University of Alberta

Effects of Maternal Management and Nutrition on Broiler Chicken Carcass Uniformity

by

Deborah Erica Holm

A thesis submitted to the Faculty of Graduate Studies and Research
in partial fulfillment of the requirements for the degree of

Master of Science

in

Animal Science

Department of *Agricultural, Food and Nutritional Science*

Fall 2010
Edmonton, Alberta

Examining Committee

Dr. Frank E. Robinson, University Student Services

Dr. Robert A. Renema, Agricultural, Food and Nutritional Science

Dr. Martin J. Zuidhof, Agricultural, Food and Nutritional Science

Dr. Bodo Steiner, Rural Economy

Dedication

To my darling daughter Anika, I would never have discovered this path without you, I am forever grateful. Love you bunches and bunches.

To my parents John and Rahel Holm, for your unwavering support, no matter how crazy my ideas seemed. I am truly blessed to have you as my parents.

Abstract

This project researched the effects of pullet-phase feed restriction methodology or management and hen-phase diet fortification on female broiler breeder BW and carcass trait uniformity as well as on performance of the broiler offspring.

Feed treatments had a significant effect on female BW and carcass trait uniformity at 22 wk of age, with sorting and scatter treatments having the highest uniformity estimates, compared to limited daily, skip-a-day and fibre-diluted programs. Feed and premix treatments did not affect traits after 22 wk of age as individual caging at 22 wk of age unified female BW uniformity across all treatments. Feed treatments did not affect the uniformity of age at sexual maturity, first egg characteristics or production parameters. Premix treatment resulted in decreased shell uniformity and increased uniformity of one of the production parameters, total egg mass. Feed treatments may have a greater effect on female broiler breeder efficiency than previously suggested.

Acknowledgements

- Anika, for patiently waiting through the hours dedicated to my research. For putting up with my chicken brain, I promise I will not ruin another glorious sunrise with “it looks like a large yellow follicle”.
- Toril Salen, thank you for being that guiding light and for always listening.
- Corinne and Adam Holm and Garett Buttram for putting up with my distracted-ness all these years. I will finally be able to participate in ‘family stuff’.
- Tabea Poth, thank you for all your support and encouragement.
- Frank Robinson, what can I say, this wouldn’t have been possible without your support, patience and understanding, thank you just isn’t enough.
- Martin Zuidhof, thank you for always pushing me to do better. For the hours you’ve spent, especially at the last minute, trying to help me understand the latest round of statistical analysis.
- Rob Renema, for all our wonderful chicken discussions over the years, and for always letting me ask ‘just a quick question’ even when you were busy.
- Val Carney and Brenda Schneider for taking the time to listen and encouraging me to talk. It’s so easy to get lost in the research.
- Felicity Dennis you were always there to help and support me as a colleague and a friend.
- Ali Pishnamazi and Luis Romero, I would still be in the barn weighing breeders. Beating the two of you at weighing birds is still at the top of my ‘to do’ list.
- Laurie Heidebrecht, Lyle Bouvier, Nigel Davidson, and Giles Hinse for all your help and understanding, especially with the problems that always seem to appear at the last minute and to Iwona Pawlina the PRC’s grad student champion.
- All the staff and students at the Poultry Research Centre, for your assistance and expertise, you helped make this a wonderfully memorable experience.
- …and of course Perywingkl, always lending a helping paw, whether I wanted it or not. Laughter IS the best medicine.

Table of Contents

List of Tables

List of Figures

Chapter 1. Introduction

1.1. The Global Poultry Meat Industry

An increase in global poultry meat production of 2.5% and a 2.4% increase in consumption are forecast for 2010 (FAO, 2009) (Table 1-1). The global financial and economic crisis led to a reduction in production and consumption during 2009 (Table 1-1); however the current outlook remains positive, expecting modest yearly increases of 2.5% for the next 9 years (Agricultural Commodity Markets Outlook, 2009). Population growth, urbanization and religious affiliation, particularly in developing countries, will drive future poultry meat production and consumption.

Developing countries will continue to play an important role in the demand of poultry meat products, bringing about 82% of the forecast growth in production (OECD/FAO, 2009). Population growth, religious affiliation and urbanization are key factors contributing to developing countries' impact on the poultry meat industry. Population growth in developing countries is expected to increase 13.0% by 2020, compared to developed countries with a 2.5% increase (Table 1-2). The developing country of Brazil is the leading exporter of poultry meat products having focused on increasing production and fostering non-traditional markets in the Middle East and Sub-Saharan Africa (OECD/FAO, 2009). The combination of higher growth rate (13.0% vs. 2.5%), larger initial population (Table 1-2) and increasing production capacity suggest developing countries will continue to have a significant impact on global poultry meat supply and demand.

A country's economic development contributes to the population shift from rural to urban centres. People move from rural to urban centres as labour intensive jobs or subsistence farming are no longer economically viable. Equipment or intensive production systems replace labour increasing production efficiency. Per capita gross national income (GNI) in 2008 was highest in developed countries (39,609 U.S./yr) and the lowest in developing countries (4,910 U.S./yr). Developing countries had the highest percent increase (88.7%) in per capital GNI between 2001 and 2008 (Table 1-3) compared to developed countries (62.4%). Urbanization is occurring at a slower rate in developed countries, approximately 1.3% every 5 years compared to 2.3% in developing countries; however the proportion of the population already residing in urban centres is much higher than in developing countries (Table 1-2). Per capita income increases, in combination with urbanization, have traditionally led to an increase in demand for high quality animal protein sources (FAO, 2009).

Poultry meat carries few religious or cultural taboos making it the ideal, unrestricted, high quality, low cost, animal protein source leading to increased demand for poultry meat products. This is particularly important in developing countries where approximately 80% of the world's Muslim population resides and where pork, poultry's leading substitution product, is restricted (Figure 1-1). The World's population currently sits at 6.91 billion; 1.57 billion or 23% are Muslim (The Pew Forum, 2009), therefore the Muslim population in developing countries is expected to have a significant effect on the demand for poultry meat products.

Global poultry meat production and consumption will depend on future population growth, economic development, urbanization and religious affiliation. Developing countries are expected to account for an increasing proportion of the shift in demand from low cost cereal grain products to high quality animal based protein sources.

1.2 Consumer Preference

Consumer preference for a particular animal protein source will vary depending on the community and country where a given consumer resides (FAO, 2009). Consumers in urban areas within a developed country tend to show preference for high quality animal protein sources. Consumers base their purchasing decisions on price as well as perceived quality of a particular product (AAFC, 2005). The consumer decision making process includes other intrinsic factors of food safety, perceived health benefits, time constraints, variety and number of meat products available, marketing and moral or religious beliefs.

Product price will affect the consumers' ability or desire to purchase a particular poultry meat product. Economic theory suggests income elasticity of demand, own-price elasticity of demand and cross-price elasticity of demand impact consumers' purchasing decisions (AAFC, 2005; Case and Fair, 2007; McEachern, 2009). Case and Fair (2007) define the factors affecting market demand as:

- Income elasticity of demand – "measures the responsiveness of demand to changes in income".

- Own-price elasticity of demand –“measures the responsiveness of demand to changes in price”.
- Cross-price elasticity of demand – “measure the response of the quantity of one good demanded to a change in the price of another good”.

The purchase of a particular product will be based on a consumer’s income, where the higher the income, the greater the amount a consumer can allocate to food purchases, in particular, a shift from low cost cereal-based staples to high cost superior goods (income elasticity of demand) (AAFC, 2005; Narrod *et al*., 2007). The price of poultry meat products must be within a range the market will tolerate, if the prices are perceived to be too high, consumers will choose an alternative or substitution product (own-price elasticity of demand) (Taylor and Weerapana, 2007; McEachern, 2009). Canadian meat consumption in 2009 was comprised of 34.1% chicken meat, 31.1% beef and 25.4% pork indicating a strong market for chicken meat products (Statistics Canada, 2010). The demand for poultry meat products increases as the price of substitution products (beef and pork) increases since consumers’ will tend to choose the highest quality, lower cost substitute (cross-price elasticity of demand) (Taylor and Weerapana, 2007; McEachern, 2009). Thurman (1987) suggests poultry meat products have changed from a substitute product with pork to an independent one where an increase or decrease in pork prices will have no effect on the demand for poultry meat, however this is not a global trend and is limited to North America where specialized markets have been developed. North American restaurants specializing in chicken products (Kentucky Fried Chicken, Swiss Chalet) have stabilized the demand for poultry meat. Consumers can easily shift their consumption of meat products in relation to increases or decreases in price; however specialized markets such as 'chicken' restaurants are unable to adjust quickly or if at all (Thurman, 1987).

Food safety is now part of consumers' selection process particularly in light of recent events, for example, *Listeria monocytogenes* contamination of processed meat in Canada and the HPAI H5N1 virus in poultry and humans (AAFC, 2005). Consumers want to feel confident in the safety of the food items they purchase (FAO, 2009). The poultry industry has focused on implementing biosecurity measures and Hazard Analysis and Critical Control Point programs (HACCP) in production and processing facilities to reduce the potential risk of bacterial or viral contamination of poultry and poultry meat products (Van Immerseel *et al*., 2009; FAO, 2009; Cox and Pavic, 2010).

Poultry meat products, in particular breast meat having a lower fat content is expected to be desirable to health conscious consumers looking for low-cost, high quality meat source (Narrod *et al*., 2007; Vukasovic, 2010). Time restrictions can be a major factor in product selection, consumers may allocate a larger proportion of their food expenditures to ready-to-eat, pre-cooked, ready-to-cook, fast or convenience food items to reduce the time devoted to meal preparation (Rae, 1998; Schmidhuber and Shetty, 2005; AAFC, 2005). Poultry meat processing has moved from whole bird to cut-up and to further processed or value-added poultry meat products in order to meet consumer demand for prepared or easily prepared products. Canadian consumers are purchasing larger quantities of cut-up and further processed products. Chicken meat sold in Canada in 2009 was 45.2% cut-up, 50.2% further processed and only 4.6% whole bird (Statistics Canada, 2010). A similar trend is found in the US between 1990 and 2007 (Figure 1-2) where the shift is not only away from whole bird but is now from whole bird and cut-up to further processed products. The National Chicken Council in the US (2008) reported 43% of poultry meat products sold were in the food service industry, with fast-food outlets representing 56% of that total. Consumer preference for out-of-home consumption of meals contributes to the overall increasing demand for further processed products. Consumer preference for specific carcass parts and prepared or partially prepared products drives the change in types of processing needed to meet market demand.

Religious or moral restrictions on consumption of certain meat products will influence purchasing behavior and negatively affect the markets of undesirable goods while positively affecting the markets of acceptable goods.   The moral beliefs held by some religious groups to abstain from violence (Buddhists, Hindus) or animal rights groups condemning animal production will affect livestock product markets; however the degree of impact will depend on the proportion of a given population holding these beliefs.

The relatively new trend of de-animalization, where the rights of animals are subordinate to the rights of society or industry, occurs when animals are used or valued for once specific task. For example, a broiler is no longer an individual bird, it is the end product(s) desired by producers and consumers. De-animalization also influences product demand as consumers, generally residing in urban centres far removed from actual animal production facilities, preferentially select products with no resemblance to the animal of origin (Magdelaine *et al*., 2008). De-animalization allows customers to distance themselves from the production animal by purchasing cut-up, further processed or value added products (Magdelaine *et al*., 2008) therefore increasing overall demand of animal based protein sources. Through de-animalization, society as a whole changes its perception of animals from an animal to a utility, in particular as food item and exploited as economic assets, particularly inherent in the intensive, vertically integrated poultry and pork production systems (Noske, 1997).

1.3 Poultry Meat Production System

The poultry meat industry has been able to provide consumers with a low-cost, high-quality protein source by taking advantage of intensive production systems which minimize input costs and maximize the efficiency of which those inputs are utilized (Narrod *et al*., 2007). Intensive production systems maximize production efficiency by substituting capital for labour, concentrating production on a minimal land base as well as maximizing the genetic potential of meat-type birds through implementation of scientifically researched management practices. The ability to substitute various types of capital for labour is essential to the continued viability of a production system when wages increase and a large proportion of production costs are labour related (Narrod *et al*., 2007). Environmental conditions may reduce the types of substitutions that can be made, for example regions with high humidity and temperatures may make operating cooling equipment too costly by requiring large amounts of electricity which would decrease the benefits of substituting capital for labour. Vertical integration, where all companies involved in poultry meat production are controlled by one owner, is used in the industry to further minimize costs and maximize production efficiency throughout, rather than for, or during one step in the poultry meat production system. Maximizing production efficiency throughout the poultry meat production process ensures end-product prices to consumers are kept at an acceptable level.

The poultry meat production system is comprised of several sections; each depending upon the previous production unit to provide an optimal base product (eggs, chicks, carcass) to maximize their efficiency of production (Figure 1-3). The parent stock eggs or chicks are supplied by primary breeder companies that own the genetics of selected great-grandparent and grand-parent pure lines. Hatching egg producers manage male and female broiler breeder chicks through rearing and reproduction phases producing fertilized eggs. The fertilized eggs are transported to hatcheries where the eggs are incubated and hatched chicks are processed (vaccinations, sexing) prior to transport to broiler producers. Broiler producers rear broilers to meet specific weight requirements, taking 37 to 40 days (d) to reach slaughter BW targets before being sent to a processing facility. Broiler carcasses are processed to meet specific product demands; cut up markets, further processed or convenience products (marinated chicken breast, chicken nuggets), or ready-to-eat markets (restaurants, fast food).

Poultry meat production is an integrated system of consisting of several steps, the system can be managed as a whole by one company (vertically integrated) or each step is managed by an independent producer or company (non-integrated system used in Canada). To provide consumers with a continued low-cost, high-quality protein source production efficiency must be maximized throughout the poultry meat production system.

1.4 End-Product Focus: Broiler Generation

Primary breeder genetic selection criteria focuses on broiler generation traits which meet consumer, processor and broiler producer demand (Pollock, 1999; Decuypere *et al*., 2003; Richards, 2003). Genetic selection for meat-type birds has aimed to increase the rate of juvenile growth, feed conversion efficiency (FCE) and breast meat yield (Costa, 1981; Siegel and Dunnington, 1985). Maximizing production efficiencies will facilitate continuing delivery of low-cost poultry meat products to consumers.

The rate of juvenile growth has increased over the past 50 years. Broilers are capable of reaching a BW of 1.82 kg in 32 d compared to 50 years ago when 101 d were required to reach the same BW (Havenstein *et al*., 2003 b). Reducing the time required for birds to reach market BW increases broiler production efficiency by reducing production costs (feed, utilities). Feed accounts for 70% of production costs with the broiler generation using 95% of the total feed consumed in the poultry meat production system and the breeder generation using 5% (Whitehead, 2000; Decuypere *et al*., 2003; Calini, 2007). An increase in FCE reduces the feed required to produce a broiler at market BW; in 2001, broilers required 2.67 kg of feed to reach a BW of 1.82 kg compared to broilers of 50 yr ago which required 8.02 kg to reach the same BW (Havenstein *et al*., 2003 b).

Increasing the production of desired carcass traits (breast meat yield) in combination with increased FCE further increases production efficiency by limiting the resources required to produce the desired gain in muscle mass.

The broiler generation requires the largest proportion of the high-cost feed input, therefore genetic selection for traits minimizing this cost are beneficial to end-product production efficiency. Genetic selection for rapid juvenile growth, increasing FCE and breast meat yield means the energy resources required to produce a gram of BW will be decreased. Production costs will be reduced with a decrease in the demand for feed resources as well as decreasing competition for grain (McKay, 2009). A short production cycle, efficient use of expensive inputs and high yield of desired carcass traits leads to reduced costs, potential for increased profit and delivery of a low-cost, high quality animal protein source to consumers.

1.5 Broiler Breeder Generation

The genetic potential for rapid juvenile growth, FCE and high breast meat yield in broilers is also inherent in the parent stock, broiler breeders. While rapid juvenile growth is desired in the offspring, it can lead to health and reproductive problems which may compromise broiler breeder welfare (Jaap and Muir, 1968; van Middelkoop and Siegel, 1976; Dunnington and Siegel, 1996; Robinson *et al*., 1995, 1998 a, b; Mench, 2002).

Broilers have a restricted life span, reaching processing BW in less than 40 d, while broiler breeders have an extended rearing and reproduction period of approximately 52 weeks (wk). Breeders are reared to develop adequate frame size and reach optimal body composition thresholds to enter sexual maturity in a timely and uniform manner as well as supporting persistent reproduction over a number of months (Brody *et al*., 1980; Soller *et al*., 1984; Renema *et al*., 1999 a; Hocking, 2004; Melnychuk *et al*., 2004). Ekmay et al. (2010) suggests the process of sexual maturity is not only regulated by BW (Hocking, 2004) but also lipid deposition and leptin secretion. Sexual maturation involves complex system of requirements; the attainment of requisite BW, lipid and protein accretion and related metabolic hormone concentrations.

Excessive muscling (attaining genetic potential for high breast meat yield) is a concern in breeders as it can lead to reproductive problems (Renema *et al*., 1999; Whitehead, 2000). Excessive breast muscle development in males will reduce reproductive efficiency as body conformation prevents proper cloacal contact during mating (Siegel and Dunnington, 1985; Etches, 1996; Duncan, 2009). Males can become too heavy for functional mating causing injuries and further reducing reproductive efficiency. Excessive BW can lead to leg problems, ascites and impaired immune function, which not only decreases reproduction but also bird welfare (Siegel and Dunnington, 1985; Decuypere *et al.*, 2003; Duncan, 2009).

Genetic selection for rapid growth has altered the birds' ability to match feed consumption with energy requirements (Denbow, 1994; Richards, 2003), where birds will consume feed until reaching their physiological limitations (gut capacity) (Barbato *et al*., 1984; Etches, 1996; Bokkers and Koene, 2003). Broiler breeder females with a positive energy balance (energy intake above requirements) will have a decrease in reproductive efficiency. Surplus energy will be partitioned toward lipid deposition and excessive follicular development resulting in increased morbidity, mortality and development of multiple hierarchies (Large yellow follicles > 10 mm) (Hocking *et al*., 1987; Katanbaf *et al*., 1989 a; Etches, 1996; Renema *et al*., 1999 b). The potential for concurrent maturation of two similar sized follicles increases in an ovary with multiple hierarchies which can lead to multiple ovulations and altered laying patterns (Hocking, 1996; Yu *et al*., 1992 b; Robinson *et al*., 2001). Jaap and Muir (1968) described the effect of excessive follicular development as erratic oviposition and defective egg syndrome (EODES) resulting in a decreased number of settable eggs. Double yolk eggs, eggs with poor shell quality, internal ovulations or lay reduce the number of settable eggs and decrease reproductive efficiency.

Hatching egg producers use strain specific target BW profiles when making weekly feed allocation decisions. Weekly restricted feed allocations are based on current flock BW mean and calculated to provide the nutrients for maintenance and desired gain to meet recommended target BW profiles. Compromised health, well-being as well as increased morbidity and mortality have been associated with excessive BW gain (Renema *et. al*., 1999; Whitehead, 2000). Feed restriction has been implemented since the 1970’s to control BW gain thereby decreasing morbidity and mortality (Heck *et al*., 2004; Bruggeman *et al*., 2005). Feed restriction is generally initiated at 3 wk of age (Aviagen, 2006), however Pishnamazi *et. al.* (2008) suggested early feed restriction (1 wk of age) reduced the risk of birds being overweight at 3 wk of age. Overweight pullets at 3 wk of age would be subject to early severe feed restriction, potentially compromising physiological development and welfare in an effort to meet projected target BW profiles. The degree of feed restriction is the severest from 8 to 16 wk of age when the difference between the feed quantities provided and the quantities consumed *ad libitum* are the greatest (Hocking *et. al*., 1993). The recommended feed increases vary quantitatively and proportionally throughout rearing. Weekly increases vary quantitatively from weekly increases of 6 g/bird/day at 3 wk to 2 g/bird/day at 6 wk and finally 9 g/bird/d at 21 wk of age (Aviagen, 2007 b). Proportional differences are found during rearing where a projected feed increase of 2 g from 7 to 8 wk of age is a proportional increase of 4.2% (48 to 50 g/bird/d; Aviagen, 2007 b), while the same 2 g increase from 13 to 14 wk is 3.3% (60 to 62 g/bird/d; Aviagen, 2007 b). Proportional differences are even greater when bird BW is considered; a 2 g feed increase at 7 wk, when a pullet has a target BW of 760 g is proportionally larger than a 2 g feed increase at 13 wk for a pullet with a target BW of 1,360 g (Aviagen, 2007 b).

Feed restriction during rearing controls growth. The nutrients provided are partitioned to maintenance and to establish the requisite frame size, carcass composition thresholds (protein accretion and lipid deposition) and production of adequate concentrations of metabolic and reproductive hormones are necessary for sexual maturity, egg production and persistency of lay.

Restricting the quantity of feed provided can increase flock BW and carcass trait variability by increasing between bird competition. A highly variable flock will have a greater proportion of pullets above or below target BW. Pullets above target BW profiles will respond to photostimulation cues as they have met the BW and body composition thresholds necessary for sexual maturity (Katanbaf *et al.*, 1989 b; Robinson and Robinson, 1991; Robinson *et al.*, 1991 a; Yu *et al.*, 1992b) while pullets below target BW will need additional time to achieve the requisite carcass composition thresholds delaying entry into lay (Brody *et. al*., 1984; Bornstein *et al*., 1984; Soller *et al*., 1984; Robinson and Robinson, 1991; Yu *et al*., 1992 a b). Large birds coming into lay early may lay a greater number of small eggs relative to small birds however both will have reduced production of settable eggs contributing to poor reproductive efficiency (Costa, 1981; Katanbaf *et al*., 1989 b; Robinson and Robinson, 1991; Robinson *et. al*., 1991; Yu et. al., 1992 b). Variability in age at sexual maturity may decrease overall production efficiency potentially reducing peak production and persistency of lay (Costa, 1981; Petitte *et al*., 1982). Variability in flock BW will reduce peak production, persistency of lay, the number of settable eggs and therefore reduce reproductive efficiency (Costa, 1981; Robinson and Robinson, 1991; Etches, 1996).

Feed restriction limits the energy resources available controlling gain however, can increase between bird competition and consequently flock BW variability. Large or aggressive birds out-compete small or timid birds, where large birds get larger (access to increased quantity of feed) and small birds get smaller (unable to compete decreasing access to feed). Feed restriction practices intend to increase the distribution of the limited energy resources throughout the flock thereby decreasing flock variability and maximizing reproductive efficiency.

1.5.1 Broiler Breeder Feed Management Practices

The purpose of feed restriction programs are to limit BW gain, to maintain target BW profiles, and to increase the distribution of the limited energy resource (feed) thereby decreasing flock variability. Feed restriction can compromise bird welfare particularly during rearing (7 – 15 wk) when restriction is severe (Bruggeman *et al.*, 1999; de Jong *et al*., 2002; Mench, 2002). Behaviours indicative of hunger and frustration have been observed in feed restricted broiler breeders; stereotypic pecking, increased activity and overdrinking have been reported (Hocking *et al*., 1993; Savory and Lariviere, 2000; de Jong *et al*., 2002). Alternative feed restriction practices attempt to maintain the reproductive and health benefits with a concurrent increase in bird welfare. Three types of feed restriction practices have been studied; quantitative and qualitative feed restriction and preemptive management.

1.5.1.1 Quantitative Feed Restriction

Quantitative feed restriction practices limit the quantity of feed available providing only the nutrients required for maintenance, controlled growth and egg production. Feed allotments are based on current flock BW mean and calculated following strain-specific BW target profiles provided by the primary breeder. Limiting the quantity of feed available can increase between bird competition resulting in increased flock variation (Costa, 1981; Petitte *et al*., 1981; Hudson *et* *al.*, 2001). van Middelkoop *et al.* (2000) suggested feeding vigor may be a factor in increasing flock BW variability under normal conditions of feed restriction.

Alternative feeding intervals may improve bird welfare and increase nutrient utilization by distributing the daily feed allocation among a number of meals (Backhouse and Gous, 2006). Quantitatively restricted feed allocations are generally fed once early in the day and consumed rapidly (Kostal *et al.*, 1992), as a result breeder females spend a number of hours fasting between feeding intervals. Restricted feed allocations combined with extended periods of time fasting compromises bird welfare (Mench, 2002). Savory *et al.* (1978) observed foraging behaviours throughout the day peaking in the early evening therefore feeding strategies which provide nutrients more than once a day including one feed interval at the end of the light period would reflect natural feeding activity, decrease the number of hours fasting and as a consequence, may increase bird welfare. Variations in feeding intervals have been examined during the reproductive phase; Spradley *et al*., (2008) and Taherkhani *et al*. (2010) reported decreased hen BW and increased egg production with feeding twice-a-day compared to once-a-day feeding. However, de Jong *et al*., (2004) found no benefit to using twice-a-day feeding during rearing. Implementing alternative feeding intervals in a commercial setting, particularly during periods of severe feed restriction may compromise bird welfare and production efficiency. Current feed delivery systems may not be able to effectively distribute smaller quantities of feed throughout the barn leading to decreased distribution of limited nutrient resources, increased flock BW variability and poor performance.

Scatter or spin feeding originated in Europe and was designed to increase flock BW uniformity. Feed is pelleted providing a balanced and concentrated energy source (Leeson and Summers, 2001). Feed is broadcast directly onto the litter by roof-mounted spin feeders. Scatter feeding increases the distribution of pelleted feed throughout the flock by spreading feed over a greater area (relative to feeder space) as well as increasing feed cleanup time (van Middelkoop *et al*., 2000) which results in increased flock BW uniformity. The proportion of small sized feed particles is increased through the pelleting process, thereby increasing the surface area available to the digestive enzymes and increasing overall digestibility (Rogel *et al*., 1987 b). Svihus *et al*. (2004) and Amerah *et al*. (2007) found using pelleted feed improved BW gain, feed to gain ratios, balanced nutrient intake and reduced waste which increased feed efficiency. Previous research has suggested scatter feeding improves pullet health and welfare by stimulating natural foraging behaviours leading to increased activity, decreasing the incidence of leg disorders and stereotypic pecking (van Middelkoop *et al*., 2000; de Jong *et al*., 2005). Pellet durability can be a problem with current transportation and feed distribution systems, available diet ingredients and particle size may contribute to the breakdown of pellets into fines (powdery texture) which could reduce the effectiveness of scatter feeding.

Skip-a-day feeding uses a combination of feed and non-feed days; 6 feed/1 non-feed, 5/2, 4/3 or true skip-a-day which alternates between feed and non-feed days. Combinations of skip-a-day programs are also used in the industry. Quantitatively restricted feed allocations are based on current flock BW mean and calculated following strain-specific target BW profiles however, actual feed day allotments are determined by dividing the total weekly feed allocation by the number of feed days. Dividing the total weekly feed allocation over fewer days increases the quantity provided on actual feed days, increasing the distribution of feed throughout the flock and thereby potentially increasing flock BW uniformity. The extended period of time between feed intervals with skip-a-day feeding causes increased frustration and stress leading to abnormal behaviours decreasing welfare (Savory *et al*., 1992; Savory and Maros, 1993). Feed /non-feed cycles can alter metabolic processes, in particular hepatic lipogenesis (Richards *et al*., 2003; de Beer *et al*., 2007). The increased nutrients provided on feed days will trigger glucose dependent lipogenesis increasing the deposition of excess triglycerides into adipose tissue (fat pad) (Richards *et al*., 2003). In the absence of nutrients on non-feed days, glucose from the liver initially maintains blood glucose levels however; once this source is depleted the process of gluconeogenesis is triggered to supply glucose (de Beer *et al*., 2007). Gluconeogenesis breaks down amino acids (protein) which will alter carcass composition producing pullets with increased lipid deposition and decreased protein accretion.

1.5.1.2 Qualitative Feed Restriction

Quantitative feed restriction decreases nutrient availability by diluting the diet with a non-nutritive filler (oat hulls, sugar beet pulp, wheat bran). Feed allocations will vary depending on the degree of dilution, feed can be provided *ad libitum* Savory *et al*., 1996; Tolkamp, 2005) or feed can be controlled (Zuidhof *et* *al*., 1995; deJong *et al*., 2005). The distribution of feed is increased by increasing the volume of feed provided which may increase flock BW uniformity. Between bird competition is outweighed by feed volume as large or aggressive pullets can eat closer to gut capacity before all the feed is consumed and as a result, small, less aggressive pullets have access to feed. Increased feed volume may also result in extended feed cleanup time allowing pullets to consume a daily allotment closer to *ad libitum* feeding without the detrimental effects of over feeding. The benefit of adding specific diluents may go beyond increasing feed volume. Oat hulls may improve starch digestibility in wheat based diets (Rogel *et al*., 1987a; Hetland et al., 2003) as well as facilitate the physical disruption of starch granules in the gizzard (Rogel *et al*., 1987a). Buttner and Muhler (1959) and Stookey and McDonald (1980) indicated the antibacterial and antifungal properties of oat hulls alter gut micro flora thereby increasing diet digestibility. Svihuis and Hetland (2001) found improvements in starch digestibility using cellulose while Enting *et al*., (2007) observed a decrease in diet digestibility with the addition of oats and sugar beet pulp. Pullets may not consume adequate quantities of nutrients even though gut capacity has been reached if diets are too nutritionally dilute (Savory *et al*., 1996; Savory and Lariviere, 2000). If the proportion of diluents in the diet is excessive, pullets will reach gut capacity before meeting their nutritional requirements, therefore the potential exists for limited availability of some nutrients (Kyrlazakis and Emmans, 1995) leading to deficiencies, compromised health and well-being or reduced flock uniformity.

1.5.1.3 Pre-emptive Management

Bird sorting, grouping or grading is implemented to match feed intake to the actual energy requirements of a group of birds with similar BW, thereby improving BW uniformity. In general, three BW groups or grades are used: light, (birds below target BW), medium (birds at target BW) and heavy (birds above target BW). Pullets receive daily feed allocations based on group BW means rather than the BW mean for the whole flock and calculated using strain-specific target BW profiles. By using group-targeted feed allotments, nutrients provided will be a closer match to actual requirements of a greater proportion of birds. The distribution of the limited nutrients throughout the flock will increase as small pullets will receive an increased quantity of feed (relative to pullets at or above target BW profile) while minimizing the effects of between bird competition within like-sized groups. Pullets are resorted if BW variability is high however, is generally limited to 2 or 3 times during rearing. Bird sorting is labour intensive therefore is generally cost prohibitive in regions where labour costs are high. In South and Latin America where labour costs are low, having staff routinely walk the barn moving birds among pens increases feed efficiency without compromising production efficiency with additional or excessive labour costs. Pullet flock BW uniformity will be increased through group-targeted feed allocations and a better distribution of limited energy resources.

1.5.2 Broiler Breeder Hen Diet Fortification

Genetic selection for production traits in the broiler generation has increased the degree of feed restriction necessary to optimize broiler breeder health, well-being and reproductive efficiency. Restricting feed allocations has the potential to limit essential micronutrients compromising sexual maturation, egg production and persistency of lay. Renema *et al*. (2007) examined the effects of increasing breeder BW, size and protein accretion during the last 30 years. Kidd (2009) suggested a concomitant increase in essential micronutrient requirements for maintenance resulting from increased BW, size and protein accretion. The availability of essential micronutrients for transfer to the egg depends upon the breeder hen's nutritional status (Wilson, 1997).

A balanced micronutrient concentration is required in the egg to optimize chick development, hatchability, quality, livability and growth (Leeson, *et al*., 1979 b; Wilson, 1997). The industry uses fortified (supplemental premix) breeder hen diets to compensate for any potential dietary shortages of essential micronutrients. Micronutrient deficiencies may occur with restricted feed allotments if the distribution of premix in the feed is decreased or between bird competition decreases the distribution of feed and therefore micronutrients throughout the flock. Diet fortification may increase the distribution of micronutrients to breeder hens and consequently to the egg and offspring.

1.5.3 Flock Uniformity

The inherent capacity for rapid juvenile growth and corresponding feed restriction can increase flock BW variability. Decreasing flock BW variability is necessary to maximize overall breeder production efficiency. The industry uses "variation from the mean" and the coefficient of variation as representative measures of flock uniformity.

1.5.3.1 Variation from the Mean

Variation from the mean provides a numerical value for the proportion of a population within a specified range where the greater the percent of the population within that range, the greater the uniformity. The industry conventionally uses ±10% or ±15% of the population mean. Variation from the mean is calculated:

$$\mu - a < \text{Range} > \mu + a = n$$

$$(n/t)*100 = \text{percent of population}$$

Where μ = population BW mean, a = μ*(.10 or .15) to determine upper and lower range limits, n = number of birds within the functional BW range, t = total number of birds weighed.

Variation from the mean does not indicate how widely a population is dispersed (standard deviation) therefore the coefficient of variation should be used as the measure of uniformity.

1.5.3.2 Coefficient of Variation

The coefficient of variation (CV) is the standard deviation as a percent of the mean. The lower the CV, the greater the proportion of a population is distributed around the mean and therefore the higher the uniformity of a particular variable within that population. A normally distributed population will have 68.2% of the population residing within one standard deviation of the population mean. A large standard deviation will result in a flatter bell curve indicating a wider distribution of a variable within a population; have a larger CV and therefore increased variability. The CV is calculated:

$$CV = (\delta / \mu)*100$$

Where δ = standard deviation, μ = population BW mean.

Outliers will bias the CV resulting in a higher CV than may actually exist; a population BW frequency distribution histogram will reveal any extremes allowing for analysis of any unusual measurements to determine their validity.

The CV was used to determine flock uniformity as it allows for comparisons between different ages. The distribution of a variable will always have 68.2% of the normally distributed population within one standard deviation of the mean, standardizing the measure and allowing for comparisons between different treatments at different ages.

1.6 The Problem

Improvements in production traits of rapid juvenile growth, FCE and increased breast meat yield are beneficial in broilers however have had a negative effect on the efficiency of broiler breeder reproduction, health and well-being. Breeders have an extended production cycle compared to broilers therefore to decrease morbidity and mortality associated with excessive BW, gain must be controlled through feed restriction. Feed restriction increases bird health and welfare by decreasing the incidence of metabolic and skeletal disorders, skeletal deformities and mortality as well as increasing immune function and disease resistance. Maintaining recommended BW target profiles through feed restriction establishes optimal body composition to support sexual maturity and persistent egg production.

Restricting feed to the degree necessary to control gain increases competition between birds and leads to increases in flock BW variability. Restricted feed allocations may also limit the availability of essential micronutrients during reproduction negatively effecting egg and chick quality and uniformity. Poor broiler chick quality will be reflected in broiler BW and carcass composition.

Determining which feed management practice(s) maintain BW targets, improve flock uniformity as well as bird welfare will assist producers by providing information that would support change in feed and BW management methods. The benefits of micronutrient increases in breeder diets will be determined and provide initial guidelines for producers.

1.7 Objectives

1.7.1 General Objective

The objective of this thesis was to examine the effect of 5 rearing feed management practices (3 to 22 wk of age) and breeder hen diet fortification (22 to 40 wk of age) on hen flock BW and carcass uniformity, sexual maturity, egg production, egg and chick quality, broiler growth and carcass yield.

1.7.2 Specific Objectives

- To manage female BB to meet and maintain target BW profiles.
- To determine the effect of rearing feed management practices on BW, carcass composition and uniformity.
- To determine the effect of rearing treatments and breeder diet fortification on uniformity of age at sexual maturity and early egg traits, quality and

hatchability, chick quality, livability, as well as broiler growth and carcass traits production.

1.8 Approach

A broiler breeder experiment was performed using 1,200 Aviagen TP16 pullets with different rearing feed management practices. Hen based data of BW, 22 wk carcass composition and flock uniformity were collected from 3 to 22 wk of age to determine if breeder hen BW target profiles, BW and carcass trait uniformity could be maintained using rear feed management practices.

A second experiment was performed using 750 remaining pullets from the first experiment to study the effects of rearing treatment and diet fortification. The effect of rearing and diet fortification treatments on breeder hen age at sexual maturity, early egg characteristics, egg and chick quality and broiler uniformity were examined. Hen body composition at sexual maturity was determined by humanely euthanizing and dissecting hens after laying their 3rd egg (450 TP16 breeder hens). Egg characteristics were determined using data collected from first 3 eggs laid for 750 breeder hens.

Three hatches were set to determine chick quality and hatchability. Two hatches recorded chick length, weight and residual yolk sac weights to determine quality. The final hatch was placed and broilers were grown out to 37 d of age and then processed to establish the effect of rearing and fortification treatments on broiler BW, carcass composition and uniformity.

1.9 References

Agriculture and Agri-Food Canada. 2005. Canadian food trends to 2020: A long range consumer outlook. Ottawa, Canada. http://www4.agr.gc.ca/resources/prod/doc/agr/pdf/ft-ta_eng.pdf. Accessed December 2009.

Aviagen. 2006. Rearing (0-15 wk). Pages 4-21in: Ross 308 Parent Stock Management Manual. Aviagen Inc., Huntsville, Alabama, USA.

Aviagen. 2007. Ross 308 Broiler Performance Objectives. Aviagen Inc., Huntsville, Alabama, USA.

Aviagen. 2007. Ross 308 PS Performance Objectives. Aviagen Inc., Huntsville, Alabama, USA.

Backhouse, D., and R. M. Gous. 2006. Responses of adult broiler breeders to feeding time. World’s Poult. Sci. J. 62:269-281.

Barbato, G. F. 1999. Genetic relationships between selection for growth and reproductive effectiveness. Poult. Sci. 78:444-452.

Bokkers, E. A., and P. Koene. 2003. Eating behaviour, and preprandial and postprandial correlations in male broiler and layer chickens. Br. Poult. Sci. 44:538-544.

Bornstein, S., I. Plavnik, and Y. Lev. 1984. Body weight and/or fatness as potential determinants of the onset of egg production in broiler breeder hens. Br. Poult. Sci. 25:232-341.

Brody, T. B., P. B. Siegel, and J. A. Cherry. 1984. Age, body-weight and body-composition requirements for the onset of sexual maturity of dwarf and normal chickens. Br. Poult. Sci. 25:245-252.

Bruggeman, V., O. Onagbesan, E. D’Hondt, N. Buys, M. Safi, D. Vanmontfort, L. Berghman, F. Vandesande, and E. Decuypere. 1999. Effect of timing and duration of feed restriction during rearing on reproductive characteristics in broiler breeder females. Poult. Sci. 78:1424-1434.

Bruggeman, V., O. Onagbesan, O. Ragot, S. Metayer, S. Cassy, F. Favreau, Y. Jego, J. J. Trevidy, K. Tona, J. Williams, E. Decuypere, and M. Picard. 2005. Feed allowance-genotype interactions in broiler breeder hens. Poult. Sci. 84:298-306.

Buyse, J., H. Michels, J. Vloeberghs, P. Saevels, J. M. Aerts, B. Ducro, D. Berckmans, and E. Decuypere. 1998. Energy and protein metabolism between 3 and 6 weeks of age of male broiler chickens selected for growth rate or for improved food efficiency. Br. Poult. Sci. 39:264-272.

Case, K. E. and R. C. Fair. 2007. Principles of Economics, 8th edition. Pearson Education, Inc., New Jersey, USA.

Cobb-Vantress. 2008. Cobb 500 Breeder Management Supplement SF. Cobb-Vantress Inc., P.O. Box 1030, Siloam Springs, Arkansas, USA.

Cobb-Vantress. 2009. Cobb 500 Broiler Management Guide. Cobb-Vantress Inc., P.O. Box 1030, Siloam Springs, Arkansas, USA.

Costa, M. S. 1981. Fundamental principles of broiler breeders nutrition and the design of feeding programmes. World's Poult. Sci. J. 37:177-192.

Cox, J. M. and A. Pavic. 2010. Advances in enteropathogen control in poultry production. J. Appl. Micro. 108:745-755.

de Beer, M., R. W. Rosebrough, B. A. Russell, S. M. Poch, M. P. Richards, and C. N. Coon. 2007. An examination of the role of feeding regimens in regulating metabolism during the broiler breeder grower period. 1. Hepatic lipid metabolism. Poult. Sci. 86:1726-1738.

Decuypere, E., V. Bruggeman, G. F. Barbato, and J. Buyse. 2003. Growth and reproduction problems associated with selection for increased broiler meat production. Pages 27-38 in: Poultry Genetics, Breeding and Biotechnology. Muir, W. M. and S. E. Aggrey ed. CABI Publishing, Wallingford, Oxon, UK.

de Jong, I. C., A. Sander Van Voorst, D. A. Ehlhardt, and H. J. Blokhuis. 2002. Effects of restricted feeding on physiological stress parameters in growing broiler breeders. Br. Poult. Sci. 43:157-168.

de Jong, I. C., M. Fillerup, and H. J. Blokhuis. 2005. Effect of scattered feeding and feeding twice a day during rearing on indicators of hunger and frustration in broiler breeders. Appl. Anim. Behaviour Sci. 92:61-76.

Denbow, D. M. 1994. Appettite and its control. Poult. Sci. Reviews 5:209-229.

Denbow, D. M. 1999. Food intake regulation in birds. J. Exp. Zool. 283:333-338.

Duncan, I. J. H. 2009. Mating behaviour and fertility. Pages 111-132 in: Biology of breeding poultry. Editor P. Hocking. CAB Int. Oxfordshire, UK.

Enting, H., A. Veldman, M. W. A. Verstegen, and P. J. van der Aar. 2007. The effect of low-density diets on broiler breeder development and nutrient digestibility during the rearing period. Poult. Sci. 86:720-726.

Etches, R. J. 1996. Reproduction in Poultry. CAB International, Wallingford, Oxon. UK.

FAO (Food and Agriculture Organization of the United Nations), 2009. The state of food and agriculture: livestock in the balance. FAO, Rome, Italy.

Havenstein, G. B., P. R. Ferket, S. E. Scheideler, and B. T. Larson. 1994. Growth, livability, and feed conversion of 1991 vs. 1957 broilers when fed “typical” 1957 and 1991 broiler diets. Poult. Sci. 73:1785-1794.

Heck, A., O. Onagbesan, K. Tona, S. Metayer, J. Putterflam, Y. Jego, J. J. Trevidy, E. Decuypere, J. Williams, M. Picard, and V. Bruggeman. 2004. Effects of ad libitum feeding on performance of different strains of broiler breeders. Br. Poult. Sci. 45:695-703.

Hetland, H., B. Svihus, and A. Krogdahl. 2003. Effects of oat hulls and wood shavings on digestion in broilers and layers fed diets based on whole or ground wheat. Br. Poult. Sci. 44:275-282.

Hocking, P. M., M. H. Maxwell, and M. A. Mitchell. 1993. Welfare assessment of broiler breeder and layer females subjected to food and water restriction during rearing. Br. Poult. Sci. 34:443-458.

Hocking, P. M. 1996. The role of body weight and food intake after photostimulation on ovarian function at first egg in broiler breeder females. Br. Poult. Sci. 37:841-851.

Hudson, B. P., R. J. Lien, and J. B. Hess. 2001. Effects of body weight uniformity and pre-peak feeding programs on broiler breeder hen performance. J. Appl. Poult. Res. 10:24-32.

Jaap, R. G., and F. V. Muir. 1967. Erratic oviposition and egg defects in broiler-type pullets. Poult. Sci. 47:417-423.

Katanbaf, M. N., E. A. Dunnington, and P. B. Siegel. 1989 a. Restricted feeding in early and late-feathering chickens 1: Growth and physiological responses. Poult. Sci. 68:344-351.

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

Kidd, M .T. 2009. Vitamins, minerals and micronutrients. Pages 361-373 in: Biology of breeding poultry. Editor P. Hocking. CAB Int. Oxfordshire, UK.

Kostal, L., C. J. Savory, and B. O. Hughes. 1992. Diurnal and individual variation in beahaviour of restricted-fed broiler breeders. Appl. Anim. Behaviour Sci. 32:361-374.

Kyriazakis, I., and G. C. Emmans. 1995. The voluntary feed intake of pigs given feeds based on wheat, bran, dried citrus pulp and grass meal, in relation to measurements of feed bulk. Br. J. Nutr. 73:191-207.

Leeson, S., B. S. Reinhart, and J. D. Summers. 1979. Response of White Leghorn and Rhode Island Red breeder hens to dietary deficiencies of synthetic vitamins 2. Embryo mortality and abnormalities. Can. J. Anim. Sci. 59:569-575.

Leeson, S., and J. D. Summers. Energy. 2001. Pages 35-99 in: Nutrition of the Chicken. 4th Ed. University Books. Guelph, ON.

Madsen, K. O., and E. J. Edmonds. 1962. Effect of rice hulls and other seed hulls on dental caries production in the cotton rat. J. Dent. Res. 41:405-412.

Maloney, M. A., J. C. Gilbreath, J. F. Tierce, and R. D. Morrison. 1967. Divergent selection for twelve-week body weight in the domestic fowl. Poult. Sci. 46:1116-1127.

McEachern, W. A. 2009. Introduction to the market system. Pages 115 to 117 in: Microeconomics, 8th edition, a contemporary introduction. South-Western Cengage Learning, Mason, OH, USA.

Mench, J. A. 2002. Broiler breeders: feed restriction and welfare. World's Poult. Sci. J. 58:23-29.

Naber, E. C. 1993. Modifying vitamin composition of eggs: A review. J. Appl. Poult. Res. 2:385-393.

Narrod, C., M. Tiongco, and A. Costales. 2007 . Global poultry sector trends and external drivers of structural change in: Poultry in the 21st Century. FAO, Animal Production and Health Division. http://www.fao.org/ag/AGAInfo/home/events/bangkok2007/docs/part1/1_1.pdf. Accessed September 2009.

National Chicken Council. 2010. Statistics and Research: How broilers are marketed. http://www.nationalchickencouncil.com/statistics/stat_detail.cfm?id=32. Accessed May 6, 2010.

OECD/FAO, 2009. Agricultural Outlook 2009 – 2018. http://www.agri-outlook.org/pages/0,2987,en_36774715_36775671_1_1_1_1_1,00.html. Accessed May 18, 2010.

Petitte, J. N., R. O. Hawes, and R. W. Gerry. 1981. Control of flock uniformity of broiler breeders through segregation according to body weight. Poult. Sci. 60:2395-2400.

Pishnamazi, A., R. A. Renema, M. J. Zuidhof, and F. E. Robinson. 2008. Effect of initial full feeding of broiler breeder pullets on carcass development and body weight variation. J. Appl. Poult. Res. 17:505-514.

Pollock, D. L. 1999. A geneticist's perspective from within a broiler primary breeder company. Poult. Sci. 78:414-418.

Renema, R. A., F. E. Robinson, J. A. Proudman, M. Newcombe, and R. I. McKay. 1999. Effects of body weight and feed allocation during sexual maturation in broiler breeder hens. 2. Ovarian morphology and plasma hormone profiles. Poult. Sci. 78:629-639.

Renema, R. A., M. E. Rustad, and F. E. Robinson. 2007. Implications of changes to commercial broiler and broiler breeder body weight targets over the past 30 years. World's Poult. Sci. J. 63:457-472.

Richards, M. P. 2003. Genetic regulation of feed intake and energy balance in poultry. Poult. Sci. 82:907-916.

Richards, M. P. 2007. Mechanisms regulating feed intake, energy expenditure, and body weight in poultry. Poult. Sci. 86:1478-1490.

Robinson, F. E., and N. A. Robinson. 1991. Reproductive performance, growth rate and body composition of broiler breeder hens differing in body weight at 21 weeks of age. Can. J. Anim. Sci. 71:1233-1239.

Robinson, F. E., N. A. Robinson, and T. A. Scott. 1991. Reproductive performance, growth rate and body composition of full-fed versus feed-restricted broiler breeder hens. Can. J. An. Sci. 71:549-556.

Robinson, F. E., N. A. Robinson, and R. T. Hardin. 1995. The effects of 20-week body weight and feed allocation during early lay on female broiler breeders. J. Appl. Poult. Res. 4:203-210.

Robinson, F. E., R. A. Renema, L. Bouvier, J. J. R. Feddes, J. L. Wilson, M. Newcombe, and R. I. McKay. 1998. Effects of photostimulatory lighting and feed allocation in female broiler breeders 1. Reproductive development. Can. J. An. Sci. 78:603-63.

Robinson, F. E., R. A. Renema, L. Bouvier, J. J. R. Feddes, M. J. Zuidhof, J. L. Wilson, M. Newcombe, and R. I. McKay. 1998. Effects of photostimulatory lighting and feed allocation in female broiler breeders 2. Egg and chick production characteristics. Can. J. An. Sci. 78:615-623.

Rogel, A. M., D. Balnave, W. L. Bryden, and E. F. Annison. 1987. Improvement of raw potato starch digestion in chickens by feeding oat hulls and other fibrous feedstuffs. Aust. J. Agric. Res. 38:629-637.

Rogel, A. M., E. F. Annison, W. L. Bryden, and D. Balnave. 1987. The digestion of wheat starch in broiler chickens. Aust. J. Agric. Res. 38:639-649.

Savory, C. J., D. G. M. Wood-gush and I. J. H. Duncan. 1978. Feeding behavior in a population of domestic fowls in the wild. Appl. Animal Ethology. 4:13-27.

Savory, C. J., E. Seawright, and A. Watson. 1992. Stereotyped behavior in broiler breeders in relation to husbandry and opioid receptor blockade. Appl. Anim. Behaviour Sci. 32:349-360.

Savory, C. J., and K. Maros. 1993. Influence of degree of food restriction, age and time of day on behavior of broiler breeder chickens. Behav. Processes. 29:179-190.

Savory, C. J., P. M. Hocking, J. S. Mann, and M. H. Maxwell. 1996. Is broiler breeder welfare improved by using qualitative rather than quantitative food restriction to limit growth rate? Anim. Welf. 5:105-127.

Savory, C. J., and J. M. Lariviere. 2000. Effects of qualitative and quantitative food restriction treatments on feeding and motivational state and general activity level of growing broiler breeders. Appl. Anim. Behaviour Sci. 69:135-147.

Siegel, P. B., and E. A. Dunnington. 1985. Reproductive complications associated with selection for broiler growth. Pages 59-72 in: Poultry Genetics and Breeding. Hill, W. G., J. H. Manson, and D. Hewitt (Ed.), Longman, Harlow, UK.

Siegel, P. B., and J. H. Wolford. 2003. A review of some results of selection for juvenile body weight in chickens. J. Poult. Sci. 40:81-91.

Soller, M., Y. Eitan, and T. Brody. 1984. Effect of diet and early quantitative restriction on the minimum weight requirement for onset of sexual maturity in White Rock broiler breeders. Poult. Sci. 63:1255-1261.

Spradley, J. M., M. E. Freeman, J. L. Wilson, and A. J. Davis. 2008. The influence of a twice-a-day feeding regimen after photostimulation on the reproductive performance of broiler breeder hens. Poult. Sci. 87:561-568.

Statistics Canada. 2010. Food Statistics 2009. Catalogue No. 21-020-X. Statistics Canada, Ottawa, Ont., Canada.

Stookey, G. K., and J. L. McDonald, Jr. 1980. Influence of combinations of oat hulls and sodium trimetaphosphate upon dental caries in the rat. J. Dent. Res. 59:838.

Svihuis, B., and H. Hetland. 2001. Ileal starch digestibility in growing broiler chickens fed on a wheat-based diet is improved by mash feeding, dilution with cellulose or whole wheat inclusion. Br. Poult. Sci. 42:633-637.

Svihuis, B., K. H. Klovstad, V. Perez, O. Zimonja, S. Sahlstrom, R. B. Schuller, W. K. Jeksrud, and E. Prestlokken. 2004. Physical and nutritional effects of pelleting of broiler chicken diets made from wheat ground to different coarsenesses by the use of roller mill and hammer mill. An. Feed Sci and Tech. 117:281-293.

Taherkhani, R., M. Zaghari, M. Shivazad, and A. Zare Shahneh. 2010. A twice-a-day feeding regimen optimizes performance in broiler breeder hens. Poult. Sci. 89:1692-1702.

Taylor, J. B. and A. Weerapana. 2007. Subtleties of supply and demand model: price floors, price ceilings and elasticity. Pages 101 and 102 in: Economics, 6th edition. Houghton Mifflin Company, Boston, MA, USA.

Thurman, W. N. 1987. The poultry market – demand stability and industry structure. Amer. J. Agr. Econ. 69:30-37.

Tolkamp, B. J., V. Sandilands, and I. Kyriazakis. 2005. Effects of qualitative feed restriction during rearing on performance of broiler breeders during rearing and lay. Poult. Sci. 84:1286-1293.

Van Immerseel, F., L. De Zutter, K. Houf, F. Pasmans, F. Haesebrouck, and R. Ducatelle. 2009. Strategies to control *Salmonella* in the broiler production chain. World's Poult. Sci. J. 65:367-392.

van Middelkoop, J. H., J. W. Van der Haar, F. E. Robinson, C. A. Luzi, and M. J. Zuidhof. 2000. The application of scatter feeding in managing feed restriction during the rearing of broiler breeders. In: Proceedings of the 21st World's Poultry Congress, Montreal.

Vukasovic, T. 2010. Buying decision-making process for poultry meat. Br. Food J. 112:125 – 139.

Wang, X., J. R. Day, and R. Vasilatos-Younken. 2001. The distribution of neuropeptide Y gene expression in the chicken brain. Mol. Cell. Endocrinol. 174:129-136.

Whitehead, C. C. 2000. Nutrition: The integrative science. Br. Poult. Sci. 41:5-15.

Wilson, H. R. 1997. Effects of maternal nutrition on hatchability. Poult. Sci. 76:134-143.

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

Yu, M.W., F.E. Robinson, and R. J. Etches. 1992b. Effect of feed allowance during rearing and breeding on female broiler breeders. 3. Ovarian steroidogenesis. Poult. Sci. 71:1762-1767.

Zuidhof, M.J., F. E. Robinson, J. J. R. Feddes, R. T. Hardin, J. L. Wilson, R. I. McKay, and M. Newcombe. 1995. The effects of nutrient dilution on the well-being and performance of female broiler breeders. Poult. Sci. 74:441-456.

Table 1-1. Global poultry meat production (thousand tonnes)

	Production			Utilization		
	2008	**2009**	**2010[1]**	**2008**	**2009**	**2010[1]**
World	93,729	91,937	94,210	93,474	92,070	94,229
Developing	53,438	51,816	53,403	54,005	52,196	53,606
Developed	40,291	40,120	40,807	39,469	39,874	40,623

[1]Projected production
Source: modified from FAO Food Outlook (2009).

Table 1-2. World Population 1950 – 2020

Year	World[2]	Developed countries			Developing countries		
		Total[2]	Rural[3]	Urban[3]	Total[2]	Rural[3]	Urban[3]
1950	2,529,346	812,026	47.4	52.6	1,717,320	82.4	17.6
2000	6,115,367	1,194,967	27.3	72.7	4,920,400	60.0	40.0
2005	6,512,276	1,216,550	26.1	73.9	5,295,726	57.2	42.8
2010[1]	6,908,688	1,237,228	24.8	75.2	5,671,460	54.9	45.1
2015[1]	7,302,186	1,254,845	23.5	76.5	6,047,341	52.6	47.4
2020[1]	7,674,833	1,268,343	22.1	77.9	6,406,489	50.2	49.8

Source: modified from United Nations, Population Division (2009).
[1]Population estimates for 2010, 2015 and 2020.
[2]Population in thousands.
[3]Percent of developed or developing countrys' total population.

Table 1-3. Per capita gross national income in developing countries, developed countries and the world

	Per capita GNI (US$/year)			**% Change from 2001 to 2008**
	2001	**2007**	**2008**	
World	5,145	8,271	8,991	+74.7
Developing	2,603	4,397	4,910	+88.7
Developed	24,390	36,946	39,609	+62.4

Source: modified from United Nations, DESA (2008).

Table 1-4. United States meat prices 2005 – 2009 (USD/tonne)

Year	Pork	Beef	Poultry
2005	2,161	3,919	847
2007	2,117	4,023	935
2009 January	2,195	3,938	904
2009 September	2,169	3,855	1,002

Source: modified from FAO Food Outlook (2009).

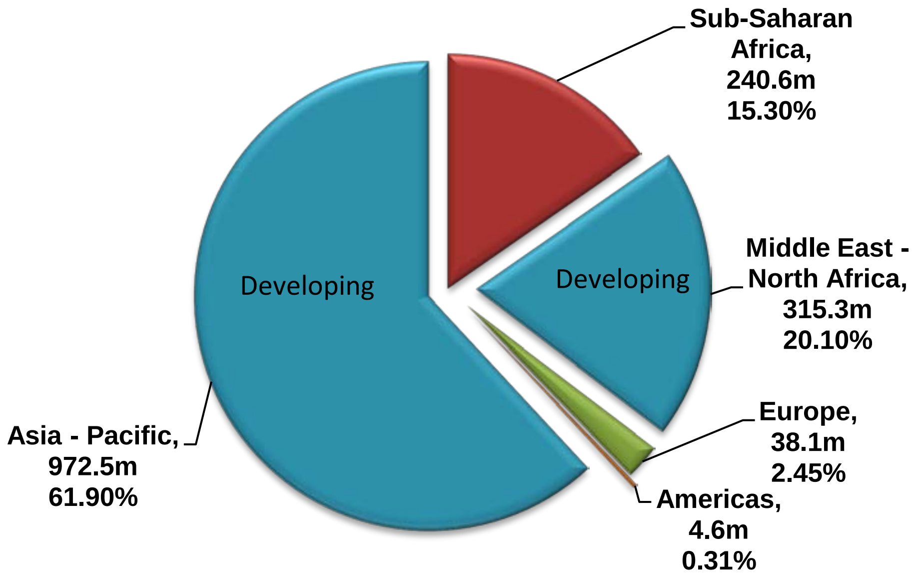

Figure 1-1. Muslim population by global region (millions)*.

Source: modified from The Pew Forum, 2009.
* Percent of global Muslim population does not equal 100% due to rounding.

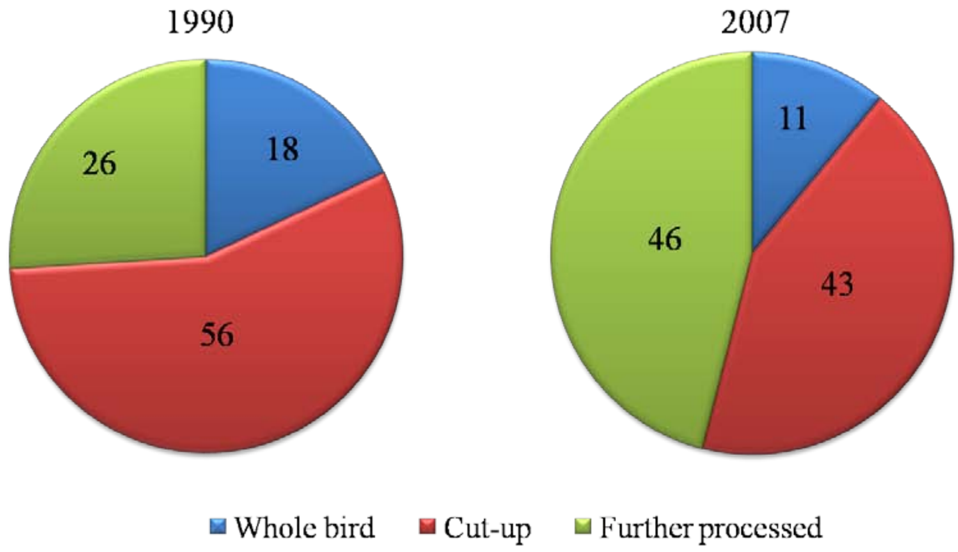

Figure 1-2. Proportion of type of broiler processing in the US (%).
Source: National Chicken Council (2010).

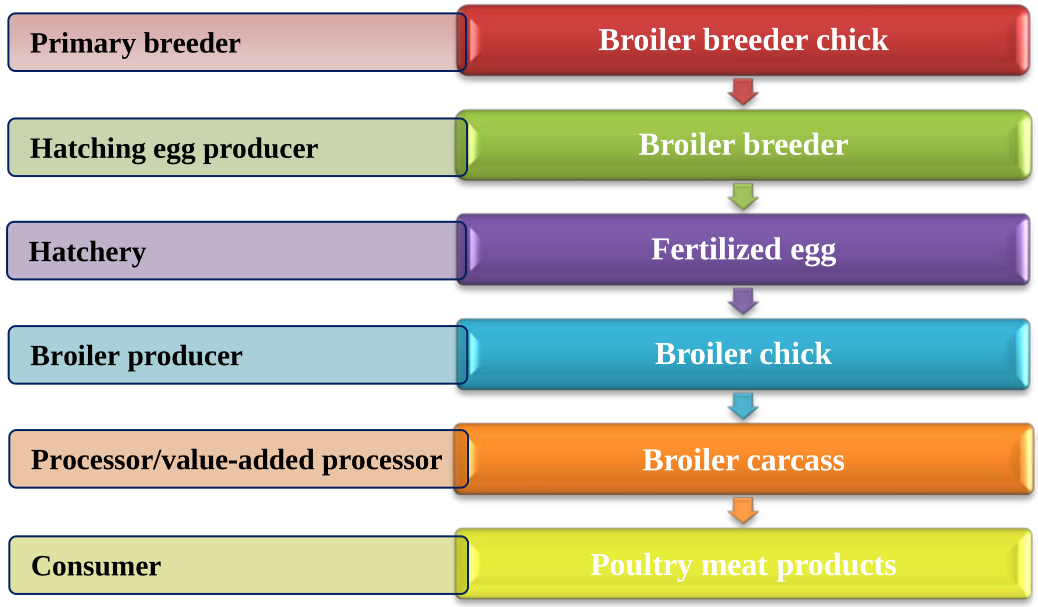

Figure 1-3. Poultry meat production system.

Chapter 2. Optimizing Broiler Breeder Pullet Uniformity through Maternal Management

2.1. Introduction

The rearing period for broiler breeder (BB) females is critical for establishing adequate skeletal development and fleshing to meet threshold necessary for the onset of sexual maturity and to maintain reproductive efficiency during the production cycle. Pullet feed management strategies are designed to provide the required nutrients necessary for maintenance and growth while concurrently maximizing flock BW uniformity and well-being. Genetic selection criteria for broilers has focused on rapid juvenile growth, feed conversion efficiency and increased yield of breast meat (Pollock, 1999; Decuypere *et al*., 2003; Richards, 2003). These traits are desired and beneficial in broiler production however they may compromise reproductive fitness and efficiency in the parent stock, broiler breeders. (Jaap and Muir, 1968; Siegel and Dunnington, 1985; Robinson *et al*., 1995, 1998 a, b).

Feed restriction programs have been implemented since the 1970’s and are now considered a necessary component of BB management. Selection for rapid juvenile growth has altered the birds’ ability to voluntarily control feed intake (Denbow, 1999; Richards, 2003) as broilers will eat until reaching physiological limitations (gut capacity) rather than meeting energy needs (Barbato, *et al*., 1984; Etches, 1996; Bokkers and Koene, 2003). Previous studies have found that selection for rapid growth and reproductive efficiency are negatively correlated (Maloney *et al*., 1967; Jaap and Muir, 1968). Havenstein *et al*. (1994) and Buyse *et al*. (1998) found increased fat deposition with selection for BW. Katanbaf *et. al*. (1989 a) found increased mortality associated with increased fat deposition. Excessive energy intake (above requirements for maintenance and controlled growth) has been shown to lead to multiple ovulations, internal ovulations, multiple hierarchies (Hocking, 1996), defective egg production and altered laying patterns (Jaap and Muir, 1968; Yu *et al*., 1992 a; Robinson *et al*., 1995, 1998b) leading to a decrease in the number of settable eggs and poor persistency of lay. Over fleshing (excessive breast muscle development – achieving genetic potential) compromises health, well-being, fertility and increases mortality (Whitehead, 2000; Renema *et al*., 1999). Primary breeders provide target BW profiles for each strain to help producers manage energy intake, thereby reducing BW gain, excessive fat deposition and over fleshing. Current feed restriction practices severely limit feed quantities available, particularly during rearing (8 - 16 wk) when the variation between *ad libitum* feed consumption and restricted feed allotment is the greatest (Hocking *et. al*., 1993). Reducing feed intake to levels needed to control BW gain increases competition between birds. Larger or aggressive pullets will out-compete smaller birds resulting in unequal access to feed, leading to increases in flock BW variation. Therefore it is essential to find a method of feed management that can reach an optimal balance between controlling growth and increasing flock uniformity.

2.1.1. Feed Management Practices

Current feed restriction practices aim to limit BW gain to meet target BW profiles and increase the distribution of the limited feed allocations ultimately increasing flock BW uniformity. Three different categories of feed practices have been studied; quantitative feed restriction, qualitative feed restriction and preemptive management.

2.1.1.1. Quantitative feed restriction

Quantitative feed restriction controls the quantity of feed available to provide only the energy necessary for maintenance, controlled growth and egg production. In the industry feed allotments are calculated using strain-specific BW target profiles provided by a primary breeder and based on the flock's current BW mean. A challenge of this type of restriction is between-bird competition (social dominance) for the limited feed resource leading to variations in flock BW based on competitive size (Costa, 1981; Petitte *et al*., 1981; Hudson *et al*., 2001). Feeding vigor may also play a role in flock BW uniformity under conditions of typical feed restriction (van Middelkoop *et al*., 2000).

Scatter feeding or spin feeding is a modified method of quantitative feed restriction that originated in Europe in an attempt to increase uniformity in flock BW. Pullets receive a daily allotment of a pelleted feed. Pellets are broadcast onto the litter by a roof-mounted feeder allowing for more uniform access to a concentrated and balanced nutrient source (Leeson and Summers, 2001). Scatter feeding improves the distribution of limited feed allocations by spreading pellets over a greater area (relative to feeder space) and increasing feed clean-up time (van Middelkoop *et al*., 2000) thereby decreasing flock variability. The pelleting process increases the proportion of small sized feed particles which leads to improved digestibility (Rogel *et al*., 1987 b). Feed in pelleted form improves BW gain, balanced feed intake, feed to gain ratio and reduces waste (Svihus et al., 2004; Amerah *et al*., 2007) which increases feed efficiency. Distributing the pellets directly onto the litter stimulates foraging behaviour leading to increased activity, decreased incidence of leg disorders as well as stereotypic object pecking (van Middelkoop *et al*., 2000; de Jong *et al*., 2005) which may improve both pullet health and welfare. Pellet durability can be a problem as diet base ingredients, particle size, handling and feed delivery systems can cause pellets to breakdown into fines (powdery texture) which could reduce the effectiveness of scatter feeding.

Skip-a-day feeding involves various combinations of feed and non-feed days. Six feed days/1 non-feed day, 5/2, 4/3 or true skip-a-day feeding where birds are fed on alternating days. Combinations of skip-a-day programs are also used. Feed allocations are based on current BW means and calculated using target BW profiles; the total weekly feed allocation is then divided by the number of feed days each week. All skip-a-day programs have increased feed-day allotments as the weekly total is divided between fewer days. By increasing the quantity on feed days, there is a corresponding increase in the distribution of feed to a greater number of birds which is expected to increase flock BW uniformity. Feed /non-feed cycles can alter metabolic processes, in particular hepatic lipogenesis (de Beer *et al*., 2007; Richards *et al*., 2003). The additional energy available on feed days supports glucose dependent lipogenesis resulting in excess triglycerides which are deposited in adipose tissue (Richards *et al*., 2003). On non-feed days, glucose from the liver initially maintains blood glucose levels, once this source is depleted; glucose is supplied through gluconeogensis (de Beer *et al*., 2007). Gluconeogenesis breaks down amino acids (protein) which will alter carcass composition producing pullets with increased fat deposition and decreased muscle mass as well as decreasing the efficiency of energy utilization.

2.1.1.2. Qualitative Feed Restriction

Qualitative feed restriction diets are diluted with a non-nutritive ingredient (i.e. oat hulls, wheat bran or sugar beet pulp) adding volume to the diet without increasing nutrient density. Feed allocations can be restricted (increased feed volume relative to standard feed restriction programs) or *ad libitum* depending on the diet density. Qualitative feed restriction increases the distribution of feed throughout the flock by increasing feed volume which is expected to increase flock BW uniformity. Competition is outweighed by feed volume as large or aggressive pullets can eat to gut capacity before all the feed is consumed, consequently small, less aggressive pullets have access to feed. Diluent dependent benefits have been observed in previous studies. Oat hulls improve diet digestibility by increasing starch digestibility in wheat based diets (Rogel *et al*., 1987a; Hetland et al., 2003), assisting in physical disruption of starch granules in the gizzard (Rogel *et al*., 1987 b) or altering gut microflora with antibacterial and antifungal properties (Buttner and Muhler, 1959; Stookey and McDonald, 1980). Diets may be too nutritionally dilute causing pullets to remain metabolically hungry even though gut capacity has been reached (Savory *et al*., 1996; Savory and Lariviere, 2000). If the proportion of diluent is excessive, the pullets cannot consume sufficient quantities to meet their needs, and the potential exists for some nutrients to be in limited supply (Kyrlazakis and Emmans, 1995) leading to deficiencies or reduced flock uniformity.

Diet dilution is accomplished by formulating to include a bulky ingredient or added dietary fibre to increase the volume without increasing the nutrient density. Dilute or reduced quality diets are fed *ad libitum* (Savory *et al*., 1996; Tolkamp, 2005) or feed can be controlled (Zuidhof *et al*., 1995; deJong *et al*., 2005) quantitatively as well. Increased feed volume results in an extended feed cleanup time allowing pullets to consume a daily allotment closer to *ad libitum* feeding without the detrimental effects of over feeding.

2.1.1.3. Preemptive Management

Bird sorting, grouping or grading can be implemented to improve BW uniformity and to more closely match feed intake to actual energy requirements. Three BW groups or grades are generally used: light (birds below target BW), medium (birds at target BW) and heavy (birds above target BW). BB pullets receive daily restricted feed allocations based on group BW means and calculated using strain-specific target BW profiles. By using group-targeted feed allotments, energy provided will be a closer match to actual requirements of a greater proportion of birds. A better distribution of feed is expected as small pullets will receive increased feed quantities while large pullets will receive decreased feed quantities (to allow birds to grow to meet BW targets) as well as minimizing the effects of competition within like-sized groups. Pullets can be periodically (generally 2 or 3 times) resorted into weight specific groups during rearing. The greater the BW variability, the more often pullets are resorted. Bird sorting is labour intensive therefore this practice is generally cost prohibitive in regions where labour costs are high. Facility constraints may also be a limiting factor to implementing bird sorting during rearing. Pullet flock BW uniformity will be increased through group-targeted feed allocations and a better distribution of limited energy resources.

2.1.2. Uniformity

Flock uniformity is essential to BB reproductive efficiency. The innate capacity for rapid growth and requisite feed restriction can increase flock variability. Current methods used by the industry to represent flock BW uniformity are “variation from the mean” and coefficient of variation.

Variation from the mean provides an estimate of the portion of the population which has a BW within a predetermined range; conventionally within ± 10% or ± 15% of the population BW mean. This method provides a numerical value for the proportion of the flock within ±10% or 15% of the mean, with the notion the greater the percent of the population within the range, the greater the uniformity. However this method does not reveal how widely the population is dispersed (standard deviation). The variation from the mean is calculated:

$$\mu - a < \text{Range} > \mu + a = n$$

$$(n/t)*100 = \text{percent of population}$$

Where μ = population BW mean, a = μ*(.10 or .15) to determine upper and lower range limits, n = number of birds within the functional BW range, t = total number of birds weighed.

The coefficient of variation (CV) is the standard deviation expressed as a percent of the mean, where the lower the CV for BW the higher the BW uniformity. In any given population with a normal distribution, 68.2% of the population will reside within 1 standard deviation (δ) of the population mean (μ).

The standard deviation indicates how widely dispersed the BW of the population are, where a large standard deviation indicates a greater spread of BW, a 'flatter' bell curve and lower BW uniformity. Outliers will bias the CV indicating higher variability than may actually exist; a population BW frequency distribution histogram will reveal any extremes allowing for analysis of any unusual measurements to determine their validity (Figure 2-2). The CV is calculated:

$$CV = (\delta / \mu)*100$$

Where δ = standard deviation, μ = population BW mean.

The CV allows for comparisons of a specific variable at different ages and between different treatments as 68.2% of the population always falls within one standard deviation of the mean.

2.2. Objectives

This study examined the effect of 5 rearing feed management practices on pullet BW and carcass trait uniformity at 22 wk of age. Qualitative, quantitative and pre-emptive bird management feed practices were studied: standard feed restriction, fibre dilute, scatter, skip-a-day and sorting.

The overall objective of this study was to increase the uniformity of 22 wk pullet broiler breeder BW and carcass traits by providing a better distribution of feed through alternative feed management practices. The specific objectives were to manage pullets to meet target BW profiles, increase flock BW uniformity and finally increase pullet BW and carcass trait uniformity at 22 wk of age.

2.3. Materials and Methods

2.3.1. Experimental Design

This experiment was the first phase of a research project studying the effects of maternal feed management practices and nutrition on the uniformity of female breeder flock BW and carcass traits, as well as of the production parameters of egg and chick quality, broiler BW and carcass traits. This experiment was a randomized complete block design with 5 tmts and was used to examine the effects of feed management practices on pullet flock variability from 3 to 22 wk of age. Prior to implementing the experimental tmts (0 to 3 wk of age), chicks were reared following Aviagen's (2007) Ross 308 management guidelines. The 5 feed tmts studied were fibre dilute, scatter, skip-a-day, sorting and control with pullets in all tmts managed to meet Ross 308 target BW profiles (Aviagen, 2007). A group of 3 pens was the experimental unit to correspond to the three BW categories (Low, Standard and High) of the sorting tmt (Figure 2-1). Sorting tmt pullets remained within the original experimental unit during resorting. At 21 d of age, 1,200 TP16 pullets were randomly assigned to one of the 5 feed tmts and randomly distributed among 6 pens/tmt (40 pullets/pen; 5.8 birds/m^2) with an initial pen BW coefficient of variation (CV) of 9.9%. Pullets in the sorting tmt were then evenly resorted among the 3 BW category pens within each experimental unit.

A wheat and corn-based mash diet was used as the base diet for all tmts (2,865 kcal; 15% CP; 0.74% lys). Daily feed allocations were based on pen BW means and calculated using the Ross 308 target BW profiles. The control tmt pens received the base mash diet and were fed daily in pan feeders. Fibre dilute tmt had a reformulated base diet containing 25% oat hulls (2,200 kcal; 11.4% CP; 0.56% lys) and were fed daily in pan feeders. The scatter tmt had the base diet in pellet form using a non-nutritive binder (Pelstik, Tembec, Quebec), fed daily by hand, scattering pellets directly on the litter. Skip-a-day tmt pens were fed on alternating days in pan feeders; feed-day allotments were calculated following the same method as the other tmts followed by dividing the total weekly feed allocation among feed days. The sorting tmt pens were fed the base diet daily in pan feeders. Sorting pullets were evenly redistributed among 3 pens (within 1 experimental unit; Figure 2-1) into 3 BW categories every 4 wk (7, 11, 15, 19 and 22 wk of age) following individual external body measurements (BW, shank length and chest width). The sorting tmt BW categories were High (BW above target), Standard (BW at or close to target) and Low (BW below target).

2.3.2. Stocks and Management

A total of 1,365 Aviagen TP16 (Aviagen Inc., Huntsville, AL) 1 day (d) old female chicks were placed in 7 floor pens with 195 birds per pen (15.6 chicks/m^2) in a light-tight facility and raised according to Ross 308 guidelines to 21 d of age. All chicks had *ad libitum* access to feed and water from 0 to 21 d of age. At 21 d, 1,200 pullets were individually identified using barcoded neck tags (Heartland Tag LLC, Fair Play, MO 65649), weighed, shank length and chest width measures recorded. Pullets were randomly assigned to 1 of 30 pens in a light-tight facility. The photoperiod was 8L:16D from 3 to 22 wk of age. Feed restriction began at 21 d, water was provided *ad libitum* throughout the experiment.

This research project was carried out in compliance with the *Guide to the Care and Use of Experimental Animals* (Canadian Council on Animal Care, 1984) and was approved by a Faculty Policy and Welfare Committee.

2.3.3. Data Collection

Pen group BWs were taken at 5 wk of age and every week thereafter. Individual BW and external body measurements of shank length and chest width were taken every 4 wk (7, 11, 15, 19 and 22 wk of age) on all 1,200 pullets. Individual BW were measured with using a Weltech hanging scale (Model BW-2050, Weltech Agri Data, USA). Shank length was measured using Absolute digital calipers

(Model CD-8”C, Mitutoyo, Japan) and was determined by measuring the *tibiotarsus* from the top of the flexed hock joint to the bottom of the foot pad. Chest width measures using Absolute digital calipers (Model CD-8”C, Mitutoyo, Japan) were taken 2.5 cm below clavicle bones at the widest point on the chest.

The coefficient of variation was used as the measure for flock uniformity. The CV is the standard deviation expressed as a percent of the mean therefore indicates how widely dispersed a particular variable is within a specified population. Standardizing the measure, as 68.2% of a normally distributed population falls within one standard deviation of the mean allows for comparisons of uniformity (CV) between different aged flocks.

At 22 wk of age, 450 pullets were humanely euthanized and dissected with *Pectoralis major*, *Pectoralis minor*, fat pad, liver, oviduct and ovary weights recorded. The remaining 750 pullets were retained for the sexual maturity and reproduction phases of the premix treatment experiment (Chapter 3).

2.3.4. Statistical Analysis

A randomized complete block design was used to evaluate the effects of 5 feed tmts on pullet flock variability. The experimental unit was a group of 3 pens. A block consists of 5 experimental units where one experimental unit representing each of the feed tmts (group of 3 pens x 5 feed tmts). Treatment effects on repeated measures were evaluated as a 3-way analysis of variance using the Mixed procedure in SAS 9.2© (SAS Institute Inc., Cary, NC). Significance was assessed at $P<0.05$ for all analyses. External body measures of shank length and chest width were also analyzed with the operator as a random effect using the Mixed procedure in SAS©. Pair-wise comparisons were used to determine differences between least squares means. A 3-way analysis statistical model used:

$$y_{ijkl} = \mu + f_i + b_j + a_k + f_ib_j + f_ia_k + b_ja_k + f_ib_ja_k + \varepsilon_{ijkl} \qquad \text{Eq. 2-1}$$

Where y_{ijkl} = dependent variable for the l^{th} pullet, μ = overall mean, f_i = the i^{th} feed tmt effect, g_j = the j^{th} block (group of 3 pens/feed tmt x 5 feed tmts) effect, a_k = the k^{th} age effect, f_ib_j = the interaction effect between feed tmt and block, f_ia_k = the interaction between feed tmt and age, b_ja_k = the interaction effect between block and age, $f_ib_ja_k$ = the interaction between feed tmt, block and age, ε_{ijkl} = the residual error.

Carcass traits at 22 wk were evaluated as a 2-way analysis of variance using the Mixed procedure of SAS 9.2© (SAS Institute Inc., Cary, NC), significance was determined at $P<0.05$. Pearson's correlation (proc Corr, SAS Institute Inc., Cary, NC) was used to examine the relationships between carcass traits. The model used for 2-way analysis of variance of carcass traits:

$$y_{ijk} = \mu + f_i + b_j + f_ib_j + \varepsilon_{ijk} \qquad \text{Eq. 2-2}$$

Where y_{ijk} = dependent variable for the k^{th} pullet, μ = overall mean, f_i = the i^{th} feed tmt effect, b_j = the j^{th} block (group of 3 pens/feed tmt x 5 feed tmts) effect, f_ib_j = the interaction effect between feed tmt and block, ε_{ijk} = the residual error.

Covariate analysis (3 and 22 wk BW) was done using the Mixed procedure of SAS 9.2© (SAS Institute Inc., Cary, NC), to determine the portion of error due to

3 wk BW, 22 wk BW and significance of feed tmt effect on pullet carcass traits at 22 wk of age. The analysis was run with 3 wk BW as the covariate and then with 22 wk BW as the covariate. The model used:

$$y_{ijk} = \mu + f_i + b_j + f_i b_j + \beta(BW_{ijk} - BW_a) + \varepsilon_{ijk} \qquad \text{Eq. 2-3}$$

Where y_{ijk} = dependent variable for the kth pullet, μ = overall mean, f_i = the ith feed tmt effect, g_j = the jth block (group of 3 pens/feed tmt x 5 feed tmts) effect, $f_i b_j$ = the interaction effect between feed tmt and block, $\beta(BW_{ijklm} - BW_a)$ = the covariate coefficient multiplied by the difference in BW of kth bird and average (either 3 wk BW or 22 wk BW) BW_a, ε_{ijk} = the residual error.

Coefficients of variation (CV) are presented as measures of variability. Variability differences were determined using the Mixed procedure of SAS 9.2© (SAS Institute Inc., Cary, NC). The statistical model used:

$$y_{ijk} = \mu + f_i + b_j + f_i b_j + \varepsilon_{ijk} \qquad \text{Eq. 2-4}$$

Where y_{ijk} = coefficient of variation (CV) for the kth pen, μ = overall CV mean, f_i = the ith feed tmt effect, b_j = the jth block (group of 3 pens/feed tmt x 5 feed tmts) effect, $f_i b_j$ = the interaction effect between feed tmt and block, ε_{ijk} = the residual error.

2.4. Results and Discussion

2.4.1. Feed Consumption and Growth.

Primary breeder BW target profiles were achieved during the growth phase (3 to 22 wk) in all 5 feed tmts. Treatment BW means at 22 wk of age were not significantly different at P=0.39 (Table 2-7). A significant tmt effect on feed consumption was observed (Table 2-3; P<0.0001). Pullets were managed to meet BW target profiles therefore it was expected the fibre dilute tmt (25% oat hulls; ME = 2,200 kcal/kg; 11.4% CP) would have higher feed intake relative to the other tmts (ME = 2,685 kcal/kg; 15.0% CP) (Table 2-4). The fibre dilute pullets consumed 24.4% more feed (11.1 kg/bird) compared to the control tmt (8.92 kg/bird) (Table 2-4) which follows expectations considering the diet contained 25% oat hulls as a diluents. Diet dilution in this group resulted in a total mean energy intake of 24,334 kcal/bird which was 5.1% below that of control birds (25,569 kcal/bird) (Table 2-5). Scatter tmt had the lowest feed intake (8.76 kg/bird) while skip-a-day tmt (9.18 kcal/bird) had the highest feed intake relative to the other tmts (control, 8.92 kg/bird; sorting, 8.96 kg/bird) (Table 2-4). Energy conversion (kcal/kg gain) showed fibre dilute tmt to have the lowest energy conversion ratio (12127kcal/kg gain), skip-a-day the highest (14384 kcal/kg gain) with control (12919 kcal/kg gain), scatter (12930 kcal/kg gain) and sorting (12985 kcal/kg gain) tmts having similar ratios.

Crude protein conversion (CP:gain) followed energetic conversion ratios with fibre dilute having the lowest ratio and skip-a-day having the highest (Table 2-5). Feed conversion ratios (FCR) reflected the increased volume of feed consumption by the fibre dilute pullets, however FCR did not accurately express actual energy intake as the diet was reformulated resulting in lower ME and CP content relative to the other tmts (2200 kcal/kg, CP = 11.4%; 2865 kcal/kg, CP = 15% respectively). As this study was designed to maintain BW target profiles, compensatory feed intake was expected to increase the total volume of feed required in the fibre dilute tmt. Density intake (kcal/bird) and energetic conversion (kcal/kg gain) were used in this study to denote actual feed tmt effects.

A significant treatment effect on carcass composition was observed as skip-a-day pullets had significantly lower weight *Pectoralis major* (392 g) and *Pectoralis minor* (121.5 g) and heavier liver weights (59.9 g) compared to all other tmts. Scatter tmt pullets were found to have the lightest fat pad (24.5g) and liver weights (48.0 g) (Table 2-8). Protein accretion (*P. major* and *P. minor)* and fat deposition did not differ between control, fibre dilute and sorting tmts.

Birds in the different feed management groups were found to have differing total energy intake even though target BW profiles were maintained in all tmts. Fibre dilute birds had the highest intake based on volume, however the lowest overall energy intake (24,618 kcal/bird) compared to scatter (25,355 kcal/bird), sorting (25,699 kcal/bird), control (25,871 kcal/bird) and skip-a-day (26,415 kcal/bird) tmts (Table 2-5). Energy consumption and energetic conversion did not differ between control and sorting tmts with similar utilization of energy resources. Fibre dilute pullets were able to maintain target BW with an energy dilute diet in restricted quantities supporting the Savory *et al*. (1996) finding that energy dilute diets fed *ad libitum* were not sufficient to limit growth. In the current study, fibre dilute pullets had the significantly lower energetic conversion rate, requiring only 12,127 kcal/kg gain compared to control pullets (12,919 kcal/kg). These results agree with Zuidhof *et al.* (1995) who observed improved feed conversion efficiency with the use of 15% dietary oat hulls. Rogel *et al*. (1987 a) and Mollah and Annison (1981) suggested that the inclusion of oat hulls improved starch granule digestibility in wheat based diets. The oat hull fibre is retained in the gizzard which assists in the physical breakdown of starch particles thereby increasing the digestibility of diet ingredients (Rogel *et al*., 1987 b).

The antibacterial and antifungal properties of oat hulls (Buttner and Muhler, 1959; Madsen and Edmonds, 1962) may improve the gut microflora (Rogel *et al*., 1987 a) leading to increased feed efficiency. Zuidhof *et al*. (1995) suggested that the energy content of oat hulls has been underestimated in agreement with Savory *et. al*. (1996) who assigned oat hulls a ME of 406 kcal/kg and CP content of 46g/kg. Calculating expected additional gain/bird using the ME value of 406 kcal/kg and the feed consumption found in the fibre dilute tmt indicates pullets consuming a diet containing 25% oat hulls would gain an additional 90g.

Pellets used in the scatter tmt provided a balanced nutrient and condensed energy feed source (Leeson and Summers, 2001) as indicated by the lower total feed and energy intake relative to the other tmts. The pelleting process increases the proportion of small sized particles which may lead to improved digestibility (Rogel *et al*., 1987 b). Svihus *et al*. (2004) suggests a pelleted diet improves feed to gain ratio. However, in the current study, the FCR and energetic conversion (energy to gain) was not significantly different from the control (Table 2-4 and

Table 2-5). The increased feeding activity (foraging for pellets) may have accounted for some loss in efficiency as a greater proportion of the restricted energy intake (relative to the other tmts) would be partitioned toward feeding activity by the scatter tmt pullets. The reduction in feed consumption may be related to a decrease in feed waste (Amerah et. al., 2007) which may decrease overall production costs related to feed, but does not effect within bird energy efficiency. The scatter tmt effect of reduced waste may be eliminated if the proportion of fines increases however pelleted feed was processed on-site and cast onto the litter by hand minimizing the effect of feed delivery on pellet integrity.

Covariate analysis which removed the portion of variation due to 22 wk BW, indicated a significant effect of BW as well as feed tmt on 22 wk carcass traits and is the preferred method of analysis to evaluate the tmt effects on the dependent variables studied (Table 2-10).

Covariate analysis (22 wk BW) found fibre dilute, control and sorting tmts were not significantly different in any of the carcass trait measurements analyzed with the exception of liver weights where control and sorting tmt pullet liver weights were heavier (Table 2-10). Scatter tmt pullets had the lowest liver and fatpad weights however *P. major* and *P. minor* weights were not significantly different from the control suggesting pullets were able to efficiently utilize the nutrients provided decreasing lipid deposition while maintaining desired protein accretion and BW.

Skip-a-day pullets exhibited increased liver weights with decreased breast muscle mass (*P. major* and *P. minor*) (Table 2-10). Fat pad weights were numerically higher but not significantly different from the control, fibre dilute or sorting tmts. This study supports Richards *et al*. (2003) and de Beer *et al*. (2007) findings that skip-a-day feeding alters metabolic processes in pullets; where the cycle of depositing excess energy in the form of triglycerides (lipogenesis) into adipose tissue on feed days and the breakdown of muscle through gluconeogenesis to produce glucose on non-feed days resulting in increased fat pad weights and decreased breast muscle mass.

Acquiring sufficient concentrations of specific nutrients (nutrient/per gram of feed) might be difficult in a low density diet, which might ultimately interfere with some metabolic processes, this study indicated that pullets were able to meet their metabolic needs with the energy dilute diet as target BW profiles were maintained throughout the experiment. Pellet quality was not compromised; pellets were cast onto the litter by hand which might have reduced the effects of feed delivery normally found in commercial production.

Feed (Table 2-3) and energy intake, energy conversion ratio (Table 2-5), carcass composition and flock uniformity were found to vary within, and between feed tmts. Pullets in the fibre dilute tmt had the lowest energy intake and lowest energy conversion ratio, however flock BW uniformity was not improved relative to control tmt. Diet dilution with the addition of 25% oat hulls may not have been sufficient to increase the distribution of nutrients throughout the fibre dilute tmt pens which resulted in no increased flock BW uniformity (relative to the control tmt). Decreased energy intake and energy conversion ratio may be the result of the intrinsic properties of oat hulls rather than the increased volume of feed.

Scatter tmt pullets had the lowest feed volume intake but did not show similar improvements in energy conversion ratio. Increased foraging behaviour required to locate feed pellets on the litter resulted in a similar energy conversion ratio to the control tmt. The nutrients provided were partitioned to maintenance, growth and increased foraging activity resulting in decreased fat pad weights relative to the other treatments. The energy to BW gain ratio did not differ from the control, however flock BW uniformity was higher in the scatter tmt (CV = 15.3% vs. CV = 10.9%) suggesting scattering a concentrated feed source directly onto the litter increases the distribution of feed to all pullets the pen thereby increasing flock BW uniformity.

The skip-a-day tmt was found to be the least efficient feed management strategy (Table 2-5). High energy intake, low BW gain and altered carcass composition (low breast muscle and high fat pad weights) may outweigh the improvement in BW uniformity at 22 wk of age (control CV = 15.3%; skip-a-day CV = 12.7%). The sorting tmt had the highest flock BW and carcass trait uniformity with energetic conversion rates similar to the control and scatter tmts (12985 kcal/kg, 12919 kcal/kg and 12930 kcal/kg respectively). Therefore the sorting treatment pullets did not require additional nutrient resources to increase BW and carcass trait uniformity.

2.4.2. Uniformity

Significant differences in pullet BW uniformity were found from 7 to 22 wk of age. Industry uses 'variation from the mean' and CV as measures for uniformity, for this research study the CV was used as an indicator of uniformity as it allows for analysis of variables with repeated measures. Initial treatment coefficients of variation (CV) at 3 wk of age were uniform across all tmts and pens at 9.9%/pen (Figure 2-3). Treatment differences were observed beginning at 7 wk (Table 2-6; Figure 2-3). The sorting tmt resulted in the highest flock BW uniformity at 22 wk of age with a CV = 6.17 % compared to control (CV = 15.3%), fibre dilute (CV = 15.2%), scatter (CV = 10.9%) and skip-a-day (CV = 12.7%). BW frequency distribution histogram indicated no outliers (Figure 2-2) in any of the tmts and is a good visual representation of the flock uniformity indicated by CV.

Broiler breeder flock BW uniformity can be improved using sorting, scatter or skip-a-day management practices as indicated by the 22 wk measures of uniformity (CV and variation from the population BW mean; Table 2-7). Flock uniformity in fibre dilute or control tmts were not significantly different (Table 2-6) throughout rearing with the fibre dilute CV of 15.2% similar to that found by Savory *et al*. (1996) of 16%.

BB pullets can be managed to maintain target BW profiles using quantitative, qualitative or preemptive management practices. Feed management strategies which showed the greatest combined improvements in BW flock uniformity and carcass composition were sorting and scatter treatments.

2.5. References

Amerah, A. M., V. Ravindran, R. G. Lentle, and D. G. Thomas. 2007. Influence of feed particle size and feed form on the performance, energy utilization, digestive tract development, and digesta parameters of broiler starters. Poult. Sci., 86:2615-2623.

Aviagen. 2007. Ross 308 PS performance objectives. Aviagen Incorporated, USA.http://67.20.64.230/ss/assets/Tech_Center/Ross_PS/Ross_308_PS_Performance_Objectives.pdf. Accessed September, 2009.

Barbato, G. F., P. B. Siegel, J. A. Cherry, and I. Nir. 1984. Selection for body-weight at 8 weeks of age. 17. Overfeeding. Poult. Sci. 63:11-18.

Bokkers, E. A., and P. Koene. 2003. Eating behaviour, and preprandial and postprandial correlations in male broiler and layer chickens. Br. Poult. Sci. 44:538-544.

Buttner, W., and J. C. Muhler. 1959. The effect of oat hulls on the dental caries experience in rats. J. Dent. Res. 38:823.

Buyse, J., H. Michels, J. Vloeberghs, P. Saevels, J. M. Aerts, B. Ducro, D. Berckmans, and E. Decuypere. 1998. Energy and protein metabolism between 3 and 6 weeks of age of male broiler chickens selected for growth rate or for improved feed efficiency. Br. Poult. Sci. 39:264-272.

Canadian Council on Animal Care. 1984. Guide to the Care and Use of Experimental Animals. Vol. 2. Can. Counc. Anim. Care, Ottawa, Ontario, Canada.

Costa, M. S. 1981. Fundamental principles of broiler breeders nutrition and the design of feeding programmes. World’s Poult. Sci. J. 37:177-192.

de Beer, M., R. W. Rosebrough, B. A. Russell, S. M. Poch, M. P. Richards, and C. N. Coon. 2007. An examination of the role of feeding regimens in regulating metabolism during the broiler breeder grower period. 1. Hepatic lipid metabolism. Poult. Sci. 86:1726-1738.

de Jong, I. C., M. Fillerup, and H. J. Blokhuis. 2005. Effect of scattered feeding and feeding twice a day during rearing on indicators of hunger and frustration in broiler breeders. Appl. Anim. Behaviour Sci. 92:61-76.

Denbow, D. M. 1999. Food intake regulation in birds. J. Exp. Zool. 283:333-338.

Etches, R. J. 1996. Reproduction in Poultry. CAB International, Wallingford, Oxon. UK.

Havenstein, G. B., P. R. Ferket, S. E. Scheideler, and B. T. Larson. 1994. Growth, livability, and feed conversion of 1991 vs. 1957 broilers when fed “typical” 1957 and 1991 broiler diets. Poult. Sci. 73:1785-1794.

Hetland, H., B. Svihus, and A. Krogdahl. 2003. Effects of oat hulls and wood shavings on digestion in broilers and layers fed diets based on whole or ground wheat. Br. Poult. Sci. 44:275-282.

Hocking, P. M., M. H. Maxwell, and M. A. Mitchell. 1993. Welfare assessment of broiler breeder and layer females subjected to food and water restriction during rearing. Br. Poult. Sci. 34:443-458.

Hocking, P. M. 1996. The role of body weight and food intake after photostimulation on ovarian function at first egg in broiler breeder females. Br. Poult. Sci. 37:841-851.

Hudson, B. P., R. J. Lien, and J. B. Hess. 2001. Effects of body weight uniformity and pre-peak feeding programs on broiler breeder hen performance. J. Appl. Poult. Res. 10:24-32.

Jaap, R. G., and F. V. Muir. 1967. Erratic oviposition and egg defects in broiler-type pullets. Poult. Sci. 47:417-423.

Katanbaf, M. N., E. A. Dunnington, and P. B. Siegel. 1989. Restricted feeding in early and late-feathering chickens 1: growth and physiological responses. Poult. Sci. 68:344-351.

Kyriazakis, I., and G. C. Emmans. 1995. The voluntary feed intake of pigs given feeds based on wheat, bran, dried citrus pulp and grass meal, in relation to measurements of feed bulk. Br. J. Nutr. 73:191-207.

Leeson, S., and J. D. Summers. Energy. 2001. Pages 35-99 in: Nutrition of the Chicken. 4th Ed. University Books. Guelph, ON.

Madsen, K. O., and E. J. Edmonds. 1962. Effect of rice hulls and other seed hulls on dental caries production in the cotton rat. J. Dent. Res. 41:405-412.

Maloney, M. A., J. C. Gilbreath, J. F. Tierce, and R. D. Morrison. 1967. Divergent selection for twelve-week body weight in the domestic fowl. Poult. Sci. 46:1116-1127.

Petitte, J. N., R. O. Hawes, and R. W. Gerry. 1981. Control of flock uniformity of broiler breeders through segregation according to body weight. Poult. Sci. 60:2395-2400.

Pollock, D. L. 1999. A geneticist's perspective from within a broiler primary breeder company. Poult. Sci. 78:414-418.

Renema, R. A., F. E. Robinson, J. A. Proudman, M. Newcombe, and R. I. McKay. 1999. Effects of body weight and feed allocation during sexual maturation in broiler breeder hens. 2. Ovarian morphology and plasma hormone profiles. Poult. Sci. 78:629-639.

Richards, M. P. 2003. Genetic regulation of feed intake and energy balance in poultry. Poult. Sci. 82:907-916.

Richards, M. P. 2007. Mechanisms regulating feed intake, energy expenditure, and body weight in poultry. Poult. Sci. 86:1478-1490.

Robinson, F. E., and N. A. Robinson. 1991. Reproductive performance, growth rate and body composition of broiler breeder hens differing in body weight at 21 weeks of age. Can. J. Anim. Sci. 71:1233-1239.

Robinson, F. E., N. A. Robinson, and R. T. Hardin. 1995. The effects of 20-week body weight and feed allocation during early lay on female broiler breeders. J. Appl. Poult. Res. 4:203-210.

Robinson, F. E., R. A. Renema, L. Bouvier, J. J. R. Feddes, J. L. Wilson, M. Newcombe, and R. I. McKay. 1998. Effects of photostimulatory lighting and feed allocation in female broiler breeders 1. reproductive development. Can. J. An. Sci. 78:603-63.

Robinson, F. E., R. A. Renema, L. Bouvier, J. J. R. Feddes, M. J. Zuidhof, J. L. Wilson, M. Newcombe, and R. I. McKay. 1998. Effects of photostimulatory lighting and feed allocation in female broiler breeders 2. Egg and chick production characteristics. Can. J. An. Sci. 78:615-623.

Rogel, A. M., D. Balnave, W. L. Bryden, and E. F. Annison. 1987. Improvement of raw potato starch digestion in chickens by feeding oat hulls and other fibrous feedstuffs. Aust. J. Agric. Res. 38:629-637.

Rogel, A. M., E. F. Annison, W. L. Bryden, and D. Balnave. 1987. The digestion of wheat starch in broiler chickens. Aust. J. Agric. Res. 38:639-649.

Savory, C. J., P. M. Hocking, J. S. Mann, and M. H. Maxwell. 1996. Is broiler breeder welfare improved by using qualitative rather than quantitative food restriction to limit growth rate? Anim. Welf. 5:105-127.

Savory, C. J., and J. M. Lariviere. 2000. Effects of qualitative and quantitative food restriction treatments on feeding and motivational state and general activity level of growing broiler breeders. Appl. Anim. Behaviour Sci. 69:135-147.

Siegel, P. B., and E. A. Dunnington. 1985. Reproductive complications associated with selection for broiler growth. Pages 59-72 in: Poultry Genetics and Breeding. Hill, W. G., J. H. Manson, and D. Hewitt (Ed.), Longman, Harlow, UK.

Stookey, G. K., and J. L. McDonald, Jr. 1980. Influence of combinations of oat hulls and sodium trimetaphosphate upon dental caries in the rat. J. Dent. Res. 59:838.

Svihus, B., K. H. Klovstad, V. Perez, O. Zimonja, S. Sahlstrom, R. B. Schuller, W. K. Jeksrud, and E. Prestlokken. 2004. Physical and nutritional effects of pelleting of broiler chicken diets made from wheat ground to different coarsenesses by the use of roller mill and hammer mill. An. Feed Sci and Tech. 117:281-293.

Tolkamp, B. J., V. Sandilands, and I. Kyriazakis. 2005. Effects of qualitative feed restriction during rearing on performance of broiler breeders during rearing and lay. Poult. Sci. 84:1286-1293.

van Middelkoop, J. H., J. W. Van der Haar, F. E. Robinson, C. A. Luzi, and M. J. Zuidhof. 2000. The application of scatter feeding in managing feed restriction during the rearing of broiler breeders. In: Proceedings of the 21st World's Poultry Congress, Montreal.

Whitehead, C. C. 2000. Nutrition: The integrative science. Br. Poult. Sci. 41:5-15.

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

Yu, M.W., F.E. Robinson, and R. J. Etches. 1992b. Effect of feed allowance during rearing and breeding on female broiler breeders. 3. Ovarian steroidogenesis. Poult. Sci. 71:1762-1767.

Zuidhof, M.J., F. E. Robinson, J. J. R. Feddes, R. T. Hardin, J. L. Wilson, R. I. McKay, and M. Newcombe. 1995. The effects of nutrient dilution on the well-being and performance of female broiler breeders. Poult. Sci. 74:441-456.

Table 2-1. Composition and analysis of broiler breeder pullet diets

Ingredient and analysis	Starter (0 to 3 wk)	Grower (3 to 22 wk)	GrowerOH[1] (3 to 22 wk)
	------------------------ g/kg ------------------------		
Ground corn	150.0	334.5	193.8
Wheat	394.1	350.0	250.0
Oat hulls	--	--	250.0
Soybean meal (47.8% CP)	175.9	66.6	45.0
Oats	150.0	61.9	135.5
Canola meal	50.0	80.0	30.4
Canola oil	23.8	10.0	10.0
Wheat bran	--	50.0	50.0
Ground limestone	15.8	15.15	11.3
Dicalcium phosphate	19.8	15.0	10.7
Choline chloride premix[2]	5.0	5.0	3.75
Premix[3]	5.0	5.0	3.75
Salt	4.54	4.0	2.6
D, L-methionine	2.07	0.9	1.0
L-lysine	3.55	1.2	1.1
L-threonine	--	0.25	0.7
Avizyme	0.5	0.5	0.4
Total:	1,000.0	1,000.0	1,000.0
Calculated nutrient composition			
CP (%)	19.0	15.0	11.4
ME (kcal/kg)	2,900	2,865	2,200
Calcium (%)	1.10	1.00	0.75
Available phosphorus (%)	0.50	0.45	0.34
Lysine (%)	1.18	0.74	0.56
Methionine (%)	0.52	0.34	0.27

[1]Diet diluted with 25% oat hulls and balanced for CP, Kcal and EAA
[2]Provided choline chloride in the diet at a level of 100 mg/kg.
[3]Premix provided per kilogram of diet: vitamin A (retinyl acetate), 10,000 IU; cholecalciferol, 4,000 IU; vitamin E (DL-α-tocopheryl acetate), 50.0 IU; vitamin K, 4.00 mg; pantothenic acid, 15.0 mg; riboflavin, 10.0 mg; folacin, 2.00 mg; niacin, 65.0 mg; thiamine, 4.00 mg; pyridoxine, 5.00 mg; vitamin B12, 0.02 mg; biotin, 0.20 mg; iodine, 1.65 mg; Mn, 120 mg; Cu, 20.0 mg; Zn, 100 mg, Se, 0.30 mg; Fe, 80.0 mg.

Table 2-2. Daily feed allotments for broiler breeder pullets in 5 pullet feed management treatments[1]

	Treatment				
Age	Control	Fibre dilute	Scatter	Skip-a-day	Sorting
-- wk --	----------------------------	g/bird/d	----------------------------		
3	32.0	40.0	32.0	32.0	32.0
5	40.0	50.0	40.0	40.0	40.0
7.1	43.0	53.8	43.0	43.0	43.0
8.4	42.7	54.6	43.0	42.8	43.2
9	43.2	56.9	43.2	45.0	43.5
10	43.3	59.4	43.5	45.7	44.3
11.1	45.4	61.5	44.7	47.0	46.5
12	46.8	63.8	45.3	48.0	47.8
13	49.7	70.2	47.7	51.3	50.5
13.9	54.5	74.2	53.2	45.7	55.5
15.1	59.5	80.4	58.3	61.7	60.7
16	68.7	91.5	68.0	70.0	69.2
17	84.5	111.7	83.8	86.7	85.7
18	94.5	124.2	93.8	96.7	95.7
19	112.5	151.0	109.8	117.7	113.5
20	111.2	134.2	108.5	117.3	111.8
21	111.3	131.5	107.5	119.3	111.8
22	111.0	130.6	109.7	119.8	112.3

[1]Pullet rearing phase from 3 to 22 wk of age.

Table 2-3. Mean feed consumption and total feed consumption of broiler breeder pullets in 5 feed treatments (3 to 22 wk of age)

		Treatment[1]					
Feed Consumption	Unit	Control	Fibre dilute	Scatter	Skip-a-day	Sorting	*Pr* > F
Consumption	kg/pen	352.0[cd]	436.2[a]	340.7[d]	364.4[b]	355.7[bc]	<0.0001
Total	kg/tmt[2]	2112.2	2617.2	2044.1	2186.1	2134.3	

[1]Feed treatments: Control: standard mash diet, fed daily; Fibre dilute: mash diet (25% oat hulls), fed daily; Scatter: standard diet in pellet form scattered on litter, fed daily; Skip-a-day: standard diet double daily allotment fed on alternate days; Sorting: standard mash diet fed every day; birds resorted every 4 wk based on BW. Pen mean BW and BW targets were used to determine daily feed allotments in all treatments.
[2]Total feed consumption calculated by: Mean treatment consumption/pen x 6 (6 pens/tmt) = Total
[a-d]LS-means within a row within effect with no common superscript differ (P<0.05).

Table 2-4. The effects of 5 broiler breeder pullet feed treatments on mean feed consumption from 3 to 22 wk of age

	Treatment[1]						
	Control	Fibre dilute	Scatter	Skip-a-day	Sorting	SEM	*P* value
Feed intake (kg/bird)							
3 – 9 wk	1.58^{c}	1.72^{a}	1.59^{b}	1.58^{c}	1.58^{c}	0.003	<0.0001
9 – 15 wk	2.04^{cd}	2.76^{a}	1.99^{d}	2.12^{b}	2.09^{bc}	0.016	<0.0001
15 – 22 wk	5.31^{c}	6.58^{a}	5.17^{c}	5.49^{b}	5.31^{c}	0.045	<0.0001
Total[2]	**8.92^{c}**	**11.1^{a}**	**8.76^{d}**	**9.18^{b}**	**8.96^{c}**	**0.042**	**<0.0001**
BW gain (g)							
3 – 9 wk	452.1^{ab}	422.2^{c}	463.8^{a}	373.6^{d}	440.4^{bc}	6.32	0.001
9 – 15 wk	387.9^{bc}	432.1^{a}	392.0^{abc}	356.1^{c}	404.2^{ab}	11.5	0.04
15 – 22 wk	1140	1154	1086	1100	1134	30.8	0.55
Total[2]	**1980^{a}**	**2008^{a}**	**1942^{a}**	**1829^{b}**	**1978^{a}**	**29.1**	**0.04**
FCR (feed/gain)							
3 – 9 wk	3.49^{b}	4.08^{a}	3.43^{b}	4.23^{a}	3.59^{b}	0.06	0.0002
9 – 15 wk	5.28^{b}	6.41^{a}	5.10^{b}	5.96^{a}	5.14^{b}	0.05	0.0003
15 – 22 wk	4.66^{b}	5.71^{a}	4.77^{b}	4.99^{b}	4.71^{b}	0.14	0.004
Total[2]	**4.51^{c}**	**5.51^{a}**	**4.51^{c}**	**5.02^{b}**	**4.53^{c}**	**0.11**	**0.005**

[1]Feed treatments: Control: standard mash diet, fed daily; Fibre dilute: mash diet (25% oat hulls), fed daily; Scatter: standard diet in pellet form scattered on litter, fed daily; Skip-a-day: standard diet double daily allotment fed on alternate days; Sorting: standard mash diet fed every day; birds resorted every 4 wk based on BW. Pen BW mean and BW targets were used to determine pen daily feed allotments in all treatments.
[2]Total = 3 to 22 wk of age.
[a-d]LS-means within a row with no common superscript differ (P<0.05).

Table 2-5. The effects of 5 broiler breeder pullet feed treatments on mean energy and crude protein consumption from 3 to 22 wk of age

	Treatment[1]						
	Control	Fibre dilute	Scatter	Skip-a-day	Sorting	SEM	*P* value
Density[3] (kcal/bird)							
3 – 9 wk	4517^{b}	3784^{c}	4555^{a}	4522^{b}	4517^{b}	8.81	<0.0001
9 – 15 wk	5854^{bc}	6079^{a}	5725^{c}	6059^{a}	5954^{ab}	45.5	0.01
15 – 22 wk	15204^{b}	14473^{c}	14807^{bc}	15729^{a}	15206^{b}	125.1	0.006
Total[2]	**25569^{b}**	**24334^{d}**	**25091^{c}**	**26301^{a}**	**25676^{b}**	**114.7**	**0.0005**
CP (g)							
3 – 9 wk	237^{b}	196^{c}	239^{a}	237^{b}	237^{b}	0.5	<0.0001
9 – 15 wk	307^{bc}	315^{ab}	300^{c}	317^{a}	312^{ab}	2.0	0.02
15 – 22 wk	796^{b}	750^{c}	775^{b}	824^{a}	796^{b}	7.0	0.004
Total[2]	**1340^{b}**	**1260^{d}**	**1310^{c}**	**1380^{a}**	**1340^{b}**	**6.0**	**0.0003**
BW gain (g)							
3 – 9 wk	452.1^{ab}	422.2^{c}	463.8^{a}	373.6^{d}	440.4^{bc}	6.32	0.001
9 – 15 wk	387.9^{bc}	432.1^{a}	392.0^{abc}	356.1^{c}	404.2^{ab}	11.5	0.04
15 – 22 wk	1140	1154	1086	1100	1134	30.8	0.55
Total[2]	**1980^{a}**	**2008^{a}**	**1942^{a}**	**1829^{b}**	**1978^{a}**	**29.1**	**0.04**
CP:gain							
3 – 9 wk	0.52^{b}	0.47^{c}	0.52^{b}	0.63^{a}	0.54^{b}	0.007	0.0001
9 – 15 wk	0.79^{b}	0.73^{b}	0.77^{b}	0.89^{a}	0.77^{b}	0.02	0.02
15 – 22 wk	0.70^{ab}	0.65^{b}	0.72^{a}	0.75^{a}	0.71^{ab}	0.02	0.06
Total[2]	**0.68^{b}**	**0.63^{c}**	**0.68^{b}**	**0.75^{a}**	**0.68^{b}**	**0.009**	**0.001**
Energetic conversion (kcal/kg)							
3 – 9 wk	9995^{b}	8967^{c}	9830^{b}	12107^{a}	10275^{b}	132.8	0.0001
9 – 15 wk	15138^{b}	14094^{b}	14612^{b}	17060^{a}	14714^{b}	390.1	0.02
15 – 22 wk	13342	12564	13664	14303	13485	308.6	0.08
Total[2]	**12919^{b}**	**12127^{c}**	**12930^{b}**	**14384^{a}**	**12985^{b}**	**162.5**	**0.002**

[1]Feed treatments: Control: standard mash diet, fed daily; Fibre dilute: mash diet (25% oat hulls), fed daily; Scatter: standard diet in pellet form scattered on litter, fed daily; Skip-a-day: standard diet double daily allotment fed on alternate days; Sorting: standard mash diet fed every day; birds resorted every 4 wk based on BW. Pen BW mean and BW targets were used to determine pen daily feed allotments in all treatments.
[2]Total = 3 to 22 wk of age.
[3]Density = dietary ME * feed volume.
[a-d]LS-means within a row with no common superscript differ (P<0.05).

Table 2-6. Effects of 5 feed treatments on broiler breeder pullet flock BW coefficient of variation

	Pullet Age					
Treatment[1]	3 wk	7 wk	11 wk	15 wk	19 wk	22 wk
	------------------------------ CV (%) -----------------------------					
Control	9.88	12.2[ab]	13.7[a]	15.7[a]	16.0[a]	15.3[a]
Fibre dilute	9.89	11.4[b]	13.9[a]	15.7[a]	15.8[a]	15.2[a]
Scatter	9.95	9.8[c]	10.3[b]	11.2[b]	11.6[b]	10.9[b]
Skip-a-day	9.85	13.4[a]	14.9[a]	15.3[a]	14.7[a]	12.7[b]
Sorting	9.91	9.6[c]	8.4[c]	8.1[c]	7.8[c]	6.2[c]
SEM	0.4	0.5	0.4	0.6	0.6	0.6
Source of variation	-------------------------- Probability --------------------------					
Feed treatment	0.58	<0.0001	0.0003	0.0006	<0.0001	<0.0001

[1]Feed treatments: Control: standard mash diet, fed daily; Fibre dilute: mash diet (25% oat hulls), fed daily; Scatter: standard diet in pellet form scattered on litter, fed daily; Skip-a-day: standard diet double daily allotment fed on alternate days; Sorting: standard mash diet fed every day; birds resorted every 4 wk based on BW. Pen mean BW and BW targets were used to determine daily feed allotments in all tmts.
[a-c]LS-means within a column with no common superscript differ ($P<0.05$).

Table 2-7. Effects of 5 feed treatments on broiler breeder pullet BW variability at 22 wk of age

Measure of Variation	Treatment[1]					
	Control	Fibre dilute	Scatter	Skip-a-day	Sorting	*Pr*>F
Mean (kg)	2.53	2.55	2.52	2.50	2.50	0.39
CV (%)	15.3[a]	15.2[a]	10.9[b]	12.7[b]	6.2[c]	<.0001
±10%	53.5[c]	55.8[c]	67.8[b]	54.1[c]	91.7[a]	<.0001
±15%	68.7[c]	70.0[c]	84.2[b]	73.7[c]	96.2[a]	<.0001

[1]Feed treatments: Control: standard mash diet, fed daily; Fibre dilute: mash diet (25% oat hulls), fed daily; Scatter: standard diet in pellet form scattered on litter, fed daily; Skip-a-day: standard diet double daily allotment fed on alternate days; Sorting: standard mash diet fed every day; birds resorted every 4 wk based on BW. Pen mean BW and BW targets were used to determine daily feed allotments in all tmts.
[a-c]LS-means within a column with no common superscript differ (P<0.05).

Table 2-8. Mean broiler breeder pullet carcass traits in 5 feed treatments at 22 wk of age

Treatment[1]	BW[2]	Shank length[3]	Chest width[4]	*P. major*	*P. minor*	Fat pad	Liver	Stroma	Oviduct
	-- g --	------ mm ------		--------------------------------- g ---------------------------------					
Control	2530.2	103.8	96.6	446.9^{a}	136.1^{a}	34.1^{ab}	51.9^{b}	1.24	1.27^{ab}
Fibre dilute	2552.5	104.7	98.0	448.0^{a}	137.0^{a}	34.5^{ab}	48.8^{c}	1.16	1.79^{a}
Scatter	2520.3	104.6	95.1	440.3^{a}	135.0^{a}	24.5^{c}	48.0^{c}	1.18	1.15^{b}
Skip-a-day	2504.3	104.4	94.3	392.0^{b}	121.5^{b}	36.7^{a}	59.9^{a}	0.99	0.76^{b}
Sorting	2499.6	104.4	97.6	441.8^{a}	135.8^{a}	30.7^{b}	50.9^{b}	1.13	1.22^{ab}
SEM	18.9	0.6	1.5	7.1	1.9	1.8	0.7	0.6	0.2
Source of variation		-- Probability --							
Feed treatment	0.39	0.85	0.34	<0.0001	<0.0001	0.0006	<0.0001	0.07	0.02

[1]Feed treatments: Control: standard mash diet, fed daily; Fibre dilute: mash diet (25% oat hulls), fed daily; Scatter: standard diet in pellet form scattered on litter, fed daily; Skip-a-day: standard diet double daily allotment fed on alternate days; Sorting: standard mash diet fed every day; birds resorted every 4 wk based on BW. Pen mean BW and BW targets were used to determine daily feed allotments in all treatments.
[2]BW taken prior to processing.
[3]Shank length = *tibiotarsus* measured from top of flexed hock joint to bottom of footpad.
[4]Chest width = measured 2.5 cm below clavicle bones at widest point on the chest.
[a-c]LS-means within a column with no common superscript differ ($P<0.05$).

Table 2-9. Effects of 5 feed treatments on broiler breeder pullet carcass trait variability (CV) at 22 wk

Treatment[1]	BW[2]	Shank length[3]	Chest width[4]	*P. major*	*P. minor*	Fat pad	Liver	Stroma
	CV (%)							
Control	15.3[a]	3.67	9.36[a]	20.2[a]	18.4[a]	68.4[ab]	19.5[ab]	44.7
Fibre dilute	15.2[a]	3.13	10.2[a]	20.9[a]	17.1[ab]	71.6[a]	23.4[a]	58.6
Scatter	10.9[b]	3.52	7.30[bc]	15.6[bc]	14.6[b]	51.6[bc]	16.7[b]	42.6
Skip-a-day	12.7[b]	3.29	8.52[ab]	18.6[ab]	17.7[ab]	46.2[c]	14.4[b]	37.9
Sorting	6.17[c]	3.08	6.37[c]	12.0[c]	10.1[c]	47.6[c]	14.6[b]	42.0
SEM	0.6	0.2	0.7	1.3	1.1	6.7	1.8	4.9
Source of variation	Probability							
Feed treatment	<0.0001	0.33	0.003	0.0003	<0.0001	0.03	0.007	0.06

[1]Feed treatments: Control: standard mash diet, fed daily; Fibre dilute: mash diet (25% oat hulls), fed daily; Scatter: standard diet in pellet form scattered on litter, fed daily; Skip-a-day: standard diet double daily allotment fed on alternate days; Sorting: standard mash diet fed every day; birds resorted every 4 wk based on BW. Pen mean BW and BW targets were used to determine daily feed allotments in all treatments.
[2]BW taken prior to processing.
[3]Shank length = t*ibiotarsus* measured from top of flexed hock joint to bottom of footpad.
[4]Chest width = measured 2.5 cm below clavicle bones at widest point on the chest.
[a-c]LS-means within a column with no common superscript differ ($P<0.05$).

Table 2-10. Covariate (22 wk BW) analysis of broiler breeder pullet carcass traits in 5 feed treatments at 22 wk of age

Treatment[1]	BW[2]	SEM	Shank length[3]	SEM	Chest width[4]	SEM	*P. major*	SEM	*P. minor*	SEM	Fat pad	SEM	Liver	SEM
	-- g --		---------------- mm ----------------				------------------------------------- g -----------------------------------							
Control	2529.0	34.0	103.8	0.42	96.3	1.82	444.3[a]	4.95	135.5[a]	1.99	33.6[a]	1.65	51.7[b]	0.88
Fibre dilute	2551.8	34.4	104.6	0.42	97.2	1.82	440.1[a]	4.97	135.1[a]	2.00	33.0[a]	1.66	48.2[cd]	0.89
Scatter	2520.2	34.6	104.6	0.42	95.1	1.82	440.3[a]	4.98	135.1[a]	2.01	24.5[b]	1.67	48.1[d]	0.90
Skip-a-day	2503.1	33.6	104.5	0.41	94.6	1.82	395.0[b]	4.92	122.3[b]	1.99	37.4[a]	1.63	60.1[a]	0.88
Sorting	2499.6	33.2	104.5	0.41	98.0	1.82	446.4[a]	4.89	137.0[a]	1.98	31.7[a]	1.62	51.3[bc]	0.87
Source of variation			-- Probability ---											
Feed treatment	0.82		0.64		0.68		0.03		0.02		0.02		0.0008	
22wk BW	--		<0.0001		<0.0001		<0.0001		<0.0001		<0.0001		<0.0001	

[1]Feed treatments: Control: standard mash diet, fed daily: Fibre dilute: mash diet (25% oat hulls), fed daily: Scatter: standard diet in pellet form scattered on litter, fed daily: Skip-a-day: standard diet double daily allotment fed on alternate days: Sorting: standard mash diet fed every day; birds resorted every 4 wk based on BW. Pen mean BW and BW targets were used to determine daily feed allotments in all treatments.
[2]BW taken prior to processing.
[3]Shank length = t*ibiotarsus* measured from top of flexed hock joint to bottom of footpad.
[4]Chest width = measured 2.5 cm below clavicle bones at widest point on the chest.
[a-d]LS-means within a column with no common superscript differ (*P*<0.05).

Table 2-11. Covariate (3 wk BW) analysis of broiler breeder pullet carcass traits in 5 feed treatments at 22 wk of age

Treatment[1]	BW[2]	SEM	Shank length[3]	SEM	Chest width[4]	SEM	*P. major*	SEM	*P. minor*	SEM	Fat pad	SEM	Liver	SEM
	-- g --		---------------- mm	----------------			---------------------------------------		g	---------------------------------------				
Control	2528.1	33.8	103.8	0.50	96.4	1.71	445.7^{a}	8.80	135.5^{a}	2.53	33.7^{ab}	2.04	51.9^{b}	0.99
Fibre dilute	2557.9	34.8	104.7	0.51	97.9	1.73	448.3^{a}	9.01	136.8^{a}	2.58	35.0^{ab}	2.10	48.9^{c}	1.02
Scatter	2517.2	35.0	104.6	0.51	94.9	1.73	438.7^{a}	9.05	134.8^{a}	2.60	24.5^{c}	2.12	48.0^{c}	1.04
Skip-a-day	2511.3	34.2	104.4	0.51	94.3	1.72	392.2^{b}	8.87	122.0^{b}	2.55	36.8^{a}	2.07	59.9^{a}	1.01
Sorting	2497.1	33.4	104.4	0.50	97.6	1.71	441.7^{a}	8.69	135.7^{a}	2.50	30.6^{b}	2.03	50.7^{bc}	0.98

Source of variation	BW	Shank length	Chest width	*P. major*	*P. minor*	Fat pad	Liver
	--		Probability		---		
Feed treatment	0.78	0.81	0.54	0.03	0.04	0.0004	0.033
3wk BW	<0.0001	0.007	0.003	0.0001	<0.0001	0.15	<0.0001

[1]Feed treatments: Control: standard mash diet, fed daily: Fibre dilute: mash diet (25% oat hulls), fed daily: Scatter: standard diet in pellet form scattered on litter, fed daily: Skip-a-day: standard diet double daily allotment fed on alternate days: Sorting: standard mash diet fed every day; birds resorted every 4 wk based on BW. Pen mean BW and BW targets were used to determine daily feed allotments in all treatments.
[2]BW taken prior to processing.
[3]Shank length = *tibiotarsus* measured from top of flexed hock joint to bottom of footpad.
[4]Chest width = measured 2.5 cm below clavicle bones at widest point on the chest.
[a-c]LS-means within a column with no common superscript differ (P<0.05).

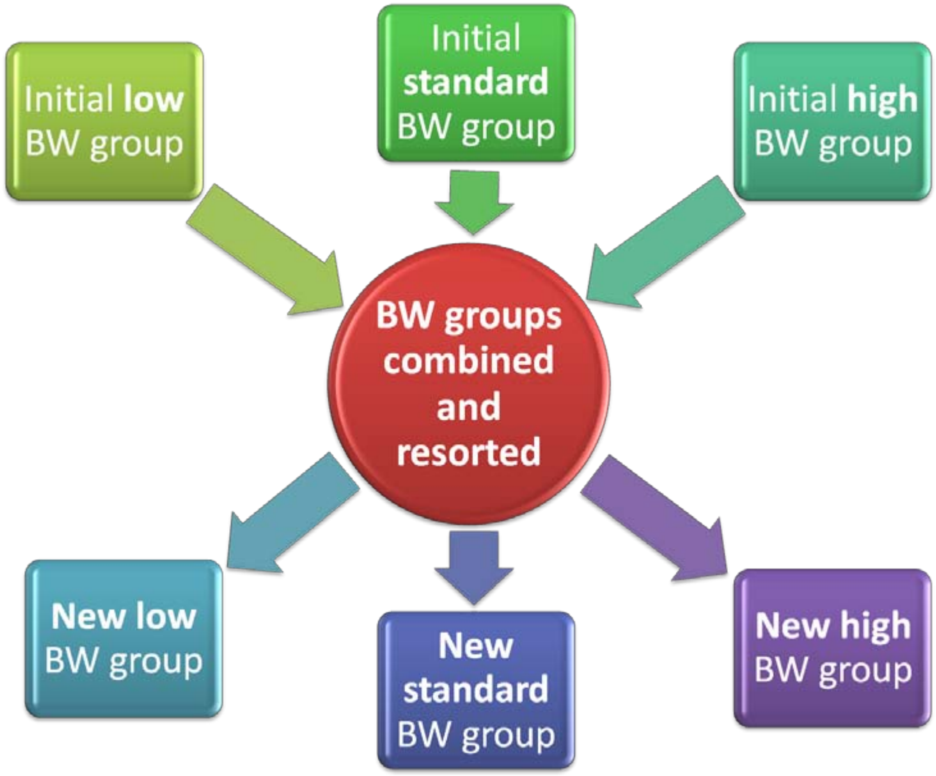

Figure 2-1. BW resorting model for one experimental unit (three pens) in sorting feed treatment. Resorting occurred every 4 wk after individually weighing pullets with resorted birds divided equally between the 3 pens/experimental unit.

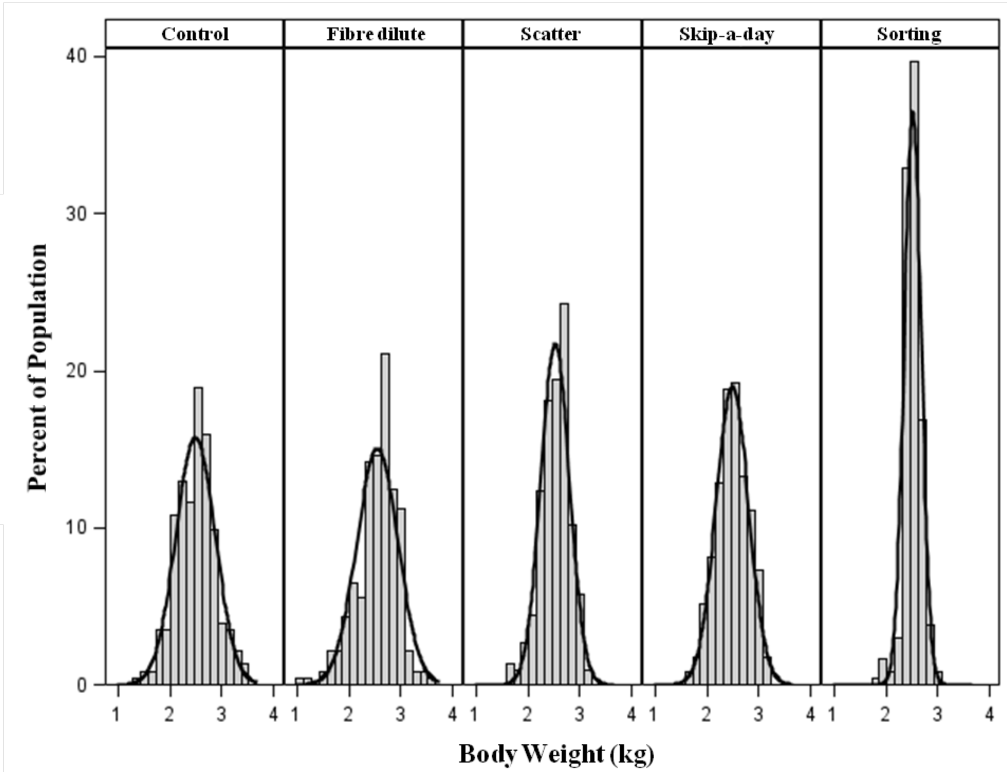

Figure 2-2. Frequency distribution of broiler breeder pullet BW at 22 wk in 5 feed management practices.

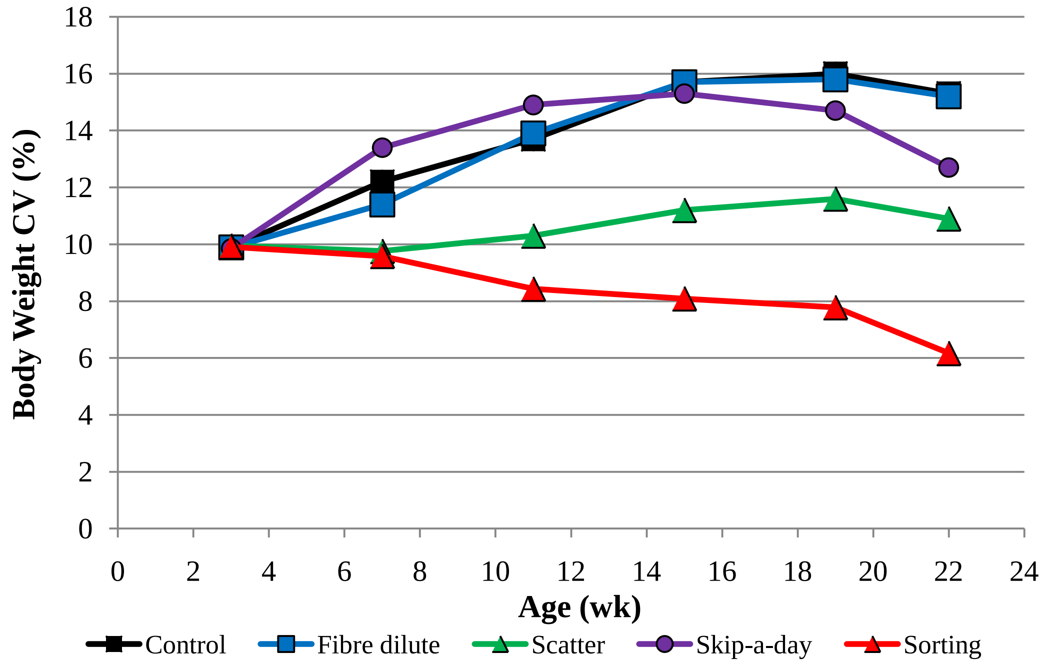

Figure 2-3. Broiler breeder pullet body weight variability in 5 feed treatments.

Chapter 3. Optimizing Broiler Breeder Hen Production, Egg and Chick Quality and Broiler BW and Carcass Trait Uniformity

3.1. Introduction

Assiduous management of broiler breeder pullets during rearing is essential in maximizing reproductive efficiency. Feed restriction programs are used during pullet rearing to control growth, meet age and BW specific energy requirements, and increase flock BW uniformity. Broiler breeder pullet feed management practices aim to reduce the incidence of problems associated with the genetic selection for juvenile growth and other broiler production traits, thereby improving the reproductive performance and well-being of the parent stock (Katanbaf *et al*., 1989 a,b; Renema *et al*., 1999).

Broiler breeder feed management strategies include targeted nutrient intake to meet the nutrient requirements for maintenance and limited growth while offsetting the negative effects of the inherent genetic potential for rapid juvenile growth. The pullet rearing phase begins with 2 to 3 wk of *ad libitum* feeding until chicks reach 3 wk target BW, at which time a feed restriction program is implemented (Costa, 1981; Aviagen, 2006; Cobb-Vantress, 2008). *Ad libitum* feeding increases the potential for the requisite feed intake to support the fundamental development of digestive, cardiovascular, immune, and skeletal systems. Unrestricted feed allocations can also decrease flock BW variability by providing a better distribution of nutrients throughout the flock. After establishing a sound physiological foundation as well as minimizing flock BW variability, the focus of feed management shifts to controlling BW gain, fleshing and fat deposition.

Genetic selection for rapid growth has altered the bird's ability to control feed intake (Denbow, 1994; Wang *et. al*., 2001), whereby birds will eat to gut capacity rather than meeting energy requirements (Etches, 1996; Bokkers and Koene, 2003). Feed restriction programs limit the energy available compensating for the bird's inability to self-regulate feed intake. Feed allotments are based on current and expected BW and calculated using strain-specific BW target profiles. Weekly feed increases not only vary quantitatively throughout rearing but vary proportionally as well. The projected proportional feed increase during the severest restriction (6 - 14 wk) ranges from a 4.5% feed increase at 6 to 7 wk (46 g/bird/d to 48 g/bird/d; Aviagen, 2007 b) to 3.4% from 13 to 14 wk of age (60 g/bird/d to 62 g/bird/d; Aviagen, 2007 b). Feed allotment adjustments are designed to meet the energy requirements for maintenance and controlled growth while concurrently limiting the incidence of over-fleshing and fat deposition.

Exiguous feed allotments can increase flock variability by increasing between bird competition, therefore the restriction practices used aim to optimize the distribution of feed throughout the barn. Restricting energy intake during rearing and leading up to sexual maturity reduces the incidence of excessive follicular development which can lead to reproductive abnormalities and decreased production (Katanbaf *et al*., 1989a; Yu *et al*., 1992b). Multiple hierarchies and ovulations, defective egg production, and altered laying patterns (Hocking, 1996; Robinson *et al*., 1995, 1998b) caused by an abundant energy supply compromise reproductive efficiency. Over-fleshing and excessive fat deposition caused by a positive energy balance can increase morbidity and mortality while decreasing well-being and fertility (Katanbaf, 1989 a; Whitehead, 2000; Renema *et al.*, 1999).

Broiler breeder feed management strategies are implemented during pullet rearing to maximize reproductive efficiency by decreasing flock BW variabiity as well as decreasing the incidence of reproductive problems due to the genetic selection for broiler production traits.

Pullet flock BW uniformity is essential in maximizing reproductive efficiency. Feed restriction can potentially limit the distribution of nutrients throughout the flock increasing the variation in flock BW. Therefore diligent monitoring of flock uniformity throughout the BB life cycle is essential. The broiler breeder industry currently uses variation from the mean and coefficient of variation to denote flock BW uniformity as no actual measure of uniformity exists.

Variation from a population BW mean gives a numerical value to the proportion of a population falling within a specified BW range. The predetermined ranges conventionally used are within ± 10% or ± 15% from the flock BW mean. This method assumes the greater percent of the population within the specified range the higher the flock uniformity, however it does not reveal how widely dispersed the BW actually are (standard deviation). The variation from the mean is calculated:

$$\mu - a < \text{Range} > \mu + a = n$$

$$(n/t)*100 = \text{percent of population}$$

Where μ = population BW mean, $a = \mu*(.10 \text{ or } .15)$ to determine upper and lower range limits, n = number of birds within the functional BW range, t = total number of birds weighed

The coefficient of variation (CV) is the ratio of the standard deviation (δ) to the population BW mean (μ), where the lower the CV the lower the variability. A normally distributed population will have 68.2% of the population fall within 1 standard deviation from the mean therefore allows for the comparison of a specific variable at different ages.

Unlike the variation from the mean, the CV does take into consideration how widely distributed the BW are (δ). Outliers can bias the CV, suggesting higher variability than may actually exist; using a population BW distribution histogram will reveal any potentially abnormal measurements. The validity of unusual BW measurements can then be determined through statistical analysis. The CV is calculated:

$$CV = (\delta/\mu)*100$$

Where δ = standard deviation, μ = population BW mean

Broiler breeder rearing feed management strategies aim to minimize flock BW and carcass trait variability in order to achieve optimal reproductive efficiency as flock variability will negatively impact both sexual maturity and egg production (Petitte et al., 1982).

The onset of sexual maturity is contingent upon a broiler breeder pullet achieving body composition and age thresholds. Feed restricted pullets must attain BW, lipid deposition, and fleshing (protein accretion) requirements (Brody *et al.*, 1984; Bornstein *et al.*, 1984; Soller *et al.*, 1984; Yu *et al*., 1992 a,b) in order to synchronize the process of sexual maturity with time of photostimulation. Flock variability will negatively affect the onset of sexual maturity as only a portion of the birds will have reached the thresholds necessary to be able to respond to lighting cues. Pullets with BW at or above target will come into production earlier (Katanbaf *et al*., 1989 b; Robinson and Robinson, 1991; Robinson *et al.*, 1991 a; Yu *et al.*, 1992b) while low BW birds will require more time to acquire the BW and body composition necessary for sexual maturity thereby reducing reproductive efficiency.

Flock BW variability leading to a range of ages at sexual maturity will carry through production with poor peak and persistency of lay (Costa, 1981). The delayed onset of egg production in low BW pullets may decrease peak production due to the wider range in age when hens reach maximum production (Robinson and Robinson, 1991). While birds with BW below target may require more time to enter lay compared to birds above target BW, both have reduced production of settable eggs (Costa, 1981; Katanabaf *et al.*, 1989 b, Robinson and Robinson, 1991; Robinson *et al.*, 1991 a; Yu *et al.*, 1992b). Hens above target BW can have increased morbidity and mortality associated with reproductive disorders (Hocking *et al*., 1996), increasing flock variability and further decreasing settable egg production. Decreased flock BW uniformity results in decreased number of settable eggs, lower peak production and poor persistency of lay which negatively impact reproductive efficiency (Costa, 1981; Robinson and Robinson, 1991; Etches, 1996).

Decreasing flock BW variability can influence the onset of sexual maturity, peak production and improve persistency of lay. Producers can maximize production efficiency with a uniform flock as hens will have attained a similar physiological state and therefore only one level of management is needed to meet their expected nutritional and energy requirements.

Feed management practices used during rearing attempt to decrease flock BW variability and establish the optimum BW and body composition for sexual maturity and persistent reproduction. Feed management practices are discussed in Chapter 2.

Genetic selection for broiler production traits continues to increase the degree of feed restriction necessary to maintain health, well-being and reproductive efficiency in breeders. Restricted feed allocations can potentially limit the availability of essential micronutrients necessary for sexual maturity, optimal and persistent egg production. Breeders have increased in BW, size and protein accretion over the past 30 years (Renema et al., 2007) therefore a concomitant increase in micronutrient requirements for maintenance is probable (Kidd, 2009). The hen's nutritional status will determine the availability of micronutrients for transfer to the egg (Wilson, 1997).

A balanced concentration of appropriate micronutrients is required in the egg to optimize chick development, hatchability, quality, livability and growth (Leeson, *et al*., 1979 b; Wilson, 1997). Fortifying the breeder diet with supplemental premix is used within the industry to compensate for any unknown dietary shortages. Exiguous feed allotments can induce deficiencies if there is an uneven distribution of premix micronutrients in the feed, or bird-to-bird competition decreases the distribution of feed, and therefore micronutrients, throughout the flock. Diet fortification can ensure a better distribution of micronutrients to hens and consequently to the egg and offspring.

3.2. Objectives

The overall objective of this study was to decrease flock variability during sexual maturity and egg production through increased 22 wk pullet flock BW uniformity and increased availability of key nutrients through diet fortification (22 to 40 wk of age). Specific objectives were to determine the effects of feed and premix tmts on the uniformity of age at sexual maturity; early egg traits, quality and hatchability; chick quality, livability, growth and broiler carcass traits.

3.3. Materials and Methods

3.3.1. Experimental Design

A completely randomized 5x2 factorial design was used to study the effect of 5 feed, 2 premix tmts and their interaction on female BW variability, carcass trait variability and production parameters. Pullets were reared in 5 feed tmts to 22 wk of age; control, fibre dilute, scatter, skip-a-day and sorting tmts (refer to Chapter 2). At 22 wk of age, 708 TP16 pullets were split into 2 experimental groups (randomly assigned at 3 wk of age): Experiment 2 - the sexual maturity phase to determine tmt effects on variability of flock BW, carcass traits, age at first egg and egg characteristics at sexual maturity (after 3rd oviposition) and Experiment 3 - the reproduction phase to determine tmt effects on variability of hen BW, hen carcass traits, egg production parameters, chick quality, broiler BW and broiler carcass traits. The experimental unit was the hen.

A wheat and corn based mash diet was used for both breeder premix treatments. The control (2,865 kcal; 15% CP; 0.71% lys; 5g/kg layer premix) and premix enriched mash diets (2,865 kcal; 15% CP; 0.71% lys; 10 g/kg layer premix) were fed daily (Table 3-1). Individual feed allocations (22 to 40 wk) were based on the weekly BW means of the Experiment 3 birds and followed Ross 308 target BW recommendations from the primary breeder.

Experiment 4 eggs for hatches 1, 2 and eggs for the broiler experiment (Experiment 5) were sorted according to hen cage number and divided into 10 groups (5 feed tmts x 2 premix tmts). Additional eggs were set for each hatch to account for mortality or infertile eggs leaving 1,200 live chicks for hatches 1 and 2 and 800 chicks for the broiler experiment. The experimental unit for Experiment 4 was the hen while the experimental unit for Experiment 5 was a pen. Hatch 3 chicks were randomly assigned to one of 10 pens and raised to 37 d of age at which time broilers were fasted overnight and processed the following morning.

3.3.2. Stocks and Management

At 22 wk of age, 708 Aviagen TP16 (Aviagen Inc., Huntsville, AL) pullets were randomly assigned to one of two premix tmts and divided between the sexual maturity (Experiment 2; 408 pullets) and reproduction phases (Experiment 3; 300 pullets) of this research. Experimental fates were randomly assigned at 3 wk after chicks were individually identified with barcoded wing bands (National Band and Tag Co., New Port, KY 41072-0430). At 22 wk of age, 60 Ross 344 (Aviagen Inc., Hunstville, AL) males were randomly selected for the reproduction phase (Experiment 3) and placed in individual cages within the same room as Experiment 3 females. Males were raised to 40 wk following Ross 308 primary breeder guidelines. Experiment 2 and Experiment 3 individual daily feed allotments were based on experiment 3, premix tmt weekly BW means. Experiment 2 and 3 pullets were photostimulated at 22 wk of age after placement in individual cages. Lighting was the same in both sexual maturity and reproduction facility rooms. The photoperiod was 12L:12D at 22 wk and gradually increased by 1 h/wk to 15L:9D by 25 wk of age where birds remained until reaching sexual maturity (Experiment 2) or 40 wk of age (Experiment 3). Eggs were collected from experiment 3 hens to determine the effect of 5 feed and 2 premix tmts on chick quality (Experiment 4: Hatches 1 and 2), and broiler BW and carcass trait uniformity (Experiment 5). The eggs for Hatch 1 were collected beginning at 33 wk, Hatch 2 beginning at 36 wk and Hatch 3 beginning at 39 wk of age. Eggs for all three hatches were collected for up to7 d before being placed in the incubator and incubated according to industry guidelines.

3.3.2.1. Experiment 1 – Rearing phase

The rearing phase examined the effect of 5 feed tmts on the variability of pullet BW and carcass traits at 22 wk of age. Experiment details are outlined in Chapter 2.

3.3.2.2. Experiment 2 - Sexual maturity phase

Four hundred and eight pullets were placed in Specht (Specht Ten Elsen GmbH & Co KG, Sonsbeck, 47665 Germany) cages (48 cages/unit: 29x44x44 cm) in the same light-tight facility used during Experiment 1. Hens were fasted overnight, euthanized and dissected within 2 hours (h) after lights on the day following 3rd oviposition.

3.3.2.3. Experiment 3 – Reproduction phase

Three hundred pullets were placed in Cagemaster individual cages (48x46x42 cm) in a separate light-tight room within the same facility used during rearing. The 60 randomly selected males were placed in individual Specht (Specht Ten Elsen GmbH & Co KG, Sonsbeck, 47665 Germany) cockerel cages (34x42x57 cm) within the same room as experiment 3 pullets and used for insemination purposes from 23 to 40 wk of age. Pooled semen (from 60 males) was used for weekly insemination of all 300 experiment 3 females from 26 wk to 39 wk of age (0.5 ml pooled semen/hen). Hens were fasted overnight, euthanized and dissected at 40 wk of age.

3.3.2.4. Experiment 4 - Chick Quality Phase

Hatch 1 had a total of 1,300 eggs which were collected over 7 d beginning at 33 wk of age and stored for up to 6 d at 16^{o} C prior to being placed in the incubator. A total of 1,300 Hatch 2 eggs were collected for 7 d from 36 wk and stored (16^{o} C) until placement in the incubator at 37 wk. For each hatch, eggs were randomly placed in incubator flats. Flats were randomly placed onto racks in a Jamesway Big J single stage incubator (Jamesway Incubator Company Inc., Cambridge, Ont.; 38^{o} C, 85% humidity) for 19 d. Eggs were transferred from egg flats to hatching baskets and randomly placed in a Jamesway Big J single stage hatcher

(Jamesway Incubator Company Inc.; 38^{o} C, 85% humidity) for 3 d. Hatch 1 and 2 chicks were removed from the hatcher and transferred to chick baskets. Chick BW and lengths were recorded; chicks were humanely euthanized, dissected with residual yolk sacs removed and weights recorded.

This research project was carried out in compliance with the *Guide to the Care and Use of Experimental Animals* (Canadian Council on Animal Care, 1984) and was approved by a Faculty Policy and Welfare Committee.

3.3.2.4. Experiment 5 - Broiler Phase

Hatch 3 eggs were collected for 7 d starting at 39 wk and stored for up to 6 d at 16^{o} C prior to being placed in the incubator at 40 wk. Eggs were randomly placed in egg flats and flats were randomly placed onto racks in a Jamesway Big J single stage incubator (Jamesway Incubator Company Inc., Cambridge, Ont.; 38^{o} C, 85% humidity) for 19 d. Eggs were transferred from egg flats to hatching baskets and randomly placed in a Jamesway Big J single stage hatcher (Jamesway Incubator Company Inc.; 38^{o} C, 85% humidity) for 3 d. Chicks were removed from the hatcher and individually identified with barcoded neck tags (Heartland Tag LLC, Fair Play, MO). Chicks were randomly placed in one of 2 pens/5 feed x 2 premix tmt for a total of 10 pens, in a light-tight facility and raised to 37 d of age following the Ross broiler (Aviagen Inc., Huntsville, AL) management guide provided by the primary breeder. Broiler diets were wheat, soybean and corn based (Table 3-1). A starter diet (3,068 kcal/kg, 23% CP, 1.35% lys) was fed ad libitum for 14 d. At 7 d of age all 800 chicks were individually weighed and wing banded with barcoded wing bands (National Band and Tag Co., New Port, KY 41072-0430). The grower diet (3,152 kcal/kg, 20.2% CP, 1.10% lys) was fed ad libitum from 15 to 28 d followed by a finisher diet (29 to 37d; 3,196 kcal/kg, 19.0% CP, 1.01% lys). Broilers were fasted overnight and processed in a federally inspected slaughter and processing facility.

3.3.3. Data Collection

Experiment 2 individual bird BW were recorded at 22 wk and after the first oviposition. Individual BW and external measures (shank length and chest width; measures detailed in Chapter 2) were taken after third oviposition, 1 d prior to euthanization and dissection. Experiment 3 birds had individual BW and external body measurements taken at 22 and 40 wk of age (1d prior to euthanization and dissection). Experiment 3 individual BWs were taken weekly and after the first oviposition.

At sexual maturity, Experiment 2 hens were fasted overnight and humanely euthanized by cervical dislocation, while experiment 3 hens were fasted overnight and humanely euthanized at 40 wk of age. Dissection of Experiment 2 and 3 hens followed euthanization to determine feed and premix tmt effects on variability of fleshing, fatness and reproductive morphology. *Pectoralis major*, *Pectoralis minor*, abdominal fat pad, liver, oviduct, and ovary weights recorded. Large yellow follicles (LYF >10mm) were removed from the ovary, number of LYF and individual LYF and stroma weights were recorded.

Eggs were collected daily, individually weighed and quality code assigned according to shell condition, shape and size. Normal eggs were defined as all eggs with shells free from defects, small eggs as those with weights <52g, and settable eggs as the number of normal eggs minus small eggs. Production traits were recorded for each experiment 3 hen.

Normal eggs were collected and set for all hatches (includes eggs weighing <52 g). Hatch 1 and 2 chicks were individually sexed, weighed and body length (from beak to toe, excluding nail) recorded at hatch. Chicks were euthanized, dissected, residual yolk sac removed and weight recorded. Hatch 3 chicks were individually weighed and external body measures recorded at hatch. Chicks were individually weighed at 7 d and at 37 d prior to processing. Broilers were slaughtered and processed at 37 d. Carcass weight, *Pectoralis major*, *Pectoralis minor*, leg, and wing weights were recorded.

3.3.4. Statistical Analysis

A completely randomized 5 x 2 factorial design was used to evaluate the effects of 5 feed tmts and 2 premix tmts on variability of female broiler breeder flock BW and carcass traits. The hen was the experimental unit. External body measures of shank length and chest width were also analyzed with the operator as a random effect using the Mixed procedure in SAS©. Treatment effects on repeated measures were evaluated as a 4-way analysis of variance using the Mixed procedure in SAS 9.2© (SAS Institute Inc., Cary, NC). Significance was assessed at P<0.05 for all analysis. Pair-wise comparisons were used to determine differences between least squares means. The 3-way analysis statistical model used:

$$y_{ijk} = \mu + f_i + p_j + fp_{ij} + a_k + fa_{ik} + pa_{jk} + \varepsilon_{ijk} \qquad \text{Eq. 3-1}$$

Where y_{ijklm} = dependent variable for the m^{th} pullet, μ = overall mean, f_i = the i^{th} feed tmt effect, p_j = the j^{th} premix tmt effect, fp_{ij} = the interaction between feed and premix tmts, a_k = the k^{th} age effect, fa_{ik} = interaction between feed tmt and age, pa_{jk} = interaction between premix tmt and age, and ε_{ijk} = the residual error.

Sexual maturity carcass traits were evaluated as a 2-way analysis of variance using the Mixed procedure of SAS 9.2© (SAS Institute Inc., Cary, NC), significance was determined at P<0.05. Pearson's correlation (proc Corr, SAS Institute Inc., Cary, NC) was used to examine the relationships between carcass traits. The model used for 3-way analysis of variance of carcass traits:

$$y_{ijk} = \mu + f_i + p_j + fp_{ij} + \varepsilon_{ijk} \qquad \text{Eq. 3-2}$$

Where y_{ijk}= dependent variable for the k^{th} pullet, μ = overall mean, f_i = the i^{th} feed tmt effect, p_j = the j^{th} premix tmt effect, fp_{ij} = the interaction between feed and premix tmts, and ε_{ijk} = the residual error.

Experiment 2 and 3 carcass trait covariate analysis (sexual maturity BW) was conducted using the Mixed procedure of SAS 9.2© (SAS Institute Inc., Cary, NC), to determine the portion of error due to BW at sexual maturity and significance and interaction of feed and premix tmt effect. The model used:

$$y_{ijkl} = \mu + f_i + p_j + fp_{ij} + \beta(BW_{ijk} - BW_a) + \varepsilon_{ijkl} \qquad \text{Eq. 3-3}$$

Where y_{ijk} = dependent variable for the l^{th} pullet, μ = overall mean, f_i = the i^{th} feed tmt effect, p_j = the j^{th} premix tmt effect, fp_{ij} = the interaction between feed and premix tmts, $\beta(BW_{ijk} - BW_a)$ = the covariate coefficient multiplied by the difference in BW of k^{th} bird and average BW_a, ε_{ijkl} = the residual error.

Coefficients of variation (CV) were presented as measures of variability. Variability differences were determined using the Mixed procedure of SAS 9.2© (SAS Institute Inc., Cary, NC). The statistical model used:

$$y_{ijkl} = \mu + f_i + p_j + fp_{ij} + a_k + fa_{ik} + pa_{jk} + \varepsilon_{ijkl} \qquad \text{Eq. 3-4}$$

Where y_{ijk}= coefficient of variation (CV) for the l^{th} pullet, μ = overall mean, f_i = the i^{th} feed tmt effect, p_j = the j^{th} premix tmt effect, fp_{ij} = the interaction between feed and premix tmts, a_k = the k^{th} age effect, fa_{ik} = interaction between feed tmt and age, pa_{jk} = interaction between premix tmt and age, ε_{ijkl} = the residual error.

Experiment 4, chick quality, and Experiment 5, broiler BW and carcass traits were evaluated as a 2-way analysis of variance using the Mixed procedure of SAS 9.2© (SAS Institute Inc., Cary, NC), significance was determined at $P<0.05$. The model used for 2-way analysis of variance of carcass traits:

$$y_{ijk} = \mu + f_i + p_j + fp_{ij} + \varepsilon_{ijk} \qquad \text{Eq. 3-5}$$

Where y_{ijkl} = dependent variable for the k^{th} chick, μ = overall mean, f_i = the i^{th} feed tmt effect, p_j = the j^{th} premix tmt effect, fp_{ij} = the interaction between feed and premix tmts, ε_{ijk} = the residual error.

Coefficients of variation (CV) are presented as measures of variability in chick quality, broiler BW and carcass traits. Variability differences were determined using the Mixed procedure of SAS 9.2© (SAS Institute Inc., Cary, NC). The statistical model used:

$$y_{ijk} = \mu + f_i + p_j + fp_{ij} + \varepsilon_{ijk} \qquad \text{Eq. 3-6}$$

Where y_{ijk} = coefficient of variation (CV) for the k^{th} , μ = overall mean, f_i = the i^{th} feed tmt effect, p_j = the j^{th} premix tmt effect, fp_{ij} = the interaction between feed and premix tmts, and ε_{ijk} = the residual error.

3.4. Results and Discussion

Premix tmt had no significant effect on any carcass trait measurements at sexual maturity (Table 3-10). Feed tmt effects on carcass traits carried through to sexual maturity with significant differences between fibre dilute (3.39 kg) and skip-a-day tmts (3.24 kg). Similar differences were observed in chest width, *Pectoralis major* and *Pectoralis minor* measures (Table 3-10). Fat pad weights were found to be significantly lower in scatter tmt hens (59.2 g) compared to the control tmt (66.2 g) which followed the trend established during rearing (3 to 22 wk). A significant feed tmt effect was found in uniformity of oviduct weight with scatter

(CV = 10.6%) and sorting (CV = 11.9%) tmts having the highest uniformity and skip-a-day (CV = 17.1%) tmt having the lowest uniformity. No significant tmt effect was found in any other carcass trait (Table 3-11). Feed tmts had a significant effect on hen BW and first egg weight at sexual maturity (Table 3-3) with fibre dilute hens having heavier mean BW (3.36 kg) and mean egg weight (49.5 g) compared to skip-a-day (3.19 kg; 47.5 g) and scatter tmt hens (3.28 kg; 48.7 g). No treatment effect on age at sexual maturity or second and third egg weights was observed. Uniformity of sexual maturity parameters was not affected by feed tmts, with only premix tmt showing a significant effect on the uniformity of first egg weights (Table 3-4). Feed and premix tmts had no significant effect on first egg composition or quality, however the premix tmt had a negative effect on first egg weight (CV = 9.76%), albumen (CV = 7.58%) and shell (CV = 13.7%) variability compared to the control tmt (CV = 8.59%, CV = 5.90% and CV = 11.4% respectively).

Feed tmt effects were evident at sexual maturity with a significant effect on hen BW as well as first egg weights. Slight numerical differences in hen age at sexual maturity were observed but the differences were not statistically significant (Figure 3-10). The fibre dilute tmt hens were heaviest (3.36 kg) compared to the control (3.25 kg), had the latest mean hen age at first egg (185.5) compared to the control (183.6 d) and as expected, delayed first oviposition resulted in heavier egg weight (49.5 g). The difference in variability of first egg characteristics in the premix tmt may have been due to excess premix ingredients causing negative interactions (Leeson and Summers, 2001) leading to variations in the deposition of yolk, albumen and egg shell. Physiological differences between pullets entering lay, interactions between fat soluble vitamins (A, D, E and K) present in the premix may lead to deficient or excess concentrations of micronutrients in breeder hens leading to variations in egg weights.

Premix tmt did not have a significant effect on female broiler breeder BW until 38 wk of age when the BW of the control tmt hens decreased. Premix tmt hens (3.67 kg) were found to be significantly heavier than the control hens (3.54 kg) (Table 3-8). Feed tmts had a significant effect on BW starting the week leading into peak production (30 wk of age) and continuing through to 33 wk. Feed tmt effects were also found at 35, 37 and 39 wk of age. At all the previous ages, significant differences occurred between skip-a-day and fibre dilute tmts where fibre dilute hens were consistently heavier than skip-a-day hens (Table 3-8). Flock BW uniformity continued to increase upon placement in individual cages. The sorting tmt had significantly higher uniformity (CV = 4.23% at 25 wk) relative to the other treatments, however by 26 wk of age the BW variability in all treatments had decreased (Table 3-9). The feed tmt effects were no longer statistically significant by 27 wk of age. No premix tmt effects on flock BW uniformity were observed. Feed tmt was found to have a significant effect on shank length and chest width at 40 wk of age; following BW the fibre dilute tmt hens had significantly longer shank length (108.7 mm) and chest width (109.0 mm) compared to the other treatments (Table 3-9). Hen carcass trait uniformity at

40 wk of age was not affected by feed tmt while premix tmt had a significant negative effect on only chest width uniformity (CV = 8.61%) compared to the control (CV = 7.25%). No treatment effects were observed on production traits (Table 3-8 and 3-9). Total eggs, hen day production and 40 wk egg weights were similar to expected values from the primary breeder guidelines (Aviagen, 2007). No treatment effects on egg production, uniformity of egg production (Table 3-18 and 3-19), chick quality or uniformity of chick quality (Table 3-16 and 3-17) were observed in 2 hatches (34 and 37 wk of age). Feed and premix tmts had no significant effect on broiler chick quality or uniformity, carcass weight, yield or carcass uniformity as well as broiler feed consumption (Table 3-15, 3-20, 3-21).

Flock BW uniformity progressively increased from the time of placement in individual cages (22 wk) to peak production (31 wk) when all feed tmt CVs converged at approximately 6.5% (Table 3-9) and significant differences between treatments no longer existed (Figure 3-1). Feed allocations were based on mean tmt BW therefore after placing in individual cages, heavier hens received less feed relative to small hens. Placing birds in individual cages eliminated between-bird competition allowing for feed intake to meet the energy requirements of a greater proportion of the flock in addition to the hens reaching the same physiological state during production led to decreased variations between mean tmt BW and flock BW uniformity. Decreased variations in mean BW resulted in small BW differences between feed tmts becoming significant at 30 wk of age (Table 3-14). Caging hens had an effect of increasing uniformity of all production parameters examined. Variations in feed tmt flock BW and carcass composition were negated by individually caging pullets at 22 wk of age. The potential toxic effects of the additional of 100% premix ingredients were not evident at 40 wk of age.

Broiler breeder flock BW and carcass trait uniformity at sexual maturity and 40 wk of age were not affected by pullet rearing or premix treatments. Individually caging pullets prior to sexual maturity eliminated between bird competition thereby increasing flock BW and carcass trait uniformity. Hen BW target profiles can be maintained using any of the feed tmts studied provided current BW and expected BW targets are used to calculate feed allotments. Weighing birds frequently and in sufficient numbers provides accurate information to base feed decisions.

3.5. References

Aviagen. 2006. Rearing (0-15 wk). Pages 4-21in: Ross 308 Parent Stock Management Manual. Aviagen Inc., Huntsville, Alabama, USA.

Aviagen. 2007. Ross 308 Broiler Performance Objectives. Aviagen Inc., Huntsville, Alabama, USA.

Aviagen. 2007. Ross 308 PS Performance Objectives. Aviagen Inc., Huntsville, Alabama, USA.

Barbato, G. F. 1999. Genetic relationships between selection for growth and reproductive effectiveness. Poult. Sci. 78:444-452.

Bokkers, E. A., and P. Koene. 2003. Eating behaviour, and preprandial and postprandial correlations in male broiler and layer chickens. Br. Poult. Sci. 44:538-544.

Bornstein, S., I. Plavnik, and Y. Lev. 1984. Body weight and/or fatness as potential determinants of the onset of egg production in broiler breeder hens. Br. Poult. Sci. 25:232-341.

Brody, T. B., P. B. Siegel, and J. A. Cherry. 1984. Age, body-weight and body-composition requirements for the onset of sexual maturity of dwarf and normal chickens. Br. Poult. Sci. 25:245-252.

Bruggeman, V., O. Onagbesan, E. D'Hondt, N. Buys, M. Safi, D. Vanmontfort, L. Berghman, F. Vandesande, and E. Decuypere. 1999. Effect of timing and duration of feed restriction during rearing on reproductive characteristics in broiler breeder females. Poult. Sci. 78:1424-1434.

Buyse, J., H. Michels, J. Vloeberghs, P. Saevels, J. M. Aerts, B. Ducro, D. Berckmans, and E. Decuypere. 1998. Energy and protein metabolism between 3 and 6 weeks of age of male broiler chickens selected for growth rate or for improved food efficiency. Br. Poult. Sci. 39:264-272.

Cobb-Vantress. 2008. Cobb 500 Breeder Management Supplement SF. Cobb-Vantress Inc., P.O. Box 1030, Siloam Springs, Arkansas, USA.

Cobb-Vantress. 2009. Cobb 500 Broiler Management Guide. Cobb-Vantress Inc., P.O. Box 1030, Siloam Springs, Arkansas, USA.

Costa, M. S. 1981. Fundamental principles of broiler breeders nutrition and the design of feeding programmes. World's Poult. Sci. J. 37:177-192.

Decuypere, E., V. Bruggeman, G. F. Barbato, and J. Buyse. 2003. Growth and reproduction problems associated with selection for increased broiler meat production. Pages 27-38 in: Poultry Genetics, Breeding and Biotechnology. Muir, W. M. and S. E. Aggrey ed. CABI Publishing, Wallingford, Oxon, UK.

Denbow, D. M. 1994. Appettite and its control. Poult. Sci. Reviews 5:209-229.

Etches, R. J. 1996. Reproduction in Poultry. CAB International, Wallingford, Oxon.

Hocking, P. M. 1996. The role of body weight and food intake after photostimulation on ovarian function at first egg in broiler breeder females. Br. Poult. Sci. 37:841-851.

Hocking, P. M., M. H. Maxwell, and M. A. Mitchell. 1996. Relationships between degree of food restriction and welfare indices in broiler breeder females. Br. Poult. Sci. 37:263-278.

Hudson, B. P., R. J. Lien, and J. B. Hess. 2001. Effects of body weight uniformity and pre-peak feeding programs on broiler breeder hen performance. J. Appl. Poult. Res. 10:24-32.

Katanbaf, M. N., E. A. Dunnington, and P. B. Siegel. 1989. Restricted feeding in early and late-feathering chickens 1: Growth and physiological responses. Poult. Sci. 68:344-351.

Kidd, M .T. 2009. Vitamins, minerals and micronutrients. Pages 361-373 in: Biology of breeding poultry. Editor P. Hocking. CAB Int. Oxfordshire, UK.

Leeson, S., B. S. Reinhart, and J. D. Summers. 1979. Response of White Leghorn and Rhode Island Red breeder hens to dietary deficiencies of synthetic vitamins 2. Embryo mortality and abnormalities. Can. J. Anim. Sci. 59:569-575.

Leeson, S. and J. D. Summers. 2001. Nutrition of the Chicken. 4th Ed. University Books. Guelph, ON.

Renema, R. A., F. E. Robinson, J. A. Proudman, M. Newcombe, and R. I. McKay. 1999. Effects of body weight and feed allocation during sexual maturation in broiler breeder hens. 2. Ovarian morphology and plasma hormone profiles. Poult. Sci. 78:629-639.

Renema, R. A., M. E. Rustad, and F. E. Robinson. 2007. Implecations of changes to commercial broiler and broiler breeder body weight targets over the past 30 years. World's Poult. Sci. J. 63:457-472.

Richards, M. P. 2003. Genetic regulation of feed intake and energy balance in poultry. Poult. Sci. 82:907-916.

Robinson, F. E., and N. A. Robinson. 1991. Reproductive performance, growth rate and body composition of broiler breeder hens differing in body weight at 21 weeks of age. Can. J. Anim. Sci. 71:1233-1239.

Robinson, F. E., N. A. Robinson, and T. A. Scott. 1991. Reproductive performance, growth rate and body composition of full-fed versus feed-restricted broiler breeder hens. Can. J. An. Sci. 71:549-556.

Robinson, F. E., N. A. Robinson, and R. T. Hardin. 1995. The effects of 20-week body weight and feed allocation during early lay on female broiler breeders. J. Appl. Poult. Res. 4:203-210.

Robinson, F. E., R. A. Renema, L. Bouvier, J. J. R. Feddes, M. J. Zuidhof, J. L. Wilson, M. Newcombe, and R. I. McKay. 1998. Effects of photostimulatory lighting and feed allocation in female broiler breeders 2. Egg and chick production characteristics. Can. J. An. Sci. 78:615-623.

Siegel, P. B., and E. A. Dunnington. Reproductive complications associated with selection for broiler growth. 1985. Pages 59-72 in: Poultry Genetics and Breeding. Hill, W. G., J. H. Manson, and D. Hewitt (Ed.), Longman, Harlow, UK.

Siegel, P. B., and J. H. Wolford. 2003. A review of some results of selection for juvenile body weight in chickens. J. Poult. Sci. 40:81-91.

Soller, M., Y. Eitan, and T. Brody. 1984. Effect of diet and early quantitative restriction on the minimum weight requirement for onset of sexual maturity in White Rock broiler breeders. Poult. Sci. 63:1255-1261.

Wang, X., J. R. Day, and R. Vasilatos-Younken. 2001. The distribution of neuropeptide Y gene expression in the chicken brain. Mol. Cell. Endocrinol. 174:129-136.

Whitehead, C. C. 2000. Nutrition: The integrative science. Br. Poult. Sci. 41:5-15.

Wilson, H. R. 1997. Effects of maternal nutrition on hatchability. Poult. Sci. 76:134-143.

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

Yu, M.W., F.E. Robinson, and R. J. Etches. 1992b. Effect of feed allowance during rearing and breeding on female broiler breeders. 3. Ovarian steroidogenesis. Poult. Sci. 71:1762-1767.

Table 3-1. Composition and analysis of broiler breeder diets

Ingredient and analysis	Breeder (22 to 40 wk)	Premix[1] (22 to 40 wk)
	---------------- g/kg	----------------
Wheat	350.0	350.0
Ground corn	367.0	367.0
Soybean meal (47.8% CP)	158.0	158.0
Canola oil	17.0	17.0
Calcium carbonate	78.0	78.0
Dicalcium phosphate	14.0	14.0
Choline chloride premix[2]	5.0	5.0
Layer premix[3]	5.0	10.0
Salt	3.7	3.7
D, L-methionine	1.5	1.5
L-lysine	0.3	0.3
Avizyme	0.5	0.5
Total:	1,000	1,000
Calculated nutrient composition		
CP (%)	15.0	15.0
ME (kcal/kg)	2,865	2,865
Calcium (%)	3.30	3.30
Available phosphorus (%)	0.39	0.39
Lysine (%)	0.71	0.71
Methionine (%)	0.39	0.39

[1]Diet included double premix.
[2]Provided choline chloride in the diet at a level of 100 mg/kg.
[3]Layer premix provided per kilogram of diet: vitamin A (retinyl acetate), 12,500 IU; cholecalciferol, 3,125 IU; vitamin E (DL-α-tocopheryl acetate), 40.0 IU; vitamin K, 2.50 mg; pantothenic acid, 12.5 mg; riboflavin, 7.50 mg; folacin, 0.63 mg; niacin, 37.5 mg; thiamine, 2.55 mg; pyridoxine, 5.00 mg; vitamin B12, 0.02 mg; biotin, 0.15 mg; iodine, 1.65 mg; Mn, 88.0 mg; Cu, 15.0 mg; Zn, 100 mg, Se, 0.30 mg; Fe, 80.0 mg.

Table 3-2. Daily feed allotments for broiler breeder females from 22 to 40 wk of age

Bird age	Control	Premix
----- wk -----	----- g/bird/d -----	
22	111	111
23	116	115
24	112	116
25	113	118
26	119	124
27	125	128
28	134	135
29	147	146
30	151	150
31	149	149
32	145	146
33	144	146
34	143	145
35	140	142
36	135	137
37	131	133
38	132	129
39	130	126

Table 3-3. Mean egg weight and hen age at sexual maturity in 5 broiler breeder feed treatments and 2 premix treatments

Treatment		Bird BW		Hen age	Egg weight		
Feed[1]	Premix[2]	22 wk[3]	At 1st egg	at 1st egg	1st	2nd	3rd
		---------- g ----------		--- d ---	------------- g -------------		
Control		2530.2	3250.5[bc]	183.6	48.5[abc]	51.1	51.1
Fibre dilute		2552.5	3361.2[a]	185.5	49.5[a]	51.0	52.2
Scatter		2520.3	3276.4[b]	183.7	48.7[ab]	51.4	51.5
Skip-a-day		2488.3	3191.3[c]	183.2	47.5[c]	49.8	50.6
Sorting		2499.6	3302.1[ab]	185.0	48.2[bc]	51.4	52.0
SEM		18.9	26.7	1.0	0.4	0.5	0.5
	Control	---[4]	3266.4	184.1	48.5	51.2	51.6
	Premix		3282.1	184.2	48.5	50.7	51.4
	SEM		24.0	0.6	0.3	0.3	0.3
Source of variation		------------------------- Probability -------------------------					
Feed treatment		0.39	0.006	0.44	0.021	0.18	0.22
Premix treatment			0.57	0.92	0.91	0.26	0.61
Feed x premix			0.08	0.45	0.08	0.45	0.78

[1]Feed treatments: Control: standard mash diet, fed daily; Fibre dilute: mash diet (25% oat hulls), fed daily; Scatter: standard diet in pellet form scattered on litter, fed daily; Skip-a-day: standard diet double daily allotment fed on alternate days; Sorting: standard mash diet fed every day; birds resorted every 4 wk based on BW. Pen mean BW and BW targets were used to determine daily feed allotments in all treatments.
[2]Premix treatments: Control standard breeder diet fed daily; Premix standard breeder diet with 100% additional premix fed daily. Mean BW and BW targets were used to determine daily feed allotments.
[3]Pullet BW at transfer to individual cages.
[4]Premix treatment started at 22 wk of age.
[a-c]LS-means within a column within effect with no common superscript differ (P<0.05).

Table 3-4. Egg weight and hen age variability (CV) at sexual maturity in 5 broiler breeder feed treatments and 2 premix treatments

Treatment		Bird BW		Hen age	Egg weight		
Feed[1]	Premix[2]	22 wk[3]	At 1st egg	at 1st egg	1st	2nd	3rd
		CV (%)					
Control		15.0[a]	8.46	5.84	10.1	8.89	8.34
Fibre dilute		15.0[a]	9.51	5.83	9.37	8.33	8.85
Scatter		11.0[b]	8.23	6.03	9.11	8.19	7.41
Skip-a-day		12.7[b]	8.04	4.85	8.38	8.09	7.90
Sorting		6.2[c]	9.04	5.33	8.96	7.99	7.25
SEM		0.8	0.5	0.4	0.5	0.5	0.5
	Control	---[4]	8.74	5.86	8.59[b]	8.04	7.98
	Premix		8.57	5.30	9.76[a]	8.56	7.92
	SEM		0.3	0.3	0.3	0.3	0.3
Source of variation		Probability					
Feed treatment		<0.0001	0.17	0.24	0.28	0.75	0.17
Premix treatment			0.72	0.13	0.011	0.24	0.91
Feed x premix			0.23	0.12	0.15	0.96	0.53

[1]Feed treatments: Control: standard mash diet, fed daily; Fibre dilute: mash diet (25% oat hulls), fed daily; Scatter: standard diet in pellet form scattered on litter, fed daily; Skip-a-day: standard diet double daily allotment fed on alternate days; Sorting: standard mash diet fed every day; birds resorted every 4 wk based on BW. Pen mean BW and BW targets were used to determine daily feed allotments in all treatments.
[2]Premix treatments: Control standard breeder diet fed daily; Premix standard breeder diet with 100% additional premix fed daily. Mean BW and BW targets were used to determine daily feed allotments.
[3]Pullet BW at transfer to individual cages.
[4] Premix treatment started at 22 wk of age.
[a,b]LS-means within a column within effect with no common superscript differ (*P*<0.05).

Table 3-5. The effects of 5 broiler breeder feed treatments and 2 premix treatments on first egg characteristics

Feed[1]	Premix[2]	Egg weight	Albumen	Yolk	Shell	Albumen quality	Shell thickness
		---- g ----	------ % of egg weight -----			-- HU[3] --	-- µm --
Control		49.1	63.6	27.6	8.85	96.7	310.1
Fibre dilute		50.0	64.1	27.3	8.63	95.4	309.5
Scatter		50.2	63.5	28.0	8.70	96.2	307.4
Skip-a-day		48.1	63.3	28.0	8.67	97.5	309.5
Sorting		49.5	63.5	27.7	8.83	95.5	310.6
SEM		0.7	0.4	0.4	0.1	0.5	4.1
	Control	49.4	63.7	27.6	8.70	96.5	307.3
	Premix	49.3	63.5	27.8	8.78	96.0	311.6
	SEM	0.5	0.2	0.2	0.1	0.4	2.3
Source of variation		-------------------------------- Probability[4] --------------------------------					
Feed treatment		0.36	0.67	0.58	0.12	0.07	0.98
Premix treatment		0.88	0.50	0.22	0.21	0.36	0.19
Feed x premix		0.73	0.80	0.92	0.15	0.47	0.98

[1]Feed treatments: Control: standard mash diet, fed daily; Fibre dilute: mash diet (25% oat hulls), fed daily; Scatter: standard diet in pellet form scattered on litter, fed daily; Skip-a-day: standard diet double daily allotment fed on alternate days; Sorting: standard mash diet fed every day; birds resorted every 4 wk based on BW. Pen mean BW and BW targets were used to determine daily feed allotments in all treatments.
[2]Premix treatments: Control standard breeder diet fed daily: Premix standard breeder diet with 100% additional premix fed daily. Mean BW and BW targets were used to determine daily feed allotments.
[3]Haugh Units. HU = 100 $\log_{10}$ (h – 1.7 $w^{0.37}$ + 7.6); h= albumen height, w= egg weight.
[4]Significance assessed at P<0.05.

Table 3-6. Effects of 5broiler breeder feed treatments and 2 premix treatments on the variability of first egg characteristics

Feed[1]	Premix[2]	Egg weight	Albumen	Yolk	Shell	Albumen quality	Shell thickness
		---------- CV (%) ----------					
Control		8.29	6.27	11.9	12.7	7.15	10.4
Fibre dilute		9.41	6.71	13.1	12.6	7.38	10.4
Scatter		8.70	7.93	13.6	13.4	6.22	8.35
Skip-a-day		7.65	6.06	11.5	12.2	6.00	10.4
Sorting		8.78	6.71	12.9	11.9	7.26	11.1
SEM		0.6	0.8	1.3	1.3	0.4	1.0
	Control	8.36	5.90[b]	11.8	11.4[b]	6.78	10.8
	Premix	8.77	7.58[a]	13.4	13.7[a]	6.82	9.42
	SEM	0.5	0.5	0.8	0.6	0.3	0.6
Source of variation		---------- Probability ----------					
Feed treatment		0.31	0.57	0.78	0.93	0.06	0.43
Premix treatment		0.45	0.016	0.15	0.02	0.92	0.13
Feed x premix		0.59	0.30	0.73	0.09	0.014	0.52

[1]Feed treatments: Control: standard mash diet, fed daily; Fibre eilute: mash diet (25% oat hulls), fed daily; Scatter: standard diet in pellet form scattered on litter, fed daily; Skip-a-day: standard diet double daily allotment fed on alternate days; Sorting: standard mash diet fed every day; birds resorted every 4 wk based on BW. Pen mean BW and BW targets were used to determine daily feed allotments in all treatments.
[2]Premix treatments: Control standard breeder diet fed daily: Premix standard breeder diet with 100% additional premix fed daily. Mean BW and BW targets were used to determine daily feed allotments.
[a,b]LS-means within a column with no common superscript differ (P<0.05).

Table 3-7. Production traits to 40 wk of age in 5 broiler breeder feed treatments and 2 premix treatments

Treatment: Feed[1]	Treatment: Premix[2]	Total eggs[3]	Normal eggs[4]	Small eggs[5]	Settable eggs[6]	Hen day	40 wk egg wt.[7]	Pre-hatch egg wt.[8]	Total egg mass	Prime sequence	Average sequence
		#				%	g			d	
Control		80.0	79.0	7.80	71.2	80.8	63.4	61.4	4694	11.6	4.10
Fibre dilute		77.2	75.5	6.89	68.6	81.4	62.8	61.4	4511	11.9	4.46
Scatter		79.9	78.7	4.92	73.8	83.6	63.6	61.9	4745	13.8	4.84
Skip-a-day		81.6	80.4	9.49	70.9	84.4	62.1	59.9	4684	14.5	4.81
Sorting		78.3	77.1	6.89	70.2	81.9	62.2	60.8	4538	11.4	4.21
SEM		1.95	1.96	1.81	1.94	1.33	0.61	0.62	110.1	1.48	0.24
	Control	78.5	77.3	6.88	70.4	81.5	62.7	61.1	4589	12.6	4.37
	P)remix	80.3	79.0	7.51	71.5	83.4	63.0	61.1	4680	12.6	4.57
	SEM	1.20	1.23	1.15	1.24	0.83	0.40	0.42	69.0	0.95	0.17
Source of variation		Probability[9]									
Feed treatment		0.55	0.48	0.52	0.46	0.31	0.26	0.30	0.50	0.51	0.12
Premix treatment		0.30	0.34	0.70	0.54	0.12	0.97	0.64	0.36	0.99	0.42
Feed x premix		0.83	0.85	0.76	0.85	0.43	0.70	0.80	0.85	0.85	0.34

[1]Feed treatments to applied to female parent stock from 3 to 22 wk of age: Control: standard mash diet, fed daily; Fibre dilute: mash diet (25% oat hulls), fed daily; Scatter: standard diet in pellet form scattered on litter, fed daily; Skip-a-day: standard diet double daily allotment fed on alternate days; Sorting: standard mash diet fed every day; birds resorted every 4 wk based on BW. Pen mean BW and BW targets were used to determine daily feed allotments in all treatments.
[2]Premix treatments to applied to female parent stock from 22 to 40 wk of age: Control standard breeder diet fed daily: Premix standard breeder diet with 100% additional premix fed daily. Mean BW and BW targets were used to determine daily feed allotments.
[3]Total eggs excluding double yolk, deform, soft shell, membranous and broken eggs. Value includes all sizes of eggs.
[4]All normal eggs.
[5]Egg weights below 52 g.
[6]Normal minus small eggs.
[7]Egg weights from 3 d prior to dissection (40 wk of age).
[8]Eggs collected for 3 d prior to collection of eggs incubated for the broiler experiment.
[9]Significance assessed at $P<0.05$.

Table 3-8. Variation in production traits to 40 wk of age in 5 broiler breeder feed treatments and 2 premix treatments

Treatment		Total	Normal	Small	Settable		40 wk	Pre-hatch	Total egg
Feed[1]	Premix[2]	eggs[3]	eggs[4]	eggs[5]	eggs[6]	Hen day	egg wt.[7]	egg wt.[8]	mass
		CV (%)							
Control		14.6	14.6	109.6	16.4	10.6	5.96	6.35	12.1
Fibre dilute		19.5	21.1	113.2	22.8	11.7	7.34	7.07	19.5
Scatter		16.6	17.1	120.6	15.4	8.7	6.30	6.62	14.5
Skip-a-day		12.7	12.5	102.9	17.3	6.97	6.96	6.77	12.5
Sorting		14.7	15.9	116.7	17.6	9.7	5.67	6.52	13.9
SEM		2.04	2.25	14.4	2.48	1.46	0.61	0.60	2.51
	Control	17.4	17.9	110.1	19.3	9.98	5.91[b]	6.36	17.0[a]
	Premix	13.9	14.4	115.1	16.5	9.06	6.99[a]	6.97	12.1[b]
	SEM	1.28	1.50	8.49	1.60	0.98	0.36	0.34	1.49
Source of variation		Probability[9]							
Feed treatment		0.23	0.15	0.92	0.30	0.25	0.93	0.31	0.28
Premix treatment		0.07	0.13	0.68	0.23	0.51	0.23	0.05	0.03
Feed x premix		0.42	0.41	0.90	0.40	0.54	0.99	0.40	0.34

[1]Feed treatments to applied to female parent stock from 3 to 22 wk of age: Control: standard mash diet, fed daily; Fibre dilute: mash diet (25% oat hulls), fed daily; Scatter: standard diet in pellet form scattered on litter, fed daily; Skip-a-day: standard diet double daily allotment fed on alternate days; Sorting: standard mash diet fed every day; birds resorted every 4 wk based on BW. Pen mean BW and BW targets were used to determine daily feed allotments in all treatments.
[2]Premix treatments to applied to female parent stock from 22 to 40 wk of age: Control standard breeder diet fed daily: Premix standard breeder diet with 100% additional premix fed daily. Mean BW and BW targets were used to determine daily feed allotments.
[3]Total eggs excluding double yolk, deform, soft shell, membranous and broken eggs. Value includes all sizes of eggs.
[4]All normal eggs.
[5]Egg weights below 52 g.
[6]Normal minus small eggs.
[7]Egg weights from 3 d prior to dissection (40 wk of age).
[8]Eggs collected for 3 d prior to collection of eggs incubated for the broiler experiment.
[9]Significance assessed at P<0.05.
[a,b]LS-means within a column with no common superscript differ (*P*<0.05).

Table 3-9. Hen carcass traits in 5 broiler breeder feed treatments and 2 premix treatments at sexual maturity[1]

Treatment		BW[4]	Shank length[5]	Chest width[6]	*P. major*	*P. minor*	Fat pad	Liver	Stroma	Oviduct	Ovary	LYF[7]	POF[8]	F1[9]
Feed[2]	Premix[3]	-- g --	-------- mm --------		---------- g ----------							------- # -------		-- g --
Control		3316[abc]	105.5	108.0[ab]	585.4[bc]	170.8[bc]	66.2[a]	51.4	7.60	59.0	65.9	7.36	4.22	13.7[a]
Fibre dilute		3394[a]	106.2	109.9[a]	617.1[a]	178.2[a]	67.1[a]	51.9	7.54	61.2	65.9	7.40	4.29	13.7[a]
Scatter		3272[bc]	106.2	107.9[ab]	589.0[abc]	172.4[ab]	59.2[b]	49.5	7.36	59.0	65.7	7.21	4.10	13.8[a]
Skip-a-day		3243[c]	105.8	106.0[b]	562.3[c]	164.6[c]	70.6[a]	51.2	7.66	56.7	68.0	7.61	4.24	13.3[b]
Sorting		3362[ab]	105.4	109.1[a]	611.9[ab]	173.7[ab]	71.9[a]	51.0	7.70	57.4	67.6	7.40	4.24	14.0[a]
SEM		32.4	0.6	0.8	10.0	2.4	2.3	0.9	0.3	1.2	1.8	0.2	0.1	0.1
	Control	3301	105.6	107.9	591.5	169.6	67.1	51.0	7.57	59.0	67.2	7.44	4.22	13.8
	Premix	3335	106.0	108.4	595.3	174.3	66.8	51.0	7.58	58.3	66.0	7.36	4.21	13.7
	SEM	25.7	0.4	0.6	8.7	1.9	2.0	0.6	0.2	0.9	1.1	0.1	0.1	0.1
Source of variation		---------- Probability ----------												
Feed treatment		0.03	0.84	0.02	0.009	0.02	0.01	0.44	0.92	0.15	0.84	0.54	0.49	0.02
Premix treatment		0.36	0.40	0.56	0.73	0.10	0.92	0.98	0.95	0.59	0.42	0.57	0.87	0.62
Feed x premix		0.05	0.38	0.05	0.10	0.006	0.11	0.72	0.95	0.24	0.96	0.92	0.94	0.23

[1]Sexual maturity after 3rd egg
[2]Feed treatments: Control: standard mash diet, fed daily: Fibre dilute: mash diet (25% oat hulls), fed daily: Scatter: standard diet in pellet form scattered on litter, fed daily: Skip-a-day: standard diet double daily allotment fed on alternate days: Sorting: standard mash diet fed every day; birds resorted every 4 wk based on BW. Pen mean BW and BW targets were used to determine daily feed allotments in all treatments.
[3]Premix treatments: Control standard breeder diet fed daily: Premix standard breeder diet with 100% additional premix fed daily. Mean BW and BW targets were used to determine daily feed allotments.
[4]BW taken prior to processing.
[5]Shank length = t*ibiotarsus* measured from top of flexed hock joint to bottom of footpad.
[6]Chest width = measured 2.5 cm below clavicle bones at widest point on the chest.
[7]LYF = large yellow follicles greater than 10 mm in diameter.
[8]POF = post ovulatory folicle.
[9]F1 = LYF on the ovary with the greatest weight.
[a-c]LS-means within a column with no common superscript differ ($P<0.05$).

Table 3-10. Covariate BW analysis of broiler breeder carcass traits in 5 feed treatments and 2 premix treatments at sexual maturity

Treatment[1]		BW[4]	SEM	Shank length[5]	SEM	Chest width[6]	SEM	*P. major*	SEM	*P. minor*	SEM	Fat pad	SEM	Liver	SEM	Stroma	SEM	Oviduct	SEM	Ovary	SEM	LYF[7]	SEM	POF[8]	SEM
Feed[2]	Premix[3]	-- g --		------------- mm -------------				---------- g ----------														-------------- # --------------			
Control		3294^{bc}	31.0	105.2	0.40	107.6	0.66	587.3^{bc}	5.11	171.7	1.95	66.3^{b}	1.88	51.8	0.86	7.48	0.21	58.4^{b}	0.91	65.9	1.57	7.32	0.16	4.24	0.08
Fibre dilute		3398^{a}	31.0	105.7	0.41	108.2	0.66	597.8^{ab}	5.16	172.8	1.97	65.1^{b}	1.90	51.2	0.87	7.36	0.21	61.1^{a}	0.92	64.6	1.59	7.33	0.16	4.26	0.08
Scatter		3271^{bc}	31.4	105.9	0.41	108.7	0.67	603.9^{a}	5.18	172.8	1.97	63.3^{b}	1.91	49.5	0.88	7.50	0.21	58.7^{ab}	0.92	67.8	1.59	7.33	0.16	4.15	0.08
Skip-a-day		3232^{c}	31.0	106.1	0.41	107.2	0.66	578.6^{c}	5.15	168.3	1.96	72.6^{a}	1.90	52.0	0.86	7.88	0.21	57.1^{b}	0.92	69.5	1.58	7.72	0.16	4.29	0.08
Sorting		3354^{ab}	31.0	105.0	0.40	108.1	0.66	597.0^{ab}	5.12	171.0	1.95	71.6^{a}	1.89	50.4	0.86	7.56	0.21	57.8^{b}	0.91	66.3	1.57	7.31	0.16	4.23	0.08
	Control	3292	20.0	105.6	0.26	108.0	0.42	595.4	3.29	170.3	1.24	67.8	1.22	51.1	0.55	7.61	0.13	59.1	0.58	67.8	1.00	7.46	0.10	4.24	0.05
	Premix	3328	19.9	105.6	0.26	108.0	0.42	590.4	3.28	172.3	1.23	67.8	1.21	50.9	0.55	7.50	0.13	58.1	0.58	65.8	1.00	7.34	0.10	4.23	0.05
Source of variation		---------- Probability ----------																							
Feed tmt		0.001		0.22		0.58		0.005		0.47		0.001		0.22		0.47		0.03		0.24		0.29		0.79	
BW		--		<0.0001		<0.0001		<0.0001		<0.0001		<0.0001		<0.0001		<0.0001		<0.0001		<0.0001		<0.0001		0.001	
Premix tmt		0.20		0.89		0.83		0.28		0.26		0.96		0.86		0.58		0.20		0.17		0.40		0.90	
BW		--		<0.0001		<0.0001		<.00001		<0.0001		<0.0001		<0.0001		<0.0001		<0.0001		<0.0001		<0.0001		<0.0001	
Feed x premix		0.004		0.26		0.88		0.02		0.66		0.008		0.26		0.47		0.03		0.54		0.68		0.96	
BW		--		<0.0001		<0.0001		<0.0001		<0.0001		<0.0001		<0.0001		<0.0001		0.001		<0.0001		<0.0001		0.001	

[1]Sexual maturity after 3rd egg
[2]Feed treatments: Control: standard mash diet, fed daily: Fibre dilute: mash diet (25% oat hulls), fed daily: Scatter: standard diet in pellet form scattered on litter, fed daily: Skip-a-day: standard diet double daily allotment fed on alternate days: Sorting: standard mash diet fed every day; birds resorted every 4 wk based on BW. Pen mean BW and BW targets were used to determine daily feed allotments in all treatments.
[3]Premix treatments: Control standard breeder diet fed daily: Premix standard breeder diet with 100% additional premix fed daily. Mean BW and BW targets were used to determine daily feed allotments.
[4]BW taken prior to processing.
[5]Shank length = t*ibiotarsus* measured from top of flexed hock joint to bottom of footpad.
[6]Chest width = measured 2.5 cm below clavicle bones at widest point on the chest.
[7]LYF = large yellow follicles greater than 10 mm in diameter.
[8]POF = post ovulatory folicle.
[a-d]LS-means within a column with no common superscript differ (P<0.05).

Table 3-11. Hen carcass trait variability (CV) in 5 broiler breeder feed treatments and 2 premix treatments at sexual maturity[1]

Treatment		BW[4]	Shank length[5]	Chest width[6]	*P. major*	*P. minor*	Fat pad	Liver	Stroma	Oviduct	Ovary	LYF[7]	POF[8]	F1[9]
Feed[2]	Premix[3]	CV (%)												
Control		8.55	3.89	6.34	11.5	11.3	27.0	14.3	27.6	14.3[ab]	23.9	22.1	17.5	10.8
Fibre dilute		9.18	4.01	7.40	14.6	15.6	25.4	15.5	31.3	14.4[ab]	21.5	19.7	15.9	10.6
Scatter		7.64	3.86	5.69	13.1	12.1	26.6	14.1	19.8	10.6[b]	20.9	18.1	9.62	11.1
Skip-a-day		7.55	3.83	7.30	14.3	14.4	24.7	15.0	22.3	17.1[a]	21.7	17.5	16.3	12.6
Sorting		8.58	3.32	7.57	14.0	13.5	30.2	18.0	28.3	11.9[b]	23.1	19.4	16.6	10.4
SEM		0.6	0.2	0.8	1.1	1.7	2.0	1.5	2.9	1.4	2.7	1.5	2.4	1.4
	Control	8.12	3.71	6.83	13.4	13.3	25.5	15.5	25.8	14.1	21.3	18.7	17.0	10.6
	Premix	8.47	3.86	6.89	13.6	13.4	28.1	15.3	26.0	13.3	23.2	20.0	13.3	11.5
	SEM	0.4	0.2	0.5	0.7	1.1	1.3	1.0	2.2	1.1	1.6	1.0	1.6	0.8
Source of variation		Probability												
Feed treatment		0.29	0.31	0.37	0.29	0.40	0.38	0.24	0.08	0.05	0.93	0.24	0.20	0.78
Premix treatment		0.53	0.51	0.93	0.90	0.96	0.17	0.87	0.96	0.62	0.41	0.38	0.11	0.41
Feed x premix		0.10	0.84	0.56	0.10	0.81	0.28	0.89	0.39	0.23	0.99	0.35	0.14	0.94

[1]Sexual maturity after 3[rd] egg

[2]Feed treatments: Control: standard mash diet, fed daily; Fibre Dilute: mash diet (25% oat hulls), fed daily; Scatter: standard diet in pellet form scattered on litter, fed daily; Skip-a-Day: standard diet double daily allotment fed on alternate days; Sorting: standard mash diet fed every day; birds resorted every 4 wk based on BW. Pen mean BW and BW targets were used to determine daily feed allotments in all treatments.

[3]Premix treatments: Control standard breeder diet fed daily; Premix standard breeder diet with 100% additional premix fed daily. Mean BW and BW targets were used to determine daily feed allotments.

[4]BW taken prior to processing.

[5]Shank length = t*ibiotarsus* measured from top of flexed hock joint to bottom of footpad.

[6]Chest width = measured 2.5 cm below clavicle bones at widest point on the chest.

[7]LYF = large yellow follicles greater than 10 mm in diameter.

[8]POF = post ovulatory folicle.

[9]F1 = LYF on the ovary with the greatest weight.

Table 3-12. Hen carcass traits in 5 broiler breeder feed treatments and 2 premix treatments at 40 wk of age

Treatment		BW[3]	Shank length[4]	Chest width[5]	*P. major*	*P. minor*	Fat pad	Liver	Stroma	Oviduct	Ovary	LYF[6]	POF[7]	F1[8]
Feed[1]	Premix[2]	-- kg --	-------- mm --------		---------------------------------- g ----------------------------------							--------- # ---------		-- g --
Control		3.69	105.2[b]	108.6[a]	619.1	189.6	105.5	57.8	8.84	64.3	57.7	5.48	3.31	16.6
Fibre dilute		3.74	108.7[a]	109.0[a]	635.0	186.0	105.1	54.7	8.97	63.9	62.0	5.88	3.80	16.0
Scatter		3.65	107.2[ab]	106.2[ab]	598.5	181.2	107.0	55.8	9.67	64.0	61.0	5.86	3.51	17.1
Skip-a-day		3.61	106.6[ab]	105.0[b]	586.9	171.6	105.8	54.5	9.43	64.3	58.4	5.38	3.88	16.8
Sorting		3.69	106.4[b]	105.6[b]	599.0	183.4	109.6	56.8	9.14	62.5	57.7	5.18	3.46	16.7
SEM		0.03	0.7	1.0	13.0	4.3	4.6	2.1	0.3	1.6	1.7	0.2	0.1	0.4
	Control	3.69	106.8	106.8	606.5	181.2	106.3	56.5	9.11	64.2	60.6	5.55	3.69	16.8
	Premix	3.66	106.8	106.9	608.9	183.6	106.9	55.3	9.31	63.4	58.1	5.56	3.50	16.5
	SEM	0.02	0.6	0.8	9.4	3.2	2.7	1.2	0.2	1.0	1.1	0.1	0.1	0.3
Source of variation		-- Probability --												
Feed treatment		0.07	0.04	0.03	0.12	0.09	0.96	0.77	0.36	0.93	0.28	0.06	0.11	0.43
Premix treatment		0.38	0.99	0.94	0.85	0.60	0.87	0.52	0.51	0.54	0.12	0.96	0.24	0.59
Feed x premix		0.45	0.12	0.07	0.56	0.14	0.89	0.34	0.68	0.52	0.18	0.05	0.29	0.14

[1]Feed treatments: Control: standard mash diet, fed daily: Fibre Dilute: mash diet (25% oat hulls), fed daily: Scatter: standard diet in pellet form scattered on litter, fed daily: Skip-a-Day: standard diet double daily allotment fed on alternate days: Sorting: standard mash diet fed every day; birds resorted every 4 wk based on BW. Pen mean BW and BW targets were used to determine daily feed allotments in all treatments.
[2]Premix treatments: Control standard breeder diet fed daily: Premix standard breeder diet with 100% additional premix fed daily. Mean BW and BW targets were used to determine daily feed allotments.
[3]BW taken prior to processing.
[4]Shank length = t*ibiotarsus* measured from top of flexed hock joint to bottom of footpad.
[5]Chest width = measured 2.5 cm below clavicle bones at widest point on the chest.
[6]LYF = large yellow follicles greater than 10 mm in diameter.
[7]POF = post ovulatory folicle.
[8]F1 = LYF on the ovary with the greatest weight.
[a,b]LS-means within a column with no common superscript differ (P<0.05).

Table 3-13. Covariate (40 wk BW) analysis of broiler breeder carcass traits in 5 feed treatments and 2 premix treatments

Treatment[1]		BW[4]	SEM	Shank length[5]	SEM	Chest width[6]	SEM	*P. major*	SEM	*P. minor*	SEM	Fat pad	SEM	Liver	SEM	Stroma	SEM	Oviduct	SEM	Ovary	SEM	LYF[7]	SEM	POF[8]	SEM
Feed[2]	Premix[3]	--kg --		------------- mm -------------				-- g --														-------------- # --------------			
Control		3.70	0.03	105.4^{b}	0.52	108.0	1.06	612.7	10.9	185.9	3.99	106.0	4.36	58.3^{a}	1.26	8.83	0.34	64.6	1.23	58.1	1.54	5.49	0.19	3.35	0.19
Fibre dilute		3.73	0.03	108.1^{a}	0.49	107.8	1.00	621.7	10.3	183.2	3.76	101.3	4.10	52.8^{b}	1.16	8.85	0.32	64.0	1.15	61.2	1.45	5.78	0.17	3.72	0.18
Scatter		3.67	0.03	106.7^{b}	0.50	106.2	1.00	608.2	10.4	178.3	3.78	109.6	4.12	57.6^{a}	1.16	9.77	0.32	64.2	1.16	61.0	1.45	5.83	0.18	3.53	0.18
Skip-a-day		3.61	0.03	106.8^{ab}	0.48	109.4	0.98	602.6	10.1	175.5	3.68	109.4	4.01	56.3^{a}	1.13	9.66	0.31	63.8	1.12	58.6	1.41	5.40	0.15	3.80	0.18
Sorting		3.69	0.03	106.2^{b}	0.49	105.2	0.99	595.9	10.2	182.5	3.71	109.0	4.05	56.4^{a}	1.13	9.08	0.32	62.8	1.14	57.9	1.43	5.19	0.17	3.50	0.18
	Control	3.69	0.02	106.6	0.32	106.4	0.64	606.6	6.56	179.4	2.39	105.7	2.60	56.1	0.75	9.13	0.21	64.4	0.73	60.5	0.92	5.54	0.10	3.64	0.12
	Premix	3.66	0.02	106.7	0.32	106.7	0.64	609.4	6.53	182.4	2.39	108.5	2.59	56.4	0.74	9.37	0.20	63.4	0.73	58.2	0.91	5.51	0.12	3.53	0.12
Source of variation		-- Probability --																							
Feed tmt		0.12		0.004		0.68		0.46		0.32		0.56		0.02		0.11		0.86		0.30		0.06		0.44	
BW		--		<0.0001		<0.0001		<0.0001		<0.0001		<0.0001		<0.0001		<0.0001		0.73		0.04		0.48		0.35	
Premix tmt		0.38		0.810		0.71		0.77		0.37		0.45		0.78		0.42		0.32		0.08		0.86		0.52	
BW		--		<0.0001		<0.0001		<0.0001		<0.0001		<0.0001		<0.0001		<0.0001		0.78		0.03		0.42		0.27	
Feed x premix		0.50		0.002		0.07		0.68		0.21		0.59		0.003		0.23		0.12		0.26		0.09		0.68	
BW		--		<0.0001		<0.0001		<0.0001		<.00001		<0.0001		<0.0001		<0.0001		0.77		0.04		0.55		0.35	

[1]Sexual maturity after 3rd egg
[2]Feed treatments: Control: standard mash diet, fed daily: Fibre dilute: mash diet (25% oat hulls), fed daily: Scatter: standard diet in pellet form scattered on litter, fed daily: Skip-a-day: standard diet double daily allotment fed on alternate days: Sorting: standard mash diet fed every day; birds resorted every 4 wk based on BW. Pen mean BW and BW targets were used to determine daily feed allotments in all treatments.
[3]Premix treatments: Control standard breeder diet fed daily: Premix standard breeder diet with 100% additional premix fed daily. Mean BW and BW targets were used to determine daily feed allotments.
[4]BW taken prior to processing.
[5]Shank length = t*ibiotarsus* measured from top of flexed hock joint to bottom of footpad.
[6]Chest width = measured 2.5 cm below clavicle bones at widest point on the chest.
[7]LYF = large yellow follicles greater than 10 mm in diameter.
[8]POF = post ovulatory folicle.
[a-b]LS-means within a column with no common superscript differ (P<0.05).

Table 3-14. Hen carcass trait variability (CV) in 5 broiler breeder feed treatments and 2 premix treatments at 40 wk of age

Treatment		BW[3]	Shank length[4]	Chest width[5]	*P. major*	*P. minor*	Fat pad	Liver	Stroma	Oviduct	Ovary	LYF[6]	POF[7]	F1[8]
Feed[1]	Premix[2]	CV (%)												
Control		5.96	3.40	7.21	18.6	17.1	33.6	15.5	29.6	14.0	17.9	16.4	31.9	20.4
Fibre dilute		6.91	3.13	7.98	16.2	19.7	32.4	12.4	26.6	13.3	18.2	14.7	34.3	33.7
Scatter		6.26	3.51	8.99	14.5	17.0	28.6	12.4	26.2	10.1	16.2	14.8	32.3	15.7
Skip-a-day		6.05	3.58	8.25	15.7	18.2	26.9	20.8	22.1	10.8	18.1	14.2	39.5	13.7
Sorting		5.78	3.55	7.21	15.6	11.2	28.0	11.7	23.7	14.2	19.7	21.6	42.5	22.8
SEM		0.9	0.4	0.7	2.3	2.3	3.4	3.3	3.5	2.4	2.5	3.9	4.1	5.7
	Control	6.46	3.61	7.25[b]	17.2	17.7	28.9	16.8	27.2	14.3	19.1	18.2	39.1	22.6
	Premix	5.92	3.25	8.61[a]	15.0	15.6	30.9	12.2	24.1	10.7	17.0	14.4	33.1	19.9
	SEM	0.6	0.2	0.4	1.3	0.4	2.1	2.1	2.1	1.4	1.5	2.5	2.6	4.0
Source of variation		Probability												
Feed treatment		0.92	0.90	0.36	0.76	0.14	0.56	0.30	0.62	0.67	0.91	0.67	0.32	0.17
Premix treatment		0.50	0.23	0.03	0.24	0.38	0.50	0.13	0.31	0.08	0.32	0.29	0.12	0.64
Feed x premix		0.90	0.84	0.16	0.92	0.05	0.71	0.24	0.87	0.62	0.74	0.24	0.26	0.36

[1]Feed treatments: Control: standard mash diet, fed daily; Fibre dilute: mash diet (25% oat hulls), fed daily; Scatter: standard diet in pellet form scattered on litter, fed daily; Skip-a-day: standard diet double daily allotment fed on alternate days; Sorting: standard mash diet fed every day; birds resorted every 4 wk based on BW. Pen mean BW and BW targets were used to determine daily feed allotments in all treatments.
[2]Premix treatments: Control standard breeder diet fed daily; Premix standard breeder diet with 100% additional premix fed daily. Mean BW and BW targets were used to determine daily feed allotments.
[3]BW taken prior to processing.
[4]Shank length = *tibiotarsus* measured from top of flexed hock joint to bottom of footpad.
[5]Chest width = measured 2.5 cm below clavicle bones at widest point on the chest.
[6]LYF = large yellow follicles greater than 10 mm in diameter.
[7]POF = post ovulatory folicle.
[8]F1 = LYF on the ovary with the greatest weight.
[a,b]LS-means within a column with no common superscript differ (P<0.05).

Table 3-15. Hen BW from 22 to 40 wk of age for 5 broiler breeder feed treatments and 2 premix treatments

Treatment		Bird Age (wk)																	
Feed[1]	Premix[2]	22[3]	23	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40 wk
									------------- kg -------------										
Control		2.53	2.69	2.98	3.09	3.16	3.18	3.24	3.32^{ab}	3.43^{ab}	3.50^{ab}	3.55^{ab}	3.60	3.67^{ab}	3.67	3.70^{ab}	3.62	3.68^{ab}	3.69
Fibre dilute		2.55	2.72	3.01	3.12	3.21	3.23	3.31	3.41^{a}	3.51^{a}	3.57^{a}	3.61^{a}	3.65	3.71^{a}	3.74	3.75^{a}	3.67	3.71^{a}	3.74
Scatter		2.52	2.67	2.96	3.07	3.14	3.15	3.26	3.34^{ab}	3.43^{ab}	3.49^{ab}	3.53^{ab}	3.58	3.63^{ab}	3.65	3.66^{ab}	3.58	3.62^{ab}	3.65
Skip-a-day		2.50	2.56	2.90	3.01	3.09	3.13	3.20	3.28^{b}	3.36^{b}	3.42^{b}	3.48^{b}	3.53	3.57^{b}	3.60	3.62^{b}	3.54	3.58^{b}	3.61
Sorting		2.50	2.67	2.95	3.06	3.14	3.18	3.25	3.33^{ab}	3.43^{ab}	3.50^{ab}	3.53^{ab}	3.58	3.63^{ab}	3.66	3.67^{ab}	3.60	3.63^{ab}	3.69
SEM		0.02	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.04	0.03	0.03	0.03	0.06	0.03	0.05	0.03	0.03
	Control	---[4]	2.66	2.95	3.06	3.13	3.16	3.24	3.33	3.44	3.50	3.55	3.59	3.65	3.67	3.69	3.54^{b}	3.63	3.69
	Premix		2.67	2.97	3.08	3.16	3.18	3.26	3.34	3.43	3.49	3.53	3.58	3.64	3.65	3.66	3.67^{a}	3.66	3.66
	SEM		0.03	0.03	0.2	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Source of variation									------------- Probability -------------										
Feed treatment		0.39	0.07	0.22	0.23	0.07	0.16	0.10	0.03	0.02	0.04	0.055	0.07	0.04	0.06	0.03	0.33	0.04	0.07
Premix treatment			0.89	0.74	0.43	0.28	0.37	0.37	0.72	0.69	0.79	0.48	0.54	0.73	0.48	0.34	0.0004	0.41	0.38
Feed x premix			0.55	0.77	0.67	0.30	0.55	0.33	0.17	0.19	0.25	0.35	0.41	0.34	0.39	0.29	0.02	0.36	0.45

[1]Feed treatments: Control: standard mash diet, fed daily; Fibre dilute: mash diet (25% oat hulls), fed daily; Scatter: standard diet in pellet form scattered on litter, fed daily; Skip-a-day: standard diet double daily allotment fed on alternate days; Sorting: standard mash diet fed every day; birds resorted every 4 wk based on BW. Pen mean BW and BW targets were used to determine daily feed allotments in all treatments.
[2]Premix treatments: Control standard breeder diet fed daily; Premix standard breeder diet with 100% additional premix fed daily. Mean BW and BW targets were used to determine daily feed allotments.
[3]Pullet BW at transfer to individual cages.
[4]Premix treatment started at 22 wk of age.
[a-b]LS-means within a column within effect with no common superscript differ (P<0.05).

Table 3-16. Hen BW variation (CV) from 22 to 40 wk of age for 5broiler breeder feed treatments and 2 premix treatments

Treatment		Bird Age																	
Feed[1]	Premix[2]	22 wk[3]	23 wk	25 wk	26 wk	27wk	28 wk	29 wk	30 wk	31 wk	32 wk	33 wk	34 wk	35 wk	36 wk	37 wk	38 wk	39 wk	40 wk
		CV (%)																	
Control		15.3^{a}	10.7^{a}	8.14^{a}	6.60^{ab}	6.09	5.83	5.97	5.93^{b}	5.75	5.74	5.68	5.61	5.37	5.24	5.45	5.55	5.71	5.96
Fibre Dilute		15.2^{a}	13.3^{a}	9.79^{a}	8.41^{a}	7.42	7.46	7.20	7.21^{a}	7.17	6.78	6.87	6.70	6.72	6.81	6.72	6.85	7.05	6.91
Scatter		10.9^{b}	9.11^{a}	7.24^{ab}	6.59^{ab}	5.92	6.19	6.93	7.41^{a}	6.89	6.74	6.87	6.51	6.45	6.37	6.39	6.54	6.47	6.26
Skip-a-Day		12.7^{b}	12.0^{a}	9.28^{a}	8.01^{a}	6.75	6.56	6.35	6.44^{b}	6.22	6.29	6.39	6.39	6.19	6.06	5.77	5.86	6.03	6.05
Sorting		6.17^{c}	4.57^{b}	4.23^{b}	4.19^{b}	4.78	5.50	5.92	6.16^{b}	6.15	5.71	5.51	5.33	5.35	5.17	5.21	5.67	5.73	5.78
SEM		0.06	1.41	1.07	0.95	0.93	0.89	0.47	0.38	0.50	0.51	0.62	0.65	0.58	0.65	0.69	0.82	0.73	0.94
	Control	---[4]	11.1	8.31	7.32	6.83	6.89	6.81	6.78	6.73	6.46	6.60	6.40	6.23	6.20	6.05	6.46	6.53	6.46
	Premix		8.78	7.17	6.20	5.55	5.73	6.14	6.48	6.14	6.03	5.93	5.82	5.81	5.66	5.76	5.73	5.87	5.92
	SEM		1.23	0.88	0.72	0.57	0.53	0.30	0.29	0.32	0.33	0.39	0.40	0.38	0.42	0.44	0.49	0.44	0.55
Source of variation		Probability																	
Feed treatment		<0.0001	0.005	0.02	0.052	0.38	0.59	0.25	0.056	0.31	0.42	0.41	0.51	0.36	0.35	0.51	0.75	0.67	0.92
Premix treatment			0.21	0.37	0.28	0.13	0.14	0.12	0.48	0.22	0.36	0.25	0.32	0.44	0.38	0.64	0.30	0.30	0.50
Feed x premix			0.03	0.09	0.18	0.37	0.45	0.33	0.20	0.23	0.38	0.27	0.51	0.62	0.54	0.84	0.80	0.77	0.90

[1]Feed treatments: Control: standard mash diet, fed daily; Fibre dilute: mash diet (25% oat hulls), fed daily; Scatter: standard diet in pellet form scattered on litter, fed daily; Skip-a-day: standard diet double daily allotment fed on alternate days; Sorting: standard mash diet fed every day; birds resorted every 4 wk based on BW. Pen mean BW and BW targets were used to determine daily feed allotments in all treatments.
[2]Premix treatments: Control standard breeder diet fed daily; Premix standard breeder diet with 100% additional premix fed daily. Mean BW and BW targets were used to determine daily feed allotments.
[3]Pullet BW at transfer to individual cages.
[4]Premix treatment started at 22 wk of age.
[a-c]LS-means within a column within effect with no common superscript differ (P<0.05).

Table 3-17. Composition and analysis of broiler diets

Ingredient and analysis	Starter (0 to 14 d)	Grower (15 to 28 d)	Finisher (29 to 37 d)
	------------------------ g/kg	------------------------	
Ground corn	180.0	180.0	150.0
Wheat	429.3	532.2	580.3
Soybean meal (47.8% CP)	268.7	162.3	151.0
Fish meal - menhaden	30.0	50.0	35.1
Vegetable fat	37.7	33.6	41.3
Calcium carbonate	15.0	10.5	10.7
Choline chloride premix	5.0	5.0	5.0
Dicalcium phosphate	15.5	10.0	10.8
Broiler premix[1]	5.0	5.0	5.0
Salt	4.24	3.4	3.6
D, L-methionine	2.28	1.0	0.9
L-lysine	2.31	1.5	1.54
L-threonine	0.47	1.0	0.26
Vitamin E (5000 IU/kg)	3.0	3.0	3.0
Generic enzyme	0.5	0.5	0.5
Coccidiostat	0.5	0.5	0.5
Antibiotic growth promoter	0.5	0.5	0.5
Total:	1,000.0	1,000.0	1,000.0
Calculated nutrient composition			
CP (%)	23.0	20.2	19.0
ME (kcal/kg)	3,068	3,152	3,196
Calcium (%)	1.10	0.90	0.85
Available phosphorus (%)	0.50	0.45	0.42
Lysine (%)	1.35	1.10	1.01
Methionine (%)	0.52	0.34	0.27

[1]Broiler premix provided per kilogram of diet: vitamin A (retinyl acetate), 10,000 IU; cholecalciferol, 4,000 IU; vitamin E (DL-α-tocopheryl acetate), 50.0 IU; vitamin K, 4.00 mg; pantothenic acid, 15.0 mg; riboflavin, 10.0 mg; folacin, 2.00 mg; niacin, 65.0 mg; thiamine, 4.00 mg; pyridoxine, 5.00 mg; vitamin B12, 0.02 mg; biotin, 0.20 mg; iodine, 1.65 mg; Mn, 120 mg; Cu, 20.0 mg; Zn, 100 mg, Se, 0.30 mg; Fe, 80.0 mg.

Table 3-18. Broiler feed consumption

Breeder treatment		Feed intake[3]			
Feed[1]	Premix[2]	Starter 0-14 d	Grower 14-28 d	Finisher 28-37 d	Total
		-------------- g/bird/d --------------			--- g ---
Control		39.3	123.4	164.5	3757.5
Fibre Dilute		42.4	130.3	158.8	3847.5
Scatter		37.8	121.5	157.8	3598.3
Skip-a-day		38.3	123.0	160.2	3699.0
Sorting		40.3	126.8	164.7	3693.3
SEM		1.24	3.48	5.36	133.6
	Control	39.6	125.9	164.4	3775.6
	Premix	39.7	124.0	158.0	3662.6
	SEM	0.90	2.25	3.06	79.6
Source of variation		----------------- Probability[4] -----------------			
Feed treatment		0.12	0.42	0.84	0.76
Premix treatment		0.95	0.55	0.16	0.33
Feed x premix		0.59	0.86	0.86	0.83

[1]Feed treatments to applied to female parent stock from 3 to 22 wk of age: Control: standard mash diet, fed daily; Fibre dilute: mash diet (25% oat hulls), fed daily; Scatter: standard diet in pellet form scattered on litter, fed daily; Skip-a-day: standard diet double daily allotment fed on alternate days; Sorting: standard mash diet fed every day; birds resorted every 4 wk based on BW. Pen mean BW and BW targets were used to determine daily feed allotments in all treatments.
[2]Premix treatments to applied to female parent stock from 22 to 40 wk of age: Control: standard breeder diet fed daily: Premix standard breeder diet with 100% additional premix fed daily. Mean BW and BW targets were used to determine daily feed allotments.
[3]Intake calculated per pen basis: total feed consumed/number of birds per pen.
[4]Significance assessed at P<0.05.

Table 3-19. Broiler chick quality in 2 hatches for 5 broiler breeder feed treatments and 2 premix treatments

Breeder treatment		Hatch #1[1]			Hatch #2[2]		
Feed[3]	Premix[4]	BW	Residual yolk sac[5]	Length[6]	BW	Residual yolk sac[5]	Length[6]
		--------- g ---------		-- mm --	--------- g ---------		-- mm --
Control		42.0	5.00	186.5	43.1	5.18	186.3
Fibre dilute		41.6	4.81	185.9	42.6	5.02	184.1
Scatter		41.8	5.09	187.2	42.9	5.45	184.4
Skip-a-day		40.9	4.53	185.8	42.1	5.59	186.2
Sorting		41.6	4.62	185.9	42.5	5.91	187.1
SEM		0.4	0.2	0.8	0.5	0.3	1.5
	Control	41.6	4.85	186.4	42.7	5.47	187.0[a]
	Premix	41.5	4.77	186.2	42.6	5.40	184.3[b]
	SEM	0.3	0.1	0.5	0.3	0.2	0.9
Source of variation		------------------------------ Probability ------------------------------					
Feed treatment		0.35	0.10	0.70	0.65	0.21	0.58
Premix treatment		0.69	0.62	0.82	0.94	0.79	0.041
Feed x premix		0.71	0.31	0.89	0.96	0.41	0.29

[1]Hatch #1 eggs collected for 7 d starting when hens reached 33 wk of age.
[2]Hatch #2 eggs collected for 7 d starting when hens reached 36 wk of age.
[3]Feed treatments to applied to female parent stock from 3 to 22 wk of age: Control: standard mash diet, fed daily; Fibre dilute: mash diet (25% oat hulls), fed daily; Scatter: standard diet in pellet form scattered on litter, fed daily; Skip-a-day: standard diet double daily allotment fed on alternate days; Sorting: standard mash diet fed every day; birds resorted every 4 wk based on BW. Pen mean BW and BW targets were used to determine daily feed allotments in all treatments.
[4]Premix treatments to applied to female parent stock from 22 to 40 wk of age: Control standard breeder diet fed daily: Premix standard breeder diet with 100% additional premix fed daily. Mean BW and BW targets were used to determine daily feed allotments.
[5]Chicks were euthanized immediately after body measurements were taken; residual yolk sac was then removed and weighed.
[6]Measured from the beak to the toe, excluding the nail.
[a,b]LS-means within a column within effect with no common superscript differ (P<0.05).

Table 3-20. Variability (CV) of broiler chick quality in 2 hatches for 5 feed treatments and 2 premix treatments

Breeder treatment		Hatch #1[1]			Hatch #2[2]		
Feed[3]	Premix[4]	BW	Residual yolk sac[5]	Length[6]	BW	Residual yolk sac[5]	Length[6]
		CV (%)					
Control		7.21	27.2	2.96	6.86	25.8	2.68
Fibre dilute		8.90	27.7	3.08	8.22	24.5	3.34
Scatter		6.86	23.5	2.81	7.34	23.8	2.71
Skip-a-day		7.52	25.2	2.85	7.44	27.1	2.58
Sorting		6.97	23.8	2.69	6.55	25.1	2.53
SEM		0.6	1.8	0.3	0.7	1.8	0.3
	Control	7.32	25.8	3.00	7.27	24.7	2.91
	Premix	7.66	25.1	2.75	7.30	25.9	2.63
	SEM	0.4	1.2	0.2	0.4	1.1	0.2
Control	Control	6.76	24.7	3.03	6.42	26.8	2.33[b]
Control	Premix	7.66	29.7	2.88	7.31	24.8	3.03[b]
Fibre dilute	Control	9.06	29.7	3.11	8.64	23.8	4.18[a]
Fibre dilute	Premix	8.74	25.8	3.06	7.80	25.2	2.49[b]
Scatter	Control	6.86	25.2	3.00	6.46	25.1	2.61[b]
Scatter	Premix	6.85	21.7	2.62	8.21	22.5	2.81[b]
Skip-a-day	Control	7.51	24.1	3.29	7.75	25.9	2.84[b]
Skip-a-day	Premix	7.53	26.3	2.41	7.14	28.4	2.32[b]
Sorting	Control	6.42	25.4	2.57	7.06	21.7	2.58[b]
Sorting	Premix	7.52	22.2	2.81	6.04	28.5	2.48[b]
SEM		1.0	2.6	0.4	1.1	2.6	0.3
Source of variation		Probability					
Feed treatment		0.17	0.39	0.86	0.51	0.75	0.34
Premix treatment		0.58	0.70	0.28	0.96	0.45	0.31
Feed x premix		0.69	0.46	0.87	0.76	0.68	0.023

[1]Hatch #1 eggs collected for 7 d starting when hens reached 33 wk of age.
[2]Hatch #2 eggs collected for 7 d starting when hens reached 36 wk of age.
[3]Feed treatments to applied to female parent stock from 3 to 22 wk of age: Control: standard mash diet, fed daily; Fibre dilute: mash diet (25% oat hulls), fed daily; Scatter: standard diet in pellet form scattered on litter, fed daily; Skip-a-day: standard diet double daily allotment fed on alternate days; Sorting: standard mash diet fed every day; birds resorted every 4 wk based on BW. Pen mean BW and BW targets were used to determine daily feed allotments in all treatments.
[4]Premix treatments to applied to female parent stock from 22 to 40 wk of age: Control standard breeder diet fed daily: Premix standard breeder diet with 100% additional premix fed daily. Mean BW and BW targets were used to determine daily feed allotments.
[5]Chicks were euthanized immediately after body measurements were taken; residual yolk sac was then removed and weighed.
[6]Measured from the beak to the toe, excluding the nail.
[a,b]LS-means within a column within effect with no common superscript differ (*P*<0.05).

Table 3-21. Broiler chick quality and carcass composition at 37 d of age for 5 feed treatments and 2 premix treatments

Breeder treatment		Hatch	Bird BW			Carcass	Carcass	*P.*	*P.*		
Feed[1]	Premix[2]	length[3]	Hatch	1 wk	Final[4]	weight[5]	yield[6]	*major*[7]	*minor*[7]	Legs[7]	Wings[7]
		-- mm --	------------------ g ------------------				% BW	------------- % carcass -------------			
Control		176.8	43.3	152.9	2400	1602	66.2	24.7	5.44	30.6	11.3
Fibre dilute		184.0	42.9	156.8	2420	1609	66.2	24.4	5.35	31.5	11.3
Scatter		182.3	43.4	149.1	2390	1596	66.6	24.4	5.33	31.2	11.2
Skip-a-day		183.8	42.8	149.6	2400	1595	66.2	24.7	5.40	31.3	11.3
Sorting		186.8	42.9	156.8	2440	1622	66.4	24.9	5.42	31.2	11.1
SEM		2.33	0.37	2.61	30.0	19.83	0.37	0.23	0.06	0.20	0.12
	Control	183.6	42.9	153.7	2390	1594	66.4	24.7	5.41	31.0	11.2
	Premix	181.9	43.2	152.4	2430	1616	66.3	24.5	5.37	31.3	11.2
	SEM	1.71	0.23	1.86	20.0	11.31	0.72	0.15	0.04	0.15	0.07
Source of variation		-- Probability[8] --									
Feed treatment		0.08	0.63	0.14	0.65	0.87	0.92	0.45	0.67	0.06	0.76
Premix treatment		0.49	0.28	0.65	0.16	0.18	0.78	0.37	0.49	0.25	0.82
Feed x premix		0.36	0.90	0.27	0.055	0.11	0.73	0.52	0.28	0.26	0.06

[1]Feed treatments to applied to female parent stock from 3 to 22 wk of age: Control: standard mash diet, fed daily; Fibre dilute: mash diet (25% oat hulls), fed daily; Scatter: standard diet in pellet form scattered on litter, fed daily; Skip-a-day: standard diet double daily allotment fed on alternate days; Sorting: standard mash diet fed every day; birds resorted every 4 wk based on BW. Pen mean BW and BW targets were used to determine daily feed allotments in all treatments.
[2]Premix treatments to applied to female parent stock from 22 to 40 wk of age: Control standard breeder diet fed daily: Premix standard breeder diet with 100% additional premix fed daily. Mean BW and BW targets were used to determine daily feed allotments.
[3]Measured from the beak to the toe, excluding the nail.
[4]Final BW taken prior to processing at 37d of age.
[5]Carcass weight = eviscerated weight.
[6]Carcass yield = as a proportion of live BW.
[7]*P. major*, *P. minor*, leg and wing weights as a proportion of carcass weight.
[8]Significance assessed at $P<0.05$.

Table 3-22. Variation (CV) in broiler chick measures at hatch and final BW and carcass composition for 5 feed treatments and 2 premix treatments

Breeder treatment		Hatch	Bird BW			Carcass	Carcass	*P.*	*P.*		
Feed[1]	Premix[2]	length[3]	Hatch	1 wk	Final[4]	weight[5]	yield[6]	*major*[7]	*minor*[7]	Legs[7]	Wings[7]
		CV (%)									
Control		2.98	7.28	12.9	9.29	9.95	2.39	5.11	6.30	4.21	4.97
Fibre dilute		3.52	8.22	14.9	10.4	10.5	2.84	7.51	7.82	3.93	5.88
Scatter		3.19	7.71	11.7	9.19	10.7	2.46	6.99	8.17	4.88	5.92
Skip-a-day		2.36	7.12	13.8	8.72	9.57	2.57	6.64	6.73	4.83	5.21
Sorting		2.18	6.43	10.7	8.19	8.95	2.56	5.29	7.73	4.87	6.89
SEM		0.41	0.64	1.04	1.24	1.10	0.40	0.78	0.79	0.63	1.37
	Control	2.95	7.13	12.9	9.38	10.1	2.55	6.30	6.90	3.84[b]	5.32
	Premix	2.74	7.57	12.8	8.94	9.78	2.58	6.32	7.79	5.25[a]	6.23
	SEM	0.29	0.42	0.77	0.75	0.67	0.24	0.55	0.49	0.31	0.81
Source of variation		Probability									
Feed treatment		0.17	0.40	0.09	0.78	0.80	0.95	0.17	0.43	0.74	0.88
Premix treatment		0.62	0.46	0.90	0.68	0.74	0.93	0.98	0.22	0.005	0.44
Feed x premix		0.17	0.61	0.24	0.87	0.89	0.28	0.47	0.38	0.46	0.66

[1]Feed treatments to applied to female parent stock from 3 to 22 wk of age: Control: standard mash diet, fed daily; Fibre dilute: mash diet (25% oat hulls), fed daily; Scatter: standard diet in pellet form scattered on litter, fed daily; Skip-a-day: standard diet double daily allotment fed on alternate days; Sorting: standard mash diet fed every day; birds resorted every 4 wk based on BW. Pen mean BW and BW targets were used to determine daily feed allotments in all treatments.
[2]Premix treatments to applied to female parent stock from 22 to 40 wk of age: Control standard breeder diet fed daily: Premix standard breeder diet with 100% additional premix fed daily. Mean BW and BW targets were used to determine daily feed allotments.
[3]Measured from the beak to the toe, excluding the nail..
[4]Final BW taken prior to processing at 37d of age.
[5]Carcass weight = eviscerated weight.
[6]Carcass yield = as a proportion of live BW.
[7]PMajor, PMinor, Leg and Wing weights as a proportion of carcass weight.
[a,b]LS-means within a column within effect with no common superscript differ (P<0.05).

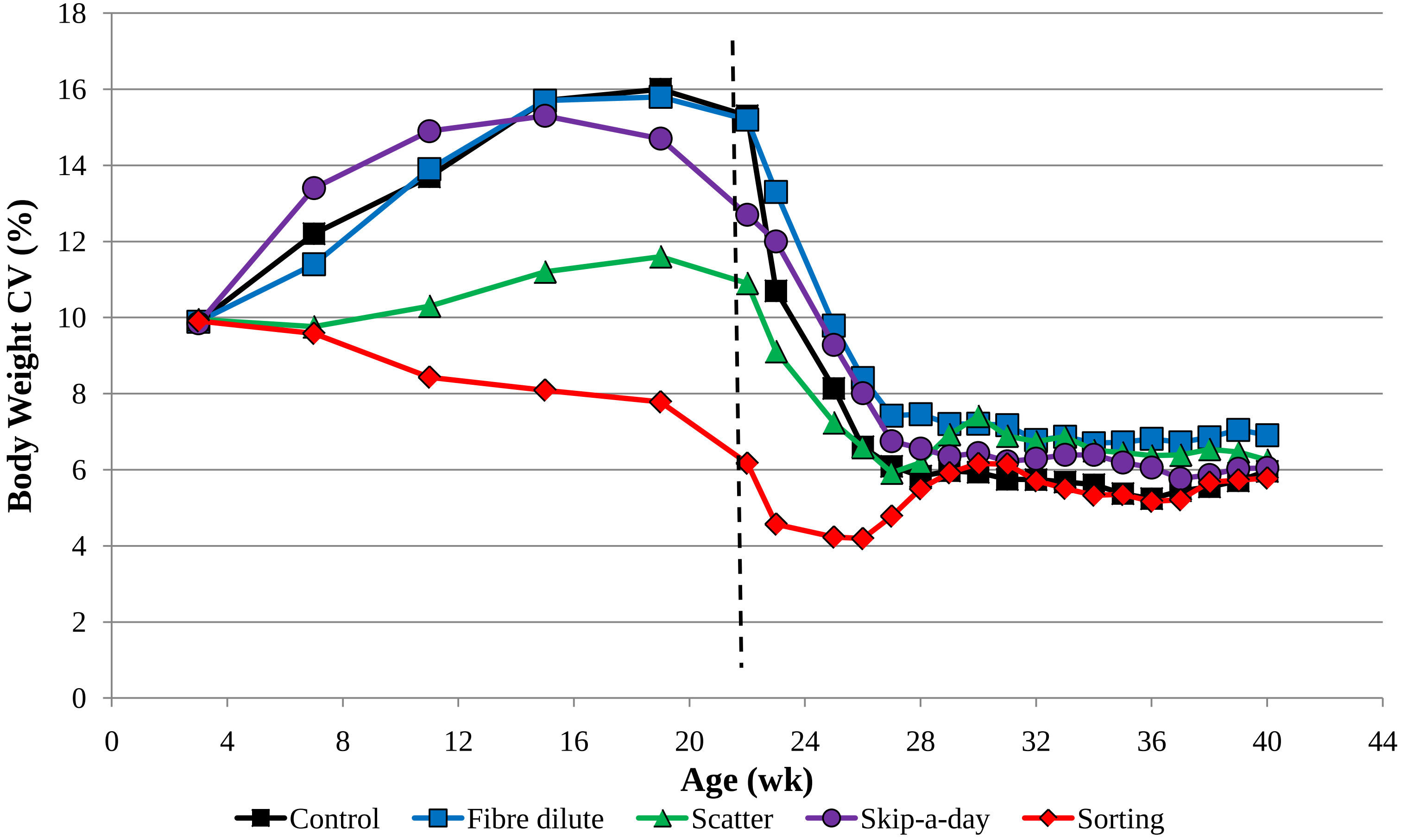

Figure 3-1. Flock BW variability from 3 to 40 wk of age in 5 pullet feed management treatments.

Chapter 4. Feed Management and Diet Fortification

4.1 Conclusions and Applications

The increasing global demand for poultry meat products and the industry's ability to diversify and market its products to a varied consumer base will reinforce the end-product focus of the poultry meat production system (FAO, 2009; AAFC; 2009). End product focus is necessary to meet market demand, however producing broilers of uniform BW and carcass composition with maximum breast meat yield requires a high quality initial base product (broiler chicks) of uniform BW (Pollock, 1999; Decuypere *et al*., 2003; Richards, 2003). Therefore, shifting the focus to the breeder hen to determine which management practices facilitate delivery of a high quality, uniform flock of broiler chicks is essential to the success of the whole poultry meat production system. Pertinent information addressing current breeder hen reproduction inefficiencies will assist breeder producers in making feed management decisions as well as increasing the production efficiency of the whole system.

This thesis demonstrated that variability in pullet flock BW and carcass traits during rearing can be affected by the feed management practice used. Two measures of flock uniformity have been used within the broiler breeder industry; 'variation from the population mean' and coefficient of variation (CV) (Aviagen, 2006). The 'variation from the population mean' represents the percent of the population within a specified range (±10 or 15% of the mean) however does not consider how widely dispersed a population is. The CV is the standard deviation expressed as a percent of the mean where in a normally distributed population 68.2% of the population will be within 1 standard deviation allowing for the comparison of a variable at various ages and between treatments. The CV was used as a measure of how uniformly a single variable was distributed within a defined population of birds. Specifically, the lower the variation or CV, the higher the uniformity of a variable's distribution within a population.

Previous feed management research has focused on bird welfare, behavior, performance and growth and development (Zuidhof *et al*., 1995; Hocking *et al*., 2004; Bachouse and Gous, 2006; Enting *et al*., 2007). However, a comparison between quantitative, qualitative and pre-emptive feed management practices and the effects on variability of flock BW and carcass traits has not been examined. Comparisons of the long-term effects of alternative rearing feed management practices on sexual maturity, reproduction and offspring have not been assessed. Feed treatments had a significant effect on the variability of flock BW at 22 wk; the sorting treatment resulted in the lowest variability. However, at sexual maturity and 40 wk of age, flock BW variability was similar in all feed treatments. Pullets were individually caged at 22 wk eliminating between bird competition, as a result energy intake was no longer dependent on the ability of a pullet to out compete conspecifics. Therefore, flock variation due to an unequal distribution of restricted feed allocations was no longer a factor as indicated by the converging BW CV curves for the feed treatments (Figure 3-1). Feed treatment affected feed and energy intake during rearing as well as how efficiently the limited resource was utilized. Feed treatment effects on carcass trait variability at 22 wk showed the same trend as BW and by sexual maturity was only evident in the oviduct weights but by 40 wk no difference in the variability of oviducts weights remained. Long-term effect of 22 wk carcass traits in skip-a-day and scatter treatments on reproduction and offspring not determined as individual caging eliminated competition and therefore treatment effects during the sexual maturity, reproductive phases. The addition of premix to the breeder diet has been used in industry to compensate for any unknown micronutrient deficiencies however, the benefits of this practices has not been examined. The premix treatment implemented at 22 wk had no effect on the variability in BW or carcass traits at sexual maturity but did have a negative effect on the variability of hen chest width at 40 wk of age. The effect of the premix treatment was found to be limited; no differences in the variability of hen BW or carcass traits was found however, there was an increase in the variability of first egg, albumen and shell weights. Feed treatment did not affect variability in first egg characteristics, production parameters, broiler chick quality or broiler BW and carcass traits at 37 d of age. Premix treatment effects on the variability in broiler chick quality at hatch as well as broiler BW and carcass traits at 37 d were restricted to chick length and leg weights at slaughter.

Challenges exist in commercial production, which can potentially affect flock variability were not factors in this research project. Pellet durability may be compromised with transportation and feed delivery systems that may decrease the proportion of feed in pellet form and increase the proportion of fines thereby decreasing the distribution of feed throughout the flock. Feed delivery systems may negatively affect the distribution of essential micronutrients as a result of poor distribution of feed or separation of diet ingredients. Feed for this project was prepared on-site, pelleted feed was distributed by hand directly onto the litter while mash diets were manually poured from feed pails into pan feeders, thereby minimizing the effects of transportation and feed delivery systems on the durability and quality of pellets and the distribution of ingredients.

Feed treatment was found to have a significant effect on 22 wk pullet carcass composition with differences in protein accretion (muscle mass), lipid deposition (fat pad) and liver weights. The feed/non-feed cycle of skip-a-day had a negative effect on carcass composition resulting in decreased *P. major* and *P. minor* weights and increased fat pad and liver weights that may delay sexual maturity or alter early egg characteristics. The trend established during rearing remained at sexual maturity with the exception of chest width and liver weights; however only external measures, shank length and chest width were significantly different at 40 wk. Covariate (BW) analysis of carcass traits at 22 wk of age revealed a significant effect of BW on carcass trait measures, however a significant feed treatment effect remained. Feed treatment effects for some carcass traits at sexual maturity and 40 wk of age were no longer significant with covariate (BW) analysis.

Feed treatment affected feed intake in Experiment 1 (3 to 22 wk) with the addition of 25% oat hulls increasing and pelleted feed decreasing the feed intake required to meet and maintain BW target profiles. Interestingly, the energetic conversion ratio (kcal/kg gain) revealed the addition of oat hulls decreased the energy required per kg gain while skip-a-day feeding increased the energy required per kg gain. Oat hulls may not be the nonnutritive filler as reported; rather oat hulls may have some nutritive value to poultry. Oat hulls may also increase feed efficiency by increasing the digestibility of wheat based diets or providing beneficial antimicrobial effects. Pelleted feed concentrates the feed source potentially decreasing waste thereby decreasing feed intake. Skip-a-day feeding altered carcass composition as well as feed efficiency, requiring increased energy intake per kg of gain. Feed and premix treatments did not affect feed intake of female breeders during the second and third experiments. Broiler feed consumption was not affected by maternal treatments.

4.2 Future Research

Pen-based research through all phases may reveal long term feed and premix treatment effects by approximating the conditions found in commercial production (relative to individual cages). Extending the end-point of the reproductive phase will determine long-term effects of feed management and premix treatments on hen BW and carcass trait uniformity as well as treatment effects on off spring. Varying the age at photostimulation may affect the variability in pullet BW and carcass traits (at sexual maturity), age of sexual maturity as well as early egg characteristics revealing treatment and age at photostimulation interactions. Delaying photostimulation would potentially increase the proportion of the flock having attained BW and carcass composition thresholds, therefore decreasing the variability in sexual maturation rates and early egg traits. Conduct carcass composition analysis to determine fee and premix treatment effects on lipid and protein deposition. Cost analysis including carcass composition and energy utilization would be beneficial in determining the efficiency of feed treatments. Cost analysis to determine the feasibility of implementing scatter or sorting feed management practices in a North American broiler breeder production setting. Conduct experimental trials in a commercial setting to establish the practical application of feed management and premix treatments.

This research project provides producers with additional information on the short-term cost of skip-a-day feeding which is widely used in the industry. The short term benefits of bird sorting and scatter feed practices as well as the potential for increasing feed efficiency with the addition of oat hulls will further assist hatching egg producers with production system decisions by providing information on opportunities which may reduce costs and increase production efficiency.

4.3. References

Agriculture and Agri-Food Canada. 2005. Canadian food trends to 2020: A long range consumer outlook. Ottawa, Canada. http://www4.agr.gc.ca/resources/prod/doc/agr/pdf/ft-ta_eng.pdf. Accessed December 2009.

Aviagen. 2006. Rearing (0-15 wk). Pages 4-21in: Ross 308 Parent Stock Management Manual. Aviagen Inc., Huntsville, Alabama, USA.

Backhouse, D., and R. M. Gous. 2006. Responses of adult broiler breeders to feeding time. World’s Poult. Sci. J. 62:269-281.

Decuypere, E., V. Bruggeman, G. F. Barbato, and J. Buyse. 2003. Growth and reproduction problems associated with selection for increased broiler meat production. Pages 27-38 in: Poultry Genetics, Breeding and Biotechnology. Muir, W. M. and S. E. Aggrey ed. CABI Publishing, Wallingford, Oxon, UK.

Enting, H., A. Veldman, M. W. A. Verstegen, and P. J. van der Aar. 2007. The effect of low-density diets on broiler breeder development and nutrient digestibility during the rearing period. Poult. Sci. 6:720-726.

FAO (Food and Agriculture Organization of the United Nations), 2009. The state of food and agriculture: livestock in the balance. FAO, Rome, Italy.

Pollock, D. L. 1999. A geneticist's perspective from within a broiler primary breeder company. Poult. Sci. 78:414-418.

Richards, M. P. 2003. Genetic regulation of feed intake and energy balance in poultry. Poult. Sci. 82:907-916.

Zuidhof, M.J., F. E. Robinson, J. J. R. Feddes, R. T. Hardin, J. L. Wilson, R. I. McKay, and M. Newcombe. 1995. The effects of nutrient dilution on the well-being and performance of female broiler breeders. Poult. Sci. 74:441-456.