REPRODUCTION IN MALE BROILER BREEDERS

by

RUTH HELEN MCGOVERN

(Under the direction of Dr. J. L. Wilson)

ABSTRACT

Male broiler breeders are feed restricted to achieve BW targets designed to maintain high and persistent semen quality and quantity resulting in high fertility. Experiments were conducted to examine the effects of (1) BW gain and loss at photostimulation on the carcass, external, and reproductive ability of caged males, (2) BW loss, from 35 wk of age, on the reproductive ability of caged males, and (3) rearing BW on mating behavior and fertility in a flock.

(1) Male broiler breeders were assigned to one of four rearing feeding treatments at 1 d of age; standard (SF) (recommended BW profile), plus 15% (P15) (BW approximately 15% heavier that the SF), plus 30% (P30), and full fed (FF). External characteristics including, head width, comb height, chest width, keel length, and shank length increased with feeding level during rearing. Full fed males endured a short period of weight loss prior to production that resulted in a

lower testis weight without negatively impacting the semen volume, concentration, or sperm motility.

(2) Males were subjected to a BW loss from 35 wk of age, late loss (LL). Standard gain (SG) treatment males were reared to 62 wk following BW recommendations. In the LL treatment, the BW loss resulted in a 14.7% lower fertility from eggs 8-14d post-insemination compared to the SG treatment at 58 wk of age. Semen volume and concentration were not negatively affected by a BW loss.

(3) Males were selected by intrinsic BW; low (2133 g), average (2624 g), and high (3100 g). Low and average BW males were subjected to a rapid (LR ans AR, respectively) increase in BW. Average standard (AS) and high standard (HS) males followed recommended BW. At 28 wk of age, high constant (HC) and high slow (HW) males had constant and minimal BW gain, respectively. At 26 wk of age, male BW was negatively correlated to the number of females in the scratch area (r=0.-65). At 54, 58, and 62 wk, the HC males had lower fertility compared to the HS treatment by 3.8, 9.6, and 7.5%, respectively. Males benefit from a consistent and gradual increase in BW.

INDEX WORDS: Male broiler breeders, chicken, reproduction, carcass characteristics, mating behavior

REPRODUCTION IN MALE BROILER BREEDERS

by

RUTH HELEN MCGOVERN

B.Sc., University of Alberta, Canada, 1995

M.Sc., University of Alberta, Canada, 1997

A Dissertation Submitted to the Graduate Faculty of The University of Georgia in Partial Fulfillment of the Requirements for the Degree

DOCTOR OF PHILOSOPHY

ATHENS, GEORGIA

2002

REPRODUCTION IN MALE BROILER BREEDERS

by

RUTH HELEN MCGOVERN

Approved:

Major Professor:	Jeanna Wilson
Committee:	Adam Davis Brian Fairchild Mike Lacy Jean Sander

Electronic Version Approved:

Gordhan L. Patel
Dean of the Graduate School
The University of Georgia
August 2002

DEDICATION

To Tom and Gill McGovern, this is theirs as much as mine.

ACKNOWLEDGMENTS

I would like to thank the Alberta Agriculture Research Institute, Poultry Industry Council, Shaver Poultry Breeding Farms Ltd., Cobb-Vantress. Inc., and the Poultry Science Department for their financial support.

Many thanks to the Poultry Unit manager at the University of Alberta, Lyle Bouvier. I have a great respect for your technical abilities, as well as, your immutable commitment to supporting students.

I would like to thank Giles Hines, Nigel Davidson, Shawn Rankin, Felicity Denis, Kim Thorsteinson, Rob Renema, and Doug Korver for their assistance in collecting data and providing animal care in Alberta.

At the University of Georgia, I would like to thank David Perry, Ken Roberts, Chris McKenzie, and the entire staff at the Poultry Research Station for their support in the feed mill and technical assistance with machinery and facilities. I would also like to thank Donna Slavin for her assistance in the hatchery.

To Doug Ard and Ben Martin, thank you for your assistance in the care, maintenance, and data collection in Georgia.

I would like to thank Jason Richardson and Emily Bowling for their help with the project in Georgia.

Thanks to Gwen Kirsh for her help and instruction in Dr. Rowland's laboratory.

I would like to thank Dr. G. Ware for assistance in statistical analysis and Dr. N. Dale, Dr. D. Froman, Dr. G. Rowland, and Dr. K. Bramwell for their guidance, assistance, instruction and time as committee members.

I would like to thank my committee members; Dr. J. Sander, Dr. A. Davis, Dr. M. Lacy, Dr. B. Fairchild, and Dr. M. Lacy for their participation and contributions to this dissertation.

I would especially like to thank Benton Hudson. I cannot thank you enough for your assistance in every aspect of this journey. I will always value the time I spent with you. Your kindness, friendship, support, and endurance are staggering. Thank you.

I would like to thank Dr. Frank Robinson for his encouragement and enthusiasm. Your energy and delectation made poultry my choice.

I would also like to Dr. Jeanna Wilson for her support and commitment. Your tenacity, strength, and vision are extraordinary.

My greatest debt of gratitude is to my parents, Tom and Gill. Thank you for all you've given me. You have been my best teachers and my greatest support. I share this with you. Also many thanks to my sister and friend Janet.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1. REPRODUCTION IN THE MALE

1.1 INTRODUCTION

Reproduction is the first and most important requisite of livestock breeding. The importance of the broiler breeder male for fertilizing eggs is rivaled only by his genetic influence on broiler breeder progeny (Fiser and Chambers, 1981). The number of fertile eggs produced for hatching dictates the ultimate profitability of the breeder flock. Rapid growth and a large appetite are desirable traits in broilers and turkeys being grown for meat yield. However, intense selection for growth, yield, and carcass characteristics have been paramount in the development of the modern broiler at the expense of the reproductive fitness of the parent stock (Harms, 1984; Reddy, 1994).

Managing the reproduction efficiency of the hen and rooster is the basis of broiler breeder production. Excessive body weight (BW) gain has adverse effects on the reproductive performance of parent breeders (Barash et al., 1992; Nir et al., 1996). Underfeeding causes failure to attain peak egg numbers, while overfeeding is more commonly associated with a very rapid decline in egg numbers following a brief period of peak egg output (McDaniel et al., 1981a; Katanbaf et al., 1989; Hocking et al., 1989; Yu et al., 1992; Hocking, 1993).

1.2 MALE ANATOMY

1.2.1 Testes

Males of all avian species have testes that are internally located in the center of the body cavity. In domestic birds, they are located just anterior to the kidneys and

are attached to the dorsal body wall. Therefore, spermatogenesis proceeds at the internal body temperature of 41^{o}C in birds as opposed to the scrotal temperature of 24-26 ^{o}C in mammals (Nickel et al., 1977). The testes of birds are larger, relative to BW, than those of mammals (Lake, 1957; Lofts and Murton, 1973). In many species of birds, there is a bilateral asymmetry, with the left gonad larger than the right (Lake, 1957; Lofts and Murton, 1973). Whether the mechanisms that are responsible for testicular asymmetry are the same as those that cause the marked ovarian asymmetry, in birds, is unknown. The color of the testes varies from white to creamy white (Parker et al., 1940). The testes are soft, lacking the connective-tissue septa commonly found in mammals.

The weight of the testes in chickens constitutes about 1% of the total BW, or about 9-30 g per testis at sexual maturity depending on the breed (Sturkie and Opel, 1976). Broiler breeder males, fed protein levels ranging from 9 to 18%, showed no difference in testes weight at 53 weeks (wk) of age (Wilson et al., 1987a). The weights of the testes were more closely associated with body size than with the level of dietary protein (Fontana et al., 1990).

1.2.2 Leydig and Sertoli cells

The testes are composed of two major cell types, Leydig and Sertoli cells. Leydig cells are dispersed in the spaces between the seminiferous tubules, where they are associated with blood and lymph vessels (Munro, 1938ab; Lake, 1957). Leydig cells contain the steroidogenic enzymes necessary for the production of androgens (testosterone and androstenedione) (reviewed by Johnson, 1986) and

respond rapidly to luteinizing hormone (LH) (Maung and Follett, 1977). Sertoli cells located within the seminiferous tubules secrete inhibin, estrogens, and androgen-binding protein. Spermatogenesis depends upon the availability of testosterone (Mann, 1954; Nalbandov, 1958), follicle stimulating hormone (FSH), Sertoli cell activity, and interactions between Sertoli and germ cells (Sharpe, 1994). There is evidence that both Sertoli cells and the epithelial cells of the epididymis can reabsorb spermatozoa in order to eliminate unejaculated sperm (Tingari and Lake, 1972).

1.2.3 Spermatogenesis

Romanoff (1960) has described the spermatogenic process and the transformations that result in the formation of spermatozoa in the fowl. Sperm development can be separated into three processes: spermatocytogenesis, spermiogenesis, and spermiation. The first stage of spermatogenesis occurs in the periphery of the seminiferous tubules lined with spermatogonia (Zlotnik, 1947). Spermatogonia are diploid dividing mitotically, to retain a constant population of stem cells for spermatogenesis, and to produce the spermatocytes (Zlotnik, 1947; Lake, 1956).

Through a total of 10 stages, spermatogonia are transformed from primary spermatocytes into two secondary spermatocytes, four spermatids, and spermatozoa. At each stage of spermatogenesis, the cell is transported closer to the lumen of the tubule, where it is finally released as a complete spermatozoon. The final phase of sperm formation, spermiogenesis, consists of the elongation of the

spermatid nucleus to form the head and the shedding of most of the cytoplasm (Lake, 1956). Since each region of the seminiferous tubule contains spermatozoa in a different stage of differentiation, the production of spermatozoa by the testes is continuous, although spermatogenesis by each section of the seminiferous tubule is phasic (Zlotnik, 1947; Aire et al., 1980).

1.2.4 Transport and storage of sperm

After the semen has been produced, the seminiferous tubules in birds are arranged as a network of interconnected ducts that empty into the rete testis (Lake, 1957; Tingari, 1971). Tightly opposed to each testis is a small structure that has often been termed an epididymis or ductus epididymis (Lake, 1957; Johnson, 1986). The epididymal region consists of efferent tubules carrying sperm from the testis to a single epididymal duct, which is apparent on the epididymal surface (Lake, 1957). This duct is short (about 2-4cm) and is quite unlike the mammalian structure of the same name.

Leading from each epididymis is a coiled tube, the vas deferens, which traverses posterior, is attached to the dorsal body wall, and terminates at a small phallus in the cloaca (Nickel et al., 1977). Just before its termination, the vas deferens become somewhat enlarged and serves as a storage site for spermatozoa, as does the entire duct (Lake, 1957; Lake, 1981). Each vas deferens terminates in small papilla and ejects the semen into the cloaca (Nickel et al., 1977). At the time of sexual excitation several small folds in the ventral cloaca become engorged with

lymphatic fluid and protrude, forming a trough-like structure to direct the flow of semen (Nishiyama, 1950; Nishiyama, 1955).

1.2.5 Sperm maturation

Maturation of spermatozoa is synchronized within regions of each seminiferous tubule and consequently, all of the germ cells within the region are in the same stage of differentiation between spermatogonia and spermatozoa (Lake and Smiles, 1952; Lake 1954). The physiological role that the various juxtesticular structures play in maturation of spermatozoa is relatively unstudied in birds. The mammalian epididymis is clearly a site of great importance in sperm maturation, (Lake, 1957; Glover and Nicander, 1971; de Reviers, 1972). Structural differentiation of spermatozoa is thought to be complete before it leaves the rete tubules (Tingari, 1973). Early studies indicate that sperm, taken from the testis or epididymis of the cock, were capable of producing fertility at a very low level because sperm motility is obtained in the vas deferens (Munro, 1938a). Estimates of total transit time from the testes to the terminal region of the vasa deferentia range from 1 to 4 d (Munro, 1938a).

1.2.6 Semen composition

Semen is a mixture of sperm cells and lymph fluid (Nishiyama, 1951; Nishiyama, 1952; Nishiyama, 1955). The composition of semen is quite variable (Esponda and Bedford, 1985), the sperm cells being mixed with secretory fluids from the engorged phallic apparatus and with digestive and urinary tract wastes. The

contributions of these factors are not easily controlled and consequently considerable variation in semen composition has been reported. Seminal plasma consists of protein, fructose, sorbitol, citric acid, inositol, glyceryl phosphoryl choline, ergothioneine, sodium, potassium, calcium, magnesium, and chloride as reviewed by Lake (1971). Parker et al. (1942) has shown that semen varies in appearance. Semen that is viscous and white has a high spermatozoa concentration, while semen that has a watery appearance is low in spermatozoa concentration (Parker et al., 1942).

1.3 HORMONES

1.3.1 Introduction

A number of hormones control sexual maturity, semen production, and the behaviors connected with reproduction, aggression, and stress in male broiler breeders. As in the female, photostimulation affects the hypothalamus causing the release of luteinizing hormone releasing hormone (LHRH) that affects the pituitary. At the onset of a photostimulatory photoperiod, there are rapid increases in blood levels of LH and FSH released from the pituitary. Removal of the pituitary (hypophysectomy) in the cock causes a rapid atrophy of the testes (Hill and Parks, 1934). Either LH or FSH stimulates testicular growth, but the gonadotrophins have different target cells (Appleby et al., 1992).

Follicle stimulating hormone stimulated growth, differentiation and spermatogenic activity of the seminiferous tubules. Luteinizing hormone affects steroidogenic activity of the Leydig cells (Brown et al., 1975). The concentration of

LH increased with BW (Etches, 1996). As sexual maturity is attained, the production of testosterone is stimulated by the rising blood concentrations of the gonadotrophin, LH (Sharp and Gow, 1983). Increased LH also stimulates the development and maintenance of accessory sexual organs (Lofts and Massa, 1980).

1.3.2 Target cells

Gonadotrophins affect the testes by binding to specific cell-surface receptors on two distinct types of testicular parenchymal cells: Sertoli and Leydig cells (Rothwell, 1973; Cooksey and Rothwell, 1973). Follicle stimulating hormone acts on Sertoli cells (Tcholakian and Steinberger, 1980). In the male, androgen production coincides with the development of spermatogenesis and testicular growth (Etches, 1996). Full testicular function is brought about by the combined action of FSH and testosterone (Sharp and Gow, 1983).

Leydig cells respond rapidly to LH through rapid increases in the secondary messenger cAMP (Woods and Domm, 1966; Garnier et al., 1973; Maung and Follett, 1977). Luteinizing hormone acts on Leydig cells to promote their development and the production of androgens such as testosterone (Nicholls and Graham, 1972). The principal steroids secreted by Leydig cells include testosterone and androstenedione, a precursor of testosterone.

1.3.3 Testosterone

Increases in testosterone production during photostimulation result in a stimulatory effect of androgens on spermatogenesis (Lofts and Murton, 1973).

Testosterone is also essential for maintenance of the excurrent ducts, maintenance of secondary sexual attributes, the expression of specific behaviors, and the alteration in pattern of GnRH secretion (McDaniel and Craig, 1959). In chickens, testosterone is secreted in discrete pulses, which closely follow LH pulses (Driot et al., 1979; Bacon et al., 1991).

There is a marked increase in the secretion of androgen in the male chick at about 30 d post-hatch (Breneman and Mason, 1951). During the onset of puberty in the male, there is an increase in plasma LH followed within 1-2 wk by an increase in plasma testosterone (from 2.3 ng/mL at 16 wk to 9.5 ng/mL at 24 wk) (Driot et al., 1979; Bacon et al., 1991). However, plasma levels of testosterone are several times lower than those found in the testicular vein (Ottinger and Brinkley, 1979). Circulating concentrations in adult male chickens have a diurnal range of 7.0 to 11.3 ng/mL (Schanbacher et al., 1974).

In broiler breeder males, Hocking and Bernard (2000) found plasma concentrations of testosterone peaked at less than 4 ng/mL at 30 wk of age and averaged 2.5 ng/mL from 40 to 60 wk of age. In caged broiler breeder males, plasma testosterone increased from 16 to 30 wk (Renden et al., 1991) followed by a linear decline in plasma testosterone from 30 to 60 wk of age (Sexton et al., 1989b; Renden et al., 1991; Hocking and Bernard, 2000). In young broiler breeders, excessive natural mating activity occurred during high plasma concentrations of testosterone (Duncan et al., 1990; Hocking and Bernard, 2000).

1.3.4 Secondary sexual characteristics and testosterone

The acquisition of secondary sex characteristics, as roosters mature, is a consequence of the hormonal secretions from the testes that, in turn, are regulated by the secretion of gonadotrophin from the anterior pituitary gland and gonadotrophin releasing hormones (GnRH) from the hypothalamus (Etches, 1996). Male secondary sex characteristics include comb, plumage, and wattle development. Androgens are also responsible for the full expression of the characteristic voice of the rooster, although capons and masculinized females will make feeble attempts to imitate the intact male (Etches, 1996).

Androgens are required to induce growth of the comb and wattles in roosters. In both sexes, the development of the comb coincides with increased plasma concentration of androgens (Etches, 1996). Mashaly and Glick (1979) suggested that dihydrotestosterone might be of greater importance in stimulating comb growth than testosterone. However, Rath et al. (1996) reported an increase in comb weight with testosterone.

1.3.5 Behavior and testosterone

Testosterone is associated with sexual activity and social aggressiveness of the cock (Davis and Domm, 1943; Collias, 1950; Guhl, 1958; Culbert et al., 1977). Exogenous gonadal hormones may cause some precocious development of certain behavior patterns, particularly agonistic and sexual behavior patterns (Guhl, 1958). Testosterone is the major hormone found to affect mating behavior in males of different avian species (Mashaly and Glick, 1979). Testosterone injected into chicks

results in precocious male sexual behavior, such as mounting, treading, and crowing (reviewed in Appleby et al., 1992).

1.3.6 Negative feedback

The testes produce and secrete a number of steroids, which are involved in a negative feedback effect on gonadotrophin secretion (Sharp and Gow, 1983). In the cockerel, the increase in plasma levels of LH, at the onset of puberty, may be the result of a decrease in the sensitivity of LHRH secreting neurons to the negative feedback effects of testicular steroids, (Sharp and Gow, 1983). Within a day, after the levels LHRH, LH, and FSH increase, negative feedback of testicular product causes the levels of these hormones to decrease. Levels of LH decline when testosterone levels are increasing (Sharp and Gow, 1983). Testosterone is the major feedback regulator of LH secretion (Sharp and Gow, 1983).

Levels of FSH decline more slowly than those of LH and do so as the testes are approaching full size. By the time testes have reached full size, FSH levels are only about one fourth the peak levels attained several weeks earlier. Sharp and Gow (1983) suggested that LH and FSH were not influenced by the same regulatory factors because of differences in the rise and decline of LH and FSH. More recently, inhibin B, produced in the Sertoli cells, has been associated with the negative feedback of the hypothalamus and pituitary (reviewed in Mather et al., 1997). Activin produced by the testes, has been associated with stimulation of the production of LHRH, LH, and FSH (reviewed in Mather et al., 1997).

1.3.7 Leptin

Adipose tissue functions very much like other endocrine tissues, releasing a hormone, leptin, into the circulatory system to relay a message to its target (reviewed in Heiman et al., 1998). The major target for this hormonal message appears to be the hypothalamus. Adipose tissue sends a message concerning fuel supply to the hypothalamus by secreting concentrations of leptin that reflect energy storage (reviewed in Heiman et al., 1998).

Leptin functions as a tropic factor for the reproductive system (reviewed in Prolo et al., 1998). The firing of GnRH-containing neurons and secretion of GnRH to the pituitary is elicited by leptin-mediated activation of leptin-receptor-expressing neurons and by other factors, such as growth hormone, neuropeptide Y, and insulin. These factors control the reproductive process (reviewed in Chehab, 2000).

Studies in men and women clearly indicate that circulating leptin values are positively correlated with quantity of body fat (reviewed in Caro et al., 1996). Matkovic et al. (1997) reported that a critical blood leptin level was necessary to trigger puberty. In a review by Hossner (1998), leptin was not considered the primary puberty-inducing factor, but leptin can induce maturation when metabolic resources are adequate.

1.3.8 Leptin and male reproduction

Leptin also affects the male reproductive system. Leptin appears to be controlled by feedback mechanisms within the male reproductive system. In boys, testosterone had a negative effect on leptin concentration, but not girls (Wabitsch et

al., 1997). Wabitsch et al. (1997) found that testosterone and dihydrotestosterone inhibited leptin secretion by 62% in human adipocytes, in vitro.

Leptin treatment increased serum LH and testosterone concentrations in fasted male mice (Ahima et al., 1996). Although homozygous obese male mice that were food restricted were also infertile, leptin treatment of these mice restored fertility and normalized testes weight and histology (Mounzih et al., 1997). In animal and human studies, weight gain significantly increases circulating leptin concentrations (Considine and Caro, 1997; Hebebrand et al., 1997; Mantzoros et al., 1997). Homozygous obese mice have low fertility (Chehab et al., 1996). Caloric restriction, of homozygous obese mice, does not restore fertility, which suggests that obesity *per se* is not the cause of infertility in leptin deficiency, and that leptin is directly related to the modifications of reproductive capacity (Chehab et al., 1996).

Male broiler breeders are not considered obese because their excessive BW gains are associated with increased breast muscle mass. Male broiler breeders are feed restricted without inhibiting fertility. In animal and human studies, weight loss results in decreased leptin levels (Considine and Caro, 1997; Hebebrand et al., 1997; Mantzoros et al., 1997). This suggests that leptin is not inhibited by feed restriction, but leptin levels may decrease if broiler breeder males are subjected to BW loss (decrease in fatpad weight).

1.3.9 Corticosterone

Stress induces corticosterone release (El Halawani et al., 1973; Eden and Siegel, 1975). Corticosterone is a hormone produced by the adrenal glands in response to adrenocorticotropic hormone (ACTH) (Appleby et al., 1992). Corticosterone acts on the brain to influence behavior by changes in perception (Appleby et al., 1992). In mammals, elevated corticosteroids counter the negative feedback of reproductive steroids by enhancing or maintaining excitatory amino acid receptors, in the brain. These receptors drive the hypothalamo-pituitary-gonadal axis (Brann and Mahesh, 1997). There is also evidence that high plasma concentrations of corticosterone can differentially inhibit behavioral components of reproduction (e.g., territoriality) without affecting the adenohypopyseal-gonadal axis (e.g., LH and testosterone) (Wingfield and Silverian, 1986).

Both short term feed deprivation and long-term energy restriction cause increased corticosterone secretion in laying chickens (Nir et al., 1975). Stress levels of corticosterone that decrease BW may leave LH and reproductive hormones unaffected (Wingfield, 1984). Possible increases in corticosterone, with mating, territorial, and nesting pressures, may require either a facilitating role for corticosterone in reproduction or an uncoupling of changes in circulating corticosterone for various reproductive parameters, in order for the reproductive phase to survive (Carsia and Harvey, 2000).

1.4 SEMEN CHARACTERISTICS

1.4.1 Semen volume and concentration

The average volume of cock ejaculate reported ranged from about 0.5 to 1.0 ml, but amounts considerably above and below this are commonly obtained (Parker et al., 1940; Sturkie and Opel, 1976). Average concentration of spermatozoa is 3.5 million per ml of semen (Sturkie and Opel, 1976). Lake (1957) reported averages of 7 billion and a maximum of 8.2 billion per ejaculate in Brown Leghorn roosters. Estimations of sperm quality, but not sperm concentration, were highly correlated with the fertilizing ability of individual male chickens (Wishart and Palmer, 1986).

1.4.2 Semen quantity and testes size

Burrows and Titus (1939) observed that there was a close association between testis size and the amount of semen produced. Males with the largest testes from 16 to 44 wk of age produced the greatest quantity of semen (de Reviers and Williams, 1984). In general, large males have large testes and therefore broiler breeder males usually produce more semen than Leghorn males (de Reviers and Williams, 1984). In contrast, Brown and McCartney (1983) found that groups of broiler breeder males at 54 wk of age with the largest testes did not produce the largest amounts of semen. The difference between experiments may be related to male age.

The number of Sertoli cells present in the testes is proportional to testicular size and therefore daily sperm production is also correlated with testicular size (Parker et al., 1940; de Reviers and Williams, 1984). However, neither the amount of semen obtained nor the weight of the testes appeared to have any effect on fertility

and hatchability of eggs (Brown and McCartney, 1983). Once the testes reach the minimum critical size (7 g), additional size increases have little effect on semen concentration. Only males with testes weighing less than 9 g at the time of necropsy yield semen irregularly throughout production (Fontana et al., 1990).

1.4.3 Semen quality

Spermatozoa quality is a more limiting factor than the number inseminated (Wishart and Palmer, 1986). Avian semen quality is often defined by four characteristics: semen volume and concentration, sperm viability (% of live spermatozoa), and sperm motility (movement) (McDaniel et al., 1998; Parker et al., 2000). Semen volume, concentration and sperm motility measurements are highly positively correlated with one another (McDaniel and Craig, 1959). However, Brown and McCartney (1983) found that neither the volume of semen obtained nor the weight of the testes appeared to have any effect on fertility and hatchability of eggs. Fertility correlates erratically with sperm concentration and volume in natural mating flocks (Wilson et al., 1979).

Sperm mobility, measured using sperm migration from one medium into another, has been used to identify low quality semen (Froman and McLean, 1996). The quality of sperm is an important factor and can vary considerably between males and samples (Wishart, 1995). Evaluating male broiler breeder semen provides a chance to eliminate extremely low semen-producing males, particularly at the beginning of production (Sexton, 1983). Handling and length of storage also affect the quality of sperm (Wishart, 1995).

Most methods of semen evaluation only assess a single characteristic of sperm, without taking the complex process of fertility into account. However, the process of fertility involves sperm transport, storage in the oviduct, sperm binding, and penetration of the ovum (Bakst et al., 1994). Fertility has shown a strong relationship with sperm motility, sperm metabolism, and percentage of abnormal or dead sperm (McDaniel and Craig, 1959). The sperm penetration assay evaluates several aspects of the fertilization process discussed in detail in the fertility section.

1.4.4 Sperm transport to the oviduct

Semen is transferred to the vagina of the female by positioning the engorged phallus in contact with the cloaca of the female. Artificial collection of semen from chickens and turkeys is widely practiced and relatively simple. Manual semen collection is accomplished by restraining a male and inducing a spinal reflex by massaging the surface of the body surrounding the vent (Burrows and Quinn, 1937). Only gentle squeezing with fingers is necessary to eject the semen into a container (Lake, 1957). In the female, the same sort of manipulation evokes vaginal eversion (Johnson, 1986).

Initially Parker et al., (1940) suggested that the greater the frequency, the lower the volume of semen and concentration of spermatozoa. McDaniel and Sexton (1977) studied the relationships between semen collection frequency, semen volume, sperm concentration, and fertility in both Leghorn and broiler breeder males. They found that regardless of the type of male, three semen collections per week yielded greater semen volumes and more sperm cells per ejaculate than other

semen collection frequencies studied. Fuquay and Renden (1980) reported that broiler breeder males ejaculated 5 times per week produced the highest total number of sperm per ejaculate.

1.4.5 Sperm storage

For sperm storage to occur, sperm must be motile and survive the environment of the vagina to reach the sperm storage tubules (SST), crypts that store sperm in the hen for extended periods of time (Donoghue, 1999). This “reservoir” of sperm within the SST insures that sperm are available between inseminations and ideally secures the sustained probability of fertilization (Donoghue, 1999). Upon release from the SST and transport to the infundibulum, the site of fertilization, sperm must be capable of binding to and penetrating the inner perivitelline layer (single acellular investments enveloping the ovum at ovulation) and then fertilizing the ovum (Donoghue, 1999). Maximal filling of the SST occurs during the first 24-48 hr after insemination and is essential for the series of fertilized eggs that typically follows a single insemination (Bakst et al., 1994). McLean and Froman (1996) hypothesized that poor sperm motility accounted for sub-optimal SST filling.

Fertility, as well as the number of sperm stored in the hen’s oviduct, increases with increasing numbers of sperm inseminated until the sperm storage tubules (SST) are filled (Bakst et al., 1994). Because sperm and oviductal characteristics both regulate the ability of sperm to be stored in the oviduct, it is possible for even large insemination doses to produce low fertility rates (Parker et al., 2000). Inseminations

performed frequently with a moderate number of spermatozoa are more efficient than inseminations performed with higher doses at longer intervals (Brillard, 1993).

1.5 FERTILITY

1.5.1 Fertile period

Female fowl can store sperm from one or more inseminations for an extended period, resulting in the production of fertilized eggs for a period of several days to weeks (Bakst et al., 1994). Dunn (1927) found that, in general, the female chickens cease to lay fertile eggs 18 d following the removal of the male, although in one case a hen laid a fertile egg on the 30^{th} d. The longest fertile period or duration of fertility recorded varies between 17 (Fronda, 1926) and 29 d (Nicholaides, 1934) with an average fertile period following mating of 14.8 d (Nicholaides, 1934). More recently, sperm from male broiler breeders produced fertile eggs for an average of 13 d (Ansah et al., 1980). Fertile eggs, laid one, two or three weeks following mating, showed no differences in hatchability (Warren and Kilpatrick, 1929).

1.5.2 Fertility and semen quantity

Burrows and Quinn (1937) reported that 0.05 to 0.1 mL of undiluted semen gave satisfactory fertility. Munro (1938b) found that fertility was affected when the number of spermatozoa inseminated fell below 1×10^8 and no fertile eggs were laid when the number was below 1×10^6. Sub-fertility following intravaginal insemination has been related to insufficient filling of the sperm storage tubules (Etches et al., 1974).

1.5.3 Sperm penetration

Fertilization takes place within the infundibular region of the upper oviduct. Sperm cross the perivitelline layer of the ovum at the germinal disc region in order to gain access to the female pronucleus (Romanoff, 1960). Sperm penetrate the inner perivitelline layer (IPVL) of the newly ovulated ovum, for fertilization (Wishart, 1995). Upon coming in contact with the perivitelline layer, sperm utilize their acrosomal enzymes to hydrolyze holes in the protein fibers of this layer and the spermatozoon gains entry into the ovum through the digestion of a hole in the perivitelline layer (Baskt and Howarth, 1977). The quantitative relationship, between fertility in chickens and the numbers of spermatozoa which interact with the egg, was first demonstrated by Wishart (1987), who correlated the numbers of spermatozoa trapped in the outer perivitelline layer with egg fertility and the length of the fertile period, in artificially inseminated hens. Within 15 minutes of fertilization, an extra proteinaceous layer, which is secreted by the oviduct and referred to as the outer perivitelline layer, is laid down around the IPVL (Wishart, 1995). This may have the purpose of strengthening the yolk or perhaps protecting the IPVL from further sperm-mediated hydrolysis (Wishart, 1995).

The presence of sperm in the IPVL can be visualized and quantified in laid eggs. The number of sperm-caused holes found in the IPVL is assessed as the number of ‘sperm penetrations’ (Bramwell et al., 1996b). The IPVL-holes are concentrated in the 1 to 2 mm diameter circle of the IPVL, that overlies the germinal disc, and reach a maximum of approximately 50 per square millimeter in chicken eggs (Wishart, 1995). Infertility is more likely when less than 5 sperm penetrate the

egg at the germinal disc (Wishart, 1995). On average 25 to 30 sperm penetrate the egg near the germinal disc before fertilization is successful (Bramwell et al., 1995). However, eggs can be fertilized with only one hole in the IPVL overlying the germinal disc (Wishart, 1995). The number of holes caused by sperm penetration of the perivitelline layer in vivo was highly correlated with fertility (Wishart, 1987; Bramwell et al., 1995).

1.5.4 Sperm storage and age

A decrease in sperm storage, in the uterovaginal sperm host glands in older hens, has been observed in turkeys (Van Krey et al., 1967) and broiler breeders (Pierson et al., 1988). The release of sperm from the sperm storage ducts in old hens (65 wk) was lower than in young hens (39 wk) since the sperm penetration was lower in old hens (Bramwell et al., 1996b). The decline in fertility in older hens may also be due to a sperm storage and transport problem in the female oviduct (Pierson et al., 1988; Fasenko et al., 1992; Brillard, 1993). Van Krey et al. (1967) and Christensen (1981) found a decline in the retention of spermatozoa by sperm host glands in aging turkeys. However, Brillard (1993) indicated that the number of sperm residing in the SST of previously virgin old and young chicken hens was equivalent.

Changes that occur with age in the composition of the hen's uterine fluid may also relate to the decline in spermatozoa viability within the hen's oviduct and the reduction in fertility (Dupuy and Blesbois, 1996). More spermatozoa was required in 49 to 52 wk old hens than 21 to 28 wk old hens to achieve maximum fertility (de Reviers and Brillard, 1986). Furthermore, *in vivo* survival of chicken embryos has

been reported to be closely dependent on the duration of sperm storage in the hen oviduct (Lodge et al., 1971). Decreased fertility in older hens can be reduced by increasing the number of sperm (de Reviers and Brillard, 1986) or by using duplicate inseminations (Brillard and McDaniel, 1986).

1.5.5 Sperm penetration, hatchability and age

Sperm penetration averages were lower for 55 wk old flocks than 37 wk old flocks (Bramwell et al., 1996b). However, fertility of old males was greater in comparison with young males when hens were inseminated with equal numbers of total spermatozoa (Bramwell et al., 1996a). Older males show a decrease in dead sperm (Bramwell et al., 1996a) and an increase in total live sperm production (Wilson et al., 1979) that may offer an explanation for high fertility in older males. However, as males aged, their ejaculate volume decreased (Lake, 1989). A reduction in the number of sperm-caused holes in older hens could be related to a lack of sperm storage (Bramwell et al., 1996b). Lower hatchability of eggs from older females could be associated with changes in shell quality or infrequent mating (Upp, 1928; Lill, 1966) leading to fertilization by ‘old’ sperm (Nalbandov and Card, 1943; Lodge et al., 1971; Lodge et al., 1974). Bramwell et al. (1996b) also suggests sperm receptors on the surface of the germinal disc may decrease in numbers or in efficacy with age of the hen.

1.6 EGG BREAKOUT

1.6.1 Candling

The success of the reproductive process can be established by egg breakouts prior to incubation, at candling, and at post-hatch (Wilson, 1995b). Candling is a process by which the egg is held against a light source so that a grader can determine certain qualitative characteristics of the internal parts of the egg without breaking the shell. Infertile eggs retain the original yolk color and the germinal disc is a distinct white or pale yellow irregular shaped spot (Kosin, 1945). Determining the age of embryo mortality can help to identify problems in the management of breeders.

1.6.2 Early embryonic mortality

In chickens, unhatched eggs examined after chicks have hatched can be used to determine the general age of embryo mortality (Wilson, 1991). Embryonic mortality is usually categorized into three time periods during the incubation process (Wilson, 1995a); early dead, mid-dead, and late dead. It is more difficult to differentiate infertile from very early dead embryos after the eggs have been incubated for 21 d (Leeson and Summers, 2000). The yolk of very early dead embryos is often paler in color and may have a mottled appearance. Embryos that died during the first wk of incubation have a blood ring or a network of blood vessels that are visible through the shell, whereas live embryos will be at a more advanced stage of development (Wilson, 1995a). Dead embryos will often adhere to the shell when the egg is rotated (Wilson, 1995a). In addition, the dead embryos and visible

blood vessels will have a darker red color than the live embryos due to pigment oxidation (Wilson, 1995a). Early dead embryos are related to improper pre-incubation egg handling and/or egg storage conditions assuming that no disease situation is involved (Leeson and Summers, 2000). A survey of broiler industry residue analysis indicates that early dead mortality averages 2.5% over the life of the flock (Wilson, 1995a).

1.6.3 Mid and late embryonic mortality

In the chicken, mid-dead embryos (7-14 d) are identified by a hard beak with a well-defined egg tooth on the upper side of the beak (Wilson, 1995a). Mid-dead embryos are rarely seen under normal conditions, although a very high incidence can be induced with inadequate diet formulation (Leeson and Summers, 2000). An industry survey indicates that mid-dead mortality averaged 0.5% and late dead mortality was approximately 2.75% over the life of the flock (Mauldin, 1989). A late dead embryo of 15 to 21 d of development is fully covered by mature down feathers (Wilson, 1995a). Late dead embryos are more likely caused by incubation conditions, and rarely relate to breeder management or nutrition (Leeson and Summers, 2000).

1.7 MALE MANAGEMENT

1.7.1 Body weight control

Body weight and condition continue to be major criteria for monitoring poultry development. With the advent of high nutrient density diets and more recently,

restricted feeding, a breeder flock can be maintained economically for a longer period of time and at higher egg production than was previously possible. During the grow-out of broiler breeder flocks, restriction of feed in order to lower BW is a common industry practice (Brown and McCartney, 1983). Body weight control benefits the reproductive performance of both female and male broiler breeders. The flock benefits from increased egg production, increased fertility, hatchability, egg quality, reduced double-yolked or malformed eggs, and reduced mortality due to BW restrictions (McDaniel et al., 1981a; Hocking et al., 1987; Katanbaf et al., 1989; Hocking et al., 1989; Fattori et al., 1991; Yu et al., 1992; Hocking, 1993; Robinson and Wilson, 1996).

Broiler breeder males are able to maintain high and persistent semen quality and quantity over an extended period of time in a caged management system. Both high semen quality and quantity could be related to close monitoring of male BW in the cage system (Ansah et al., 1980). Male BW influenced the percentage of males producing semen (Harris et al., 1984). McDaniel et al., (1981a), found fertility problems in both overweight and underweight broiler breeder males.

1.7.2 Rearing body weight and adult recommendations

Body weight management of broiler breeder males during rearing may impact the reproductive efficiency of males throughout production. Most commercial broiler breeders are feed-restricted during rearing to limit BW (McDaniel, 1983; Summers and Leeson, 1985). At present, there is a tendency to start restricting food intake for males at a very early age (3 wk) (Van Wambeke et al., 1979). Feed restriction of

males is intended to produce healthy birds that remain reproductively active throughout the laying cycle.

Male broiler breeders have an optimum BW range that changes with age for maximum semen production and sperm quality. The challenge of feeding broiler breeders is to temper their growth potential in order to maximize reproductive performance. Body weight is positively correlated with the percentage of sexually mature males, and the percentage of males producing semen (Cerolini et al., 1995). As male BW deviates from the recommended BW, the fertilizing ability of males decreases compared to males that adhere to standard BW (Hocking, 1990b).

There are several recommendations for controlling male BW to optimize reproductive performance. Males restricted to 100% and 85% of the recommended feed allowance from 30 to 46 wk of age produced the largest average semen volume (Brown and McCartney, 1986). Testes weight was also greatest in males that gained or lost the least amount of BW and were fed closest to the recommended feed intake (Brown and McCartney, 1986). Sexton et al. (1989a) reported that the percentage of carcass fat was positively correlated with the percentage of sexually active males, semen production and semen concentration.

Cerolini et al. (1995) reported that the optimal daily food supply for the best reproductive performance was 130g/bird/d, corresponding to 15.6 g of CP and 358 kcal metabolizable energy (ME) for Ross breeder males. Males gaining an average of 28 g per bird over a 24 wk period, from 30 to 54 wk of age, had the largest testes per bird, but produced significantly less semen on the average than males being fed 15% less (Brown and McCartney, 1983). Sexton et al., (1989b) reported that

increasing the daily metabolizable energy of the diet increased fertility. Behavior problems, particularly egg eating by low BW males, suggests that males should be permitted to grow by allocating increasing quantities of food throughout the breeding period (Hocking 1990b).

1.7.3 Underfeeding

Parker and McSpadden (1943) were the first to report that severe restriction between 42 to 72% of free choice had a detrimental effect on male fertility. Sexual maturity in female and male broiler breeders can also be delayed by underfeeding (Lister et al., 1966; Wilson et al., 1971; Brody et al., 1980; Katanbaf et al., 1989). In male broiler breeders, Harris et al. (1984) found a tendency for the lighter male birds to come into semen production at about 35 wk of age.

Males not producing semen tend to have less carcass fat than males producing semen (Wilson et al., 1987b). Broiler breeder males on a severe feed restriction program also experience decreased semen volume and sperm concentration per ejaculate (Sexton et al., 1989a). However, level of dietary protein intake (12 or 14%) has no adverse effects on semen volume or fertilizing capacity in broiler breeder males (Wilson et al., 1987a).

Severe feed restriction (55%) resulted in decreased testes size as well as BW (Brown and McCartney, 1986). At some levels of feed restriction (85%), the productive performance of breeder males is unaffected, although testes size decreases as the level of feed restriction increases (Brown and McCartney, 1983).

Feed intake can be lowered without a loss in reproductive capabilities (Buckner et al., 1986).

1.7.4 Overfeeding

The reproductive function of male broiler breeders in cages is more sensitive to underfeeding than overfeeding. *Ad libitum* feeding of young male broiler breeders stimulated some males to produced viable semen as early as 11 wk of age (McCartney, 1978). The males that produced semen at 11 wk of age also had fertility levels of 85 to 100% (McCartney, 1978).

In caged broiler breeder males, *ad libitum* feeding did not cause excessive body fat and even improved the quality and quantity of sperm (Sexton et al., 1989a). The semen concentration was higher for *ad libitum* fed males than restricted males, but only from 31 to 39 wk of age (Sexton et al., 1989a). Body and testes weight was increased with increased energy allotment, but carcass composition was unaltered (Attia et al., 1995).

1.7.5 Excess body weight and natural mating

In several commercial flocks experiencing depressed fertility, a significant negative relationship was reported between male BW and both mating activity and fertility (Burke and Mauldin, 1985). In broiler breeder flocks, fertility may be negatively affected by males fed *ad libitum* because they have a reduced success rate in natural mating. Full-size males can become obese and as a result suffer from foot and skeletal problems making males unwilling or unable to mate (Hocking and

Bernard, 1997a). Van Wambeke et al. (1981) reported a sharp decline in fertility after 54 wk of age. The males were unable to mate due to physical handicaps such as excessively high BW and leg problems. Hocking and Duff (1989) found male BW to have a greater effect on mating ability and therefore fertility than the occurrence of leg lesions at 60 wk of age. In broiler breeder males, feed restriction reduced the amount of weight the legs had to support, resulting in effective mating and greater fertility (Van Wambeke et al., 1979).

1.7.6 Competition

The problem remains that in a large flock situation some males are more aggressive at the feeder and consume more than their allotment of feed. Although acceptable fertility can be achieved by males within a wide range of BW to 40 wk of age, from 40 to 60 wk the optimum BW falls in an increasingly narrow range and fertility declines rapidly as BW deviates from this range (Hocking, 1990b). Poultry managers are continually forced to find a balance between sustaining the low BW males while preventing the high BW males from gaining an excess of breast muscle.

1.8 SKELETAL AND EXTERNAL CHARACTERISTICS

1.8.1 Sex separate feeding

Because of their privileged position in the social order, roosters consume more feed than the females in a restricted program (Van Wambeke and Okerman, 1976). Therefore, an effective control of feed consumption is only possible when broiler breeder males are reared separately from the females. Currently, almost all

breeder flocks are fed gender separate, meaning that the hens and roosters will have separate feeding systems (Hocking and Bernard, 2000).

Although the idea of sex separate feeding was developed mainly for better control of male feed intake and growth, excluding the males from the hen feeder also results in increased accuracy in the amount females eat. This is advantageous since fast growth is associated with low fertility in females (Soller and Rappaport, 1971). McDaniel (1987) reported that a simultaneous increase in fertility was associated with decreased male BW in breeder houses where sex-separate feeding was used.

Males are prevented from accessing the female feeders by using specialized equipment. A narrow grill over the feeder prevents males, which have wider head widths than females, from accessing the female feed. The difference between the male and female, head width and comb height, permits managers to use the sex separate feeding system. Hocking (1990b) reported female pullets averaged head widths of approximately 36 mm at 20 wk of age and this increases to approximately 38 mm by the end of the breeder cycle. Male broiler breeders had an average head width of 43 mm after 26 wk of age (Hocking, 1990b). But since there is variation in head width of both male and females, the system is not perfect, especially for young breeders (Hocking, 1990a).

1.8.2 Benefits of separate feeding

The body condition of individual hens also affects fertility, many of the reproductive problems associated with heavy breeders were the result of birds becoming overweight (McDaniel et al., 1981b). Fertility and the number of chicks per

hen can be increased if the sexes are fed separately using a specially designed, two-feeder arrangement (McDaniel, 1986). Optimal fertility was achieved in hens that are within 10% of mean BW for each age as specified by the primary breeder (Leeson and Summers, 2000).

Separate sex feeding of hens and roosters is almost universally accepted, although there has been a trend away from using specialized male diets, with all birds being fed diets formulated to the needs of the breeder hen (Leeson and Summers, 2000). This choice of diet for the males is based simply on convenience for the manager. Because the hen diet is of a higher nutrient density than specialized male diets, lower quantities are given, and in part this accounts for male aggressiveness in some flocks (Wood-Gush, 1971).

1.8.3 Skeletal size

Skeletal frame size is important to broiler breeder management for sex separate feeding systems. The height of the male feeder prevents the female from consuming male feed in broiler breeder housing systems. Males must be of greater height than the female to access the male feeder. Shank length has been suggested as a reliable measure of skeletal size (Jaap, 1938). Male frame size can be more thoroughly assessed with additional measurements of chest width and keel length.

Lerner (1937) suggested that body size may be limited by skeletal size and that increasing early skeletal size could result in an increase in body size. At the beginning of the production cycle there is overlap in body size between the male and female that makes accurate feed restriction difficult. Increasing early skeletal size in

male broiler breeders would be beneficial in separating the genders. Nutrition can markedly affect skeletal size, but not without affecting body size due to genetic correlation (Jull and Glazner, 1946). Jull and Glazner (1946) suggest that there is a concomitant increase in body weight, including breast muscle weight, with increasing skeletal size.

Different planes of nutrition can influence body composition and skeletal development in pullets with similar BW (Lilburn et al., 1989; Lilburn and Myers-Miller, 1990). However, while starter dietary protein level influences early skeletal size, protein level has little effect on mature BW or skeletal size (Hocking, 1990a). Correlation between BW and parameters of skeletal dimension declined with age (Hocking, 1990a).

1.8.4 Secondary sex characteristics

Easily observable traits of poultry, secondary sex characteristics, are used as a gauge of reproductive maturity and health status. Consequently secondary sex characteristics have been studied as an aid to management. Comb size is commonly used as a surrogate measure for development of reproductive function in chickens (Lowry, 1958). The effect of androgens on comb growth is well established and has been used as the basis of a relatively sensitive bioassay for androgens (Munson and Sheps, 1958).

During the period of rapid comb development in the hen, comb size is a measure of relative sexual development, in that birds with larger combs subsequently enter lay earlier than those with smaller combs (Eitan et al., 1998).

Fertility is poorly correlated with the physical characteristics of the male in natural mating (Wilson et al., 1979; Amann, 1999). Burrow and Titus (1939) observed that certain external characteristics such as size, color of wattles and comb, and libido are not reliable indices of the volume of semen a male can produce.

1.9 GROUP DYNAMICS

Animal behavior is the reaction of the whole organism to certain stimuli, or the manner in which it reacts to its environment (Ensminger, 1980). Behavior is important in obtaining maximum fertility and production efficiency. Maximum fertility is only achieved when males and females show competent mating behavior. Female laying behavior contributes to the production efficiency of the flock. However, poultry behavior has received less attention than the quantity and quality of the eggs and meat produced. This is due to a number of factors including the complexity of experimental design, difficulty in quantifying behavior, and differences between strains.

1.9.1 Confinement

Confinement has not only limited space, but it has interfered with the habit and social organization to which, through thousands of years of evolution, the species became adapted and best suited (Ensminger, 1980). Traditionally, chickens were kept in small groups with unlimited space. Presently, commercial chickens are confined in artificial spaces in large groups creating not only stress, but also a

difficult environment for studying behavior. In the study of behavior, research has focused on the aggression behavior, social status, and the nature of groups.

1.9.2 Aggression and dominance

In chickens, aggressive behavior includes attack, escape, avoiding, and submissive behavior (Ensminger, 1980). In a farmyard flock, as in a wild group, the first aggression experienced by young birds is probably that received from other members of the flock, when they move too close, or when they are in the way of older birds (Appleby et al., 1992). Later, particular chicks themselves become aggressive to contemporaries. Aggressive males denote their intentions by raising the hackles (feathers on the top of the neck) to make them look more formidable (Ensminger, 1980).

Birds quickly learn that they should avoid others, which will obviously be aggressive towards them, and that they will be able to beat others, which are much smaller or weaker (Appleby et al., 1992). In these circumstances, the most common form of aggression is pecking the head of the opponent (Wood-Gush, 1956). Birds that are not submissive avoid the most aggressive ones and join the attacks on the most submissive members of the flock (Appleby et al., 1992).

1.9.3 Social hierarchy

A relationship between two individuals in which one (the subordinate) avoids confrontation with the other (dominant) is called social dominance and the set of such relationships in a group is called a dominance hierarchy or peck order

(Schjelderup-Ebbe, 1922). Habits of either attack or escape are formed between all pair combinations in the flock (Guhl, 1958). There are usually certain individuals, perhaps smaller or weaker than others, which are frequently attacked (Appleby et al., 1992). Several factors may be associated with social status of birds, one of those being BW (Schjelderup-Ebbe, 1935; Allee et al., 1939). The posture and movement of birds, indicating confidence or the lack of it, reflects their status (Wood-Gush, 1971). A low crouch is a submissive response (Ensminger, 1980).

Birds that are more evenly matched are more likely to fight, in face-to-face encounters (Appleby et al., 1992). Some individuals give way without a fight, whereas others may challenge the winner again and again before dominance is established (Ensminger, 1980). The winner of these contests thereafter asserts its dominance by repeated pecking or threatening while the loser submits or avoids the dominant bird, thus reinforcing the decision reached at the first meeting (Guhl, 1958). Hard fought encounters may be followed by reinforcement activity by the dominant bird (Guhl, 1958). Some individuals may continue with symbolic threatening (Guhl, 1958). The result is the social inertia, which well acquainted flocks show as toleration (Guhl and Allee, 1944).

1.9.4 Recognition in groups

If the group is small enough for members to recognize each other individually, they remember the results of such fights and avoid fighting with others that have beaten them previously (Appleby et al., 1992). In a small, stable group aggression is

provoked by special circumstances such as restricted feeding space, because subordinates avoid dominant birds whenever possible (Appleby et al., 1992).

In commercial conditions, some birds become particularly aggressive and some birds are the recipients of repeated aggression, depending upon group size and stocking density. When frustrated, cockerels show a large increase in overt aggression towards hens that they normally passively dominate (Duncan and Wood-Gush, 1971). The most common aggressive behavior is forcing the hen into a crouch position (Jones et al., 2001). In larger groups, typical of most housing systems, there is no complete hierarchy (Appleby et al., 1992).

1.9.5 Stocking density and aggression

Aggression tends to decline as stocking density increases, perhaps because bird movements become restricted. In a perchery system with litter, the number of aggressive interactions per bird recorded was lower than in a comparison flock housed in cages (McLean et al., 1986), perhaps because hens were able to withdraw from potential interactions in three dimensions. If aggression is frequent, it can be reduced, along with other activity, by dim lighting (Hughes and Duncan, 1972). The other main management technique that reduces the effects of aggressive pecking is beak trimming (Gentle, 1986).

1.10 MATING BEHAVIOR

1.10.1 Introduction

Mating behavior can either contribute or limit the level of fertility of the flock. In chickens, one male monopolizes the mating of a group of females. Studies of feral fowl have described harems of four to twelve hens (McBride et al., 1969), but these must also depend on precise local conditions. The male usually takes the initiative in mating (Appleby et al., 1992). However, a female will usually only be receptive after courtship by a male, which varies between species and so ensures that the offspring will be viable. Social interactions that result in a reluctance of females to mate could impair the welfare of the birds owing to an increase in forced and aggressive mating (Millman et al., 1996; Millman et al., 1997).

Behavioral displays in the male are closely synchronized with those of the female, and are paralleled by endogenous changes in reproductive hormones (Feder et al., 1977; Silver et al., 1974). The frequency of mating by roosters of egg-type stocks was determined primarily by male libido and the fertility level attained was associated with the sex ratio (Craig et al., 1977). Mating behavior is affected not only by male aggression and female receptivity, but also by social interactions and the ratio of males to females.

1.10.2 Courtship

In jungle and domestic fowl, courtship is quite complex in its full form, with a pattern of stimulus and response between the male and female (Wood-Gush, 1956; Wood-Gush, 1971; Fischer, 1975). Early in courtship, the male performs some

movements that also occur in aggression between males, such as wing flapping, waltzing, cornering, tidbiting and feather ruffling (Wood-Gush, 1956; Wood-Gush, 1971). Waltzing is a sideways or circling movement with one wing trailing (Wood-Gush, 1954) that may intimidate the hen and encourage her to crouch (Ottinger and Brinkley, 1979). Cornering of females involves stamping and calling in a corner and often attracts the hen to approach (McBride et al., 1969). Tidbiting is when the male pecks and scratches at the ground (Wood-Gush, 1956).

Commercially reared broiler breeder males exhibit few of these courtship displays. Males usually approach the female from behind and attempt to mate regardless of the hen's receptivity (Jones et al., 2001). In most species, female receptivity involves crouching for the male to mount, although this does not occur in quail (Ottinger and Brinkley, 1979).

1.10.3 Sexual potential

Attempts to assess the sexual potential of males very early in life have not been successful (Wood-Gush, 1963), but tests of libido soon after sexual maturity give good predictions of fertility of subsequent mating (McDaniel and Craig, 1959). Wood-Gush and Osborne (1956) selected five cockerels highest in sex drive from a group and noted that they fertilized more females than the five lowest males. Males usually take the initiative in copulation and male libido is one of the main determinants of mating success (Justice et al., 1962). Individual males vary in libido, which suggests the possibility of selecting males based on mating behavior (Justice

et al., 1962). Unfortunately, selection for frequent mating tends to result in low semen volume (Appleby et al., 1992).

1.10.4 Forced mating

Jones et al. (2001) found that out of 365 recorded matings in groups of broiler breeders (4 males: 38 hens) 55% were forced, 49% unsuccessful, 83% exhibited no courtship and 47% exhibited aggressive behavior. Similarly, Millman et al. (1996) found 50% of matings were forced. Millman et al. (1996) hypothesized that deficiencies in male courtship behavior may result in the hens' lack of arousal and hence a reduction in crouching. Males would then adopt forced copulation as a mating strategy using their superior strength to force a hen to submit (Jones et al., 2001).

Intensive artificial selection may have produced a hen that requires little courtship behavior. Hens can 'escape' from the males by moving away during an attempt at mating (Jones et al., 2001). The most common form of unsuccessful mating behavior was due to the hen escaping (29% of all mating), followed in frequency by the male falling off the hen (17%) or the male being stopped by the presence of another male (3%) (Jones et al., 2001).

1.10.5 Preferential mating

The possibility remains that the lack of social interaction among birds in large flocks may contribute to poor fertility. Mating preferences have been observed in both males and females (Upp, 1928; Lill, 1966; Jones and Mench, 1991). Upp

(1928) reported that hens experienced a variation in the number of copulations, which indicates definite preferences were shown for certain hens. Jones (2001) found some evidence that hens may make choices between cockerels. Regardless of whether the male or female is responsible, it is evident that there are differences in the amount of mating seen in individuals.

1.10.6 Social experience and mating

Factors such as early social experience, hormonal levels, and preferential mating influence the level of sexual behavior (Parker et al., 1940). Earlier separation of males from females is associated with lower sexual performance by males (Ensminger, 1980). Guhl et al. (1945) observed that the sexual activity of low ranking cocks is suppressed when in competition with socially superior males. When several roosters are placed with a flock of hens, the dominant male is usually most successful in mating, fertilizing a large number of eggs, and siring a greater proportion of chicks (Guhl and Warren, 1946). Dominance among hens negatively affects mating, because such hens do not readily submit to the crouch (Ensminger, 1980).

1.10.7 Mating interference

Males often interfere with the mating of others, particularly with those that are subordinate. In certain conditions mating of low-ranking males can become completely suppressed, resulting in what has been called ‘psychological castration’ (Guhl et al., 1945). These conditions are not known in detail but probably involve

small groups and crowding, which encourage a strong hierarchy among the males (Appleby et al., 1992). High stocking density directly restricts courtship and mating (Kratzer and Craig, 1980).

In larger groups, rank seems to have less effect on mating by different males (Craig et al., 1977). In very large groups, it used to be thought that birds would form sub-groups (McBride and Foenander, 1962) that might act in a similar way to harems, but actually both males and females wander widely over most or all of the area (Appleby et al., 1985). It is possible that this leads to less interference in mating than in smaller groups.

1.10.8 Sex ratio

The number of females that one male is responsible for mating equals the sex ratio of a flock. Commonly used sex ratios for commercial flocks range from 6 to 14 males per 100 females with an average of 9 males per 100 females (Appleby et al., 1992). In New Hampshire flocks, maximum fertility was found with 6 or more roosters per 100 hens (Parker and Bernier, 1950). The upper limit for the number of White Leghorn females to which one male may mate and obtain optimum fertility is approximately 15 (Brantas et al., 1972).

The mating success of a flock will be affected not just by the sex ratio, but also by the precise housing conditions and the behavior of the birds. Variation in the sexual activity of individual males is likely to mean that the effective sex ratio is different from the actual sex ratio (Appleby et al., 1992). Little is known about these

aspects of reproduction because there have been almost no systematic studies of mating in commercial conditions.

1.10.9 Distribution of mating

Distribution of mating through the day is affected by the egg-laying cycle because fertility is lower when hen's are inseminated or mated around the time of oviposition. The majority of eggs are laid in the morning and so the chances for spermatozoa to encounter a hard-shelled eggs in the oviduct are greater (Upp, 1928). Correspondingly, males mate more frequently in the afternoon as opposed to the morning (Heuser, 1916; Upp, 1928; Parker et al., 1940; Craig and Bhagwat, 1974). Afternoon sexual receptivity among female quail that lay eggs in the afternoon is also decreased (Ottinger et al., 1982). The female's role in reproductive behavior is subtle compared to that of the male, but can have significant impact on mating patterns and individual success.

1.10.10 Frequency of mating

Males mate up to 41 times per day (Martin and Anderson, 1918; Parker et al., 1940). Craig et al. (1977) reported that males mated an average of 5 times per day. The average number of mating did not increase even with a sex ratio of 24 females per male (Craig et al., 1977).

Females in pens are often mated more than once daily (Kratzer and Craig, 1980). In a commercial broiler breeder house, however, hens averaged 0.48 matings

per day (Appleby et al., 1992). This appears to be more than sufficient considering that when hens are fertilized by artificial insemination, weekly intervals are used to maintain fertility (Craig, 1981; Clayton et al., 1985).

1.10.11 Sexual activity and offspring

Under conditions of natural mating lighter roosters are believed to copulate more frequently than heavier males and as a result a higher number of chicks originate from these males (Van Wambeke et al., 1979). However, sexual activity was not considered a reliable index of a male's reproductive capacity (Craft et al. 1926). Craft et al. (1926) suggested that sexually active birds often produce a higher percentage of dead or weak sperm than less active males.

Wood-Gush (1960) selected for high and low mating frequency and found that the high mating line produced relatively few ejaculations, suggesting that mating activity is not necessarily a reliable indicator of fertility. In natural mating, semen volume and sperm cell numbers decreased with each successive ejaculation and that very few sperm cells were observed after 3 or 4 ejaculations within a 60-min period (Parker et al., 1940). Sexton (1983) reported that broiler breeder males ejaculated five times per wk produced the highest total number of sperm per ejaculate.

1.11 REPRODUCTIVE DETERIORATION

1.11.1 Fertility declines with age

Age has an adverse effect on the reproductive success of birds (Mather and Laughlin, 1979; Noble et al., 1986; O'Sullivan et al., 1991; Latour et al., 1996). The age-related decrease in avian fertility is due, in part, to a decline in egg production (Atwood, 1929; Bahr and Palmer, 1989; Etches, 1990; Robinson et al., 1990). Lerner et al. (1993) reported a decline in fertility occurs once the species-specific maximum for egg production has been reached. While fertility over 95% can be achieved at the beginning of the reproductive period, fertility declines with increasing age after 45-50 wk of age in broiler breeder flocks (Hocking and Bernard, 1997b). Fiser and Chambers (1981) reported declines in fertility of 4.3 to 8.2% due to increased age (39 to 59 wk of age). In contrast, Bramwell et al. (1996b) reported fertility in naturally mated broiler breeder flocks reached 98% at 37 wk and decreased to 92.3% at 63 wk of age. In commercial production flocks, hatchability declines by 12% over a 40 wk period of lay from peak observations of 89% hatchability (North, 1984). In contrast, Hocking and Bernard (2000) found the age of the males had no effect on fertility or hatchability (to 57 wk).

1.11.2 Male contribution

Although males and females contribute to decreased fertility, low fertility is thought to be largely due to the male in broiler breeder flocks. As males age, there is a reduction in the number of spermatozoa in the ejaculate and also a reduction in semen volume (Renden et al., 1991; Rosenstrauch et al., 1994; de Reviers and

Brillard, 1986; Lake, 1989; Sexton et al., 1989a). Rosenstrauch et al. (1994) suggested that the age-related reduction in spermatozoa output per ejaculate could be a consequence of spermatozoa remaining trapped by Sertoli cells. The function of Sertoli cells may be impaired, resulting in their inability to release mature spermatozoa. Fertility levels can be maintained by artificial insemination although a greater number of spermatozoa may be required in late production (Soller et al., 1965). In contrast, Bramwell et al. (1996b) reported that fertility did not differ when hens were artificially inseminated using semen collected from either 39 or 63 wk old roosters.

1.11.3 Mating behavior declines with age

Mating frequency declines with age, but this may not directly result in lower fertility possibly because early mating is more frequent than necessary. Duncan et al., (1990) showed that the mating activity of the males was high during the early part of the breeding period when fertility was relatively poor. It is possible that both sexes are inexperienced during this time and that many apparent copulation's are not effective in transferring semen (Hocking and Bernard, 1997a).

The decline in motivation of the male is not caused by fatigue, but by habituation to the female stimulus. The male will resume active mating if another receptive female is available (Appleby et al., 1992). Habituation to particular females should not be a problem in large breeding flocks. It is not known however, whether it can occur in small breeding pens or cages (Appleby et al., 1992). Females contribute to the decline in mating frequency when they are not receptive to the male

because they are not in lay or have poor reproductive function and depressed estrogen synthesis late in lay (Hocking and Bernard, 2000).

The age-related decline in male fertility is due to a decline in libido, changes in body conformation that inhibit mating and in part to a reduction in sperm quality, (Brillard and McDaniel, 1986). Mating was observed more frequently in young (27 to 29 wk old) compared with mature (35 to 37 wk of age) males with both young and mature females (Hocking and Bernard, 2000). Broiler breeder males become very large and broad breasted towards the end of the reproductive period and may find it anatomically difficult to achieve cloacal contact (Hocking and Bernard, 1997a).

1.11.4 Spiking

Under natural mating situations a decline in fertility is common (Ottinger and Mench, 1989; Duncan et al., 1990; Hocking and Bernard, 1997a). In broiler breeder flocks, “spiking” is the addition of young males to a flock in mid production in an attempt to reduce declining fertility (Appleby et al., 1992). Males may also have to be added to breeding flocks if many of the original males die or have to be culled.

The need for spiking is probably related to ability or willingness of males to mate successfully, rather than to the fertilizing capacity of those males that are maintaining fertility of the flock (Casanovas, 1999). The introduction of young males to the flock increases the mating frequency both through the mating activity of young males themselves and indirectly through stimulation of the resident, older males (Appleby et al., 1992; Casanovas, 1999).

1.11.5 Mating proficiency

There is some evidence that the proficiency of mating by males increases with time (Guhl and Warren, 1946; Kratzer and Craig, 1980). Fertility of hens was improved when they were mated to older roosters (64 vs. 39 wk age) and improved fertility was correlated to more sperm penetration (Bramwell et al., 1996b). Young males have a lower percentage of complete mating when initially added to the flock, but show increased success over time (Appleby et al., 1992). The proportion of mountings that led to complete mating increased from 37% initially to 69% five wk after the males were introduced to a flock of hens (Kratzer and Craig, 1980).

Mating proficiency of the male is related to reception and participation by the hen's acceptance. Infertility is associated with a relatively small percentage of hens at any age. In naturally mated hens, about 4% of the hens were found to produce 40% of the unfertilized eggs (Leeson and Summers, 2000). Once these hens were inseminated, fertility was almost normal. This suggests that periods of infertility for individual hens are likely caused by hens not being sexually responsive to males or preferential mating of selected hens by the males (Leeson and Summers, 2000).

1.12 CONCLUSIONS

The production of fertile hatching eggs is the purpose of the broiler breeder flock. The number of fertile eggs produced for hatching dictates the ultimate profitability of the breeder flock. Selecting breeding males that have a high fertilizing capacity is a matter of economic importance because it has been estimated that about 10 to 15% of all chicken eggs incubated are infertile (Parker, 1949).

Broiler breeder males have a tendency to become overweight with age. Rapid growth and large appetite are desirable traits in broilers being grown for their meat. In the parent stock, this can inhibit reproductive performance resulting in a requirement for some form of controlled feeding. The breeder manager, to some extent, can manipulate reproductive processes by controlling BW and BW gain in both sexes. A decline in the fertility of commercial flocks is likely to be the result of management failures, particularly in the control of male BW.

Hormones largely control sexual behavior involving courtship and mating. The stocking density, sex ratio, and environmental conditions of the flock affect aggression, dominance and mating behavior. These factors can in turn affect the mating frequency of the flock altering the fertility of the hatching eggs produced. An understanding of reproductive physiology, hormones, BW management and behavior will aid producers in attaining the optimum performance from broiler breeders.

1.13 OBJECTIVES

Primary breeder companies have used the 6 wk BW of male broiler breeder parent stock to select the males with rapid growth rates. By feeding parent stock a broiler diet (broilerizing) to 6 wk of age, the broiler breeder males reach their 14 wk BW target at 6 wk of age. The males must then undergo a period of severe feed restriction to keep BW under control (Van Wambeke et al., 1979).

Body weight has been associated with increased skeletal frame size. Shank length (Jaap, 1938) and more recently chest width, keel length and head width have

been associated with skeletal frame size. Skeletal frame size, in particular head width, impacts the ability of the producer to control male BW.

Feed restriction is used to control BW. To maintain all males at an average BW, severe feed restriction levels are required. However, even under severe feed restriction, males have a wide range in BW. In some cases, broiler breeder males in typical housing systems are under-fed due to competition with large males. Male broiler breeders that are not as successful at the feeder can begin to lose BW. High BW males that are over the recommended target BW in rearing often maintain above average BW throughout production. Although all males are managed as an average BW bird, the differences in rearing BW may impact the reproductive abilities of these birds.

Broiler breeder managers have been searching for methods of assessing male reproductive performance. External characteristics such as comb height and shank color are easily observable and could be related to male reproduction. Comb growth has not been assessed in relation to testes weight. Shank color is typically yellow in young birds. A stripe of red pigmentation has been observed in reproductively active males.

Producing viable semen for reproduction is a primary function of the male. In the case of natural mating, the function of the male is to produce viable sperm in the testes and then to efficiently transport these to the cloaca of the hen during mating (Nishiyama, 1955). Sexual behavior involves courtship and mating. The breeder manager to some extent can manipulate reproductive processes in both sexes. An

understanding of reproductive physiology, BW management, and behavior will aid producers in attaining the optimum performance from broiler breeders.

The objectives of this research were to assess the:

1. effects of rearing BW and severe feed restriction before photostimulation on:
    - carcass characteristics,
    - external characteristics,
    - skeletal frame size, and
    - reproductive characteristics.
2. relationship between
    - shank color and testes weight and
    - comb height and semen production.
3. effect of BW loss in adult male broiler breeders on:
    - reproductive characteristics.
4. effect of BW gains in adult male broiler breeders on:
    - the interactions between male and female broiler breeders,
    - mating behavior, and
    - fertility.

1.14 REFERENCES

Ahima, R. S., D. Prabakaran, C. Mantzoros, D. Q. Qu, B. Lowell, E. Maratos-Flier, and J. S. Flier, 1996. Role of leptin in the neuroendocrine response to fasting. Nature. 382:250-252.

Aire, T. A., M. O. Olowo-okorun, and J. S. Ayeni, 1980. The seminiferous epithelium in the Guinea Fowl (*Numidia meleagris*). Cell Tissue Res. 205:319-329.

Allee, W. C., N. E. Collias and C. Z. Lutherman, 1939. Modifications of the social order in flocks of hens by the injection of testosterone propionate. Physiol. Zool. 12:412-440.

Amann, R. P., 1999. Lessons for the poultry industry gleaned from experiences with other commodity species. Poult. Sci. 78:419-427.

Ansah G. A., D. C. Crober, R. B. Buckland, A. E. Sefton, and B. W. Kennedy, 1980. Artificial insemination of individually caged broiler breeders. 1. Reproductive performance of males in relation to age and strain of females. Poult. Sci. 59:428-37.

Appleby, M. C., S. N. Maguire, and H. E. McRae, 1985. Movement by domestic fowl in commercial flocks. Poult. Sci. 64:48-50.

Appleby, M. C., B. O. Huges, and H. A. Elson, 1992. Poultry Production Systems: Behavior, Management and Welfare. CAB International, Wallingford, Oxon, UK.

Attia, Y. A., W. H. Burke, K. A. Yamani, and L. S. Jensen, 1995. Daily energy allotments and performance of broiler breeders. 1. Males. Poult. Sci. 74:247-260.

Atwood, H., 1929. Observations concerning the time factor in egg production. Poult. Sci. 8:137-140.

Bacon, W. L., J. A. Proudman, D. N. Foster, and P. A. Renner, 1991. Pattern of secretion of luteinizing hormone and testosterone in the sexually mature male turkey. Gen. Comp. Endocrinol. 84:447-460.

Bahr, J. M. and S. S. Palmer, 1989. The influence of aging on ovarian function. Crit. Rev. Poultry Biol. 2:103-110.

Bakst, M. R. and B. Howarth, Jr., 1977. Hydrolysis of the hen's perivitelline layer by cock sperm in vitro. Biol. Reprod. 17:370-379.

Bakst, M. R., G. Wishart, and J. P. Brillard, 1994. Oviductal sperm selection, transport, and storage in poultry. Poult. Sci. Rev., 5:117-143.

Barash, I., Z. Nitsan, and I. Nir, 1992. Metabolic activity and behavioral adaptation of light-bodied chicks to meal feeding. Br. Poult. Sci. 33:271-278.

Bramwell, R. K., H. L. Marks, and B. Howarth, 1995. Quantitative determination of spermatozoa penetration of the perivitelline layer of the hen's ovum as assessed on oviposited eggs. Poult. Sci. 74:1875-1883.

Bramwell R. K., C. D. McDaniel, W. H. Burke, J. L. Wilson, and B. Howarth, 1996a. Influence of male broiler breeder dietary energy intake on reproduction and progeny growth. Poult. Sci. 75:767-775.

Bramwell R. K., C. D. McDaniel, J. L. Wilson, and B. Howarth, 1996b. Age effect of male and female broiler breeders on sperm penetration of the perivitelline layer overlying the germinal disc. Poult. Sci. 75:755-762.

Brann, D. W. and V. B. Mahesh, 1997. Excitatory amino acids: Evidence for a role in the control of reproduction and anterior pituitary hormone secretion. Endocr. Rev. 18:678-700.

Brantas, G. C., H. G. Dennert, and A. L. Dennert-Distelbrink, 1972. The influence of the number of cocks on the conception rate among White Leghorns. Arck. Gefleugelkd. 36:16.

Breneman, W. R. and R. C. Mason, 1951. Androgen influence on pituitary-gonad relationships in the chick. Poult. Sci. 30:231-239.

Brillard, J. P., 1993. Sperm storage and transport following natural mating and artificial insemination. Poult. Sci. 72:923-928.

Brillard J. P. and G. R. McDaniel, 1986. Influence of spermatozoa numbers and insemination frequency on fertility in dwarf broiler breeder hens. Poult. Sci. 65:2300-2334.

Brody, T., Y. Eitan, M. Soller, I. Nir, and Z. Nitsan, 1980. Compensatory growth and sexual maturity in broiler females reared under severe food restriction from day of hatching. Br. Poult. Sci. 21: 437-446.

Brown, H. B. and M. G. McCartney, 1983. Effects of dietary restriction on reproductive performance of broiler breeder males. Poult. Sci. 62:1885-1888.

Brown, H. B. and M. G. McCartney, 1986. Restricted feeding and reproductive performance of individually caged broiler breeder males. Poult. Sci. 65:850-855.

Brown, N. L., J. D. Bayle, C. G. Scanes, and B. K. Follet, 1975. Chicken gonadotrophins: Their effects on the testes of immature and hypophysectomized Japanese quail. Cell Tissue Res. 156:499.

Buckner R. E., J. A. Renden, and T. F. Savage, 1986. The effect of feeding programs on reproductive traits and selected blood chemistries of caged broiler breeder males. Poult. Sci. 65:85-91.

Burke, W. H. and J. M. Mauldin, 1985. Reproductive characteristics of broiler breeder males from flocks with low fertility. Poult. Sci. 64(Suppl.1):73.(Abstr.).

Burrows, W. H. and J. P. Quinn, 1937. The collection of spermatozoa from the domestic fowl and turkey. Poult. Sci. 16:19-24.

Burrows, W. H. and H. W. Titus, 1939. Some observations on the semen production of the male fowl. Poult. Sci. 18:8-10.

Caro, J. F., M. K. Sinha, J. W. Kolaczynski, P. L. Zhang, and R. V. Considine, 1996. Leptin: The tale of an obesity gene. Diabetes. 45-1455-1462.

Carsia R. V. and S. Harvey, 2000. Adrenals. In Sturkie's Avian Physiology (G. C. Whittow, ed.), 5th edition, pp.489-537. Academic Press, San Diego, CA.

Casanovas, P., 1999. Methods of alleviating the age-related decline in the fertility of broiler breeder males. M. S. Thesis, The University of Georgia, Athens, GA.

Cerolini S., C. Mantovani, F. Bellagamba, M. G. Mangiagalli, L. G. Cavalchini, and R. Reniero, 1995. Effect of restricted and *ad libitum* feeding on semen production and fertility in broiler breeder males. Br. Poult. Sci. 36:677-82.

Chehab, F. F., 2000. Leptin as a regulator of adipose mass and reproduction. Trends Pharm. Sci. 21:309-314.

Chehab, F. F., M. E. Lim, and Lu RongHua, 1996. Correction of the sterility defect in homozygous obese female mice by treatment with human recombinant leptin. Nat. Genet. 12:316-320.

Christensen, V. L., 1981. Effects of insemination intervals on oviductal sperm storage in turkeys. Poult. Sci. 60:2150-2156.

Clayton, G. A., P. E. Lake, C. Nixey, D. R. Jones, D. R. Charles, J. R. Hopkins, J. A. Binstead, and R. Pickett, 1985. Turkey Production: Breeding and Husbandry, Ministry of Agriculture, Fisheries and Food. Ref. 242. London, Her Majesty's Stationery Office.

Collias, N. E., 1950. Hormones and behavior with special reference to birds and the mechanisms of hormone action. A Symposium on Steroid Hormones, 277-329. University of Wisconsin Press, Madison.

Considine, R. V. and J. F. Caro, 1997. Leptin and the regulation of body weight. Int. J. Biochem. Cell Biol. 29:1255-1272.

Cooksey, E. J. and B. Rothwell, 1973.The ultrastructure of the Sertoli cell and its differentiation in the domestic fowl (*Gallus domesticus*). J. Anat.114:329-345.

Craft, W. A., C. H. McElroy, and R. Penquite, 1926. The influence of certain feeds upon the production of spermatozoa by the domestic chicken. Poult. Sci. 5:187-198.

Craig, J. V., 1981. Domestic animal behavior: Causes and implications for animal care management, New Jersey, Prentice Hall.

Craig, J. V. and A. L. Bhagwat, 1974. Agonistic and mating behavior of adult chickens modified by social and physical environments. Appl. Anim. Et. 56:762-772.

Craig, J. V., B. Al-Rawi, and D. D. Kratzer, 1977. Social status and sex ratio effects on mating frequency of cockerels. Poult. Sci. 56:767-772.

Culbert, J., P. J. Sharp, and J. W. Wells, 1977. Concentrations of androstenedione, testosterone and LH in the blood before and after the onset of spermatogenesis in the cockerel. J Repro. Fert. 51:153-154.

Davis, D. E. and L. V. Domm, 1943. The influence of hormones of the sexual behavior of domestic fowl. Essay in Biology, 171-181, University of California Press, Berkeley.

Donoghue, A. M., 1999. Prospective approach to avoid flock fertility problems: Predictive assessment of sperm function traits in poultry. Poult. Sci. 78:437-443.

Driot, F. J. M., M. de Reviers, and J. B. Williams, 1979. Plasma testosterone levels in intact and hemicastrated growing cockerels. J. Endocr. 81:169-174.

Duncan, I. J. H., P. M. Hocking, and E. Seawright, 1990. Sexual behavior and fertility in broiler breeder domestic fowl. Appl. Anim. Behavior Sci. 26:1-12.

Duncan, I. J. H., and D. G. M. Wood-Gush, 1971. Frustration and aggression in the domestic fowl. Anim. Behav. 19:500-504.

Dunn, L. C., 1927. Selective fertilization in fowls. Poult. Sci. 6:201-214.

Dupuy, V. and E. Blesbois, 1996. The effects of age on the composition of uterine fluid of broiler breeder hens on maintenance of quality of fowl spermatozoa

when stored in uterine fluid of in a synthetic medium. Theriogenology. 45:1221-1234.

Eden, F. W. and H. S. Siegel, 1975. Adrenal responses in high and low ACTH response lines of chickens during acute heat stress. J. Comp. Endo. 25:64-73.

Eitan, Y., M. Soller, and I. Rozenboim, 1998.Comb size and estrogen levels towards the onset of lay in broiler layer strain females under *ad libitum* and restricted feeding. Poult. Sci. 77:1593-1600.

El Halawani, E. M., E. P. Waibel, R. J. Appel, and L. A. Good, 1973. Effects of temperature stress on catecholamines and corticosterone of male turkeys. Am. J. Phy. 224:384-388.

Ensminger, M. E., 1980. Poultry Science. 2nd ed. The Interstate Printers & Publishers, INC. Danville, Illinois.

Esponda, P. and J. M. Bedford, 1985. Surface of the rooster spermatozoan changes in passing through the Wolffian ducts. J. Exp. Zool. 234:441-449.

Etches, R. J., 1990. The ovulatory cycle of the hen. Crit. Rev. Poult. Biol. 2:293-318.

Etches, R. J., 1996. Reproduction in Poultry. CAB International, University Press, Cambridge, UK.

Etches, R. J., R. B. Buckland, and R. O. Hawes, 1974. The effect of genes for rose comb and polydactyly on sperm transport in the hen's oviduct. Poult. Sci. 53:422-424.

Fasenko, G. M., R. T. Hardin, and F. E. Robinson, 1992. Relationship of hen age and sequence position with fertility, hatchability, viability, and preincubation embryonic development in broiler breeders. Poult. Sci. 71: 1374-1383.

Fattori, T. R., H. R. Wilson, R. H. Harms, and R. D. Miless, 1991. Response of broiler breeder females to feed restriction below recommended levels. 1. Growth and reproductive performance. Poult. Sci. 70:26-36.

Feder, H. H., A. Storey, D. Goodwin, C. Reboulleau, and R. Silver, 1977. Testosterone and "5á –dihydrotestosterone" levels in peripheral plasma of male and female ring doves (*Streptopelia risoria*) during the reproductive cycle. Biol. Reprod. 16:666.

Fischer, G. J., 1975. The behavior of chickens. In: The Behavior of Domestic Animals, 3rd edn. (Hafez, E.S.E. ed.) 454-489. London, Bailliere Tindall.

Fiser, P.S. and J. R. Chambers, 1981. Determination of male fertility in thirteen commercial lines of broiler parents. Poult. Sci. 60:2316-2321.

Fontana, E. A., W. D. Weaver Jr., and H. P. Van Krey, 1990. Effects of various feeding regimens on reproduction in broiler-breeder males. Poult. Sci. 69:209-16.

Froman, D. P. and D. J. McLean, 1996. Objective measurement of sperm motility based upon sperm penetration of Accudenz. Poult. Sci. 75:776-784.

Fronda, F. M., 1926. Studies on fertility in the hen's egg. Phillipine Agriculturist. 15:349-360.

Fuquay, J. I. And J. A. Renden, 1980. Reproductive performance of broiler breeders maintained in cages or on floors through 59 weeks of age. Poult. Sci. 59:2525-2531.

Garnier, D. H., A. Tixier-Vidal, D. Gourdji, and R. Picart, 1973. Ultrastructure des cellules de Sertoli au caurs du cycle testiculaire du Canard Pekin. Z. Zellforsch. Mikrosk. Anat. 144:369.

Gentle, M. J., 1986. Beak trimming in poultry. World's Poult. Sci. J. 42:268-275.

Glover, T. D. and L. Nicander, 1971. Some aspects of structure and function in the mammalian epididymis. J. Reprod. Fert. Suppl. 13:39-50.

Guhl, A. M., 1958. The development and social organization in the domestic chick. Brit. J. Anim. Behav. 6:92-111.

Guhl, A. M. and W. C. Allee, 1944. Some measurable effects of social organization in flocks of hens. Physiol. Zool. 17:320-347.

Guhl, A. M., N. E. Collias, and W. C. Allee, 1945. Mating behavior and the social hierarchy in small flocks of White Leghorns. Phys. Zoology. 18:365-390.

Guhl, A. M. and D. C. Warren, 1946. Number of offspring sired by cockerel's related to social dominance in chickens. Poult. Sci. 25:460-472.

Harms, R. H., 1984. The influence of feeding program on peak production and avoiding sudden declines in production with broiler breeders. Poult. Sci. 63:1667-1668.

Harris G. C. Jr., J. A. Benson, and R. S. Sellers, 1984. The influence of day length, body weight, and age on the reproductive ability of broiler breeder cockerels. Poult. Sci. 71:1705-1710.

Hebebrand, J., W. F. Blum, N. Barth, H. Coners, P. Englaro, A. Juul, A. Ziegler, A. Warnke, W. Rascher, and H. Remschmidt, 1997. Leptin levels in patients with anorexia nervosa are reduced in the acute stage and elevated upon short-term weight restoration. Mol. Psychiatry. 2:330-334.

Heiman, M. L., Y. Chen, and J. F. Caro, 1998. Leptin participates in the regulation of glucocorticoid and growth hormone axes. J. Nutr. Biochem. 9:553-559.

Heuser, G. F., 1916. A study of the mating behavior of the domestic fowl. Thesis, Cornell Univ.

Hill, R. T. and A. S. Parks, 1934. Hypophysectomy of birds. III. Effect on gonads, accessory organs, and head furnishing. Proc. Roy. Soc. London, B. 116:221-236.

Hocking, P.M., 1990a. Assessment of the effects of separate sex feeding on the welfare and productivity of broiler breeder females. Br. Poult. Sci. 31:457-463.

Hocking, P.M., 1990b. The relationships between dietary crude protein, body weight, and fertility in naturally mated broiler breeder males. Br. Poult. Sci. 31:743-757.

Hocking, P. M., 1993. Effects of body weight at sexual maturity and the degree and age of restriction during rearing on the ovarian follicular hierarchy of broiler breeder females. Br. Poult. Sci. 34:793-801.

Hocking, P. M. and R. Bernard, 1997a. Effects of male body weight, strain and dietary protein content on fertility and musculo-skeletal disease in naturally mated broiler breeder males. Br. Poult. Sci. 38:29-37.

Hocking, P. M. and R. Bernard, 1997b. Effects of dietary crude protein content and food intake on the production of semen in two lines of broiler breeder males. Br. Poult. Sci. 28:199-202.

Hocking, P. M. and R. Bernard, 2000. Effects of age of male and female broiler breeders on sexual behavior, fertility and hatchability of eggs. Br. Poult. Sci. 41:370-377.

Hocking, P. M. and S. R. I. Duff, 1989. The incidence of musculo-skeletal lesions in adult male broiler breeder fowls and their relationships with body weight and fertility at 60 wk of age. Br. Poult. Sci. 30:777-784.

Hocking, P. M., A. B. Gilbert, M. Walker, and D. Waddington, 1987. Ovarian follicular structure of White Leghorns fed *ad libitum* and dwarf and normal birds fed *ad libitum* or restricted to point of lay. Br. Poult. Sci. 28:493-506.

Hocking, P. M., D. Waddington, M. Walker, and A. B. Gilbert, 1989. Control of the development of the follicular hierarchy in broiler breeder pullets by food restriction during rearing. Br. Poult. Sci. 30:161-174.

Hossner, K. L., 1998. Cellular, molecular and physiological aspects of leptin: Potential application in animal production. Can. J. Anim. Sci. 78:463-472.

Hughes, B. O. and I. J. H. Duncan, 1972. The influence of strain and environmental factors upon feather pecking and cannibalism in fowls. Br. Poult. Sci. 13:525-547.

Jaap, R. G., 1938. Breeding for body shape in chickens. US Egg Poultry Mag. 44:488-503.

Johnson, A. L., 1986. Reproduction in the Male. In: Avian Physiology. Springer-Verlag, New York, NY. Chp. 19.

Jones, E. K. M., N. B. Prescott, P. Cook, R. P. White, and C. M. Wathes, 2001. Ultraviolet light and mating behavior in domestic broiler breeders. Br. Poult. Sci. 42:23-32.

Jones, M. E. S. and J. A. Mench, 1991. Behavioral correlates of male success in multisire flock as determined by DNA fingerprinting. Poult. Sci. 70:1493-1498.

Jull, M. A. and E. W. Glazner, 1946. Rate of growth in progeny to ten weeks in relation to shank length of parents. Poult. Sci. 25:256-261.

Justice, W. P., G. R. McDaniel, and J. V. Craig, 1962. Techniques for measuring sexual effectiveness in male chickens. Poult. Sci. 41:732-739.

Katanbaf, M. N., E. A. Dunnington, and P. B. Siegel, 1989. Restricted feeding in early and late-feathering chickens. 2. Reproductive Responses. Poult. Sci. 68:352-358.

Kosin, I. I., 1945. The accuracy of the macroscopic method in identifying fertile unincubated germ discs. Poult. Sci. 24:281-295.

Kratzer, D. D. and J. V. Craig, 1980. Mating behavior of cockerels: Effects of social status, group size and group density. Appl. Anim. Ethology. 6:49-62.

Lake, P. E., 1954. The relationship between morphology and function in fowl spermatozoa. Proc. X. World's Poultry Congr. Sec A, p.79.

Lake, P. E., 1956. The structure of the germinal epithelium of the fowl testis with special reference to the presence of multinuclear cells. Q. J. Microscopical Sci. 97:487-497.

Lake, P. E., 1957. The male reproductive tract of the fowl. J. Anatomy. 91:116-129.

Lake, P. E., 1971. The male in reproduction. In: Physiology and Biochemistry of the Domestic Fowl, Vol III. (D. J. Bell and B. M. Freeman, eds.). London and New York. Academic Press, Chp 60.

Lake, P. E., 1981. Male genital organs. In: Form and Function in Birds, vol. 2. (A. S. King and J. M. McLelland. Academic Press, London, pp. 1-61.

Lake, P. E., 1989. Recent progress in poultry production. World's Poult. Sci. J. 45:53-59.

Lake, P. E. and J. Smiles, 1952. Some observations on the morphology of fowl spermatozoa. Proc. Soc. Study of Fertility. 4:18.

Latour, M. A., E. D. Peebles, C. R. Boyle, S. M. Doyle, T. Pansky, and J. D. Brake, 1996. Effects of breeder hen age and dietary fat on embryonic and neonatal broiler serum lipids and glucose. Poult. Sci. 75:695-701.

Leeson, S. and J. D. Summers, 2000. Broiler Breeder Production. University Books, Guelph, Ontario, Canada.

Lerner, I. M., 1937. Shank length as a criterion of inherent size. Poult. Sci. 16:213-215.

Lerner, S. P., N. French, D. McIntyre, and C. Baxter-Jones, 1993. Age-related changes in egg production, fertility, embryonic mortality, and hatchability in commercial turkey flocks. Poult. Sci. 72:1025-1039.

Liburn, M. S., and D. J. Myers-Miller, 1990. Effect of body weight, feed allowance, and dietary protein intake during the prebreeder period on early reproductive performance of broiler breeder hens. Poult. Sci. 69:1118-1125.

Liburn, M. S., K. Ngiam-Rilling, and D. J. Myers-Miller, 1989. Growth and development of broiler breeders. 2. Independent effects of dietary formulation versus body weight on skeletal and muscle growth. Poult. Sci. 68:1274-1281.

Lill, A., 1966. A review of non-random mating behavior in domestic poultry. Poult. Rev. 6:51-56.

Lister, D., T. Cowen, and R. A. McCance, 1966. Severe under-nutrition in growing and adult animals. 16. The ultimate results of rehabilitation. Poult. Br. J. Nutr. 20-663-339.

Lodge, J. R., R. L. Ax, and N. S. Fechheimer, 1974. Chromosome aberrations in embryos from *in vivo* aged chicken sperm. Poult. Sci. 53:1816-1819.

Lodge, J. R., N. S. Fechheimer, and R. G. Jaap, 1971. The relationship of *in vivo* sperm storage interval to fertility and embryonic survival in the chicken. Biol. Reprod. 5:252-257.

Lofts, B. and R. Massa, 1980. Male Reproduction. In: Avian Endocrinology (a. Epple and M. H. Stetson, Eds.). London and New York: Academic Press, p. 413.

Lofts, B. and R. K. Murton, 1973. Reproduction in Birds. In: Avian Biology, Vol. 3. (D. S. Farner, J. R. King, and K. C. Parkes, Eds.). London and New York: Academic Press. Chp 1.

Lowry, M. M., 1958. Compensatory testicular adjustments following injection of small quantities of androgen into unilaterally castrated White Leghorn cockerels. Poult. Sci. 37:1129-1136.

Mann, T., 1954. The biochemistry of semen. John Wiley and Sons, Inc. pp. 54-82.

Mantzoros, C., J. S. Flier, M. D. Lesem, T. D. Brewerton, and D. C. Jimerson. 1997. Cerebrospinal fluid and leptin in anorexia nervosa: correlation with nutritional status and potential role in resistance to weight gain. J. Clin. Endocrinol. Met. 82: 1845-1851.

Martin, J. H. and W. S. Anderson, 1918. The result of single one day mating. J. Amer. Instr. and Inves. Poultry Husb. 5:22-23

Mashaly, M. M. and B. Glick, 1979. Comparison of androgen levels in normal males (*Gallus domesticus*) and in males made sexually inactive by embryonic exposure to testosterone propionate. Gen. Comp. Endocrin. 38:105-110.

Mather, C. M. and K. F. Laughlin, 1979. Storage of hatching eggs: The interaction between parental age and early embryonic development. Br. Poult. Sci. 20:595-604.

Mather, J. P., A. Moore, and R. Li, 1997. Activins, inhibins, and follistatins: Further thoughts on a growing family of regulators. Proc. Soc. Exp. Biol. Med. 215:209-222.

Matkovic, V., J. Z. Ilich, M. Skugor, N. E. Badenhop, P. Goel, A. Clairmont, D. Klisovic, R. W. Nahhas, and J. D. Landoll, 1997. Leptin is inversely related to age at menarche in human females. J. Clin. Endocrinol. Metab. 82:3239-3245.

Mauldin, J. M., 1989. An analysis of reproductive efficiency in Georgia hatcheries. In: Proceedings from 22nd World's Poultry Science Association Symposium on Avian Embryology and Incubation. West of Scotland College, Ayr, Scotland, UK.

Maung, Z. W. and B. K. Follett, 1977. Effects of chicken and ovine luteinizing hormone on androgen release and cyclic AMP production by isolated ells from the quail testis. Gen. Comp. Endocrinol. 33:242-253.

McBride, G., I. P. Parer, and F. Foenander, 1969. The social organization and behavior of the feral domestic fowl. Anim. Behav. Monographs. 2:125-181.

McBride, G. and F. Foenander, 1962. Territorial behavior in flocks of domestic fowls. Nature. 194:102.

McCartney, M. G., 1978. Sexual maturity in broiler breeder males. Poult. Sci. 57:1720-1722.

McDaniel C. D., J. L. Hannah, H. M. Parker, T. W. Smith, C. D. Schultz, and C.D. Zumwalt, 1998. Use of a sperm analyzer for evaluating broiler breeder males. 1. Effects of altering sperm quality and quantity on the sperm motility index. Poult. Sci. 77:888-93.

McDaniel, G. R., 1983. Factors affecting broiler breeder performance. 5. Effects of preproduction feeding regimens on reproductive performance. Poult. Sci. 62:1949-1953.

McDaniel, G. R., 1986. Sex separate feeding of broiler parent stock. Zootech. Int. 11:54-58.

McDaniel, G. R., 1987. Relationship of fertility, hatchability, and average weight of males to diet in separate feeding systems. Poult. Sci. 66(Suppl. 1):141. (Abstr.)

McDaniel, G. R., J. Brake, and R. D. Bushong, 1981a. Factors affecting broiler breeder performance. 1. Relationship of daily feed intake level to reproductive performance of pullets. Poult. Sci. 60:307-312.

McDaniel, G. R., J. Brake, and R. D. Bushong, 1981b. Factors affecting broiler breeder performance. 4. The interrelationship of some reproductive traits. Poult. Sci. 60:1792-1797.

McDaniel, G. R. and J. V. Craig, 1959. Behavior traits, semen measurements and fertility of White Leghorn males. Poult. Sci. 38:1005-1014.

McDaniel, G. R. and T. J. Sexton, 1977. Frequency of semen collection in relation to semen volume, sperm concentration and fertility in the chicken. Poult. Sci. 56:1989-1993.

McLean, D. J. and D. P. Froman, 1996. Identification of a sperm cell attributed responsible for subfertility of roosters homozygous for the rose comb allele. Bio. Repro. 54:168-172.

McLean, K. A., M. R. Baxter, and W. Michie, 1986. A comparison of the welfare of laying hens in battery cages and in a perchery. Res. and Dev. in Ag. 3:93-98.

Millman, S. T., I. J. H. Duncan, and T. M. Widowski, 1996. Forced copulations by broiler breeder males. Proceedings of the 30th International Congress of the ISAE, Guelph, p. 50.

Millman, S. T., I. J. H. Duncan, and T. M. Widowski, 1997. Extreme aggression in male broiler breeder fowl. Proceedings of the 31th International Congress of the ISAE, Prague, p. 188.

Mounzih, K., R. Lu, and F. F. Chehab, 1997. Leptin treatment rescues the sterility of genetically obese ob/ob males. Endocrinology. 138:1190-1193.

Munro, S. S., 1938a. Functional changes in fowl sperm during their passage through the excurrent ducts of the male. J. Exp. Zool. 79:71-92.

Munro, S. S., 1938b. The effect of dilution and density on fertilizing capacity of fowl sperm suspensions. Can. J. Res. 16:281-297.

Munson, P. L. and M. C. Sheps, 1958. An improved procedure for the biological assay of androgens by direct application to the combs of bay chicks. Endocrinology. 62:173.

Nalbandov, A. V., 1958. Reproductive Physiology. W. H. Freeman and Company, San Francisco. pp. 49-97.

Nalbandov, A. V. and L. E. Card, 1943. Effect of stale sperm on fertility and hatchability of chicken eggs. Poult. Sci. 22:218-226.

Nickel, R., A. Schummer, E. Seiferle, W. G. Siller, and P. A. L. Wight, 1977. Urogenital system. In: Anatomy of the Domestic Birds, Springer-Verlag, Berlin. Pp. 70-84.

Nicholaides, C., 1934. Fertility studies in poultry. Poult. Sci. 13:178-183.

Nicholls, T. J. and G. P. Graham, 1972. Observations on the ultrastructure and differentiation of Leydig cells in the testes of Japanese quail (*Coturnix coturnix japonica*). Biol. Reprod. 6:179.

Nir, I., Z. Nitsan, E. A. Dunnington, and P. B. Siegel, 1996. Aspects of food intake restriction in young domestic fowl: Metabolic and genetic considerations. World's Poult. Sci. J. 52:251-266.

Nir, I., D. Yam, and M. Perek, 1975. Effects of stress on the corticosterone content of the blood plasma and adrenal gland of intact and bursectomized *Gallus domesticus*. Poult. Sci. 54:2101-2110.

Nishiyama, H., 1950. On the difference of the forms of phallus in the adult cock. Sci. Bull. Fac. Agric. Kyushu, 12:47-50.

Nishiyama, H., 1951. Studies on the physiology of reproduction in the male fowl. III. On the addition of transparent fluid to the cock's semen. Sci. Bull. Fac. Agric. Kyushu. 13:377-387.

Nishiyama, H., 1952. Studies on the physiology of reproduction in the male fowl. IV. On the mechanism of the ejection of transparent fluid. Sci. Bull. Fac. Agric. Kyushu. 12:283-292.

Nishiyama, H., 1955. Studies on the accessory reproductive organs in the cock. J. Fac. Agric. Kyushu Univ., 10:277-305.

Noble, R. C., F. Lonsdale, K. Conner, and D. Brown, 1986. Changes in lipid metabolism in the chick embryo with parent age. Poult. Sci. 65:409-416.

North, M. O., 1984. Commercial Chicken Production Manual. AVI Publishing Co. Inc. Westport, Connecticut.

O'Sullivan, N. P., E. A. Dunnington, and P. B. Siegel, 1991. Relationships among age of dam, egg components, embryo lipid transfer, and hatchability of broiler breeder eggs. Poult. Sci. 70:2180-2185.

Ottinger, M. A. and H. J. Brinkley, 1979. The ontogeny of crowing and copulatory behavior in Japanese quail (Coturnix coturnix japonica). Behav. Pro. 4:43-51.

Ottinger, M. A. and J. A. Mench, 1989. Reproductive behavior in poultry: Implications for artificial insemination technology. Br. Poult. Sci. 30:431-442.

Ottinger, M. A., W. M. Schleidt, and E. Russek, 1982. Daily patterns in courtship and mating behavior in the male Japanese quail. Behav. Pro. 7:223-233.

Parker, H. M., J. B. Yeatman, C. D. Schults, C. D. Zumwalt, and C. D. McDaniel, 2000. Use of a sperm analyzer of evaluating broiler breeder males. 2. Selection of young broiler breeder roosters for the sperm quality index increases fertile egg production. Poult. Sci. 79:771-777.

Parker, J. E., 1949. Fertility in chickens and turkeys. In: Fertility and Hatchability of Chicken and Turkey Egg, (L. E. Taylor, Ed.) John Wiley & Sons, New York City, pp. 95-149.

Parker, J. E. and P. E. Bernier, 1950. Relation of male to female ratio in New Hampshire breeder flocks to fertility of eggs. Poult. Sci. 29:377-380.

Parker, J. E., F. F. McKenzie, and H. L. Kempster, 1940. Observations on the sexual behavior of New Hampshire males. Poult. Sci. 19:191-197.

Parker, J. E., F. F. McKenzie, and H. L. Kempster, 1942. Fertility in the male domestic fowl. Missouri Agr. Expt. Sta. Bul. 347.

Parker, J. E. and B. J. McSpadden, 1943. Influence of feed restriction on fertility in male domestic fowls. Poult. Sci. 22:170-177.

Pierson, E. E., L. M. Krista, and G. R. McDaniel, 1988. Effect of age and physiological status on sperm storage 24 hr after artificial insemination in broiler breeder hens. Br. Poult. Sci. 29:193-197.

Prolo, P., M. Wong, and J. Licinio, 1998. Leptin. Int. J. Biochem. Cell Bio. 30:1285-1290.

Rath N. C., W. E. Huff, J. M. Balog, and G. R. Bayari, 1996. Effect of gonadal steroids on bone and other physiological parameters of male broiler chickens. Poult. Sci. 75:556-562.

Reddy, R. P., 1994. Artificial insemination of broilers: Economic management implications. Pages 73-89. In: Proceedings of the First International Symposium on the Artificial Insemination of Poultry. The Poult. Sci. Assoc., Inc. Savoy, IL.

Renden, J. A., S. S. Oates, and M. S. West, 1991. Performance of two males broiler breeder strains raised and maintained on various constant photoschedules. Poult. Sci. 70:1602-1609.

Reviers, M., de, 1972. Evaluation des reserves spermatiques dans les voies deferentes due Coq. Annls. Biol. Anim. Biochim. Biophys. 12:5-11.

Reviers, M., de and J. P. Brillard, 1986. Variations in the sperm production, the sperm output and in the number of sperms to be inseminated in aging broiler breeders. World's Poult. Sci. J., 42:98 (Abstr.)

Reviers, M., de and J. B. Williams, 1984. Testis development and production of spermatozoa in the cockerel (*Gallus domesticus*). In Reproductive Biology of Poultry. (F. J. Cunningham, P. E. Lake, and D. Hewitt, eds.) Br. Poult. Sci. Harlow, pp.183-202.

Robinson, F. E., R. T. Hardin, and A. R. Robblee, 1990. Reproductive senescence in domestic fowl: Egg production, sequence length and intersequence pause length. Br. Poult. Sci. 38:871-879.

Robinson, F. E. and J. L. Wilson, 1996. Reproductive failure in overweight male and female broiler breeders. Anim. Feed Sci. Tech. 58:143-150.

Romanoff, A. L., 1960. Fertilization and fertility. Pages 75-111 In: The Avian Embryo The MacMillan Co., New York, NY.

Rosenstrauch, A., A. Allan Degen, and M. Friedlander, 1994. Spermatozoa retention by Sertoli cells during the decline in fertility in aging roosters. Phys. Reprod. 50:129-136.

Rothwell, B, 1973. The ultrastructure of the Leydig cells in the testis of the domestic fowl. J. Anat. 116:245-253.

Schanbacher, B. D., W. R. Gomes, and N. L. Van Demark, 1974. Diurnal rhythm in serum testosterone levels and thymidine uptake by testes in domestic fowl. J. Anim. Sci. 38:1245.

Schjelderup-Ebbe, T. 1922. Beitrage zur sozialpsychologie des haushuhns. Zeitschrift fur Psychologie. 88:225-252.

Schjelderup-Ebbe, T. 1935. Social behavior in birds. Chap. XX. Murchison's Hand Book of Social Psychology, pp. 947-972. Clark University Press, Worcester.

Sexton T. J., 1983. Maximizing the utilization of the male breeder: A Review. Poult. Sci. 62:1700-1710.

Sexton K. J., J. A. Renden, D. N. Marple, and R. J. Kemppainen, 1989a. Effects of *ad libitum* and restricted feeding on semen quantity and quality, body

composition, and blood chemistry of caged broiler breeder males. Poult. Sci. 68:569-576.

Sexton K. J., J. A. Renden, D. N. Marple, and R. J. Kemppainen, 1989b. Effects of dietary energy on semen production, fertility, plasma testosterone, and carcass composition of broiler-breeder males. Poult. Sci. 68:1688-1694.

Silver, R., C. Reboulleau, D. S. Lehrman, and H. H. Feder, 1974. Radioimmunoassay of plasma progesterone during the reproductive cycle of male and female ring doves (*Streptopelia risoria*). Endocrin. 94:1547.

Sharp, P. J. and C. B. Gow, 1983. Neuroendocrine control of reproduction in the cockerel. Poult. Sci. 62:1971.

Sharpe, R. M., 1994. Regulation of spermatogenesis. In: The Physiology of Reproduction (E. Knobil and J. D. Neill, eds), 2nd edition, Vol. 1, pp. 1363-1434. Raven Press, NY.

Soller, M. and S. Rappaport, 1971. The correlation between growth rate and male fertility and some observations on selecting for male fertility in broiler stocks. Poult. Sci. 50: 248-256.

Soller, M., H. Schindler, and S. Bornstein, 1965. Semen characteristics, failure of chickens insemination and fertility in Cornish and White Rock Males. Poult. Sci. 44:424.

Sturkie, P. D. and H. Opel, 1976. Reproduction in the male, fertilization, and early embryonic development. In: Avian Reproduction (3rd ed.) (P. D. Sturkie, Ed.). New York: Springer- Verlag, Chp. 17.

Summers, J. D. and S. Leeson, 1985. Poultry Nutrition Handbook. University of Guelph, Guelph, ON, Canada.

Tcholakian, R. K. and A. Steinberger, 1980. *In vitro* metabolism of testosterone by Sertoli cells and interstitial cells and the effect of FSH. In: Testicular development, Structure, and Function. Raven Press, New York, pp. 177-183.

Tingari, M. D., 1971. On the structure of the epididymal region and ductus deferens of the domestic fowl (*Gallus Domesticus*). J. Anat. 109:423-435.

Tingari, M. D., 1973. Observations on the fine structure of spermatozoa in the testis and excurrent ducts of the male fowl (*Gallus Domesticus*). J. Reprod. Fertil. 34:255.

Tingari, M. D. and P. E. Lake, 1972. Ultrastructural evidence for resorption of spermatozoa and testicular fluid in the excurrent ducts of the testes of domestic fowl (*Gallus Domesticus*). J. Reprod. Fertil. 31:373.

Upp, C. W., 1928. Preferential mating of fowls. Poult. Sci. 7:225-232.

Van Krey, H. P., A. T. Leighton, Jr., and L. M. Potter, 1967. Sperm gland populations and late seasonal declines in fertility. Poult. Sci. 46:1332. (Abstr.)

Van Wambeke, F. and F. Okerman, 1976. The effect of quantitative and qualitative feed restriction during the rearing period on the development and reproductive performances of broiler breeders. Arch. Geflugelkd. 40:64-71.

Van Wambeke, F., R. Moermans, and G. de Groote, 1979. Early body-weight selection of broiler breeder males in relation to reproductive and growth performance of their offspring. Br. Poult. Sci. 20:565-70.

Van Wambeke, F., R. Moermans, and G. de Groote, 1981. A comparison of the reproductive and growth performance of offspring from broiler breeder males selected for early growth rate using artificial insemination and unselected males kept on deep litter. Reprod. Nutr. Develop. 6B:1059-1065.

Wabitsch, M., W. F. Blum, R. Munche, M. Braun, F. Hube, W. Rascher, E. Heinze, W. Teller, and H. Hauner, 1997. Contribution of androgens to the gender difference in leptin production in obese children and adolescents. J. Clin. Invest. 100:808-813.

Warren, D. C. and L. Kilpatrick, 1929. Fertilization in the domestic fowl. Poult. Sci. 8:237-256.

Wilson, H. R., 1991. Crack your hatchability problems. Int. Hatchery Practice. Vol. 6:29,31,33,35-37,39.

Wilson, H. R., N. P. Piesco, E. R. Miller, and W. G. Nesbeth, 1979. Prediction of the fertility potential of broiler breeder males. World's Poult. Sci. J. 35:95-118.

Wilson, H. R., L. O. Rowland, Jr., and R. H. Harms, 1971. Use of low protein grower diets to delay sexual maturity of broiler breeder males. Br. Poult. Sci. 12:157-163.

Wilson, J. L., 1995a. Hatching egg breakout for better hatchery and breeder flock management. Midwest Poultry Federation. The University of Georgia, Athens, GA. p. 119-127.

Wilson, J. L., 1995b. Breakout fertility. In: Proceedings First International Symposium on the Artificial Insemination of Poultry (M. R. Bakst and G. J. Wishart, ed). The Poultry Science association, Inc. Savoy, Illinois. p. 197-206.

Wilson, J. L., G. R. McDaniel, and C. D. Sutton, 1987a. Dietary protein levels for broiler breeder males. Poult. Sci. 66:237-242.

Wilson, J. L., G. R. McDaniel, C. D. Sutton, and J. A. Renden, 1987b. Semen and carcass evaluation of broiler breeder males fed low protein diets. Poult. Sci. 66:1535-1540.

Wingfield, J. C., 1984. Influence of weather on reproduction. J. Exp. Zool. 232, 589-594.

Wingfield, J. C. and B. Silverian, 1986. Effects of corticosterone on territorial behavior of free-living male song sparrows. *Melospiza melodia*. Horm. Behav. 20:405-417.

Wishart, G. J., 1987. Regulation of the length of the fertile period in the domestic fowl by numbers of oviductal spermatozoa. J. Reprod. Fertil. 80:493-498.

Wishart, G. J., 1995. Evaluating male and female fertility. In: Proceedings First International Symposium on the Artificial Insemination of Poultry (M. R. Bakst and G. J. Wishart, ed). The Poultry Science association, Inc. Savoy, Illinois.

Wishart, G. J. and F. H. Palmer, 1986. Correlation of the fertilizing ability of semen from individual male fowl with sperm motility and ATP content. Br. Poult. Sci. 27:97-102.

Wood-Gush, D. G. M., 1954. The courtship of the Brown Leghorn cock. Br. J. Animal Behavior. 2:95-102.

Wood-Gush, D. G. M., 1956. The agonistic and courtship behavior of the Brown Leghorn cock. Br. J. Animal Behav. 4:133-142.

Wood-Gush, D. G. M., 1960. A study of sex drive of two strains of cockerels through three generations. Anim. Behav. 8:43-53.

Wood-Gush, D. G. M., 1963. The relationship between hormonally-induced sexual behavior in male chicks and their adult sexual behavior. Anim. Behav. 11:400-402.

Wood-Gush, D. G. M., 1971. The behavior of the domestic fowl. London, Heinemann.

Wood-Gush, D. G. M. and R. Osborne, 1956. A study of differences in the sex drive of cockerels . British J. Anim. Behav. 4:102-110.

Woods, J. E. and L. V. Domm, 1966. A histochemical identification of the androgen-producing cells in the gonad of the domestic fowl and albino rat. Gen. Comp. Endorinol. 7:559.

Yu, M. W., F. E. Robinson, R. G. Charles, and R. Weingardt, 1992. Effect of feed allowance during rearing and breeding on female broiler breeders. 2. Ovarian morphology and production. Poult. Sci. 71:1750-1761.

Zlotnik, I., 1947. The cytoplasmic components of germ-cells during spermatogenesis in the domestic fowl. Qty. J. Microscopical. Sci. 88:353-365.

CHAPTER 2

EFFECTS OF REARING FEED INTAKE ON CARCASS, EXTERNAL, AND REPRODUCTIVE CHARACTERISTICS OF MALE BROILER BREEDERS[1]

[1] R. H. McGovern, J. L. Wilson, F. E. Robinson, L. F. Bouvier, K. A. Thorsteinson, and R. A. Renema. To be submitted to *Poultry Science*.

2.1 ABSTRACT Male grandparent broiler breeders are selected based on BW at 6 wk of age and expected to successfully reproduce. Effects of BW gain and loss at photostimulation on carcass, external, and reproductive characteristics have not been assessed. Male broiler breeders (n=480) were assigned to one of the following four rearing feed level treatments at 1 d of age: standard (SF) (recommended BW profile), plus 15% (P15; BW approximately 15% heavier that SF), plus 30% (P30), and full fed (FF). Shank and keel length, chest and head width, testes weight, abdominal fat pad weight, and *pectoralis* major and minor muscle weight were determined for 40 birds at 6, 12, 18, 20, 22, 23, 24, 25, 26, and 62 wk of age. Comb height and shank color were assessed from 12 wk. Semen concentration, semen volume, sperm motility, fertility, fertile period, and plasma testosterone were determined at 28, 32, 36, 40, 44, 50, 54, 58, and 62 wk of age for 45 birds.

Skeletal characteristics increased with feeding level to 12 wk of age. The FF males lost BW (22 to 24 wk) resulting in smaller testes weight than the P30, P15, and SF treatments at 24 wk (11.7 g, 26.6 g, 29.2 g, and 25.5 g, respectively). Across the treatments, semen volume, semen concentration, and sperm motility averaged 0.28 g, 1.06 billion/mL, and 134, respectively throughout the experiment. Male broiler breeders appear resilient to a short period of weight loss, prior to production, without a negative impact on reproduction.

(*Keywords:* male broiler breeder, testes, carcass characteristics, fertility, sperm)

2.2 INTRODUCTION

As part of the genetic selection process, practiced by primary breeders, male grandparent broiler breeders are “broilerized”. The birds are fed *ad libitum*, as broilers, for the first 6 wk of production in order to assess their growth potential. Males are selected based upon broiler characteristics, growth rate and breast muscle deposition to produce the next generation. The same males are then expected to reproduce. Overfeeding of male broiler breeders, “broilerizing”, often results in birds that are heavier at 42 days of age than what is recommended at sexual maturity. Hocking and Duff (1989) postulated that the increased muscularity of heavy males reduced mating efficiency. Therefore, males weighing 1.9 or 2.0 kg at 6 wk of age are subjected to severe feed restriction and a BW loss to return the birds to target BW at photostimulation.

The external characteristics (chest width, keel length, shank length, comb height, shank score, and shank color) of male broiler breeders have been proposed as methods of evaluating reproductive potential. In male broiler breeders, the chest width becomes very large as the breast thickens towards the end of the reproductive period. Male broiler breeders may find it anatomically difficult to achieve cloacal contact with increased chest width (Hocking and Bernard, 1997). Shank length (Jaap, 1938) and more recently keel length have been associated with skeletal frame size. Head width is of interest because of sex separate feeding methods (McDaniel, 1986; Robinson et al., 1996). Fitting simple barriers to the female feeding trough to exclude the males which have larger heads has made it possible to feed male and female broiler breeders different diets and quantities (McDaniel, 1986;

Hocking, 1990b). Comb development has been considered an external sex characteristic that mirrors reproductive development of both males and females (Lowry, 1958; Hocking, 1990ab). In both sexes, the development of the comb coincides with increased plasma concentration of androgens (Etches, 1996). Red color along the length of the shank has been observed in some broiler breeder flocks. It has been proposed that a red shank, as opposed to a purely yellow colored shank, may relate to a reproductively active male (J. Brake, North Carolina State University, Raleigh, NC, 27695, USA, personal communication).

During rearing, body weight management of broiler breeder males may impact the reproductive efficiency of males throughout production. The long-term reproductive consequences of early rapid growth combined with severe feed restriction to reach target BW at photostimulation have not been studied in roosters. Parker and McSpadden (1943) reported that severe restriction between 42 to 72% of free choice, after photostimulation, had a detrimental effect on male fertility.

The first objective of this experiment was to assess the effect of rearing BW and BW loss at photostimulation on male carcass characteristics including breast muscle, fatpad, and testes weight. The second objective of this study was to assess the effects of rearing BW and BW loss at photostimulation on external conformation and skeletal characteristics of male broiler breeders. The third objective of this research was to assess the effects of rearing feed intake on reproductive performance (semen volume, semen concentration, sperm motility index [SMI], percentage of males producing semen [PMPS], fertility, fertile period, and plasma testosterone level) of broiler breeder males.

2.3 MATERIALS AND METHODS

2.3.1 *Stocks and Management*

At 1 d of age, 480 commercial male broiler breeders were placed in 12 floor pens (3 pens /treatment) for rearing. The photoperiod consisted of 23 h of light and 1 h of darkness (23L: 1D) for the first 3 d. From 3 d to 22 wk of age, the birds received 8 h of light (8L: 16D) provided at 10 lux intensity. From 22 to 62 wk of age, 15L: 9D lighting schedule was provided. From 3 wk to 20 wk of age, birds were fed on alternate days with twice the daily feed allotment fed each feed day (skip-a-day feeding) to promote higher flock uniformity.

All birds were fed a wheat-based broiler breeder starter ration containing 18% CP and 2783 kcal ME/kg from 1 d to 6 wk of age. From 6 to 21 wk of age, a grower diet, containing 15% CP and 2711 kcal ME/kg, was fed. The adult ration, fed from 22 to 62 wk of age, consisted of 14.5% CP and 2500 kcal ME/kg.

At 1 d of age, birds were wing-banded and randomly assigned to one of four feeding level treatments: standard fed (SF), plus 15% of standard (P15), plus 30% of standard (P30), and full fed (*ad libitum* to 6 wk of age, FF). Birds in the SF treatment were reared to 62 wk following the recommended BW profile. Full fed birds were reared to be approximately 60% heavier than the SF treatment. Birds were weighed individually on a weekly basis (n=480). The BW gains were calculated weekly for each individual using their previous BW. Body weights were used to determine feed allocations that were set by treatment. Forty birds (10 birds /treatment) were randomly assigned to a sample time (6, 12, 18, 20, and weekly from 22 to 26 wk of

age). The sample group was used to determine conformation, skeletal measurements, and carcass characteristics.

At 6 wk of age, the FF males consumed peak feed allotment of 131 g/bird. The SF, P15, and P30 males were fed 60, 73, and 88 g/bird at 6 wk of age, respectively. Birds in the FF treatment were maintained on 130g/day to 8 wk of age to achieve BW closer to broiler target BW (1.9 kg at 6 wk of age). At 8 wk of age, males in the SF, P15, and P30 received 66, 78, and 92 g/bird, respectively. By 12 wk of age, the FF males were restricted to 122 g/bird/day. Standard fed, P15, and P30 males received 78, 84, and 94 g/bird at 12 wk of age.

Feed allocated to the FF and P30 treatments was severely decreased from 13 to 20 wk of age in order to reach the 24 wk target BW (3500g). By 20 wk of age, the feed allocation of FF males was reduced to 58 g/bird/day to return males to recommended BW at 24 wk of age. The SF, P15, and P30 males were allocated 119, 108, and 89 g/bird at 20 wk of age. All birds reached the breeder recommended BW at 24 wk of age (Figure 2.1). The P30 treatment was removed at 30 wk due to difficulties with record management. Forty-five birds were individually caged at 20 wk and individually fed for assessment of the reproductive characteristics. The Animal Policy and Welfare Committee of the Faculty of Agriculture, Forestry and Home Economics of the University of Alberta approved the experimental protocol.

2.3.2 *External Conformational Measurements*

Shank lengths, keel lengths, chest widths, and head widths were measured to the nearest mm for 40 birds using calipers, and recorded at 6, 12, 18, 20 wk of age

and weekly from 22 to 26 wk of age. From 32 to 62 wk of age, external measurements were recorded on the 45 males used for the assessment of reproductive characteristics. Shank (tarsometatatsus) length was measured as the distance from the middle of the foot pad to the hock joint on the left leg (Robinson et al., 1996). Keel length was measured from the point of fusion in the clavicle to the ventral portion of the sternum. The chest width was assessed approximately 20 mm below the shoulder joint measuring from the transverse distance across the *pectoralis* major muscle. Head width was assessed across the two posterior bony projections of the mandible. All roosters had single combs. Comb height measurements were taken by image analysis (Northern Exposure, 2000[2]) at 12, 18, 20 and weekly from 22 to 26 wk of age on the 40 males processed for carcass characteristics. Comb height was measured, on the second blade of the comb, along the length of the blade from the top of the comb to the body of the comb.

Shank color was assessed at 12, 18, 20 and weekly from 22 to 26 wk of age using Paintshop Pro (Jasc Software Ver. 6.00) to assign a red green blue (RGB) value for three positions on the right shank of each bird. A high shank color value, 600 RGB corresponds to yellow (Imperial yellow, Behr® Paints and Stains). The shank color was also subjectively evaluated by visual scoring. A yellow shank was given a score of zero while shanks that appeared pink in color were considered a score of one. A red colored shank was given a score of two. Red shank color, when prevalent, appears as a vertical strip of scales covering the metatarsus (approximately 3 to 5 mm wide) on the plantar surface of the shank.

[2] Northern Exposure ® by Empix Imaging Inc., Mississauga, ON, Canada, L5L 5M6.

2.3.3 *Carcass Measurements*

Testes, abdominal fat pad, *pectoralis* major, and *pectoralis* minor muscle weights were recorded on ten birds per treatment randomly selected at 1 d of age. Birds were killed by cervical dislocation at 6, 12, 18, 20 and weekly from 22 to 26 wk of age. At 62 wk, the 45 males, used for reproductive evaluation, were killed and the same carcass measurements taken. The p*ectoralis major* was digitally photographed using image analysis software (Joseph et al., 2000). From the whole breast digital image, the area of the whole breast was calculated.

2.3.4 *Reproduction*

Semen was ejaculated from 45 males (15 males / treatment in the SF, P15, and FF treatments) on three non-consecutive days per wk. From 26 to 32 wk of age, semen volume, spermatozoa concentration, and spermatozoa motility was measured for all males. Semen volume was measured indirectly by weight (1 mL ≅ 1 g; Brillard and de Reviers, 1981). Semen concentration was determined using a spectrophotometer measuring optical density (Carson et al., 1995). Sperm Motility Index (SMI) was determined using the Sperm Quality Analyzer®3 that measures the "activity" of sperm in a semen sample (McDaniel et al., 1998). The SMI was defined as the number and amplitude of deflections in a light path per second as a result of sperm movement within a capillary tube (McDaniel et al., 1998).

The percentage of males producing semen (PMPS) was calculated as a percent of the 15 males per treatment from which semen could be collected. Fertility was evaluated on six commercial Single Comb White Leghorn (SCWL) hens per

male. A 10 µl quantity of fresh undiluted semen from each male was inseminated intravaginally to the hens. All inseminations were performed in the afternoon to maximize fertility (Parker, 1950). Eggs were collected on a daily basis for 3 wk by cage and incubated weekly for 7 d to assess fertility. The eggs were stored at 16 to 17 C and approximately 75% relative humidity.

Percent fertility of each hen was calculated for two periods post insemination. The 1 to 7 d post-insemination percent fertility and the 8 to 14 d post-insemination percent fertility were the number of fertile eggs divided by the total number of settable eggs laid during the interval then multiplied by 100. Fertile period was found using the total consecutive number of fertile eggs laid prior to two consecutive infertile eggs (Ansah et al., 1980). Fertility was assessed by breakout after 7 d of incubation. At 44 wk of age, the SCWL flock was 16 wk older (60 wk) than the male broiler breeders and was replaced with 22 wk old Leghorn hens. The replacement of the SCWL flock was schedule prior to the initiation of this experiment and was considered beneficial because any age-related decline in fertility due to females was eliminated with the replacement of SCWL hens.

2.3.5 *Radio-immunoassay*

Blood plasma testosterone concentrations were determined at 28, 32, 36, 40, 44, 50, 54, 58, and 62 wk of age for the 45 males. Plasma testosterone concentration was determined using duplicate 200 µL samples in four RIA[4]. Samples fell within the linear range of the standard curve. The standard curve coefficient was

[3] Introtech, San Diego, CA 92122.
[4] Kit Number TKTT, Diagnostic Products Corp., Los Angeles, CA 90045-5597

r=0.9891 or greater. Several samples with high concentrations of plasma testosterone were pooled to assess the inter-assay coefficient of variation for a high concentration of plasma testosterone. The same procedure was used to find the inter-assay coefficient of variation for a low concentration of plasma testosterone. The mean inter-assay coefficient of variation for the high and low plasma testosterone samples was less than 1.90% and 7.46%, respectively and the intra-assay coefficient of variation for the samples was less than 4.42%. Samples were randomized by treatment and age within and between assays. The assay sensitivity was determined to be 20 pg/mL. The antiserum was highly specific for testosterone with a relatively low cross reactivity to other naturally occurring steroids in the plasma sample as stated by the manufacturer. All tested compounds had a cross-reactivity of less than 1% with the exception of 5á-Dihydrotestosterone (3%), 19-Hydoxyandrostenedione (2%), 11-Ketotestosterone (16%), 4-Estren-17-ol-3-one (20%), 19-Nortestosterone (20%), and Methyltestosterone (1.7%).

2.3.6 *Statistical Analysis*

All treatment main effects and the interactions were tested for significance at P 0.05 using the General Linear Models procedure of SAS ® (SAS Institute Inc., 1999). When main effects or their interactions were significant, the P-Diff test of SAS was used to separate significantly different means (Steel and Torrie, 1997). Pearson correlation coefficients of SAS® were generated to compare testis weight, BW, head width, comb height, and plasma testosterone concentration (Steel and

Torrie, 1997). The coefficient of variation (CV) was found using the General Linear Models procedure and separated using F table comparisons.

2.4 RESULTS AND DISCUSSION

2.4.1 *Body Weight*

Initial BW separation of the treatments occurred at 4 wk of age (Figure 2.1). Full fed males were heavier than the P15 and SF males at 4 wk of age by 75 and 106 g, respectively. The 40 birds processed at 6 wk had similar BW (1049 g) (Table 2.1). However, there were treatment differences in BW at 6 wk of age for the remaining population of 348 males. The FF males processed at 6 wk had the greatest gain (334 g), approximately 193 g, 180 g, and 162 g greater than the P30, P15, and SF males, respectively. At 12 wk of age, SF males with a BW of 1640 g were at the recommended target BW (1635 g). The BW of the SF males was numerically lower (343 g) than P15 birds at 12 wk of age. Males in the SF treatment were lighter than either the P30 or FF treatments (557 g and 966 g, respectively) at 12 wk of age. This excessive BW gain during rearing required severe feed restriction starting at 13 wk of age in order to return the birds to the breeder recommended target BW. Similarly, Van Wambeke et al. (1979) found feeding a starter diet *ad libitum* to 6 wk results in BW that were too heavy and subsequent restriction had to be very severe to keep BW under control.

Full fed males gained 38 g from 17 to 18 wk of age. At 18 wk of age, males in the FF treatment were consuming litter, in response to the level of feed restriction

that may have lead to a coccidiosis outbreak at 19 wk of age. The males in the FF treatment were treated for the coccidiosis and recovered by 20 wk of age.

There were no significant differences in BW gain at 18 and 20 wk of age among the four treatments. Full fed males maintained the greatest BW at 18 and 20 wk of age (3395 g and 3747 g, respectively). The FF males lost weight at 22, 23, and 24 wk of age due to the level of feed restriction in order to reach the SF target BW at 24 wk of age. However, the BW of the FF males at 23 wk was greater than at 22 wk (3474 g compared to 3346 g) because the group of males was randomly selected at placement for processing. The FF and P30 treatment birds lost BW compared to the P15 and SF treatment birds that continued to gain BW at 22 wk. The FF males continued to loose BW at 23 and 24 wk of age (-63.1 g, and –120.9 g, respectively). The differences in BW at 25 wk were primarily associated with the random selection of birds at 1 d of age to process group as mentioned earlier. The BW for the remaining population of, approximately, 100 males (25 wk of age) was not different among the treatments from 25 to 62 wk of age. There were no differences in BW at 26 or 62 wk among the males used to assess carcass characteristics.

2.4.2 *External Characteristics*

Comb Height. At 12 wk, there were no differences in comb height among the four BW treatments (Table 2.1). There was a greater increase in comb height in the FF compared to the SF treatment by 0.83 and 0.89cm at 18 and 20 wk of age, respectively. As BW increased, comb height was correlated to BW (r=0.76,

P<0.0001) throughout this experiment. Comb height was greatest in the FF treatment at 22 wk, but was not different among the treatments at either 23 or 24 wk of age. Preceding photostimulation, FF males had the greatest comb height and BW. At 22 wk of age, BW were similar across the treatments. At 23 and 24 wk of age, comb heights were similar among the treatments. As the SF males attain BW similar to the FF males, comb heights were also similar. From 25 to 26 wk, the greatest increase in comb height was recorded in the SF treatment, 31 mm. Comb height was lowest in the FF birds at 25 wk compared to the P30 and P15 birds (1.68, 2.23, and 2.18 cm, respectively).

Comb growth increased with BW regardless of photostimulation or sexual maturity as did testes weight though increases in testes weight were not significant. Testes weight was correlated to comb height (r=0.70, P<0.0001). Eitan et al. (1998) suggests that comb size represent the integration of the response of the hypothalamic-pituitary-gonadal axis to photostimulation. The similarity in comb heights across treatments at 23 wk may be due to the attainment of threshold BW and the response to increased day length. The high BW birds matured first and as the lower BW males gained BW and matured, comb height became similar among the treatments. One week after testes weight decreased in the FF treatment, comb height also decreased by 30 mm to 168 mm at 25 wk of age. Comb height was not different among the males at 26 or 62 wk of age. Comb height was not correlated to semen volume (r=-0.022, P=0.51). However, comb height was negatively correlated to semen concentration throughout the experiment (r=-0.36, P<0.0001). Comb height appears to be a good indicator of BW and testes weight, but was a poor

indicator of semen volume and concentration. Similarly, Brown and McCartney (1983) found that groups of broiler breeder males with the largest testes did not produce the largest amounts of semen at 54 wk of age.

Head width. Head width increased with feeding level at 12 and 20 wk of age (Figure 2.2). Head width was similar between the FF and P30 males (34 mm) compared to the P15 and SF birds (32 mm) at 12 wk of age. At 18 wk of age, there were no differences in head width among the treatments. However, at 20 and 24 wk, the average head width in the FF treatment was 2 mm wider than the SF birds. The average head width at 20 and 26 wk of age was 38 mm and 42 mm, respectively. Similarly, Hocking (1990ab) found an average head width of 42.1 mm at 20 wk of age and 43.7 mm at 26 wk of age. All birds maintained a head width of 40 to 43 mm to 62 wk of age. Male head width shows very little overlap with female head width at 26 wk of age (Hocking, 1990a). In the present study, testes weight was correlated to head width ($r=0.64$, $P<0.0001$).

Chest width. At 12 wk of age, chest width increased with feeding level (Figure 2.3). The FF males had the greatest chest width compared to the P30, P15, and SF treatments, at 18 wk of age. The difference in chest width at 18 wk between the FF treatment and the P30, P15, SF males was 8 mm, 11 mm, and 17 mm, respectively. The increase in the chest width, *pectoralis* major muscle weights, and breast area of the FF males was evidence of increased breast muscle deposition as a function of BW. Chest width was not different from 22 to 25 or from 32 to 62 wk of age among the BW treatments. While there was a difference at 26 wk with the SF males having the smallest chest width, generally after BW became similar there was

little difference in chest width. The SF treatment birds had the smallest chest width at 26 wk compared to the P15 birds (79 and 85 mm, respectively). At 62 wk of age, chest width averaged 105 mm across the treatments. The differences in chest width noted in rearing suggest this is a reliable method of measuring breast muscle deposition in male broiler breeders.

Keel and shank length. Keel length increased by 38 mm from 6 to 12 wk of age across the treatments (Figure 2.4). At 18 wk, keel length was greatest in the FF treatment compared to the P30, P15, and SF treatments by 12, 15, and 15 mm, respectively. Shank length was also greater in the FF males than all other treatments by a minimum of 5 mm at 18 wk (132 mm) (Figure 2.5).

Shank length has been suggested as a reliable measure of skeletal size (Jaap, 1938). The increasing the frame of the FF birds allowed for a proportional increase in BW. The males in the FF treatment had a greater skeletal size compared to the SF treatment from 12 to 25 wk of age, as assessed by the shank length. Shank length was longer in the FF birds than the P15 birds at 26 wk by 6 mm. Keel lengths were similar among the birds from 25 to 62 wk of age. At 62 wk, there were no differences in shank length among the SF and FF birds. Leeson and Summers (1984) also found that the correlation between BW and parameters of skeletal dimension declined with age.

Skeletal (chest width, keel length, and shank length) characteristics and comb height were altered in male BB for a short period (12 to 18 wk of age). However, as the growth curves merged to the target BW, the skeletal frame size and comb height became similar across the treatments starting at 22 and 23 wk, respectively.

Similarly, starter dietary protein level was shown to influence early skeletal size, however there was little effect on mature BW or skeletal size of broiler breeder pullets (Leeson and Summers, 1984).

Shank Color. Shank color of male broiler breeders has been considered as a possible management technique for selecting the reproductively superior males in commercial settings (J. Brake, North Carolina State University, Raleigh, NC, 27695, USA, personal communication). There were no differences in shank score or shank color among the treatments at 12 or 18 wk of age (Figure 2.6). Visual shank score was negatively correlated to the computer evaluated shank color (r= -0.20, P=0.0005) as expected. The correlation was negative because a high visual shank score and a low shank color were both indications of a red shank. The low correlation between the two methods may be related to the relatively small scale used in visually scoring the shank color. Shank color, however, was not correlated to testes weight. Shank color was also not correlated to plasma testosterone concentration. There were no differences in shank color at 62 wk of age among the treatments. Very few males had a red shank color at any age, which may be related to breed rather than sexual development or nutritional status. The feed used was wheat based rather than corn based which might have contributed to the lack of red shank color.

2.4.3 *Carcass Characteristics*

Abdominal fatpad. At 6 wk, the FF and P30 treatments had the greatest fatpad weight compared to the SF males by 9.8 and 10.7 g, respectively (Table 2.1).

Fatpad weight was greatest in the FF treatment at 12 wk compared to the P30, P15, and SF treatments by 14.8, 19.1, and 26.4 g, respectively. At 18 and 20 wk of age, there was no difference in fatpad weight among the BW treatments. Full fed males likely utilized the fatpad between 12 and 18 wk of age resulting in a 9.0 g fatpad at 18 wk of age.

In the excessive BW males, the trend in high fatpad weight was reversed as the males lost BW and/or BW gains declined. The SF males had the most consistent dietary intake and BW gains and had the greatest fatpad at 22 and 25 wk of age. At 23 wk, fatpad weight was 16.4 g, 14.4 g, and 13.3 g heavier in the SF than the FF, P30, or P15 treatments, respectively. Fatpad weight was similar for all birds at 24, 26, and 62 wk of age. To a large extent, body fat acts as an energy reserve. As the feed allocation decreased and BW declined in the FF treatment, the fatpad was utilized as a source of energy.

Breast Muscle. *Pectoralis* minor or *pectoralis* major muscle weights were not different among treatments at 6 wk of age (Table 2.1). The FF males had greater *pectoralis* minor muscle weights than the SF males at 12, 18, and 20 wk of age by 5.8, 59.3 and 58.1 g, respectively. *Pectoralis* major muscle weight was also greater in the FF males than the SF males at 12, 18, and 20 wk by 27.3, 212.7, and 208.3 g, respectively. Excessive breast muscle weight has been considered a disadvantage to male health and flock fertility. High BW males tend to weigh more and have more footpad and leg problems, which reduces flock fertility in naturally mated flocks (Van Wambeke et al., 1981). Broiler breeder males that become very large and broad

breasted towards the end of the reproductive period may find it anatomically difficult to achieve cloacal contact (Hocking and Bernard, 1997).

There were no differences in *pectoralis* minor and major muscle weight at 22 wk across treatments. The *pectoralis* minor and major muscle weight was affected by the weight loss experienced by the FF males. At 24 wk, the FF males had a lower *pectoralis* minor and major muscle weight than the P30 males by 35.6 g and 73.7 g, respectively.

The FF males had the lowest BW at 25 wk compared to the SF treatment by 556 g. Low BW in the FF treatment related to a lower *pectoralis* major muscle weight at 25 wk. At 25 wk of age, *pectoralis* major muscle weight was 127.8 g lighter in the FF males than the SF treatment birds. However, the *pectoralis* minor muscle weight was 38 g heavier in the FF males at 25 wk compared to both the P30 and P15 males. There was no difference in the *pectoralis* minor muscle weight between the FF and SF males at 26 wk. All remaining birds had similar average BW and gains at 62 wk. The BW of the males was strongly correlated to the breast muscle wt, chest width, keel length, shank length, head width, and comb height (r= 0.97, 0.86, 0.89, 0.83, 0.85, 0.76, respectively) suggesting that these measurements are good assessments of body size. Growth of the skeletal system and the accumulation of muscle mass were closely related. Lerner (1937) suggested skeletal size to be the limiting factor in increasing body size.

Male broiler breeders, able to fulfill their genetic potential in skeletal frame size, used excess energy to increase muscle mass and fatpad. Robinson et al., (1996), found that female broiler breeders that reached mature frame size at

photostimulation put remaining energy into tissue accretion. Similarly, the FF males had increased breast muscle before reaching adult skeletal frame size. There were no differences among the four treatments in *pectoralis* minor and major muscle weight at 62 wk.

Testes. There were no treatment differences in testes weight or testes weight as a percent of BW at 6 wk of age (Table 2.1). Although the FF males had a greater BW and breast muscle development at 12, 18, and 20, this did not result in greater pre-pubertal testes development. At 18 wk of age (prior to photostimulation) some males showed testicular development. The FF males had testes weight that ranged in size from 0.27 g to 25.75 g compared to the P30 male testes that ranged from 0.16 to 10.53 g. Early testicular development suggests that *ad libitum* feeding resulted in earlier onset of sexual maturity, presumably due to attainment of a threshold BW, carcass fat, or carcass protein level. The variation in testes weight at 18 wk of age produced a coefficient of variation (CV) of 51.8 and 70.3% for the SF and P15 treatments, respectively. The P30 testes weight had a greater CV (86.2%) than either the SF or P15 treatments, but a lower CV than the FF treatment (135.5%). Fontana et al. (1990) also found the weights of the testes were closely associated with body size. It appears that high BW males may have a greater potential for early development of testes, but, for the majority of males, reproductive development was cued by photostimulation.

Testes weight of the FF males was negatively affected by BW loss. Two wk after photostimulation, the FF males had the lowest testes weight in comparison to the P30, P15, and SF males at 24 wk by 14.9, 17.5, and 13.8 g, respectively,

suggesting that testicular development was hindered by BW loss. Testes weight as a percent of BW was lower in the FF males at 23 wk than in the P15 males (0.39% and 0.61%, respectively). Similarly, McCartney and Brown (1980) found that testes weight decreased as the amount of feed restriction increased.

Although the FF males did not lose weight at 25 wk, compared to the SF males, the FF males had smaller testes by 11.8 g. Testes weight as a percent of BW was 38% smaller in the FF males than the other treatments at 25 wk of age. This was consistent with the statement made by Brown and McCartney (1986) that males gaining or losing the least amount of BW, closest to optimum feed intake, had the largest testes as a percentage of BW.

The FF males lost a greater amount of BW than the P30 treatment and consequently required a longer period of recovery for testes growth. The P30 treatment experienced a BW weight loss from 21 to 22 wk of age that appeared to have no antagonistic result on the breast muscle, fatpad or testes weights. This suggests that a severe feed restriction resulting in a loss of weight at sexual maturity may not be detrimental to the bird when it occurs in a short period (maximum of 1 wk). Average testes weight (29.9 g) were similar across the treatments at 62 wk of age. Buckner et al. (1986) also found testes weight of 31.2 g at 60 wk of age.

The strongest correlation between testes weight and BW was r=0.80 at 24 wk of age. Testes weight was correlated to BW at r=0.66 across all ages. Similarly, Buckner et al. (1986) correlated testes weight to BW (r=0.62) at 60 wk of age. In this study, testes weight fluctuated with BW, however, BW loss had no long-term detrimental impact on testes weight.

Breast Muscle Analysis. Breast muscle area was similar among all treatments at 6 wk averaging 101.7 cm^2 (Appendix 2.1). Development of the breast muscle over the skeletal frame relates to the breadth and length of the chest. By 12 wk, the FF birds not only had the heaviest *pectoralis* minor and major muscle weights, but breast conformation showed a greater breast area than either the P15 or the SF males (41.4 and 60.8 cm^2, respectively). An increase in rearing feed intake not only increased the muscle mass of the male broiler breeder, but increases in breast muscle area suggest an increase in the size of the rib cage.

At 18 wk, the difference in breast area between the FF males and the P30, P15, SF was 44.9 cm^2, 62.4 cm^2, and 79.9 cm^2, respectively. The increase in breast muscle area was not related to an increase in breast muscle thickness (Appendix 2.2), but rather to a widening of the chest and a lengthening of the keel, indicating an increase in skeletal frame size. At 18 wk, breast muscle thickness averaged 3.0 cm among the treatments. Though there was an increase in the amount of muscle deposited for the FF males (*pectoralis* major and minor muscle weight), the muscle was deposited uniformly over the rib cage. Breast area of the birds was not different among the treatments at either 22 or 23 wk of age (306 cm^2 and 297.2 cm^2, respectively) (Appendix 2.2). At 24 wk, after the period of weight loss, the FF treatment birds had the smallest breast area, 42.4 cm^2 smaller than the P30 treatment birds.

2.4.4 *Reproductive Characteristics*

Semen Quality. The semen volume, semen concentration, and sperm motility index (SMI) were not different among the treatments from 28 to 62 wk of age (Table 2.2). Males endured a short period of testes weight loss prior to production without a negative impact on the semen volume, concentration, or sperm motility. Across the treatments, semen volume, semen concentration, and sperm motility averaged 0.28 g, 1.06 billion/mL, and 134 sperm motility index, respectively throughout the experiment. At 62 wk of age, testes weight was correlated to semen concentration (r=0.49; P=0.0003), but was not correlated to semen volume.

Sexton et al. (1989a) found that severe feed restriction programs resulted in decreased semen volume and sperm concentration per ejaculate. However in this experiment, BW loss occurred at photostimulation. Although the BW loss and photostimulation appear to be contradictory signals, the FF males have attained the necessary BW to respond to photostimulation. This may have prevented a permanent loss in testes weight and any detrimental affect on semen quality.

Fertility. Fertility and length of the fertile period were not affected by the BW treatments throughout production, 28 to 62 wk of age (Table 2.2). Large numerical differences in fertility were due to the number of hens inseminated (semen from one male was used to inseminate up to 6 SCWL hens) and the concentration of semen inseminated. Initially, fertility (1-7 d) was 94.5% across the treatments at 28 wk of age. At 62 wk of age, fertility (1-7 d) maintained an average of 92.5%. These data agree with those of Brown and McCartney (1983) who found that male feed restriction had no effect on the fertility or hatchability of the eggs produced by

inseminated females. In contrast, Ansah et al. (1980) found fertility decreased to 83.3% at 60 wk. In this experiment, maintenance of the percent fertility may be associated with the Leghorn hens. A second flock of young Leghorn hens replaced the original flock when the males were 44 wk of age eliminating the age-related decline in reproduction and fertility typically associated with the female (Ansah et al., 1980; Kirk et al., 1980).

Fertile period averaged 14 d throughout the experiment. The fertile period, in commercial broiler breeder hens inseminated with a greater quantity (0.1 mL) of fresh undiluted semen, ranged from 12.7 to 13.5 d throughout the lay cycle (Ansah et al., 1980). When Sexton et al. (1989b) fed roosters *ad libitum* throughout their lives they produced greater volumes of semen and more roosters were in semen production, but the authors suggested heavier males might not be physically able to mate. In this experiment, the males that were subjected to a weight loss were in good physical condition throughout the experiment and were probably in better condition for natural mating than the males, in Sexton et al. (1989b), fed on an *ad libitum* basis throughout the production period.

There was no decrease in PMPS with increasing age in the SF treatment. In the SF treatment, at 28 wk of age, 100% of the males were producing semen. By 62 wk of age, 93% of the SF males were still in production. The PMPS was numerically lower at 87% in the FF treatment in comparison to the SF males at 62 wk, which was numerically different from the SF males. At 58 and 62 wk, the P15 treatment had fewer PMPS compared to the SF treatment by 20%. The P15 males gained 6.9 g per wk from 38 to 62 wk of age. Low BW gain in the P15 treatment may have

resulted in the decrease in PMPS at 62 wk. In general, PMPS declined slightly with age. Similarly, in Bramwell et al. (1996), the PMPS decreased with increasing age in standard fed males.

Excess BW may not have negatively impacted the FF males because of the ages at which they gained and lost weight. The early BW gain appeared in the fat pad and *pectoralis* major muscle. Photostimulation appears to impel the reproductive system of birds into production. Female broiler breeders appear to have an age (maturity) requirement as well as a minimum BW requirement before they are receptive to photostimulation (Brody et al., 1980). Similarly, the FF males must have adequate maturity (receptive to photostimulation) and exceed the minimum BW required for onset of reproductive development. Hence from 22 to 24 wk of age, the reproductive system of the males appears to disregard BW loss in favor of reproduction.

2.4.5 *Testosterone Assay*

Plasma testosterone concentrations were not different among the treatments after 28 wk of age averaging 2.09 ng/mL (Table 2.2). The BW loss in the FF males had no effect on testosterone of the males at 28 wk. Similarly in SCWL males, Bachman et al. (1987) reported the highest concentration of plasma testosterone was 2.25 ± 0.78 ng/mL. Sexton et al. (1989b) found testosterone levels between 0.3 and 2.7 ng/mL from 36 to 60 wk of age in male broiler breeders on a 2000 kcal ME/kg. In contrast, Hocking and Bernard (2000) found higher concentrations of plasma testosterone, 2.5 ng/mL, in male broiler breeders from 40 to 60 wk of age.

Peak testosterone levels occurred at 26 and 28 wk of age, averaging 2.37 and 2.38 ng/mL. In contrast, Hocking and Bernard (2000) found peak levels of testosterone at over 3.5 ng/mL in male broiler breeders. Culbert et al. (1977) reported a range of testosterone levels at 25 to 34 wk of age (3.4 to 5.4 ng/mL) that increased at 37 to 44 wk of age (7.3 to 9.3 ng/mL). In the present study, the highest level of testosterone recorded occurred at 30 wk reaching 4.94 ng/mL in a single SF male.

2.5 CONCLUSION

Rearing gains and BW losses affect the early external characteristics of male broiler breeders. Head width, comb height, chest width, keel length, and shank length increased in early rearing with increased feed allocation. Leeson and Summers (1984) reported that early skeletal size could be manipulated by protein level and by feed allocation. In this experiment, BW affected early skeletal size, but mature skeletal size remains unaffected by feeding regimes.

Comb height increased with BW gain, but did not decrease with BW loss. It has been suggested that comb size reflects the reproductive status of the male broiler breeder and this study would support using comb size as an external assessment of reproductive status. However, the height of the comb continues to grow at a slow rate, throughout the life of the rooster, without a concurrent increase in testes weight. Shank colors were not indicative of reproductive development or status.

In FF males, breast muscle and fatpad weights increased with increasing BW. Increases in breast muscle area suggest the increase in BW was concomitant with an increase in skeletal frame size prior to photostimulation. The BW lost by the FF males corresponds to a situation in which males gained an excessive amount of weight during rearing and were restricted heavily in order to return the birds to the breeder recommended target BW. A 3 wk period of BW loss resulted in reduced breast muscle, fatpad, and testes weight in the FF treatment. The P30 males experienced BW loss at 22 wk of age without having a detrimental affect on the breast muscle, fatpad, or testes weights. Feed restriction regimes that result in BW loss may not be detrimental to reproduction depending upon the length of restriction, the initial BW condition of the bird, and the age when the BW loss occurs.

Male broiler breeders, subjected to various level of overfeeding and feed restriction in rearing to maintain or attain BW targets, produced adequate sperm quantity and viability to achieve high levels of fertility. Fertility and the fertile period were not affected by the BW treatments. In rearing, FF males were subjected to severe feed reductions before they lost BW. Male reproduction was resilient to excessive BW gains and losses before responding to photostimulation. Regardless of BW treatment the percent of males in production decreased at 58 wk of age. Testosterone levels were not affected by the BW loss in rearing. Loss of BW at photostimulation had no long lasting impact on semen production or fertility in an artificially inseminated flock.

2.6 REFERENCES

Ansah G. A., D. C. Crober, R. B. Buckland, A. E. Sefton, and B. W. Kennedy, 1980. Artificial insemination of individually caged broiler breeders. 1. Reproductive performance of males in relation to age and strain of females. Poult. Sci. 59:428-37.

Bachman, S. E., J. M. Bachman, and M. M. Mashaly, 1987. Effect of photoperiod on the diurnal rhythm of plasma testosterone, dihydrotestosterone and androstenedione in mature male chickens. Comp. Biochem. Physiol. Vol. 87:775-779.

Bramwell, R. K., C. D. McDaniel, W. H. Burke, J. L. Wilson, and B. Howarth, 1996. Influence of male broiler breeder dietary energy intake on reproduction and progeny growth. Poult. Sci. 75:767-775.

Brillard J. P. and M. de Reviers, 1981. Testis development and daily sperm output in guinea-fowl raised under constant daily photoperiods. Reprod. Nutr. Dev., 21:1105-1112.

Brody, T., Y. Eitan, M. Soller, I. Nir, and Z. Nitsan, 1980. Compensatory growth and sexual maturity in broiler females reared under severe food restriction from day of hatching. Br. Poult. Sci. 21:437-446.

Brown H. B. and M. G. McCartney, 1983. Effects of dietary restriction on reproductive performance of broiler breeder males. Poult. Sci. 62:1885-1888.

Brown H. B. and M. G. McCartney, 1986. Restricted feeding and reproductive performance of individually caged broiler breeder males. Poult. Sci. 65:850-855.

Buckner R. E., J. A. Renden, and T. F. Savage, 1986. The effect of feeding programs on reproductive traits and selected blood chemistries of caged broiler breeder males. Poult. Sci. 65:85-91.

Carson J. D., F. W. Lorenz, and V. S. Asmundson, 1995. Semen production in the turkey male. 1. Seasonal variation. Poult. Sci. 34:336-343.

Culbert J., P. J. Sharp, and J. W. Wells, 1977. Concentrations of androstenedione, testosterone, and LH in the blood before and after the onset of spermatogenesis in the cockerel. J. Reprod. Fertil., 51:153-154.

Eitan, Y., M. Soller, and I. Rozenboim, 1998. Comb size and estrogen levels toward the onset of lay in broiler and layer strain females under *ad libitum* and restricted feeding. Poult. Sci. 77:1593-1600.

Fontana, E. A., W. D. Weaver Jr., and H. P. Van Krey, 1990. Effects of various feeding regimens on reproduction in broiler-breeder males. Poult. Sci. 69:209-216.

Hocking, P. M., 1990a. Assessment of the effects of separate sex feeding on the welfare and productivity of broiler breeder females. Br. Poult. Sci. 31:457-463.

Hocking P. M., 1990b. The relationships between dietary CP, body weight, and fertility in naturally mated broiler breeder males. Br. Poult. Sci. 31:743-757.

Hocking, P. M. and R. Bernard, 1997. Effects of male body weight, strain and dietary protein content on fertility and musculo-skeletal disease in naturally mated broiler breeder males. Br. Poult. Sci. 38:29-37.

Hocking, P. M. and R. Bernard, 2000. Effects of age of male and female broiler breeders on sexual behavior, fertility and hatchability of eggs. Br. Poult. Sci. 41:370-377.

Hocking P. M. and S. R. I. Duff, 1989. The incidence of musculo-skeletal lesions in adult male broiler breeder fowls and their relationships with body weight and fertility at 60 wk of age. Br. Poult. Sci. 30:777-784.

Jaap, R. G., 1938. Breeding for body shape in chickens. US Egg Poultry Mag. 44:488-503.

Joseph, N. S., 2000. Maximizing early egg size in broiler breeder females by delaying age at photostimulation. M.Sc. Thesis. University of Alberta, Edmonton, Alberta, Canada.

Kirk, S., G. C. Emmans, R. McDonald, and D. Arnot, 1980. Factors affecting the hatchability of eggs from broiler breeders. Br. Poult. Sci. 21:37-53.

Leeson, S. and J. D. Summers, 1984. Influence of nutritional modification on skeletal size of leghorn and broiler breeder pullets. Poult. Sci. 63:1222-1228.

Lerner, I. M., 1937. Shank length as a criterion of inherent size. Poult. Sci. 16:213-215.

Lowry, M. M., 1958. Compensatory testicular adjustments following injection of small quantities of androgen into unilaterally castrated White Leghorn cockerels. Poult. Sci. 37:1129-1136.

McCartney, M. G. and H. B. Brown, 1980. Effects of feed restriction on reproductive performance of broiler breeder males. Poult. Sci. 59:2583-2585.

McDaniel C. D., J. L. Hannah, H. M. Parker, T. W. Smith, C. D. Schultz, C.D. Zumwalt, 1998. Use of a sperm analyzer for evaluating broiler breeder males. 1. Effects of altering sperm quality and quantity on the sperm motility index. Poult. Sci. 77:888-93.

McDaniel, G. R., 1986. Sex separate feeding of broiler parent stock. Zootech. Int. 11:54-58.

Parker, J. E., 1950. The effect of restricted mating in flocks of New Hampshire chickens on fertility and hatchability of eggs. Poult. Sci. 29:268-270.

Parker, J. E. and B. J. McSpadden, 1943. Influence of feed restriction on fertility in male domestic fowls. Poult. Sci. 22:170-177.

Robinson, F.E., T. A. Wautier, R. T. Hardin, N. A. Robinson, J. L. Wilson, N. Newcombe, and R. I. McKay, 1996. Effects of age at photostimulation on reproductive efficiency and carcass characteristics. 1. Broiler breeder hens. Can. J. An. Sci. 76:275-282.

SAS Institute Inc., 1999. SAS User's Guide. SAS Institute Inc., Cary, NC.

Sexton K. J., J. A. Renden, D. N. Marple, and R. J. Kemppainen, 1989a. Effects of *ad libitum* and restricted feeding on semen quantity and quality, body composition, and blood chemistry of caged broiler breeder males. Poult. Sci. 68:569-576.

Sexton K. J., J. A. Renden, D. N. Marple, and R. J. Kemppainen, 1989b. Effects of dietary energy on semen production, fertility, plasma testosterone, and carcass composition of broiler-breeder males. Poult. Sci. 68:1688-1694.

Steel, R. G. D., and J. H. Torrie, 1997. Principles and Procedures of Statistics: A Biometrical Approach. McGraw-Hill Book Company Inc., New York, NY.

Van Wambeke, F., R. Moermans, and G. Groote, 1979. Early body-weight selection of broiler breeder males in relation to reproductive and growth performance of their offspring. Br. Poult. Sci. 20:565-70.

Van Wambeke, F., R. Moermans, and G. de Groote, 1981. A comparison of the reproductive and growth performance of offspring from broiler breeder males selected for early growth rate using artificial insemination and unselected males kept on deep litter. Reprod. Nutr. Develop. 6B:1059-1065.

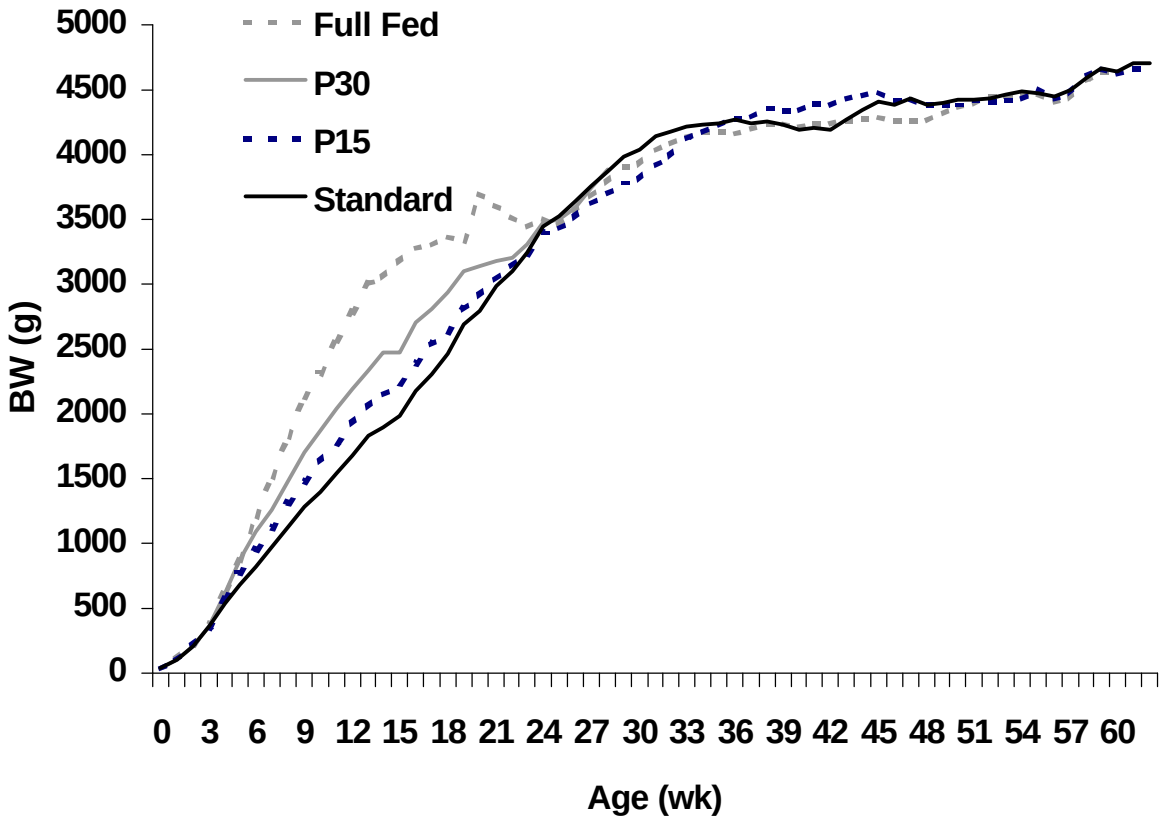


FIGURE 2.1. Body weight curves of four feeding treatments. Male BW were individually assessed from 1 d of age (n=480). Forty males were processed at 6, 12, 18, 20 and weekly from 22 to 26 wk of age and 45 males were individually caged at 20 wk of age. The decrease in average BW in the full fed (FF) treatment at 19 wk of age was related to an outbreak of coccidiosis. SF =standard fed; P15 =plus 15%; P30 =plus 30%.

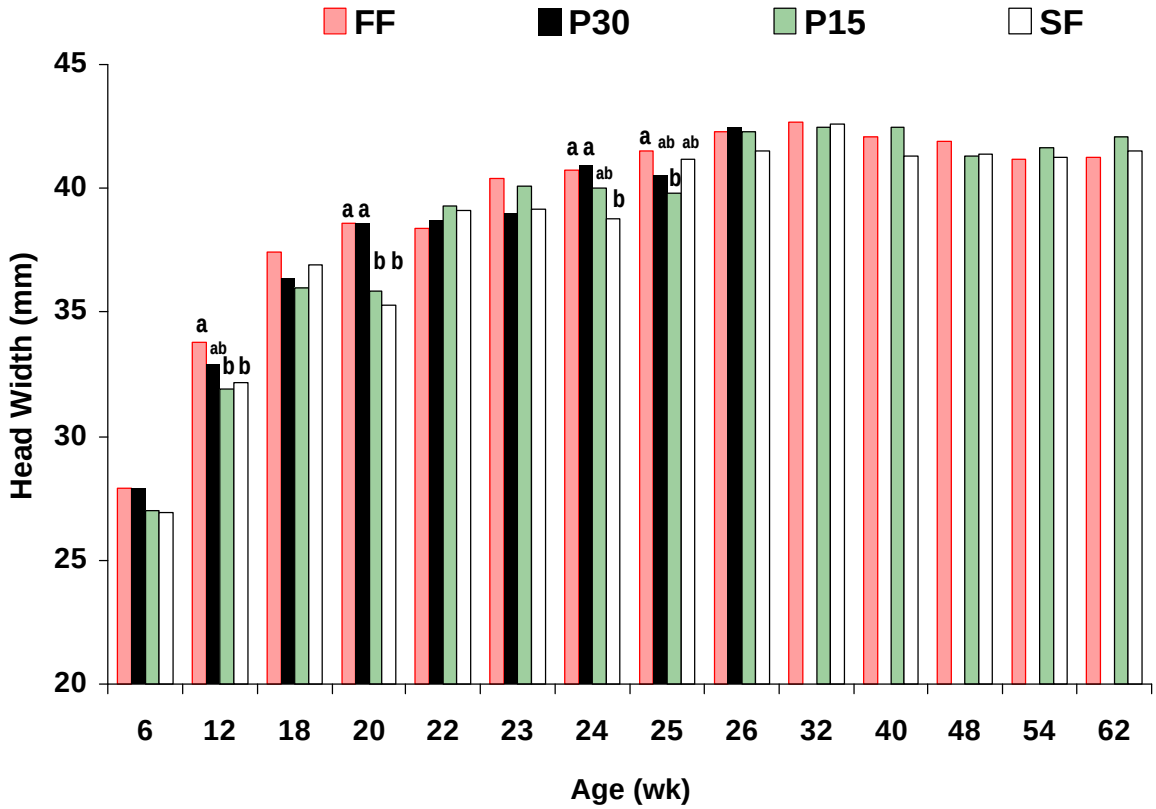


FIGURE 2.2. Head width was assessed across the two posterior bony projections of the mandible (n=40 to 26 wk of age; n=45 to 62 wk of age). Birds in the standard fed (SF) treatment were reared to 62 wk following the recommended BW profile. The P15 were reared to be 15% heavier than the SF treatment from 4 wk to 24 wk of age. Birds in the P30 were 30% heavier than the birds in the SF. Full fed (FF) treatment birds were reared to be 60% heavier than the SF treatment. All birds returned to the breeder recommended BW at 24 wk of age. $^{a-b}$ values with no common superscript within a column at each age were significantly different ($P<0.05$).

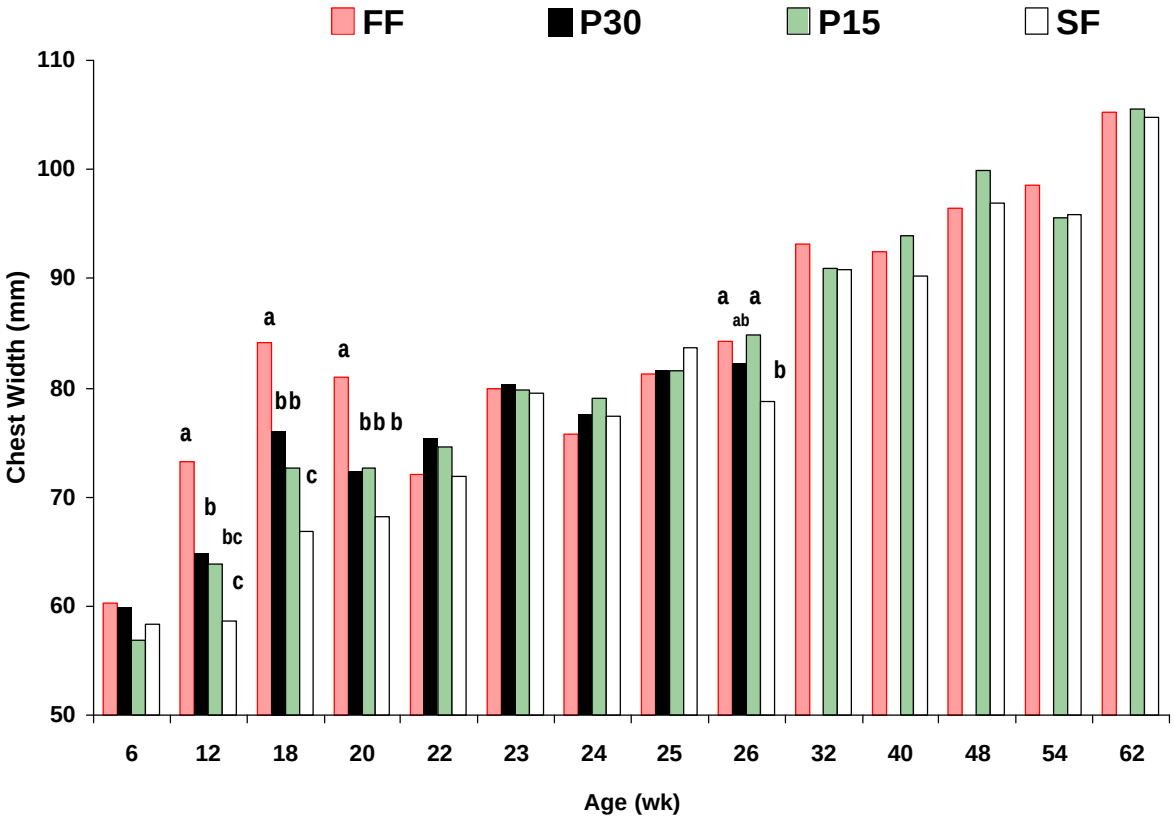


FIGURE 2.3. The chest width was assessed approximately 20 mm below the shoulder joint measuring from the transverse distance across the *pectoralis* major muscle (n=40 up to 26 wk of age; n=45 from 32 to 62 wk of age). Birds in the standard fed (SF) treatment were reared to 62 wk following the recommended BW profile. The P15 were reared to be 15% heavier than the SF treatment from 4 wk to 24 wk of age. Birds in the P30 were 30% heavier than the birds in the SF. Full fed (FF) treatment birds were reared to be 60% heavier than the SF treatment. All birds returned to the breeder recommended BW at 24 wk of age. $^{a-c}$ values with no common superscript within a column at each age were significantly different ($P<0.05$).

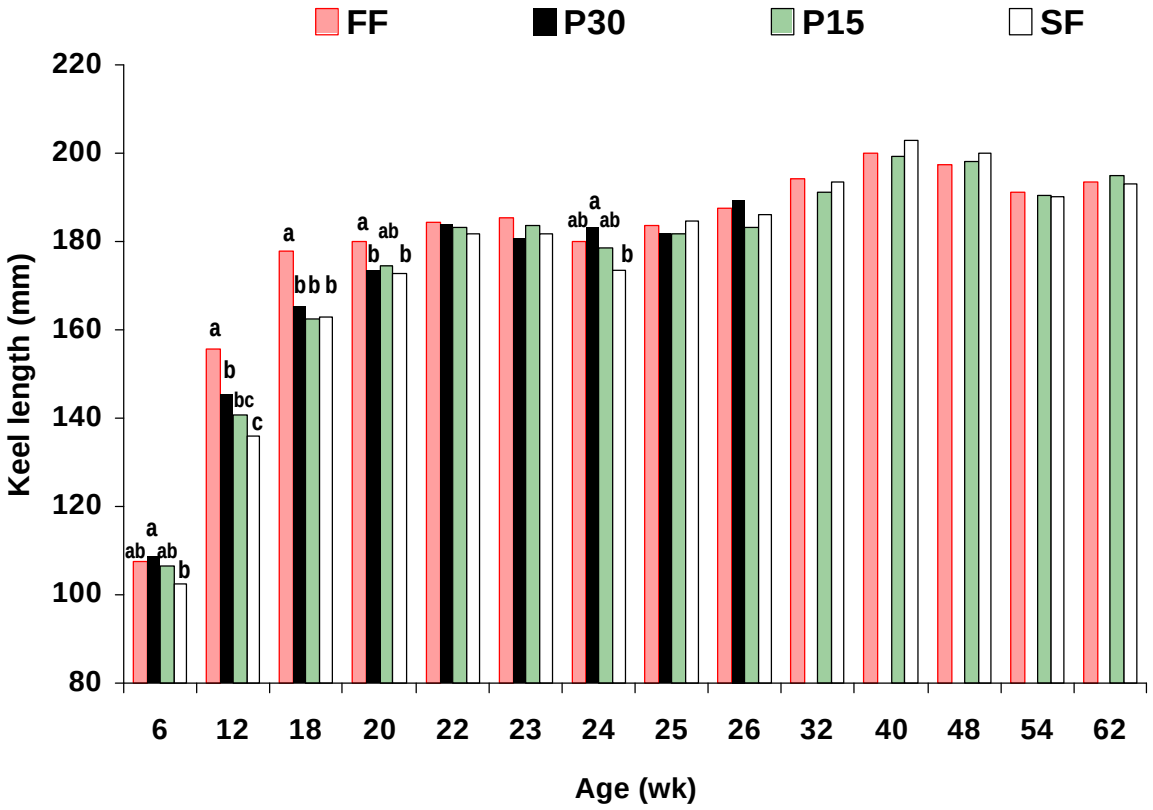


FIGURE 2.4. Keel length was measured from the point of fusion in the clavical to the ventral portion of the sternum (n=40 up to 26 wk of age; n=45 from 32 to 62 wk of age). Birds in the standard fed (SF) treatment were reared to 62 wk following the recommended BW profile. The P15 were reared to be 15% heavier than the SF treatment from 4 wk to 24 wk of age. Birds in the P30 were 30% heavier than the birds in the SF. Full fed (FF) treatment birds were reared to be 60% heavier than the SF treatment. All birds returned to the breeder recommended BW at 24 wk of age. $^{a\text{-}c}$ values with no common superscript within a column at each age were significantly different ($P<0.05$).

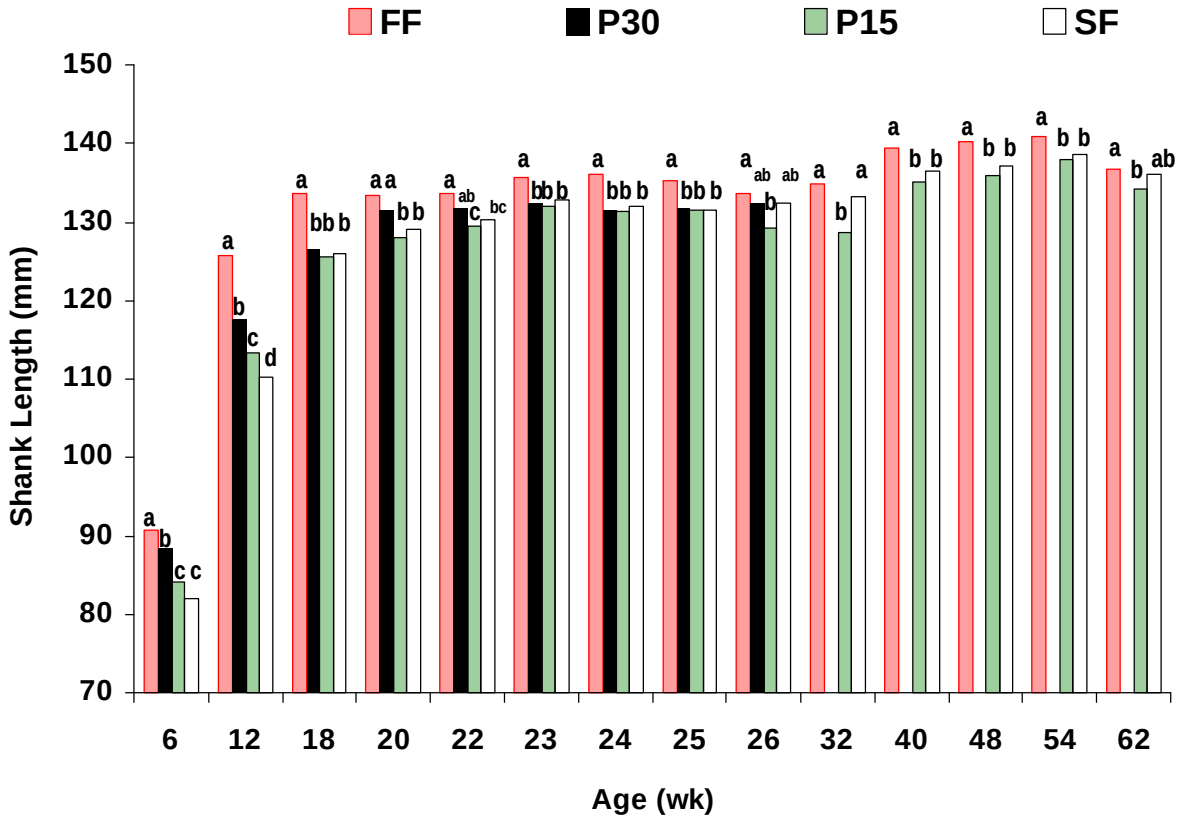


FIGURE 2.5. Shank length was measured from the hock to the junction between the second and third digit while flexed (n=40 up to 26 wk of age; n=45 from 32 to 62 wk of age). Birds in the standard fed (SF) treatment were reared to 62 wk following the recommended BW profile. The P15 were reared to be 15% heavier than the SF treatment from 4 wk to 24 wk of age. Birds in the P30 were 30% heavier than the birds in the SF. Full fed (FF) treatment birds were reared to be 60% heavier than the SF treatment. All birds returned to the breeder recommended BW at 24 wk of age. $^{a-d}$ values with no common superscript within a column at each age were significantly different ($P<0.05$).

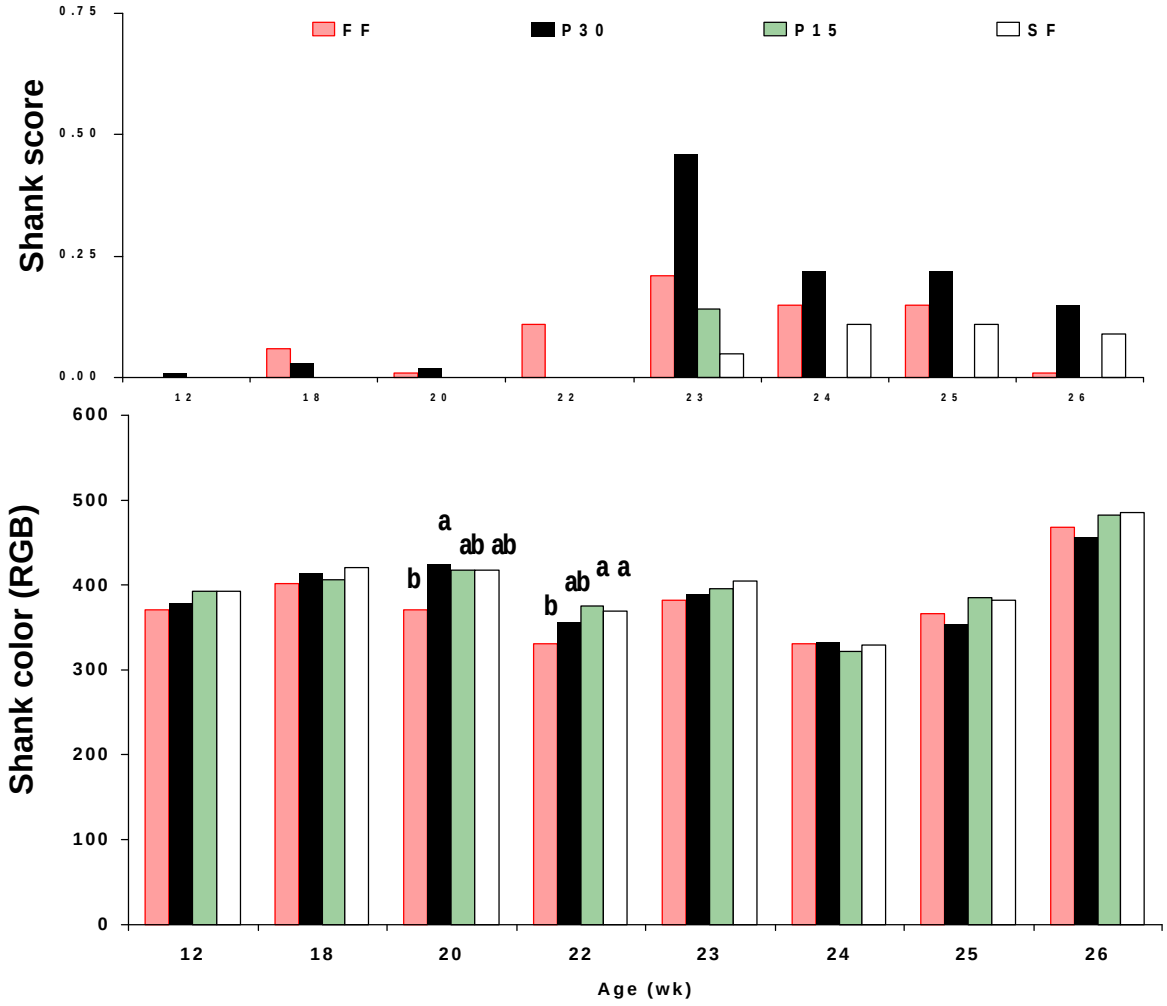


FIGURE 2.6. Shank color was assessed using Paintshop Pro (Jasc Software Ver. 6.00) to assign a red green blue (RGB) value for 3 positions on the right shank of each bird (n=40). A high shank color value, 600 RGB corresponds to yellow (Imperial yellow, Behr® Paints and Stains). Shank score was subjectively evaluation of the color. A yellow shank was given a score of zero while shanks that appeared pink in color were considered a score of one. A red colored shank was given a score of two. Birds in the standard fed (SF) treatment were reared to 62 wk following the recommended BW profile. The P15 were reared to be 15% heavier than the SF treatment from 4 wk to 24 wk of age. Birds in the P30 were 30% heavier than the birds in the SF. Full fed (FF) treatment birds were reared to be 60% heavier than the SF treatment. All birds returned to the breeder recommended BW at 24 wk of age. $^{a-b}$ values with no common superscript within a column at each age were significantly different ($P<0.05$).

TABLE 2.1. Body weight, weekly BW gain, fatpad, *pectoralis* minor muscle, *pectoralis* major muscle, testes weight, and comb height of males by feeding treatment from 6 to 62 wk of age

Feed tmt [1]	Age	BW	Gain[2]	Fat pad	*P.* minor	*P.* major	Testes	Testes[3]	Comb height[4]
	(wk)				g			(%)	(cm)
FF	6	1147.1[a]	334.0[a]	17.3[a]	28.3[a]	102.0[a]	0.18[a]	0.015[a]	
P30		1164.4[a]	193.4[b]	18.2[a]	30.1[a]	97.7[a]	0.17[a]	0.014[a]	
P15		997.8[a]	180.6[b]	12.9[ab]	24.0[a]	86.9[a]	0.12[a]	0.012[a]	
SF		889.8[a]	162.4[b]	7.5[b]	22.5[a]	74.7[a]	0.11[a]	0.013[a]	
FF	12	2605.9[a]	245.0[a]	35.3[a]	28.3[a]	102.0[a]	0.18[a]	0.019[a]	0.97[a]
P30		2196.7[b]	186.4[ab]	20.5[b]	30.1[ab]	97.7[ab]	0.17[a]	0.017[a]	0.93[a]
P15		1983.1[bc]	185.3[ab]	16.2[bc]	24.0[ab]	86.9[b]	0.12[a]	0.015[a]	0.88[a]
SF		1639.7[c]	144.7[b]	8.9[c]	22.5[b]	74.7[b]	0.11[a]	0.019[a]	0.77[a]
FF	18	3394.6[a]	67.6[a]	9.0[a]	146.0[a]	473.4[a]	5.03[a]	0.125[a]	1.76[a]
P30		2805.8[b]	113.8[a]	11.6[a]	112.8[b]	348.6[b]	2.00[a]	0.063[a]	1.45[ab]
P15		2598.9[bc]	110.8[a]	6.1[a]	105.3[b]	303.1[bc]	1.11[a]	0.041[a]	1.18[bc]
SF		2381.7[c]	151.2[a]	5.4[a]	86.7[b]	260.7[c]	0.73[a]	0.028[a]	0.93[c]
FF	20	3746.7[a]	179.7[a]	12.1[a]	169.7[a]	533.6[a]	5.49[a]	0.145[a]	2.09[a]
P30		3102.1[b]	92.9[a]	13.4[a]	141.3[ab]	430.8[b]	2.78[a]	0.086[a]	1.58[b]
P15		2866.2[bc]	93.9[a]	8.2[a]	128.8[b]	365.2[bc]	0.96[a]	0.033[a]	1.07[c]
SF		2700.6[c]	109.4[a]	4.6[a]	111.6[b]	325.3[c]	0.67[a]	0.024[a]	1.20[c]
FF	22	3345.8[a]	-115.0[a]	1.8[a]	152.0[a]	477.5[a]	5.07[a]	0.148[a]	1.94[a]
P30		3310.6[a]	-73.6[a]	6.6[a]	152.9[a]	464.2[a]	5.64[a]	0.159[a]	1.58[ab]
P15		3349.1[a]	80.5[b]	6.1[a]	158.1[a]	466.6[a]	8.44[a]	0.243[a]	1.67[ab]
SF		3211.6[a]	98.5[b]	11.3[a]	141.0[a]	434.8[a]	7.11[a]	0.223[a]	1.46[b]
FF	23	3473.9[a]	-63.1[a]	1.4[a]	151.2[a]	489.1[a]	14.57[a]	0.386[b]	1.98[a]
P30		3149.1[a]	18.7[a]	3.4[a]	152.9[a]	460.8[a]	17.39[a]	0.551[ab]	1.67[a]
P15		3489.0[a]	114.5[b]	4.5[a]	158.0[a]	489.0[a]	21.67[a]	0.609[a]	2.02[a]
SF		3289.0[a]	133.4[b]	17.8[b]	143.1[a]	447.2[a]	14.07[a]	0.425[ab]	1.69[a]
FF	24	3081.3[b]	-120.9[a]	0.7[a]	132.3[b]	397.3[b]	11.70[b]	0.344[b]	1.98[a]
P30		3440.7[ab]	67.6[b]	4.5[a]	167.9[a]	471.0[a]	26.61[a]	0.767[a]	2.22[a]
P15		3556.8[a]	192.7[c]	7.3[a]	160.8[ab]	461.4[ab]	29.24[a]	0.801[a]	2.18[a]
SF		3400.3[ab]	278.2[c]	9.7[a]	145.6[ab]	417.7[ab]	25.54[a]	0.732[a]	1.95[a]
FF	25	3201.6[b]	59.4[a]	0.8[a]	194.5[a]	359.6[b]	18.41[b]	0.553[b]	1.68[b]
P30		3341.8[ab]	46.1[a]	1.5[a]	156.7[b]	455.5[a]	31.81[a]	0.944[a]	2.23[a]
P15		3496.2[ab]	96.9[a]	4.8[a]	156.6[b]	443.3[a]	30.76[a]	0.865[a]	2.18[a]
SF		3757.3[a]	51.8[a]	23.2[b]	176.1[ab]	487.4[a]	30.21[a]	0.810[a]	1.93[ab]
FF	26	3419.3[a]	69.4[a]	1.3[a]	145.7[a]	461.2[a]	24.39[c]	0.713[c]	2.12[a]
P30		3704.5[a]	-59.7[b]	2.1[a]	168.6[a]	430.8[a]	33.06[b]	0.886[bc]	2.06[a]
P15		3805.7[a]	-19.4[ab]	7.5[a]	173.8[a]	365.2[a]	42.82[a]	1.114[a]	1.88[a]
SF		3637.0[a]	15.0[ab]	4.6[a]	164.6[a]	325.3[a]	37.07[ab]	1.022[ab]	2.24[a]
FF	62	4644.8[a]	-2.4[a]	1.1[a]	160.8[b]	665.6[a]	27.80[a]	0.601[a]	2.74[a]
P15		4652.9[a]	4.0[a]	1.8[a]	215.2[a]	659.6[a]	30.45[a]	0.650[a]	2.90[a]
SF		4720.1[a]	-6.6[a]	3.2[a]	179.1[b]	667.4[a]	31.44[a]	0.674[a]	2.90[a]
Pooled SEM		172.7	41.8	3.43	10.6	25.8	2.98	0.0862	0.17

[1] Ten birds per treatment were randomly selected at 1 d of age to assess carcass characteristics. At 62 wk of age, 15 males per treatment were processed. Birds in the SF treatment were reared to 62 wk following the recommended BW profile. The P15 were reared to be 15% heavier than the SF treatment from 4 wk to 24 wk of age. Birds in the P30 were 30% heavier than the birds in the SF. FF treatment birds were reared to be 60% heavier than the SF treatment. All birds returned to the breeder recommended BW at 24 wk of age. The P30 treatment was removed at 30 wk due to technical difficulties.
[2] The BW gains were calculated weekly for each individual using their previous BW. Negative gain values were the average weight lost for the males in the treatment.
[3] Testes weight as a percent of BW.
[4] Comb height measurements were taken by image analysis (Northern Exposure, 2000) on the second blade of the comb, from the top of the comb to the body of the comb. Comb height was not collected at 6 wk of age.
[a-c] values with no common superscript within a column at each age were significantly different ($P<0.05$).

TABLE 2.2. Percent of males in semen production, fertility, fertile period, semen characteristics and testosterone level by feeding treatment from 28 to 62 wk of age

Feed tmt [1]	Age	PMPS[2]	Fertility[3] (1-7 d)	Fertility (8-14d)	Duration[4]	Semen volume	Sperm Conc.	SMI[5]	T[6]
	(wk)	(%)	(%)	(%)	(d)	(g)	(bil/mL)		(ng/mL)
FF	28	100 [a]	96.2 [a]	80.8 [a]	16.2 [a]	0.29 [a]	1.23 [a]	190 [a]	2.27 [a]
P15		87 [a]	90.7 [a]	71.0 [a]	15.0 [a]	0.22 [a]	1.07 [a]	141 [a]	2.45 [a]
SF		100 [a]	96.7 [a]	78.0 [a]	15.7 [a]	0.33 [a]	1.09 [a]	139 [a]	2.40 [a]
FF	32	100 [a]	93.6 [a]	62.9 [a]	14.8 [a]	0.39 [a]	1.14 [a]	169 [a]	2.55 [a]
P15		87 [a]	84.1 [a]	53.4 [a]	13.5 [a]	0.21 [a]	1.13 [a]	145 [a]	1.99 [a]
SF		100 [a]	93.7 [a]	60.5 [a]	13.7 [a]	0.28 [a]	1.25 [a]	178 [a]	2.28 [a]
FF	36	100 [a]	94.0 [a]	66.7 [a]	14.3 [a]	0.35 [a]	1.22 [a]	157 [a]	2.39 [a]
P15		93 [a]	83.9 [a]	42.2 [a]	12.6 [a]	0.33 [a]	1.01 [a]	126 [a]	1.88 [a]
SF		100 [a]	93.3 [a]	59.6 [a]	13.2 [a]	0.39 [a]	1.26 [a]	99 [a]	2.02 [a]
FF	40	93 [a]	97.1 [a]	60.5 [a]	14.2 [a]	0.36 [a]	1.17 [a]	143 [a]	2.45 [a]
P15		93 [a]	92.0 [a]	48.6 [a]	13.2 [a]	0.24 [a]	1.06 [a]	111 [a]	1.95 [a]
SF		100 [a]	92.7 [a]	55.5 [a]	13.2 [a]	0.32 [a]	1.21 [a]	123 [a]	2.19 [a]
FF	44	80 [a]	78.9 [a]	45.9 [a]	13.4 [a]	0.32 [a]	0.64 [a]	188 [a]	1.75 [a]
P15		87 [a]	70.9 [a]	34.2 [a]	12.0 [a]	0.26 [a]	0.57 [a]	111 [a]	2.16 [a]
SF		93 [a]	78.2 [a]	49.9 [a]	13.4 [a]	0.31 [a]	0.62 [a]	133 [a]	2.18 [a]
FF	50	93 [a]	89.3 [a]	72.0 [a]	15.5 [a]	0.26 [a]	1.01 [a]	111 [a]	1.90 [a]
P15		80 [a]	83.0 [a]	56.7 [a]	14.3 [a]	0.25 [a]	0.91 [a]	99 [a]	2.51 [a]
SF		93 [a]	91.8 [a]	70.6 [a]	15.3 [a]	0.32 [a]	1.24 [a]	99 [a]	1.70 [a]
FF	54	100 [a]	88.7 [a]	62.9 [a]	14.0 [a]	0.29 [a]	1.10 [a]	131 [a]	1.60 [a]
P15		93 [a]	82.4 [a]	54.5 [a]	13.4 [a]	0.27 [a]	1.04 [a]	194 [a]	1.94 [a]
SF		93 [a]	91.7 [a]	71.3 [a]	14.3 [a]	0.28 [a]	1.22 [a]	121 [a]	1.37 [a]
FF	58	93 [a]	89.7 [a]	63.8 [a]	14.3 [a]	0.24 [a]	0.81 [a]	117 [a]	1.99 [a]
P15		67 [b]	83.7 [a]	55.4 [a]	14.4 [a]	0.15 [a]	1.02 [a]	133 [a]	2.05 [a]
SF		87 [a]	91.9 [a]	67.0 [a]	14.7 [a]	0.20 [a]	0.84 [a]	97 [a]	2.03 [a]
FF	62	87 [ab]	90.7 [a]	67.9 [a]	16.8 [a]	0.43 [a]	1.14 [a]	119 [a]	1.84 [a]
P15		73 [b]	91.7 [a]	71.3 [a]	16.5 [a]	0.35 [a]	1.35 [a]	143 [a]	2.24 [a]
SF		93 [a]	95.2 [a]	78.4 [a]	17.7 [a]	0.37 [a]	1.33 [a]	112 [a]	2.32 [a]
Pooled SEM		6.65	3.98	4.15	0.75	0.046	0.138	33.1	0.648

[1] Fifteen birds per treatment were randomly selected at 1 d of age to assess reproductive characteristics. At 62 wk of age, 15 males per treatment were processed. Birds in the SF treatment were reared to 62 wk following the recommended BW profile. The P15 were reared to be 15% heavier than the SF treatment from 4 wk to 24 wk of age. FF treatment birds were reared to be 60% heavier than the SF treatment. All birds returned to the breeder recommended BW at 24 wk of age. The Single Comb White Leghorn flock was 16 wk older than the male broiler breeders. Hens were replaced at wk 44 (corresponds to male age) with 22 wk old Leghorn hens.

[2] Percent of Males Producing Semen

[3] Fertility was calculated as the percent of fertile eggs laid over a 7 d period.

[4] Fertile period was calculated from the number of fertile eggs laid prior to three consecutive infertile eggs.
[5] Sperm Motility Index found using the Sperm Quality Analyzer® defined as the number and amplitude of deflections in a light path per second as a result of sperm movement within a capillary tube.
[6] Serum samples were analyzed for total testosterone (T) content by radioimmunoassay (Diagnostic Products, 5700 W. 96th St. Los Angeles, CA; kit # PITKTT).
[a-c] values with no common superscript within a column were significantly different ($P<0.05$).

APPENDIX 2.1. Breast muscle characteristics by feeding treatment from 6 to 62 wk of age

Feed tmt [1]	Age	Breast area[2]	Right diagonal[3]	Widest width[4]	mid width[5]	Center length[6]
	(wk)	cm [2]	---------- cm ----------			
FF	6	102.7 [a]	12.4 [a]	12.4 [a]	12.0 [ab]	9.3 [a]
P30		107.1 [a]	12.9 [a]	12.7 [a]	12.2 [a]	9.6 [a]
P15		102.4 [a]	13.0 [a]	12.4 [a]	11.5 [ab]	9.2 [a]
SF		94.5 [a]	12.5 [a]	11.7 [a]	10.6 [b]	9.1 [a]
FF	12	215.1 [a]	18.4 [a]	16.7 [a]	17.1 [a]	14.8 [a]
P30		188.4 [ab]	16.9 [b]	15.4 [ab]	15.8 [ab]	12.9 [b]
P15		173.7 [bc]	16.1 [bc]	15.1 [bc]	15.4 [bc]	12.7 [b]
SF		154.8 [c]	15.4 [c]	14.1 [c]	14.4 [c]	11.9 [b]
FF	18	300.1 [a]	21.8 [a]	18.7 [a]	18.5 [a]	17.0 [a]
P30		255.2 [b]	19.9 [b]	18.2 [ab]	17.6 [ab]	15.1 [b]
P15		237.7 [bc]	19.6 [b]	17.3 [bc]	16.8 [bc]	14.9 [b]
SF		220.2 [c]	19.1 [b]	16.2 [c]	15.7 [c]	14.6 [b]
FF	20	332.0 [a]	22.1 [a]	21.0 [a]	20.5 [a]	17.3 [a]
P30		300.5 [b]	21.2 [a]	20.4 [a]	20.0 [a]	16.1 [bc]
P15		310.3 [ab]	22.1 [a]	20.2 [a]	19.4 [a]	16.9 [ab]
SF		255.1 [c]	19.8 [b]	18.3 [b]	17.8 [b]	15.4 [c]
FF	22	310.1 [a]	21.2 [a]	21.0 [a]	20.6 [a]	16.8 [a]
P30		304.7 [a]	21.2 [a]	20.8 [a]	20.1 [a]	16.8 [a]
P15		304.7 [a]	21.2 [a]	20.8 [a]	20.5 [a]	16.4 [a]
SF		304.6 [a]	21.4 [a]	20.7 [a]	19.9 [a]	16.6 [a]
FF	23	300.1 [a]	21.6 [a]	20.2 [a]	19.6 [a]	16.7 [a]
P30		290.8 [a]	21.3 [a]	19.7 [a]	19.1 [a]	16.4 [a]
P15		303.2 [a]	21.4 [a]	20.4 [a]	19.5 [a]	16.9 [a]
SF		294.8 [a]	20.8 [a]	20.4 [a]	19.8 [a]	16.5 [a]
FF	24	273.1 [a]	20.9 [b]	19.4 [b]	18.4 [b]	16.0 [a]
P30		315.5 [b]	21.7 [ab]	21.4 [a]	20.4 [a]	17.0 [a]
P15		310.4 [b]	21.6 [ab]	21.1 [a]	20.1 [a]	17.0 [a]
SF		301.2 [b]	22.2 [a]	20.6 [ab]	19.1 [ab]	16.5 [a]
FF	25	276.8 [a]	20.8 [a]	19.4 [a]	18.2 [b]	16.4 [a]
P30		297.3 [a]	21.3 [a]	20.2 [a]	19.5 [ab]	16.3 [a]
P15		293.2 [a]	20.6 [a]	20.1 [a]	19.2 [ab]	16.3 [a]
SF		304.1 [a]	21.6 [a]	20.8 [a]	20.2 [a]	16.1 [a]
FF	26	314.0 [a]	23.6 [a]	18.3 [b]	17.5 [a]	18.4 [a]
P30 [7]		329.9 [a]	23.7 [a]	20.0 [a]	18.7 [a]	18.6 [a]
P15		305.1 [a]	22.7 [a]	19.4 [ab]	18.4 [a]	17.0 [b]
SF		315.6 [a]	23.1 [a]	19.9 [a]	18.8 [a]	17.9 [ab]
FF	62	318.1 [a]	21.8 [a]	21.1 [a]	20.5 [a]	16.9 [a]
P15		319.6 [a]	21.9 [a]	21.6 [a]	20.4 [a]	17.1 [a]
SF		328.9 [a]	22.3 [a]	21.1 [a]	20.5 [a]	17.1 [a]
Pooled SEM		10.4	0.53	0.57	0.61	0.48

[1] Ten birds per treatment were randomly selected at 1 d of age to assess carcass characteristics. At 62 wk of age, 15 males per treatment were processed. Birds in the SF treatment were reared to 62 wk following the recommended BW profile. The P15 were reared to be 15% heavier than the SF treatment from 4 wk to 24 wk of age. Birds in the P30 were 30% heavier than the birds in the SF. FF treatment birds were reared to be 60% heavier than the SF treatment. All birds returned to the breeder recommended BW at 24 wk of age.
[2] Breast area encompasses the surface area of the *pectoralis* major muscle.
[3] Right diagonal length was measured from the upper most right point of the *pectoralis* major muscle to the point of attachment of the breast muscle to the keel.
[4] Widest width was measured on a line perpendicular to keel at widest point of the breast.
[5] Mid width was measured on a line perpendicular to the keel at the mid point (one half the total length of the breast) of the breast.
[6] Center length was measured along the attachment line of the breast to the keel.
[a-c] values with no common superscript within a column at each age were significantly different ($P<0.05$).

APPENDIX 2.2. Breast muscle slice characteristics by feeding treatment from 6 to 62 wk of age

Feed	Age	Long slice			Short slice			
tmt [1]		Thick	Midwidth	Thin	Length	Widest	Length	Area
	(wk)	---------- cm ----------						cm [2]
FF	6	1.89 [a]	1.16 [a]	0.68 [a]	14.2 [a]	1.60 [a]	6.75 [a]	8.81 [a]
P30		1.93 [a]	0.99 [a]	0.60 [a]	14.3 [a]	1.63 [a]	7.10 [a]	8.91 [a]
P15		1.72 [a]	0.97 [a]	0.65 [a]	14.8 [a]	1.61 [a]	7.00 [a]	8.61 [a]
SF		1.82 [a]	1.01 [a]	0.65 [a]	14.1 [a]	1.57 [a]	6.72 [a]	8.26 [a]
FF	12	2.39 [a]	1.39 [a]	0.75 [a]	20.6 [a]	2.03 [b]	16.43 [a]	10.12 [a]
P30		2.42 [a]	1.51 [a]	0.74 [a]	18.7 [a]	2.19 [b]	16.01 [a]	9.36 [ab]
P15		2.38 [a]	1.37 [a]	0.78 [a]	19.3 [a]	3.64 [a]	13.89 [a]	7.60 [b]
SF		2.30 [a]	1.32 [a]	0.72 [a]	19.2 [a]	2.17 [b]	14.32 [a]	9.01 [a]
FF	18	3.37 [a]	1.89 [a]	1.00 [a]	25.7 [a]	2.89 [a]	13.01 [a]	29.37 [a]
P30		3.12 [a]	1.66 [a]	0.83 [a]	23.9 [ab]	2.78 [a]	11.55 [a]	24.47 [b]
P15		2.89 [a]	1.57 [a]	0.83 [a]	22.6 [b]	2.56 [a]	11.51 [a]	23.57 [b]
SF		2.63 [a]	1.51 [a]	0.72 [a]	22.5 [b]	2.33 [a]	10.48 [a]	21.07 [c]
FF	20	3.09 [a]	1.64 [a]	0.92 [a]	31.6 [a]	2.90 [a]	13.10 [a]	26.18 [a]
P30		3.13 [a]	1.67 [a]	0.98 [a]	29.1 [ab]	2.83 [a]	12.23 [a]	25.14 [ab]
P15		3.20 [a]	1.56 [a]	0.82 [a]	28.4 [b]	2.63 [a]	13.34 [a]	25.42 [a]
SF		3.02 [a]	1.62 [a]	0.95 [a]	26.9 [b]	2.66 [a]	12.79 [a]	23.45 [b]
FF	22	3.11 [a]	1.70 [a]	1.07 [a]	25.0 [ab]	2.60 [a]	12.35 [a]	25.85 [a]
P30		3.13 [a]	1.72 [a]	1.05 [a]	27.9 [a]	2.90 [a]	12.66 [a]	25.81 [a]
P15		3.08 [a]	1.59 [a]	0.97 [a]	25.8 [ab]	2.74 [a]	11.78 [a]	26.05 [a]
SF		2.61 [a]	1.59 [a]	0.88 [a]	24.8 [b]	2.54 [a]	12.09 [a]	25.93 [a]
FF	23	2.94 [a]	1.64 [a]	0.94 [a]	22.8 [b]	2.52 [a]	10.84 [a]	26.81 [a]
P30		3.22 [a]	1.71 [a]	0.98 [a]	24.3 [ab]	2.88 [a]	11.26 [a]	26.21 [a]
P15		3.04 [a]	1.71 [a]	0.86 [a]	25.7 [a]	2.96 [a]	10.81 [a]	26.06 [a]
SF		3.13 [a]	1.60 [a]	0.96 [a]	24.8 [ab]	2.93 [a]	11.35 [a]	25.81 [a]
FF	24	2.80 [a]	1.56 [a]	0.90 [a]	22.4 [a]	2.57 [b]	10.37 [a]	26.32 [a]
P30		3.01 [a]	1.81 [a]	0.88 [a]	25.1 [a]	3.62 [a]	9.67 [a]	26.72 [a]
P15		3.07 [a]	1.76 [a]	0.76 [a]	24.8 [a]	2.60 [b]	11.23 [a]	26.00 [a]
SF		2.80 [a]	1.62 [a]	0.85 [a]	24.4 [a]	2.94 [ab]	11.03 [a]	26.47 [a]
FF	25	2.99 [a]	1.57 [a]	0.90 [a]	24.0 [b]	3.38 [a]	11.21 [a]	25.47 [a]
P30		3.10 [a]	1.74 [a]	1.00 [a]	24.2 [ab]	2.45 [b]	11.29 [a]	25.09 [a]
P15		2.96 [a]	1.60 [a]	0.94 [a]	23.9 [b]	2.66 [b]	11.36 [a]	24.49 [a]
SF		3.16 [a]	1.70 [a]	0.93 [a]	27.1 [a]	2.71 [ab]	12.63 [a]	25.59 [a]
FF	26	2.70 [a]	1.77 [a]	0.97 [a]	24.9 [b]	2.26 [b]	10.84 [a]	26.44 [a]
P30 [2]		2.82 [a]	1.84 [a]	0.98 [a]	25.9 [ab]	2.52 [b]	11.49 [a]	27.82 [a]
P15		3.14 [a]	1.84 [a]	0.96 [a]	27.9 [a]	3.44 [a]	10.15 [a]	26.15 [a]
SF		2.92 [a]	1.68 [a]	0.90 [a]	26.5 [ab]	2.65 [ab]	11.16 [a]	26.99 [a]
FF	62	3.48 [a]	1.97 [a]	1.23 [a]	25.5 [a]	3.24 [a]	10.82 [a]	29.4 [a]
P15		3.43 [a]	1.95 [a]	1.07 [a]	27.9 [a]	3.20 [a]	11.25 [a]	29.6 [a]
SF		3.39 [a]	2.14 [a]	1.36 [a]	26.0 [a]	3.24 [a]	10.85 [a]	28.8 [a]
Pooled SEM		1.00	0.14	0.08	1.00	0.36	0.71	0.82

[1] Ten birds per treatment were randomly selected at 1 d of age to assess carcass characteristics. At 62 wk of age, 15 males per treatment were processed. Birds in the SF treatment were reared to 62 wk following the recommended BW profile. The P15 were reared to be 15% heavier than the SF treatment from 4 wk to 24 wk of age. Birds in the P30 were 30% heavier than the birds in the SF. FF treatment birds were reared to be 60% heavier than the SF treatment. All birds returned to the breeder recommended BW at 24 wk of age.
[2] Half = line perpendicular to keel at the midpoint of the breast.
[3] Widest = line perpendicular to keel at widest point of the breast.
[4] Long slice = 1 cm wide slice following line 1 of the whole breast. Transverse section of *P. Major* taken from the left side of the muscle beginning at the top of the shoulder and continuing downwards to the keel.
[5] Thickest = upper part of the breast, nearest the shoulder and wing attachment.
[6] Wide slice = 1 cm wide slice following widest line. Transverse section of the *P. Major* taken from the right beginning at the keel and continuing to the end of the muscle.
[7] Inner = innermost thickness towards the keel.
[a-c] values with no common superscript within a column at each age were significantly different ($P<0.05$).

CHAPTER 3

RESEARCH NOTE: EFFECTS OF DECREASING BODY WEIGHT AFTER SEXUAL MATURITY ON REPRODUCTIVE CHARACTERISTICS IN MALE BROILER BREEDERS[5]

[5] R. H. McGovern, J. L. Wilson, F. E. Robinson, L. F. Bouvier, K. A. Thorsteinson, and R. A. Renema. To be submitted to *Poultry Science*.

3.1 ABSTRACT Broiler breeder males are managed to maintain high levels of fertility throughout the life of the flock by preventing excess BW gain or a BW loss. Two BW treatments were imposed on 15 males per treatment that were individually caged at 21 wk of age. Birds in the standard gain (SG) treatment were reared to 62 wk following standard recommended BW. Males in the late loss (LL) treatment were fed in order to decrease BW by 200 g from 35 wk of age. Semen volume, sperm concentration, percentage of males in production (PMPS), fertility (1-7d and 8-14d post-insemination), fertile period (consecutive number of days in which a fertile egg was laid post-insemination), and testosterone concentrations were measured for all males at 28, 32, 36, 40, 44, 50, 54, 58, and 62 wk of age. The fertility (8-14d) was 14.7% and 12% lower in the LL treatment than the SG treatment at 58 and 62 wk of age, respectively. Fertility was 95.3% at 62 wk of age in the SG treatment. Fertile period was reduced by 2 d in the LL males at 50 and 58 wk of age. Testosterone levels were not different between the LL and the SG males. There was no difference in semen volume or concentration between the BW treatments. Some males (46% of the LL) responded to decreasing BW by cessation of semen production. Males that maintain semen production, with a decrease in BW, have reduced fertility suggesting that sperm viability may be affected since volume and concentration were not affected.

(*Keywords:* male broiler breeder, weight loss, fertility, sperm concentration, testosterone)

3.2 INTRODUCTION

Male broiler breeders late in production show an age-related decrease in mating activity (Duncan et al., 1990). Meanwhile aging females are also less responsive to the attempts of males to mate (Duncan et al., 1990). Overweight males are also less likely to complete a mating due to leg problems. Parker and Arscott (1964) found that decreasing the energy level of the diet resulted in lower levels of spermatozoa production and fertility in White Leghorn males. Sexton et al. (1989) found that decreased fertility has resulted from feed restriction, which was primarily related to a deficiency in energy consumption.

Brown and McCartney (1983) reported that feed restriction of broiler breeder males to 85% of amount fed to controls gave the best results in terms of reproductive performance to 46 wk of age, although birds lost BW over a 24-wk-breeder period. The restricted males produced a greater amount of semen than the control males from 30 to 46 wk of age (Brown and McCartney, 1983). The objective of the present study was to assess the long-term effects of a decrease in BW on the reproductive characteristics of male broiler breeders.

3.3 MATERIALS AND METHODS

3.3.1 *Stocks and Management*

Thirty commercial male broiler breeders were reared to recommended BW at 24 wk of age. The photoperiod consisted of 23 hr of light and 1 hr of darkness (23L:1D) for the first 3 d. From 3 d to 22 wk of age, the birds received 8 hr of light

(8L: 16D) provided at 10 lux intensity. From 22 to 62 wk of age, a photoperiod of 15L: 9D was provided to the male broiler breeders. From 3 wk to 20 wk of age, the birds were fed on alternate days with twice the daily feed allotment fed each feed day (skip-a-day feeding) to promote higher flock uniformity. All birds were fed a wheat-based broiler breeder starter ration containing 18% CP and 2783 kcal ME/kg from 1 d to 6 wk of age. From 6 to 21 wk of age, a grower diet containing 15% CP and 2711 kcal ME/kg was fed to the males. The laying ration, fed from 22 to 62 wk of age, consisted of 14.5% CP and 2500 kcal ME/kg.

The birds were wing-banded and individually weighed on a weekly basis. All birds were assigned to one of two feeding level treatments at 1 d of age either standard gain (SG) or late loss (LL). Birds in the SG treatment were reared to 62 wk following the recommended BW profile. Males in the LL treatment were allocated enough feed to maintain a gradual BW loss from 35 wk of age (Figure 3.1). At 34 wk of age, all males were given 132 g/male. By 62 wk of age, males in the LL treatment received 112 g/bird while males in the SG treatment were allocated 144 g/bird. At 21 wk of age, 15 males per BW treatment were individually caged. Body weight gains or losses were calculated weekly. The Animal Policy and Welfare Committee of the Faculty of Agriculture, Forestry and Home Economics of the University of Alberta approved the experimental protocol.

3.3.2 *Reproduction*

Semen was ejaculated from males on 3 non-consecutive days per week. Semen volume and semen concentration was measured for all males at 28, 32, 36,

40, 44, 50, 54, 58, and 62 wk of age. Semen volume was measured indirectly by weight (1 mL ≅ 1 g; Brillard and de Reviers, 1981). Semen concentration was determined using a spectrophotometer measuring optical density (Carson et al., 1995). Semen was also collected from the 30 producing males and used to inseminate 6 commercial Single Comb White Leghorn hens per male for evaluation of fertility. A 10 µl quantity of fresh undiluted semen from each male was artificially inseminated intravaginally to the hens. All inseminations were performed in the afternoon to maximize fertility (Parker, 1950). Eggs were collected on a daily basis for 21 d post-insemination by cage and incubated weekly for 7 d to assess fertility. The eggs were stored at 16 to 17 C and approximately 75% relative humidity. Fertility and plasma testosterone concentrations were assessed as described in Chapter 2.

3.3.3 *Statistical Analysis*

All treatment main effects and the interactions were tested for significance at P 0.05 using the General Linear Models procedure according to SAS ® (SAS Institute Inc., 1999). When main effects or their interactions were significant, the P-Diff test of SAS was used to separate significantly different means (Steel and Torrie, 1997).

3.4 RESULTS AND DISCUSSION

Males in the LL treatment had similar BW to the SG males to 44 wk of age (Table 4.1). In the SG treatment, one male was removed at 37 wk of age due to a

foot pad infection contributing to the decrease in average BW at 40 wk of age. From 44 to 62 wk of age, the LL males maintained a lower BW than the SG males by an average difference of 490 g that ranged from 263 to 639 g at 44 and 62 wk, respectively. At 50 wk of age, the LL males lost 35.8 g of BW.

The PMPS decreased to approximately 50% in the LL treatment at 40 wk of age and remained lower than the SG treatment to 62 wk of age. Roosters in the LL treatment that stopped producing semen were of average BW and could not sustain semen production with a concurrent BW loss. Similarly, Buckner et al. (1986) and Sexton et al. (1989) showed that severe restrictions caused a decline in the number of birds producing semen.

In the SG treatment, there was no decrease in the PMPS with age (93% at 62 wk of age). Revington et al. (1991) also found no difference in the PMPS at any age and the PMPS was 96% at 66 wk of age in roosters fed a standard ration. In contrast, Zhang et al. (1999) found that the PMPS decreased with age from 94% at 28 wk to about 30% at 52 wk of age.

Although there was a reduction in the PMPS as early as 44 wk, the fertile period and fertility were not affected in the remaining LL males until 50 and 58 wk of age, respectively. The fertility (8-14 d) in the LL treatment was 14.7% and 12% lower than the SG treatment at 58 and 62 wk of age, respectively. The fertile period was also reduced in the LL males by approximately 2 d compared to the SG treatment at 50 and 58 wk of age. Fertility showed a gradual decline in the SG treatment from 96.6% at 28 wk to 73.6% at 44 wk at which time the flock of hens was replaced.

In early reports, age-related decreases in hen fertility have been associated with a decline in egg production (Atwood, 1929; Etches, 1990) and the associated decline in hen receptivity to natural mating (Duncan et al., 1990). However, all hens were artificially inseminated in this study and old hens were replaced at 44 wk, eliminating these potential hen influence. In the males, the age-related decline in fertility has been related to a reduction in sperm quality (Brillard and McDaniel, 1986), a decline in libido and in some cases changes in body conformation that inhibit mating (Hocking and Bernard, 1997).

Although the semen volume and concentration were not affected by the males BW loss in the LL treatment (averaging 0.27 mL and 1.13 billion/mL, respectively throughout the experiment), fertility and the fertile period was lower in the LL treatment than the SG treatment. The decrease in fertility, of the males that were able to maintain semen production with a decrease in BW, suggests sperm viability may be affected by decreasing BW. Semen concentration was correlated to BW ($r=0.66$, $P<0.0001$).

Reductions in feed intake (75% of standard) have been shown to decrease semen production by almost 40% in caged broiler breeder males (Sexton et al., 1989). In this experiment, the LL treatment received 80% of the standard feed intake. Each male in the LL treatment received an average of 26 g less feed than the SF males from 40 wk of age. Although there were no differences in semen volume or concentration in this experiment, the feed restriction levels used may be considered extreme due to the overall decrease in the PMPS by 36.5% in the LL treatment.

Parker and Arscott (1964) showed a reduction in semen production associated with a BW loss of 16% in SCWL males and complete infertility resulted with a BW loss of 30%. Although SCWL males do not tend to have the BW reserves commonly associated with broiler breeder males, the broiler breeder males used in this experiment were not considered overweight compared to the recommended BW. A BW loss of 5% was induced from 32 to 50 wk of age that could be considered severe because the males were not overweight.

Testosterone levels were not different between the LL treatment and SG males throughout the trial averaging 1.8 ng/mL from 40 to 62 wk of age. Hocking and Bernard (2000) found testosterone levels averaged approximately 2.5 ng/mL from 40 to 60 wk of age in male broiler breeders fed wheat based diets. Roosters did not show any change in testosterone level in response to a 5% BW loss. Males in both treatments were not overweight when the treatments were imposed, consequently the LL males responded negatively to the BW loss by reductions in PMPS, fertility, and fertile period late in production.

3.5 CONCLUSIONS

Producing viable semen for reproduction is the function of male broiler breeders. The consequences of BW loss in male broiler breeders were a reduction in semen quality and quantity. Semen quality was affected late in production as shown by the decrease in fertility (8-14 d post-insemination) and fertile period at 58 wk of age. Semen quantity was indirectly affected by the reduction in the PMPS starting at 44 wk of age. In an artificially inseminated flock, a decrease in PMPS

would decrease the total quantity of pooled semen, which would affect the number of females that could be inseminated. The reproductive function of broiler breeder males was sensitive to a 5% BW loss depending on initial BW. However, if standard artificial insemination techniques, including higher doses of pooled semen inseminated at 7 d intervals, had been used, differences between the SG and LL treatments would not have been apparent as fertility (1-7d) averaged 93% in both treatments at 62 wk of age.

3.6 REFERENCES

Atwood, H., 1929. Observations concerning the time factor in egg production. Poult. Sci. 8:137-140.

Brillard J. P. and G. R. McDaniel, 1986. Influence of spermatozoa numbers and insemination frequency on fertility in dwarf broiler breeder hens. Poult. Sci. 65:2300-2334.

Brillard J. P. and M. de Reviers, 1981. Testis development and daily sperm output in guinea-fowl raised under constant daily photoperiods. Reprod. Nutr. Dev., 21:1105-1112.

Brown H. B. and M. G. McCartney, 1983. Effects of dietary restriction on reproductive performance of broiler breeder males. Poult. Sci. 62:1885-8.

Buckner, R. E., J. A. Renden, and T. F. Savage, 1986. The effect of feeding programs on reproductive traits and selected blood chemistries of caged broiler breeder males. Poult. Sci. 65:85-91.

Carson J. D., F. W. Lorenz, and V. S. Asmundson, 1995. Semen production in the turkey male. 1. Seasonal variation. Poult. Sci. 34:336-343.

Duncan, I. J. H., P. M. Hocking, and E. Seawright, 1990. Sexual behavior and fertility in broiler breeder domestic fowl. Applied Animal Behavior Sci. 26:1-12.

Etches, R. J., 1990. The ovulatory cycle of the hen. Crit. Rev. Poultry Biol., 2:293-318.

Hocking, P. M. and R. Bernard, 1997. Effects of male body weight, strain and dietary protein content on fertility and musculo-skeletal disease in naturally mated broiler breeder males. Br. Poult. Sci. 38:29-37.

Hocking, P. M. and R. Bernard, 2000. Effects of age of male and female broiler breeders on sexual behavior, fertility and hatchability of eggs. Br. Poult. Sci. 41:370-377.

Parker J. E., 1950. The effect of restricted mating in flocks of New Hampshire chickens on fertility and hatchability of eggs. Poult. Sci. 29:268-270.

Parker, J. E. and G. H. Arscott, 1964. Energy intake and fertility of male chickens. J. Nutr. 82:183-187.

Revington, W. H., E. T. Moran, JR., and G. R. McDaniel, 1991. Performance of broiler breeder males given low protein feed. Poult. Sci. 70:139-145.

SAS Institute Inc., 1999. SAS User's Guide. SAS Institute Inc., Cary, NC.

Sexton K. J., J. A. Renden, D. N. Marple, and R. J. Kemppainen, 1989. Effects of *ad libitum* and restricted feeding on semen quantity and quality, body composition, and blood chemistry of caged broiler breeder males. Poult. Sci. 68:569-576.

Steel, R. G. D., and J. H. Torrie, 1997. Principles and Procedures of Statistics: A Biometrical Approach. McGraw-Hill Book Company Inc., New York, NY.

Zhang, X., W. D. Berry, G. R. McDaniel, D. A. Roland, P. Liu, C. Calvert, and R. Wilhite, 1999. Body weight and semen production of broiler breeder males as influenced by CP levels and feeding regimens during rearing. Poult. Sci. 78:190-196.

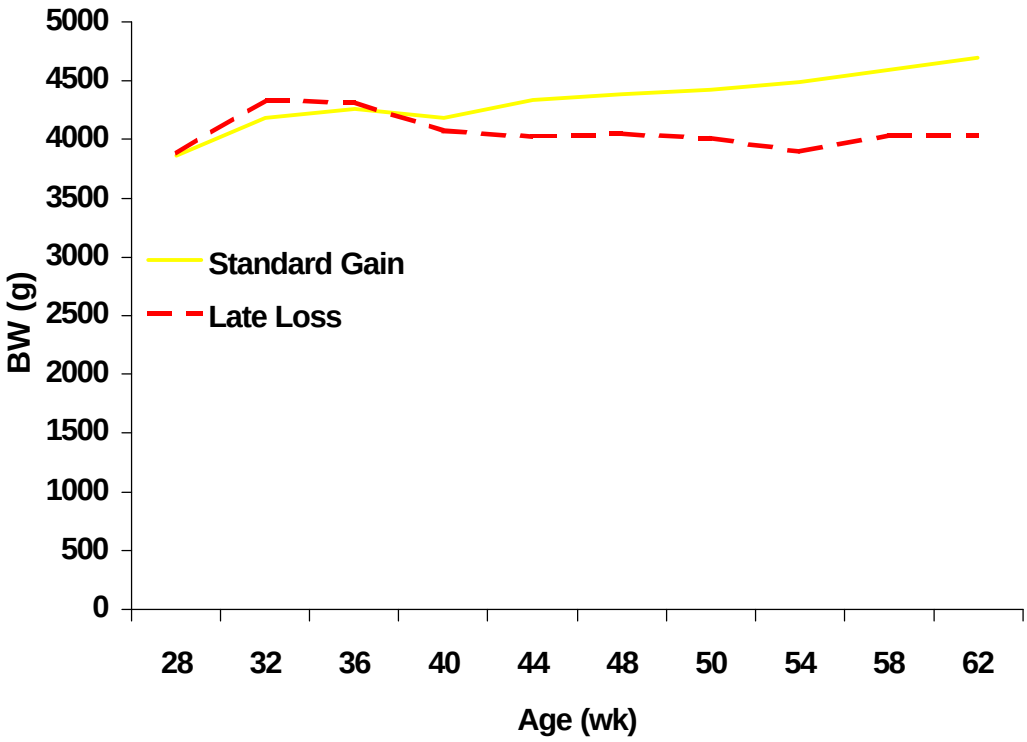


Figure 3.1. Males in the late loss treatment were lighter than standard gain males from 44 to 62 wk of age (15 males/treatment).

TABLE 3.1. BW, BW gain, percent of males producing semen, fertility, fertile period semen volume, semen concentration, and testosterone levels from 28 to 62 wk of age by feeding treatment.

Feed tmt [1]	Age	BW	Gain	PMPS[2]	Fertility[3] (1-7 d)	Fertility (8-14d)	Duration[4]	Semen Volume[5]	Semen Conc. [6]	T[7]
	(wk)	---------- (g) ----------		---------- (%) ----------			(d)	(mL)	(billion/mL)	(ng/mL)
LL	28	3866 [a]	136.2 [a]	87 [a]	97.9 [a]	79.3 [a]	15.0 [a]	0.26 [a]	1.21 [a]	2.24 [a]
SG		3902 [a]	107.1 [a]	100 [a]	96.7 [a]	77.9 [a]	15.7 [a]	0.33 [a]	1.09 [a]	2.40 [a]
LL	32	4297 [a]	44.2 [a]	87 [a]	95.3 [a]	71.2 [a]	14.3 [a]	0.23 [a]	1.26 [a]	2.20 [a]
SG		4211 [a]	34.7 [a]	100 [a]	93.7 [a]	60.5 [b]	13.7 [a]	0.28 [a]	1.25 [a]	2.28 [a]
LL	36	4288 [a]	2.1 [a]	93 [a]	89.3 [a]	61.1 [a]	13.4 [a]	0.25 [a]	1.47 [a]	2.32 [a]
SG		4270 [a]	15.2 [a]	100 [a]	93.3 [a]	59.7 [a]	13.2 [a]	0.39 [a]	1.26 [a]	2.02 [a]
LL	40	4104 [a]	-3.7 [a]	73 [b]	90.1 [a]	54.9 [a]	13.2 [a]	0.31 [a]	1.23 [a]	1.77 [a]
SG		4195 [a]	13.6 [a]	100 [a]	84.0 [a]	55.3 [a]	13.2 [a]	0.32 [a]	1.21 [a]	2.19 [a]
LL	44	4076 [b]	-1.3 [b]	67 [b]	65.3 [a]	33.4 [a]	11.6 [a]	0.24 [a]	0.55 [a]	1.86 [a]
SG		4339 [a]	74.8 [a]	93 [a]	73.6 [a]	42.1 [a]	13.4 [a]	0.31 [a]	0.62 [a]	2.18 [a]
LL	50	4014 [b]	-35.8 [b]	53 [b]	82.4 [a]	61.5 [a]	13.1 [b]	0.14 [a]	1.57 [a]	1.36 [a]
SG		4427 [a]	26.9 [a]	93 [a]	91.8 [a]	70.6 [a]	15.3 [a]	0.32 [a]	1.24 [a]	1.70 [a]
LL	54	3909 [b]	-26.5 [a]	53 [b]	90.9 [a]	68.6 [a]	13.3 [a]	0.20 [a]	0.82 [a]	1.19 [a]
SG		4500 [a]	25.2 [a]	93 [a]	91.8 [a]	71.4 [a]	14.3 [a]	0.28 [a]	1.22 [a]	1.37 [a]
LL	58	4075 [b]	96.6 [a]	47 [b]	86.3 [a]	52.4 [b]	12.5 [b]	0.16 [a]	0.87 [a]	1.04 [a]
SG		4611 [a]	89.0 [a]	87 [a]	92.0 [a]	67.1 [a]	14.7 [a]	0.20 [a]	0.84 [a]	2.03 [a]
LL	62	4081 [b]	-10.3 [a]	47 [b]	91.5 [a]	66.5 [b]	16.30 [a]	0.23 [a]	1.24 [a]	2.24 [a]
SG		4720 [a]	-6.6 [a]	93 [a]	95.3 [a]	78.5 [a]	17.67 [a]	0.37 [a]	1.33 [a]	2.32 [a]

Pooled SEM	58.7	24.49	6.7	4.75	4.44	0.92	0.05	0.14	0.648

[1] Birds in the SF treatment were reared to 62 wk following the recommended BW profile. The Single Comb White Leghorn flock was 16 wk older than the male broiler breeders. Hens were replaced at wk 44 (corresponds to male age) with 22 wk old Leghorn hens.
[2] Percent of Males Producing Semen was calculated as a percent of the 15 males per treatment.
[3] Fertility was calculated as the percent of fertile eggs laid over a seven-d period starting 1 d after hens were inseminated.
[4] Fertile period was the number of fertile eggs laid prior to three consecutive infertile eggs.
[5] Semen volume was measured indirectly by weight (1 mL ≅ 1 g).
[6] Semen concentration was determined using a spectrophotometer measuring optical density.
[7] Serum samples were analyzed for total testosterone (T) content by radio-immunoassay (Diagnostic Products, 5700 W. 96th St. Los Angeles, CA; kit # PITKTT).
[8] The Single Comb White Leghorn flock was 16 wk older than the male broiler breeders. Hens were replaced at wk 44 (corresponds to male age) with 22 wk old Leghorn hens.
[a-b] values with no common superscript within a column at each age were significantly different ($P<0.05$).

CHAPTER 4

MATING BEHAVIOR AND REPRODUCTIVE PERFORMANCE IN MALE BROILER BREEDERS WITH INTRINSICALLY HIGH, AVERAGE, AND LOW BODY WEIGHTS[1]

[1] R. H. McGovern, J. L. Wilson, B. P. Hudson, F. E. Robinson. To be submitted to *Poultry Science*.

4.1 ABSTRACT In broiler breeders, both the physical ability of the male to reproduce and his interaction with the females are affected by BW. At 20 wk of age, males were selected in LOW (2133 g), AVERAGE (2624 g), or HIGH (3100 g) rearing BW categories. At 24 wk of age, low rapid (LR) and average rapid (AR) males had a rapid increase in BW. Average standard (AS) and high standard (HS) males followed the standard BW gains. From 28 wk of age, high constant (HC) males and high slow (HW) males had constant and minimal BW gains, respectively. The six BW treatments were imposed on 21 males per rearing BW category. The objective of this experiment was to examine the effect of male BW on mating behavior, aggressive behavior, scratch area occupied by females, sperm penetrations, and fertility to 62 wk of age.

The area of the scratch occupied by females was negatively correlated to male BW at 26, 27, and 28 wk of age (r= -0.54, -0.49, -0.45, respectively). At 27 and 28 wk, fewer females occupied the scratch area in the HIGH category than the LR treatment by 28.3 and 42.8%, respectively. At 54, 58, and 62 wk, the HC males had lower fertility compared to the HS treatment by 3.8, 9.6, and 7.5%, respectively. Although mortality was 29%, high levels of fertility persisted through late production in the LR treatment. Male broiler breeder's benefit reproductively from a consistent and gradual increase in BW.

(*Keywords:* male broiler breeder, body weight, fertility, sperm penetration, behavior)

4.2 INTRODUCTION

Male BW, flock age, the interaction between males and females, mating behavior, mating frequency, and aggressiveness all affect fertility. Although the BW average is strictly controlled during rearing, there is a wide range in individual male BW. High, average, and low BW males are managed as average BW males. High and low BW males may not only have different BW from the average males, but may also behave differently towards females.

When males are housed with females, the small males have an opportunity to steal feed from the female feeder. Low and average BW males may experience a rapid increase in BW while they are able to eat out of the female feeder. McDaniel et al. (1981), found fertility problems in both overweight and underweight broiler breeder males. It has also been suggested that there is an optimum BW for maximum fertility that changes with age (Hocking, 1990). Fertility in naturally mated broiler breeder flocks normally peaks at 95 to 98% between 30 and 38 wk of age (Kirk et al., 1980). The fertility of a broiler breeder flock is dependent upon the number of roosters in semen production, the number and quality of spermatozoa produced by the male, and the number of completed matings (CM) (Harris et al., 1984).

Early social experience influences the level of sexual behavior (Parker et al., 1940). The interactions between males and females can contribute to positive mating behavior and the frequency of mating, whereas aggression between males discourages female association with males. Male libido primarily determines the frequency of mating (Craig et al., 1977). Very early work on the

libido of the White Leghorn rooster indicated that daily mating frequencies ranged from 0 to 41 per male (Guhl, 1951). An increase in forced and aggressive mating occurs when social interactions result in a reluctance of females to mate (Millman et al., 1996). The present study was conducted to evaluate the effects of rearing BW (intrinsically high, average, and low BW) and subsequent feeding programs on mating ability and reproductive performance of broiler breeder males.

4.3 MATERIALS AND METHODS

4.3.1 *Stocks and Management*

Six hundred Cobb male broiler breeders were individually weighed bimonthly starting at 2 wk of age. Cockerels were full-fed for the first 3 wk and fed on a 4 d on: 3 d off program until 21 wk of age. The photoperiod was 23L:1D at day old decreasing to 12L:12D at 4 d of age and 8L:16D at 4 wk of age. The photoperiod was increased to 14L:10D at 21 wk of age. Twelve hundred pullets were reared under the same program in separate pens. All diets were corn and soybean meal based, and formulation was typical of those used by poultry integrators. A broiler breeder starter diet was fed for first four wk (2954 cal ME/kg and 17.8% CP). The grower diet was fed from 4 to 21 wk of age (2860 cal ME/kg and 15% CP). From 22 to 44 wk of age, all birds were fed a breeder 1 diet (2855 cal ME/kg, 16% CP, and 3% Ca) to maintain their recommended BW. At 44 wk of age, all birds were fed a broiler breeder 2 diet (2855 cal ME/kg, 15% CP, and 3.3% Ca) to maintain shell quality and egg weight.

At 20 wk of age, 126 males were selected from the 600 birds placed.

Individual BW was used to separate the males into three rearing categories; LOW (2133 g), AVERAGE (2624 g), and HIGH (3100 g) (Figure 4.1). There was a maximum of a 140 g BW difference between males within a rearing category at selection and a minimum of 400 g difference between rearing categories.

Adult gain treatments were initiated at two ages. At 24 wk of age, a rapid increase in feed allocation was given to the LOW category and designated the low rapid (LR) treatment. Males in the LR treatment were subjected to a rapid increase in BW that simulates males stealing feed from the female feeder in a commercial setting. The AVERAGE category was separated into two treatments. Average standard (AS) treatment males followed the breeder recommended growth curve, while average rapid (AR) males were supplied with a greater feed allocation as in the LR treatment, but started with a greater initial BW.

At 28 wk of age, HIGH category males were separated into three treatments; high constant (HC), high standard (HS), and high slow (HW). In commercial production, HIGH BW males gradually gain excess BW throughout the life of the flock. The HC males were subjected to the greatest BW gain (1400 g) through to 62 wk of age. The HS treatment followed a standard growth curve after 28 wk of age with a small but continual BW gain totaling 1080 g. Males in the HW treatment represent males that exceed the target BW at 28 wk and are restricted to prevent extreme BW gains and therefore were subjected to minimal weekly gains (460 g) to 62 wk of age.

The HC, HS, and HW treatments did not differ from one another in mid production. It is possible that we attained peak BW in the HIGH category that

prevented BW separation from 28 to 42 wk of age. Males from the HIGH category received large feed allocations and had a placid attitude towards feeding. Females stealing male feed may have contributed to the difficulty in separating the HIGH category in mid-production. At 37 wk of age, mortality of the smallest birds in the HW treatment resulted in an artificial increase in the BW average at 38, 42, and 46 wk of age, but there was only a 50 g BW gain per wk in the remaining males.

4.3.2 *Reproductive Characteristics*

Eggs were incubated biweekly for analysis of fertility, hatchability and hatch of fertile. The eggs were candled at 10 d of incubation, and all infertile or early dead embryos recorded and removed. Fertility was assessed on 105 eggs per treatment at 26 wk and 264 eggs per treatment at 27 and 28 wk of age. As egg production increased, fertility was assessed on 540 eggs per treatment from 30 to 50 wk of age and 405 eggs per treatment from 54 to 62 wk of age. The number of eggs incubated was reduced near the end of the experiment due to the natural decrease in egg production.

Sperm penetration (SP) assessments were made on a 30-egg sample monthly from every pen (30, 34, 38, 42, 46, 50, 54, 58, and 62 wk of age) (Bramwell et al., 1995). The number of SP was recorded on 1.48 mm by 1.98 mm area of the perivitelline layer of the ovum at the site of the germinal disc using Image-Pro Plus® software version 4.0^2 (x50). Many ova had germinal discs that had overlapping SP surrounding the ovum and in some cases only a

small portion of the germinal disc remained (Appendix 4.1). An SP number of 1000 was assigned to these germinal discs, approximately 400 more holes than could be precisely assessed.

4.3.3 *Behavioral observations*

Behavioral observations were made for 30 min biweekly within 3 hr of the lights going off for the day (McDaniel and Craig, 1959). Each male was individually tagged and wing banded so that individual male mating performance could be recorded weekly from 26 to 28 wk and monthly from 30 to 62 wk of age. Complete mating, incomplete mating, attempted mating, mating interference, and aggressive behavior was observed for each individual male. A CM was recorded only when males made cloacal contact with the female. When males mounted the female without making cloacal contact, an incomplete mating was recorded. Attempted mating included physical contact between the male and female for the purpose of mating without mounting by the male.

Positive activity was calculated as the sum of CM, incomplete mating, and attempted mating. Mating interference occurred when more dominant males prevented other males from completing a mating. Behaviors such as males raising their hackles (feathers on the top of the neck) (Ensminger, 1980), pecking, or engaging in a fight, were recorded as aggression. Negative activity was calculated as the sum of interference and aggression. From 30 through 62 wk of age, observations coincided with SP measurements. The percentage of females in the scratch area during the mating observations was also recorded

[2] The Proven Solution™, Media Cybernetics, L.P., USA

from a possible full scratch area, 3 m long. The percentage of active males per pen was equal to the number of males showing any positive activity during the behavioral observations over the total number of males in the pen multiplied by 100.

At 21 wk of age, 7 cockerels and 60 pullets (7:60) or 11.7:100 to express the ratio on a per 100 hen basis were commingled in each of 18 laying pens. Males were replaced at 27 and 28 wk to maintain the ratio. At 29 wk, mortality was not replaced and all pens were reduced to a ratio of 6 males: 60 hens (10:100). This procedure was repeated at 34 wk of age, at which time the male: female ratio was reduced to 5:60 (8.3:100). Any mortality that occurred from 35 to 62 wk of age was not replaced. There were at least four males per pen at 62 wk of age. The male: female ratio (8.3:100) was maintained by removal of females and female feeder space.

4.3.4 *Statistical Analysis*

All treatment main effects and interactions were tested for significance at P 0.05 using the General Linear Models procedure according to the SAS ® (SAS Institute Inc., 1999). The experimental unit for the body weight and behavioral data was the male and was tested using pen nested within treatment as the error term. The reproductive data was recorded by pen and tested using pen nested within treatment as the error term. When main effects or their interactions were significant, the P-Diff test of SAS was used to separate significantly different means (Steel and Torrie, 1997). Pearson correlation

coefficients of SAS ® were generated to compare BW to the behavioral characteristics, SP, and fertility (Steel and Torrie, 1997).

4.4 RESULTS AND DISCUSSION

4.4.1 *Body weight*

At 26 wk of age, the LR males had the lightest BW by 285 g compared to the AS males (Table 4.1). Males in the LR treatment continued to have the lowest BW at 27 wk of age although they gained 221 g. From 26 to 28 wk of age, males in the AR treatment were heavier than males in the AS treatment by at least 111 g. There was a 60 g difference (P=0.062) in BW gain between the AS and AR treatment at 26 wk and a 75 g difference in gain at 25 wk of age. Females stealing male feed during this period may have contributed to the difficulty found in separating the treatment BW. By 30 wk of age, there was no difference in BW between the LR, AS, and AR treatments. Males in the HIGH category were 744g, 459 g, and 308 g heavier than in the LR, AS, and AR treatments at 26 wk, respectively.

At 22 and 26 wk, males in the LR were only 4% and 6% heavier in BW, respectively, than the females (Figure 4.2). Males in the LR and AS treatments were 176 and 460 g, respectively, heavier than the females at 26 wk of age. Males in the AS and HS were 17% and 36% greater in BW, respectively, than the females at 26 wk. The males in the HIGH category, and the AS and LR

treatments were 920 g, 460 g, 176 g heavier than the females at 26 wk of age, respectively.

The disadvantage, in using LR males, was a high level of mortality (23%) from 26 to 28 wk of age. Throughout the experiment, mortality totaled 29, 4.8 and 7.9% in the LR, AVERAGE (AS and AR), and HIGH treatments with the majority of the mortality in the LR treatment occurred during early production. Sex ratio at placement may need to be increased for low BW males due to mortality. High mortality and males that loose BW are likely to negatively affect the functional sex ratio.

Although the three HIGH treatments were imposed at 28 wk of age, the treatments did not have significantly different BW until 58 wk of age (Table 4.2). Body weight differences attained at 54, 58, and 62 wk of age may be related to a decline in reproductive and physical activity. As the males became more sedentary with age, the HC males were heavier than the HS. Males in the HW treatment were managed so that their BW increased weekly at a minimal rate.

At 50 wk of age, males in the HC treatment had an average BW of 4912 g that increased by 597 g at 62 wk of age. By 62 wk of age, some individuals in the HC treatment weighed in excess of 6 kg. Accordingly, Cherms (1984) stated that broiler breeder males would not produce adequate levels of fertility by natural mating if permitted to grow to their full genetic potential. Hocking and Bernard (1997) also suggest that the large, broad breasted broiler breeder males have difficulty making cloacal contact with hens.

4.4.2 *Reproductive Characteristics*

Fertility and Hatchability. Hatchability started at 84% and averaged 87% over the life of the flock. The initial sex ratio (11.7 males: 100 females) was relatively high from 28 to 30 wk of age and may have concealed treatment differences in fertility and hatchability. During the two weeks from 28 to 30 wk of age, fertility decreased from 96.7% to an average of 84.7% across all treatments (Table 4.1). Fertility was affected by an outbreak of fowl mites at 29 wk of age. Fertility levels returned to 97% across the treatments at 34 wk of age after the birds were treated.

Fertility was higher in the LR treatment compared to the AS treatment at 38, 46, 50, 58, and 62 wk by 3.9, 6.4, 3.9, 4.7 and 7.0%, respectively (Tables 4.1 and 4.2). At 42 and 54 wk, there was no difference in fertility between the AS and LR treatments. Although there was no advantage in fertility with the LR treatment at the onset of lay, the LR males produced fertility levels among the highest in late production.

There were no differences in fertility between the AS and AR treatments throughout the experiment with the exception of 46 wk fertility. At 46 wk, fertility was lower in the AS compared to the AR treatment by 7.4%. The reduction may be associated with inadequate BW gains in the AS treatment.

At 46, 50, 54, 58, and 62 wk, the HW treatment had lower fertility than the HS treatment by 5.7, 5.1, 13.0, 21.0, and 8.0%, respectively. At 58 wk, embryo mortality was highest in the HW treatment compared to the HC and HS treatments (1.9, 0.4, and 0.2%, respectively). The HW males were managed for

minimal gains in BW that resulted in decreased fertility. Similarly, Sexton et al. (1989) observed that BW gain was necessary to optimize the number of spermatozoa per ejaculate during the late breeding period, after 46 wk of age.

The HC and HS treatments had similar levels of fertility to 50 wk of age. At 54, 58, and 62 wk, the HC males had lower fertility compared to the HS treatment by 3.8, 9.6, and 7.5%, respectively. The decline in fertility in the HC treatment may have been related to the reduction in the percentage of active males at 58 wk of age. Anatomically, full-size males would not be suitable for small female because *ad libitum* fed males become obese and suffer from foot and skeletal problems (Appleby et al., 1992) that can decrease mating activity.

There was no difference in BW between the HS and AS treatment at 62 wk, yet the HS had higher fertility by 9.5%. The AS males gained 20.5 g/wk BW gain compared to 14.8 g/wk in the HS treatment over the last 4 wk of production. This may have been excessive for their skeletal frame size resulting in the reduced fertility. All males appear to reproductively benefit from a consistent and gradual increase in BW. Males in the HC and HW treatments had lower fertility than the HS treatments from 54 wk of age. If a subtle difference in BW gains, such as, excessive BW gains in the HC treatment and minimal BW gains in the HW treatment, significantly affect fertility, a more uniform group of birds would be easier to manage than a wide range of BW.

Sperm penetration. Sperm penetration was greatest in the AS treatment compared to the HS, HW, AR, and LR treatments at 30 wk of age (Table 4.1). Sperm penetration was positively correlated to the area of the scratch occupied

by females and the percent fertility at r=0.38 and r=0.36, respectively, throughout the experiment. At 34 wk of age, the HS males had the lowest percentage of CM and number of SP, yet the fertility was over 97%. The lack of correlation may be attributed to male semen quality, concentration, and volume (not measured in this study). Perhaps decreases in mating activity can be compensated for by females with good ability to store spermatozoa or by males with superior semen quality.

The HC and HW had extremely high numbers of sperm penetrating the ovum, 720 and 666 respectively at 34 wk. Bramwell and Howarth (1992) observed samples of completely digested perivitelline layers with high concentrations of spermatozoa, but did not assign a value to these samples. In this experiment, by using a larger area and Image-Pro Plus® software, the assessment of SP was extremely accurate. The correlation between fertility and SP was r=0.34 ($P<0.05$) throughout this experiment. Bramwell et al. (1996) found the correlation between fertility and SP was r=0.73 across four groups of artificially inseminated birds while in one group of birds a non-significant correlation between fertility and SP was reported ($r = 0.59$, $P > 0.16$). They suggested SP values that are too high might increase early embryonic mortality. In this experiment, high numbers of sperm penetrations were recorded at 34 wk and were not correlated to an increase or decrease in fertility, hatch of fertile, or early embryonic mortality (data not shown).

The high number of sperm holes in the perivitelline layer was neither related to higher levels of CM nor was it related to higher levels of positive

activity. Perhaps a combination of a high semen concentration, volume stored in the female (not assessed in this study), and multiple matings resulted in the extremely high SP values. There was no benefit to the high numbers of SP in terms of fertility or hatch of fertile.

4.4.3 *Mating behavior*

Active males. The rapid increase in BW in the LR treatment appears to contribute to an increase (14.3%) in the percentage of active males. This increase in the percentage of active males may relate to an increase in their ability to socially dominate the females (Grosse and Craig, 1960) without exhibiting physically aggressive behavior sometimes observed with the higher BW male. As the males in the LR treatment gained BW, they became more dominant and the females may have been more willing to mate. The rapid BW gain in the AR treatment did not produce an increase in the percentage of males that were active; however from initial observations the AR males had the greatest activity numerically.

In the LR treatment, the percentage of active males were numerically greater and significantly greater than in the AS treatment at 58 and 62 wk, respectively (Table 4.2). A greater percentage of active males at the end of production may have contributed to the higher levels of fertility. At 62 wk of age, the percentage of active males was higher in the LR than the AS treatment by 1.3%.

Scratch area. At 28 wk, there were 60% more females in the scratch area of the LR compared to the AS treatment. The initial period during which the males and females became acquainted (Justice et al., 1962) may have produced females that were more responsive to males once the males reached an adequate BW. At 30 wk of age, the LR treatment continued to have a greater percentage of females in the scratch area than the AS treatment by 17.5%.

The HIGH BW males had 24 and 35% fewer females in the scratch area, respectively, than either the AS or LR males at 26 wk. Females might have been intimidated by the size of the males in the HIGH category. At 27 and 28 wk, there continued to be fewer females occupying the scratch area in the HIGH than the LR treatment by 28.3% and 42.8%, respectively. The number of females in the scratch area was negatively correlated to male BW at 26, 27, and 28 wk of age (r= -0.54, -0.49, -0.45, respectively). At 28 wk, HIGH and AS males maintained a BW difference of 953 g and 570 g with the females, respectively. The high initial sex ratio (11.7 males: 100 females) may have compounded the negative impact of the HIGH category males on the area of scratch occupied by females and inhibited interactions between males and females. Casanovas and Wilson (1999) found higher levels of aggression and sexual interference with high sex ratios (15:100). It appears that the sexual activity of the LR males did not inhibit the females from entering the scratch area as it did in the other treatments.

By 34 wk, there was no difference in the percentage of females occupying the scratch area between the LR and AS treatments. From 38 wk, the area of the scratch occupied by hens averaged approximately 66% across all treatments,

which was an increase from the 46% at 34 wk of age. The decrease in male: female ratio to 8.3 at 34 wk of age may have contributed to the increase in hens in the scratch area. It took an extra 8 wk for females in the HIGH category to occupy the same amount of the scratch area as those in the LR treatment. Hens may have matured during this period or simply taken longer to become acquainted with males in the HIGH category.

A greater percentage of females in the scratch area provided the males in the LR treatment a greater opportunity to mate; no increase in CM was observed in the LR treatment. In general, fewer females in the scratch area may cause a lack of acquaintance of males with females and this lack of acquaintance may ultimately reduce mating activity (Justice et al., 1962). In the LR treatment, more females spent time in the scratch area without being subjected to 'forced' copulation. Forced and aggressive matings, which could impair the welfare of the birds, are social interactions that result in reluctance of females to mate (Millman et al., 1996). Increased contact between the LR males and females may have been behaviorally beneficial to the females, but because over-mating occurs in early production there was no reproductive advantage. Duncan et al., (1990) showed that the mating activity of the males was high during the early part of the breeding period.

The increase in the percentage of females in the scratch area was greater as the hens aged. This may not have contributed to mating activity or CM because of a reduction in receptivity to mating. Craig and Bhagwat (1974) observed a decline in mating in old Single Comb White Leghorn males (48-56

wk) in comparison to younger males (32- 40 wk) along with a reduction in receptivity in older hens. Reductions in mating activity have stimulated managers to add new males to 40 to 45 wk old broiler breeder flocks, and this practice is called ‘spiking’ (Bramwell et al., 1996).

Complete mating and positive activity. Completed matings averaged 6.2 and 8.4% across treatments at 26 wk of age and throughout the life of the flock, respectively. Similarly, Hocking and Bernard (2000) found no detectable differences in the number of CM for any age of male or female. These data suggest that CM may not be the most revealing behavioral observation.

The percentage of CM was not different among the treatments for the first 4 wk of production. Grosse and Craig (1960) found young males, sexually mature as indicated by sperm production, failed to mate with mature hens that they were unable to dominate socially. In this experiment, the LR males were as successful with the females as the other BW treatments. The relatively passive behavior of the males may have also contributed to higher numbers of females in the scratch area and therefore the similar percentage of completed matings.

Males in the HC treatment had lower positive activity than the HS treatment at 58 wk and this may have contributed to the decrease in fertility. In some cases, a decrease in the percentage of active males did not coincide with decreased fertility perhaps because less dominant males were allowed an opportunity to mate. In the LR and AS treatments, the percentage of CM and positive activity were not different between the males at 50 and 58 wk (Table 4.2).

Hocking and Bernard (2000) found a decline in mating frequency near the end of the production cycle. They suggested that the decline in mating frequency could be due to females that may not be receptive to the male because they are not in lay or have poor reproductive function and depressed estrogen synthesis late in lay. In this experiment, there was no decline in the percentage of positive activity from 50 to 62 wk of age among the treatments. There were no differences in egg production between the treatments, although egg production was low at the end of the production cycle.

Negative Activity. Although the increase in feed allocation to the AR treatment did not result in a BW difference between the AR and AS treatment, the management of these males resulted in a difference in the behavior of these males. In this experiment, AR males had a greater percentage of negative activity than the LR treatment by 8% at 26 wk of age. Heavy BW or rapid gains in the HIGH and AR treatments may have contributed to the aggression resulting in a lower percentage of hens in the scratch area. The combination of high BW and high sex ratio may have also caused more negative activity by suppressing the sexual activity of some males within each pen. At 58 wk, the HC displayed some negative activity that had not been observed since 46 wk of age. The HS also showed some negative activity at 58 wk that was not a result of the addition of new males, but may be related to the re-establishment of the peck order due to mortality of the dominant male.

Mating behavior and body weight. From 42 to 46 wk of age, the two heaviest males in the LR treatment had the greatest percentage of incomplete

matings (16.6%). The lowest BW males had the lowest percent (2%) of incomplete matings across treatments from 42 to 46 wk of age. In the HS treatment, the lowest BW males were also the most aggressive males. Only in the HC and LR treatments were the heaviest BW males more aggressive than the lightest BW males. The HC and LR treatments received the greatest feed allocation of all treatments, which may have contributed to more passive low BW males because they were not forced to compete for feed to the same degree as the low BW males in the AR and HS treatments. At 65 wk, there were no differences in the average testes weight (23 g) among the treatments.

4.5 CONCLUSIONS

Low BW males have been viewed with pessimism and have often been the first males to be culled from a flock. However, these males may be more beneficial to the flock than was once considered. Low BW males may appear less intimidating to females possibly due to the similarity in BW. The result is a greater percentage of females occupying the scratch area at an early age. In a commercial setting, this would be advantageous for all males as mating expertise must be acquired with practice.

There were some disadvantages to the AR treatment. The area of scratch occupied by the females and SP was lower in the AR treatment compared to the AS treatment at 30 wk. A rapid increase in BW has no advantage in flock fertility. A greater gain in the AR may have produced problems especially if males were allowed to become severely overweight.

HIGH BW males reduce the area of the scratch occupied by females in early production. Females avoided HIGH BW males possibly because the males intimidate the females. Although the reluctance of the females to enter the scratch area did not affect fertility, excessive mating in early production may have compensated. Female occupancy of the scratch area was correlated to fertility. If females avoid the scratch area, males may resolve to mate on the slat area. In some cases, males mated on the wire slat area because fewer females were available in the scratch area or other males repeatedly interfere with attempts at mating. This situation may be a problem because it is more difficult to successfully mate on wooden slats and secondly fewer males attempt mating on the slat.

Management of male broiler breeders remains dependent on the strict control of BW. Small males can continue to gain BW throughout the life of the flock because of low initial BW. Preventing males from eating at the female feeder continues to be beneficial in the reproductive performance of the flock. High BW males require diligent management to the end of the flock. High BW males are susceptible to becoming overweight, but when severely restricted may not receive enough feed to gain BW and sustain reproductive function or libido. Both excessive BW gains and minimal BW gains result in reduced fertility.

4.6 REFERENCES

Appleby, M. C., B. O. Huges, and H. A. Elson, 1992. Poultry Production Systems: Behavior, Management and Welfare. CAB International, Wallingford, Oxon, UK.

Bramwell, R. K. and B. Howarth, Jr., 1992. Preferential attachment of cock spermatozoa to the perivitelline layer directly over the germinal disc of the hen's ovum. Biol. Repro. 47:1113-1117.

Bramwell, R. K., H. L. Marks, and B. Howarth, 1995. Quantitative determination of spermatozoa penetration of the perivitelline layer of the hen's ovum as assessed on oviposited eggs. Poult. Sci. 74:1875-1883.

Bramwell R. K., C. D. McDaniel, J. L. Wilson, and B. Howarth, 1996. Age effect of male and female broiler breeders on sperm penetration of the perivitelline layer overlying the germinal disc. Poult. Sci. 75:755-762.

Casanovas, P and J. L. Wilson, 1999. Fertility and reproductive behavior of broiler breeder males: Sex ratio effects. In *Methods of alleviating the age-related decline in the fertility of broiler breeder males*. M. S. Thesis, The University of Georgia, Athens, GA.

Cherms, F. L, 1984. Management of the male in poultry production. *Reproductive Biology of Poultry*. (F. J. Cunningham, P. E. Lake, and D. Hewitt, eds.) pp. 145-150. Longman Group, Harlow.

Craig, J. V., B. Al-Rawi, and D. D. Kratzer, 1977. Social status and sex ratio effects on mating frequency of cockerels. Poult. Sci. 56:767-772.

Craig, J. V. and A. L. Bhagwat, 1974. Agonistic and mating behavior of adult chickens modified by social and physical environments. Appl. Animal Ethol. 1:57-65.

Duncan, I. J. H., P. M. Hocking, and E. Seawright, 1990. Sexual behavior and fertility in broiler breeder domestic fowl. Appl. Anim. Behavior Sci. 26:1-12.

Ensminger, M. E., 1980. *Poultry Science*. 2nd ed. The Interstate Printers & Publishers, INC. Danville, Illinois.

Grosse, A. E. and J. V. Craig, 1960. Sexual maturity of males representing twelve strains of six breeds of chickens. Poult. Sci. 39:164-172.

Guhl, A. M., 1951. Measurable differences in mating behavior of cocks. Poult. Sci. 30:687-693.

Harris G. C. Jr., J. A. Benson, R. S. Sellers, 1984. The influence of day length, body weight, and age on the reproductive ability of broiler breeder cockerels. Poult. Sci. 71:1705-10.

Hocking, P. M., 1990. The relationships between dietary CP, body weight, and fertility in naturally mated broiler breeder males. Br. Poult. Sci. 31:743-757.

Hocking, P. M. and R. Bernard, 1997. Effects of male body weight, strain and dietary protein content on fertility and musculo-skeletal disease in naturally mated broiler breeder males. Br. Poult. Sci. 38:29-37.

Hocking, P. M. and R. Bernard, 2000. Effects of age of male and female broiler breeders on sexual behavior, fertility and hatchability of eggs. Br. Poult. Sci. 41:370-377.

Justice, W. P., G. R. McDaniel, and J. V. Craig, 1962. Techniques for measuring sexual effectiveness in male chickens. Poult. Sci. 41:732-739.

Kirk, S., G. C. Emmans, R. McDonald, and D. Arnot, 1980. Factors affecting the hatchability of eggs from broiler breeders. Br. Poult. Sci. 21:37-53.

McDaniel, G. R., J. Brake, and R. D. Bushong, 1981. Factors Affecting Broiler Breeder Performance. 1. Relationship of daily feed intake level to reproductive performance of pullets. Poult. Sci. 60:307-312.

McDaniel, G. R. and J. V. Craig, 1959. Behavior traits, semen measurements and fertility of White Leghorn males. Poult. Sci. 38:1005-1014.

Millman, S. T., I. J. H. Duncan, and T. M. Widowski, 1996. Forced copulations by broiler breeder males. *Proceedings of the 30th International Congress of the ISAE,* Guelph, p. 50.

Parker, J. E., F. F. McKenzie, and H. L. Kempster, 1940. Observations on the sexual behavior of New Hampshire males. Poult. Sci. 29:377-380.

SAS Institute Inc., 1999. SAS User's Guide. SAS Institute Inc., Cary, NC.

Sexton, K. J., J. A. Renden, D. N. Marple, and R. J. Kempainen, 1989. Effects of dietary energy on semen production, fertility, plasma testosterone, and carcass composition of broiler-breeder males in cages. Poult. Sci. 68:1688-1694.

Steel, R. G. D., and J. H. Torrie, 1997. Principles and Procedures of Statistics: A Biometrical Approach. McGraw-Hill Book Company Inc., New York, NY.

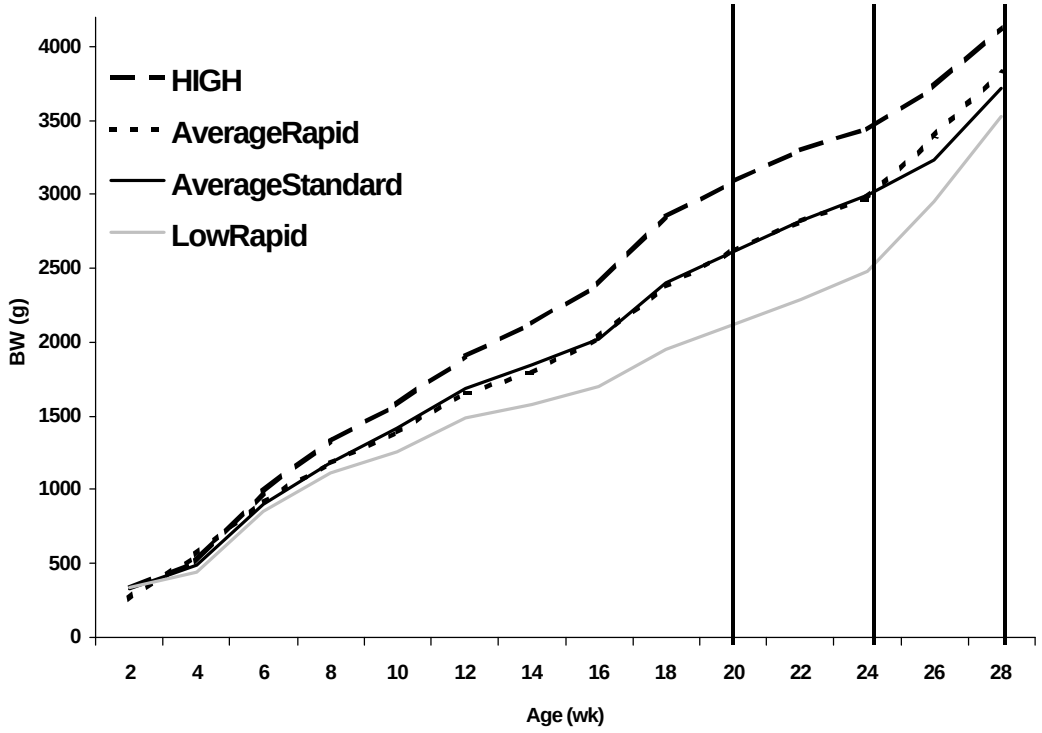


Figure 4.1. Males were selected based on BW at 20 wk of age. At 22 wk of age, the AVERAGE category males had a greater BW than the low rapid (LR) males by 494 g. The difference between the average standard (AS) and HIGH male BW was 414 g at 22 wk of age. At 24 wk of age the LR and average rapid (AR) treatments started. At 28 wk of age, males in the HIGH treatment were subjected to one of three treatments; constant, standard, or slow feed increases.

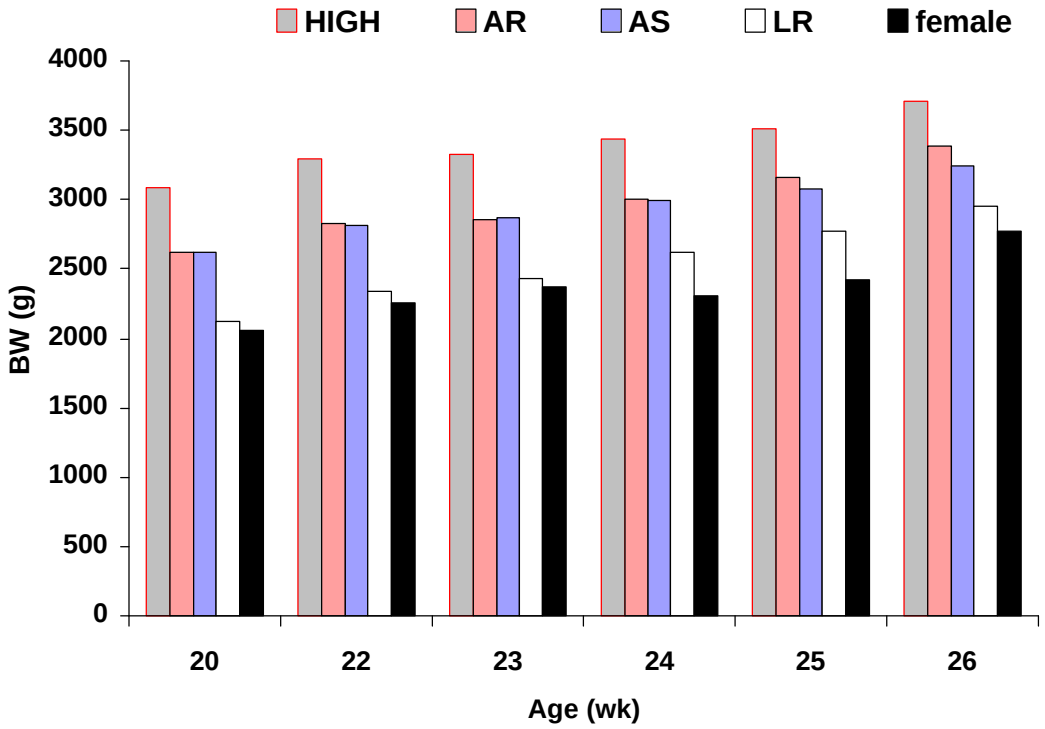


Figure 4.2. Female BW were within 90 g of the average LR male BW at 20, 22, and 23 wk of age.

TABLE 4.1. BW, percentage active males, percentage of females in the scratch area, positive mating activity, negative mating activity, number of sperm holes, and fertility for all feeding treatments weekly from 26 to 28 wk of age and monthly from 30 to 42 wk of age

Age	Feed tmt [1]	BW	Active Males[2]	Scratch[3]	CM[4]	Positive Activity[5]	Neg. Activity[6]	Sperm Holes[7]	Fertility[8]
(wk)		(g)	---------- (%) ----------					#	(%)
26	HIGH	3695 a	27.8 a	31.1 b	4.1 a	30.3 a	2.9 a		87.6 a
	AR	3387 b	38.1 a	13.3 c	10.0 a	37.3 a	5.6 a		95.6 a
	AS	3236 b	31.0 a	41.7 b	5.1 a	30.3 a	4.6 a		74.0 a
	LR	2951 c	28.6 a	66.7 a	5.4 a	32.1 a	1.2 a		93.2 a
27	HIGH	3867 a	39.7 a	30.0 b	4.7 a	41.4 a	1.8 a		93.7 a
	AR	3558 b	45.2 a	31.7 c	5.4 a	44.1 a	3.6 a		93.5 a
	AS	3447 b	42.9 a	38.3 b	3.7 a	48.6 a	1.4 a		92.8 a
	LR	3172 c	42.9 a	58.3 a	4.9 a	43.1 a	0.8 a		90.8 a
28	HIGH	4089 a	42.1 a	32.2 b	8.7 a	46.9 a	2.0 a		95.7 a
	AR	3835 ab	42.9 a	33.3 b	3.7 a	48.8 a	1.2 a		97.7 a
	AS	3706 b	44.8 a	26.7 b	6.1 a	47.4 a	0.0 a		96.9 a
	LR	3520 c	49.6 a	75.0 a	5.7 a	48.4 a	1.6 a		97.0 a
30	HC	4311 a	30.6 bc	15.0 cd	5.8 a	30.0 ab	1.5 a	305 ab	79.9 a
	HS	4253 a	16.7 d	10.0 d	7.5 a	21.2 b	0.0 a	257 b	85.3 a
	HW	4302 a	25.0 cd	20.0 bc	2.6 a	32.4 ab	3.7 a	301 b	86.0 a
	AR	4112 ab	44.4 a	9.2 d	4.4 a	50.0 a	2.8 a	229 b	83.2 a
	AS	3953 b	36.1 ab	22.5 b	3.9 a	37.5 ab	1.4 a	491 a	84.8 a
	LR	3992 b	22.2 cd	40.0 a	0.9 a	22.2 b	0.0 a	275 b	86.6 a
34	HC	4481 a	33.3 b	48.3 a	7.2 ab	30.0 b	0.0 a	720 a	99.1 a
	HS	4324 abc	35.0 b	40.0 b	3.9 b	38.3 ab	1.7 a	185 c	97.6 a
	HW	4230 bc	43.3 b	49.2 a	11.1 ab	45.8 ab	0.8 a	666 a	95.9 a
	AR	4414 abc	59.7 a	45.0 ab	9.2 ab	53.6 ab	1.7 a	340 bc	98.3 a
	AS	4195 c	56.7 a	46.7 a	16.1 a	60.0 a	0.0 a	528 ab	96.9 a
	LR	4430 ab	43.3 b	48.3 a	13.3 ab	40.0 ab	0.0 a	424 b	98.3 a
38	HC	4598 a	30.0 c	71.7 a	1.6 b	31.1 a	3.4 a	398 ab	95.3 a
	HS	4300 b	56.7 a	65.0 bc	17.7 a	54.2 a	2.5 a	179 c	91.9 ab
	HW	4113 b	33.3 bc	65.0 bc	8.4 ab	35.6 a	3.5 a	542 a	93.6 ab
	AR	4261 b	43.3 b	63.3 c	5.8 b	44.7 a	0.0 a	337 b	94.4 ab
	AS	4258 b	26.7 c	61.7 c	12.9 ab	31.0 a	0.0 a	264 bc	91.2 b
	LR	4464 ab	33.3 bc	70.0 ab	8.1 ab	39.7 a	3.9 a	398 ab	95.1 a
42	HC	4591 a	40.0 a	66.7 bc	18.2 ab	41.7 a	1.7 a	96 ab	90.4 bc
	HS	4252 c	36.7 ab	71.7 ab	10.0 bc	43.3 a	0.0 a	119 ab	90.2 bc
	HW	4424 b	36.7 ab	66.7 bc	20.6 a	36.7 a	0.0 a	63 b	87.6 c
	AR	4397 ab	26.7 b	76.7 a	2.6 c	32.4 a	3.6 a	180 ab	93.8 a
	AS	4481 a	43.3 a	61.7 c	13.3 abc	43.3 a	0.0 a	125 ab	90.8 abc
	LR	4445 ab	36.7 ab	75.0 a	11.1 abc	46.7 a	0.0 a	253 a	93.1 ab
Pooled SEM		78.59	3.775	2.648	4.956	18.96	13.41	59.03	5.492

[1] Males in the high constant (HC), high standard (HS), and high slow (HW) treatments were not subjected to their respective BW treatment until 28 wk of

age and therefore are grouped as HIGH. Males in the average rapid (AR) and low rapid (LR) treatments had a rapid increase in BW at 24 wk of age. The average standard (AS) male BW followed the breeder BW recommendations.
[2] The percentage of active males was equal to the number of males that showed any positive activity in each pen divided by the total number of males in the pen. The percentage of active males was recorded on 12 occasions for each treatment at each age.
[3] The number of hens in the scratch area was visually assessed from a 3 m area marked across the front of the scratch area at 12 times for each treatment at each age. A full scratch area, with birds covering the entire floor area, was considered to have 100% of area occupied. An empty scratch area, with only males in the scratch area, was assessed as 10% occupied.
[4] Complete mating recorded only when males made cloacal contact with the female. Activity was recorded for a 90-minute period per treatment.
[5] Positive activity was the sum of the complete, incomplete, and attempted mating observed from males in each treatment.
[6] Negative activity was the sum of interference and aggression observations made on males in each treatment.
[7] The number of sperm holes penetrating the perivitelline layer overlying the germinal disc was determined from a 1.48 mm by 1.98 mm area of the blastoderm on approximately 90 eggs per treatment. Sperm holes were not assessed until 30 wk of age due to egg production.
[8] Fertility was assessed on 105 eggs per treatment at 26 wk and 264 eggs per treatment at 27 and 28 wk of age. All eggs were incubated and hatched. The eggs were candled at 10 d of incubation, and all infertile or early dead embryos removed.
[a-d] values with no common superscript within a column were significantly different ($P<0.05$).

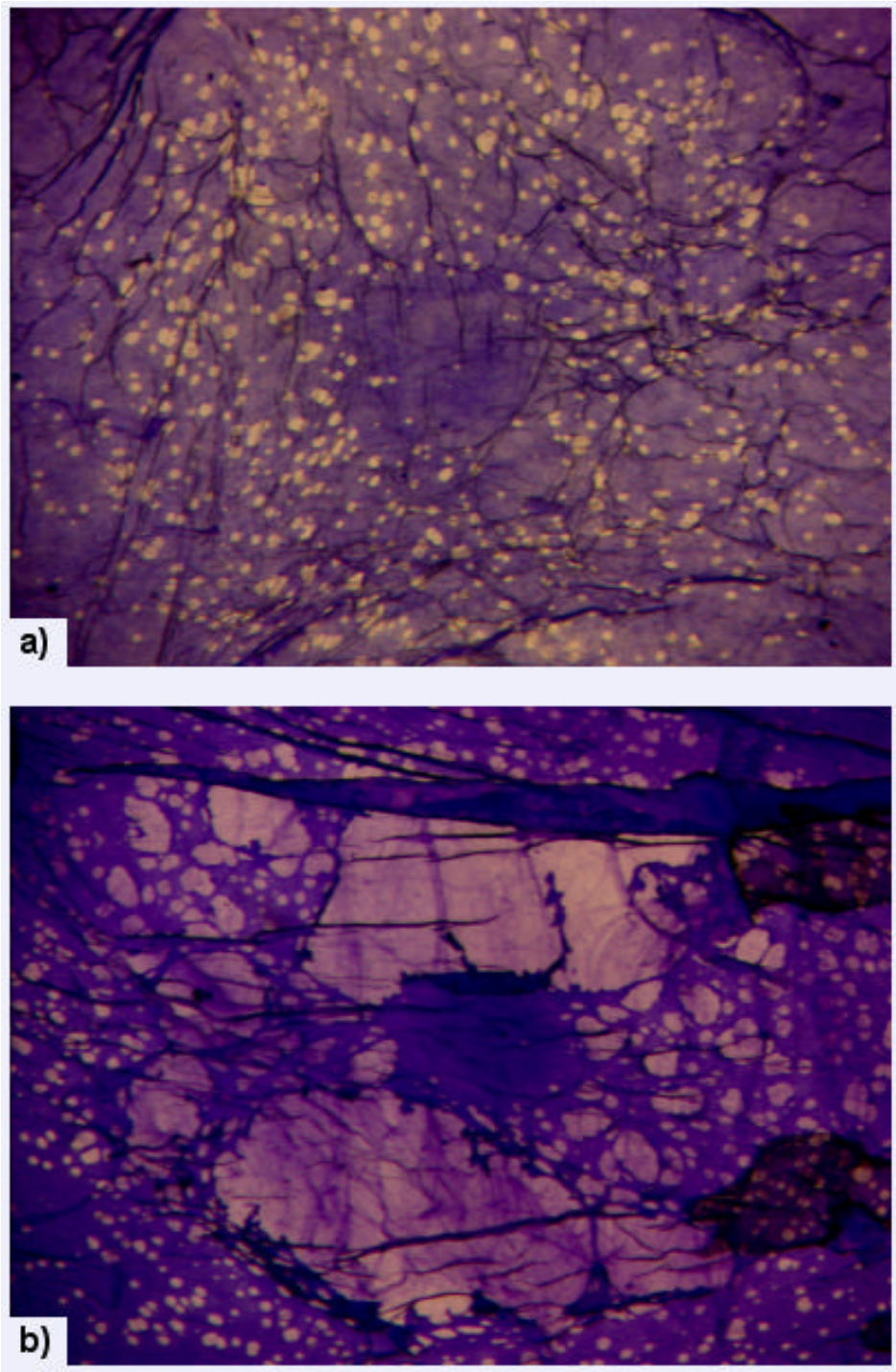
TABLE 4.2. BW, percentage active males, percentage of females in the scratch area, positive mating activity, negative mating activity, number of sperm holes, fertility and percentage live pips and live in shell across feeding treatments monthly from 46 to 62 wk of age

Age	Feed tmt [1]	BW	Active Males[2]	Scratch[3]	CM[4]	Positive Activity[5]	Negative Activity[6]	Sperm Holes[7]	Fertility[8]
(wk)		(g)	---------- (%) ----------					(#)	(%)
46	HC	4564 a	40.0 b	71.7 abc	10.3 ab	46.7 ab	6.7 a	105 a	86.5 b
	HS	4326 b	33.3 b	73.3 ab	6.2 ab	33.3 b	0.0 a	99 a	85.3 b
	HW	4397 ab	40.8 b	60.8 d	10.3 ab	48.4 ab	0.0 a	138 a	79.6 c
	AR	4433 ab	60.0 a	76.7 a	8.9 ab	63.3 a	3.3 a	134 a	91.6 a
	AS	4492 ab	51.7 a	66.7 cd	16.1 a	55.1 ab	0.0 a	98 a	84.2 b
	LR	4455 ab	36.7 b	70.0 bc	3.0 b	39.3 ab	0.0 a	132 a	90.6 a
50	HC	4912 a	44.2 b	76.7 abc	15.9 a	48.3 a	0.1 a	120 a	94.8 ab
	HS	4720 b	36.7 bc	74.2 bc	4.2 a	36.7 a	0.0 a	118 a	92.2 b
	HW	4454 c	33.3 c	75.0 bc	11.1 a	39.4 a	0.6 a	55 a	87.1 c
	AR	4767 bc	60.0 a	71.7 c	5.7 a	63.3 a	3.3 a	99 a	92.5 b
	AS	4728 b	30.0 c	81.7 a	8.3 a	36.7 a	0.0 a	84 a	92.9 b
	LR	4642 bc	40.0 bc	80.0 ab	7.0 a	43.3 a	0.0 a	119 a	96.8 a
54	HC	4954 a	26.7 bc	71.7 ab	8.3 a	30.0 ab	0.0 a	114 a	93.6 b
	HS	4845 ab	10.0 d	65.8 bc	9.4 a	18.3 b	1.7 a	91 a	97.4 a
	HW	4344 c	33.3 abc	73.3 a	5.0 a	33.3 ab	3.3 a	145 a	84.4 c
	AR	4758 bc	40.0 a	65.0 c	9.7 a	50.0 a	0.0 a	113 a	92.9 b
	AS	4794 ab	36.7 ac	68.3 abc	7.2 a	40.0 ab	0.0 a	115 a	94.7 ab
	LR	4630 b	23.3 c	69.2 abc	13.7 a	23.3 b	0.0 a	182 a	92.1 b
58	HC	5190 a	16.7 b	80.0 a	3.3 a	16.7 b	3.3 a	123 a	81.3 bc
	HS	5053 b	36.7 a	65.0 d	8.5 a	43.3 a	6.7 a	84 a	90.9 a
	HW	4426 d	40.0 a	76.7 ab	5.9 a	40.0 ab	0.0 a	91 a	69.9 e
	AR	4813 b	33.3 a	70.0 cd	6.7 a	40.0 ab	0.0 a	151 a	75.3 d
	AS	4913 bc	30.0 a	75.0 ac	14.2 a	30.0 ab	0.0 a	94 a	78.6 cd
	LR	4754 c	36.7 a	71.7 bc	11.9 a	41.7 a	5.0 a	123 a	83.3 b
62	HC	5509 a	33.3 bc	64.2 b	9.4 a	40.0 ab	0.0 a	146 a	83.7 b
	HS	5171 b	40.0 b	78.3 a	9.2 a	41.7 ab	1.7 a	111 a	91.2 a
	HW	4551 d	30.0 bc	77.5 a	12.8 a	30.0 ab	3.3 a	183 a	83.2 bc
	AR	4819 c	23.3 c	72.5 a	8.3 a	26.7 b	0.0 a	148 a	80.0 c
	AS	5077 b	40.0 b	65.0 b	10.2 a	41.3 ab	0.0 a	106 a	81.7 bc
	LR	4950 bc	52.5 a	73.3 a	10.9 a	51.7 a	0.0 a	134 a	88.7 a
Pooled SEM		84.12	3.727	2.378	5.438	2.104	2.236	59.03	1.243

[1] Males in the high constant (HC), high standard (HS), and high slow (HW) treatments were not subjected to their respective BW treatment until 28 wk of age. Males in the average rapid (AR) and low rapid (LR) treatments had a rapid increase in BW at 24 wk of age. The average standard (AS) male BW followed the breeder BW recommendations.

[2] The percentage of active males was equal to the number of males that showed any positive activity in each pen divided by the total number of males in the pen. The percentage of active males was recorded on 12 occasions for each treatment at each age.

[3] The number of hens in the scratch area was visually assessed from a 3 m area marked across the front of the scratch area at 12 times for each treatment at each age. A full scratch area, with birds covering the entire floor area, was considered to have 100% of area occupied. An empty scratch area, with only males in the scratch area, was assessed as 10% occupied.
[4] Complete mating recorded only when males made cloacal contact with the female. Activity was recorded for a 90-minute period per treatment.
[5] Positive activity was the sum of the complete, incomplete, and attempted mating observed from males in each treatment.
[6] Negative activity was the sum of interference and aggression observations made on males in each treatment.
[7] The number of sperm holes penetrating the perivitelline layer overlying the germinal disc was determined from a 1.48 mm by 1.98 mm area of the blastoderm on approximately 90 eggs per treatment.
[8] Fertility was assessed on 540 eggs per treatment at 50 wk and 405 eggs per treatment from 54 to 62 wk of age. All eggs were incubated and hatched. The eggs were candled at 10 d of incubation, and all infertile or early dead embryos removed.
[a-d] values with no common superscript within a column were significantly different ($P<0.05$).



Appendix 4.1. Sperm penetration. (a) The greatest number of sperm holes recorded on a single germinal disc was approximately 600 penetrations. The number of sperm holes was found on a 1.48 mm by 1.98 mm area of the perivitelline layer of the ovum at the site of the germinal disc. (b) Sperm hole penetrations to the degree to which portions of the germinal disc are missing were given a value of 1000 sperm holes.

CHAPTER 5. CONCLUSIONS

Consistent BW gain is essential in maintaining healthy reproductively active males. Broiler breeder males can be successfully managed for optimal semen production through BW control. Body weight management of male broiler breeder is challenging. The success of BW management is a reflection of the accuracy of the BW data collected. A large sample of males, weighed weekly is necessary for an accurate assessment of current BW so that the following feed allocation will enable males to gain an adequate amount of BW. Better BW management is achievable through good management practices.

Carcass characteristics of the male can be altered in early production, however, long-term alterations of skeletal frame size cannot be affected by BW gain. Broilerizing males for genetic selection, produces males with a greater breast muscle mass and stimulates early testicular weight. Chest width, head width, comb height, keel length, and shank length are also increased during early rearing with increased BW. The problem that results with overfeeding of males during rearing is excessive BW that inhibits reproduction. Overweight males are often physically unable to mate. In order to return these males to standard BW, a BW loss is required. A BW loss in conjunction with photostimulation produces a healthy adult male with adequate semen production even though testes weight decreases for a short period. Males that lose BW, as an adult are not reliable in their production of semen, have reduced semen quality, and fewer males are

able to sustain semen production. Males that are able to withstand a BW loss may have energy reserves in excess fatpad weight.

Body weight not only affects the males reproductive performance, but also impacts the relationship between males and females. Intrinsically low, average and high BW males require different quantities of feed to maintain optimum BW gains. Different BW males require different management techniques to optimize mating behavior. By managing for the BW average, the reproductive potential of both high and low BW males has not been optimized. There are advantages and disadvantages to low, average, and high BW males. Once the type of male has been assessed, high levels of flock fertility can be achieved by managing for their requirements. Management includes feeder height, nutrition, feed availability, environmental conditions (temperature, litter, ventilation) as well as BW control.

Low BW males are less intimidating and appear more social with females, but have greater mortality. Managers with a flock of low BW males could adjust the initial sex ratio accordingly or have a greater number of males available for spiking the flock. In a non-uniform group of males, the low BW males may be detrimental to the flock. Low BW males have difficulty competing with large males for feed and are often culled, starve, or steal female feed. Management of these males has not been thoroughly investigated and knowledge of the male's skeletal and carcass characteristics would be an asset.

The standard BW male is more aggressive than the low BW male resulting in a reduction in contact between males and females. However, the greatest amount of available knowledge concerns managing a standard BW male.

Management of these males has been study and the best template for BW gain can be found in the broiler breeder management guides supplied with the flock. These males can be mis-managed as easily as any other group of birds.

High BW males that are not appropriately managed can become overweight leading to leg problems, lower libido, and mortality. High BW males are also aggressive, but maintain high levels of fertility when gaining BW at a constant rate. Excess BW gains in high BW males can decrease the fertility of the flock. These males are prone to leg and foot problems and may have trouble mating. With selection pressures for increased breast muscle mass, a greater proportion of males seem to fall into the high BW category. Stringent management can produce a high BW male with a high level of fertility.

In a large flock, uniformity would be an asset to BW control for successful broiler breeder management. When males are transferred to the breeding facility, selecting males based on their BW would provide the producer with a uniform group of males. A uniform group of males would allow the manager to adjust feed allowances for low or high BW males and prevent over or under-feeding of the males, thus improving life long fertility.

Low BW males have the greatest potential for longevity. Starting with a low BW male allows the producer more room for error in adjusting the feeding level in early production. There appear to be no negative consequences in over-feeding a low BW male in early production. Once these males have attained enough BW to initiate reproduction, feed can be allocated to continue BW gain.

Male broiler breeders are under enormous selection pressures. Good management of these males can produce reproductively active males with high levels of fertility. Because of the precision with which the genetics are selected, there is very little room for error in their management. A male broiler breeder that is mis-managed rapidly exhibits the characteristics of the broiler.