THE PRODUCTIVE RESPONSE OF BROILER BREEDER HENS TO LIGHTING AND GROWTH MANIPULATION DURING REARING

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DECLARATION

We hereby declare that the research reported in this thesis does not contain material which as been accepted for the award of any other degree or diploma in another University and to the best of our knowledge, material previously published or written by another person, except where due reference is made in the text.

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ABSTRACT

This study was designed to provide information that would enable the development of a theory to predict age at sexual maturation and settable egg production in broiler breeder hens submitted to a variety of constant or increasing photoperiods and with diverse growth curves. Six trials were conducted using three strains of broiler breeder females housed in floor pens or individual cages. The treatments covered a wide range of growth profiles during the rearing period, from slow growth to achieve 2100g at 24 weeks, to fast growth achieving 2100g at 15 weeks of age. The lighting treatments included 8, 11 and 16-h constant photoperiods, photostimulation at various ages between 10 and 24 weeks, abrupt or gradual increases in daylength, and transfers to a10, 11, 12 or 16-h final photoperiod in lay.

The results show that broiler breeders exhibit photorefractoriness, and that the adult form starts developing from about 56 weeks of age. They also suggest that photorefractoriness contributes towards the accelerated decline in egg production observed at the end of the laying period. Relaxations of feed restriction during the rearing period and earlier transfers to a stimulatory photoperiod were successfully used to advance sexual maturity by up to 3 weeks compared with conventionally managed controls. Furthermore, birds subjected to constant photoperiods reached sexual maturity later than birds that had been photostimulated at 20 weeks of age. Settable egg production progressively improved when birds were transferred to stimulatory daylengths at older ages, until about 20 weeks, but subsequent delays in photostimulation did not result in any further increase in egg numbers. Delaying photostimulation of conventionally grown birds beyond 28 weeks and maintaining them on constant 8 or 16-h photoperiods negatively affected egg production. Maintaining birds on constant 11-h photoperiods had a less deleterious effect on egg production. Increasing the photoperiod from 8 to 12 h resulted in a significant improvement in settable egg production compared with birds transferred to16 h.

Prediction equations were produced to estimate mean age at sexual maturity for control birds subjected to constant photoperiods, and for birds reared on a control or fast growth curve and photostimulated at between 10 and 24 weeks of age. Data presented in this thesis suggest that, to minimise the accentuated decline in egg production typically seen late in the laying period, birds kept in light-tight houses should be transferred to photoperiods shorter than the currently recommended 16 h. Finally, photorefractoriness provides an improved understanding of the causes of erratic performance frequently observed in out-of-season flocks kept in open sided houses.

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CHAPTER 1

GENERAL INTRODUCTION

Genetic selection programmes for broiler breeders have in the past focused almost entirely on improving several quantitative productive traits such as rapid growth, good skeletal and cardiovascular development, and feed conversion, which are then passed to their progeny. Only recently have primary breeders started to include reproductive characteristics into their selection programmes. As a result, genetic progress in reproductive traits has lagged far behind the rate of progress made in the traits for growth and feed efficiency. Consequently, reproductive performance is relatively poor, and until genetic selection has improved this, it is worth investigating alternative methods of management of the birds and the environment in which they live, as this is the only option available for improving performance in the short term.

In addition to the relative absence of any selection pressure for reproductive traits, the heritability of these traits is generally low, and the expression of their genes in the bird depends to a great extent on the environment on which the bird is placed. Although there are many environmental factors that may affect the development of pullets, some are relatively easy to manage and control, such as health status, which can be maintained on a protective level for the birds through the use of regular vaccinations and correct hygiene. Other factors that are as easy to manage and control, such as feeding programmes, growth curves and the management of lighting programmes, can substantially influence the reproductive performance of a broiler breeder flock, but there is little useful information on the consequences of deviating from the specific recommendations in the husbandry manuals provided by the breeding companies. Their management techniques are considered to be the most appropriate to achieve good performance consistent with maintaining the health and welfare of the flock. Two of the factors that are likely to have the most profound effect on the future performance of a broiler breeder flock are related to the growth of the pullets to reach a determined body state by the time they become sexually mature, and the lighting regimen used during growth and early lay to synchronise and to stimulate maturity. The analysis of breeding manuals and literature published previously suggests that broiler breeder performance may be improved further by manipulating feed restriction and lighting programmes.

An improvement in breeder performance is possible if the factors controlling the several anomalies observed in this type of bird can be clearly identified and correctly managed. Body weight and feed allocation during rearing have been identified as the most important factors controlling ovarian function and therefore, they have been widely manipulated over many years. Many experiments had been conducted in the past in this field, comparing the benefits of restricting feed over *ad libitum* feeding. The effects of different degrees of restriction during rearing and early laying periods have been explored but often the trials reported are poorly planned and in consequence their results are contradictory, making it difficult to draw useful conclusions from them. It will be helpful for drawing better conclusions, to run a few more trials looking at similar rearing treatments to those previously done, but applying strictly controlled conditions.

Little research has been done in comparing the effects of varying the shape of the growth curve to achieve a given body weight target at 20 weeks of age. The growth curve recommended by breeding companies follows the shape of the physiological development of the birds, controlling any possible excess in body weight gain but providing the nutrients required to allow the different vital organs and tissues to develop during the first weeks of life.

It is well known that applying feed restriction during the rearing period will result in a delay in the attainment of sexual maturity, but can have a negative effect on flock uniformity, thereby affecting the response of birds to a lighting stimulus. If birds are subjected to an early photostimulation when the uniformity of the flock is poor, some birds will start laying while still undergoing skeletal development, which will result in an increased mortality during lay. When birds are subjected to a later photostimulation programme, a higher proportion of birds will have reached a mature frame size, so more birds will be able to respond to the lighting stimulus and will start reproductive activity at the same time. In spite of the benefits in flock uniformity, as well as the increase in initial egg weight, the delay in photostimulation results in a loss of potential days for lay. The effects of relaxing feed restriction and applying an early photostimulation to manipulate age at sexual maturity and possible improvement in settable egg production in modern broiler breeder hens have not been reported to date. Allowing the birds to grow faster during the rearing period and applying an earlier photostimulation could result in an improvement in the efficiency of use of rearing farms, as well as an improvement in settable egg production and welfare of the birds. This could also contribute to the present knowledge of the physiology of this type of bird in response to early photostimulation and may identify possible interactions between body weight profiles and lighting programmes. The response of broiler breeder hens to different lighting programmes is still not clearly defined. Little research has been conducted to identify the optimum age at photostimulation, the effects of different patterns and sizes of increments in daylength and the final daylength applied on age at sexual maturity and egg production of broiler breeder hens. Whilst all those aspects of lighting management will clearly influence the reproductive behaviour of broiler breeder females, there is another aspect of the physiological response to light that requires further investigation. The development of photorefractoriness at different stages in the life of breeder hens has only recently been identified. Since this phenomenon does not occur in egg-type layers (where most of the lighting research has been conducted) this subject has in the past been ignored in broiler breeder hens. The development of such a condition in either the juvenile or adult stage will affect the age at maturity and possibly the performance of broiler breeder flocks and it is important to determine the conditions that produce this photorefractory state in broiler breeder hens as well as those that dissipate the condition in order that lighting programmes may be applied that will minimise the deleterious effect of this condition.

This study was designed to gather information about the response of broiler breeder hens to changes in growth during the rearing period, feed allocation programmes early in lay and the effects of age and pattern of photostimulation on several reproductive traits and body composition. The results of the research reported in this thesis should help to improve our understanding of the reproductive response of this type of bird to changes in growth profile and lighting regimen, as well as the mechanisms through which body weight and lighting programmes affect the sexual development of broiler breeder pullets. This information will be used to develop a theory to explain the effects of lighting and growth on subsequent performance, which could lead to the development of new management techniques, and as a result, improve subsequent reproductive performance of broiler breeder flocks.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

During the last 40 years, improvements made in the potential growth rate of broiler chickens have had a profound negative effect on reproductive performance of the female parent stock. In order to identify better management strategies that could improve settable egg production of breeder females a considerable amount of research has been conducted. This Chapter is directed to review only the literature pertaining to treatments applied during the growing period up to peak production. Treatments applied after the birds come into lay will also influence egg and chick output, but they are out of the scope of this thesis, therefore they will not be described here.

There are several factors affecting ovarian development during the rearing and early laying period of broiler breeder hens and, in consequence, subsequent egg production. High stocking density, body weight uniformity, *ad libitum* feeding, inappropriate lighting programmes, infectious diseases and poor stockmanship can affect pullet development and hence, ovarian function. Most of the research in the past 20 years has centred on restricting feeding, changing the shape of the growth curve, altering body weight at 20 weeks of age, and varying the age at which feed restriction is lifted. Even though feed restriction and body weight control during rearing and the early laying period are considered important management tools to decrease the number of unsettable eggs, it is known that these practices delay sexual maturity and affect flock uniformity. A high uniformity is desirable when stimulating pullets to reach sexual maturity by means of increasing the numbers of hours of light per day and an increment of feed allocation. A lack of uniformity will result in these stimuli being applied whilst a high percentage of birds are still immature, which will result in a high incidence of reproductive anomalies, such as uterus prolaps, internal ovulations, and peritonitis, and as a consequence a high mortality rate is likely. Excessive body weight gain during the pullet-layer transition is considered by some to be the principal factor negatively affecting egg production, and some research has attempted to determine the correct feeding procedure in this period.

The lighting programme applied to pullets can critically determine the future reproductive behaviour of the flock. Previous research in this field has included the use of different ages at which the lighting stimulus is applied, slow or fast increases in daylength, and different patterns of photostimulation. Most of the literature assumes that broiler breeders will respond in the same way to different lighting programmes as do commercial pullets, so this aspect of broiler breeder management has received far less attention than that associated with growth curves and feed restriction programmes in the rearing period.

There appear to be two critical periods in the development of broiler breeder pullets during which the management of environmental factors plays an important role in determining the number of hatchable eggs that will be produced by the flock. The first period, between 14 weeks of age and first photostimulation, is the period during which the reproductive tract and the ovary undergo their major development. The second period, from the time of photostimulation to peak production, is important because a feed stimulus during this period should be correctly applied in order to maximize egg production. The uniformity of the flock at photostimulation is the critical factor determining the rate at which food increases during this period should be applied.

The objective of this Chapter is to review the relevant research conducted on the management of broiler breeders during the growing period to peak production, to get a sense of the work that has been done, which will lead to a better understanding of the factors of importance in controlling the ovulation process and subsequent reproductive performance of the flock. In describing the different factors affecting egg production in broiler breeders, some duplication of material is unavoidable due to the nature of the research conducted.

2.2 REPRODUCTIVE CHARACTERISTICS IN LAYING HENS

The major development of the ovary and reproductive tract in pullets occurs during the pullet-layer transition. During this period, it is essential to provide environmental and nutritional conditions that will allow the pullet to grow and reach sexual maturity. This goal is relatively easy to achieve when managing laying type pullets, which are allowed to access food *ad libitum* throughout their lives. Management of broiler breeder pullets is more complex. They are subjected to feed restriction from an early age, which makes nutritional management a difficult task. *Ad libitum* feeding at any stage during the life of a broiler breeder results in poor reproductive performance, and hence poor chick production. It is therefore essential that the feed restriction programme applied provides the right amount of nutrients to allow some growth to occur, but it must avoid any excess in growth or fattening in order to control reproductive anomalies.

2.2.1 Ovarian function and follicular development in commercial laying hens

The development of ovarian follicles in hens can be divided into three major phases: 1) a period of slow growth, characterised by the deposition of mainly neutral fat, 2) an intermediate phase, when white yolk is added, lasting about 60 days, and 3) a final period, lasting from seven to 11 days, culminating in ovulation or atresia (Gilbert, 1971).

In the first stages, in follicles from about one to 3.5 mm diameter, primordial (or white) yolk is formed. Thereafter both primordial and yellow yolk is accumulated until the follicle reaches about 7 mm diameter, when production of white yolk stops (Griffin *et al.*, 1984). A follicle takes between 5 and 6 days to increase in diameter from about 1 to 3-4 mm, and 3 to 4 days to increase in diameter from 3-4 to 8 mm. Since probably 1 d is required to grow from 6 to 8 mm diameter, an average increase in diameter of 1 mm per d is a reasonable assumption for small follicles (Gilbert, 1984).

The adult ovary of a hen contains several million oocytes but only many hundreds can be seen with the naked eye (Gilbert, 1984). Approximately, there are less than 100 follicles with diameters greater than 1 mm. There are usually 18 follicles present in the ovary with sizes of between 1 and 2 mm, from which one with a diameter of about 6 to 8 mm is randomly selected to enter the hierarchy and that will be ovulated. Presumably about 17 follicles are lost over the 5 to 6 days that it takes to grow to the larger size. Thus, there must be a mechanism that prevents a number of follicles from proceeding further. Gilbert *et al.* (1980) suggested that the number of follicles in the hierarchy, which is related to the number of eggs produced, would depend on the difference between the rate of production of follicles of one mm (or less) and the rate of atresia thereafter. In normal laying hens, atresia is mainly associated with the smaller follicles. Larger follicles seldom become atretic, except towards the end of the laying period (Gilbert, 1972).

The ovary of a laying hen contains between 5 to 7 ovarian follicles arranged in a single hierarchy of increasing size, which is maintained by the daily recruitment of a single small follicle, and the ovulation of the most mature one (Hocking, 1996). Progressively the follicle increases in size and is ovulated when it is sufficiently mature to produce hormones at levels that will stimulate the release of gonadotrophins to detach the follicle from the ovary (Robinson *et al.*, 1993). Details of the time required to grow during the last phase are shown in Table 2.1.

Table 2.1. *Stages in the maturation of ovarian follicles. Data adapted from Gilbert (1971).*

Characteristic	Stage								
	1	2	3	4	5	6	7	8	9
Follicle diameter (mm)	0.05-1	2-3	4-6	6-9	10-14	20	26	32	37
Yolk weight (g)	*	0.006	0.04	0.15	1	4	8	13	17
Yolk type	Neutral fat	White	White	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow
Phase of Marza and Marza (1935)	1	2	2	3	3	3	3	3	3
Approximate day of rapid growth in normal hierarchy	-	-	-	-	1	2	3	5	7

Phase of Marza and Marza as cited by Gilbert (1971)
* Values not available due to the small size of the follicles.

Ovulations occur in sequences, resulting in periods of consecutive ovipositions that are terminated by a pause of one or more days. The length of the sequence, or clutch, varies from one egg to as many as 360 eggs, being longer on average in laying hens than in broiler breeder hens. It is likely that the rate of egg production is dependent on sequence length and the factors controlling it (Etches, 1984), and consequently, the shorter length of the laying sequence in broiler breeders may be one of the factors negatively influencing egg production.

2.2.2 Laying cycle in commercial laying hens and broiler breeder hens

The laying cycle in commercial laying hens is characterized by a rapid increment in egg production to reach a peak at approximately 30 weeks of age, with percentages of egg production near to 100%. The normal egg production curve shows a slow, linear decline in the successive weeks, reaching about 80% at 66 weeks of age. Broiler breeder hens fed *ad libitum* achieve lower peak production and they have a poor persistency of lay (Robinson *et* *al.*, 1993). Broiler breeders fed under commercial restriction programmes sometimes achieve a peak production comparable to that of egg-type hens, with a maximum performance of about 85%, but with a more abrupt decrease in production after peak. The normal shape of the egg production curves of commercial laying hens in which sexual maturity has been delayed with feed restriction and lighting programme are compared in Figure 2.1 (T. R. Morris, unpublished). Egg production curves of broiler breeder hens are likely to show the same trends.

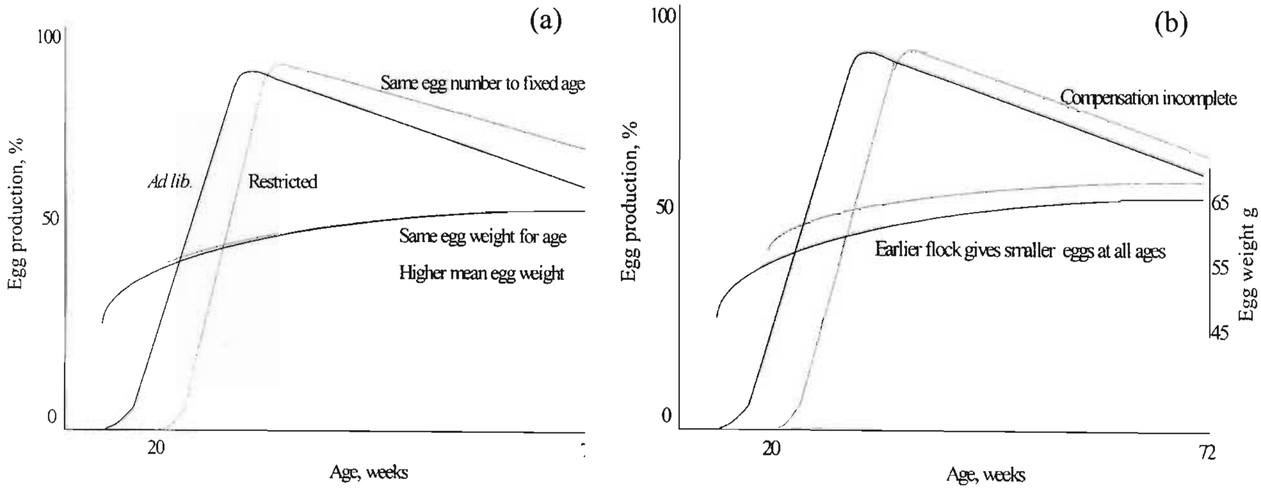


Figure 2.1. *A comparison of the effects of two methods of delaying the onset of sexual maturity in commercial layer pullets on rate of lay and egg weight. (a) Feed restriction and (b) the use of photoperiod. (T.R. Morris, unpublished).*

As discussed above, the reproductive performance of a broiler breeder hen is substantially poorer than that of a laying hen and therefore there is an opportunity to increase the number of chicks produced per broiler breeder hen if the factors limiting reproductive performance of hens selected for rapid growth rate can be identified. The alterations responsible for the poorer egg production of broiler breeder hens are to be described in detail in the following section.

2.2.3 Alterations in reproductive function in broiler breeder hens

Most of the research in reproductive behaviour and function of chickens has been made in commercial laying hens, and it was assumed to be the same in broiler breeders. However, the validity of the latter assumption is questionable since the genetic selection to improve the growth rate of broiler breeders has impaired their ability to reproduce, while the rate of follicular maturation has been increased (Etches and MacGregor, 1983). As a result, ovulation in *ad libitum*-fed broiler breeders is not as orderly a process as that in commercial laying hens. The most frequent problems associated with low production of settable eggs in broiler breeder hens are internal and multiple ovulations (Hocking *et al.*, 1987; Hocking *et al.*, 1989; Robinson *et al.*, 1991; Yu *et al.*, 1992a; Hocking, 1996; Robinson *et al.*, 1998a, and Renema *et al.*, 1999). The effect of feeding programmes on the incidence of internal ovulations is shown in Figure 2.2.

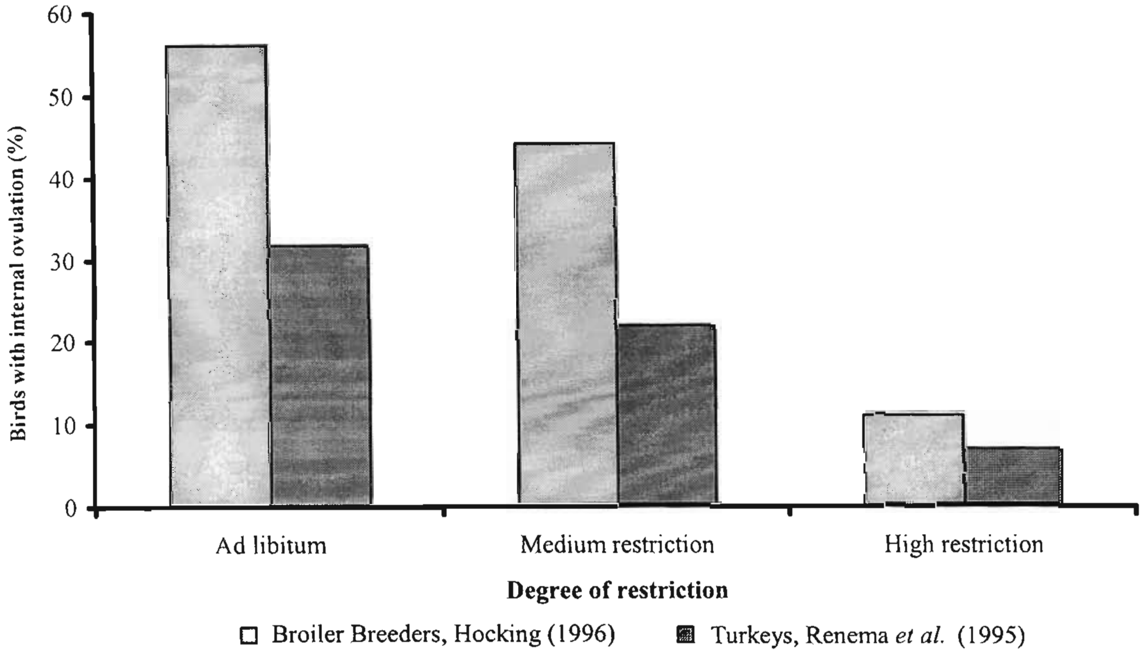


Figure 2.2. *Effects of feed restriction on the incidence of internal ovulations in broiler breeder and turkey hens.*

Internal ovulation in broiler breeder hens fed *ad libitum* is presumed to be due to a reduced rate of oviduct maturation relative to ovary development resulting in the loss of potential eggs due to oviduct incompetence (Robinson *et al.*, 1998a). The incidence of internal ovulations was initially thought to be influenced by body weight, since Hocking (1993) found a positive relationship between these two variables, in a study conducted with hens of a female broiler breeder line. A positive correlation between the incidence of internal ovulation and body weight was also found in an experiment conducted with turkey hens of a male-line (Renema *et al.*, 1995). Male-line turkeys have been almost exclusively selected for growth characteristics (Renema *et al.*, 1995). Therefore, rate of lay for a male-line hen is less than half that of a female-line hen (Hocking, 1992).

In broiler breeder and turkey hens, the presence of postovulatory follicles before the onset of lay has been reported (Renema *et al.*, 1995; Melnychuk *et al.*, 1997; Robinson *et al.*, 1998a and Renema *et al.*, 1999). Follicles ovulated prior to first oviposition are presumably lost in processes such as internal ovulation. Renema *et al.* (1995), in an experiment with a male-line turkey breeder, found that 4.8 follicles are lost in full-fed hens before the occurrence of the first oviposition. In a study comparing the reproductive development in two lines of female turkeys, Melnychuk *et al.* (1997) found that the number of postovulatory follicles was positively correlated with the incidence of internal ovulation. The female line had fewer unexplained postovulatory follicles than the male line (1.6 *vs.* 3.0) and a numerically lower incidence of internal ovulations (70.8 *vs.* 87.5).

Hocking (1996), in contrast with previous work, found that the proportion of birds with internal ovulation was a function only of the feed allocation programme during rearing. The feed allocations used were *ad libitum* and restricted feeding to reach either 0.4 or 0.7 of the body weight of a*d libitum* birds at 20 weeks of age. In contrast with Hocking (1996), Renema *et al.* (1999) found no significant relationship between internal ovulation and the other variables measured in an experiment with birds reared in a commercial feed restriction programme until 20 weeks of age. The effects of feed restriction during rearing and body weight prior to sexual maturity, on the proportion of birds with multiple arrangement of ovarian follicles, are shown in Figures 2.3 and 2.4 respectively.

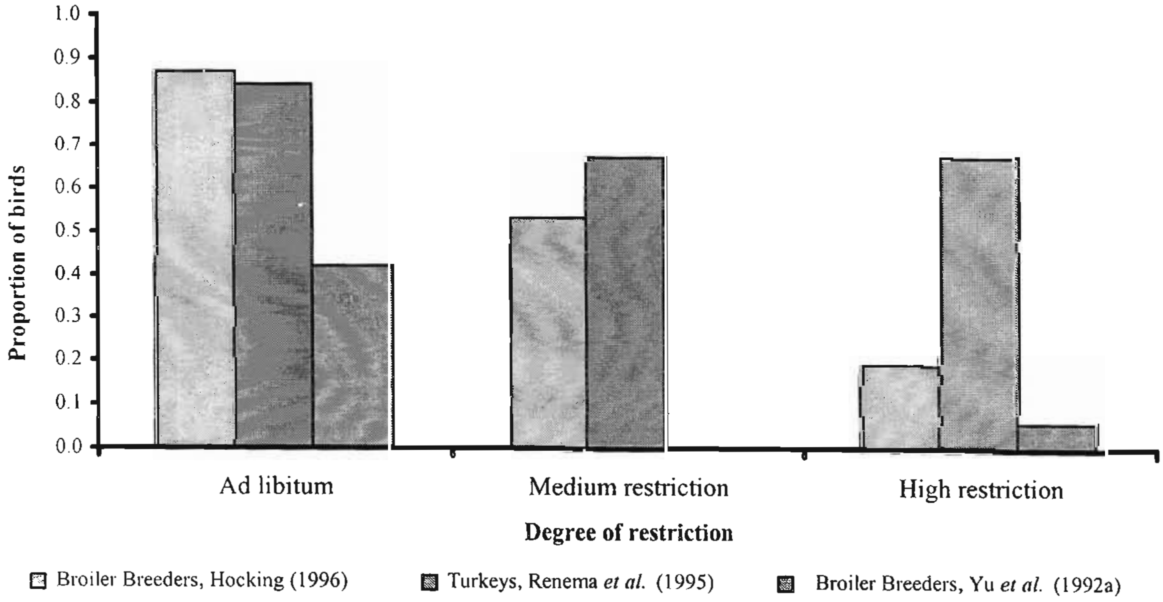
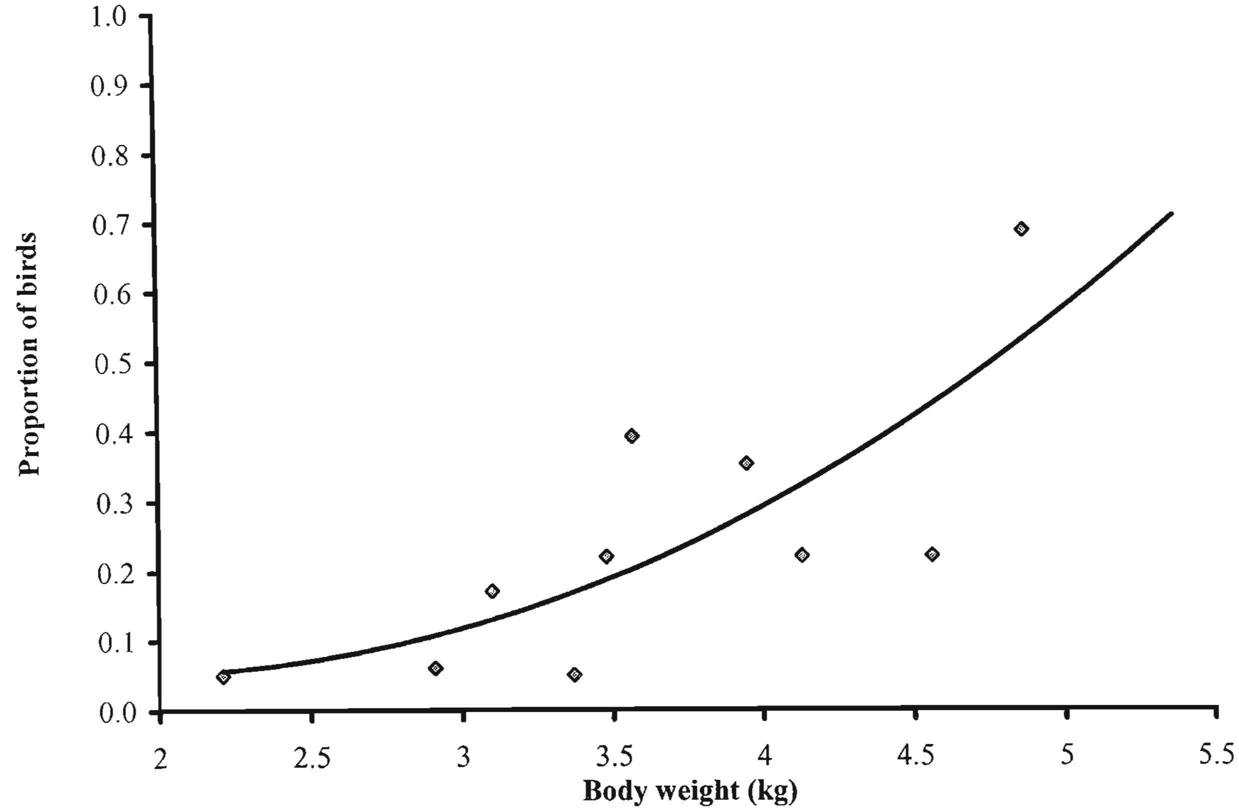


Figure 2.3. *Effects of feed restriction during rearing on the multiple arrangement of ovarian follicles*



in broiler breeder and turkey hens.

Figure 2.4. *Effects of body weight at 22 weeks of age on the proportion of birds with multiple arrangement of ovarian follicles. From Hocking (1993)*

In an unpublished experiment with broiler breeder hens conducted at this University, there was no incidence of internal ovulation or multiple development of ovarian follicles in hens reared on different growth curves designed to reach different body weights at 20 weeks of age and subjected to different photostimulation programmes. Of the two growth curves used in that experiment, one reached the desired body weight at 20 weeks of age, with an increase in body weight from 15 weeks of age, whilst the other was designed to achieve the target body weight at 15 weeks, with almost no growth occurring to 20 weeks of age thereby ensuring that the pullets were not stimulated to grow during the period immediately prior to 20 weeks of age. The incidence of multiple ovulations may thus be as much a function of the genotype used as the feeding programme used during rearing. The broiler breeder strain used by Hocking may have been more susceptible to this condition than modern female lines of the various broiler breeder strains available.

Multiple ovulations occur when more than one follicle is simultaneously recruited to the hierarchy, resulting in the development of two or more follicles capable of ovulating simultaneously. Hocking *et al.* (1989) determined that restricting food intake of pullets during rearing was effective in controlling the number of normal yellow follicles in the hierarchy, when this restriction was applied after 14 weeks of age.

Hocking (1993) reported that the number of yellow follicles at sexual maturity is directly proportional to body weight and the age at which the restriction is applied and not to the degree of feed restriction. The number of yellow follicles increased by about 1.6 follicles / kg increase in body weight at sexual maturity, in birds with the same degree of feed restriction.

Hocking (1996) investigated the role of body weight (BW) and food intake after photostimulation on ovarian function in broiler breeder hens reared on three growth curves (*ad libitum*, 0.7 and 0.4 of BW of the *ad libitum* group). Restricted feeding after photostimulation delayed sexual maturity only in birds reared in the commercial programme (0.4 of BW of the *ad libitum* group), but showed no effect on birds allowed to achieve heavier BW at sexual maturity. In birds restricted during rearing, *ad libitum* feeding after photostimulation increased the number of yellow follicles, but there were no differences in the number of yellow follicles due to the different feed allocations applied during the rearing period and after photostimulation. These results suggest that the rearing treatments have a larger influence on ovarian function at the onset of lay than does food restriction after photostimulation. On this basis, it could be concluded that severe restriction during rearing (0.4 of BW fed *ad libitum*) and the lowest feed allocation of 115 g/d after photostimulation are both needed to control multiple ovulation in broiler breeder hens.

Renema *et al.* (1999) reported that ovary weight did not differ due to body size in broiler breeders reared on a commercial restriction programme. However, the effect of overfeeding at sexual maturity may alter ovarian morphology at the level of the pre-hierarchical follicles, evidenced by the significant differences in stroma weight once the follicles were removed from the ovary. These findings are in agreement with Hocking (1996), who showed that feed restriction after photostimulation affected the number of positions in the hierarchy, suggesting that this may inhibit the recruitment of follicles.

2.2.4 Egg quality: effect and impact on chick production

Alterations described in the ovulation process in broiler breeder hens have a major negative impact on chick production, due to a decrease in the total number of eggs per hen, as well as a decrease in the number of settable and hatchable eggs. The high incidence of multiple ovulations has been recognized to be the most important factor negatively affecting chick production in broiler breeder hens fed *ad libitum* (Robinson *et al.*, 1993). While other anomalies contribute to a decrease in the number of settable eggs, namely, the loss of eggs due to internal ovulations, soft-shelled eggs and shell-less eggs, all these anomalies are related to high body weight at sexual maturity, fast growth rate and high feed intake during rearing and in the pre-breeding period.

There is another factor describing the quality of the eggs produced by a broiler breeder flock that impacts on subsequent chick production. The weight of the newly hatched chick is about 72% of the weight of the egg, and because day old chicks weighing less than 36 g are difficult to manage, the South African broiler industry requires hatching eggs to weigh not less than 50 g, and not more than 75 g, and to be uniform in size. Chronological age is a major determinant of egg size in all forms of poultry (Etches, 1996a). At the onset of lay, egg weight is much lower than during the subsequent weeks of production. In attempting to increase egg weight at the onset of lay, breeder managers purposely delay sexual maturity by continuing to apply feed restriction programmes or by delaying the exposure of the birds to photostimulatory programmes. The effects of such treatments in subsequent egg production of broiler breeder hens will be described in subsequent chapters.

2.3 FACTORS AFFECTING REPRODUCTIVE PERFORMANCE IN BROILER BREEDER HENS

2.3.1 Body weight at 20 weeks of age and the shape of the growth curve

Although body weight has been identified as one of the most important effectors of the development of multiple ovarian hierarchies (Hocking, 1993), it may not be the only variable to be considered. Fisher (1999) suggested that body weight of pullets at 20 weeks might not be as critical as the shape of the growth curve, and the uniformity of the pullets.

Sexual maturity in broiler breeders is reached earlier when hens are fed *ad libitum* or when they achieve higher body weights at 20 weeks (Robinson and Robinson, 1991; Hocking, 1993, 1996; Yuan *et al.*, 1994; Robinson *et al.*, 1998b). Even though they reach maturity earlier, with higher egg production in early lay, they usually exhibit an early and abrupt decrease in egg production. Body weight at 18 to 25 weeks of age (g) was regressed on age at sexual maturity (ASM), and the regression equation was:

$$y = 199\ (\pm 4.83) - 0.0088\ (\pm 0.001)\ BW \qquad (P \leq 0.001)$$

Where y = age at sexual maturity (d) and BW = body weight (g) of birds between 18 and 25 weeks of age.

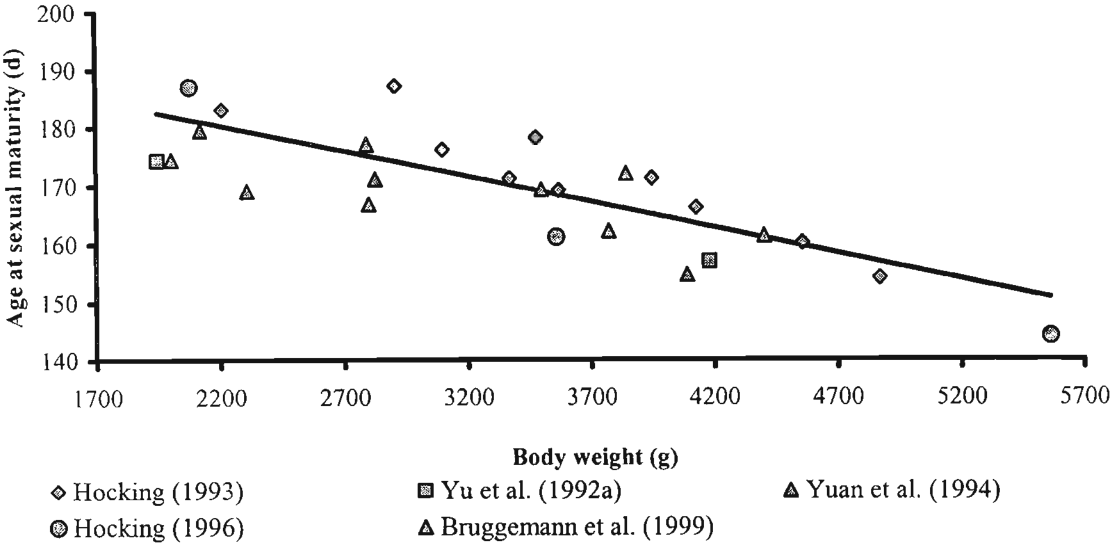


Figure 2.5. *Effect of body weight at 18 to 25 weeks of age on age at sexual maturity.*

Robinson and Robinson (1991) showed that broiler breeder hens that were underweight around 21 weeks of are reached sexual maturity significantly later and showed lower total and settable egg production. In another experiment, conducted in this University during 1999, sexual maturity was delayed about 1 d per every 65 g reduction in BW at 20 weeks of age. Commercial rearing programmes are designed to achieve a target of around 40% of the body weight of a broiler breeder fed *ad libitum*, allowing increases in body weight gain during the weeks preceding sexual maturity, which are designed to stimulate the hens to start laying. Excessive body weight gain should result in the excessive development of ovarian follicles, which leads to the production of double-yolked eggs (Hocking, 1993).

Wilson *et al.* (1995) used three levels of feed allocation in order to determine if changes in growth curve to 24 weeks of age influenced laying performance. Birds were reared on a standard curve (with linear increases in feed intake), an early slow growth curve (with lower feed allocation from 1 to 19 weeks of age and a higher feed allocation from 20 to 26 weeks) and an early fast curve (with a greater feed allocation than standard from 1 to 19 weeks, changing to a similar feed allocation from 20 to 26 weeks). Changing the shape of the growth curve in their experiment did not affect significantly the age at first egg (AFE) or BW at first egg (178.0, 174.1 and 172.7 d for early slow, standard and early fast respectively). The total egg production did not differ significantly among treatments (170.2, 183.5 and 181.3 d for early slow, standard and early fast respectively). Hens reared on the early slow curve laid significantly fewer settable eggs than hens on the standard and early fast curves (153.3, 167.4 and 168.4 respectively). The authors suggested that this effect might be due to a higher fat deposition in underweight hens subjected to a high increase in feed allocation before sexual maturity, which impacted negatively on reproductive performance. They concluded that egg production of broiler breeder hens reared on a growth curve emphasizing fast growth late in the rearing period is poorer than that of birds grown on a more linear curve or on a curve emphasizing early fast growth. No significant differences were found in mean egg weight or in the production of double-yolked eggs. The number of large ovarian follicles was not significantly affected by feed allocation. This result is in agreement with Hocking (1996) who suggested that BW at sexual maturity and, to a lesser extent, the amount of food consumed between photostimulation and maturity, are the major determinants of multiple ovulations.

Robinson *et al.* (1995) reported the consequences of different feed allocations in birds of five different body weight categories at sexual maturity, and the effects of varying feed allocation in birds of the same body weight (BW) between 24 and 32 weeks of age. Feed allocation treatments were a standard (fewer large weekly changes in feed allocation), an early slow (provided with lower than usual feed allocation) and an early fast programme (fed with higher than usual feed allocation). Within feed allocation groups, the five different body weight groups received the same amount of feed. BW at 20 weeks was not limiting in attaining sexual maturity in this experiment. There were no significant differences in body weight gain during the period between 20 and 24 weeks of age, which, on average was about 16 to 18 g/d. The maximum production of double-yolked eggs was only 1.35 / 100 hens housed, suggesting that low body weight gains in the period prior to sexual maturity would result in an increment of settable egg production. Total egg production, total production of settable eggs, number of double-yolked eggs laid and egg weight did not differ when BW at 20 weeks of age varied within 20% of the programmed target.

Robinson *et al.* (1998b) suggested that minor changes in feed allocation strategies in the five weeks following photostimulation can alter egg and chick production traits. Providing 20-week old pullets with small, multiple feed increases altered the growth curve of pullets as they became sexually mature, which improved egg production through an increase in laying sequence length. Total and settable egg production was improved (by about 10.9 and 11.2 eggs per hen respectively) when feed increments were small. Feeding programmes had no significant effect on egg weight, but mean sequence length was significantly increased in the slow treatment, by about 0.54 d.

In an experiment conducted in this University (1999, unpublished) the hypothesis that reproductive performance in broiler breeder hens is influenced by body weight at 20 weeks of age and the growth curve used to achieve that weight was tested. Two growth curves (see Figure 2.6) were applied to reach 1552, 2155, 2500 and 2850g/bird body weight targets at 20 weeks of age. Neither the shape of the growth curve nor the different body weights at 20 weeks of age had significant effects in hen day production throughout the laying period (25 to 60 weeks).

Even though there were no significant differences due to the shape of the growth curve applied, the difference of 4.8 eggs/hen for the birds reared in the curve allowing growth to occur in the weeks prior to sexual maturity suggest that birds reared on a growth curve emphasizing early fast growth, but avoiding high increments in body weight gain between 16 and 20 week of age, exhibited lower egg production due to a lack of nutritional stimulus prior to the attainment of sexual maturity. This lack of stimulus produced a delay in sexual maturity of 7.2 d compared with birds allowed to grow during the same period. The total number of eggs and the production of settable eggs were not affected by BW at 20 weeks. There were no differences in the hen day production, suggesting that 20 week BW is not a good measure of subsequent reproductive performance. The shape of the growth curve did not affect the number of double-yolked eggs produced. This variable was only influenced by 20 week BW, increasing 0.3% per every extra kg of BW at 20 weeks. In spite of the differences in food intake in birds reared on both growth curves from 18 weeks onwards, there was no difference in the production of double-yolked eggs. This suggests that the production of double-yolked eggs may be affected by factors other than food intake between 20 weeks and sexual maturity.

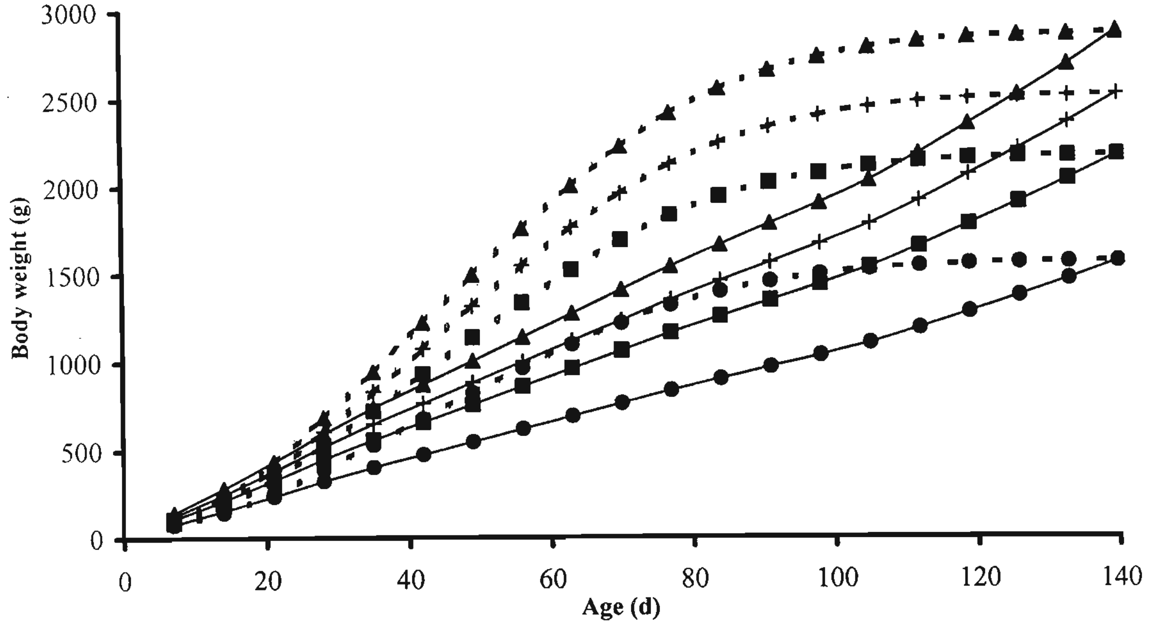


Figure 2.6. Growth curves used in the experiment: Curve A (____) and Curve B (..........); 20 week body weights: -28% (●), control (■), +16%, (+) and +32% (▲).

2.3.2 Feed restriction programmes

2.3.2.1 The rearing period

Feed restriction in broiler breeders has been widely applied commercially for many years. There are several theories about when and how this restriction should be applied. Hocking (1993) suggested that feed restriction is effective in controlling the number of normal yellow follicles when applied after 14 weeks of age. Later, Bruggeman *et al.* (1999) narrowed that period to between 7 and 15 weeks of age. In spite of this, feed restriction is usually applied in commercial conditions from as early as 1 or 2 weeks of age, in order to keep body weight on the target recommended by the primary breeder. Feed restriction during rearing also became a helpful economic tool, due to the major impact of feed costs to the company.

One of the most important consequences of feed restriction is the lack of uniformity in growth due to competition for food. Uniformity in body weight of pullets is desirable so that all birds can reach sexual maturity together and have similar rates of lay and egg size. In order to determine the effects of variability in BW on reproductive performance of broiler breeder hens, Robinson and Robinson (1991) reared pullets to reach a BW target of 2030 g at 21 weeks on a commercial feeding programme. At this age, birds were weighed and classified depending on BW in three groups, low-BW (1547 ± 24g) medium-BW (2057 ± 12g) and high-BW (2545 ± 12g). Birds in the three BW groups were allocated the same amount of food, determined by the feed allocation of the standard treatment. Low-BW hens reached sexual maturity significantly later (13.2 d compared with the medium-BW treatment) and laid fewer eggs than medium and high-BW hens (140.5, 176.2 and 169.2 eggs respectively). There were no significant differences between the medium and high-BW treatments for ASM or total egg production. These results indicate that flocks with a high proportion of low-weight hens may exhibit poorer efficiency, in agreement with a later report where Robinson *et al.* (1995) suggested that differences of about 5% in body weight at 20 weeks can result in differences in maintenance requirements, thereby decreasing reproductive performance in flocks with poor uniformity.

Yu *et al.* (1992a, b) investigated the effects of feed allowance during the rearing period (4 to 18 weeks) on growth, ovarian morphology and egg production. Birds were fed *ad libitum* during the first 4 weeks. From 4 weeks until 18 weeks of age birds were allocated to one of two different feed allocation programmes: *ad libitum* feeding or feed restricted according to the recommendations provided by the primary breeder (37.2% of *ad libitum* intake). In this experiment, ASM (oviposition of the first egg) in restricted birds during rearing was significantly delayed by 2.5 weeks. The authors suggest that feed intake and growth during the rearing period are the most important determinants of ASM. Feeding programme during rearing and breeding had no significant effect on egg weight, but restricting feeding during the rearing period significantly increased the production of settable eggs during early lay (19 to 34 weeks). Restricted hens laid 6.7 more settable eggs/bird during this period when restriction was applied during rearing. This difference in total and settable production when birds where restricted during rearing was not observed when considering the total laying period (19 to 62 weeks).

There is still controversy about the timing of feed restriction during rearing of broiler breeder pullets. Bruggeman *et al.* (1999) compared the effects of feed allocation during rearing, to determine whether a critical period existed during rearing when restricted feeding can be most beneficial for subsequent egg production. Dividing the rearing period into three periods (first, from 2 to 6 weeks; second, from 7 to 15 weeks; and third, from 16 weeks to first egg) and allocating birds to *ad libitum* or restricted programmes (see Table 2.2 for details of the feeding treatments). During the first period, feed intake in restricted birds was 45.1% of *ad libitum* birds. In the second period, restricted birds consumed 33% of *ad libitum* intake. Birds restricted during the first period and fed *ad libitum* during this (second) period consumed 96.3% of those fed *ad libitum* from the beginning of the experiment. In the third period, those pullets reared on restricted treatments were allocated 33% of *ad libitum* intake, irrespective of the previous feeding programme. Birds restricted during the first and second period, that were allocated to the *ad libitum* feeding during the third period, consumed 18.3% more food than the birds fed *ad libitum* throughout the three periods, which suggest a compensatory effect due to the prior restriction.

Table 2.2. *Feeding programmes during rearing and pre-breeding period. From Bruggeman et al. (1999)*

First Week	First Period	Second Period	Third Period	Laying Period
	Week 2-6	Week 7-15	Week 16-first egg	1st egg to 50 weeks
Ad libitum	Restricted (R)	Restricted (RR)	Restricted (RRR)	*Ad libitum*
			Ad libitum (RRA)	
		Ad libitum (RA)	Restricted (RAR)	
			Ad libitum (RAA)	
	Ad libitum (A)	Restricted (AR)	Restricted (ARR)	
			Ad libitum (ARA)	
		Ad libitum (AA)	Restricted (AAR)	
			Ad libitum (AAA)	

A similar effect was observed in those birds restricted during the first period (1.7% more than *ad libitum* birds) and during the first and second period (14.8% of *ad libitum*) and allocated to *ad libitum* feeding thereafter. The results suggest that feed restriction from seven weeks of age until sexual maturity is a more important determinant of age and BW at first egg than restriction in the other two periods only. AFE was significantly delayed when feed restriction was applied during the second and third periods (18.2, 15.7 and 13.2d later than *ad libitum* birds for RRR, RRA and ARR respectively). A negative correlation between AFE and BW at first egg was found in birds fed *ad libitum* (AAA/RAA) and restricted (ARR/RRR) during the second and third period. Birds restricted during the period from 7 to 15 weeks of age, and fed *ad libitum* from 16 weeks of age until first egg, showed the highest average weekly egg production, the highest cumulative egg production and the highest production of settable eggs

(Table 2.3). These findings indicate that there are relationships between levels of feeding during rearing, the period when restriction is applied and subsequent reproductive performance. The group restricted during 7 and 15 weeks of age achieved the best performance.

Table 2.3. *Weekly egg production, total and settable cumulative egg production from onset of lay until 50 weeks. From Bruggeman et al. (1999)*

Feeding Programme	Total production (egg/hen. week)	Total Cumulative (egg/hen. week)	Settable Cumulative (egg/hen. week)
RRR	4.44^{ab}	108.21^{b}	91.15^{b}
RRA	4.49^{ab}	111.03^{b}	92.73^{b}
RAR	3.54^{c}	91.48^{c}	69.77^{d}
RAA	3.40^{c}	94.90^{c}	80.39^{c}
ARR	4.53^{ab}	113.64^{b}	96.08^{ab}
ARA	4.75^{a}	124.38^{a}	103.43^{a}
AAR	4.25^{ab}	108.62^{b}	83.32^{c}
AAA	3.08^{d}	83.07^{d}	69.59^{d}

$^{a-d}$ Means within a column with no common superscript differ ($P<0.05$)

The results in this study narrowed the critical period, which may be between 7 and 15 weeks of age, to improve reproductive performance in broiler breeder hens. In a previous report, Hocking (1993) concluded that feed restriction should continue until the onset of lay to control multiple ovulations, which are a major source of lost egg production. However, although the production of yellow follicles was significantly decreased when feed restriction was applied from 14 weeks of age onwards, the effects of that feeding programme could not be supported with the results of subsequent egg production because the birds were killed within three days of the first oviposition in order to determine ovarian development at first egg.

The results of an unpublished experiment conducted in this University suggest that a nutritional stimulus or a lighting stimulus or both are needed just prior to sexual maturity in order to maximise egg production. The nutritional stimulus is discussed in the next section, whilst the effects of a lighting stimulus on reproductive performance are discussed later.

2.3.2.2 Period from age at photostimulation to peak production

The degree of restriction, the period over which this is applied and the basis on which feed increments are given, are critical factors when managing broiler breeders flocks. Cave (1990) evaluated the effects of different feed allocations from 125 days to maturity. Four different treatments were designed to gain 15, 20, 25 or 30 g/d until mature weight was achieved. Total feed allocations, expressed as a percentage of the treatment with the highest body weight gain during the experimental period, were 81.2, 88.5, 95.4 and 100% respectively. ASM was significantly delayed, by 2.6 d, in hens fed the smallest allocation. Total egg production and egg weight were not significantly affected by feeding regimen.

Yu *et al.* (1992a, b) investigated the effects of feed allowance during the pre-breeding period (18 to 23 weeks) and the early egg production period (23 to 33 weeks) on growth, ovarian morphology and egg production. Feed intake during the pre-breeding period in restricted birds during both periods (RR birds) was 63.3% of the intake of birds fed *ad libitum* throughout the experimental period (FF birds), whilst birds restricted during rearing but allowed *ad libitum* access to feed during this period (RF birds) consumed 32.8 % more than FF birds. During the early laying period, RR birds were allowed to consume 89.9% of what FF birds consumed and a similar compensatory effect was observed in those RF birds but in a lesser amount (4.9% more than FF birds). Birds that were full fed during the breeding period (FF and RF birds) had significantly higher occurrences of simultaneous development of follicles and a higher percentage of double-yolked eggs. Birds full fed during rearing and breeding had the highest incidence of erratic ovipositions, and production of soft shelled and shell-less eggs (Table 2.4).

Table 2.4. *Effects of feed allowance during breeding on the number of simultaneous development of ovarian follicles at 34 weeks of age and the incidence of multiple yolked and shell-defective eggs between 19 and 29 weeks of age. From Yu et al. (1992a)*

Feeding regimen	*Number of simultaneous development*	*Multiple yolked eggs (%)*	*Soft + shell-less eggs (%)*
FF	1.71^{ab}	18.1^{a}	32.6^{a}
FR	1.00^{ab}	13.5^{a}	22.7^{b}
RF	2.25^{a}	12.6^{a}	20.0^{b}
RR	0.56^{b}	2.3^{b}	13.3^{c}

$^{a-c}$ Means within a column with no common superscript differ ($P<0.05$)

Feed restriction imposed just prior to the onset of sexual maturity resulted in the greatest total number of eggs produced during the early lay period, whilst there were no significant differences in the number of settable eggs in those birds restricted during the breeding period (Table 2.5), probably due to a higher production of unsettable eggs in those birds full fed during rearing.

Table 2.5. *Effects of feeding programme on early (19 to 34 weeks) and total egg production (19 to 62 weeks) (eggs/hen) of age. From Yu et al. (1992a)*

Feeding regimen	Early egg production		Total egg production	
	Total	Settable	Total	Settable
FF	45.4^{c}	30.6^{c}	122.2^{c}	102.6^{c}
FR	62.6^{a}	48.7^{a}	162.9^{ab}	143.9^{ab}
RF	51.4^{bc}	41.3^{b}	132.5^{bc}	118.2^{bc}
RR	54.2^{b}	52.2^{a}	176.6^{a}	172.4^{a}

$^{a\text{-}c}$ Means within a column with no common superscript differ ($P<0.05$)

Robinson *et al.* (1995) reported that AFE was not affected when hens were allocated different amounts of food during early lay (from 24 to 32 weeks of age). Birds in the early slow treatment consumed 95.3% of the intake of standard birds and those in the early fast group consumed 2.7% more food than the standard birds. Birds in the early fast treatment had a poorer egg production compared with those in the standard treatment (167.7 *vs.* 183.5 eggs/hen respectively). Birds in this group laid significantly fewer settable eggs than the standard group (149.8 *vs.* 167.2 respectively). They suggested that this might be the result of the heavier body weights of those at first egg (140 g heavier). These data provide evidence that an excessive feed allocation during sexual maturity and during early lay results in less than optimal egg production and, as a result, a poorer chick production.

Renema *et al.* (1999) evaluated the effects of feed restriction after photostimulation at 21 weeks of age. Pullets were reared on a commercial restriction programme until 20 weeks, when birds were weighed and sorted in low, standard or high BW and assigned to *ad libitum* or restricted feeding, where increments greater than 4 g in feed allocation were divided in two to three smaller increases per week. Birds fed *ad libitum* after photostimulation reached sexual maturity 13.6 d earlier than restricted birds. *Ad libitum* feeding resulted in the development of 3.9 more large yellow follicles and a significant difference of 0.47 follicular hierarchies (with the number of hierarchies represents the average number of follicles that can potentially ovulate on a given day). Within the restricted group, birds in the low BW group had a reduction of 1.2 large yellow follicles compared with birds in the standard and high BW groups.

2.3.3 Lighting programmes

2.3.3.1 The rearing period

Broiler breeder manuals indicate the use of changes in daylength to stimulate and synchronize a rapid onset of egg laying and optimise reproductive performance. The lighting management of broiler breeder flocks depends, in many cases, on the facilities available and the time of the year, and location of the rearing farm. Different combinations of lighting treatments are recommended due to different types of facilities being used in the rearing and production periods. These could be controlled environment rearing and laying, open house rearing and laying, and controlled environment/blackout rearing and open house laying. Flocks commercially reared into light-tight facilities are kept for the first days of life on daylengths of 23 or 24 hours light. From approximately 2 d of age, daylength is reduced to approximately 8 h and is kept constant until the age at photostimulation, which is normally applied when birds are transferred into the laying houses (irrespective of whether the conditions in the laying facility can be controlled). The success of the lighting management in this case depends mostly on the light proofing of the house. When rearing occurs in open houses, and flocks are placed from September to February in the Southern hemisphere (when natural daylengths are long), birds will come into lay later and tend to have a lower peak and less predictable performance throughout lay than the so-called in-season flocks (birds placed from March to August, i.e. winter months). Some management guides provided by breeding companies suggest various changes to the rearing protocols for out-of-season flocks. These include advancing the age at which the first light stimulus is given from 19 weeks to 18 weeks of age, and to grow females according to a heavier body weight profile, thereby relaxing the degree of restriction and advancing the age at maturity (Aviagen, 2001). Conversely, Cobb (2001) advises against rearing broiler breeding stock in open houses. This is unhelpful, since many rearing facilities in South Africa (and in many other developing countries) are open-sided houses.

The late maturation and poor production observed in out-of-season flocks could be related to some vestige of seasonal reproductive behaviour due to photorefractoriness. This latter concept has been observed in mammals, as well as birds (for a review, Nicholls *et al.*, 1988) and has been reviewed by Sharp (1993) in chickens and other birds. Briefly, when birds that are seasonal breeders are reared on long days, they develop a condition that has evolved to prevent such birds from breeding in the year in which they are hatched, and this condition is known as juvenile photorefractoriness (Nicholls *et al.*, 1988; Sharp, 1993). If such birds are reared on short days, juvenile photorefractoriness will not develop, and consequently, as observed in the starling, sexual maturation will occur earlier than in birds reared on long days. When birds are subjected to short daylengths for long periods of time, juvenile photorefractoriness is completely dissipated; hence egg laying can be stimulated, whereas on long days, some species will take extremely long time to start to lay (Woodard *et al.*, 1980).

In seasonal birds, the breeding season is terminated by the development of adult photorefractoriness, which prevents birds from reproducing when the environmental conditions are not propitious for the survival of parents and offspring. The onset of adult photorefractoriness is thought to be programmed at the time of photostimulation or shortly thereafter (Proudman and Siopes, 2002). The development of a refractory state while exposed to long days is indicated by rapid gonadal regression, decreased LH and gonadal steroid secretion that can terminate reproduction (Sharp, 1993; Proudman and Siopes, 2002). Adult photorefractoriness can be dissipated, and birds can recover their reproductive function after transfer from long days to short days at the end of the breeding season (Nicholls *et al.*, 1988).

Turkeys are seasonal birds, and their reproduction is controlled by photoperiod, and this is a balance between two physiological states, photosensitivity and photorefractoriness (Proudman and Siopes, 2002). Like broiler breeders, turkey hens have not been subjected to the same rigorous selection for egg production that has been applied to egg-type hybrids, which appear not to exhibit photorefractoriness (Sharp *et al.*, 1992). Sexual maturity of modern egg-type hybrids is not delayed when exposed to constant long-days (Lewis *et al.*, 1998a) and the age-related decline in rate of lay (at least to 72 weeks of age) is not reduced by exposure to lighting programmes designed to minimise the effects of photorefractoriness (Morris *et al.*, 1995). It is probable that photorefractoriness has been minimised in commercial laying-hens by the intense selection for egg numbers that has taken place in this type of stock.

Photorefractoriness has not been extensively explored in modern broiler breeder hens. A few studies were reported about 10 years ago, but mostly with Dwarf broiler breeder females. These studies explored juvenile and adult photorefractoriness, as well as the daylength required to regulate the reproductive function.

Dunn and Sharp (1990) conducted a study with the objective of establishing photoperiodic response curves for the release of Luteinizing Hormone (LH) in Dwarf broiler breeder and egg-type hens, and to establish whether these are affected by conventional dietary restrictions, as this might alter the photoperiodic response. In this study, critical and saturation daylength for Dwarf broiler breeders and commercial layers was also determined. The critical daylength was defined as the minimal daylength required to stimulate gonadotrophin secretion in chickens reared on short days; while the saturation daylength, was the minimum daylength required to stimulate the maximum release of the same hormones. The results of this study showed that feed restriction (to conventional levels) did not depress photoinduced LH release, meaning that commercial feed restriction programmes did not affect the photoperiodic response of birds of either strain. The critical daylength for Dwarf broiler breeders was 10.5 h, while for commercial layers was between 10.5 and 12.75 h. The saturation daylength was between 10.5 and 12.75 h for dwarf broiler breeders and between 12.75 and 15.25 h for commercial layers. These results suggest that the most effective increases should be between photoperiods of 10.25 and 12.75 h for dwarf broiler breeders. These findings are similar to those described by Sharp *et al.* (1992), who indicated that an 11-h photoperiod seemed to be sufficiently stimulatory to enhance reproductive function, but not to drive the hens towards the development of adult photorefractoriness as rapidly as when exposed to 20 h. The results of the study conducted by Dunn and Sharp (1990) indicates that photoinduced changes in the concentration of plasmatic LH could be used to determine photoperiodic response curves in domestic chickens.

Sharp *et al.* (1992) proposed that the decline in egg laying observed in commercial hens maintained for up to 2 years on a stimulatory daylength could be caused by the development of adult photorefractoriness. This would result in a decrease in Gonadotrophin Releasing Hormone (GnRH) by the hypothalamus, and hence, reduced gonadotrophin secretion. In order to establish whether reduced persistency of lay was due to the development of adult photorefractoriness, three studies using Dwarf broiler breeders were conducted. The first study was designed to measure the effect of short-day treatment combined with dietary restriction and return to long days on the dissipation of photorefractoriness. Sixty-five-week old hens, with a poor rate of lay were transferred from long (14 h) to short-days (3 h) for 6 weeks and moulting was induced by restricting feed intake. Changes in gonadotrophin levels and egg production were measured in moulted and unmoulted hens (control) after transferring the birds to their original lighting (14 h) and feeding conditions. Four weeks after transfer, birds of the moulted and unmoulted groups were allocated to the following treatments: maintained on 14-h photoperiod, decrease daylength from 14 to 11, or 8 h, and increase from 14 to 17-h photoperiod. In this study, control hens maintained on long-days continued to lay, while egg production of hens transferred to short days and subjected to dietary restriction ceased 4 weeks after transfer. Six weeks after returning to long-days, egg production and plasma LH levels were higher in moulted hens compared with control (unmoulted hens). A reduction in reproductive activity in moulted and unmoulted hens was observed after daylength was decreased from 14 to 8 h. Egg production and plasma LH were not affected when birds were maintained on 14 h. An increase in daylength to 14 or 17 h was associated with an increase in egg production in moulted hens, but not in the control group. There were no changes in plasma LH levels in those birds.

The second study was conducted to establish whether recovery of hypothalamic-pituitary-gland function in the first study was due to the short-day treatment alone or to dietary restriction. Groups of old hens exposed to 14-h photoperiod with records of poor production were transferred to continuous light for 14 weeks to enhance the development of photorefractoriness. Moult was induced in a group of birds by reducing feed intake, while they were maintained on continuous light. Egg production, weights of ovaries and oviducts and plasma LH were measured after increasing the daylength or food intake. In this experiment, egg production stopped within 2 weeks of transfer from continuous light to 3-h photoperiod or after dietary restriction, and resumed 2 to 3 weeks after returning the birds to their original lighting or feeding treatments. After returning to continuous light, plasma LH levels increased rapidly to a peak, which was higher in moulted hens compared with the control birds. Peak plasma LH was the same between birds transferred to 3 h and those subjected to dietary restriction. Four weeks after returning to their original lighting or feeding treatments, the proportion of birds laying in each group was not different, but higher than the control hens. Egg production of birds on the short-day and dietary restriction treatments was similar, and higher than in control birds (2.62 and 2.64 *vs.* 1.73 eggs/hen/week, $P<0.05$).

The third study was designed to investigate the effects of daylength on persistency of lay. The hens that had been laying for a year were transferred to 3h photoperiod and subjected to feed restriction to induce moult. After this, birds were transferred from 3 to 11 or 20-h photoperiod. The hypothesis to be tested was that transfer to 20 h would induce photorefractoriness and result in a reduced persistency of lay, while this effect would not be observed in hens transferred to 11 h (considered as a marginally stimulatory daylength). At the end of this experiment, the birds were transferred to different daylengths and the functional status of the hypothalamic-gonadotroph axis was assessed. The treatments were applied as follows: hens exposed to 3 or 11-h photoperiods were transferred to 20 h, and hens exposed to 20-h photoperiod were transferred to 3 h. It was predicted that egg production of birds subjected to an increase in daylength would increase, while those transferred from 20 to 3 h would cease egg laying. After 15 weeks of photostimulation, the rate of lay of hens exposed to 11 h was consistently greater than in those exposed to 20 h. Thirty-two weeks after photostimulation, egg production of hens exposed to 20 h decreased to that seen in control hens exposed to 3-h photoperiod, while egg production of hens exposed to 11 h remained significantly greater. At the end of the study, 42 weeks after photostimulation, the total number of eggs laid by hens exposed to 11 or 20-h photoperiod was not significantly different (109 *vs.* 103 egg/hen), but was significantly greater than the number of eggs laid by hens exposed to 3-h photoperiod (54 eggs/hen).

The results of these three studies indicate that a reduced gonadotrophin function is a major factor determining a reduced egg production in hens that have been exposed to a stimulatory daylength for a prolonged time. The reduction in gonadotrophin function could be partly a function of age *per se*, which results in an impairment in the receptors for the hormones or in some of the signal transduction pathways. The finding that reproductive function in old hens improved after a moult and ovarian regression induced by reducing food intake without decreasing the daylength suggests that dietary restriction *per se* may dissipate photorefractoriness. The enhanced persistency of lay observed in hens photostimulated into a second year of egg production by transfer to a marginally stimulatory 11-h daylength is consistent with previous reports by Nicholls *et al.* (1988). The 11-h daylength seems to be sufficiently stimulatory to enhance reproductive function, but not to drive hens towards photorefractoriness as rapidly as exposure to 20 h photoperiod. In summary, these studies provide evidence that the poor rate of lay observed in domestic hens after exposure to continuous long days for several months may in part be due to photorefractoriness, but other factors such as feed restriction and ageing must be also taken into account.

Despite the few studies conducted to investigate the photoperiodic response of broiler breeders, other aspects of the use of lighting in broiler breeders have been researched in the past. Several studies have been designed to evaluate the effects of different ages at, and patterns of photostimulation on ASM, egg production and egg size in broiler breeder hens.

Yuan *et al.* (1994) evaluated the effects of early photostimulation on egg production. Broiler breeder pullets were subjected to photostimulation with 15 h photoperiod either at 14, 17 or 20 weeks of age, after attaining greater than recommended BW during rearing, in order to determine the effects of different ages at photostimulation on age at the onset of lay, egg weight and egg production. AFE was significantly delayed by about two weeks when photostimulation was applied at 20 weeks, whilst there were no statistical differences between photostimulation at 14 and 17 weeks of age. However, the lack of a control treatment (constant photoperiod) and the fact that the birds were transferred to cages at the time of photostimulation, which could have a negative effect on AFE (Lewis *et al.*, 1997) and therefore, making these results unreliable. Egg production up to 30 weeks of age was significantly higher in the 14 and 17-week treatments than in the 20-week treatment (31, 31 and 25 eggs/hen respectively). However, egg production in the 20-week treatment was significantly higher than the other treatments from 30 to 35 weeks of age. Total and settable egg production through the 64-week laying period did not differ significantly due to age at photostimulation. Birds photostimulated at 14 weeks exhibited lower peak and total egg production, but the early production of settable eggs, mean egg weights and total production of settable eggs did not differ significantly from the other two lighting treatments. The lack of significant interactions between growth profile and age at photostimulation in AFE is in disagreement with previous results by Leeson and Summers (1983). It has to be noted that both reports (Leeson and Summers, 1983 and Yuan *et al.*, 1994) have been conducted with old genotypes, which had less selection for growth and superior egg production levels than modern breeders. In consequence, their results in term of AFE and egg numbers could be significantly different to the numbers expected from breeder flocks at present, making difficult to compare with the results of current research.

Robinson *et al.* (1996) researched the effects of altering the age at photostimulation on subsequent reproductive performance. Birds were reared on 23-h photoperiod from day old until 2 weeks of age when the daylength was decreased to 8-h photoperiod and kept constant until the birds were photostimulated at 120, 130, 140, 150 or 160 d of age when the photoperiod was increased to 14 h photoperiod. Birds were maintained on 14-h photoperiod until the experiment was terminated at 60 weeks. ASM was not significantly delayed with photostimulation at 130, 140 or 150 d *vs.* 120 d (Table 2.6).

Table 2.6. *Effects of age at photostimulation (PHO) on reproductive performance. From Robinson et al. (1996)*

Variables	Age at photostimulation (d)				
	120	130	140	150	160
Age at sexual maturity (d)	173.0^{bc}	170.8^{c}	175.2^{b}	175.6^{b}	181.5^{a}
Days from PHO to sexual maturity	50.6^{a}	42.3^{b}	34.2^{c}	27.9^{d}	24.2^{d}
Mean egg weight (g)	56.6	55.7	55.0	56.4	56.4
Egg production [1]	160.6	155.2	162.8	162.0	158.0
Number of unsettable eggs	2.3	2.2	1.6	1.7	2.0

[a-d] Means within a row with no common superscript differ ($P<0.05$) [1] from onset of lay to 60 weeks of age.

In those birds photostimulated at 160 d sexual maturity was significantly delayed by about 6.3 d (compared with birds photostimulated at 140 d). However, this group had the least number of days from photostimulation to sexual maturity (Table 2.6). Age at photostimulation did not affect mean egg weight, total egg production or total production of settable eggs, in agreement with the results of Yuan *et al.* (1994).

In an experiment conducted in this University (1999, unpublished) the effects of a step up increase *vs.* a constant photoperiod were evaluated. The effects of the lighting programmes on reproductive performance will be discussed in section 2.3.3.2, but there is an important consideration to be made about the different timing of photostimulation and daylength during rearing on sexual maturity. In this experiment, ASM was significantly delayed, by 26 d, when birds were subjected to 17-h constant photoperiod. This effect was possibly due to juvenile photorefractoriness. Lewis (2000) suggested that the longer the period over which the pullets are kept on long days, the longer it takes for juvenile photorefractoriness to be dissipated. Juvenile photorefractoriness has been previously described in commercial layers by Sharp (1984) and Lewis (2000), and in turkey hens by Siopes (1984, 1994 and 2001), but there is no previous description of this effect in modern broiler breeder hens.

2.3.3.2 Period from age at photostimulation to peak production

Once daylength is to be increased, two relevant questions arise: what is the basis on which light increments are given, and what are the subsequent effects on reproductive performance? Many different strategies have been applied when studying the effects of photostimulation on reproductive performance in broiler breeders. Bringing forward the age at photostimulation is a possible tool to counteract the delay in ASM brought about by feed restriction programmes. Varying the pattern of lighting stimulus, from a single increase in daylength, to step-up programmes, using different weekly increments, to reach different final daylengths during the breeding period, have also been researched.

Most of the relevant studies on photostimulation in broiler breeders have been made in the timing of photostimulation rather than with the pattern applied. Robinson *et al.* (1998a) studied different patterns of photostimulation. Pullets were reared from 4 d of age on 8-h photoperiod until 20 weeks of age. At this time, two different lighting programmes were applied, one consisting of a sudden increase from 8 to 15 h, and the other, a step-up programme, where daylength was increased from 8 to 11 h at 20 weeks by 1 h/d, on a weekly basis, to reach 15 h at 24 weeks of age. In this experiment, photostimulation treatments did not affect the apparent rate of oviduct development, the ovary characteristics, or the weight of the oviduct at sexual maturity. Ovarian morphology was highly influenced by photostimulation programme. Birds on the step-up programme had 8.9 large yellow follicles compared with 8.0 with those given a sudden increase in daylength. This indicates a greater stimulatory role of the gradually increasing photostimulation than a single, sudden increase in daylength. There were no differences in multiple follicle arrangement of large yellow follicles due to photostimulation pattern. In a companion paper, Robinson *et al.* (1998b) evaluated the effects of lighting pattern on egg production and laying pattern characteristics. AFE was significantly delayed by the slow photostimulation pattern, by about 2.3 d. Mean egg weight was significantly higher for the slow pattern than for the fast lighting pattern. Total egg production and production of settable eggs did not differ among lighting treatments. Hen day production did not differ during early lay due to photostimulation treatment. However, hens subjected to the step-up programme showed a higher persistency of lay (58 *vs.* 54.6%). In spite of the effect on mean egg weight, the results of this experiment suggest that the pattern of photostimulation does not greatly influence egg production traits.

In a previous experiment at this University (1999, unpublished) the effects of a step-up programme *vs.* a constant photoperiod throughout the life of the birds were studied. Pullets were reared on two different daylengths, one of 17 h from 4 d old onwards and the other programme consisting of a constant 8 h until 19 weeks of age, when the pullets were subjected to step-up increments in daylength to achieve 16 h at 27 weeks. Pullets on the step-up programme reached sexual maturity 27 d earlier than the others. In these birds, the number of double-yolked eggs laid was lower (but not statistically significant) than those in the 17-h constant photoperiod. Hens on the step-up treatment produced 7.3 more eggs (in early lay) than hens on the 17-h treatment. However, in the latter group, peak production was marginally higher (78 *vs.* 77 eggs/100 bird.d) and persistency of lay was significantly higher (57 *vs.* 50 eggs/100 hen.d), perhaps due to a compensation for the delay in sexual maturation. In contrast with Robinson *et al.* (1998b), egg weight of hens subjected to progressive increases in daylength was significantly lighter (67.9 *vs.* 69.1 g) but this is due to the considerably earlier maturation of these hens. The most likely explanation for the considerable delay in achieving sexual maturity on a long daylength, measured in this experiment, is that broiler breeders exhibit juvenile photorefractoriness, and this prompted a number of subsequent trials to address this issue. These trials are ongoing at present.

Two reports by Joseph *et al.* (2002a, b) can be found in the literature describing the effects of manipulating age at photostimulation. The results of these reports are not included in this review since their experimental design and statistical analysis are not completely reliable. Joseph *et al.* (2002a) reported the effects of age at photostimulation and dietary protein intake on reproductive efficiency in three strains of broiler breeder hens varying in breast yield. In this study, the experimental design was meant to be a 3 x 2 x 2 factorial, with main effects of strain (CLASSIC, FSY and EXP), dietary protein (LOW and HIGH protein) and age at photostimulation (20 *vs.* 23 weeks of age). The birds were transferred into individual cages in a light-tight facility at 19 weeks of age. This facility was divided into two rooms by means of a plastic curtain. Birds housed in the one half of the house were transferred from 8 to 15 h at 20 weeks, while the remaining half was maintained on 8 h until 23 weeks of age. At this point, the plastic curtain was removed and all the birds were in a common room. Such a design is acceptable if only strain and dietary protein content were being compared, as the number of replications per treatment was adequate in order to perform an analysis of variance, as stated in the statistical methods section by the authors. However, by dividing the laying facility into two, and subjecting the birds to photostimulation by increasing the daylength in each half at different ages, each lighting treatment was replicated only once, leaving no degrees of freedom for performing such an analysis. A similar design was used in a second experiment reported by Joseph *et al* (2002b). Thus no conclusive statements could be made on the effects of the lighting treatments applied in the two experiments on the reproductive efficiency of broiler breeder hens.

2.4 DISCUSSION

During the last 20 years a great deal of research has been conducted in order to determine the factors capable of reducing the incidence of reproductive anomalies due to genetic selection for rapid growth in broiler breeder hens. The effects of *ad libitum* feeding on the incidence of reproductive anomalies, namely, internal ovulation, development of multiple sets of ovarian follicles, production of large ovarian follicles and the production of unsettable eggs (double-yolked, soft shelled and shell-less eggs) has been well documented. These anomalies appear to be more frequent in male line hens, which have been highly selected for rapid growth at the expense of egg production traits.

Many different factors affecting the reproductive behaviour in broiler breeder and turkey hens have been reviewed here, such as feed restriction, body weight control, the shape of the growth curve applied, and the response to different lighting programmes. The details of treatments applied and the effects on several reproductive traits, such as total and settable egg production, peak production and persistency of lay, have been described in the previous sections. In this discussion, some aspects of the research conducted are discussed, viz. experimental design, reporting treatment details, and results.

Feed restriction has been applied during different stages of the rearing and pre-laying periods, and to a lesser extent during the laying period. It is clear that feed restriction applied during rearing, and prior to sexual maturity, has a positive effect in controlling the ovarian activity of broiler breeder and turkey hens, and is an effective management tool in delaying sexual maturity.

The benefits of delaying sexual maturity on broiler breeders when feed restriction or lighting programmes are applied can be summarised as follows:

- the number of small eggs at the beginning of the laying period is reduced,
- mortality during the breeding period is reduced,
- the production of total and settable eggs is increased,
- the production of double and multiple yolked eggs is reduced,
- the quality of the eggs (including shell quality) is improved,
- mean egg weight (when lighting programme delays sexual maturity) is increased

due to a reduction in the number of small, unsettable eggs at the beginning of lay.

There is a lack of detailed information in several reports regarding feeding programmes applied, the total amount of feed consumed by the birds on different treatments, and the amount of feed allocated throughout the experimental period, which makes it difficult to understand the effects of the programme applied and to replicate the experiments. When testing the effects of feed allocation on subsequent egg production there are two patterns of treatments applied: the first one, allocating birds a fixed amount of feed and planning feed increments, appears to be more adequate in testing this effect, as it avoids the confusion with body weight effects. The second includes feed increments designed to follow a determined body weight curve or to reach a certain body weight target prior to sexual maturity, which might result in a confounding effect with those factors during rearing.

The body weight reached by the pullets around 20 weeks of age has been identified as one of the principal factors affecting ovarian function and egg production in broiler breeders, but more recently it has been suggested that it is not only the body weight reached that has an effect, but also the shape of the growth curve to achieve those weights. It is likely that small increments in body weight gain during the five weeks prior to sexual maturity, brought about by small increments in feed allocation during that period, stimulate the pullets to start laying, whilst avoiding the stimulus on ovarian function that occurs when birds are given either *ad libitum* access to feed or large increments in feed, both of which lead to greater increments in body weight gain. In many cases, body weight treatments, and body weights achieved due to a specific programme, are poorly described in the literature. It might be helpful, in order to make comparisons between experiments easier, that researchers select a reference value, for example, body weight at 20 weeks of age.

It has been shown that male-line broiler breeder hens develop more reproductive anomalies than do those of female lines. Selection programmes applied to female broiler breeder lines consider, either directly or, more likely, indirectly, some of the reproductive traits but this is not done with male-line females. Consequently, when researchers conduct experiments using male-line broiler breeders hens, the incidence of anomalies in the reproductive performance is likely to be higher than with female-line hens. Therefore, findings and conclusions have to be carefully analysed when these are applied to different breeder lines.

There are still some issues that should be addressed in order to maximize egg production of broiler breeder hens. As has been described previously, feeding programmes and body weight control have been explored widely during the rearing and pre-breeding periods. Less has been done concerning feeding programmes during the laying period. Therefore, there might be some potential to improve persistency of lay through manipulating either feed allowance or body weight after the onset of lay.

In most of the research reviewed here, experiments have been conducted with birds in individual cages. These types of experiments provide valuable information, due to the fact that the conditions allow the researcher to control tightly those environmental factors that can affect the results. They are also important in giving a complete description of the hen's response to different experimental treatments under controlled circumstances. On the other hand, there are two difficulties associated with this type of experiment. Firstly, the numbers of birds used in such a system are generally very limited, and the results may therefore be not completely reliable. Secondly, there are factors that in a flock situation can influence these results, and trying to apply them in a commercial situation may be a difficult issue. As an example, competition for food and territorial behaviour of hens within a flock has been shown to lead to a lack of uniformity and, as a consequence, a reduced egg production.

The lighting programmes applied commercially in broiler breeders are being adapted from those applied in commercial layers. Research conducted on lighting programmes in broiler breeders generally include variations in the age at which photostimulation is applied. Little has been done with patterns of photostimulation applied or with the physiology of the response to lighting stimuli in modern breeder hens or the possibility of exhibiting juvenile or adult photorefractoriness. If broiler breeders were shown to exhibit juvenile and or adult photorefractoriness, then this would help to explain many of the anomalies that have been reported (particularly in out-of-season flocks reared in open houses) regarding lighting programmes for broiler breeders.

The aim of this chapter was to review the relevant research conducted on the management of broiler breeders during the rearing and early laying periods, to understand and gather information about the factors of importance in controlling the ovulation process. Such information is essential if research strategies are to be designed to describe as clearly and completely as possible the reproductive behaviour of broiler breeder hens. Valuable research has been done, particularly in describing the individual response of broiler breeder hens, but little has been done in describing the responses in a flock situation, which might suggest that more research needs to be done in order to describe the reproductive performance of the population under different management conditions.

CHAPTER 3

THE EFFECTS OF 20-WEEK BODY WEIGHT AND AGE AT PHOTOSTIMULATION FOR BROILER BREEDER HENS: I. SEXUAL MATURATION AND EGG PRODUCTION

3.1 INTRODUCTION

Improvements in the potential growth rate of broiler chickens have had a profound negative effect on the reproductive performance of the broiler breeder females. Two of the most frequent causes of poor reproductive performance are internal and multiple ovulations (Hocking *et al.*, 1987; 1989; Robinson *et al.*, 1991; 1998a; Yu *et al.*, 1992a; Hocking, 1996; and Renema *et al.*, 1999). Further, the relatively low number of total and of settable eggs have major impacts on chick production. These anomalies are influenced by excessive body weight at sexual maturity, a fast growth rate and high feed intake during the rearing and pre-breeding periods (Hocking, 1993, 1996).

Most broiler breeder research in the past 20 years has centred on feed restriction, the growth curve, body weight at 20 weeks of age, and the age at which feed restriction is eased. However, excessive body weight gain during the pullet-layer transition is possibly the single most important factor affecting egg production. Whilst feed restriction and body weight control during rearing and in the early part of the laying period are considered important management tools for reducing the number of unsettable eggs, it is known that these practices also delay sexual maturity and adversely affect flock uniformity. However, delaying sexual maturity beneficially minimises the production of small eggs (Etches, 1996b). Notwithstanding that body weight has been identified as one of the most influential factors involved in the development of multiple ovarian hierarchies (Hocking, 1993), Fisher (1999) suggested that the shape of the growth curve and flock uniformity might also be important.

Robinson *et al.* (1996) suggested that when pullets are photostimulated early, they reach sexual maturity while they are still undergoing skeletal growth, whilst those photostimulated later start reproductive activity with a mature skeletal frame. And in recent years, broiler breeders have tended to be photostimulated at older ages to improve egg production.

This trial studied the effects of 4 different growth curves to 20 weeks of age, two ages at photostimulation, and two peak feed allocations in early lay on subsequent reproductive performance of broiler breeder hens. Four body weights at 20 weeks were achieved by following different growth curves between 15 and 20 weeks of age. Birds were photostimulated at 20 or 24 weeks of age. Daily feed allocations of 150 or 160 g were provided between 35 and 46 weeks of age.

3.2 MATERIALS AND METHODS

Four thousand, one hundred and sixty broiler breeder females (Ross 308; Ross Poultry Breeders Ltd., Meyerton, South Africa) were housed at 1 d on litter at 12 birds per m^2 in 8 light-tight rooms, with each room subdivided into two pens. Six hundred and thirty five males were reared in an adjacent light-tight room.

In order to ensure that the variation in body weight was below 11 percent, birds were sorted into three categories (small, medium and large) between 6 and 9 weeks of age, with the small group being allocated 1.24 and the large group 0.83 of the feed allocated to the medium group.

At 11 weeks of age, 3200 birds were transferred into a light-tight layer house that was divided into 8 rooms, each subdivided into 4 pens (100 pullets per pen). At 19 weeks, 10 males were added to each pen, creating a stocking density of 5 birds per m^2. All birds were fed *ad libitum* for the first 14 d, followed by restricted feeding according to the primary breeder's recommendation (Table 3.1). Up to three weeks, birds were fed a commercial pullet starter crumbles (217 g CP/kg, 12.5 MJ AMEn/kg and 12.8 g Ca /kg). Followed by a broiler breeder developer to 20 weeks of age (190 g CP/kg, 12.0 MJ AMEn/kg and 10.7 g Ca/kg), when a pelleted broiler breeder layer feed (140 g CP/kg, 11.0 MJ AMEn/kg and 30.8 g Ca/kg) was introduced, and this was fed to the end of the trial.

Birds were reared according to the primary breeder's recommended growth curve (Ross Breeders, 1998) until 15 weeks of age. Thereafter, 4 different feeding programmes were applied to achieve 28, 34, 40 and 46% of the predicted a*d libitum* body weight (0.70, 0.85, 1.00 and 1.15 of the recommended weight – Treatments FT1, FT2, FT3, FT4) by 20 weeks of age.

Table 3.1. *Feed allocation from 2 to 31 weeks of age*

Age (weeks)	Feed intake (g/bird d)	Age (weeks)	Feed intake (g/bird.d) Feeding Treatment			
			FT1	FT2	FT3	FT4
2	30	16	60	60	74	85
3	30	17	60	60	85	90
4	30	18	50	50	90	100
5	35	19	55	65	95	115
6	42	20	50	60	95	120
7	51	21	50	65	100	120
8	51	22	60	75	110	125
9	55	23	70	85	120	125
10	55	24	80	95	130	135
11	55	25	90	105	140	145
12	58	26	100	115	150	150
13	58	27	110	125	150	150
14	64	28	120	135	150	150
15	66	29	130	145	150	150
		30	140	150	150	150
		31	150	150	150	150

FT1, FT2, FT3 and FT4: designed to give 0.70, 0.85, 1.0 and 1.15 of breeding company's recommended target body weight at 20 weeks of age.

The daily feed allocation for each treatment, as detailed in Table 3.1, was revised weekly taking into consideration the average body weight gained in the previous week (mean of a 0.3 sample) and the body weight required to be achieved during the succeeding week. From 21 weeks, twice-weekly feed increments of 5 g/bird were given until the daily intake reached a maximum of 150 g/bird.d (Table 3.1). Between 35 and 46 weeks of age, the daily feed allocation for half of each body weight/photostimulation combination was increased from 150 to 160 g, followed by a return to 150 g at 46 weeks, whilst controls were maintained on 150 g throughout.

All birds were given 24 h of light at 1 d, followed by a step-down in daylength to reach 8 h at 7 d. At 20 weeks, daylength was increased to 10 h in 4 of the 8 rooms, followed by weekly increments of 1 h to reach 16 h by 26 weeks (LT1). The remaining birds received the same increments in daylength, but from 24 weeks, to reach 16 h at 30 weeks (LT2). Body weights at photostimulation can be seen in Table 3.3.

The experiment had a 4 x 2 x 2 factorial design, with feed allocation during rearing (FT1 – FT4), photostimulation age (LT1 and LT2) and daily feed allocation during the early laying period (150 and160 g/bird.d) as variables. Birds were randomly allocated to 8 light-tight rooms. Each of the 4 rearing-feed treatments was randomly allocated to a pen within each room. There were 4 replications of each lighting treatment, 8 replications of each feeding treatment applied during rearing, and 16 replications of the feeding treatments applied in lay. Age at sexual maturity (ASM) was defined as the day on which the mean rate of lay over a 2-d period first exceeded 50 eggs per 100 bird.d. The total eggs, and number of double-yolked, and soft-shelled eggs were recorded daily. Abnormally large eggs were assumed to be double-yolked, and those, as well as any soft-shelled eggs were excluded from daily egg weighing. Settable eggs were considered as those eggs weighing more than 50 g, single yolked and without shell alterations. All data were subjected to an ANOVA using a general linear model (Minitab, 1998), and significant differences between two means were identified using a Student's *t* test.

3.3 RESULTS

Although most variables were significantly affected by the feeding and/or the lighting treatments, there were no significant interactions.

3.3.1 Body weight at 20 weeks

It proved to be very difficult to achieve the desired weekly body weight gains, with FT1 generally above and FT2, FT3 and FT4 below target (Table 3.2). As a consequence, the achieved mean relative body weights for FT1 (0.7), FT2 (0.85) and FT4 (1.15) in the 16 to 30 week period were 0.82, 0.86 and 1.06 of FT3 respectively. From 15 to 34 weeks of age, birds on FT1 and FT2 were allocated 0.23 and 0.16 less feed than those on FT3, while birds on FT4 received 0.06 more feed than the FT3 birds. However, despite the range being narrower than planned, body weights for the four treatment groups were still significantly different from each other throughout the 19-week period.

Sexual maturity, as measured by age at 50 percent (bird.d basis) rate of lay, was negatively correlated with 20-week body weight, with all treatment groups significantly different from each other (Table 3.3). The strong influence of pre-pubertal body weight on sexual development is demonstrated by a significant linear regression of age at 50 percent rate of lay on 20-week body weight, with maturity being advanced by 3.3 d for each 100 g increase in body weight.

Table 3. 3. *Mean weekly body weight (g) for broiler breeder hens subjected to different feeding and lighting treatments from 15 to 30 weeks of age. Deviance from target weight in parentheses.*

Age	Feeding treatments			
(weeks)	FT1	FT2	FT3	FT4
16	1624 (+99)	1609 (+84)	1620 (-20)	1701 (-15)
17	1716 (+191)	1704 (+179)	1774 (+9)	1833 (-74)
18	1680 (+155)	1677 (+152)	1902 (+12)	1986 (-112)
19	1824 (+299)	1835 (+156)	2082 (+62)	2185 (-104)
20	1678 (+153)	1726 (-106)	2028 (-127)	2235 (-245)
21	1723 (+53)	1765 (-212)	2209 (-91)	2390 (-235)
22	1837 (+2)	1944 (-198)	2396 (-69)	2610 (-180)
23	1899 (-111)	2051 (-260)	2513 (-127)	2723 (-242)
24	2026 (-144)	2226 (-251)	2685 (-115)	2962 (-163)
25	2213 (-97)	2336 (-281)	2893 (-47)	3111 (-154)
26	2290 (-150)	2443 (-304)	2989 (-81)	3190 (-205)
27	2413 (-167)	2615 (-242)	3010 (-170)	3175 (-330)
28	2498 (-142)	2637 (-310)	3072 (-198)	3182 (-413)
29	2540 (-170)	2677 (-340)	2989 (-351)	3084 (-581)
30	2618 (-142)	2700 (-367)	2979 (-411)	3052 (-663)
LT1	1678 (+161)	1785 (-47)	2084 (-71)	2221 (-259)
LT2	2017 (-153)	2296 (-181)	2664 (-136)	2986 (-139)

FT1, FT2, FT3 and FT4: designed to give 0.70, 0.85, 1.0 and 1.15 of breeding company's recommended target body weight at 20 weeks of age. LT1: photostimulation at 20 weeks, LT2: photostimulation at 24 weeks.

FT3 and FT4 birds had a significantly higher peak rate of lay than FT1 and FT2 birds, but peak production was reached approximately 3 weeks after mean age at 50 percent egg production in all cases (Table 3.4). Birds on FT1 reached peak production 12, 22 and 23 d later than birds on FT2, FT3 and FT4 respectively. Total egg numbers to 56 weeks were significantly poorer for FT1 and FT2 than for FT3 and FT4 birds. However, a significantly higher incidence of double-yolked eggs for FT3 and FT4 birds resulted in all groups producing similar numbers of settable eggs. Mean egg weight for FT1 birds was significantly lighter than that for FT3 and FT4 birds, with FT2 intermediate between FT1 and FT3 (Table 3.3).

3.3.2 Age at photostimulation

Whilst age at photostimulation did not significantly affect body weight at a given age (Table 3.2), there was a significant 6-d advance in sexual maturity for birds photostimulated at 20 weeks compared with 24 weeks (Table 3.3).

Both groups achieved a similar peak rate of lay, and at a similar time, but the birds photostimulated at 20 weeks significantly produced 5.6 more total eggs to 56 weeks. Mean egg weight for birds photostimulated at 24 weeks was 0.5 g significantly heavier than birds photostimulated at 20 weeks (Table 3.3).

Table 3.3. *Mean in age at 50% lay, peak egg production and age at peak production, total and settable egg numbers, total production of unsettable eggs and mean egg weight for broiler breeder hens subjected to different feeding and lighting treatments from 23 to 56 weeks of age*

		Peak production		Age 50%	Total eggs	Settable eggs	Unsettable	Mean egg
Feed	Light	Rate of lay	Age (d)	lay (d)	(hen.week basis)	(hen.week basis)	(per hen*)	weight (g)
FT1	LT1	73.9	242	205	121.9	117.2	4.8	61.7
FT1	LT2	75.1	237	207	116.4	112.1	4.3	61.9
FT2	LT1	73.2	228	198	122.7	118.6	4.0	62.1
FT2	LT2	76.1	226	205	118.4	115.4	3.0	62.7
FT3	LT1	82.0	214	187	135.1	120.9	14.3	62.6
FT3	LT2	81.4	221	195	126.6	118.1	8.5	63.1
FT4	LT1	79.4	210	184	129.5	113.1	16.3	62.4
FT4	LT2	78.9	223	189	124.7	111.2	13.5	63.3
Main effects								
Feed	FT1	74.5	239	206	119.2	114.6	4.5	61.8
	FT2	74.6	227	201	120.6	117.0	3.5	62.4
	FT3	81.7	217	191	130.9	119.5	11.4	62.9
	FT4	79.1	216	187	127.1	112.2	14.9	62.9
SED		6.4	4.7	3.7	14.9	40.4	0.17	0.18
Light	LT1	77.1	227	193	127.3	117.5	9.8	62.2
	LT2	77.9	226	199	121.5	114.2	7.3	62.7
SED		9.1	6.7	5.4	7.4	57.1	0.24	0.27

**(eggs per 100 bird.d).* FT1, FT2, FT3 and FT4: designed to give 0.70, 0.85, 1.0 and 1.15 of breeding company's recommended target body weight at 20 weeks of age. LT1: photostimulation at 20 weeks, LT2: photostimulation at 24 weeks.

3.3.3 Peak daily feed allocation

Hens allocated an extra 10 g of feed per d between 35 and 46 weeks of age produced a significantly higher number of total and settable eggs than birds limited to 150 g/bird.d, but egg weight and the proportion of double-yolked eggs were not significantly affected.

3.4 DISCUSSION

The delay observed in sexual maturity due to the feeding treatments concurs with the findings of Robinson and Robinson (1991) that sexual maturity occurs earlier when broiler breeders are either fed *ad libitum* or when grown to a higher 20-week body weight. However, these findings contradict those of Robinson *et al.* (1995), Fisher (1999) and Joseph *et al.* (2002a), who reported that increasing the 20-week body weight above the target weight recommended by the breeding company did not affect sexual maturity. It is possible, therefore, that body weights lighter than those recommended by the breeding company exert a greater effect on sexual maturity than body weights that are above target.

The 6-d delay in sexual maturity produced by the 4-week delay in photostimulation was associated with the production of 5.8 fewer eggs to 56 weeks of age (Table 3.3). However, because 3.7 eggs of this difference had occurred by 34 weeks of age, and mean egg weight during the 35 to 56 weeks was only 0.5 g heavier for this treatment, it is likely that the lower egg production was primarily caused by the later-maturing birds simply having fewer days in production, and that broiler breeders are unable to compensate, in terms of egg numbers, for retarded maturity. Similar observations were made by Yuan *et al.* (1994). The 0.21 d rate of delay for each 1 d delay in photostimulation is similar to the 0.22 d recorded by Robinson *et al.* (1996), but contrasts with 0.50 d by Leeson and Summers (1983) and 0.57 d by Yuan *et al.* (1994). One of the reasons for the difference in rate of response will be the size of the initial increment in photoperiod. In this trial daylength was only increased to 10 h, followed by step-ups to 16 h, but birds in the other trials were abruptly transferred to a final photoperiod of 14 or 15 h. Because these findings agree with the more recent reports, it is also possible, though mildly so, that there has been a genetic change in the photosensitivity of breeding stock.

Although the feeding treatments during the rearing period affected all production variables during the early laying period, egg production was not significantly different after 35 weeks. This indicates that the feeding programmes in the 15 to 20 week period have a greater influence on egg production in the early part of the laying cycle than in the later part.

As all birds were given the same feed allocation in the laying period, irrespective of 20-week body weight, it might have been expected that the heavier birds (FT3 and FT4) would have had a larger maintenance requirement, so leaving less nutrients available for production, with the reverse scenario for the smaller birds. However, the laying performance of the smaller birds (FT1 and FT2) was significantly inferior to that of the birds with heavier 20-week body weights (Table 4). One possibility is that this was due to a lack of nutritional stimulus before sexual maturity, as similar findings were reported by Robinson and Robinson (1991) for broiler breeders that had been reared under severe feed restriction, and unpublished data from another trial conducted at the University of Natal, in which birds were reared on a growth curve emphasizing fast early growth and avoiding large increments in body weight between 16 and 20 weeks, also had inferior egg production to conventionally grown controls. This suggests that broiler breeders require a rising plane of nutrition immediately prior to sexual maturation for optimal egg production, in a manner similar to that observed in sheep (Adam *et al.*, 1998).

The higher egg production of the birds given an extra 10 g of food per d between 35 and 46 weeks indicates that performance during this period was limited by the provision of only 150 g. However, it is not surprising that the proportion of double-yolked eggs was unaffected by the extra feed, because the laying of double-yolked eggs is principally caused by precocity and the feeding regime around sexual maturation (and birds were drawn from all body weight/photostimulation combinations) and is, in any case, minimal at this stage of the laying period (Lewis *et al.*, 1997).

The positive relationships of double-yolked egg production with earlier sexual maturation and heavier peripubertal body weights were not surprising (Lewis *et al.*, 1997). A significant linear regression showed that each 100 g increase in body weight resulted in about two more double-yolked eggs. These results support the conclusions of Hocking (1993) that body weight, together with the amount of food consumed between photostimulation and maturity, might be considered to be two of the most important causal factors of multiple ovarian hierarchies. However, further research would appear to be prudent, because unpublished data from the University of Natal has shown that the production of double-yolked eggs was affected by neither the amount of food consumed during the rearing period nor by the shape of the growth curve.

The effect of different growth curves on mean egg weight was not unexpected, because of the known relationships between mean egg weight and body weight at sexual maturity (Lewis *et al.*, 1994a). In this trial, mean egg weight was significantly correlated with body weight at both 20 weeks and 50 percent rate of lay (estimated from data in Tables 3.3 and 3.4), increasing by 0.15 g for each 100 g increase in body weight, after removal of the effects of delayed photostimulation.

An initial look at the mean egg weight and age at 50 percent rate of lay data for the various body weight/photostimulation groups (Table 3.3) suggests that egg weight is negatively correlated with ASM. Whilst this appears contradictory to the findings of Lewis *et al.* (1994) for egg-type hybrids, a multiple regression of mean egg weight on body weight and ASM revealed that egg weight increased significantly by 1 g for each 20-d delay in 50 percent egg production. The difference between this regression slope and the 1 g per 6-d delay in sexual maturity reported for egg-laying hybrids might be a result of broiler breeders being control-fed and egg-type birds being fed *ad libitum*. The similarity of egg weight for FT3 and FT4 birds is in agreement with the observations of Robinson *et al.* (1998b), that the feeding programmes applied in their experiment (Slow or Fast Feeding) had no significant effect on egg weight. It might also have been expected, with 20-week body weights for FT4 birds only 6 percent heavier than FT3. However, the heavier mean egg weight for the birds photostimulated at the older age contrasts with the reports of no link between egg weight and age at photostimulation of Yuan *et al.* (1994) and Robinson *et al.* (1996), but concur with the findings of Leeson and Summers (1983) for meat-type pullets and Leeson *et al.* (1991) and Lewis *et al.* (1996, 1997) for egg-laying pullets.

In conclusion, these findings indicate that all egg-laying parameters for broiler breeders are significantly influenced by feeding and lighting treatments during the rearing period, even when they are applied after 15 weeks of age. However, compared with the other treatments applied in this investigation, current commercial feeding and lighting protocols (FT3-LT1) appear satisfactory in terms of egg numbers, but further study of the factors predisposing multiple ovulation would be prudent. The increased egg production during the 35 to 46 week period, in response to the provision of an extra 10 g daily feed allocation, suggests that this is a further area for investigation.

CHAPTER 4

THE EFFECTS OF 20-WEEK BODY WEIGHT AND AGE AT PHOTOSTIMULATION FOR BROILER BREEDER HENS: II. SEXUAL MATURITY, EARLY EGG WEIGHT AND CARCASS COMPOSITION

4.1 INTRODUCTION

Body weight and age at photostimulation both influence the ASM in broiler breeder hens (Yuan *et al.*, 1994). Robinson and Robinson (1991) reported that sexual maturity is reached earlier in broiler breeders fed *ad libitum* or when they achieve higher body weights at 20 weeks. Nevertheless, the advantages of bringing forward the onset of lay by increasing the body weight profiles during rearing appear to be nullified due to the early production of small eggs (Yuan *et al.*, 1994).

Feed restriction applied to control body weight and growth of broiler breeders might also affect the response of the bird to photostimulation programmes. It is well known that restrictive feeding practices can negatively affect flock uniformity, in which case, the later the photostimulation is applied, the higher the proportion of birds that will be able to respond to light and commence reproductive development (Robinson *et al.*, 1996). The reduction in potential laying days due to a delayed photostimulation may be compensated for by an increment in the initial egg weight (Joseph *et al.*, 2002a). Previous research has focused almost exclusively on varying age at which the light stimulus is applied, in order to bring forward maturity, as happens with commercial laying hens. But very little has been done to explore the effects of different increments in daylength on sexual maturity and early egg weight of broiler breeder hens.

The effects of different body weight at 20 weeks on carcass composition at sexual maturity and during the late productive period have been investigated by Robinson *et al.* (1995) and Wilson *et al.* (1995). However, little literature is available describing the changes in body composition of broiler breeders during the early laying period. A better understanding of the variations of carcass composition during the post-peak production period might help to understand the erratic laying behaviour of broiler breeder hens.

The objectives of the experiment reported here were to determine the effects of different body weights at 20 weeks of age, and the effects of different age at, and pattern of photostimulation, on ASM and early egg weight of broiler breeder hens. A second objective was to determine whether the erratic laying behaviour could be explained by differences in body composition and the morphology in reproductive organs.

4.2 MATERIALS AND METHODS

Four hundred and eighty 19 week-old broiler breeder pullets (Ross 308; Ross Poultry Breeders Ltd., Meyerton, South Africa) were placed in 8 light-tight rooms, each housing 60 birds in individual cages. These birds were taken from a larger population of broiler breeders, in which the effect of different rates of gain in body weight from 15 to 20 weeks of age on reproductive performance was measured. The husbandry and growth profiles followed to 19 weeks of age have been described in Chapter 3. Birds were selected from each of 4 body weight categories. Mean body weights were 1525, 1679, 2020, 2289g for FT1, FT2, FT3 and FT4, with coefficients of variation of 5 percent for each of the 4 treatments.

The initial feed allocation for each treatment was the amount being fed to the pullets for the main experiment, namely, 55, 65, 95 and 115 g/bird. Feed increments were given by 5-g/bird.d twice a week until a maximum of 150 g was reached at 29, 28, 25 and 23 weeks of age on treatments FT1, FT2, FT3 and FT4 respectively. The total feed consumed by birds on the 4 body weight groups over the 15-week experimental period was 13.30, 13.97, 15.54 and 16.24 kg/bird for FT1, FT2, FT3 and FT4 respectively. From 19 weeks of age to the end of the experiment, a broiler breeder layer feed (89.6 %DM, 140 g CP/kg, 11.03 MJ AME/kg and 30.8 g Ca/kg) was offered.

All birds were subjected to a lighting programme of 24 h light at day old. Daylength was reduced during the first week to 8 h, and maintained to 19 weeks of age, when 5 lighting programmes were applied as follows: LT1: 8 h constant to 34 weeks (control treatment); LT2: single increment in daylength from 8 to 10 h at 19 weeks of age; LT3: single increment in daylength from 8 to 16 h at 19 weeks; LT4: step-up increments in daylength at 19 weeks of age from 8 to 10 h the first week, and 1 h/week increment thereafter to achieve a maximum daylength of 16 h and LT5: step-up increments in daylength (increments given as for LT4) from 23 weeks.

At 34 weeks of age, 24 birds were selected for the analysis of reproductive morphology, presence of internal or multiple ovulations, and carcass composition. Birds were selected based on their laying performance and classified in 3 groups: good layers (hens showing an early age at first egg and regular egg production records), poor layers (birds showing an erratic laying performance) and non-layers (hens who did not lay any eggs during the experiment). Birds in the first two groups were randomly selected, while all birds which did not lay eggs were selected for this study. Birds to be sampled were fasted for 24 h prior to being euthanased by carbon dioxide asphyxiation. Body weight, feather weight and abdominal fat pad weight were recorded. An inspection of the abdominal cavity was performed in order to identify signs of internal ovulation. The reproductive tract (from the infundibulum to the cloacae terminal) was detached and weighed, as well as the oviduct. The ovary weight was recorded and the number of follicular hierarchies was counted. Ovarian follicles were separated from the stroma, and classified as greater or smaller than 10 mm diameter, and counted. All organs were returned to the carcass, which was minced for further chemical analysis. The samples were freeze-dried for 72 hours for moisture determination (AOAC, 1990). Crude protein was determined with a LECO FP2000 Nitrogen Analyser, based on the Dumas combustion method (AOAC, 1990). The lipid content of the carcass was calculated from the following formula developed in our laboratory:

$$L = -0.8756 + 0.04754 * GE$$

Where L is the lipid content (g/g) and GE is the gross energy (MJ/kg) of the sample. Gross energy was determined using a DDS isothermal CP500 bomb calorimeter.

The experiment had a 4 x 5 factorial design, with body weight at 20 weeks (FT1-FT4) and lighting programme (LT4-LT2) as variables. Birds were allocated to 8 light-tight rooms where each of the 5 lighting treatments was randomly allocated. Fifteen birds selected from each of the 4 body weight groups were randomly allocated into indivicual cages. There were 2 replications of each lighting treatment, except for LT1 and LT2, where there was 1 replication of each. ASM, the total number of eggs produced to 34 weeks and the average egg weight during the first week of lay were individually recorded. Due to the unbalanced nature of the experiment, data were analysed using a Residual Maximum Likelihood Model (REML, Genstat 6th Edition), with FT*LT as a fixed model, and FT.LT.room.cage as random model. REML provides with an average SED, as well as maximum and minimum values. Significant differences ($P \leq 0.05$) between means were identified using the appropriate SED and a Student's *t*-test. Simple and multiple regression analyses were performed where appropriate.

4.3 RESULTS

4.3.1 Sexual maturity and early egg weight

Mean age at first egg (AFE) is given in Table 4.1. A significant interaction between body weight at 20 weeks and the lighting programme applied was found. Birds on FT4-LT3 achieved the earliest AFE. Birds severely restricted in their body weight profiles started laying significantly later, under any of the different lighting programmes applied. AFE was not affected when an increment in daylength from 8 to 16 h was given in single or multiple steps in any of the body weight groups.

Table 4.1. *Mean age at first egg as influenced by body weight at 20 weeks and lighting programme during rearing.*

				AFE (d)				
	FT1	n	FT2	n	FT3	n	FT4	n
LT1	212.3^{a}	14	205.2^{a}	13	198.2^{a}	15	195.0^{a}	13
LT2	196.7^{b}	15	199.3^{ab}	15	183.3^{b}	15	176.9^{c}	15
LT3	196.6^{b}	28	188.9^{c}	30	176.6^{c}	30	169.1^{d}	28
LT4	195.6^{b}	29	187.8^{c}	29	178.1^{bc}	29	172.1^{cd}	30
LT5	201.2^{b}	29	197.1^{b}	30	191.7^{a}	29	186.6^{b}	30
SED	Average		3.143					
	Min		2.628		*Residual d.f. = 447*			
	Max		3.992					
Main effects	FT	AFE (d)	n			LT	AFE (d)	n
	1	200.5	115			1	202.9	55
	2	195.6	117			2	189.1	60
	3	185.6	118			3	182.8	116
	4	179.9	116			4	183.4	117
						5	194.2	118
SED	Average	1.14			SED	Average	1.574	
	Min	1.408				Min	1.328	
	Max	1.426				Max	1.902	

$^{a-d}$ *Means within a column with no common superscript differ (P<0.05). FT1, FT2, FT3 and FT4: 1525, 1679, 2020 and 2289 at 20 weeks of age, LT1: 8h constant, LT2: single increment from 8 to 10 h at 19 weeks of age, LT3: single increment 8 to 16 h at 19 weeks, LT4: step-up increments from 8 to 16 h at 19 weeks and LT5: step-up increments 8 to 16 h at 23 weeks*

Increasing the daylength to 10 h resulted in a 5 d delay in AFE for birds on FT3-LT2 and FT4-LT2, compared with birds that were photostimulated using a step-up programme (FT3-LT4 and FT4-LT4), although this difference was not significant. However, there was a significant delay of about 7 and 8 d when birds on FT3 and FT4 were photostimulated from 8 to 10 h (LT2), compared with those subjected to an increase to 16 h in a single step FT4-LT3). Birds on LT1-FT1 reached sexual maturity 44 d later than birds on FT4-LT3.

The delay in sexual maturity resulted in a decrease in egg production of 0.83 eggs per surviving hen (see Figure 4.1a), but also resulted in a significant increase of 1 g per 3.6 d on the weight of the initial eggs produced (see Figure 4.1b).

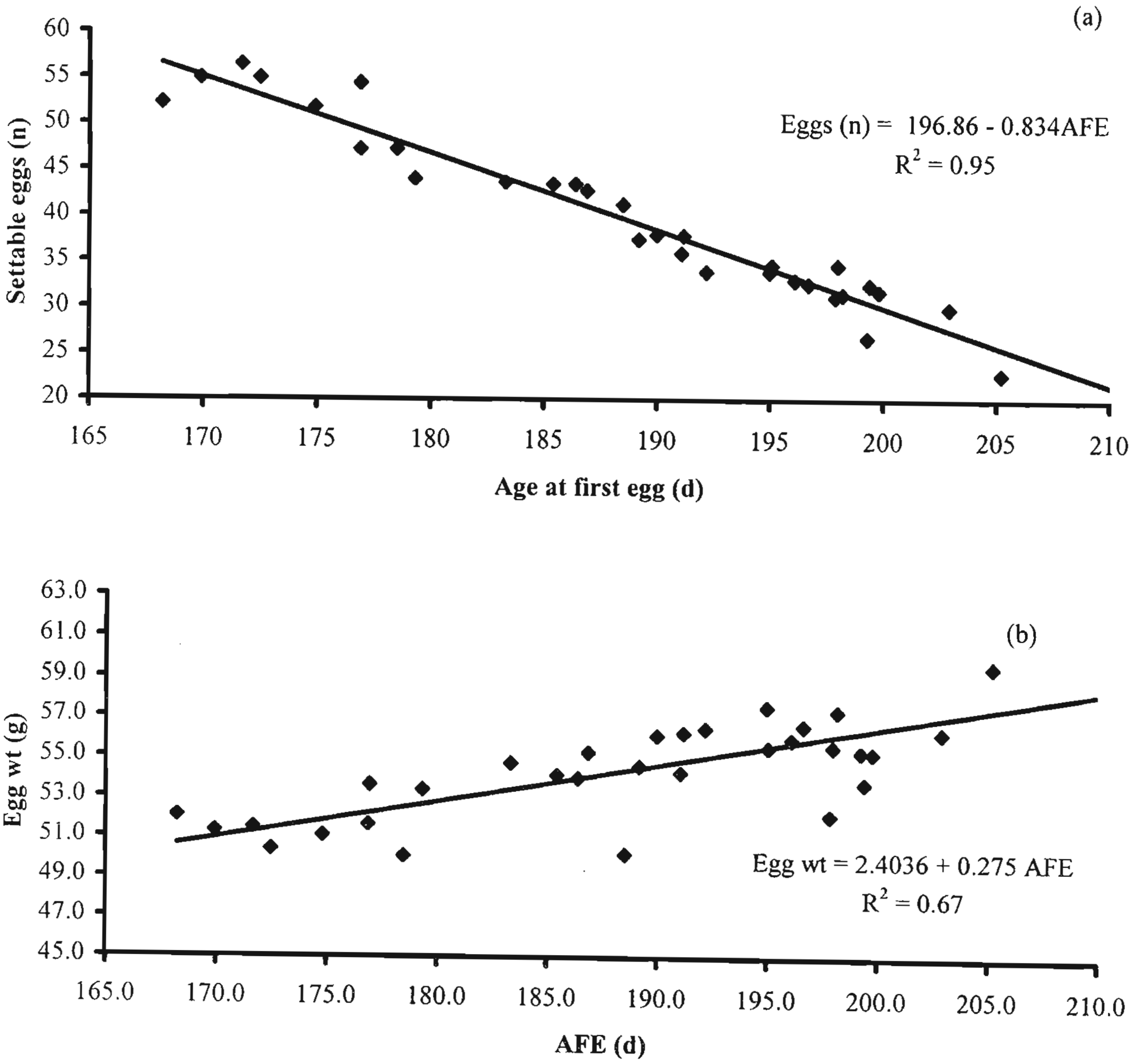


Figure 4.1. *Effects of mean age at first egg (AFE) on (a) average settable egg per surviving hen, and on (b) initial egg weight in broiler breeder hens of different body weight at 20 weeks and subjected to different lighting programmes to 34 weeks*

Most of the birds produced eggs at the beginning of lay that could be considered a settable weight (Table 4.2). Birds on LT1 produced the heaviest initial eggs. There were no significant differences in initial egg weight of birds on LT4 and LT3. Initial egg weight of birds on LT2 was significantly heavier than those produced by birds on LT4 and LT3.

Table 4.2. *Initial egg weight in broiler breeder hens of different body weight at 20 weeks of age and subjected to different lighting programmes*

	Initial egg weight (g)							
	FT1	n	FT2	n	FT3	n	FT4	n
LT1	60.3	14	59.6	13	57.3	15	57.5	13
LT2	56.6	15	55.3	15	54.7	15	53.6	15
LT3	53.7	28	52.4	30	50.5	30	51.6	28
LT4	54.7	29	55.1	29	52.5	29	50.9	30
LT5	55.0	29	55.7	30	56.6	29	54.6	30
SED	Average	1.683						
	Min	2.134			*Residual d.f. = 447*			
	Max	1.403						

Main effects	FT	Initial egg weight (g)	n	LT	Initial egg weight (g)	n
	1	56.1^{a}	115	1	58.7^{a}	55
	2	55.6^{a}	117	2	55.0^{b}	60
	3	54.3^{b}	118	3	52.1^{cd}	116
	4	53.6^{b}	116	4	53.3^{c}	117
				5	55.4^{bc}	118
	SED	Average	0.7587	SED	Average	0.8428
		Max	0.7655		Max	1.02
		Min	0.7518		Min	0.7092

FT1, FT2, FT3 and FT4: 1525, 1679, 2020 and 2289 at 20 weeks of age. LT1: 8h constant, LT2: single increment from 8 to 10 h at 19 weeks, LT3: single increment 8 to 16 h at 19 weeks LT4: step-up increments from 8 to 16 h at 19 weeks and LT5: step-up increments 8 to 16 h at 23 weeks.

There were no significant differences between the initial egg weight of birds on FT1 and FT2, or between the initial egg weight of birds on FT3 and FT4. Initial egg weights produced by birds on FT1 and FT2 were significantly heavier than those produced by hens on FT3 and FT4.

4.3.2 Carcass analysis and reproductive morphology

The results of the carcass analysis are shown in Table 4.3. Hens that had never laid during the 34-week period showed a significantly lower body weight and feather-free body weight than birds on the other treatments. No significant differences were found in the carcass composition of hens showing different laying efficiencies.

The analysis of the reproductive morphology showed that there were no significant differences in any of the variables examined (Table 4.3). Non-laying birds exhibited normal ovarian development, with a normal number of small and large yellow ovarian follicles. No significant differences were found in the number of small yellow follicles, the number of large yellow follicles or in the proportion of large to small yellow follicles and there were no evidence of internal ovulations or development of double or multiple ovarian hierarchies.

Table 4.3. *Chemical composition and reproductive morphology of broiler breeder hens exhibiting different egg laying efficiencies (across treatments)*

Variable	Non layer	Poor layer	Good layer	SEM	Significance [1]
Body weight (g)	3064	3281	3426	61.2	*
Feather weight (g)	95.1	117	123	7.40	NS
Feather-free body weight (g)	2969	3164	3304	50.6	*
Water content (%)	62.5	61.0	62.6	0.33	*
Water weight (g)	1854	1929	2067	29.4	NS
Protein content (%)	16.7	16.6	16.7	0.12	NS
Protein weight (g)	497	524	551	8.63	NS
Lipid content (%)	16.4	17.6	16.3	0.39	NS
Lipid weight (g)	486	560	540	17.3	NS
Ash content (%)	6.91	6.44	6.90	0.19	NS
Ash weight (g)	67.0	76.6	77.5	4.98	NS
Fat pad content (%)	3.38	3.33	3.33	0.14	NS
Fat pad weight (g)	97.1	107	110	5.01	NS
Ovary content (%)	2.00	1.85	1.93	0.08	NS
Ovary weight (g)	59.0	58.4	63.2	2.75	NS
Reproductive tract content (%)	2.35	2.33	2.35	0.07	NS
Reproductive tract weight (g)	69.4	72.6	76.6	1.76	NS
Oviduct content (%)	1.28	1.36	1.29	0.05	NS
Oviduct weight (g)	37.8	42.7	42.5	1.74	NS
Small Yellow follicles	9.88	12.8	14.1	1.03	NS
Large yellow follicles	6.63	6.00	6.75	0.26	NS
L: S ratio	0.70	0.64	0.69	0.09	NS

[1] *P<0.05; ** P<0.01; NS = Not significant (P> 0.05)

4.4 DISCUSSION

The delay in AFE observed in birds on FT1-LT2 and FT2-LT2 compared with birds on FT4-LT2 suggests that body weight and composition may interact with the lighting stimulus in determining the ASM. The lack of significant differences in sexual maturity observed in birds on FT3 and FT4, given an increment in daylength from 8 to 10 h compared with those subjected to an increase to 16 h in a step up programme, could be the result of the initial increase in daylength being the same for both groups. These results also indicate that 10-h photoperiod was sufficient to stimulate the release of hormones responsible for the onset of lay in pullets on FT3 and FT4. This finding is in agreement with Dunn and Sharp (1990), who showed that the shortest photoperiod required to stimulate the release of LH in Dwarf broiler breeders was less than 10.5 h. However, the lack of differences in AFE between birds on the lighter body weight groups that were maintained on 8 h constant or photostimulated to 10 h (FT1-LT2, FT2-LT2, FT3-LT1 and FT4-LT1), suggests that 10-h photoperiod was not successful in bringing forward maturity in birds severely restricted in growth rate prior to sexual maturity.

Delaying sexual maturity by means of a delayed photostimulation appeared to improve the rate of lay during the early laying period. The slope of 0.83 in Figure 4.1.a. indicates that a delay in maturity of 10 d resulted in a decrease in production of only 8 eggs up to 34 weeks of age. However, this improvement in rate of lay could be nullified in strains of broiler breeders that produce very large eggs, by the significant increase in egg weight observed when maturity is delayed by a later photostimulation. In this experiment, egg size at 34 weeks was increased by 3 g in birds photostimulated 3 weeks later than the breeder's standard. Joseph *et al.* (2002a) showed that delaying photostimulation could be used as a means of improving initial egg size in broiler breeder strains that produce eggs lighter than 50 g at the onset of lay. However, in strains where the problem is not with small eggs at the start of lay, but with large eggs towards the end of the laying period, the egg size problem is exacerbated when sexual maturity is delayed in this way.

Pullets that were kept on an 8 h daylength throughout the experiment came into lay 20 days later than those photostimulated at a commercial age, suggesting, in agreement with Sharp (1993), that factors other than photostimulation would in such cases influence sexual maturation, such as body weight, fat deposition in the body, the time since last exposed to long days, and the genotype. In a previous report, Robinson *et al.* (1996) indicated that broiler breeders did not initiate sexual maturation until they were exposed to photostimulation. However, in that experiment no constant daylengths were used as a control that could confirm such a conclusion.

The initial egg weight was, in all cases, heavier than 50 g (Table 4.2), indicating that small egg size is not an issue when the strain used here is subjected to the conditions applied in this experiment. The regression equation shown in Figure 4.1.b. indicates that for this strain, an acceptable initial egg weight (> 50 g) would be achieved with an AFE of 173 d. The heaviest initial egg weight observed, in birds given 8 h constant, is probably due to the significant delay in sexual maturity brought about by this treatment. These results concur with those of Lewis *et al.*, (1997) in which two strains of egg-type hens were used. Although no significant interaction was found between body weight at 20 weeks and lighting treatment in initial egg weight, the delay in sexual maturity of birds on FT1 and FT2 could result in a higher initial egg weight than those produced by birds on FT3 and FT4.

It is possible that the non-laying birds, which on examination had normal ovaries and oviducts, might have started laying had they been allowed to live longer. Unfortunately, this experiment had to be terminated at that stage because most of the birds started to develop severe leg problems.

The lack of differences in body composition and in reproductive morphology at 34 weeks disproves the hypothesis that laying performance could be explained by differences in body lipid, protein content or under-developed reproductive organs. Robinson *et al.* (1995), Wilson *et al.* (1995) and Robinson *et al.* (1996) showed that once birds reach sexual maturity the content of different chemical components in the body do not differ, providing birds are not fed *ad libitum*. However, in those reports, the reproductive efficiency of the birds was not included, therefore could no be linked to possible changes in carcass composition.

The absence of multiple ovarian hierarchies or internal ovulations in the birds used in this trial, which were subjected to a wide range of rearing treatments, contrasts sharply with two reports by Hocking (1993, 1996), and may be due to the broiler breeder strain used in this trial. It is possible that the female-line hens used for this trial, and other unpublished trials conducted at this University over the past five years were less succeptible to this problem, showing virtually no incidences of these anomalies.

The results presented here confirm that broiler breeders do not require a lighting stimulus in order to start ovarian activity, and that in this case, body composition could play a more important role than body weight in enabling the birds to attain sexual maturity. However, when a lighting stimulus is given, factors such as body weight and body composition become relatively less important in regulating the age at maturity.

CHAPTER 5 (*)

PHOTOREFRACTORINESS IN BROILER BREEDERS: SEXUAL MATURITY AND EGG PRODUCTION EVIDENCE

5.1 INTRODUCTION

Photorefractoriness is a condition that prevents animals from responding photosexually to an otherwise stimulatory daylength. In its extreme, the juvenile form prevents most wild birds from becoming sexually mature in their first year, whereas the adult form terminates reproduction, ends nesting behaviour and induces a moult. The condition, which is in some way facilitated by thyroxine (e.g., Follett and Nicholls, 1984; Bentley *et al.*, 1997; Dawson *et al.*, 2001; Proudman and Siopes, 2002), can be dissipated by a period of non-stimulatory daylengths (e.g., Follett, 1991; Boulakoud and Goldsmith, 1995), by a reduction in illuminance for birds maintained on stimulatory daylengths (e.g., Marsden and Lucas, 1964; Siopes and Wilson, 1981; Siopes, 1984) and by pharmacologically induced hypothyroidism (Siopes, 1997). Additionally, there appears to be a species-specific involvement of prolactin, since elevated plasma concentration has been associated with gonadal regression at the onset of photorefractoriness in starlings (Dawson and Goldsmith, 1983), although this does not directly cause photorefractoriness (Dawson and Sharp, 1998), and, in turkeys, plasma prolactin is higher in birds that remain photosensitive than those that become photorefractory (Lien and Siopes, 1989; Proudman and Siopes, 2002).

When birds are exposed to constant daylengths from, or soon after hatching, the rate at which juvenile photorefractoriness is dissipated is inversely related to photoperiod (Farner and Follett, 1966). Accordingly, lighting programmes for commercially maintained flocks of turkeys and game birds invariably include at least 2 months of short days prior to photostimulation.

In contrast, the adult form, which is thought to be programmed simultaneously with the initiation of gonadal maturation (e.g., Dawson, 2001; Proudman and Siopes, 2002), develops more quickly under longer photoperiods (Dawson and Goldsmith, 1983).

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Parts of the text in Italics are marking the original work of the Senior Author: Dr. P. D. Lewis.

Whereas most seasonal-breeding wild birds exhibit an absolute form of photorefractoriness, and terminate reproduction abruptly and uniformly (e.g., 4 to 6 weeks in starlings - Bentley *et al.*, 1998), some species, such as domestic turkeys (Siopes, 2001; Proudman and Siopes, 2002) and Japanese quail (Follett and Nicholls, 1984), possess a 'relative' form that allows them to reach sexual maturity during their first year and to have an extended laying season. Additionally, there is variability in the degree of photorefractoriness expressed, with some turkey hens stopping egg production within 2 to 3 months of photostimulation, whilst others continue to lay long after the majority of the flock has become refractory (Siopes, 2001; Proudman and Siopes, 2002).

Modern egg-laying domestic fowl, however, do not appear to exhibit photorefractoriness: exposure to constant long-days does not delay sexual maturity (Lewis *et al.*, 1998a) and the age-related decline in rate of lay (at least to 72 weeks of age) is not reduced by exposure to lighting programmes designed to minimise the effects of photorefractoriness (Morris *et al.*, 1995). It is probable that photorefractoriness has been minimised in commercial laying-hens by the intense selection for egg numbers that has taken place in this type of stock. Contrastingly, broiler breeders, which have not undergone the same rigorous selection for egg production, lay fewer eggs (typically, about 70 less eggs to 60 weeks of age) and have a more rapid age-related decline in rate of lay (<0.50 compared with almost 0.80 eggs/hen.d at 60 weeks of age) than egg-type hybrids. Whilst juvenile photorefractoriness is not seen in broiler breeders kept in controlled environment housing, because they are normally reared from a young age on short days, their poor rate of egg production after only 8 or 9 months of lay might indicate that they still possess a vestige of photorefractoriness. It is likely, also, that the condition, if present, will be more severe in a low egg-producing male-line than in a more productive female-line.

Accordingly, two trials were conducted to investigate photorefractoriness in commercial meat-type hybrids. In one, juvenile photorefractoriness was assessed in individually caged male-line and female-line pullets maintained on various constant daylengths from soon after hatch. This trial also investigated the rate at which feed-restricted broiler breeders dissipate photorefractoriness when reared on short-days. In the second trial, photorefractoriness was assessed by maintaining commercial broiler breeder parents on constant 11 or 16-h photoperiods, or by transferring them from 8 to 11-h or from 8 to 16-h photoperiods at 20 weeks of age. The mildly stimulatory 11-h photoperiod was chosen because it had been reported to have inhibited, or at least delayed, the manifestation of adult photorefractoriness in starlings (e.g., Hamner, 1971; Dawson and Goldsmith, 1983).

5.2 MATERIALS AND METHODS

Three hundred and sixty male-line and 3600 female-line broiler breeder pullets from Ross Poultry Breeders (South Africa) were equally distributed at 1 d of age (11.5 birds/m^2) among 8 light-tight rooms. All birds were given an initial 2 d of continuous illumination before being transferred to 16-h photoperiods. At 7 d, daylength in 6 of the rooms was reduced to 11 h, with a further reduction to 8 h at 14 d in 4 of these rooms. At 67 d, 88 pullets in one of the rooms on 8-h photoperiods was transferred to 16-h (the remaining pullets were transferred into the layer house and maintained on 8 h until 20 weeks of age). The light source in each room was 4 x 100W incandescent lamps, located at a height of 1.8 m and producing a mean illuminance of 43 ± 6.3 lx at 40 cm above floor-level. At 12 weeks, 3200 of the female-line birds were randomly transferred to 8 light-tight layer-rooms, each room comprising 4 floor-pens with each pen holding 100 pullets (400 per room). Two rooms acted as constant 11-h controls, two rooms as constant 16-h controls, and, at 20 weeks, two rooms were transferred from 8 to 11-h photoperiods and the remaining two rooms from 8 to 16-h photoperiods. Each of the 4 lighting treatments was represented in each half of the facilities. Light was provided by a single 100W incandescent lamp located at a height of 2.2 m in the centre of each pen, producing a mean light intensity of 25 ± 4.4 lx at a height of 40 cm. At 15 weeks, 240 male-line and 240 female-line pullets were randomly transferred to individual-bird cages in a second suite of 8 light-tight rooms (30 male-line and 30 female-line birds per room). There were two rooms each of constant 8, 11 and 16-h controls, one room with birds that had been transferred (in the rearing facilities) from 8 to 16 h at 67 d, and one room that was subsequently transferred from 8 to 16 h at 124 d. Light was provided by two 100W incandescent lamps, with mean light intensities of 110±7.0, 60±3.3, and 34±1.8 lx at the feed trough of the top, middle and bottom tier of cages respectively. Birds were fed individually on a daily basis.

All birds were fed *ad libitum* from 1 d of age and transferred at 2 weeks to a controlled feeding programme, recommended by the primary breeding company, to achieve a 20-week mean body weight of 2100 g. A 214 g CP/kg, 12.9 MJ AME/kg crumbed diet was provided from 0 to 3 weeks, a 190 g CP/kg, 12.0 MJ AME/kg pelleted diet from 3 to 15 weeks, a 153 g

CP/kg, 11.8 MJ AME/kg mash diet from 15 weeks to 5% egg production, and a 140 g CP/kg, 11.0 MJ AME/kg mash diet thereafter.

Egg numbers were recorded daily to 56 weeks of age for the floor-birds and to 58 weeks for the individually-caged birds. Age at first egg (AFE) for cage birds and the age at which mean rate of lay for a 2-d period first exceeded 0.50 eggs/hen.d for the floor-birds were used as definitions of sexual maturity. Mean rate of lay for, and the number of caged-birds that had not laid an egg in, the final 10-d period (days 397-406), and the mean rate of lay in the floor-birds during the final 28-d period (days 365-392), were used as measurements of persistency and as assessments of adult photorefractoriness.

A subjective look at the AFE data for the individually caged-birds revealed differences between the male-line and female-line birds in the amplitude of the response to the lighting treatments, and so data for the two genotypes were analysed separately. All data analyses were performed using programmes from Genstat 6th Edition (Lawes Agricultural Trust, 2002), and, because of partial confounding of treatment and room factors, the variance components for Room and Room.Treatment were analysed using a linear mixed residual maximum likelihood model (REML) to determine if 'Room' could be dropped from the analysis mode - this proved to be possible for all data sets. The floor-pen data were then subjected to a one-way ANOVA with Treatment as the variable. However, because the design in the cage facilities was unbalanced, these data were further analysed with REML, using Treatment as the fixed model and Treatment.Room.Bird as the random model. Treatments within a subordinate trial, in which a different feeding time was given in each half-house of floor-pens, appeared to marginally influence sexual development, and so half-house differences (about 4 d) for the mean for age at 0.50 eggs/hen.d rate of lay were removed using least squares analysis prior to conducting the REML analysis. Significant differences ($P \leq 0.05$) between means were identified using a Student's *t*-test.

5.3 RESULTS

5.3.1 Individually caged-birds

Mean AFE for male-line birds maintained on 11-h photoperiods was 8 d earlier ($P < 0.01$) than constant 8-h birds, but a significant 23 d earlier than birds maintained on 16 h (Table 5.1).

Similarly, female-line birds kept on 11-h matured 3 d earlier than those maintained on 8-h photoperiods, but 25 d significantly earlier than constant 16-h birds. In both genotypes, sexual maturity for birds transferred from 8 to 16-h photoperiods at 67 d was significantly later than both the short-day controls (male-line +11 d, female-line 'non-responders' +19 d) and the birds photostimulated at 124 d (male-line +48 d, female-line 'responders' +46 d), but not significantly different from the long-day controls (Table 5.1 and Figure 5.1). The first female-line bird in this group, which was the only bird that appeared to respond to the increment, matured 31 d earlier than the remainder of the group (Table 5.1 and Figure 5.1). Although only three of the male-line birds (because of a high number of sexing errors) that had been transferred from 8 to 16-h photoperiods at 124 d provided first egg information; all matured before any of the long-day controls or the birds photostimulated at 67 d (Figure 5.1).

Table 5.1. *Mean±SEM for age at first egg for male-line and female-line broiler breeder pullets (bird numbers in parentheses) housed in individual cages and maintained on 8, 11 or 16-h photoperiods or transferred from 8 to 16-h photoperiods at 67 or 124 d of age. And mean±SEM age at 0.50 eggs/hen.d for female-line broiler breeder pullets housed in litter-floor pens and maintained on 11 or 16-h photoperiods or transferred from 8 to 11 or 16-h photoperiods at 140 d of age*

Individually caged-birds	Age at first egg (d)				
	Constant photoperiods			Transfer 8 to 16 h at	
	8 h	11 h	16 h	67 d	124 d
Male-line	223.3±4.07	215.0±2.22	237.8±3.14	234.1±3.09	186.0±12.10
Female-line	207.6±1.71	204.2±1.60	228.8±2.02	174.0 †	173.4±0.79 †
	(54)	(60)	(56)	(1)	(19)
				226.7±2.13 ‡	203.0±3.81 ‡
				(27)	(4)
Male-line	SED Maximum = 10.78, minimum = 3.88, Residual df = 130, χ^2 probability = 0.001.				
Female-line	SED Maximum = 13.99, minimum = 2.33, Residual df = 216, χ^2 probability = 0.001.				

Floor penned birds	Age at sexual maturity (d)			
	Constant photoperiods		Transfer at 140 d from	
	11 h	16 h	8 to 11 h	8 to 16 h
Female-line only	196.3±1.15	218.0±1.02	186.8±0.59	182.8±0.98
Pooled SED = 1.35, Residual df = 28, *P*<0.001				

† Mean for birds that appeared to respond to the increase in photoperiod.
‡ Mean for birds that appeared not to respond to the increase in photoperiod

There was a bi-modal distribution for the female-line birds that had been photostimulated at 124 d, with 19 of the 23 surviving birds having a mean AFE that was 30 d significantly earlier than that of the 4 apparent non-responders, 34 d significantly earlier than the constant short-day and 55 d significantly earlier than the constant long-day controls (Table 5.1 and Figure 5.1).

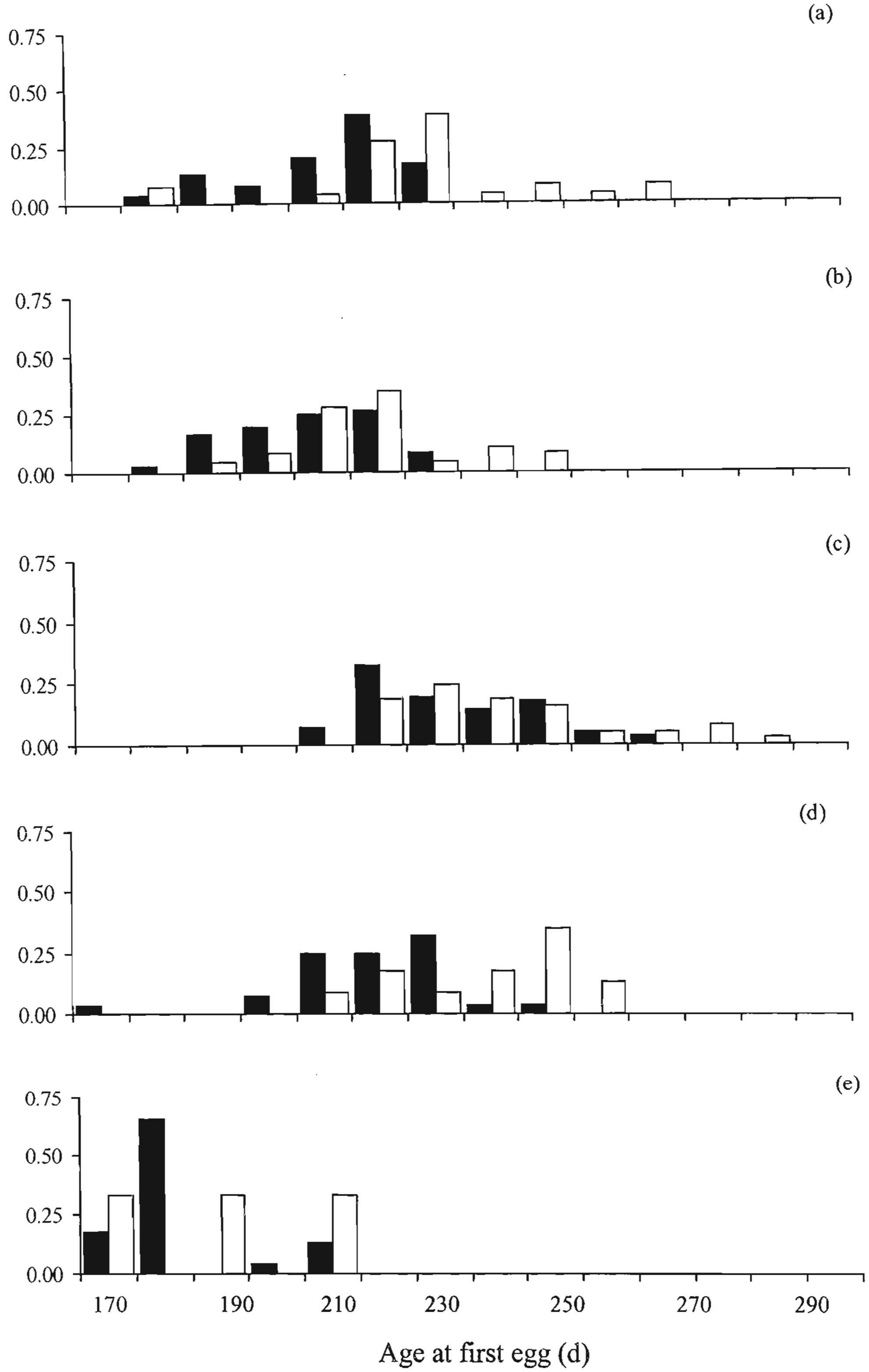

Figure 5.1. *Distributions of age at first egg (in 10 d classes) for male-line (open bars) and female-line (solid bars) broiler breeder pullets housed in individual cages and maintained on 8-h (a), 11-h (b) or 16-h photoperiods (c), or transferred from 8 to 16-h photoperiods at 67(d) or 124 d of age (e).*

Male-line hens maintained on 11-h days produced significantly more eggs to 58 weeks than either the constant 8 and 16-h groups or those photostimulated at 67 d (Table 5.2). Data for the two surviving hens in the 124-d photostimulated group were excluded from the analysis.

Table 5.2. *Total eggs to 58 weeks for surviving birds only, the proportion of birds that did not lay an egg between days 397 and 406 (number of surviving birds in parentheses), and mean rate of lay for male-line and female-line broiler breeder pullets housed in individual cages and maintained on 8, 11 or 16-h photoperiods or transferred from 8 to 16-h photoperiods at 67 or 124 d of age.*

	Constant photoperiods			Transfer 8 to 16 h at	
	8 h	11 h	16 h	67 d	124 d
Total eggs					
Male-line	90.4±8.50	116.9±3.65	90.0±4.44	89.4±5.26	116.9
Female-line	126.1±3.36	139.1±2.52	114.7±2.53	112.2±4.16	151.6±3.04
Male line SED Maximum = 8.40, minimum = 6.47, Residual df = 102, χ^2 probability = <0.001. Note that data for the two surviving birds for photostimulation at 124 d were not analysed Female line SED Maximum = 5.89, minimum = 3.78, Residual df = 201, χ^2 probability = <0.001					
Proportion of birds that did not lay between 397 and 406 d					
Male-line	0.13 (18)	0.06 (35)	0.50 (31)	0.30 (20)	0.00 (2)
Female-line	0.15 (49)	0.04 (56)	0.15 (53)	0.28 (25)	0.05 (21)
Male line (excluding photostimulation at 124 d) SED Maximum = 0.312, minimum = 0.255, Residual df = 3, χ^2 probability = 0.315 Female line SED Maximum = 0.085, minimum = 0.060, Residual df = 3, χ^2 probability = 0.009					
Mean rate of lay between days 397 and 406(eggs/hen.d)					
Male-line	0.38±0.057	0.46±0.029	0.30±0.049	0.29±0.058	0.60†
Female-line	0.43±0.031	0.50±0.020	0.40±0.029	0.37±0.051	0.46±0.035
Male-line (excluding photostimulation at 124 d) SED Maximum = 0.018, minimum = 0.006, Residual df = 102, χ^2 probability = 0.014 Female-line SED Maximum = 0.059, minimum = 0.038, Residual df = 201, χ^2 probability = 0.029					

† Only two birds surviving at 397 d

Female-line birds responded similarly, with the 11-h controls and 124 d photostimulated birds laying significantly more eggs than the other groups, but in this genotype, the 8-h controls laid significantly more eggs than either the 16-h controls or the birds photostimulated at 67 d. There were differences among the lighting groups for the proportion of hens that did not lay an egg in the final 10 d of the trial (397 to 406 d), but, despite the ranking of the treatments being similar for both genotypes, these differences were only significant for female line hens. In both lines, constant 11-h hens and those photostimulated at 124 d had fewer non-layers than the other three groups (Table 5.2). Not surprisingly, the differences in the number of hens in lay during the final 10 d were associated with corresponding differences in rate of lay.

In the male-line, constant 11-h hens had significantly better egg production than the constant 16-h or the 67-d-photostimulated birds, whilst constant 8-h birds and those photostimulated at 124 d were intermediate between, though not significantly different from, the other three groups (Table 5.2). Data for the two surviving hens that had been photostimulated at 124 d were again excluded from the analysis. In the female-line, egg production for the constant 11-h hens was significantly higher than the other 4 treatments, though the latter were not significantly different from each other (Table 5.2).

5.3.2 Floor penned birds

Mean age at 0.50 eggs/hen.d rate of lay for birds maintained on 11-h photoperiods was 22 d earlier than constant 16-h birds (Table 5.1). Maturity for birds transferred from 8 to 11 h at 140 d was advanced by 10 d compared with constant 11-h controls, but birds transferred to 16-h photoperiods matured 35 d earlier than constant 16-h controls. Sexual maturity for birds transferred from 8 to 16 h was 4 d earlier than for those transferred from 8 to 11 h. All differences were significant.

There were no significant differences in total egg production to 56 weeks of age between the two photostimulated groups and the hens maintained on 11-h photoperiods, but all three groups produced significantly more eggs than the constant 16-h controls (Table 5.3).

Table 5.3. *Total eggs to 56 weeks of age for surviving birds only, rate of lay in the 24th week of production after 0.50 eggs/hen.d rate of lay first achieved, and rate of lay between 383 and 392 d for female-line broiler breeder pullets (housed on litter floors) maintained on 11 or 16-h photoperiods or transferred from 8 to 11 or 16-h photoperiods at 140 d of age.*

	Constant photoperiods		Transfer at 140 d from	
	11 h	16 h	8 to 11 h	8 to 16 h
Total eggs	135.7±2.09	118.3±2.30	137.4±2.22	140.8±2.84
Pooled SED = 3.37, Residual df =28, *P*<0.001				
Rate of lay in '24th week'	0.59±0.018	0.57±0.013	0.60±0.012	0.58±0.014
Pooled SED = 0.020, Residual df =27, *P*=0.589				
Rate of lay between 383 and 392 d of age (eggs/hen.d)	0.57±0.018	0.57±0.015	0.53±0.021	0.53±0.12
Pooled SED = 0.023, Residual df =28, *P*=0.181				

There was a tendency (*P*=0.18) for hens on constant 11-h and 16-h photoperiods to have better production in the final 10-d period (383-392 d) than hens transferred from 8 to 11 h or from 8 to 16 h photoperiods (Table 5.3). However, there were no significant differences among the groups when egg production was compared at the same period (24 weeks) following the week in which a 0.50 eggs/hen.d rate of lay was first reached.

5.4 DISCUSSION

5.4.1 Current data

Whereas male-line birds consistently matured 1 to 2 weeks later than female-line birds, the two genotypes responded similarly to the various lighting treatments (Table 5.1 and Figure 5.1). This presumably reflects either a difference in genetic sexual maturity between the two lines or a difference in their response to the feed restriction applied in this trial. It also indicates that there are minimal differences between male-line and female-line genotypes for the amount of photorefractoriness. Although mean AFE for caged-birds on 11-h photoperiods was slightly earlier than, but not significantly different from, the constant 8-h birds, the advance was similar to the 3.2 d predicted for *ad libitum* fed egg-laying pullets using the model of Lewis *et al.* (1998a). In contrast, the consistent 3-week delay in sexual maturity for birds maintained on 16-h photoperiods, relative to constant 11-h birds, differed markedly from the 1.5 d delay predicted for egg-laying hybrids. This delayed maturity for birds maintained on 16-h days from soon after hatch is strongly indicative of juvenile photorefractoriness, and, although far less dramatic, concurs with the 21-month retardation in sexual development observed by Woodard *et al.* (1980) in Red-legged partridges maintained on 16-h photoperiods from hatch (median AFE, 968 d) compared with constant 8-h birds (median AFE, 339 d).

The similar mean AFE for the constant 16-h controls and for the majority of birds transferred from 8 to 16 h at 67 d indicates that the birds given the increment did not respond to it, but matured as if they had always been on 16-h photoperiods (Table 5.1 and Figure 5.1). This contrasts with the findings of Lewis *et al.* (2002) that an increment in daylength given to *ad libitum* fed egg-laying pullets at this age results in the largest advance in sexual maturation. Follett (1991) suggested that 2 months of short days would dissipate photorefractoriness (*sic*, when birds are fed *ad libitum*), but it is possible that more than 2 months is required to obtain photosensitivity in feed restricted birds. Eitan *et al.* (1998) and Eitan and Soller (2001) suggested that feed restriction *per se* decreases photoperiod responsiveness, putting forward two alternative explanations for the effect: (a) sexual maturation is delayed endo-physiologically during feed control in anticipation of better breeding conditions, or (b) that a simple nutritional imbalance is created by the feed-restriction. A further possibility is that at 10 weeks of age the hypothalamic-pituitary axis of feed restricted birds is still insufficiently developed to permit a photosexually induced increase in Follicle Stimulating Hormone (FSH) release. This hypothesis was offered by Lewis *et al.*, (1998b) to explain the failure of a transfer from 8 to 14 h at 35 d of age to advance AFE in *ad libitum*-fed egg-laying pullets when the same increment given to sister-birds at 56 d advanced AFE by 3 weeks. Additionally, Dunn and Sharp (1990) thought there were probably genotypic differences in the extent to which FSH release is suppressed by feed restriction.

The fact that one of the female-line birds transferred from 8 to 16 h at 67 d laid its first egg at 174 d, more than 4 weeks earlier than the rest of the group or any of the constant 16-h controls, but at a similar age to the earliest maturing of the 8 and 11-h controls (Figure 5.1), suggests that broiler breeders that have been feed restricted (at least to the degree to which they had been in this trial) do not start to dissipate photorefractoriness until about 10 weeks of age. Additionally, the small number of 124-d-photostimulated birds (4/23) that did not respond to the increment indicates that photorefractoriness takes more than 18 weeks to be completely dissipated from a flock. However, these timings for the attainment of photosensitivity would undoubtedly be different for birds given other levels of feed restriction, and possibly also for birds exposed to other light intensities. *In this trial, the illuminance (means of 43 lx to 15 weeks, and 34 to 110 lx after 15 weeks) might have mildly retarded the elimination of photorefractoriness in some individuals. In support of this suggestion, Siopes (1984) reported that whereas a transient 8-week transfer from 55 to 0.5 lx was sufficient to completely dissipate adult refractoriness in turkeys held on 16-h photoperiods, temporary transfers to 2.2, 4.3 or 7.6 lx saw only 0.44, 0.38 and 0.11 of the respective group resume egg production (6-h controls, 1.00). Similar findings have been reported for adult chukar partridges maintained on 16-h photoperiods, where the proportion of birds that resumed egg production following 6 weeks of 1, 3 or 5 lx, and a return to 50 lx, was 0.82, 0.79 and 0.15 respectively (8-h controls, 0.89) - no eggs were laid by birds given a transient 7 lx intensity (Siopes and Wilson, 1981). Siopes (1992) also observed that turkeys maintained on 270 lx and transferred from 8 to 16-h days at 30 weeks of age took* *significantly longer to reach a 0.50 eggs /hen.d rate of lay than birds given the same increment in photoperiod but exposed to 22 lx illumination. A consensus of these findings and other evidence for turkeys (Marsden and Lucas, 1964), chukar partridges (Siopes and Wilson, 1978), and golden-crowned sparrows (Turek, 1975) suggest that illuminance needs to be substantially less than 1 lx to completely dissipate photorefractoriness (at least the adult form) if birds are maintained on long days.*

Interactions of feeding regime and body weight with sexual development are well established (Lee *et al.*, 1971), however, the responses of the cage-birds in this trial appear to be truly photoperiodic, because regressions of individual AFE for the two photostimulation treatments on 14-week (P=0.763) and 22-week (P=0.495) body weights indicated that body weight had little influence on AFE. Indeed, 100-g increases in 14 and 22-week body weight was associated with changes of only 0.2 and 0.7 d in AFE respectively.

The 4 d difference in mean age at 0.50 eggs/hen.d rate of lay between the floor-birds transferred from 8 to 11 h and those changed from 8 to 16 h at 20 weeks is similar to the 6 d observed in Chapter 4 for broiler breeders transferred from 8 to 10-h or from 8 to 16-h daylengths at 19 weeks, and the 1.8 d reported by Lewis *et al.* (1997) for egg-type genotypes transferred from 8 to 10 h or from 8 to 16 h at 20 weeks.

A regression of total egg production in the laying period on ASM for all hens in the trial, with differences between the floor hens and cage hens removed by least squares analysis, indicated that most of the variation in egg production among lighting treatments could be explained by differences in ASM (Figure 5.2). The equation for this regression was:

$$y = 267.0 - 0.683M \ (r^2 = 0.924, \text{Slope SE} = 0.099, P<0.001)$$

Where y = eggs to 56 weeks of age (n), and M = mean age at sexual maturity (d), i.e., 0.50 eggs/hen.d for floor hens and AFE for caged hens. Figure 5.2 also shows that egg production for the three constant 11-h groups was superior to other lighting treatments.

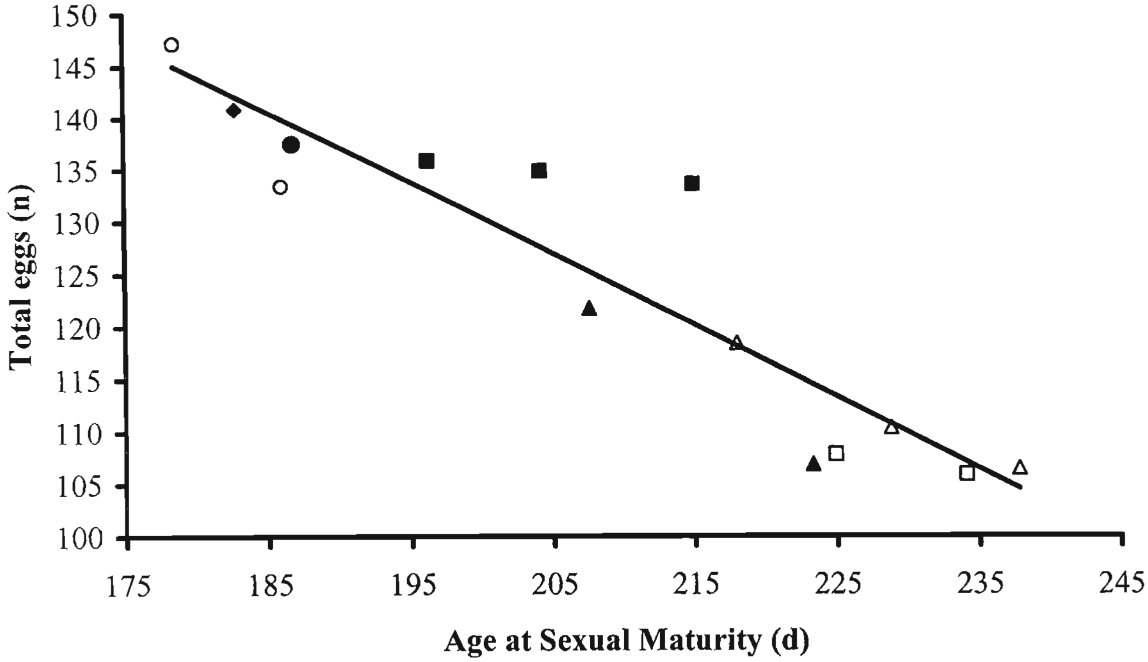

Figure 5.2. *The relationship between age at sexual maturity and total egg production for broiler breeder pullets maintained on 8 (▲), 11 (■), or 16-h (△) photoperiods or transferred from 8 to 11 h at 140 d (●) or from 8 to 16 h at 67 (□), 124 (○) or 140 d (◆). Data from floor penned female-line and individually caged female and male-line hens.*

The earlier sexual maturity but more persistent egg production for cage-hens photostimulated at 124 d, compared with constant 16-h controls or birds photostimulated at 67 d, suggests that the rate at which adult photorefractoriness develops is inversely related to the rate at which the juvenile form is dissipated.

Regressions of mean rate of lay (ROL) in the final 10 d (eggs/hen.d) on the proportion of cage birds that had not laid an egg (NL) in the same period (Table 5.2) showed no significant difference in the slopes of the regression for the two genotypes (male-line -0.504, female-line -0.510). After adjustment of the male-line egg production (+0.022 eggs/hen.d) by meta analysis, to remove differences from the female-line, a further regression revealed a highly significant negative correlation ($ROL = 0.50 - 0.51NL$, $r^2 = 0.951$, Slope SE = 0.040, $P < 0.0001$), with the regression equation succinctly predicting that rate of lay when all hens are still laying will be 0.50 egg/hen.d (quite typical for commercial broiler breeder flocks at this age) and zero when all birds have become non-layers. It is possible, therefore, that the relatively poor ultimate rates of egg production in broiler breeder flocks are the result, in part, of a proportion of the hens becoming photorefractory. This would reflect the situation in turkeys, where egg production at the end of a 27-week laying period has been demonstrated to be inversely related to the number of hens that become photorefractory (Lien and Siopes, 1989), and where hens have been classified as exhibiting absolute photorefractoriness, relative photorefractoriness or continued photosensitivity subsequent to a reduction in photoperiod to 13 h given after 19 weeks of 18-h days (Proudman and Siopes, 2002).

The similar rate of egg production during the final 10 d for constant 11-h compared with 16-h hens housed on the floor (depleted at 56 weeks) contrasts with the markedly higher number of non-layers in the constant 16-h group during the final 10 d before depletion at 58 weeks in cages. Part of this difference can be explained by the cage birds being 2 weeks older, as the mean proportion of female-line and male-line hens that did not lay in the 10 d preceding 58 weeks of age was 0.12 and 0.23 respectively, whereas the figures for the 10 d preceding 56 weeks (same age as depletion for the floor-birds) was only 0.05 and 0.15 respectively. This suggests that the minimum age at which adult photorefractoriness is manifest in the strain of broiler breeders used in this investigation might be close to 56 weeks.

A meta analysis of data for hens maintained on 16-h photoperiods or transferred from 8 to 16 h at 67, 124 or 140 d showed a significant negative relationship between rate of lay (eggs/hen.d) during the final 28 d and ASM ($P = 0.011$, $r^2 = 0.753$, $SE = 0.0004$), with ultimate rate of lay decreasing by 0.01 eggs/hen.d for each 7-d delay in sexual maturity. Delays in sexual maturity for egg-type hybrids are commonly associated with improved persistency, so the reverse relationship in this trial might again be indicative of photorefractoriness in broiler breeders. It should be noted, however, that part of the poorer egg production by the constant 16-h hens in both housing systems was a function of the increased egg weight affected by the delayed sexual maturity for this treatment group.

In caged male-line and female lines maintained on 16-h daylengths or transferred from 8 to 16 h at 67 d, total egg production to 58 weeks, compared with either constant 11-h controls or birds photostimulated at 124 d, was significantly reduced by the combination of a delay in maturity and an increased proportion of non-layers at the end of the laying-period (Table 5.2). However, the marked difference in total egg numbers between constant 8 and 11-h controls, despite the groups having a similar mean AFE, was likely to have been due to the 8-h days being non-stimulatory and providing insufficient photoperiodic drive to maximally stimulate the hypothalamic-pituitary system (Sharp, 1993).

5.4.2 Sexual maturity and constant photoperiods - an integration of data

Female sexual maturity data from this trial, from Chapter 4 and unpublished data from University of Natal, together with male maturation data from Parker and McCluskey (1965) and Renden et al. (1991), was regressed on constant photoperiod using a model which divided the data into a lower and upper range with lines fitted separately above and below a hinge point (found by iteration) and with differences among data sets removed by fitting constants by least squares. The regression revealed a slope of -1.47 d/h (SE = 0.327) for <11 h photoperiods and +4.39 d/h (SE = 0.670) for >11 h photoperiods (Figure 5.3). This means that sexual maturity is advanced by 1.47 d for each extra 1 h of photoperiod up to 11 h, but retarded by 4.39 d for each further 1 h extension above 11 h. Overall, the SE of observations was 3.28 d.

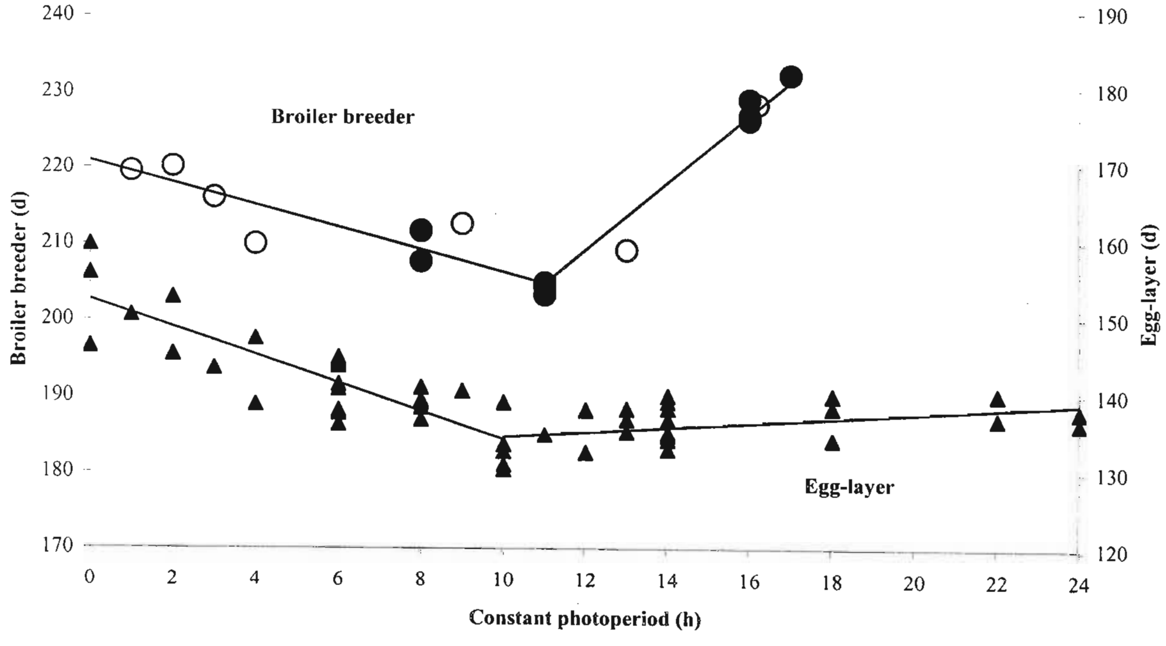

Figure 5.3. *The relationship between constant photoperiod and age at sexual maturity for broiler breeders (females represented by solid circles - data from Table 4.1, and unpublished data from University of Natal, and males represented by open circles - Parker and McCluskey, 1965; Renden et al., 1991), and type hybrids (Lewis et al., 1998a - triangles).*

A test for equality of slopes showed that the -1.47 d/h rate of change in maturity for photoperiods <11 h was not significantly different from the 1.73 d/h advance reported by Lewis et al. (1998a) for egg-laying pullets on constant daylengths of <10 h. However, the 4.39 d/h rate of retardation in maturity for broiler breeders maintained on photoperiods longer than 11 h was significantly greater than the +0.30 d/h figure reported for egg-type *hybrids maintained on >10-h daylengths. The similar slopes for both types of bird maintained on non-stimulatory daylengths, but markedly steeper slope for meat-type genotypes maintained on stimulatory photoperiods provides strong evidence for photorefractoriness. The similar rates of change for initial semen production by heavy pure-line (Parker and McCluskey, 1965) and broiler breeder (Renden et al., 1991) males and for first egg for females indicate that the relationship between photoperiod and sexual development for meat-type birds is similar for both sexes.*

5.5 CONCLUSIONS

Even though there has been some selection for improved reproductivity in broiler breeder stock, the sexual maturity and egg production data recorded in these trials, and the integrated model for constant photoperiods, strongly indicate that meat-type hybrids still exhibit photorefractoriness. However, despite the male-line birds being heavier, having a later maturity and laying fewer eggs than the female-line, there appears to be minimal difference between the two genotypes in terms of photorefractoriness. The delayed AFE for birds reared on constant long-days, their subsequent increased egg weight and the minimal effect of an increment in photoperiod below 10 weeks of age suggest that maintaining spring-hatched birds on long photoperiods (to avoid increasing daylengths from infiltrating natural light) in poorly light-proofed housing might not be the right approach, especially as the marked delay in AFE will result in above-target body weights at sexual maturity. Whilst evidence for turkeys, partridges and sparrows indicate that low light intensity may be used to eliminate photorefractoriness in birds maintained on long-days, the necessary <1 lx illuminance to successfully achieve this would dictate the use of controlled environment housing and, in such circumstances, short-days would be the preferred approach.

The significant differences in sexual maturity and egg production between the various constant 11 and 16-h groups suggest that further research is needed to investigate the optimum daylength among the intermediate photoperiods. Additionally, the bi-modal distributions for AFE observed in the groups photostimulated at 67 or 124 d, and the evidence reported earlier for the effect of illuminance on the dissipation of photorefractoriness in turkeys, indicates that photostimulation-age and light intensity during rearing are also areas worthy of further investigation.

CHAPTER 6

THE EFFECTS OF FAST GROWTH, DIFFERENT DAYLENGTHS AND AGE AT PHOTOSTIMULATION ON SEXUAL MATURITY AND SETTABLE EGG PRODUCTION IN BROILER BREEDER HENS

6.1 INTRODUCTION

Reproductive problems in broiler breeder females are often attributed to the intense selection pressure for weight and feed conversion, which has been carried out in these lines (for a review, see Chapter 2). However, it is possible that a significant amount of the failure to reach potential performance results from mismanagement or misunderstanding of the needs of the broiler breeder. Programmes for managing broiler breeders have evolved over time by adopting those management protocols that appeared to achieve the best performance. Whereas this was possible for many years because the birds were grown on day-old-to-death farms (they were reared and brought into lay in the same house), subjective observations suggest that, despite the obvious changes in breeder performance as a result of the advances in broiler performance, there has been little change in management protocols.

There has been a move away from day-old-to-death housing to a rear-and-move production system, in which specialized rearing farms grow the birds to about 20 weeks, and then moved to the laying farm until depletion at about 60 weeks. Thus a system of 20 weeks rear plus cleanout period fitted well with a 40-week laying period plus cleanout – one rearing farm would supply two laying farms on a regular cycle. As a consequence, broiler breeder productive systems were fixed to a 20/21-week transfer, and utilisation of any genetic or management trends, designed to allow an advance in sexual maturity, were effectively prevented. However, if the birds can be managed to permit earlier light stimulation, there could be considerable economic gains, and, potentially, beneficial influences for production and bird welfare. The next youngest age at which a management system could be made to work would be transfer and light stimulation at 15/16 weeks. This would present an opportunity for either earlier depletion than the current 60-65 weeks, or the possibility to achieve better persistency (Sharp *et al.,* 1992) from birds that had not been subjected to the stringent body weight control currently applied. If successful, this would allow three batches of pullets to be raised in rearing houses each year.

Previous attempts to bring broiler breeders into early maturity have met with little success. Leeson and Summers (1983) showed that sexual maturity occurred at around 20 weeks when birds were grown more quickly and photostimulated when they achieved an arbitrary body weight of 2100 g. However, those birds were able to achieve an earlier maturity because 2100 g represented a higher proportion of their mature body weight than would be the case in modern genotypes. Yuan *et al.* (1994) investigated the possibility of reducing rearing costs and maximising settable egg production by subjecting broiler breeders to early photostimulation after allowing them to achieve heavier than normal body weights. However, data from this trial are not completely reliable due to its poor experimental design (page 28), and this makes it difficult to draw any useful conclusions from them.

Two trials were conducted. In the first, which investigated the possibility of reducing the age at sexual maturity by photostimulating 5 weeks earlier than the conventional 20 weeks and modifying the growth curve to achieve 2100 g at 15 weeks, the birds were housed in groups in floor pens. A further objective of this trial was to investigate the effects of 12 and 16-h daylengths during the laying period. In the second trial, birds were housed in individual cages and transferred from 8 to 16-h daylengths at 10, 11, 12, 14, 16 or 18 weeks to determine when they become photosensitive. Other birds were maintained on 8-h daylengths as short-day controls. Additionally, the birds were grown to achieve 2100 g at either 15 or 20 weeks to investigate possible interactions between age at photostimulation and body weight.

6.2 MATERIALS AND METHODS

6.2.1 Experiment 1: Floor penned birds

6.2.1.1 Birds and housing

Four thousand day-old females and 560 day-old males (Cobb 500, Cobb Breeders South Africa) were placed in a light-tight rearing facility. The females were placed separately in 8 light-tight rooms, with each room separated into two pens (16 pens in total), at a stocking density of 12 birds/m^2. Males were housed initially in two pens in one room, with half of the birds being moved to an adjacent room at 4 weeks of age. At 9 weeks of age, 3200 females were moved into the laying facility, while the remaining pullets were moved to cages, to be used for Experiment 2. The laying facility comprised 8 light-tight, independent rooms, with each room sub-divided into 4 pens (32 pens in total). Males, which had been reared separately, were mixed with the females when the average egg production for a room reached 5 eggs/100 bird.d. Ten males were placed with 100 females in each pen, at a stocking density of 5 birds/m^2. Feed was provided on a daily basis at 07:00. The experiment was terminated when the birds reached 60 weeks of age. A detail of the treatments used for this experiment is shown in Table 6.1.

Table. 6. 1. *Detail of the experimental treatments used for Experiment 1*

Growth	Age at phosotimulation (weeks)	Daylength (h)	Pens (n)	Birds / pen.
F	15	12	4	100
F	15	16	8	100
C	20	12	8	100
C	20	16	4	100

6.2.1.2 Growth curves

Two growth curves were applied to test the hypothesis that sexual maturity in broiler breeder pullets could be advanced if photostimulated 5 weeks earlier than those subjected to a commercial management programme and the rate of body weight gain was increased. Half the birds (16 pens) were reared on the growth curve recommended by the primary breeder (Cobb 500 management guide, 2001), with a target body weight of 2100g at 20 weeks (Control), and the other pullets, reared on the second growth curve (Fast), were fed to achieve a body weight of 2100g at 15 weeks of age. Weekly body weights and deviances from the weekly targets for both growth profiles are given in Table 6.2.

6.2.1.3 Feeding treatments

Birds were fed a commercial broiler starter crumble (191 g CP/kg, 10.4 MJ AMEn/kg, 12 g Ca /kg) up to 3 weeks, a broiler breeder starter pellet (198 g CP/kg, 11.0 MJ AMEn/kg, 12 g Ca/kg) from 4 to 6 weeks, a broiler breeder grower pellet (177 g CP/kg, 11.2 MJ AMEn/kg, 11 g Ca/kg) from 7 weeks to a 5-egg/100 bird.d rate of lay, and then a broiler breeder layer pellet (142 g CP/kg, 11.1 MJ AMEn/kg, 28 g Ca/kg) until the end of the trial at 60 weeks.

Table 6.2. *Mean weekly body weight of pullets subjected to different growth curves (Control and Fast) to 20 weeks. Deviations from target weights are given in parentheses.*

Age (weeks)	Control growth (g)	Fast growth (g)
1	100 (-20)	101 (-19)
2	247 (-13)	249 (-11)
3	447 (+47)	540 (-20)
4	639 (+119)	774 (+44)
5	745 (+125)	892 (+12)
6	784 (+64)	961 (-60)
7	866 (+46)	1047 (-113)
8	992 (+2)	1154 (-136)
9	1040 (+20)	1311 (-109)
10	1151 (+31)	1503 (-38)
11	1237 (+17)	1630 (-10)
12	1314 (+14)	1805 (+65)
13	1389 (+9)	1986 (+126)
14	1483 (+43)	2103 (+103)
15	1564 (+44)	2234 (+64)
16	1673 (+73)	2318 (-32)
17	1742 (+42)	2465 (-55)
18	1856 (+36)	2598 (-82)
19	1931 (-29)	2724 (-106)
20	2123 (-37)	2817 (-133)

6.2.1.4 Lighting programmes

The chicks were given 22-h photoperiods for the first 2 days, 18-h photoperiods for days 3 and 4, and 14-h photoperiods for days 5 and 6. On day 7, daylength was decreased to 8 h and maintained until photostimulation at 15 (Fast) or 20 (Control) weeks (Table 6.1). At these respective ages, birds were abruptly transferred to either 12 or 16-h photoperiods. The experimental design was therefore a 2 x 2 factorial, with two growth-curve/photostimulation-age combinations by two lighting treatments in lay.

6.2.1.5 Measurements, experimental design and statistical analysis

The daily feed allocation for each treatment was revised weekly, taking into consideration the average body weight gained in the previous week (mean of a 0.3 sample weighed on empty crops) and the body weight required to be achieved by the end of the succeeding week. All eggs laid were recorded daily to 60 weeks. Abnormally large, obvious double-yolked, and soft-shelled eggs were recorded, but not weighed. Settable eggs were considered to be those weighing more than 50 g, single yolked and with no shell abnormalities. These eggs were weighed on three consecutive days each week. Age at sexual maturity (ASM) was defined as the age at which mean rate of lay for a 2-d period first exceeded 50 eggs/100 bird.d.

Although the experiment was designed as a 2 x 2 factorial with main effects of growth-curve/photostimulation-age (Control *vs.* Fast) and different daylengths from photostimulation (12 *vs.* 16 h), two rooms had to be excluded from the trial because they did not comply with the original design. Accidentally, ages at photostimulation were inverted in these two rooms, resulting in Fast growth photostimulated at 19 weeks and Control growth photostimulated at 15 weeks treatments. However, settable egg production data for the Control birds photostimulated at 15 weeks have been used in the regression of settable eggs on age at photostimulation (Figure 7.4). After exclusion of the two rooms, the design of the experiment was unbalanced, and so data for the remaining 6 rooms were analysed using REML (Residual maximum likelihood model) from Genstat 6th Edition (Lawes Agricultural Trust, 2002), using Growth-curve*Photoperiod as the fixed model, and Growth-curve.Photoperiod.Room as the random model. Significant differences ($P \leq 0.05$) between means were identified using the appropriate SED and a Student's *t*-test.

6.2.2 Experiment 2: individually caged-birds

6.2.2.1 Birds and housing

Two hundred and forty broiler breeder pullets were randomly selected at 9 weeks of age from each of the two growth curve treatments described above. At this age, the birds were moved into individual cages in 8 light-tight rooms, with each room housing 30 birds from each growth profile.

6.2.2.2 Growth curves

The growth profiles and diets used for this trial were the same as described for Experiment 1. Mean body weights at photostimulation are given in Table 6.4.

6.2.2.3 Lighting programmes

The lighting programme used for these pullets until they were moved to the cages was the same as for pullets on Experiment 1. In the cage facility, pullets in two rooms were maintained on 8-h photoperiods throughout the trial, while those in the 6 remaining rooms were given an abrupt increase in daylength from 8 to 16 h at 10, 11, 12, 14, 16 or 18 weeks.

6.2.2.4 Experimental design, measurements and statistical analysis

The age at which a bird laid its first egg was used as the definition of sexual maturity (ASM). The weight of the first egg and the body weight of the hen on that day were recorded. At 52 weeks, all birds that had not laid an egg were euthanased to examine the state of the reproductive tract. These data were analysed with REML because the design of this experiment was unbalanced, using Growth-curve*Photostimulation-age as the fixed model, and Growth-curve.Photostimulation-age.Room.Bird as the random model. Significant differences ($P \leq 0.05$) between means were identified using the appropriate SED and a Student's *t*-test.

6.3 RESULTS

6.3.1 Experiment 1: Floor penned birds

6.3.1.1 Growth curves

ASM (mean of 12 and 16-h groups) for the birds on the Fast treatment occurred 15 d significantly earlier, but total egg numbers to 60 weeks were 6 eggs significantly fewer, than the controls (Table 6.3). However, there was a further significant 3-egg reduction in the number of settable eggs for the Fast group as a result of an increase in the number of eggs rejected because of inferior size or shell faults. There were no significant differences in mean egg weight to 60 weeks of age.

Table 6.3. *The effects of different growth curves and photoperiod in lay on age at sexual maturity (ASM), total and unsettable egg numbers, and mean egg weight of broiler breeder hens to 60 weeks of age (Experiment 1). Pen numbers are given in parentheses.*

Growth	Photoperiod	ASM (d)	Total eggs *(hen.week basis)*	Unsettable eggs *(hen.week basis)*	Mean egg weight (g)
Control	12 (8)	183	160	0.22	65.4
	16 (4)	182	150	0.21	65.2
Fast	12 (4)	168	151	2.81	65.0
	16 (8)	167	146	3.18	65.1
SED	Average	1.1	4.1	0.29	0.31
	Max	1.3	4.8	0.33	0.36
	Min	0.9	3.4	0.25	0.25
Main effects					
Growth	Control (12)	182	155	0.22	65.3
	Fast (12)	167	149	2.99	65.0
	SED	0.8	2.9	0.20	0.22
Photoperiod	12 (12)	175	155	1.52	65.2
	16 (12)	174	148	1.69	65.2
	SED	0.8	2.9	0.20	0.22

Residual d.f. = 20.

6.3.1.2 Lighting programmes

ASM was not significantly different for the 12 and 16-h daylengths, but the birds on the 12-h daylength laid 7 eggs significantly more than those on 16-h (Table 6.3). There was no significant difference in the number of unsettable eggs or mean egg weight to 60 weeks of age between the two daylengths.

No significant interactions were found between the growth curves and the daylengths in lay for any of the variables studied. Mortality rates were similar for all treatment groups, being 8.8, 8.8, 7.8, and 6.0% from 20 to 60 weeks (for Fast-12, Fast-16, Control-12 and Control-16 respectively).

6.3.2 Experiment 2: individually caged-birds

ASM, body weight at sexual maturity, and initial egg weight were significantly affected by the growth curve and age at photostimulation, however, there was a significant interaction between the two treatments (Table 6.4).

6.3.2.1 Growth curves

ASM, body weight at sexual maturity and initial egg weight are shown in Table 6.4. The difference in ASM between the growth treatments was 25 d. Body weight at sexual maturity was 200 g heavier for birds on the Fast growth curve. The initial weight of the eggs produced by the Fast birds was 3.6 g lighter than those produced by birds on the Control curve.

6.3.2.2 Lighting programmes

Compared with the constant 8-h controls, birds transferred to 16 h at 11 or 12 weeks matured approximately 10 d later, but birds photostimulated at 14 and 16 weeks matured 18 d earlier, and those photostimulated at 18 weeks matured 33 d earlier (Table 6.4). Pullets that had been photostimulated at 10 weeks were not significantly different from the constant 8-h controls.

Birds photostimulated at 18 weeks had the lightest body weight at sexual maturity and produced the smallest first eggs (Table 6.4). There was no significant difference between body weight at sexual maturity for the constant 8-h control group and the groups photostimulated at 10, 11 or 12 weeks. However, all were significantly heavier than the birds photostimulated at 14 and 16 weeks, which were, in turn, significantly heavier than the 18-week stimulated group (Table 6.4).

Eggs laid by pullets photostimulated at 18 weeks were 3 g significantly lighter than for birds photostimulated at 14 and 16 weeks, which were in turn significantly lighter than for the constant 8-h controls or birds transferred to 16-h photoperiods at 10, 11 or 12 weeks of age (Table 6.4).

6.3.2.3 Growth curve and lighting programme interaction

A significant interaction was found between growth curve and age at photostimulation for ASM, with birds photostimulated at 18 weeks and the constant 8-h controls having a much smaller difference between the Control and Fast growth than birds photostimulated at ages between 10 and 16 weeks (Table 6.4).

Separate regressions of the body weight at sexual maturity on the age at sexual maturity for the two growth curve groups produced significant linear relationships in each case (Figure 6.1).

Table 6.4. *The effects of growth curve and age at photostimulation (PHO) on mean (±SEM) age at sexual maturity (ASM), body weight at PHO, body weight at sexual maturity (SM) and initial egg weight of broiler breeder hens (Experiment 2). Bird numbers are given in parentheses.*

Growth curve	PHO (weeks)	ASM (d)	Body weight at PHO (g)	Body weight at SM (g)	Initial egg weight (g)
Control	Constant 8 h (55)	212±3.2	*	3796±57.5	54.9±1.2
	10 (26)	219±4.3	1061±32.5	3824±65.2	57.4±1.2
	11 (28)	235±4.6	1153±39.2	4017±78.7	57.4±1.9
	12 (25)	223±5.8	1386±41.9	3816±94.2	55.8±1.3
	14 (28)	218±4.5	1481±22.0	3763±63.8	55.2±1.3
	16 (29)	201±4.4	1643±20.2	3587±88.7	54.5±1.7
	18 (29)	179±1.6	1793±12.3	3124±46.4	48.0±1.1
Fast	Constant 8 h (54)	202±4.4	*	4259±63.9	55.1±1.3
	10 (27)	195±5.4	1375±75.9	4067±89.0	54.8±1.8
	11 (26)	197±7.5	1625±48.5	4035±91.9	53.8±2.0
	12 (21)	212±11.4	1672±46.0	4114±121.6	54.8±1.9
	14 (28)	161±4.3	1965±26.4	3532±84.0	45.0±1.3
	16 (26)	176±6.2	2256±62.6	3692±80.4	48.2±1.6
	18 (29)	168±3.7	2388±54.2	3739±74.1	45.8±1.0
SED	Average	6.81	62.3	104.1	1.97
	Max	7.59	63.7	116.1	2.19
	Min	4.91	62.0	75.2	1.42
Main effects					
Growth curve	Control (220)	212	1420	3704	54.7
	Fast (211)	187	1880	3920	51.1
	SED	2.58	37.6	39.5	0.75
PHO	Constant 8 h (109)	206	*	4028	55.0
	10 (53)	207	1218	3946	56.1
	11 (54)	216	1389	4026	55.6
	12 (46)	217	1529	3965	55.3
	14 (56)	189	1723	3647	50.1
	16 (55)	188	1949	3640	51.4
	18 (58)	173	2090	3431	46.9
	SED	4.82	64.5	73.7	1.39

Residual d.f. = 417

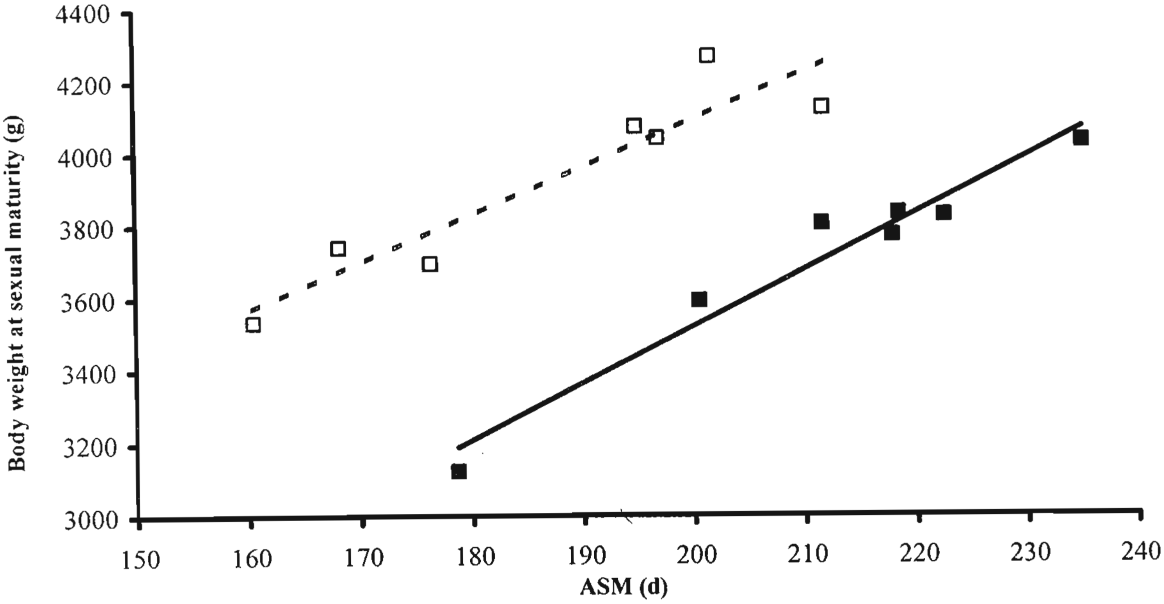

Figure 6.1. *The relationship between age at sexual maturity (ASM) and body weight at sexual maturity of broiler breeder hens reared on Control (■) and Fast (□) growth curves and photostimulated at different ages.*

The regressions for each of the growth rates applied showed no significant differences in their slopes, with the regression equations being:

Control growth: $y = 692\ (\pm 288) + 14.2\ (\pm 1.35)\ ASM$ ($r^2 = 0.952$, $P \leq 0.05$)

Fast growth: $y = 1264\ (\pm 345) + 15.5\ (\pm 1.98)\ ASM$ ($r^2 = 0.871$, $P \leq 0.05$)

Where y = body weight at sexual maturity (g), and ASM = age at sexual maturity (d).

6.4 DISCUSSION

6.4.1 Experiment 1

This experiment was designed to investigate the effects on sexual maturity and subsequent laying performance of advancing photostimulation by 5 weeks whilst manipulating the growth curve to achieve the same target body weight at photostimulation as recommended for conventional broiler breeder management (2100 g at 20 weeks). Additionally this trial measured the responses to two daylengths in the laying period.

In this trial, when the birds were photostimulated at different ages, but at the same body weight, ASM was advanced by 15 d following photostimulation at 15 compared with 20 weeks. However, this response slope of a 0.43 d advance in maturity for each 1 d earlier photostimulation (15 d earlier ASM for 35 d earlier photostimulation) is a smaller response than would have been predicted from the model of Lewis *et al.* (2002) for egg-type hybrids transferred from 8 to 12 or 16-h photoperiods. Whilst the fact that the egg-type hybrids were fed *ad libitum* and broiler breeders are feed-restricted might suggest a nutritional explanation for the disparity, the difference in amplitude of response between the two types of bird could also be due to genetic differences, because Lewis *et al.* (1997) reported different responses for white and brown-egg-laying hens given the same increment in photoperiod. In contrast, the similarity of ASM in response to the two increases in photoperiod given at 20 weeks (8 to 12 h and 8 to 16 h) is not surprising, because the saturation daylength for gonadotrophin release in broiler breeders, although in a dwarf strain, has been observed to be about 12.5 h (Dunn and Sharp, 1990). It seems that 12 and 16-h daylengths are almost equally stimulatory for initiating rapid gonadal development in broiler breeders.

An important criterion to be considered before embarking on a novel management programme that modifies performance is the impact that this will have on the profitability of the enterprise. In this regard there are a number of factors that need to be considered, namely, the cost of implementing the new strategy in terms of infrastructure, changes in labour requirement, and hardware maintenance, together with any changes in the amount of feed required to get the birds to point of lay, and in rates of settable egg production, hatchability and mortality. Despite the important contribution that this research has made to the understanding of broiler breeder reproductive physiology, the advanced sexual maturation brought about by the new husbandry technique employed resulted in fewer total and settable eggs and an increased production of reject eggs (due mainly to their weight being below the 50-g threshold for setting). However, if the rearing period could be shortened to 15 weeks, one rearing house would be able to supply point-of-lay pullets to three layer houses in a 60-65 week cycle, instead of two with the current practice of transferring at about 20 weeks. It would mean that one third of the rearing facilities could be made redundant, resulting in reductions in maintenance, land and labour costs. If fewer rearing farms could be maintained, the liberated capital could be used to improve the remaining facilities. This is particularly relevant in countries like South Africa where the majority of rearing houses are still open–sided. These could be converted into light-tight facilities that would improve the standard of rearing management of the pullets, and further increase the gross profitability of the enterprise.

Although the birds on the Fast growth curve that had been photostimulated at 15 weeks reached sexual maturity sooner, the lag between photostimulation and sexual maturity was 20 d longer than for the Controls that had been photostimulated at 20 weeks. However, using data presented in Figure 6.2, one would have expected a difference closer to 50 d, and this suggests that the growth curve itself accelerated maturity by about 30 d. One result of this longer period between photostimulation and sexual maturity was that the birds consumed 1.3 kg more feed to point of lay. As a consequence, body weight at sexual maturity was heavier for this group than for the controls, and this might possibly have contributed to their inferior rate of egg production. A modification of the feed allocation schedule to reduce body weight gain in the period between photostimulation and sexual maturity might be an approach worth pursuing to minimise the adverse effects of the new management protocol. The consequent reduced growth rate might also reduce the number of double-yolked eggs. Figure 6.3 shows that the average egg weight for birds on the Fast growth curve was below the minimum setting-threshold weight of 50 g longer than Control birds. Nutritional modifications to the diet used prior to, and in, this early phase of the laying cycle might reduce this negative characteristic of early maturity. A complete revision of the nutrient requirements of the early maturing broiler breeder pullet prior to sexual maturation and in the initial part of the laying period is clearly indicated.

Even though faster growth during the rearing period coupled with early photostimulation does not seem to be a feasible strategy at present, this study has shown that a reduction in the maximum daylength given to conventionally managed broiler breeders during lay will improve settable egg production. The significantly higher number of settable eggs produced by hens given a 12-h daylength in lay suggests that the recommendations of the primary breeders to provide a daylength of at least 16 h (Cobb 500 Breeder Management Guide, 2001) could be compromising the laying performance through a more rapid development of adult photorefractoriness (Lewis *et al.*, 2003). The rate at which adult photorefractoriness develops has been demonstrated to be proportional to photoperiod in non-domesticated avian species (Dawson and Goldsmith, 1983). Other supportive evidence is found in Sharp (1993), where broiler breeder hens given 11-h photoperiods, had better egg production than birds given 20-h photoperiods. A further contributing factor to the negative effect of long photoperiods could be a higher energy expenditure – birds at zero activity require 1 %/h more energy in light than in darkness (Lewis *et al.*, 1994b). As a consequence, birds on 16 h have a higher maintenance requirement than birds on shorter daylengths, and, as a corollary, fewer nutrients are available for egg production.

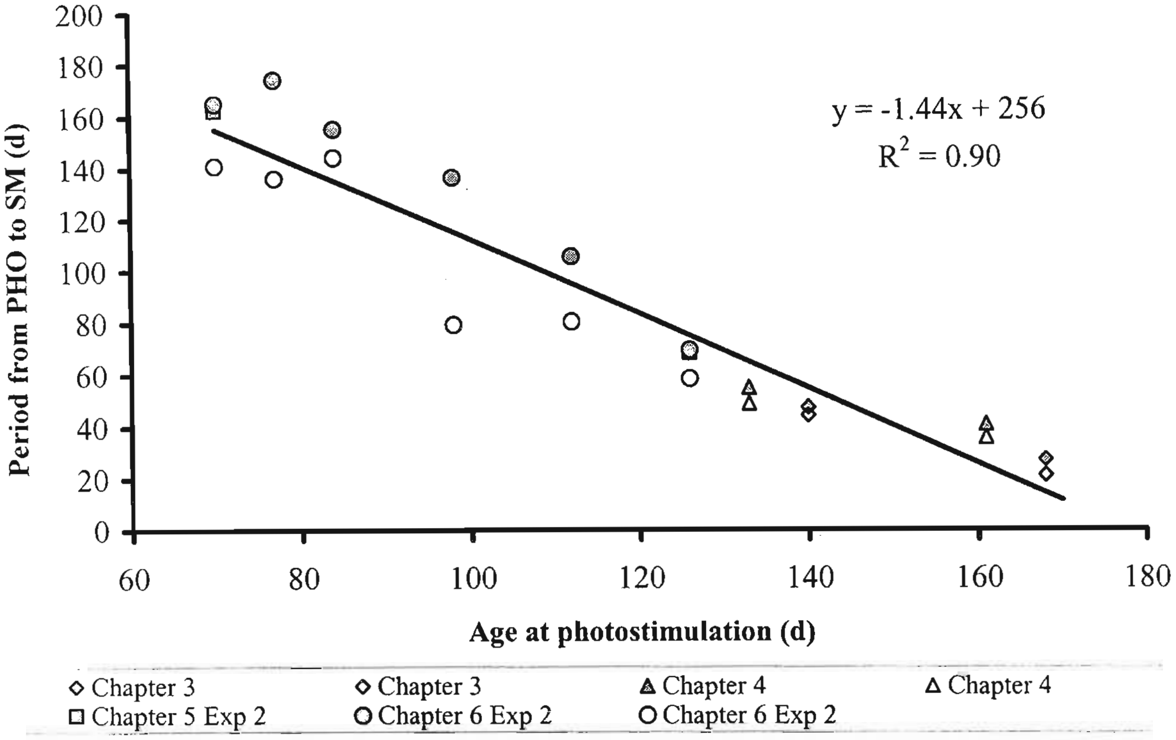

Figure 6.2. *The effects of age at photostimulation on the period from photostimulation (PHO) to sexual maturity (SM) in broiler breeder hens.*

6.4.2 Experiment 2

This experiment was designed to identify the age at which broiler breeders grown to achieve 2100g at 20 weeks become photosensitive, and to assess the influence of modifying body weight gain on this age.

Although the analysis of ASM data was performed following the approach used by Lewis *et al.* (2002), for convenience, the data shown in Figure 6.4 have been plotted linearly.

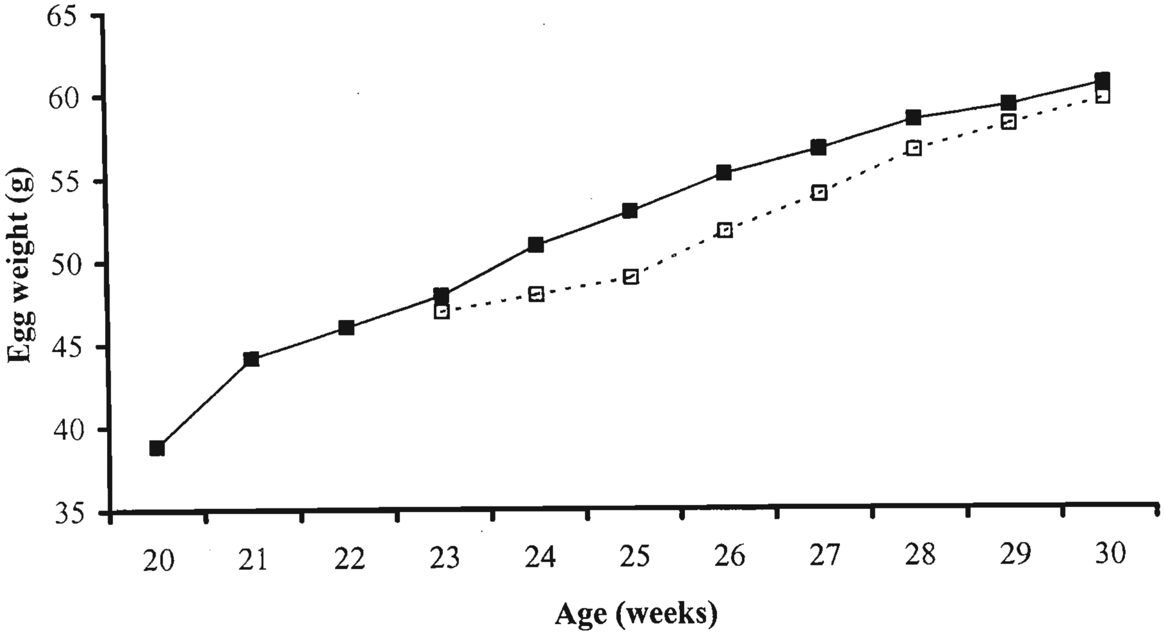

Figure 6.3. *Mean weekly egg weight in broiler breeders reared on a Control (open line and symbols) or Fast growth curve (solid line and symbols).*

However, the proportions of birds within a flock that have achieved photosensitivity at any given age are likely to form a normal distribution. Data from Chapter 5 indicated that birds maintained on constant 16-h photoperiod mature about 20 d later than birds held on 8-h photoperiods. Although there was not a constant 16-h control in this trial, sexual maturity for such a treatment has been estimated using the constant 8-h data in this trial and the differential between the two treatments observed in the earlier work (Figure 6.4). The age at which the first bird in a flock of broiler breeders dissipates juvenile photorefractoriness (and become photosensitive) is determined by an extrapolation of the regression for sexual maturities achieved following photostimulations between 10 and 18 weeks back to where it intersects the estimated ASM for constant long-days. This point was about 10 weeks for birds reared on the Control growth curve, an age that agrees remarkably well with the findings from the earlier experiment, in which, there was no significant difference between the ASM for birds transferred from 8 to 16 h at 10 weeks and constant 16-h controls. An examination of data from individual birds indicates that the point at which all birds in this group became photosensitive was about 19 weeks. After this point, it is likely that the birds would have become progressively less responsive to an increment in photoperiod until approximately 2 weeks prior to mean ASM of short-day controls (indicating that birds have started rapid gonadal development spontaneously), as occurs in full-fed egg-type hybrids (Lewis *et al.*, 2002). This means that birds reared according to current breeders' body weight recommendations are unlikely to respond to an increment in photoperiod after about 28 weeks.

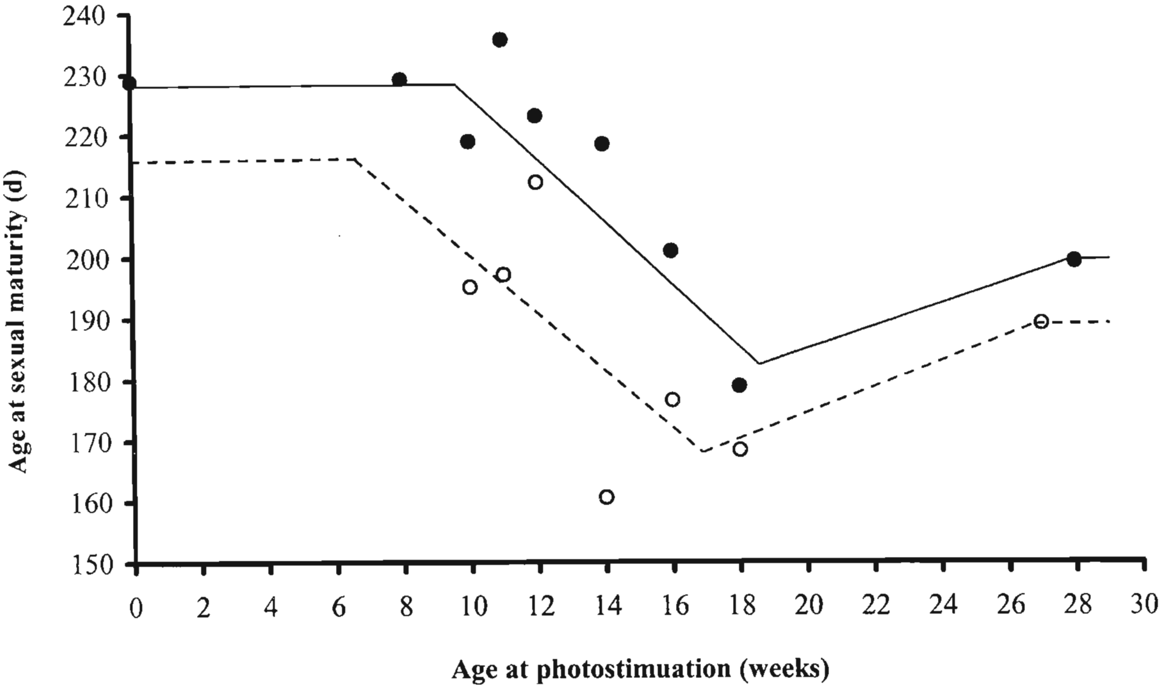

Figure 6.4. *The effects of age at photostimulation on age at sexual maturity of broiler breeder hens reared on Control* (●) *and Fast* (○) *growth curves. Points representing age at sexual maturity of birds on 8 h constant photoperiods (right end of curve) were calculated by subtracting 13 d to the mean age at sexual maturity (Lewis et al, 2002)*

When birds are reared on a more relaxed feed restriction programme, the response seems to have the same shape and amplitude as described for the controls, but at a different level. By using the same procedure mentioned above, the age at which the first birds in the flock would become photosensitive appears to be about 7 weeks. And the point when all the birds in a group become photosensitive is between 17 and 18 weeks, indicating that the length of time for all birds within a group to become photosensitive is probably unaffected by the severity of feed restriction, and probably under genetic control. In order to confirm these assumptions and to test the temporal limits of successful photostimulation, more experimentation is required to more accurately identify the age at which broiler breeders dissipate photorefractoriness when reared on accelerated growth curves.

Body weight at sexual maturity of birds in both growth curves was affected by the age at photostimulation. It is evident in Figure 6.1 that birds that achieved sexual maturity earlier had lighter body weights, while those that were retarded, due principally to late photostimulation, were much heavier. This excess body weight gain was the consequence of applying a common feeding programme to all the birds, irrespective of their age at maturity. This is seen in commercial practice in out-of-season flocks reared in open sided houses, where feed allocations are increased at 15 weeks even though sexual maturity could be delayed by up to 5 weeks by the natural changes in photoperiod. Under such conditions the birds become excessively heavy before reaching sexual maturity and have inferior egg laying performance. As suggested before, new feeding strategies have to be researched to overcome this problem by avoiding large increments in body weight gain during this period.

In conclusion, the results of these trials have shown that age at sexual maturity in broiler breeder pullets can be significantly advanced. However, in spite of the advance in the onset of lay in these birds, such a change in management, whilst using currently available diets and feeding schedules, would only be profitable through the advantages of being able to use one rearing unit to service three, instead of two, laying farms. Because broiler breeders have been shown to exhibit photorefractoriness, a sensible change would be to invest in light-tight rearing houses, where short daylengths could be used, thereby allowing a more rapid dissipation of the condition. Where light-tight laying houses are available, the maximum daylength given to the hens during the laying period could be reduced, advantageously, below 16 h, resulting not only in a significant reduction in the cost of illuminating the birds, but also in a significant improvement in egg production. The results of these trials indicate that there are still opportunities to optimise ASM and performance through manipulations of age and body weight at photostimulation, and through a shorter photoperiod during the laying period.

CHAPTER 7

GENERAL DISCUSSION

A series of six experiments was conducted to gather information on how various growth and environmental variables could be used to develop a theory for the effects of growth curve and lighting programme on subsequent performance in broiler breeder hens. As a means of producing data for such a theory, widely differing treatments were used: growth curves were manipulated so that pullets achieved the desired body weight at photostimulation as early as 15 weeks, constant photoperiods of various lengths were used, as were different ages at photostimulation. The effect of these treatments on age at sexual maturity (ASM) and settable egg production provides the basis for the following discussion.

7.1 Age at sexual maturity

ASM is controlled by the daylength during the rearing period, and will be delayed in birds maintained on 16-h photoperiods (Figure 5.3) or in those given an early transfer from 8 to 16 h (Figure 6.4), because of the slower rate at which juvenile photorefractoriness is dissipated under long photoperiods (Farner and Follett, 1966). In contrast, ASM occurs earlier in birds reared on short-days or in birds photostimulated after they have become photosensitive. In the second experiment, birds were transferred to long-days abruptly or in a series of smaller increases, but this variation in how increments were given had no significant effect on ASM.

Sexual maturity is affected by the size of the increment in photoperiod at photostimulation (Lewis *et al.*, 2002). Of the photoperiods investigated in these trials, the maximum advance in ASM was achieved when birds were transferred from 8 to 16 h (trials 2, 3 and 4). ASM was significantly delayed, relative to a transfer to 16 h, in conventionally reared birds when daylength was increased from 8 to 10 or 11 h, whereas there was no significant difference in ASM when daylength was increased to 12 h. These finding suggests that 10 and 11-h photoperiods are less stimulatory than either 12 or 16 h.

ASM data from experiment 6 (Figure 6.4), from the other experiments reported in this thesis, and for full-fed egg-type hybrids from Lewis *et al.* (2002) have been integrated in Figure 7.1. When a 2100 g body weight was achieved at 15 weeks (approximately 50% of *ad libitum* body weight) by relaxing the level of feed restriction, ASM was advanced by 15 d in birds transferred from 8 to 16 h, and by 10 d in birds maintained on 8-h (Table 6.3). These changes in ASM concur remarkably well with those reported by Lee *et al.* (1971), who predicted a delay in ASM of 1d for each 1% decrease in body weight, compared with *ad libitum* egg-type hybrids. If these results apply to modern broiler breeders, and this advance in maturity continues linearly, then this suggests that *ad libitum*-fed broiler breeders photostimulated at a weight of 2100 g (about 6 weeks) might well have an ASM of less than 20 weeks (Figure 7.1, dotted line). The coincidence of this theorised ASM for broiler breeders with the observed ASM for *ad libitum* fed egg-type hybrids adds credence to this scenario. These similarities also suggest that the rate at which feed restriction modifies ASM, and hence body weight at sexual maturity, is independent of genotype. However, a limiting factor for this advance in sexual maturity might be the time taken for juvenile photorefractoriness to be dissipated in current genotypes of broiler breeders reared on short days.

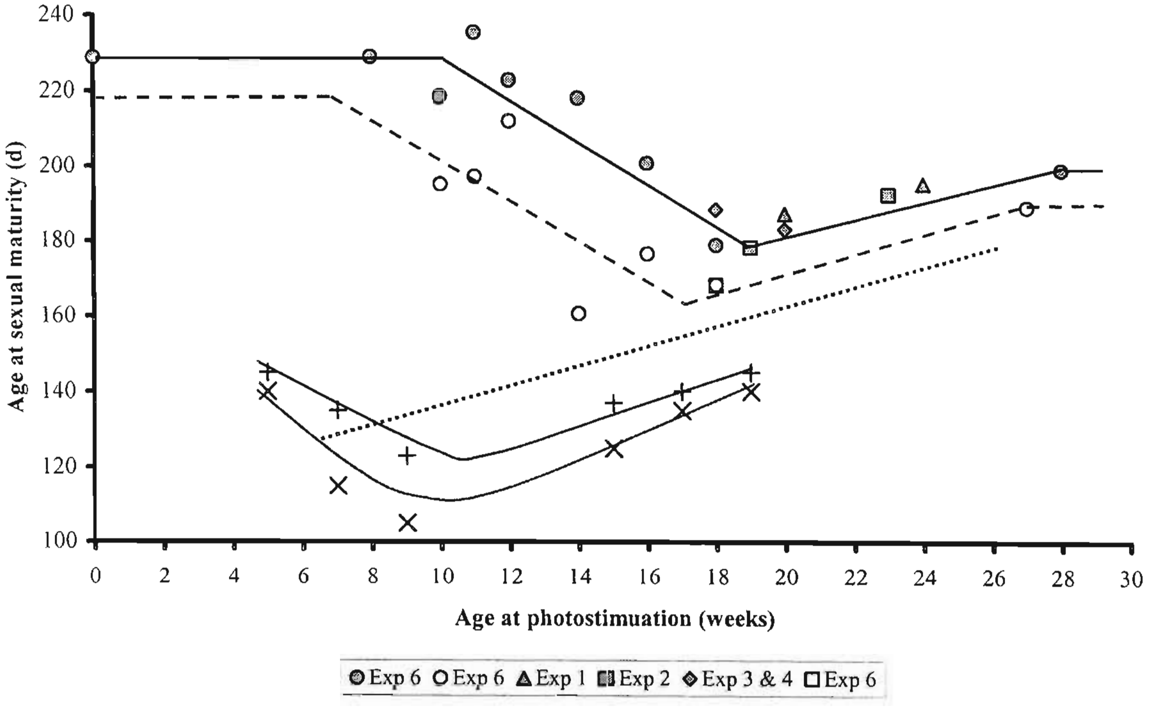

Figure 7.1. *The effects of age at photostimulation on age at sexual maturity of broiler breeder hens reared on Fast (open symbols) or Control (solid symbols) growth curves, and data from Lewis et al. (2002) for two genotypes of egg-type layers: Shaver 288 white-egg (+) and ISA Brown brown-egg (x).*

A regression of ASM on body weight at photostimulation using results from the trials reported in this thesis, and from the literature, revealed a significant negative correlation (Figure 7.2), with ASM advancing about 1.1 d for each 100-g increment in body weight at photostimulation. This differs from a slope of 0.8 d/100g for the regression conducted using data from the literature (Figure 2.5).

The regression equation in Figure 7.2 was:

$$y = 211\ (\pm 4.65) - 0.011\ (\pm 0.0012)BW\ \ (r^2 = 0.869, P \leq 0.05)$$

Where y = age at sexual maturity (d), and BW = body weight at photostimulation (g).

Three possible explanations for this discrepancy are, (a) a different growth profile despite having the same body weight at photostimulation, (b) different genotypes, and (c) differences in the level of feed restriction required to achieve a given body weight.

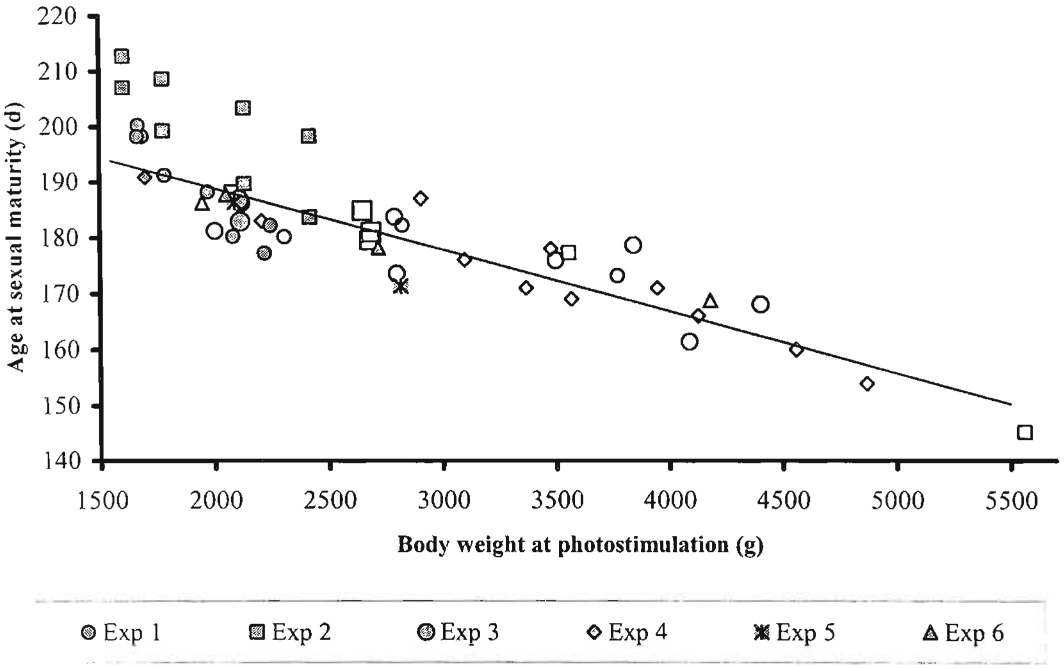

Figure 7.2 *The effects of body weight at photostimulation in age at sexual maturity of broiler breeder hens. Data from this research (solid symbols) and from Yu et al. (1992a) (Δ); Hocking (1993) (◇); Yuan et al. (1994) (○); Wilson et al. (1995) (□); Hocking (1996) (□) and Bruggeman et al (1999)(○)*

Although there is a good fit for this linear regression, logically the linearity cannot continue because at the lower end, small body weights are likely to mean either ultra-severe feed restriction or very young ages, and both would prohibit a photosexual response. At the upper end, birds are likely to mature spontaneously before this photostimulation body weight can be achieved or have their performance compromised by obesity.

7.2 Settable egg production

It would be useful to be able to predict the settable egg production from the way in which broiler breeder pullets are managed during rearing, and to this end, the relationship between body weight during rearing and settable egg production was investigated. The body weights of the birds at 10, 15 and 20 weeks of age, and at photostimulation were chosen as possible predictors of settable egg production to 60 weeks. However, none of these parameters could be used as a reliable predictor of settable egg numbers. As an example, Figure 7.3 shows the effects of body weight at 20 weeks of age on settable egg production.

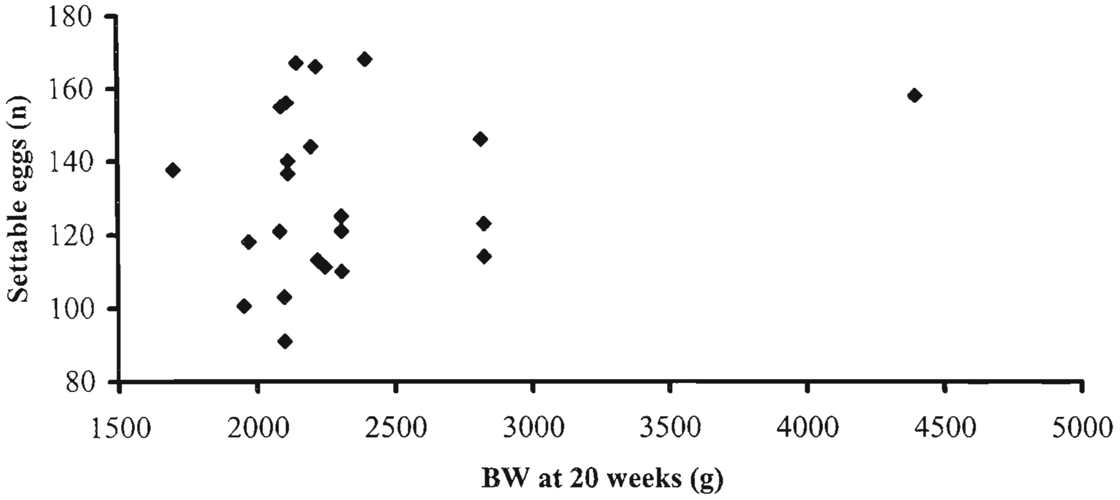

Figure 7.3. *Effect of body weight at 20 weeks of age on settable egg production to 60 weeks of age for broiler breeder hens.*

Since body weight at 20 weeks was not a good predictor of the settable egg production, a different approach was tested. The response in settable egg production of birds reared on a Control growth curve and transferred to fully stimulatory daylengths at different ages can be seen in Figure 7.4. A 'broken-stick' regression was performed after differences between trial means had been removed by least squares analysis. This shows that the number of settable eggs increases by about 4 (SE = 1.0) for each 1-week delay in photostimulation up to 19 weeks. It also indicates that equal numbers of settable eggs will be produced following photostimulation at 19 weeks or at older ages, but the response plateau will not continue indefinitely, ending, as it must, at about 2 weeks prior to the mean ASM for spontaneously maturing short-day controls.

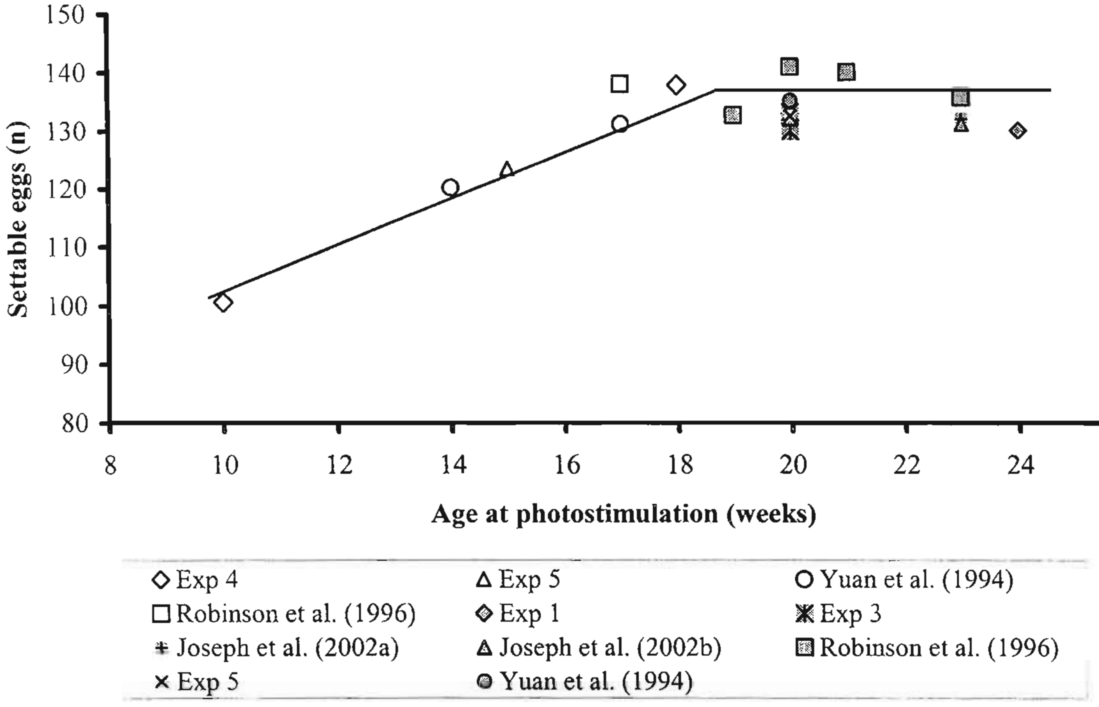

Figure 7.4. *The effects of age at photostimulation on settable egg production for broiler breeder hens reared on a Control growth curve. Photostimulation from 10 to 19 weeks are represented by open symbols, and 19 weeks onwards by solid symbols.*

The findings from these trials indicated that when broiler breeders are transferred from an 8 h rearing photoperiod to a mildly stimulatory one (11 or 12 h), the number of settable eggs produced is significantly more than for 16-h photoperiods. They also confirmed that broiler breeders still possess a vestige of seasonal breeding, and this is undoubtedly a contributing factor to the reduced number of settable eggs produced on 16 h photoperiods. However, even birds on mildly stimulatory daylengths will eventually become photorefractory, with the time taken reach this state being proportional to photoperiod (Dawson and Goldsmith, 1983).

7.3 Conclusions

Despite the contribution of this research to the knowledge of the reproductive response of broiler breeder hens to changes in growth and lighting programmes, there are still some areas that need further investigation.

1. There should be an optimum combination of body weight and age at photostimulation that will result in both an earlier age at sexual maturity and a maximisation of settable egg production. It was proposed in Chapter 6 that it might be possible to advance sexual maturity by growing the birds to a heavier weight and subjecting them to earlier photostimulation. It seems that the lines in Figure 6.5 are shifted and maturity is advanced as feed restriction is relaxed. This is also supported by the fact that age at sexual maturity in full-fed egg-type layers has been shown to follow the same trend, where maturity can be achieved as early as 105 d (Figure 6.4). It is unlikely that broiler breeders would achieve such an early age at sexual maturity, but in principle this is a strategy that could be employed to reduce ASM.

2. The response of the birds to constant photoperiods requires more research. In Figure 5.3 the relevant research conducted to date has been summarised. However, more trials are needed to plug the gaps in our knowledge. It will be useful to measure the ASM in birds maintained on 6, 10, 12 and 14 h photoperiods. The slopes of the lines to 11-h photoperiods for layers and broiler breeders were not significantly different. However, egg-type hybrids respond to the constant photoperiods up to 11 h by achieving sexual maturity earlier than the broiler breeder females subjected to the same photoperiods. This suggests that by growing broiler breeders to a heavier body weight than the standards recommended by the primary breeding companies, the birds could achieve maturity earlier and, as a consequence, overcome the delay observed in out-of-season flocks when they are reared in open sided houses.

3. There is evidence that the hatchability of all, and of fertile, eggs from young flocks is depressed (Roque and Soares, 1994, Heier and Jarp, 2001). And so the effects of reducing ASM on fertility and hatchability, as well as liveability and the performance of the broilers hatched from very young breeder flocks, need to be explored to evaluate the possible impact in broiler performance.

4. The experiments in this study were designed to gather information about the effects of various growth curves and lighting programmes on the reproductive performance of broiler breeder hens. Although three genotypes were used in the series of trials, the observed responses when the same treatments were given to each indicate that there were no genotype-treatment interactions. This statement may need to be verified.

5. The research demonstrated that broiler breeders exhibit photorefractoriness, and also identified ages at which birds given different levels of feed restriction become photosensitive. These findings require consolidation.

6. Although prediction equations were put forward for the ASM of birds maintained on constant daylengths and those photostimulated at ages between 10 and 24 weeks, further research would probably increase the confidence that can be placed in the use of these predictors.

7. Additional analyses enabled the formation of a prediction equation for the number of settable eggs produced by broiler breeders reared on a conventional growth curve and photostimulated between 10 and 24 weeks. This will undoubtedly be different for birds grown on different growth profiles, but this needs to be established.

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