Strain A broilers were more likely to display angular deformations

(0.30 vs. 0.24) than strain B chickens at 4 wk of age. A large scale survey in Sweden showed differences between commercial broiler strains. In that survey, Cobb 500 broilers exhibited decreased walking ability, higher tibial dyschondroplasia, and more valgus-varus deformities than Ross 308 broilers at 35 d of age (Sanotra et al., 2003).

Bonnet et al. (1997) and Hacina et al. (1996) concluded that Cobb broilers have a faster growth rate than Ross. Faster growing crosses of commercial broilers have poorer walking ability (Kestin et al., 1992) and higher leg problem prevalence than slower growing crosses. However, in the current experiment, the first leg inspection was performed early in broiler life when there might be less effect of growth rate on leg health. Thus, the best possible explanation for the difference of angular deformation prevalence of these two strains might be related to eggshell properties that differed between these two strains. Strain B eggs had lower albumen height, percentage eggshell and eggshell membrane thickness that resulted in higher water vapor eggshell conductance. Oviedo-Rondón et al. (2008) reported that higher concentrations of O_2 during the last stages of incubation affected relative BW and length of bones, and improved RA of limbs.

At 4 wk of age, strain B broilers coming from breeders fed according to the LS feeding program were less likely to exhibit crooked toes than were strain B chickens from hens restricted to the LF feeding program. Even though there were differences in BW at 49 d between broilers from the two maternal feeding programs evaluated, early leg inspection should not be influenced by BW. Breeders fed according to LS feeding program laid eggs that tended to have higher egg pore concentration and had a significantly higher numbers of pores in the equator of the egg that might have contributed to improved gas diffusion capacity of the eggshell during critical periods of incubation (Christensen et al., 1995).

The intake of corn based diets along with the implementation of more maternal feeder space availability early in life increased chances to observe locomotion problems in broiler progeny compared to the provision of less feeder space availability for breeders during the laying period. There was a dramatic difference in BW at 49 d (3,860 vs. 3,650 g) of broilers from 32-wk old broiler breeders from these two groups that might indicate a faster growth rate. Furthermore, breeders given more feeder space availability laid eggs that had lower eggshell relative weight, but eggshell conductance was not influenced. It seems that there were other mechanisms by which maternal feeder space availability influenced progeny BW and prevalence of leg problems. Changes in yolk nutrient deposition rate or chemical yolk composition might be possible explanations as they have been proven to affect bone development (Hargis and Van Elswyk, 1993; Liu and Denbow, 2001; Oviedo-Rondón, et al., 2008b).

The utilization of wheat based diets dramatically increased the probability (0.12 vs. 0.04) of observing chickens with crooked toes compared to the use of corn based diets, but only in strain B breeders given less feeder space availability (2 hens/cage). This might be a result of the higher NSP in wheat (Choct, 1997) that reduced digestibility of nutrients including minerals and other cofactors that were involved in bone development and growth. In addition, wheat has lower bioavailable biotin that has been related to leg problems in broilers (Watkins, 2002; Farquharson, 2003). Both diets had supplemental biotin in this study. However, corn diets may have more biotin available than wheat diets.

Leg evaluation at 6 wk demonstrated similar results to the ones observed at 4 wk. However, the consumption of corn based diets increased the probability (0.26 vs. 0.09) of observing chickens with locomotion problems compared to the use of wheat based diets, but only when strain B breeders were provided with less feeder space availability. This might be related to higher BW gain.

Progeny from 44-wk-old broiler breeders showed that strain A broilers had heavier and more asymmetric shanks, higher BMC of shanks and tibias, and greater asymmetry of tibia BMD and BMC than strain B chickens, regardless of all other factors evaluated. However, progeny produced at 32 wk from the same breeder flock were not affected by strain or any bone characteristic. At that breeder age, an interaction between diet type and strain was detected for tibia length, and also between relative weight and width of shanks, but no significant differences were observed between these two strains. It was interesting that strain did not influence percentage eggshell at 31 wk, but did at 47 wk. Moreover, diet type did not affect albumen height at 31 wk, but it did at 47 wk of age. Thus, it seems that the differences in bone traits, BMD, BMC, and RA of some bilateral bones observed in strain A broilers from 44-wk-old breeders might be related to changes in egg characteristics. This supported our hypothesis that egg characteristics, specifically eggshell properties, have an important role in bone development during incubation. Another possible effect of higher relative weight of eggshell on bone development might be the increment of available minerals to the embryo accelerating rate of mineralization during development. Eusebio-Balcazar et al. (2009) suggested that higher bone ash content at hatching indicated faster rate of mineralization during incubation that was related to increase RA of bones, and consequently higher prevalence of leg problems in broilers at 42 d of age.

There was an interaction effect of strain and diet type that indicated that feeding corn based diets increased relative weight and thickness of shanks, and length of tibias of broiler progeny compared to the consumption of wheat based diets only in strain A broilers, whereas bones were not affected by these treatments in strain B chickens. This result might indicate that strain A broilers were more sensitive to dietary changes compared to strain B broilers; however this interaction was no longer observed when the breeder parent flock was 47 wk. The effects of corn based diets on tibia, and shank morphological traits were still observed in progeny at 47 wk, regardless of strain. Broilers fed corn based diets had higher BMD in all leg bones evaluated herein in the second experiment, and higher shank BMD and BMC in the first experiment. Furthermore, broilers fed corn based diets suffered more leg problems than those fed wheat based diets at 6 wk of age.

Broilers that had greater prevalence of leg problems also exhibited higher BMD or BMC. These results were in agreement with Talaty et al. (2010) who found a low but significant positive correlation (r = 0.11) between walking impairment and BMD. In fact, Rath et al. (2000) showed that tibias from 5-wk-old chickens were strong but brittle because of low collagen crosslinks and higher mineral content. It was suggested that bone maturity may be related to its crosslink content rather than mineral content.

CONCLUSIONS

The use of the LS maternal feeding program along with the supplementation of more maternal feeder space during the layer phase reduced the chances to observe locomotion problems at 6 wk of age in strain B broilers. In addition, broiler progeny from strain B breeders fed restricted to the LS feeding program and provided with more feeder space were less likely to display crooked toes at 4 and 6 wk of age. Moreover, the feeding of wheat based diets increased the probabilities of observing crooked toes of broiler progeny at 4 and 6 wk of age, particularly when strain B breeders were given less feeder space. On the other hand, probabilities of observing crooked toes and locomotion issues in strain A broilers were not influenced by diet type, maternal feeding program or maternal feeder space. However, the chances to observe angular deformations on strain A broilers were greater when breeders were fed according to the LS feeding program and given less feeder space. Thus, according to the data of leg health collected in broiler progeny, it seems that strain A and strain B respond similarly to breeder feeding program; however, strain B strain was more sensitive to effects of diet type and availability of feeder space during lay. Feeding breeders according to the LS feeding program along with more feeder space reduced the chances of observing leg problems of progeny and might be associated to the improved gas exchange capacity of eggshells in the B strain.

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SUMMARY

Maternal feeding programs to 29 wk, and feeder space change at photostimulation were evaluated on Cobb 500 broiler breeders housed in floor pens during lay. Their effects on leg health of broiler progeny were assessed feeding corn or wheat based diets. Breeders fed-wheat based diets were slightly and consistently heavier than breeders fed corn-based diets from 10 to 52 wk of age. Differences in BW caused by the diet type may be a response of the larger amount of poultry fat (~1%) in wheat-based diets to balance both diet types for ME. Mortality was similar during pullet rearing phase, but breeders fed wheat-based diets had higher hen mortality during the layer phase. Feeding program influenced BW only during the layer phase, in which breeders fed according to the LF feeding program exhibited higher BW compared to those restricted to the LS feeding program. In addition, breeders fed following the LF feeding program had higher hen mortality only during the pullet rearing phase compared to those fed according to the LS feeding program. Higher mortality was observed in hens fed according to LF feeding program between 17 to 19 wk of age, which might be a result from the smaller increments of feed amounts from 14 to 16 wk of age. Regarding reproductive performance, breeders fed wheat-based diets increased egg production and laid eggs with higher Y:A ratio compared to those fed corn-based diets. Breeders fed according to the LS feeding program had better fertility, and laid eggs with smaller percentage eggshell that might be related to lower early embryonic mortality compared to hens fed restricted to LF feeding program. Even though feeder space did not influence hen BW or internal egg characteristics, change in feeder space at photostimulation induced breeders to mature earlier and produce more eggs than without change in feeder space.

Effects of maternal treatments were also evaluated on the broiler progeny. Breeders fed wheat-based diets produced progeny with lower weight of femurs and shorter shanks at hatching compared to those fed corn-based diets only when breeders were given more feeder space at photostimulation. However, diet type did not influence eggshell conductance, hatchling BW without yolk, residual relative yolk weight, or any RA of bilateral leg bones at hatching. Broiler

breeders restricted to the LS feeding program laid eggs with greater eggshell conductance compared to those managed with the LF feeding program. However, the maternal feeding program did not affect any progeny bone morphological traits or the RA of leg bones at hatching. Eggs from breeders given more feeder space at photostimulation had higher eggshell conductance than those from breeders provided with similar feeder space. Maternal feeder space change did not influence BW without yolk; however, breeders given more feeder space produced progeny with heavier femurs and longer shanks compared to those provided similar feeder space, but only when breeders were fed corn-based diets. Moreover, the increased maternal feeder space at photostimulation was associated with an increased RA of femur length in the progeny. The utilization of wheat based diets increased the probability of observing crooked toes in broiler progeny at 6 wk compared to the use of corn based diets, only when breeders were fed according to the LF feeding program and given similar feeder space at photostimulation. Nevertheless, the use of corn based diets worsened the walking ability of progeny more than the utilization of wheat based diets, but only when breeders were fed according to the LS feeding program and provided with more feeder space at photostimulation. It appears that walking ability of broilers fed corn based diets was influenced by the faster growth rate observed in those chickens. In addition, breeders given more feeder space at photostimulation produced progeny with more locomotion problems as compared to those from breeders provided with similar feeder space, but only when corn based diets were used and the LS feeding program was applied to the breeders. This result appears to be related to a higher relative asymmetry of femur weights observed at hatching from 33-wk-old breeders given more feeder space at photostimulation. Finally, the breeder feeding program interacted with other factors to influence broiler leg health but it did not influence by itself walking ability or leg problems of progeny.

Two maternal feeding programs and feeder space availability after photostimulation were also evaluated on broiler breeders of two strains (A and B) housed in cages during lay. The effects of breeder treatments were assessed on the leg health of broiler progeny obtained by artificial insemination and pedigreed. Breeders and broilers were fed either corn or wheat based diets. The use of the LS feeding program along with the supplementation of more feeder space was less likely to induce locomotion issues and toe malformations in strain B broilers. However, strain A broilers from breeders fed according to LS feeding program and given less feeder space were less likely to display angular deformations. The improvement of leg health of strain B progeny from breeders fed according to the LS feeding program and provided with more feeder space seems to be related to the higher eggshell conductance observed in this group.

Thus, eggshell conductance influenced by breeder feeding management seems to be the most consistent egg variable influencing the probability to observe leg problems in broiler progeny. It was concluded that strain A and strain B respond similarly to breeder feeding program; however, the strain B was more sensitive to effects of diet type and maternal feeder space change according to the data of leg health collected in the broiler progeny.