AUSTRALIAN EGG CORPORATION LIMITED

Pullet and layer flock uniformity, persistency and longevity: an epidemiological, industry-based approach to improve feed efficiency

Final Project Report

A report for the Australian Egg Corporation Limited

by G.B. Parkinson, J. Roberts and R. Horn

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Researcher/Author Contact Details
Name: Greg Parkinson; Juliet Roberts; Rowly Horn
Address: 86 Wilson St, Brunswick, VIC 3065;
Animal Science, SERS, University of New England
Armidale, NSW 2351;
8 Ann Place, Bligh Park, NSW 2756.
Phone: 03 9387 8828 0417 506 574
02 6773 1995 0428 968 473
02 4572 0318 0409 772 045
Fax: 02 6773 3922
02 4572 0328
Email: livornoconsulting@pacific.net.au; jrobert2@une.edu.au;
rowly@rowlyhorn.com

In submitting this report, the researcher has agreed to AECL publishing this material in its edited form.

AECL Contact Details:

Australian Egg Corporation Limited
A.B.N: 6610 2859 585
Suite 4.02, Level 4, 107 Mount St
North Sydney NSW 2060

Phone: 02 9409 6999
Fax: 02 9954 3133
Email: research@aecl.org
Website: www.aecl.org/r-and-d/

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Foreword

Flock uniformity is widely recognised as being of major importance. Maintaining high body weight uniformity is a major objective during the rearing period. Although uniformity is mentioned repeatedly in the production manuals for all of the major breeds of layer, there has been surprisingly little scientific research conducted into ways of ensuring pullet flock uniformity and then maintaining uniformity throughout lay. This project examined these issues in more depth focussing on the upper and lower thresholds for maximum persistency of production, and the interactions of these thresholds with management and environmental factors across the Australian Industry. Research was planned to then overlay questions of skeletal integrity, skeletal size and obesity in both persistency of production and eggshell quality.

The development of improved objective standards for these issues, and their interaction with environmental factors, will enable a long-term plan to be implemented, which looks at improving flock longevity and/or achieving further reduction in flock body weights to improve feed conversion efficiency.

A thorough understanding of these parameters provides an important platform for large efficiency gains by the Australian Egg Industry, albeit progressive and incremental.

The project aimed to:

1. Develop a seminar series on uniformity standards and production efficiency for the national industry.
2. Encourage elite producers to undertake their own uniformity studies focussing on day old weights, 6, 12, 16, 30 and 40 weeks of age.
3. Identify elite performing flocks for ongoing uniformity studies.
4. Consider laboratory models of body weight thresholds and performance to establish clearer causal relationships, with productivity and shell quality.
5. Instigate a workshop with consultant nutritionists and the Stockfeed industry to discuss the interacting issues of flock growth patterns, flock uniformity and nutrition.

This project was funded from industry revenue, which is matched by funds provided by the Australian Government.

This report is an addition to AECL's range of peer reviewed research publications and an output of our R&D program, which aims to support improved efficiency, sustainability, product quality, education and technology transfer in the Australian egg industry.

Most of our publications are available for viewing or downloading through our website:

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Printed copies of this report are available for a nominal postage and handling fee and can be requested by phoning (02) 9409 6999 or emailing research@aecl.org.

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About the Authors

Dr Greg Parkinson has a long history in Poultry Science in Victoria and Australia, and in recent years has provided support for Egg Industry research, through roles on AECL Industry Consultative Committees, and the Scientific Advisory Committee for the Poultry Cooperative Research Centre (CRC). Greg has had a long term scientific interest in issues of growth and metabolism in egg layers, and this project continues these studies with focus on the definition of maximum physiological potential of the modern egg layer and/or achieving a more scientific definition of the maximum egg mass output in the smallest possible bird.

Juliet (Julie) Roberts is an Associate Professor in Animal Science at the University of New England. She teaches physiology and poultry science to undergraduate and postgraduate students, and supervises postgraduate research students. She has more than 30 years' experience in avian research and her main area of research interest is factors affecting egg quality in laying hens. She has successfully completed many research projects for AECL and its predecessor organisations.

Rowly Horn of Rowly Horn Services has 50 years' experience in poultry extension and is well known to the members of the Australian egg industry.

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Abbreviations

AECL	Australian Egg Corporation Limited
BW	Body weight
CT	Computed tomography
CV	Statistical coefficient of variation
EM	Egg mass
EPRID	Egg Producer Research Innovation and Development Program (AECL)
FCR	Feed conversion ratio
g	Gram
G	Growth
kcal	Kilocalories
kg	Kilogram
Kj	Kilojoule
kv	Kilovolt
μm	Micrometer (micron)
mA	Milliampere
ME	Metabolisable energy
Mj	Megajoule
mm	Millimetre
P	Statistical probability
R^2	R squared (a statistical measure of how close data are fitted to a regression line)
T	Temperature
UNE	University of New England
W	Body weight
wk	Week

Executive Summary

The research undertaken in this project has achieved very good support and co-operation with a number of the more sophisticated and/or elite producers, and there is widespread interest amongst Victorian and interstate producers in identifying new managerial approaches that can improve persistency of production and reduce the losses through defective shells.

This research project has aimed to investigate the variability among farms and flocks, for flock growth rates and uniformity, and to establish benchmarks of industry performance. Some laboratory modelling has also been undertaken on important issues to clarify causal relationships that can then be compared to data obtained from the cross sectional and experimental farm studies.

At the commencement of the research project, the model of flock uniformity was based on information derived from hatchery sources, some controlled studies undertaken by Balnave (1984), and our own studies undertaken for the AECL 2007 (Parkinson et al*.,* 2007).

Previous research undertaken in EPRID Project No. 1 (Parkinson et al*.,* 2007) suggests that uniformities at point of lay in excess of 90% with coefficients of variation (CV) of 6-7% are achievable, despite significant variation in the day old chick quality and uniformity. A few commercial flocks had been identified that achieved uniformity or CV close to those achieved in the laboratory, and these few flocks have exceptional production performance. Unfortunately, the number of these elite flocks was relatively limited, and it is difficult to precisely apportion a causal relationship, but the association between high uniformity standards and high persistency outcomes in experimental flocks seemed very promising.

The traditional approach for defining flock uniformity recommended by the International Hatcheries relies strongly on the concepts of normal distribution, with considerations of body weight variation plus or minus 10% from the mean, or concepts of the standard deviation and the coefficient of variation. This approach fails to take account of skewness on body weight distributions in individual flocks that do not closely conform to normal distributions.

The authors have proposed an alternative approach using a set of upper and lower body weight thresholds that define as closely as possible 100% of the flock body weight distribution. The conceptual idea behind this model is that 100% of the flock can then be made physiologically functional and the experimental models developed on one commercial farm, and at the University of New England, indicate that these concepts are valid. At this stage it is proposed that the ideal lower threshold could be 1.5 kg and the upper threshold 2.4 kg at 40-50 weeks of age in all brown egg layers.

At this stage it appears that an increasing proportion of obese birds during lay can be strongly correlated with both loss of persistency in egg production and poor shell quality. Management of obesity in flocks should assume equal significance to the management of under-weight birds.

Large improvements in production performance will be achieved if the Australian Egg Industry can strive for an increasingly narrow body weight distribution around the breed standard or a standard weight for age that is considered optimal, and there is a great opportunity to reduce the current variation among flocks and to look for new benchmarks of evenness. Many of the elite producers are currently taking up this challenge and the intervention studies undertaken by two major farms have demonstrated that flocks managed to body weights at, or slightly below, the breeder standards have achieved highly significant improvements in production performance, with markedly improved persistency of egg production in lighter, more efficient flocks.

These efficiency changes can be mathematically modelled by existing equations that predict energy requirements and feed intake from average body weights and egg mass. These predictions accurately describe the biological efficiency changes that were estimated at the start of the research, and provide methods for accurately costing the efficiency gains achieved with smaller/lighter flocks.

The large jumbo size eggs associated with the heavy birds in the flocks contain disproportionate amounts of yolk and albumen relative to shell, and shells become much thinner. For optimum shell quality, egg size probably needs to be managed in the range of 60-65 grams with jumbo sized eggs eliminated as much as possible. The overall management of egg size could be improved in the industry by more attention to flock uniformity and the proportions of large obese birds.

A thorough integration of studies on flock uniformity to improve persistence of production with a more effective management of shell percentage/thickness provides a significant opportunity for many producers to extend flock longevity. Improvements in flock longevity cannot, however, be reconciled with the production of a significant category of jumbo sized eggs.

There is an anecdotal view amongst poultry welfare researchers that high production performance results in egg laying hen “burn out” or metabolic collapse. Our research group has the opposite view, that the selection of birds in single bird cages has established a metabolic or physiological balance of body weight, tissue research and nutrient turnover that enables prolonged and persistent outputs of yolk, albumen and shell. The majority of the dysfunctionality and welfare problems arise in egg laying birds when this metabolic equilibrium has been disrupted by inappropriate body weights, tissue reserves, and nutrient intake. This disrupted metabolic balance can arise through poor compliance with growth management, inadequate nutrition, and poor behavioural management of flocks and to a lesser degree infectious disease. Providing more definitive proof to support this hypothesis can only be achieved by more systematic studies that compare laboratory models using both single and group cages to well matched commercial flocks.

Clearly, standardisation of flock average growth rates and point of lay uniformities will be pivotal in resolving these questions, because it is now apparent that flocks with body weights below breed standards can achieve elite egg production beyond current breeder standards. These findings bring into question the anecdotal view that very high and increasing egg production produces a metabolic collapse in flocks and individual birds.

Overall Conclusions

The maximum physiological potential for caged birds defined in these studies, occurs with body weights at or slightly below the breed standards, with high point of lay uniformities (90% or greater), and limited weight gain during egg production. This body weight standard could achieve sustained peak production levels of 98-100%, with a persistency of production as high as 90% at 72 weeks of age. Both experimental models and commercial flock studies suggest that average body weights at low as 1.75 to 1.80 kg are associated with elite high sustained peak production, and it may be possible to maintain flocks at these lower weights and maintain elite persistency of production.

This model of production efficiency shifts the efficiency paradigm and places less reliance on tissue reserves to maintain egg production, and will facilitate significant improvements in the management of egg size and shell quality.

Most free range flocks achieve performances well below these standards because of inappropriate growth rates and poor compliance with uniformities standards.

Outlying free range flocks have achieved high commercial performances at body weights slightly under the existing breed standards, where feed intake patterns in the transition between point of lay and peak production have matched breeder standards.

There is a strong argument to continue investigating the minimum body size required for high sustained egg production below 1.8 kg (30-50 weeks of age), and then assess the ability of the commercial industry to manage the environmental interactions at this new metabolic plateau. Applications of these concepts in cages will inevitably lead to their adoption or application in free range, which has inherently much great environmental variation.

The information developed in this research should enable egg producers with sophisticated management capabilities to initiate a movement away from overweight flocks and the gains will be substantial. The most important pitfalls are likely to be poor pullet uniformities in lighter pullets, and the ability to achieve the prescribed nutrient intakes in the transition between point of lay and peak.

The key to this new efficiency paradigm is to achieve uniform feed intakes in 100 percent of the flock body weight distribution, particularly between point of lay and peak production.

1 Introduction

1.1 Background Information

Historically, it has been found difficult to extrapolate from laboratory models and controlled studies of performance developed in research institutions, to all the variability in the commercial industry. Findings of published research, in many circumstances deviate significantly from commercial practice, and in a converse, but similar manner, laboratory research is sometimes poorly standardised against commercial practice, because of the continuous drift in production performance, technology and ideas adopted by industry.

In an attempt to overcome some of these limitations, the researchers deliberately shaped a research program involving initial epidemiological studies, some “on farm” interventions, and some supporting controlled laboratory studies, carefully standardised against industry practice to achieve an enhanced definition of causal relationships.

The important management information from the International Hatcheries provides recommendations on nutrition and body weight management that achieve high average performance for their particular genotypes. The key to additional production efficiency opportunities is therefore to understand the major variables and mechanisms that influence this performance, and to systematically improve the management of these variables to achieve new and improved performance standards.

The international hatchery manuals describe a complex model, involving pullet factors, growth patterns, uniformity standards, nutritional recommendations and standardised feed intake patterns. This basic managerial information has been very useful in standardising performance, but can limit further innovation, and rarely describes the impacts on performance where important variables such as body weight and body weight uniformity deviate from the prescribed standards. In addition, there are always new recommendations and ideas that arise from industry that are not objectively described in the existing manuals, and have at times been beyond the scope of systematic laboratory research.

These new variables have included managerial strategies to stimulate feed intake, particularly during the transition between point of lay and peak, and more precise management of body weight gain in lay. The causal impacts of these variables on performance need more investigation.

Relatively recent research undertaken on commercial strains in Europe (Lescoat et al., (2010), has also provided evidence that the relationships between body weight and production can be improved. Average body weights significantly below the hatchery recommendations have produced net improvements in efficiency, because egg mass and egg output have been able to be maintained on conventional diets in significantly lighter flocks.

These findings support the general hypothesis behind this research that questions the existing body weight standards, recommended by the International Hatcheries. It has been speculated that the existing standards have a significant safety margin, and it has been proposed that additional efficiency gains can be achieved in commercial laying stocks by more precise management of flock body weights and nutrient intakes.

For this innovative efficiency strategy to be applied, it will be important for it to be advanced incrementally to ensure that all the important variables are understood and managed. Promoting rules of thumb to industry can produce unexpected negative outcomes if not closely monitored.

The complexity of the model that may explain most of the variation in commercial flock performance can only be thoroughly unravelled by a combination of epidemiological studies, that associate managerial variables with performance, and then well-controlled studies where variables can be isolated and causal relationships proved. Historical long-term analysis may also assist in unravelling some of the important variables, particularly if systematic comparisons can be undertaken.

This research therefore attempts to integrate all these approaches using historical knowledge, farm experience, hatchery information, observational research, interventions, and some controlled studies.

The long-term aim is to establish an objective system for the continuous improvement of feed efficiency by lowering body mass, but maintaining the egg mass output for the Australian Egg Industry.

1.2 Historic data derived from EPRID Project No. 1, 2007

Previous studies funded by AECL during the period 2005 to 2007, found that most producers were farming with birds in cages above breed body weight standards (2.0-2.1 kg versus 1.95 kg) (Parkinson et al., 2007) (Table 1). Research was needed to know why this was occurring, and why producers had adopted these managerial strategies. These earlier studies also illustrated a marked loss of uniformity in lay, particularly with the larger birds “blowing out” after 35 weeks of age. These problems need to be highlighted and the production and economic consequences defined.

A schematic representation of the average growth rates achieved in cage flocks between 16 and 63 weeks of age, between 2005 and 2007 (Figure 1), illustrates the significant loss of uniformity after 33 weeks of age, which is closely associated with the increase in the proportions of heavy obese birds. This model contrasts with breeder recommendation that suggest a much reduced average or mean growth rate after 35-40 weeks of age.

The total variation in flock weights ranged from about 800-1300 grams by approximately 60 weeks of age.

Table 1 **Comparison of body weight variables among 12 Victorian flocks (2007) – flocks are all housed in controlled environment conditions and are either Strain 1, 2, or 3**

Flock (age)	Ave. body wt. (gms)	Body wt range (gms)	Range/ave. (%)	*Uniformity (%)	#Co-efficient of variation
A1 (3)	191 (190)	143	74.9	69.8	12
A1 (15)	1359 (1370)	645	47.5	82.9	7.6
A1 (35)	2152 (1920)	1050	49	74.6	9.3
A2 (44)	2066 (1920)	1300	62	63.9	11.7
B1 (3)	290 (202)	111	38.3	76.4	8.5
B1 (16)	1532 (1380)	570	37.2	84.2	7.1
B1 (33)	1974 (1888)	870	44.1	80	8.2
B1 (63)	2144 (1975)	990	46.2	74.0	8.8
B1 (84)	2334	1080	46.3	64.4	10.7
B2 (42)	2153 (1935)	980	45	70	9.5
C (16)	1440 (1430)	430	29.9	86	7.1
D1 (18)	1393 (1500)	1230	88	33	21
D1 (31)	1835 (1875)	820	44.7	82	8.2
E (21)	1714 (1705)	730	42.5	71.8	9.6
F (21)	1688 (1705)	600	35.5	80	7.7
G (22)	1808 (1760)	770	42	69	9.5
H1 (25)	1771 (1815)	680	38.4	78	8.1
H1 (34)	1989 (1890)	1350	68	70.4	11.2
J (38)	1976 (1910)	950	48	79	9
K (40)	1771 (1920)	880	49.7	67	10.5

* Uniformity – percentage of birds within plus or minus 10% of the average body weight.
# Co-efficient of variation of body weight – standard deviation/average expressed as a percentage.

Age is in weeks.
Flocks with the same letter and number are the same flock sampled at different ages.
Flocks with the same letter but a different number are different flocks from the same farm.
Breed standard body weight is provided in parentheses.

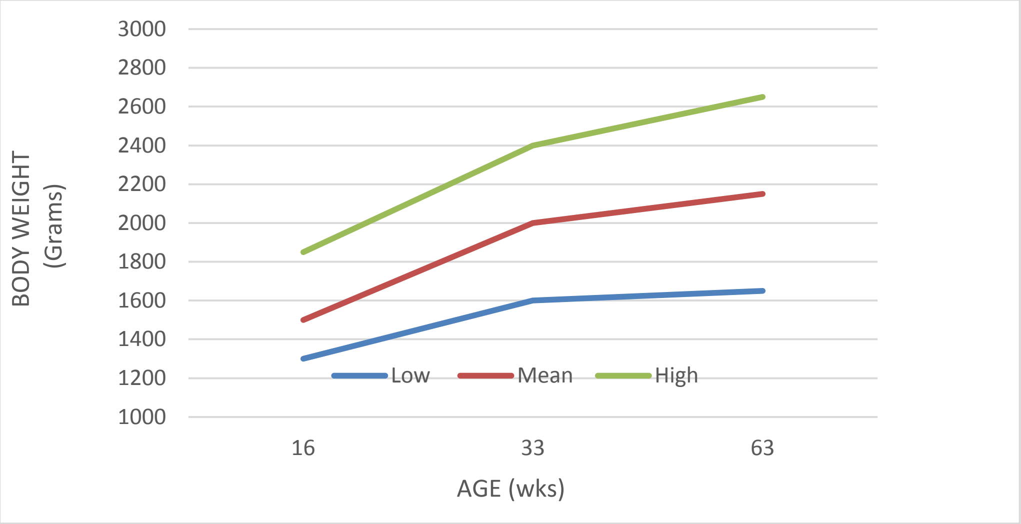


Figure 1 Schematic of the growth rates and total body weight variation of commercial caged flocks between 2005 and 2007 (Parkinson et al., 2007)

High equates to largest, and low the smallest birds in the body weight distribution.

Mathematical and biological studies indicated that the negative effects of excessive weight in flocks are: loss of feed efficiency (200 grams additional live weight equates to an additional feed intake of 5-6 grams per bird per day) plus additional feed partitioned by birds to large eggs, larger eggs with lower ovulation rates, much larger eggs with lower shell strengths, and possibly loss of birds with excessive fat accumulation and fatty liver syndromes.

Proposed outcomes of the new Research Proposal, which commenced in 2011 were to move beyond defining the problem, to find managerial approaches to capture these economic losses and improve production efficiency, through:

- documentation of industry practice in various states with respect to achievement of flock uniformity
- developing Industry guidelines for best practice flock uniformity at a farm level
- stimulating improvements in persistency by 5% and longevity by 20% (10 weeks)
- stimulating improvements in both peak production (1-2%) and persistency of production (5%)
- stimulating the adoption of a long term feed efficiency strategy within the industry by progressively lowering mature body weights.

The project conducted an epidemiological survey of commercial flocks to ascertain correlations between flock uniformity, management and husbandry. Selective experimental investigations were conducted to verify aspects of the broader production process that were found, in the survey, to be critical to the achievement and maintenance of flock uniformity. Equipment available for testing carcass composition (fatness, skeletal integrity) was investigated in some small-scale preliminary studies.

The researchers have attempted to engage with elite producers around the concepts of lowering flock average weights, and were directed by the collaborating producers with regards to the experimental design, relevant to their concerns/constraints of adopting these ideas. One elite producer was very adventurous and the other interested but more constrained. Since completing this report a third elite producer has been identified who has adopted the lighter average bird strategy with very good success, completely independent of these researchers.

2 Objectives and methodology

2.1 Objectives and outcomes

The stated objectives and the outcomes (in bold) arising from the project are listed below:

- To increase the economic longevity of first cycle flocks from the current 72 weeks until 80-85 weeks by sustaining egg production and shell quality and colour.
  - Not achieved across large parts of the industry.
  - **Mechanisms to improve flock persistency and shell quality have begun to be identified but require ongoing extension of concepts to industry**.

- To investigate the relationship between husbandry practices and body weight management (flock uniformity) on shell quality.
  - Objective achieved with these studies and in EPRID Project No.1, 2007.
  - **A relationship has been established between large body size, obesity and low shell percentage/thickness.**

- To review indicators and benchmarks for flock uniformity in rearing and production to improve persistency and longevity in egg production.
  - Objective achieved.
  - **A comprehensive set of data has been generated that describes the uniformity standards across industry and has consolidated current industry best practice.**

- To provide guidelines on managing the genotype-phenotype interaction within production systems.
  - Objective only partially achieved.
  - **Elite production performance has been identified in some experimental models that exceeds current industry practice, and the causal environmental factors have been in part described.**

- To improve standardisation of industry wide performance.
  - Objective beginning to be achieved.
  - **The project has generated significant interest by elite producers in measurements of growth, uniformity, and feed intake patterns.**

- To establish an objective system for continuous improvement of feed efficiency by lowering body mass but maintaining egg mass output.
  - Objective achieved.
  - **The biological and mathematical models described in the research provide a mechanism for significant and continuous improvements in feed efficiency in the medium term.**

2.1.1 Major outcomes of the proposed research

- Industry participation in the project
- A user-friendly report
- Industry guidelines on achieving flock uniformity
- Training activities for Industry
- Improvements in both peak production (1-2%) and persistency of production (5%)
- Extend flock longevity by 10-20 weeks
- Stimulate the adoption of a feed efficiency strategy within the industry by lowering mature body weights

2.2 Experimental methods

The first six months of the project were spent in consultation and extension activities in relation to the existing data from Dr Parkinson’s previous studies in this field. The researchers consulted with representatives of the major breeding companies, large layer facilities, small layer facilities, and industry representative bodies. Key nutritionists were consulted on the epidemiological analysis, and strategic support was sought from the AECL Industry Consultative Committee.

A protocol was developed for monitoring uniformity in commercial flocks of pullets and layers. The uniformity standards were determined using the traditional method of expressing the percentage of the subsample distributed within plus or minus 10% of the average body weight or recommended body weight. The sample size ranged from 100-200 birds weighed individually, and a range of sample sizes was necessary to take account of the capacity for data collection on farm. The intention was to actively involve industry personnel in the gathering of data for the project.

Later, more detailed investigations were introduced to monitor skeletal integrity and body fat composition. The types of equipment that have been used in the past in the field are now no longer available (often for safety reasons) and have been replaced by portable X-ray equipment more suitable for use by veterinarians. Therefore, a CT scanner available at UNE was used for these evaluations.

Our initial focus was on large-scale cage layer operations and free-range operations where problems with uniformity tend to be greater. Hatcheries and breeder farms were incorporated into the study where appropriate. The project attempted to “tease out” correlations among body weight uniformity, and factors such as economic indicators, mortality, performance, egg quality, skeletal size and integrity and level of fatness.

Experiments were conducted on-farm and in experimental facilities at UNE.

2.3 Communications/adoption/commercialisation strategy

The project incorporated industry personnel as active participants, so the project itself incorporated investigation and adoption. The knowledge obtained from this project has been presented at industry and scientific meetings, and published in the Final Report. This will be extended to scientific journals and industry publications. Industry extension activities will be undertaken to disseminate the knowledge gained from the project by liaison between the investigators and the AECL Extension Officer.

2.4 Experimental structure

Initial Epidemiological Studies on Caged Commercial Farms (Chapter 3).

- Aim: To evaluate the average growth patterns of commercial flocks compared to historic data collected between 2005 and 2007 (EPRID No. 1, 2007), and to validate the problems of excessive weight gain in caged flocks.

Experimental study of a caged commercial flock graded into different weight categories at point of lay (Chapter 3).

- Aim: To evaluate the impact of a broad range of body weights on production performance in an elite commercial cage facility.

Laboratory model of three different weight categories undertaken in caged birds at UNE (Chapter 3).

- Aim: To validate the impacts of a range of body weights on production performance for birds housed in single bird cages, which mimicked the weight ranges of the earlier commercial farm study, and to utilise these birds in detailed carcass analysis studies.

Carcass Analysis of light, medium and heavy birds from UNE Experimental Study (Chapter 3).

- Aim: To develop some new methodologies for defining carcass composition in relationship to body weight and productive capacity.

Managerial Interventions to align flock body weight to breed standards on caged commercial farms (Chapter 4).

- Aim: To introduce some managerial interventions to align flock growth rates with existing breed standards and to evaluate the productive consequences in a commercial environment.

Mathematical modelling of metabolisable energy requirements and feed intakes (Chapter 5).

- Aim: To develop mathematical models that enable feed efficiency gains to be calculated on farm, which predict the responses to production with lighter and heavier flocks.

Modified free choice or sequential feeding (Chapter 6)

- Aim: To model the production impacts of lighter flocks achieved by sequential feeding on production outcomes in a commercial environment.

Epidemiological studies of free range flocks (Chapter 7)

- Aim: To evaluate the average growth and uniformity patterns of commercial free range flocks, and compare these to patterns observed for cages.

3 Results

3.1 Initial epidemiological studies of caged commercial farms

Aim: To evaluate the average growth patterns of commercial flocks compared to historic data collected between 2005 and 2007 (EPRID Project No. 1, 2007), and to validate the problems of excessive weight gain in caged flocks.

In the initial phases of the research, reliable data on flock average weight were able to be achieved from some 4 commercial cage farms and 8 flocks using sample sizes of 100 to 200 individual birds, between 19 and 60 weeks of age.

These data were accumulated to evaluate the patterns observed in the period 2012 to 2015 compared to the patterns described between 2005 and 2007 in the AECL EPRID Project No. 1.

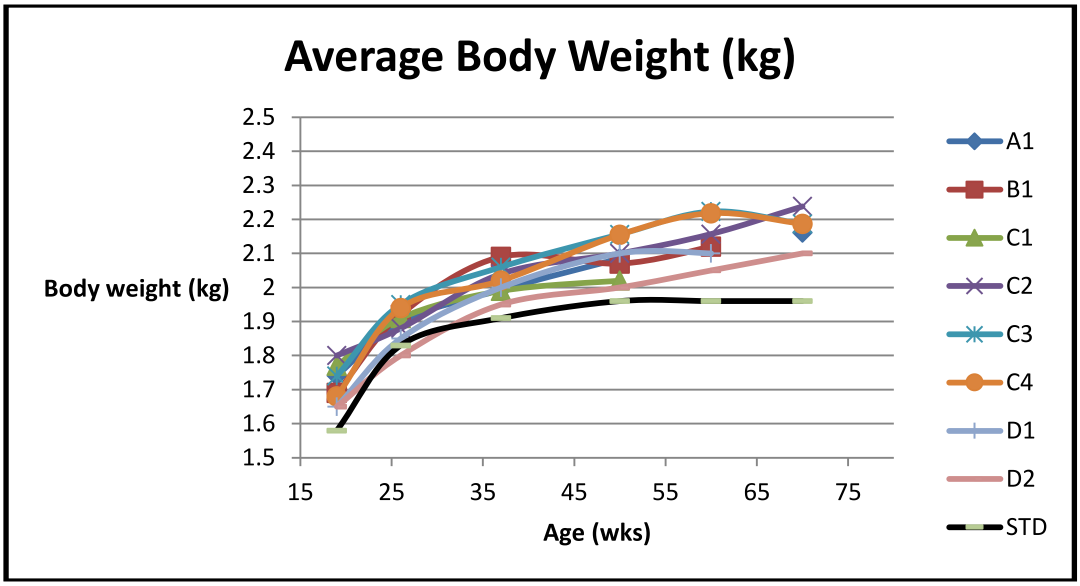


Figure 2 Flock average growth rates for caged birds from 4 farms (A, B, C, D), 8 flocks and both commercial strains

STD (black line) equals breed standard growth pattern.

The pattern observed in the current study aligned very closely with the earlier studies and illustrated a trend toward heavier pullets at 19 weeks than prescribed by the breeder companies (Figure 2). The average growth rate also accelerated after 37 weeks of age, relative to the breed standard, and reflects an increase in the proportion of heavy birds.

As found in the earlier studies, the average body weight ranged from 2.1 to 2.2 kg, which is 200-250 grams above the prescribed breed standard.

3.2 Experimental study of a caged commercial flock graded into different weight categories at point of lay

Aim: To evaluate the impact of a broad range of body weights on production performance in an elite commercial cage facility.

A subsample of birds from a commercial flock of brown egg layers (36,000 birds) was weighed at placement in a layer shed, and divided into 6 groups based on body weight at 16-17 weeks:

Group 1 –	<1.31 kg	(n = 2404)
Group 2 –	1.31 - 1.41 kg	(n = 2399)
Group 3 –	1.41 - 1.50 kg	(n = 2400)
Group 4 –	1.51 - 1.60 kg	(n = 2397)
Group 5 –	1.61 - 1.65 kg	(n = 1189)
Group 6 –	>1.65 kg	(n = 1200)

A total population of 11,989 birds was used in the body weight trial, and another 24,011 ungraded birds were maintained in the same shed. The average body weight of the ungraded birds was 1.552 kg at 17 weeks of age, and 2.161 kg at 72 weeks of age. The uniformity of the ungraded birds was 85.4% and 68.1% at 17 and 70 weeks of age respectively.

The average pullet weight at 17 weeks of age in the body weight trial was 1.50 kg, which is 100 grams above the prescribed breed standard. Birds were housed in 5 bird cages and managed as per normal commercial practice.

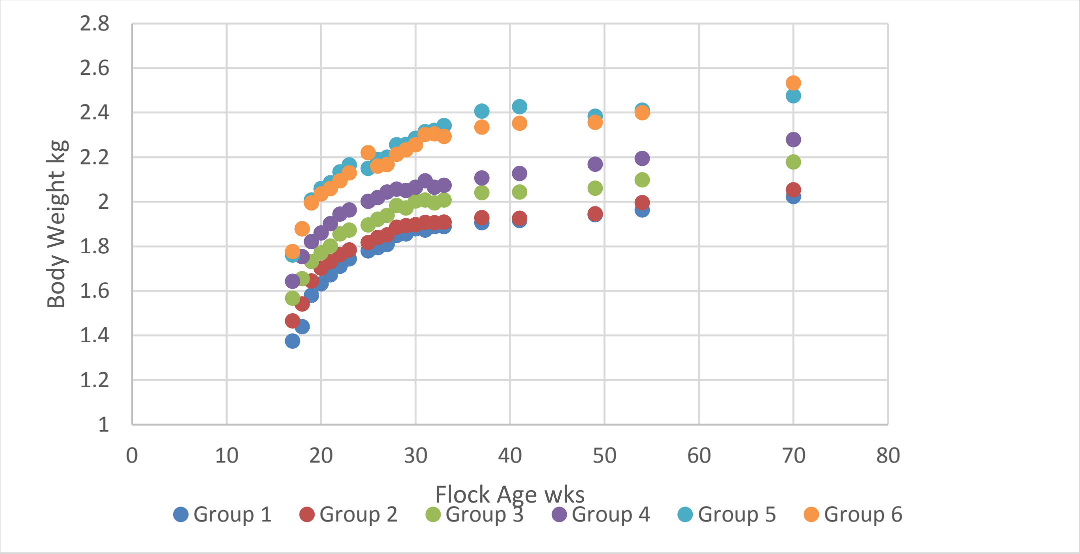


Figure 3 Average growth rate patterns of a commercial flock graded into 6 different pullet weight categories

Group 3 is closely aligned to the growth rate of the average of all 6 weight categories.

The experimental model achieved final weights at 70 weeks of age ranging from 2.0 to 2.55 kg and effectively simulates the weight range of the heavier part of the weight distribution in most commercial flocks (Figure 3). This model does not describe the lower part of the flock distribution from 1.5 kg to 2.0 kg.

Table 2 Average mortality of the 6 body weight categories and the ungraded flock, between 17 and 60 weeks of age

Weight category (kg)	Mortality (%)
Group 1 <1.31 kg	3.8
Group 2 1.31-1.40	2.6
Group 3 1.41-1.50	2.0
Group 4 1.51-1.60	3.1
Group 5 1.61-1.65	1.9
Group 6 >1.65	3.9
Ungraded	4.2

The average mortality for the ungraded flock was slightly greater that the 6 graded pullet weight groups, and there was a trend to higher mortality in both the smallest and heaviest body weight categories (Table 2).

Uniformity was determined using the traditional method of expressing the percentage of the 100-bird sample distributed within plus or minus 10% of the average body weight.

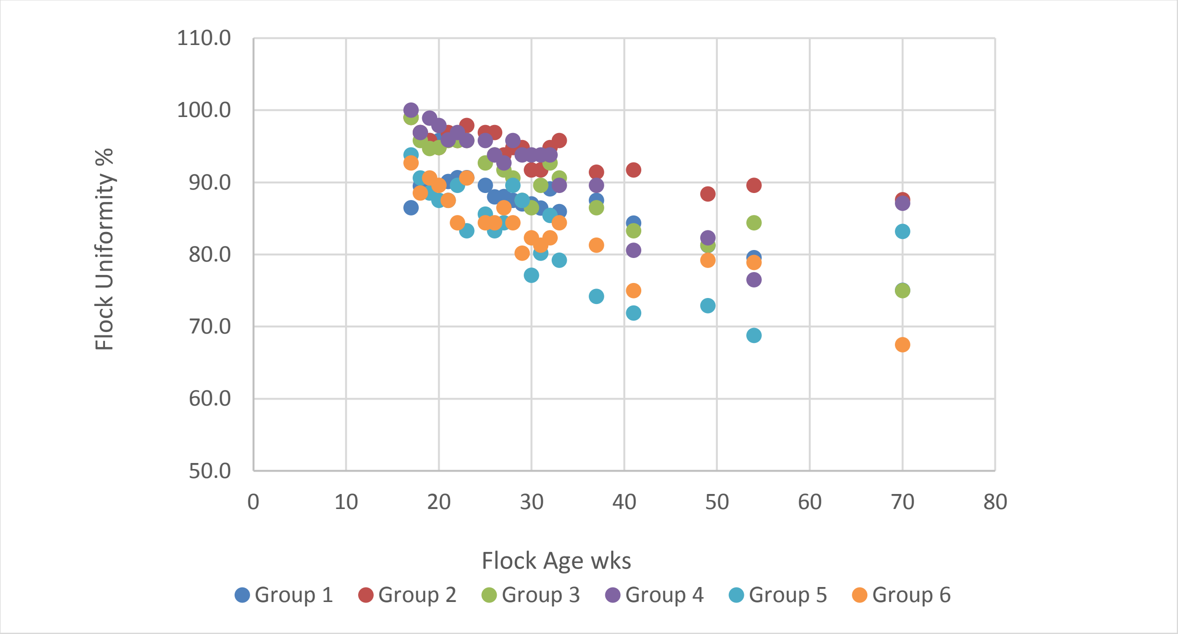


Figure 4 Average uniformity patterns of a commercial flock graded into 6 different pullet weight categories, by flock age

Group 3 is closely aligned to the average of all 6 weight categories.

Very uniform flocks that have an average mature weight of 2.0-2.1 kg (Groups 1 and 2) (Figure 4) can achieve peak egg production of approximately 96-98%, and production of 85% at 70 weeks of age (Figures 5, 6), with an average egg weight of about 61 grams (Figures 7, 8).

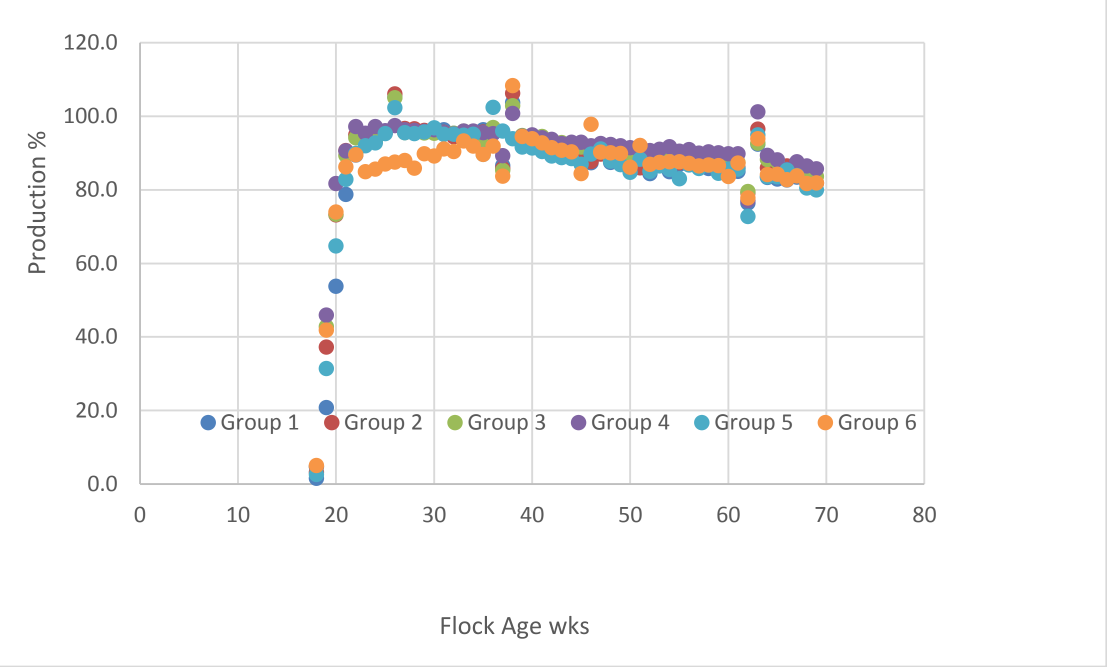


Figure 5 Egg Production patterns of a commercial flock graded into 6 different pullet weight categories, by flock age

Group 3 is close to the average of all 6 weight categories.

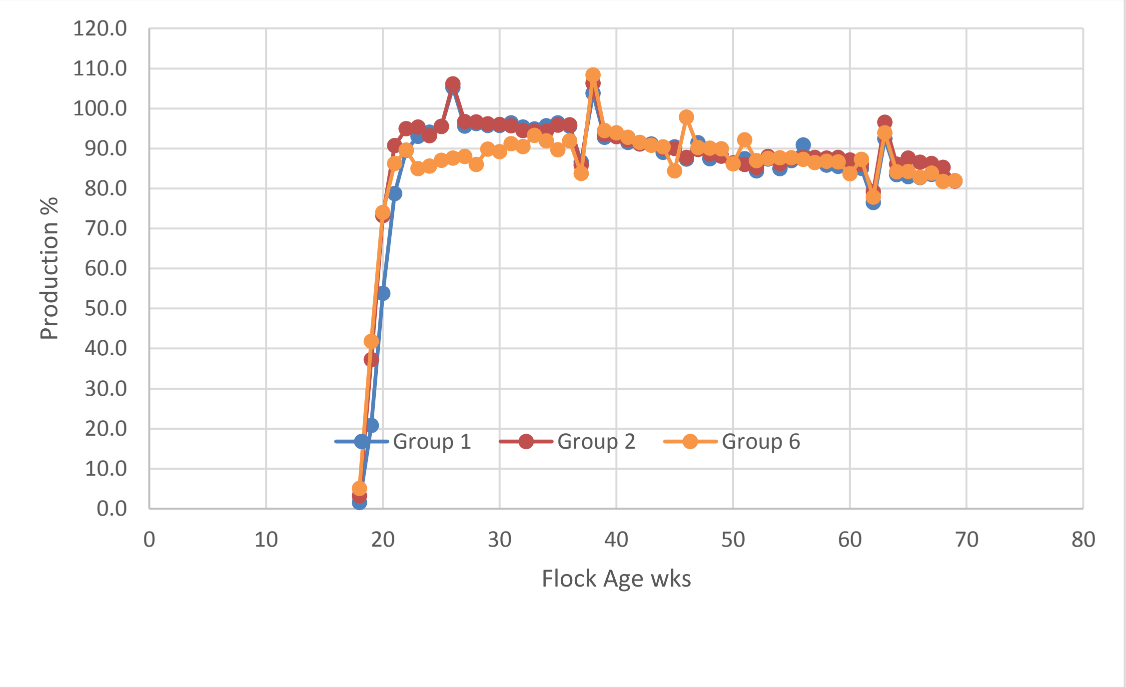


Figure 6 Egg production patterns of a commercial flock graded into 3 different divergent pullet weight categories, by flock age

Groups 1 and 2 plus the heaviest group, Group 6.

The extreme heavy group (Group 6) had a markedly compromised peak production and lower persistency than the lighter groups (Group 1 and 2) (Figures 5, 6).

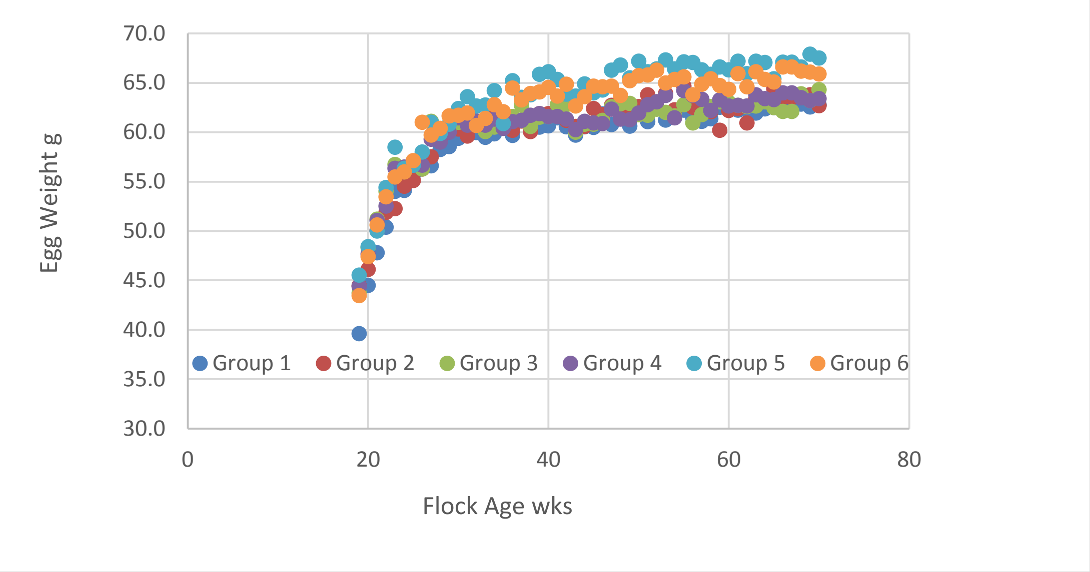


Figure 7 Average egg weight patterns of a commercial flock graded into 6 different pullet weight categories, by flock age

Group 3 is closely aligned to average of all 6 weight categories.

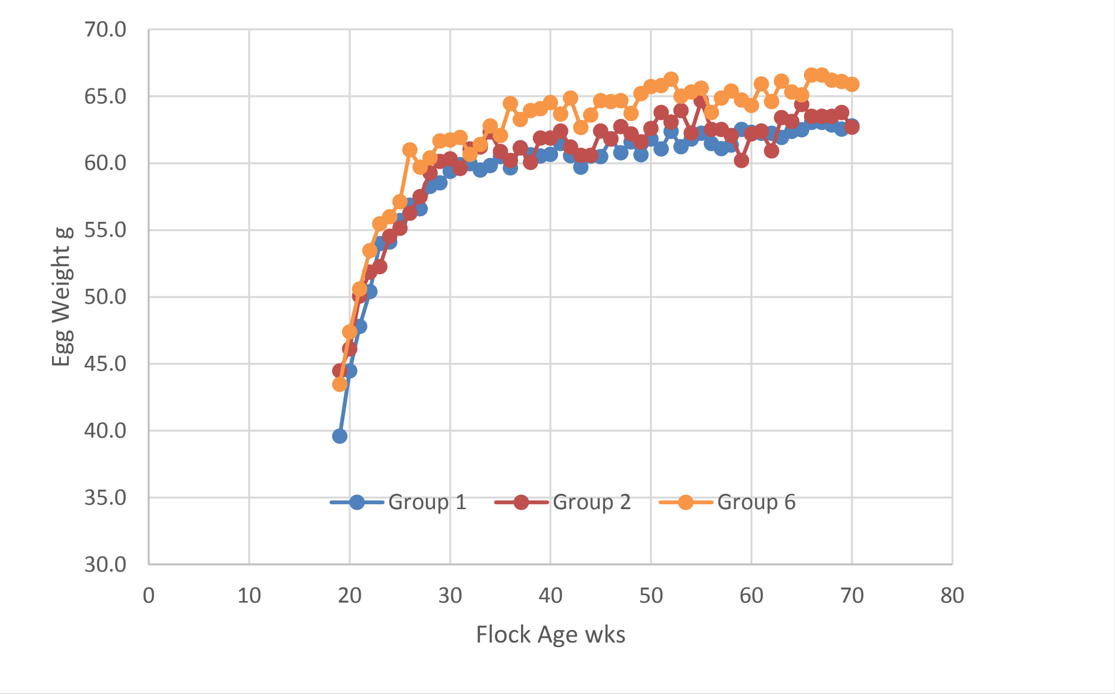


Figure 8 Average egg weight patterns of a commercial flock graded into 3 different divergent pullet weight categories, by flock age

Groups 1 and 2 plus the heaviest group, Group 6.

The average egg weight is 5-6 grams heavier for Group 6 than Groups 1 and 2 (Figures 7, and 8), and the average body weight increased from 2.0 kg to 2.55 kg (Figure 3). The increase in body weight appears to produce a linear increase in average egg size.

Overall, the data suggest that the heaviest birds, with a pullet weight greater than 1.65 kg at 17 weeks and a mature weight of 2.55 kg at 72 weeks, have a markedly compromised egg production. This suggests that the ideal threshold weight for maximum egg production is less than 2.55 kg. Birds with a pullet weight of <1.32 to 1.41kg, mature weights of 2.0 kg and a uniformity of 100% achieved sustained peak production of 96-98%, and maintained production at above 87-88%% to 70 weeks of age.

3.3 Laboratory model of three different weight categories undertaken in caged birds at the University of New England

Aim: To validate the impacts of a range of body weights on production performance for birds housed in single bird cages, which mimicked the weight ranges of the earlier commercial farm study, and to utilise these birds in detailed carcass analysis studies.

To more precisely examine the growth and uniformity patterns identified in the experimental study from the commercial farm (described in Chapter 3.2), birds were sourced from a commercial producer, and selected on the basis of body weight and carcass characteristics and graded into body weight groups in single bird cages. Twenty birds were allocated to each weight category to make a total of 60 birds in single bird cages.

The groups of low, medium and heavy pullets were fed a conventional density diet in conventional shedding, and attempts were made to simulate or mimic the weight categories recorded for the trial undertaken on the commercial farm.

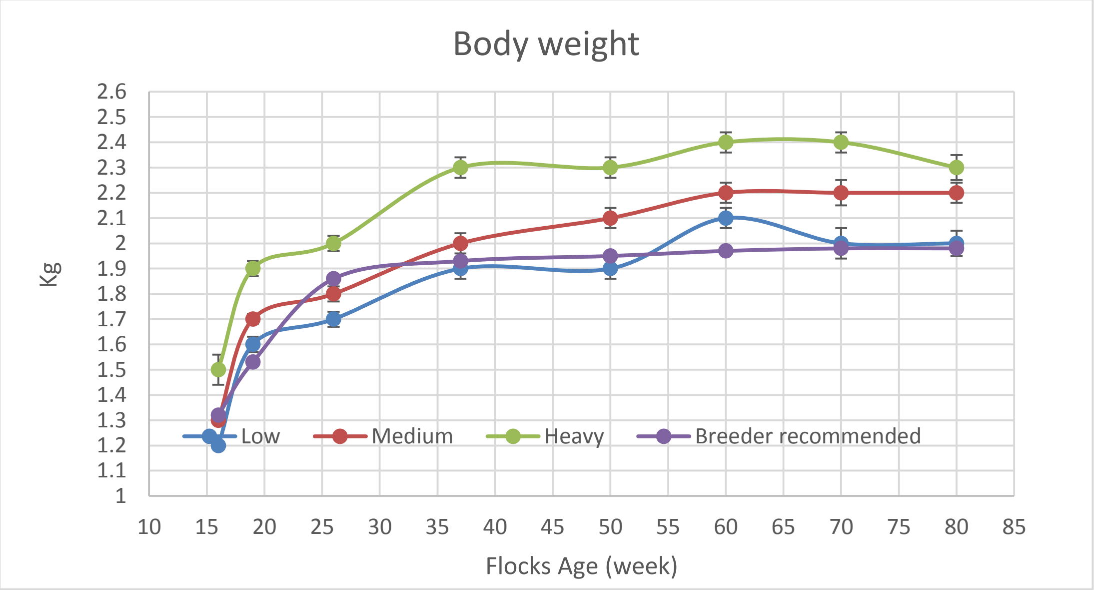


Figure 9 Average growth rates of low, medium and heavy body weight groups between 16 and 80 weeks of age

N=20 per weight group.
Breed standard is shown as the purple line.

Table 3 Body weight uniformity of body weight groups from age 16 to 80 weeks (as a percentage)

Body weight groups	Flock Age (wks)							
	16	19	26	37	50	60	70	80
Low	100	90	80	85	83	75	61	67
Medium	100	100	80	75	80	75	70	80
Heavy	95	90	95	90	89	84	84	84

The marked deterioration of uniformity percentage in the low group may be attributable to the inadvertent period of water deprivation at 43-45 weeks of age.

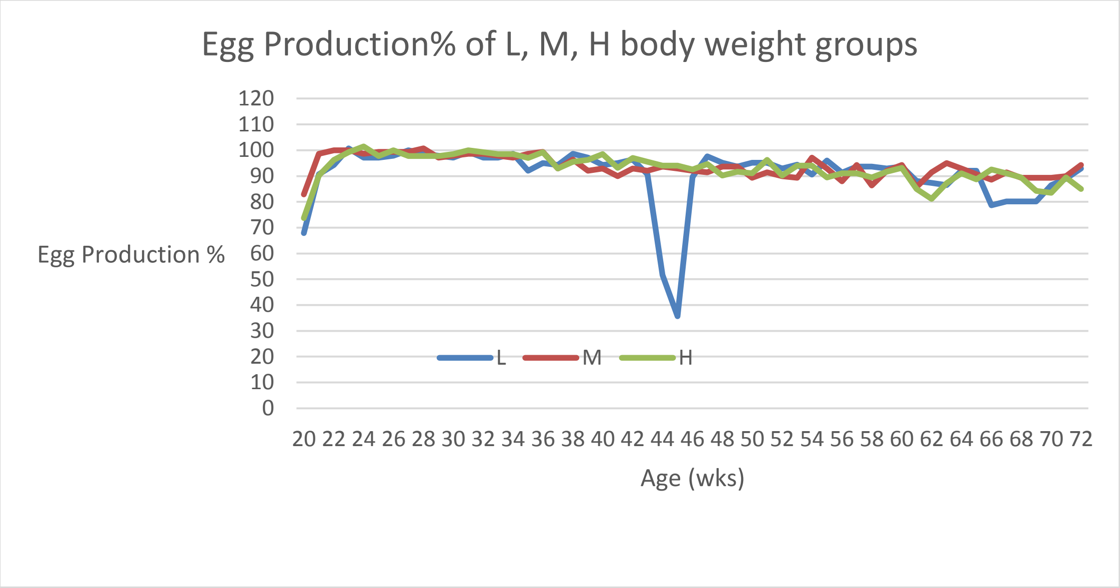


Figure 10 Egg production (Hen Day %) of the low, medium and heavy body weight groups

The marked deterioration of egg production percentage in the low group may be attributable to the inadvertent period of water deprivation at 43-45 weeks of age.

Table 4 Egg production (Hen Day %) for low, medium and heavy body weight groups

Flock Age	Light	Medium	Heavy	Flock Age	Light	Medium	Heavy
20 wk	67.9	82.9	73.7	51 wk	95.2	91.4	96.2
21 wk	90.7	98.6	90.2	52 wk	92.9	90.0	90.2
22 wk	94.3	100.0	96.2	53 wk	94.4	89.3	94.0
23 wk	100.7	100.0	99.2	54 wk	90.5	97.1	94.0
24 wk	97.1	98.6	101.5	55 wk	96.0	92.9	89.5
25 wk	97.1	99.3	97.7	56 wk	91.3	87.9	91.0
26 wk	97.9	99.3	100.0	57 wk	93.7	94.3	91.0
27 wk	100.0	99.3	97.7	58 wk	93.7	86.4	89.5
28 wk	98.6	100.7	97.7	59 wk	92.9	92.1	91.7
29 wk	97.9	97.1	97.7	60 wk	93.7	94.3	93.2
30 wk	97.1	97.9	98.5	61 wk	88.1	85.7	85.0
31 wk	99.3	98.6	100.0	62 wk	87.3	91.4	81.2
32 wk	97.1	98.6	99.2	63 wk	86.5	95.0	87.2
33 wk	97.1	97.9	98.5	64 wk	92.1	92.9	91.0
34 wk	98.6	97.1	98.5	65 wk	92.1	90.7	88.7
35 wk	92.1	98.6	97.0	66 wk	78.6	88.6	92.5
36 wk	95.0	99.3	99.2	67 wk	80.2	91.4	91.0
37 wk	94.3	92.9	92.9	68 wk	80.2	89.3	89.5
38 wk	98.6	96.4	95.5	69 wk	80.2	89.3	84.2
39 wk	97.1	92.1	96.2	70 wk	86.5	89.3	83.5
40 wk	94.3	92.9	98.5	71 wk	88.9	90.0	89.5
41 wk	95.0	90.0	93.2	72 wk	92.9	94.3	85.0
42 wk	96.4	92.9	97.0	73 wk	91.3	88.6	87.2
43 wk	90.7	92.1	95.5	74 wk	89.7	94.3	82.7
44 wk	51.6	93.6	94.0	75 wk	87.3	87.9	83.5
45 wk	35.7	92.9	94.0	76 wk	88.9	89.3	89.5
46 wk	89.7	92.1	92.5	77 wk	90.5	85.7	82.7
47 wk	97.6	91.4	94.7	78 wk	90.5	90.7	84.2
48 wk	95.2	93.6	90.2	79 wk	90.5	82.1	76.7
49 wk	93.7	93.6	91.7	80 wk	85.7	80.7	69.0
50 wk	95.2	89.3	91.0				

N=20 birds per group in single bird cages.

Throughout the entire production phase, one egg was collected weekly from each bird in each body weight group and average egg quality traits calculated. Table 5 shows the average egg quality values for the three body weight groups, for all weeks combined.

Table 5 Shell quality and internal quality assessments for the three body weight groups, for all ages combined

Measurement	Low	Medium	Heavy	P value
Shell Quality				
Translucency Score (after Stain)	2.6±0.02^{a}	2.4±0.02^{c}	2.5±0.02^{b}	<0.0001
Shell Reflectivity %	25.19±0.11^{c}	27.91±0.13^{a}	26.42±0.12^{b}	<0.0001
Egg Weight g	59.5±0.2^{c}	61.8±0.2^{b}	63.7±0.2^{a}	<0.0001
Breaking Strength N	40.6±0.2^{a}	38.6±0.2^{b}	38.8±0.0 ^{b}	<0.0001
Deformation µm	282.3 ±1.7^{a}	265.5±1.3^{b}	267.1±1.2^{b}	<0.0001
Shell Weight g	5.5±0.02^{c}	5.6±0.02^{b}	5.7±0.02^{a}	<0.0001
Percentage Shell %	9.2±0.03^{a}	9.1±0.03^{b}	8.9±0.03^{c}	<0.0001
Shell Thickness µm	394.6±1.0^{a}	392.4±0.9^{a}	389.8±1.0^{b}	=0.0005
Internal Quality				
Albumen Ht mm	8.8±0.04^{b}	8.9±0.05^{b}	9.1±0.04^{a}	<0.0002
Haugh Unit	93.7±0.2^{a}	93.2±0.2^{b}	93.7±0.3^{a}	ns
Yolk Colour Score	9.7±0.05^{c}	9.9±0.04^{b}	10.0±0.04^{a}	<0.0001

^{a,b,c} Across a row, values with different superscripts are significantly different from each other.
Values are Means ± SE.
ns not statistically significant.

The shell thickness of all three body weight groups was plotted from 19-80 weeks of age (Figure 11).

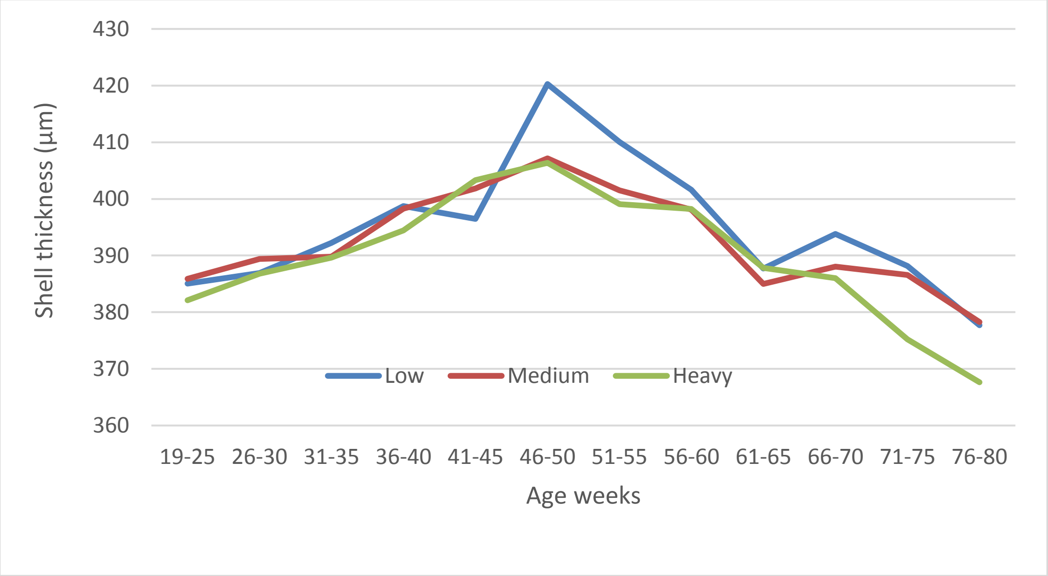


Figure 11 Eggshell thickness from the low/light, medium and heavy body weight groups

The shift in shell thickness for the low group at 46-50 weeks of age may be a consequence of the water deprivation between 43 and 45 weeks, and the lower production in this period (Figure 10 and Table 4).

Overall, the low body weight group with very high uniformities achieved very high peak production (100%) and very good persistency of production (90%) at 72 weeks of age despite an accidental period of water deprivation between 43 and 45 weeks of age (Figures 9,10; Tables 3, 4).

The low body weight group also had the best shell quality (Table 4 and Figure 11) with a slightly smaller average egg size than the medium body weight group (59.5 vs. 61.8 grams).

The body weight patterns in the experimental trial at UNE expanded the range of weights able to be systematically assessed to less than 2.0 kg, and more closely assessed the treatment group (Low) that was at or slightly below the existing breeder recommendations.

Very high peak egg production was achieved in the low body weight birds between 25 and 30 weeks of age in birds averaging 1.7-1.8 kg, well below the established breed standards (Figures 9, 10 and Table 4).

3.4 Carcass analysis of light, medium and heavy birds from the University of New England experimental study

Aim: To develop some new methodologies for defining carcass composition in relationship to body weight and productive capacity.

From the 60 trial birds, 6 birds from each body weight group (low, medium, heavy – a total of 18 birds), weighing 1.87-2.73 kg at 80 weeks of age, were evaluated for fat, lean and mineral (bone).

Live weights were recorded immediately prior to scanning on an electronic weighing scale (VEIT electronics Poultry scale BAT 1) with maximum weight 30 kg, then euthanised using CO_2. Birds were scanned in groups of three. Following CT scanning, the abdominal fat depots were taken out and weighed.

A whole body scan with regular intervals was performed using a GE HiSpeed QXi 4 Slice CT scanner (manufactured June 2003). The acquisition parameters of the CT scanner were as follows: helical scanning120 kV; 140 mA; 5 mm thickness; 5 mm spacing and 1 s scanning time.

The resulting images were analysed using the software programs OsiriX, ImageJ and AutoCAT as described by Haynes and colleagues (Haynes et al., 2010; Fuller et al., 1994; Rosset et al., 2004; McEvoy 2007).

Table 6 Carcass analysis of birds from the 3 body weight groups (low, medium and heavy)

	Low	Medium	Heavy
Measured BW kg	2.149±0.07	2.13±0.07	2.27±0.10
Fat pad g	120±0.01	90±0.02	98±0.02
Predicted CT entire weight (%)			
Fat	16.81±1.03	14.71±1.58	15.99±1.50
Lean	69.97±0.94	71.38±1.39	70.66±1.18
Bone	13.21±0.77	13.92±0.69	13.35±0.52
Predicted CT carcass weight (%)			
Fat	14.15±0.65	13.13±1.19	15.43±1.45
Lean	67.44±0.92	68.16±0.98	66.45±0.97
Bone	18.41±0.91	18.71±0.73	18.12±0.72

N=6 per treatment and total of 18 birds.
“Entire” refers to the whole body of the bird, including viscera.
“Carcass” is the body without viscera.

There was significant correlation between measured body weight and measured abdominal fat pad weight and CT predicted entire percentage fat (Figures 10, 11).

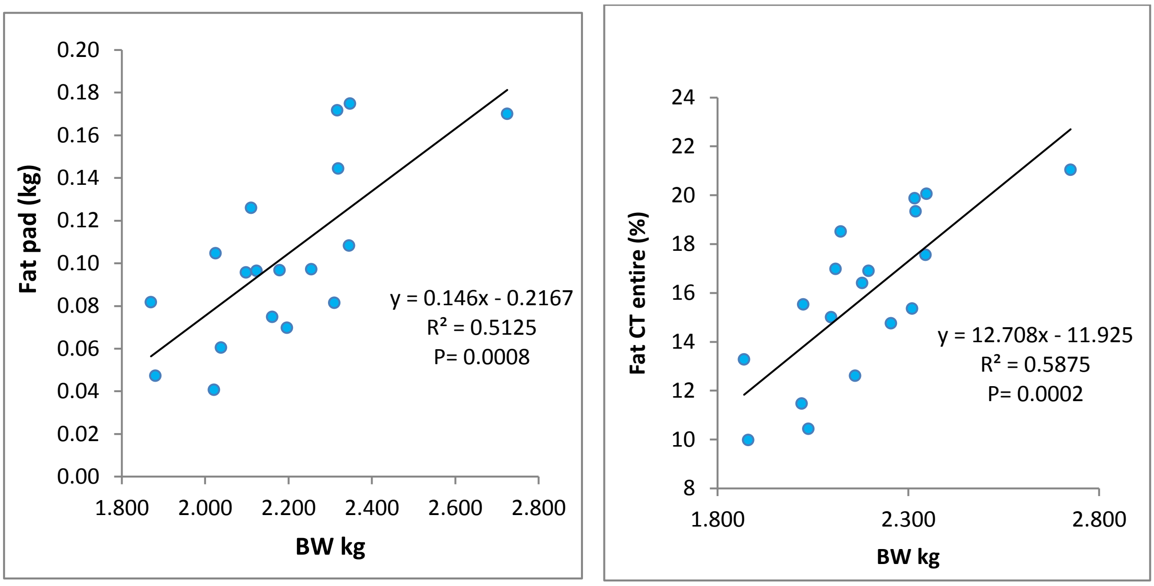


Figure 12 Relationship between body weight and fat pad weight, and entire carcass fat estimated by CT scanner

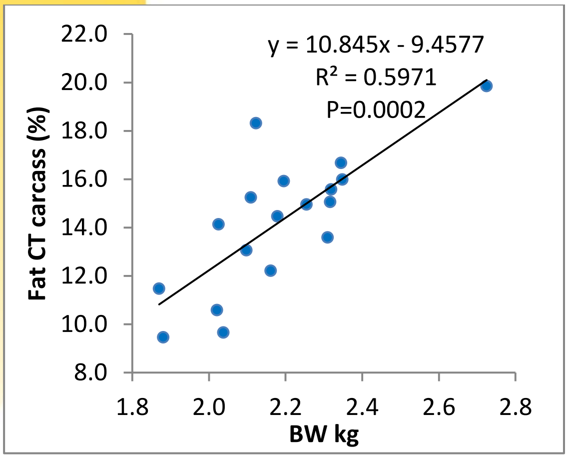


Figure 13 Relationship between body weight and carcass fat estimated by CT scanner

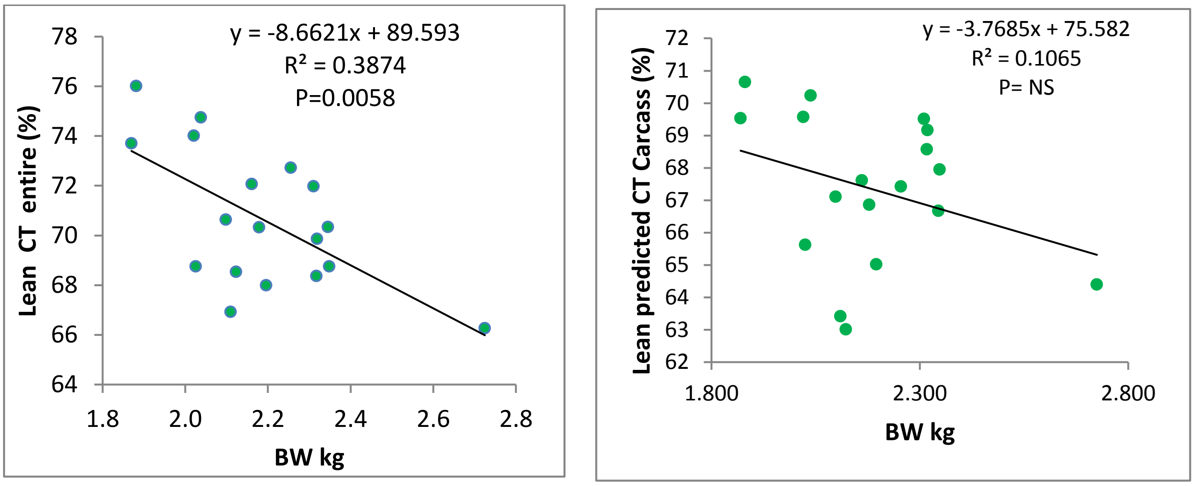


Figure 14 Relationship between body weight and predicted entire lean and predicted carcass lean, estimated by CT scanner

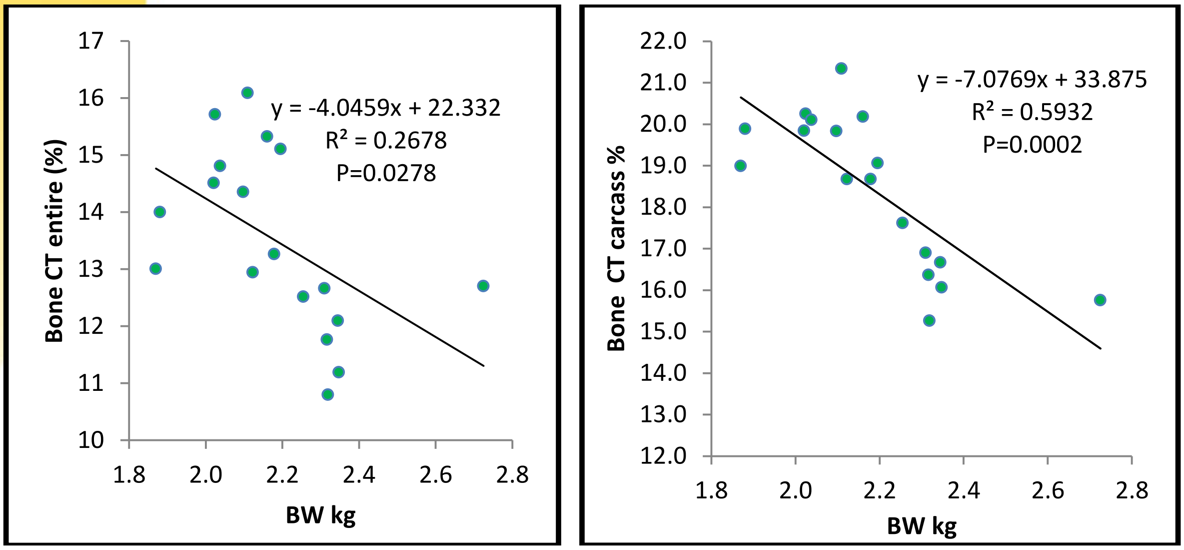


Figure 15 Relationship between body weight and entire bone and carcass bone, estimated by CT scanner

Table 7 Correlation between body weight (kg) and fat pad weight, CT Fat, CT Lean and CT Bone

	Laboratory (UNE)
BW vs. Fat pad	P=0.0008 R^2=0.5125
BW vs. CT Fat entire	P=0.0002 R^2=0.5875
BW vs. CT Lean entire	P= 0.0058 R^2=0.3874
BW vs. CT Bone entire	P= 0.0278 R^2=0.268
BW vs. CT Fat carcass	P= 0.0002 R^2=0.5971
BW vs. CT Lean carcass	P=NS R^2=0.1065
BW vs. CT Bone carcass	P=0.0002 R^2=0.5932
Fat pad vs. CT Fat entire	P<0.0001 R^2=0.7855
Fat pad vs. CT Lean entire	P=0.0004 R^2=0.5476
Fat pad vs. CT Bone entire	P=0.0151 R^2=0.3162
Fat pad vs. CT Fat carcass	P=0.0009 R^2=0.503
Fat pad vs. CT Lean carcass	P= NS R^2=0.1078

For the 18 birds that had been scanned at 80 weeks of age, egg production was able to be correlated with body weight and carcass characteristics (Table 8 and Figure 16). The strongest correlation was with the estimates for entire carcass bone (Figure 16). Carcass bone appears to explain approximately 20% of the variation in total egg production to 72 weeks of age, and there was also a slight negative correlation between total egg production and entire carcass fat estimated by CT scanning (data not presented).

Table 8 Body weight at 80 weeks of age and egg numbers to 72 weeks of age, for the individual scanned birds from all groups

BW kg	Eggs 72
1.873	312
2.151	340
2.335	340
2.354	347
2.127	345
2.161	326
1.997	353
2.185	335
2.391	372
2.335	367
1.887	361
2.053	333
2.258	357
2.718	359
2.088	356
2.12	342
2.161	365
2.397	331
N=18	

N=18 birds.

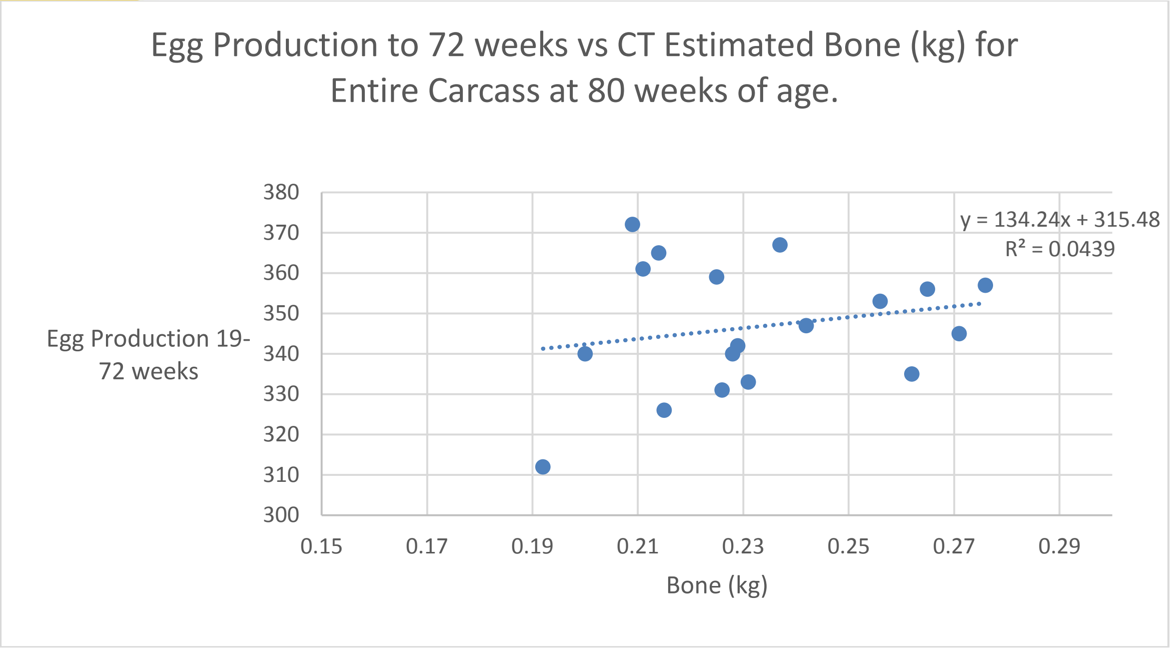


Figure 16 Egg production to 72 weeks vs. CT estimated bone, for entire carcass at 80 weeks of age

The small sample size in these studies constrains the ability to interpret the relationships between body weight, egg production and carcass characteristics, particularly because the sample is restricted to a limited number of birds in the weight range of 1.87 to 2.72 kg (Table 8). These methods need to be applied to larger numbers of birds over a broader weight range of 1.5 kg to 2.8 kg.

A critical analysis will be required to determine the carcass characteristics of the most highly productive and smallest birds. It does seem, however, that this type of CT scanning could be a most useful method for defining the maximum physiological potential of the egg laying fowl, albeit in a retrospective manner.

4 Managerial interventions to align flock body weights with breed standards on caged commercial farms

Aim: To introduce some managerial interventions to align flock growth rates with existing breed standards and to evaluate the productive consequences in a commercial environment.

Two flocks on commercial farms were identified where the body weight was able to be maintained at or below the breeder body weight standards, and that were not subject to the marked loss of uniformity associated with the divergence of the larger birds (Figure 17).

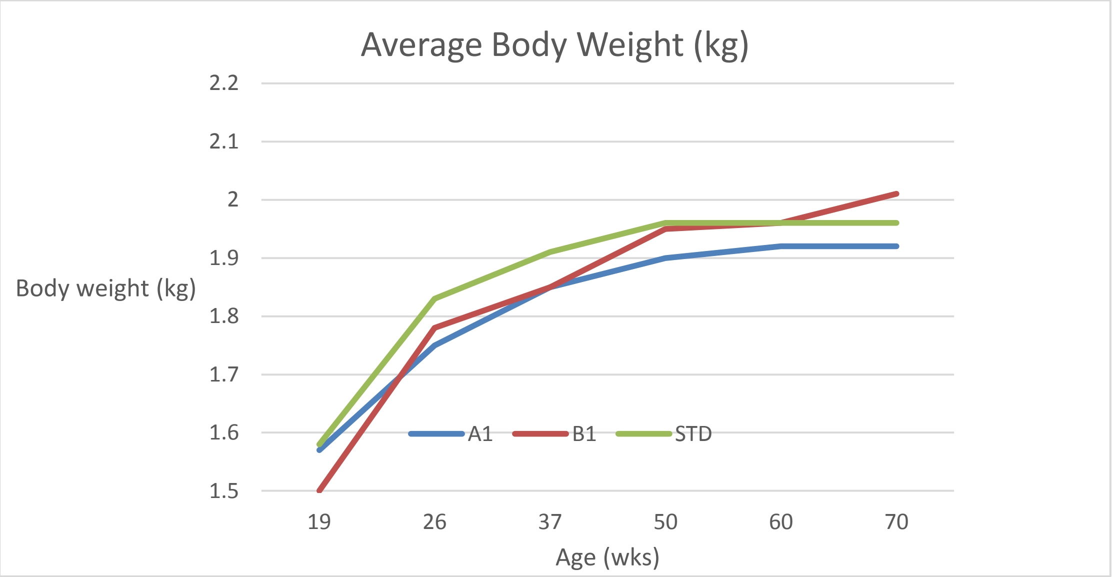


Figure 17 Average growth patterns of 2 flocks from 2 strains (A and B) that align closely or are below breed standards (STD) (2014)

N=100-200 birds weighed.

These two elite flocks, A1 and B1 from different strains, aligned closely with the schematic model proposed that achieves a marked reduction in the proportion of larger obese birds above 2.4 kg live weight (Figures 18, 19). The schematic model represents the likely body weight variation around the recommended average live weight of 1.95 kg (Figure 18).

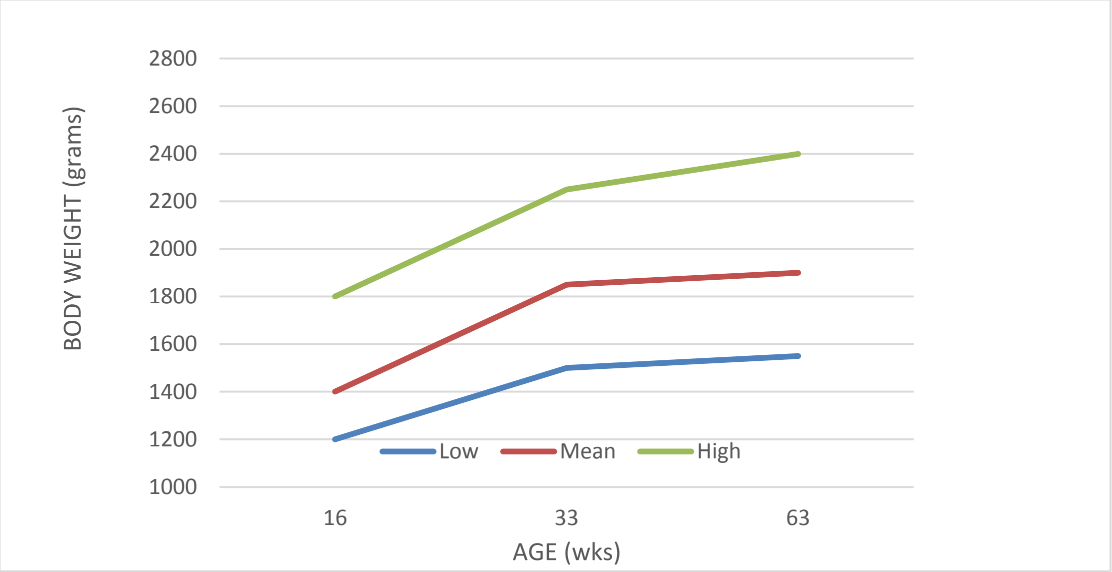


Figure 18 Schematic model designed to simulate the range of body weights in a flock that more closely aligned with the breed body weight standard

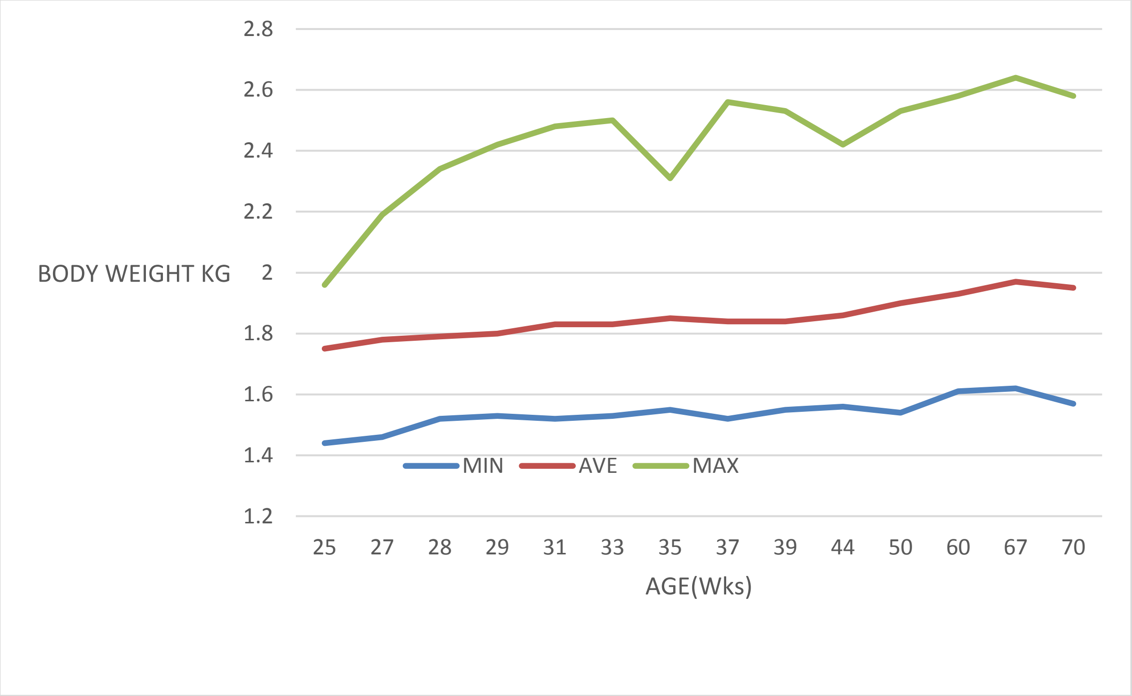


Figure 19 Total weight variation in Flock A1 that involves maximum, minimum and average body weight recorded for 190 birds weighed individually between 25 and 72 weeks of age

Some 38 cages were consistently monitored throughout the trial period from 25 to 72 weeks of age.

The flock uniformity of Flock A1 was at high standards at 25 weeks of age, but the uniformity declined rapidly after this age (Table 9 and Figure 19).

Table 9 Flock uniformity standard from Flock A1 compared to historic uniformity standards for the commercial farm

Age (wks)	Historic Farm Patten (2005)	Flock A1 (2014)
16	84%	n.a.
25	n.a.	87%
33	80%	n.a.
61	n.a.	74%
63	74%	n.a.
67	n.a.	81%
70	n.a.	71%

n.a. data not available.
N=100-200 birds weighed individually.
Uniformity determined by the traditional recommended method described in Chapter 2.2.

The lower average body weight in Flock A1 was associated with a significant reduction in the proportion of birds above 2.4 kg, and uniformity in early egg production (25 weeks) was high relative to historic patterns (Figure 19 and Table 9). Average weight gain increased after 50 weeks of age, which corresponded with a period of extreme hot weather and an increase in diet nutrient density provided to the flock in this period (Figures 17, 19).

The superior weight control in both of these flocks was associated with a marked improvement in the persistency of production relative to the breeder recommendations (Figures 17, 20, 21). For Flock A1, a very high persistent peak production was able to be achieved between 25 and 38 weeks of age at average flock weights between 1.70 and 1.85 kg (Figure 17).

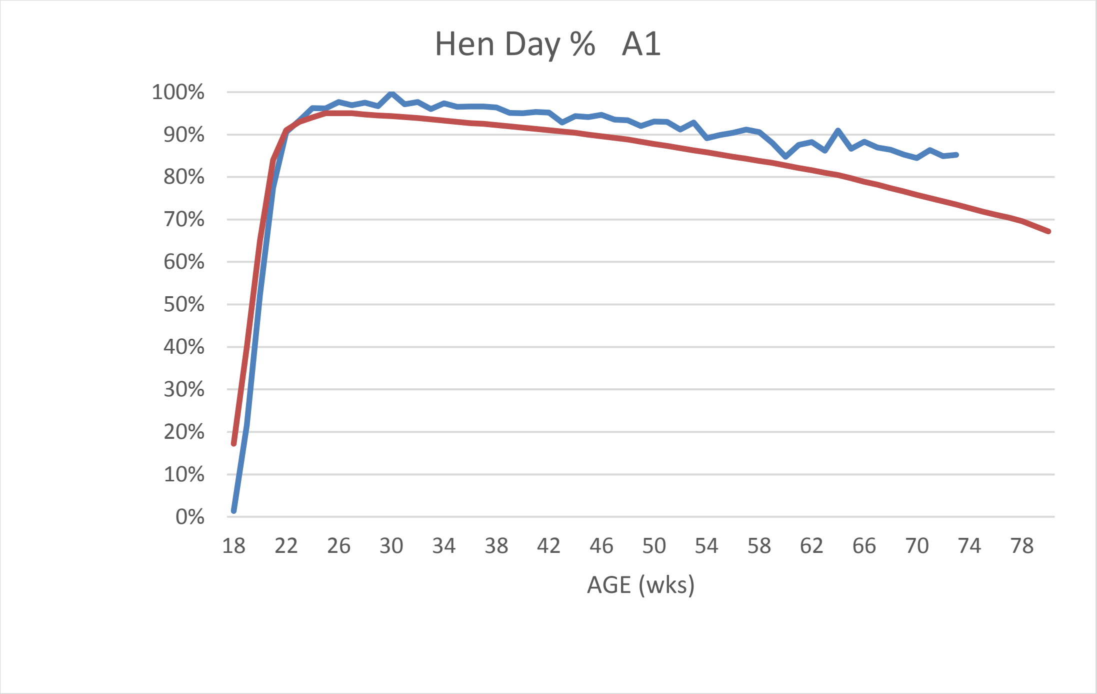


Figure 20 Egg production performance of Flock A1 that had average growth rates below the breed standard

N=performance of 60,000 hens.

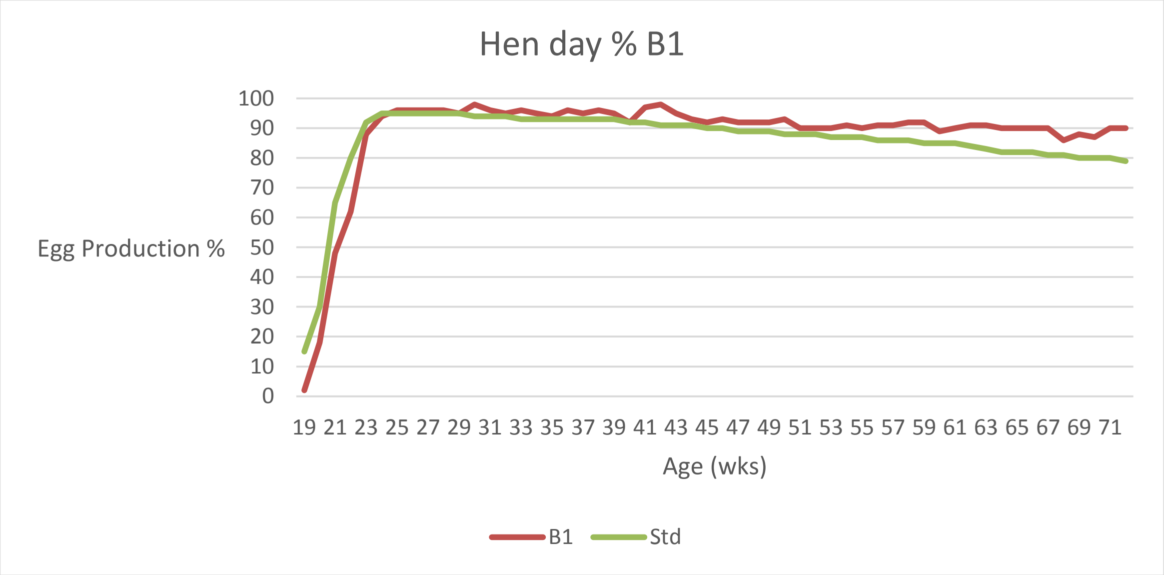


Figure 21 Egg production performance of Flock B1 that had average growth rates aligning with the breed standard

N=performance of 45,000 hens.

Clearly the closer alignment of the flock growth rates achieved by Flocks A1 and B1 was associated with above breeder recommendation for egg production performance, and Flock A1 indicates that body weights 100 grams below the breed standard can still achieve elite performance.

5 Modelling of metabolisable energy requirements and feed intakes for caged flocks

Aim: To develop mathematical models that enable feed efficiency gains to be calculated on farm, which predict the responses to production with lighter and heavier flocks.

During the On-Farm studies it was possible to undertake some modelling of the feed intake patterns to reconcile the actual recorded feed intakes with some predictive models. These techniques provide a valuable tool for predicting the economic advantages of lowering flock body weights and validating the estimated metabolisable energy density of the stockfeed.

Two different equations were applied to different farms and flocks. The initial equation was developed by Connor (1980) and described by Farrell (1984), and the second published in the Hy-Line Management Manual (1998).

5.1 Modelling of energy requirements and feed intake

Equation 1

Connor Equation (1980) $\mathbf{ME = 4.18W^{0.653} \times (1.0 + (0.015 \times 21.3 - T)) + 13.10G + 13.18EM}$

ME = Kj/day or Mj/day
W = Body weight g
T = Temperature $^{\circ}$C
EM = Egg mass g/day
G = Growth g/day

Application of Farm 1 data to the Connor Equation

FARM 1 SHED 2 Strain A Caged birds aged 38-40 weeks of age. Low Body Weight

Body weight = 1850 g
Growth = 0.5 g/day
Egg production = 95%
Egg weight = 60 g
Egg mass = 57.0 g

FARM 1 SHED 3 Strain A Caged birds aged 38-40 weeks of age. Higher Body Weight

Body weight = 2000 g
Growth = 0.5 g/day
Egg production = 94%
Egg weight = 61.4 g
Egg Mass = 57.7 g

Assumption (Farm 1 Sheds 2 and 3): Shed temperature is 23°C.

Metabolisable energy requirement calculations

Shed 2 Low Body Weight
Metaboliseable Energy Requirements

Body weight & growth = 561 Kj
Egg mass = 751 Kj
Total = 1312 Kj

Shed 3 High Body Weight
Metaboliseable Energy Requirements

Body weight & growth = 589 Kj
Egg mass = 760 Kj
Total = 1349 Kj
Energy density of feed = 11.4 Mj/kg

Feed intake calculations

Farm 1 Shed 2 Strain A Low Body Weight
Feed Intakes

ME requirement = 1.312 Mj/bird/day
Predicted = 115.1 g/day
Actual = 115 g/day

Farm 1 Shed 3 Strain A High Body Weight
Feed Intakes

ME requirement =1. 349 Mj/day
Predicted = 118.3 g/day
Actual = 119 g/day

The reconciliation of the predicted and actual daily feed intakes per bird was very precise, with less than 1% error for the Connor Equation applied to Strain A birds and this is consistent with similar analysis undertaken between 1999 and 2007 by the authors on a large range of genotypes.

Equation 2

Hy-Line Equation (1998) ME =W x (140-2T) + 5 G + 2EM

ME = Kcal/day
W = Body weight kg
T = Temperature 0C
EM = Egg mass g/day
G = Growth g/day

Validation Study:

Experimental Model University of Queensland, 2012, using Strain B brown egg layer aged 40 weeks Low Body Weight (Li et al., 2016)

ME = Kcal/day Strain B
W = Body weight kg 1.92 kg
T = Temperature 22 ^{0}C
EM = Egg mass g/day 58.8
G = Growth g/day 1.0 g/day

ME = W x (140-2T) + 5 G + 2EM
ME = 1.92 x (140-2X 22) + 5 x 1.0 + 2x 58.2
ME = 184 + 5 + 116
ME = 305 kcal/bird/day
ME of feed = 2800 kcal/kg
Predicted feed intake = 109 g/bird/day
Actual feed intake = 106-109 g/day

Connor Equation Prediction = 117 g/bird/day for birds with this body weight and egg mass.

The Hy-Line International equation (1998) predicted that the actual feed intakes with much greater precision than the Connor (1980) equation for the experimental model carried out at the University of Queensland in 2012.

An opportunity arose to validate both equations on an additional farm (Farm 2). Data were able to be accumulated on two different strains (A and B), using 3 flocks per strain fed the same diets.

Table 10 Commercial farm studies (Farm 2) comparing strains, body weight and egg mass related to the actual recorded feed consumption versus the predicted feed consumption using the Connor Equation (1980)

Strain	Flock No.	BW (g)	Egg Mass (g)	FI Actual (g)	Predicted (g) Connor Equation
A	60404	2034	60.5	117	118
A	61304	2070	60.4	119	120
A	60303	2079	58.9	112	118
B	60304	2195	60.1	111	122
B	60104	1988	61.2	110	120
B	61405	2096	60.6	108	120

Body weight (BW), egg mass and actual feed intake (FI) recorded at 40 weeks of age.

Clearly the Connor Equation is consistent in predicting feed intake for Strain A, but not for Strain B. There is a very significant error in the prediction for Strain B (Table 10).

Table 11 Commercial farm studies (Farm 2) comparing strains, body weight and egg mass related to the actual recorded feed consumption, versus the predicted feed consumption, using both the Hy-Line International Equation (1998) and the Connor Equation (1980)

Strain	**Flock No.**	**BW (g)**	**Egg Mass (g)**	**FI Actual (g)**	**Predicted (g)**
B	60304	2195	60.1	111	116
B	60104	1988	61.2	110	110
B	61405	2096	60.6	108	111
A Hy-Line Equation	60404	2034	60.5	117	112
A Connor Equation	60404	2034	60.5	117	118

Body weight (BW), egg mass and actual feed intake (FI) recorded at 40 weeks of age.

The predictive equation developed by Connor (1980) seems reliable in estimating the metabolisable energy requirement of the Strain A birds, and this is consistent with historic analysis of biological data undertaken since the late 1990s for a range of different genotypes of laying stock (Tables 10, 11)

The complete analysis illustrates, however, a clear divergence of the Strain B birds, with the Connor equation unable to predict the appropriate ME requirements. The Connor Equation over-predicts ME requirements by approximately 8%. More precise predictions can be achieved in this strain by applying the Hy-Line Equation (1998) where the predicted requirements are more accurately reconciled with the actual recorded energy intakes (Tables 10, 11).

6 Modified free choice feeding or sequential feeding experiment in caged hens

Aim: To model the production impacts of lighter flocks achieved by sequential feeding on production outcomes in a commercial environment.

Research undertaken in Europe using a novel sequential feeding system illustrated that flock average weight was lowered by approximately 11-12% whilst egg production, egg weight and egg mass were maintained at commercial standards (Table 12) (Lescoat et al., 2010)

Table 12 Comparisons of production performance of Strain A birds fed a conventional diet versus those fed a sequential diet with the breed standards (Lescoate, 2010)

	Control	Sequential feeding	Breed STD
Feed Intake g/bird/day	115.2	109.3	n.a.
Wheat g/bird/day	n.a.	49.2	n.a.
Concentrate g/bird/day	n.a.	60.1	n.a.
Egg production %	93.1	93.1	90%
Egg weight g	59.1	58.8	60.9
Egg mass g/day	55.2	55.0	54.8
FCR	2.09	1.99	2.03
Body weight g @ 46 weeks	1823	1723	1950

n.a. data not available.

A commercial cage farm established a trial to reproduce these findings, using the same nutritional design and the same commercial strain, to investigate the prospects for farming with flocks below the breed standard in a commercial environment.

Modified choice feeding or sequential feeding program

Protein/Calcium concentrate and whole wheat feeding.
Diurnal pattern
4:00-8:00 hrs Morning feed: of Protein/Calcium concentrate
8:00-15:00 hrs Mid period: Whole Wheat
15:00-20:00 hrs Evening feed: Protein/Calcium concentrate

Nutrient density of protein concentrate

Crude Protein = 23%
Ash = 22.07
Calcium = 7.20%
Total Phosphorus = 0.76%
ME = 2,380 kcal/kg

Nutrient density of wheat

Crude Protein = 11.90%
Ash = 1.60%
Calcium = 0.03%
Total Phosphorus = 0.32%
ME =3,120 kcal/kg

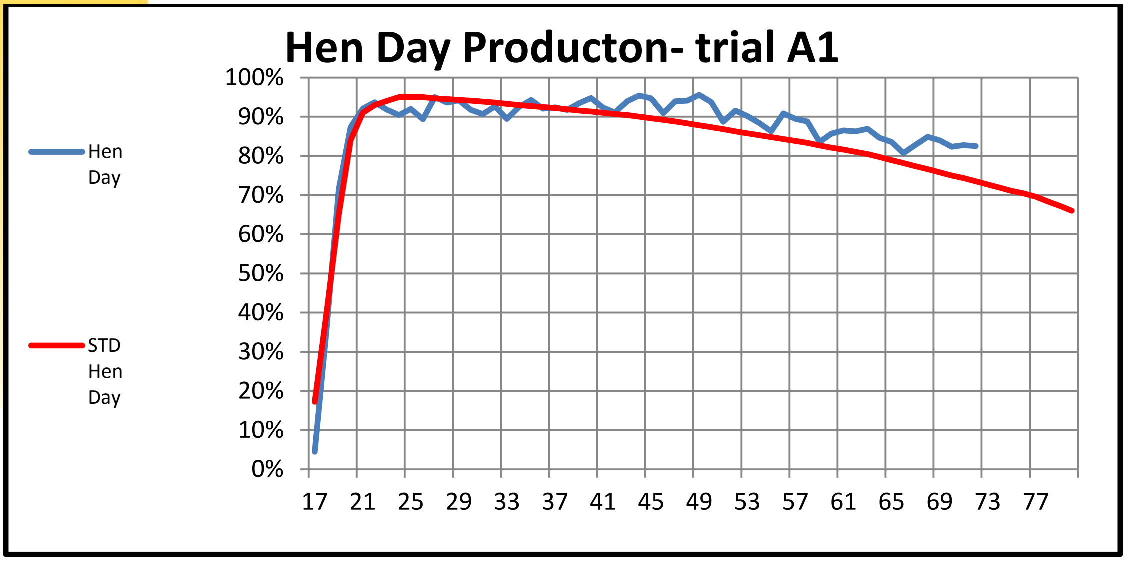
Nutrient density of control diet

Crude Protein =17.52%
Ash = 11.71%
Calcium = 3.61%
Total Phosphorus = 0.53%
ME = 2,750 kcal/kg

Lescoat et al., 2010, described dietary phosphorus levels as total rather than available and the experimental model utilised adopted the same approach.

A trial of sequential feeding on a commercial farm using Strain A was undertaken using two replicates for control diet (A1 and A2) and two replicates (B1 and B2) for sequential feeding. Each treatment group consisted of 500 hens, and body weight was estimated using 80 individual birds.

Figures 22-25 show egg production performance (Hen Day %) from the two dietary treatment and two replicates.



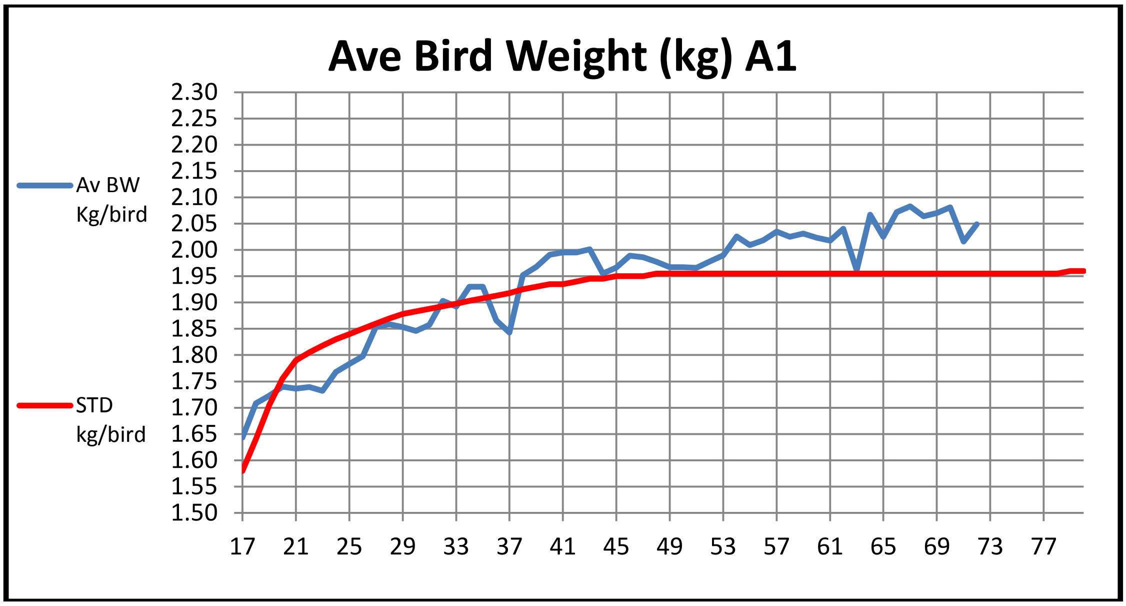
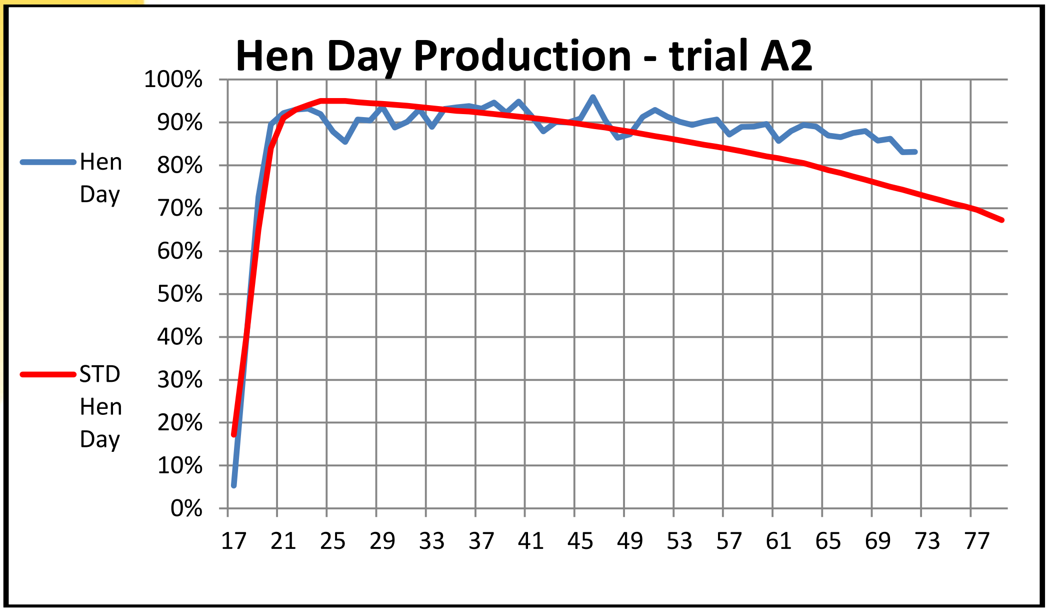


Figure 22 Egg production performance (Hen Day %) and bird weight for control diet A1

N=average of 500 birds.
Body weight estimated from 80 birds.



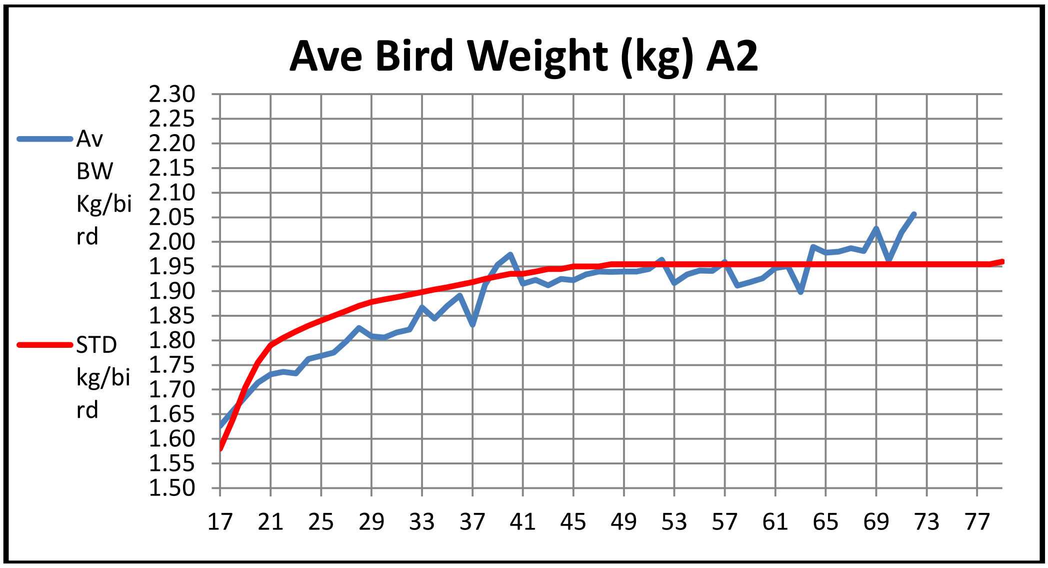
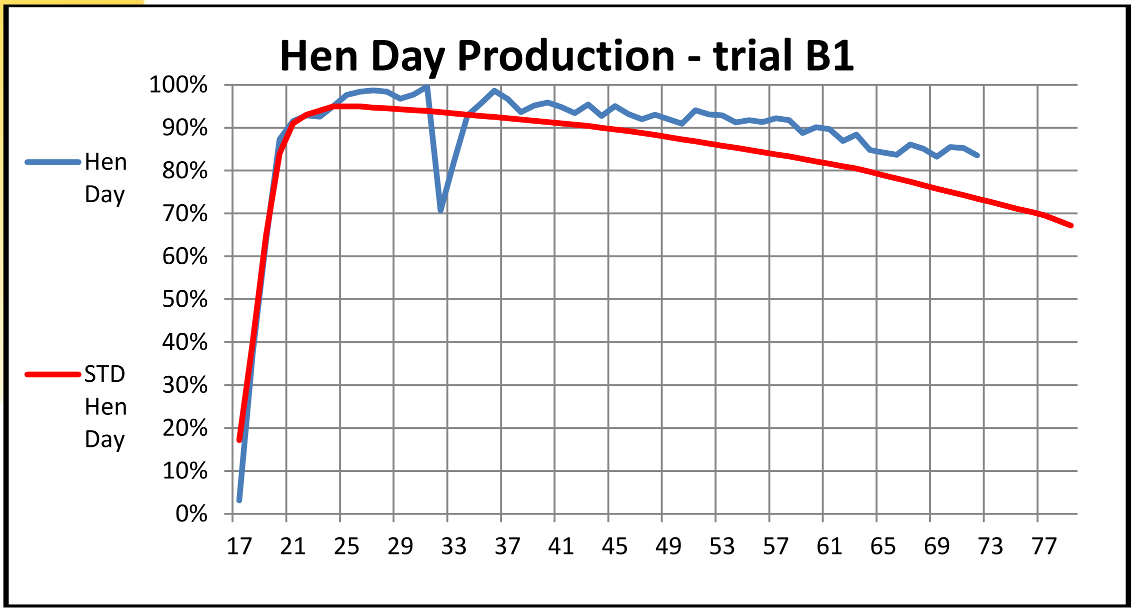


Figure 23 Egg production performance (Hen Day %) and bird weight for control diet A2

N=average of 500 birds.
Body weight estimated from 80 birds.



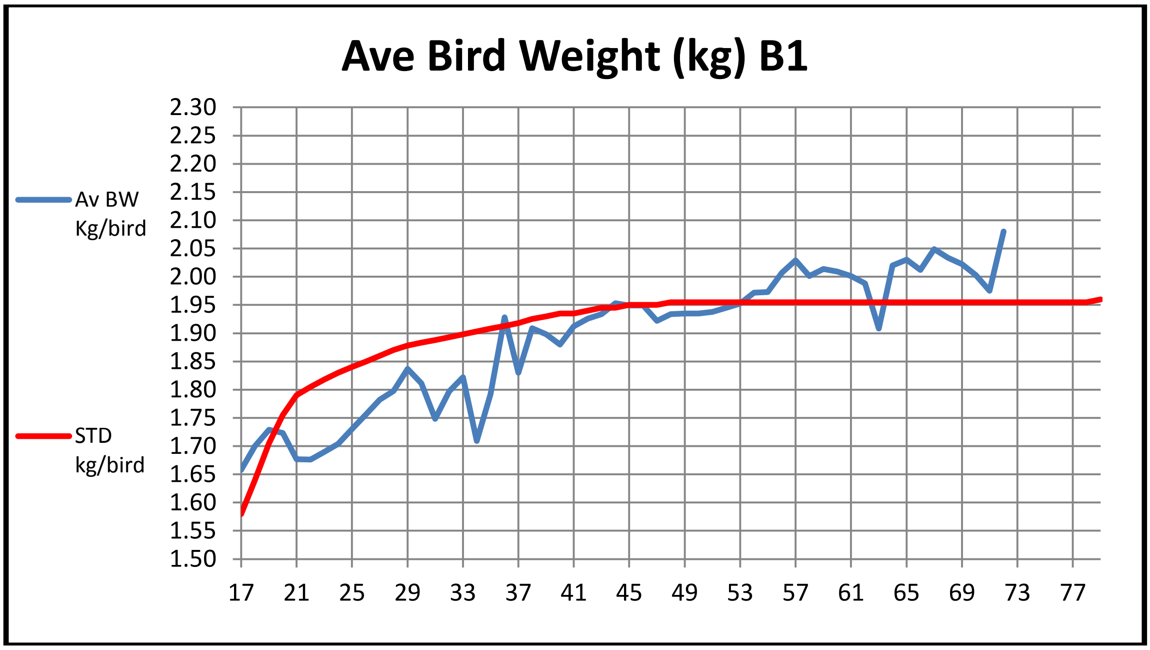
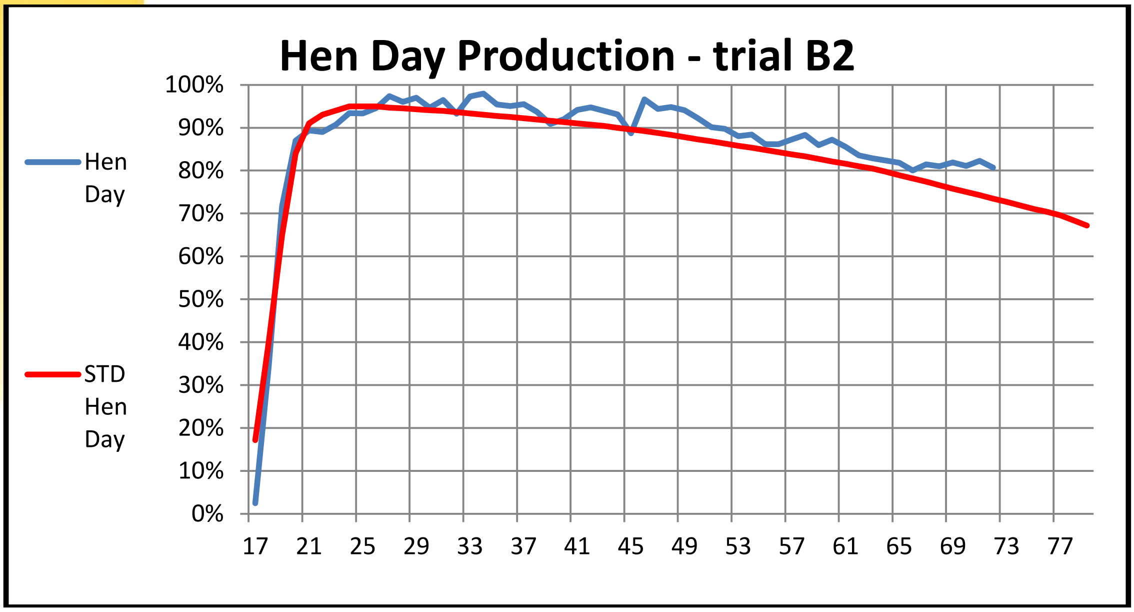


Figure 24 Egg production performance (Hen Day %) and bird weight for sequential diet B1

Average of 500 birds.
Body weight estimated from 80 birds.



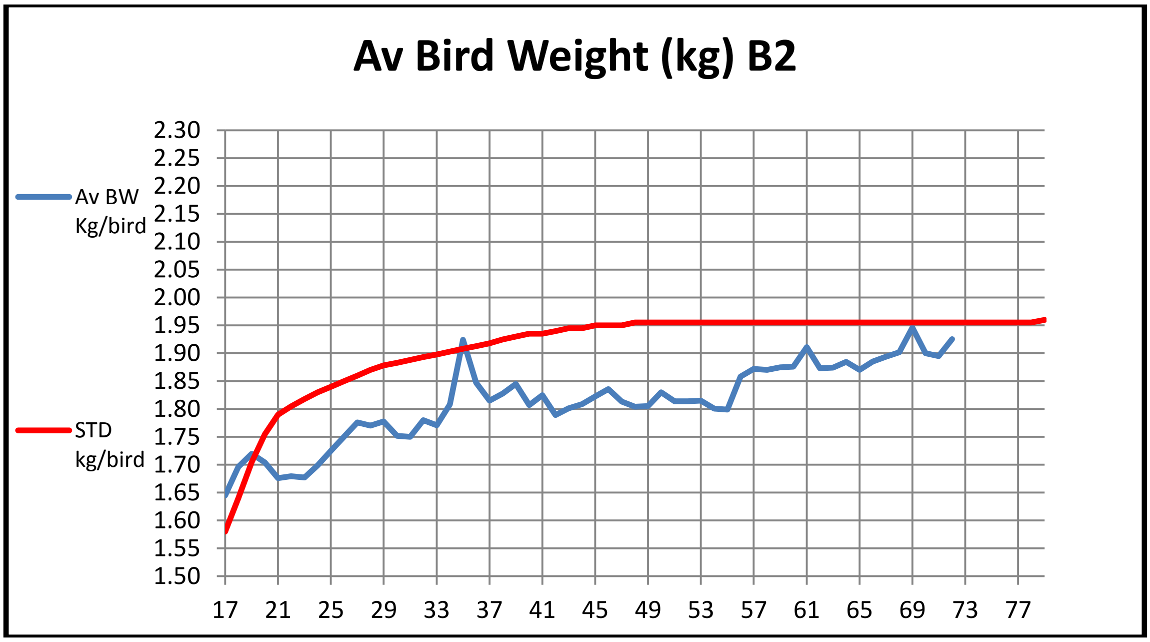


Figure 25 Egg production performance (Hen Day %) and body weight for sequential diet B2

N=average of 500 birds.
Body weight estimated from 80 birds.

Table 13 Average body weight and uniformity percentage of birds fed control diet A1 and A2, and sequentially fed birds B1 and B2

Age (wks)	A1	A2	B1	B2
27	1.78 kg (97%)	1.80 kg (87.6%)	1.78 kg (93%)	1.78 kg (97.3%)
52	1.98 kg (81.8%)	1.96 kg (67.6%)	1.95 kg (88.8%)	1.85 kg (86%)

N=80 individual birds.

Table 14 Average body weights and uniformity estimates at 52 weeks of age for A1, A2, B1, B2, with estimates of the variation around the average

A1	AVE	1.98kg	81.8%	MIN	<1.78 kg	7%	MAX	> 2.18 kg	11%
A2	AVE	1.96 kg	67%	MIN	< 1.78 kg	13%	MAX	> 2.16 kg	20%
B1	AVE	1.95 kg	88.8%	MIN	< 1.75 kg	6%	MAX	> 2.14 kg	5%
B2	AVE	1.85 kg	86%	MIN	< 1.647 kg	7%	MAX	> 2.01 kg	8%

N=80 individual birds.
Min=birds with body weights 10% below average.
Max=birds with body weights 10% above average.

The sequential feeding may have improved the peak production performance for B1 and B2, and it is clear that the performance of Group B2 achieved high peak production at average body weights of 1.75 to 1.80 kg, which is similar to the findings of Lescoat (2010) (Figure 25). The additional body weight in group B1 arose from a managerial error with provision of the concentrate feed source (Figure 24). The group B2 fed the sequential diet is a closer replication of the findings expected from the trial, and mimics the pattern described by the earlier European research (Lescoat, 2010), where the control group achieved an average live weight 100 grams heavier than the sequentially fed birds (Figures 22, 23, 24, 25; Tables 13, 14).

For both sequentially fed treatments B1 and B2, the uniformity at 52 weeks of age is very high relative to other experimental models in Chapters 3 and 4, and the proportion of larger birds is reduced (Table 14).

7 Epidemiological studies of growth rates and uniformity patterns for free range flocks

Aim: To evaluate the average growth and uniformity patterns of commercial free range flocks and compare these to patterns observed for cages.

Epidemiological evidence from Industry suggested that flock growth rates and uniformity patterns from free range flocks may differ significantly from those recorded in cage production, and this deviation from established standards may be important in the lower production performances achieved in these alternative systems.

Systematic analysis was undertaken on 8 typical commercial free range flocks, which related flock growth rates and uniformity patterns to production performance, and compared these findings to the patterns observed in cages. Flock size for the seven flocks shown in Table 13 ranged from 15,314-18,476 birds, with an average of 16,228 birds. The sample size to estimate average growth and uniformity percentage was 100 birds weighed individually.

Table 15 Seven free range flocks recorded for average body weights (kg) between 19 and 60 weeks of age

Flocks		Hen age (wks)			
	19	**26**	**37**	**50**	**60**
1	1.45 ± 0.02^{a}	1.89 ± 0.02^{a}	1.97 ± 0.02^{a}	1.95 ± 0.02^{ab}	1.92 ± 0.02^{bc}
2	1.48 ± 0.02^{b}	1.78 ± 0.02^{b}	2.0 ± 0.01^{a}	1.94 ± 0.02^{ab}	1.96 ± 0.02^{b}
3	1.68 ± 0.02^{a}	1.86 ± 0.01^{a}	1.92 ± 0.02^{b}	1.98 ± 0.02^{a}	2.03 ± 0.02^{a}
4	1.48 ± 0.02^{b}	1.81 ± 0.02^{b}	1.92 ± 0.01^{b}	1.94 ± 0.01^{ab}	2.0 ± 0.02^{ab}
5	1.72 ± 0.01^{c}	1.72 ± 0.01^{c}	1.77 ± 0.01^{d}	1.96 ± 0.02^{ab}	1.97 ± 0.02^{b}
6	n.a.	1.85 ± 0.01^{a}	1.86 ± 0.01^{c}	1.91 ± 0.02^{b}	1.89 ± 0.02^{cd}
7	1.62 ± 0.02^{a}	1.87 ± 0.02^{a}	1.84 ± 0.02^{c}	1.87 ± 0.01^{c}	1.86 ± 0.01^{d}
STD	1.65	1.85	1.92	1.96	1.96
P Value		<0.0001	<0.0001	0.0001	<0.0001

^{a,b,c,d} within a column, values with different superscripts are significantly different from each other.
Values are Means ± SE.
n.a. data not available.
N=100 birds.

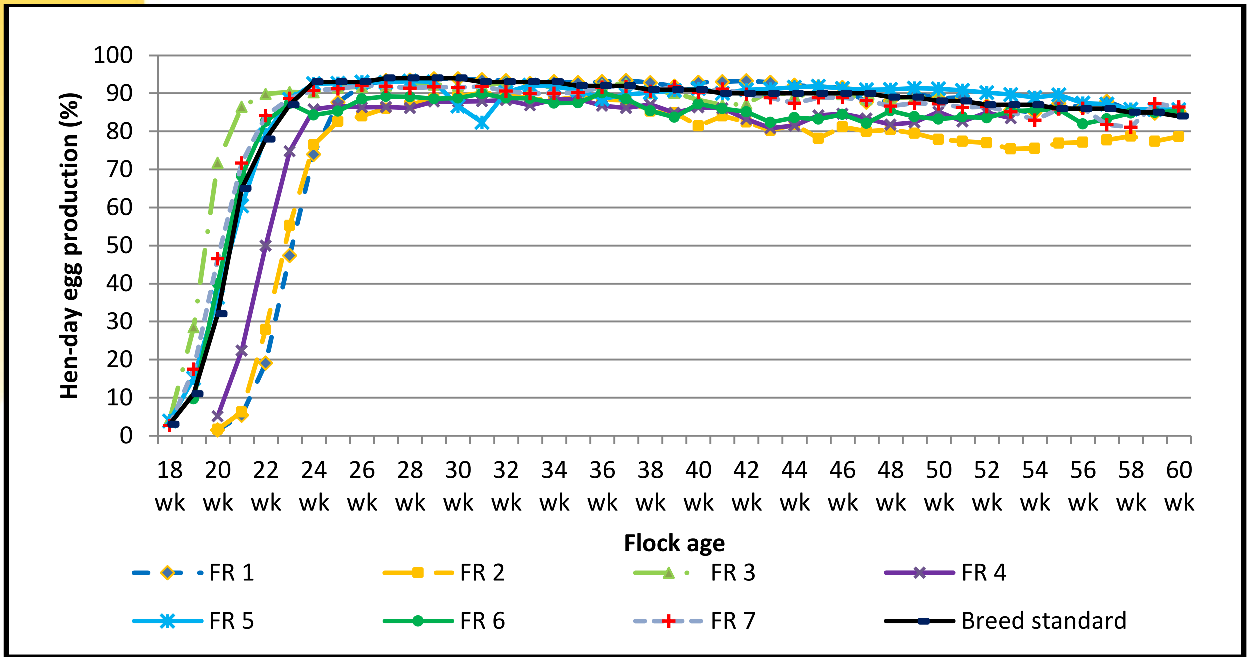


Figure 26 Egg production (Hen Day %) from the seven free range flocks

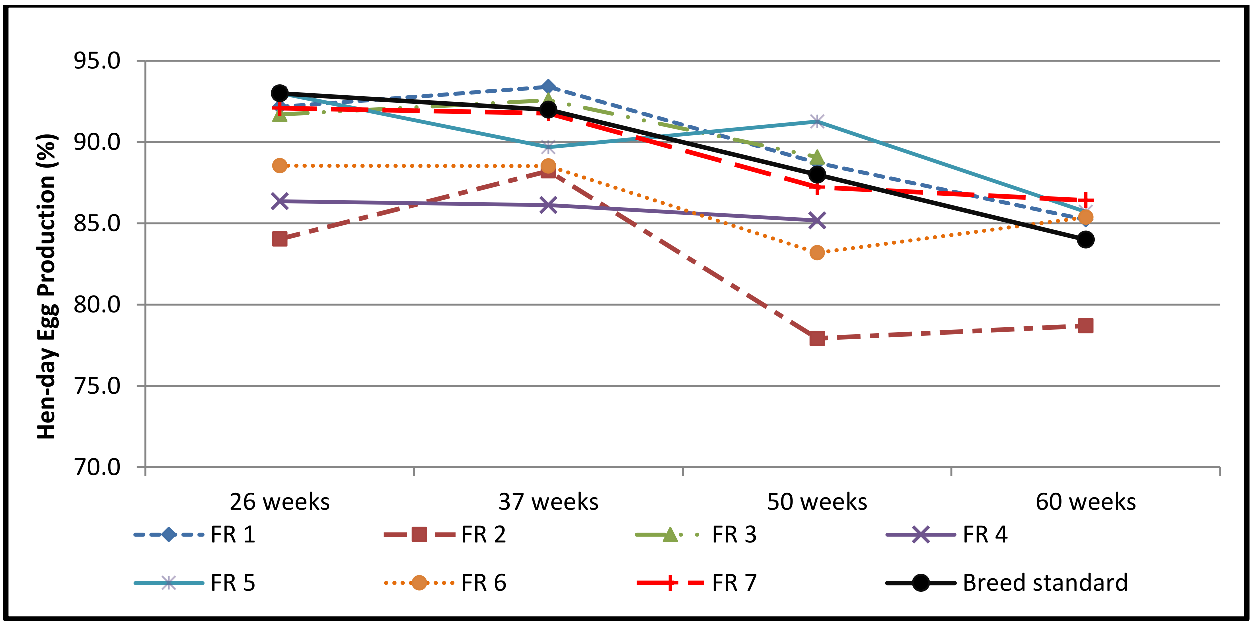


Figure 27 Egg production (Hen Day %) from the seven free range flocks

Table 16 Flock uniformity percentages between ages of 6 and 60 weeks of age for the seven free range flocks

Flocks	Flock Uniformity (%)						
	6	16	19	26	37	50	60
1	72.6	84.7	80.9	83.7	85.5	81.3	75
2	71.4	85.4	80	79.1	72.2	78	76
3	73.9	89.2	77.5	84.9	76.7	78.9	79.4
4	68.8	88.9	n.a.	74	74.4	81.8	73.8
5	72.3	62.0	68.2	83.1	77.4	80.4	77.3
6	n.a.	n.a.	83.5	84.2	80	81	80.8
7	n.a.	84.1	79.4	76.3	73.3	81	84.3

n.a. data not available.
N=100 birds.

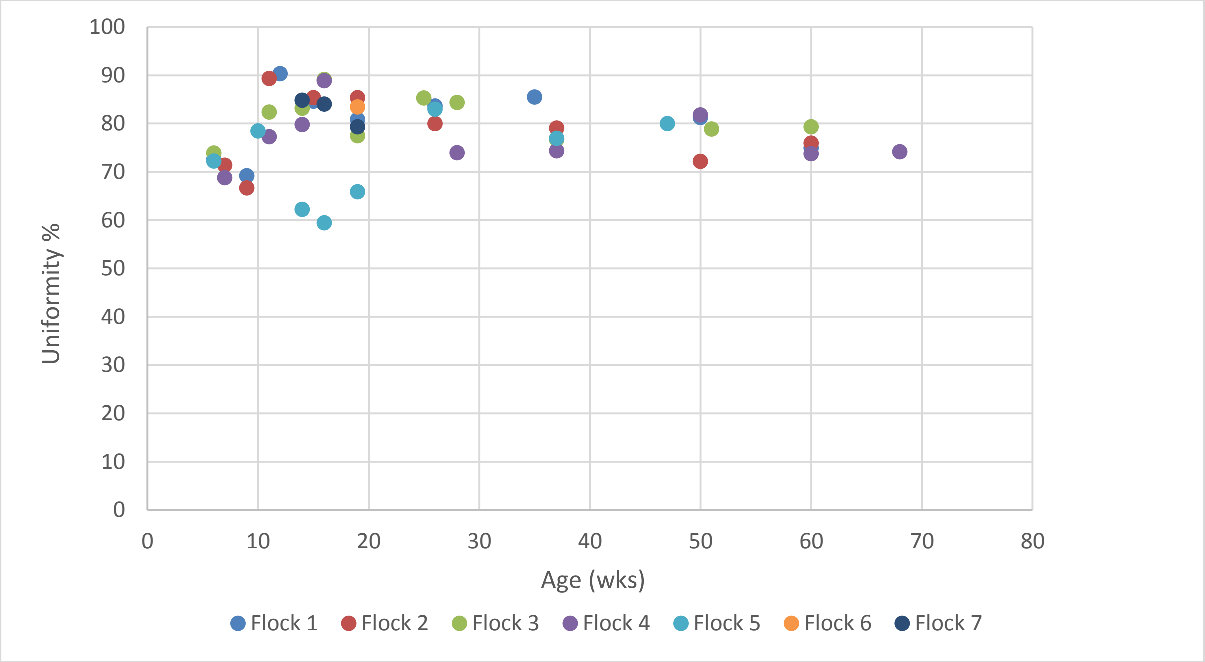


Figure 28 Graphical representation of the uniformity percentage of the seven free range flocks

Only one of the free range flocks (Flock 1) achieved expected average growth rate patterns, with acceptable uniformity patterns and egg production performance that aligned with breed standards for both peak production and persistency (Tables 15,16; Figures, 26, 27, 28). This flock (Flock 1) had a below standard pullet weight at 19 weeks of age, but was able to achieve breed standard growth rates to 37 weeks of age and achieved a mature weight of 1.92-1.95 kg that closely aligns with the breed standard.

Three of the flocks had heavy pullet weights at 19 weeks of age and, in two of these flocks, the growth patterns in the transition to peak production were well below expectations. Overall, the growth rate patterns of all free range flocks were much reduced compared to cage flocks and there was no “blow out” in average weight after 37 weeks of age, as was recorded in caged birds.

Elite performance for free range

The growth pattern of an elite free range Flock C1 (Flock 8) had average body weight well below the breed standard (Figure 29), but still achieved elite egg production performance (Figure 30), with peak production sustained at 94-96% between 25 and 35 weeks of age.

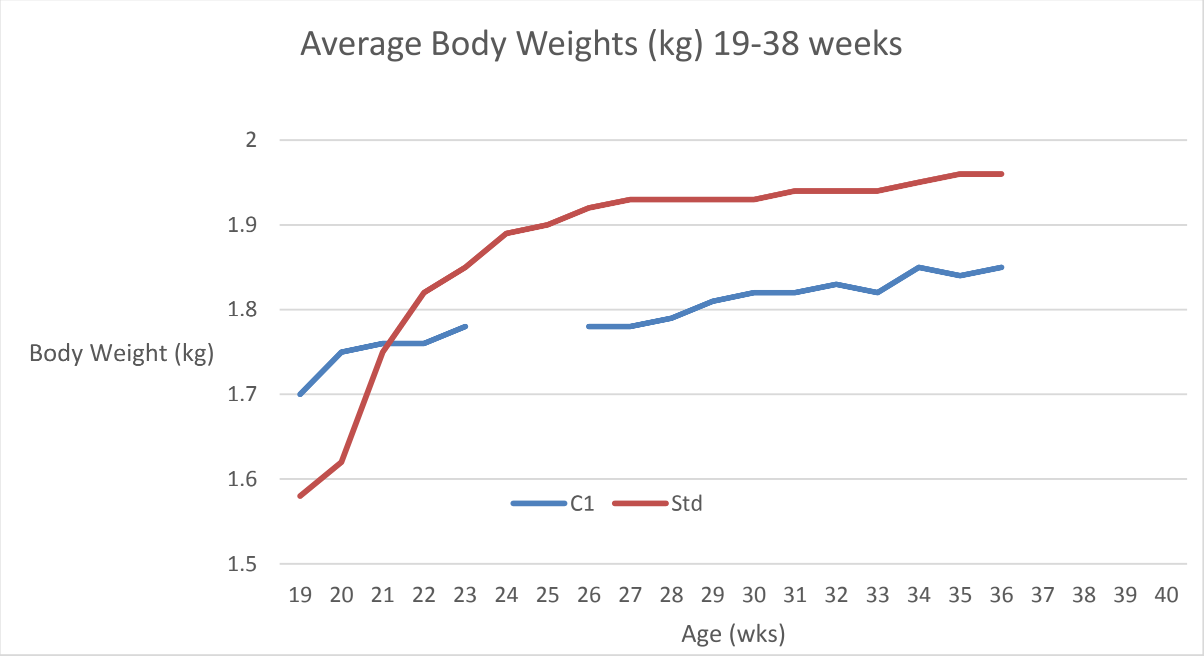


Figure 29 Average growth rate of an elite free range flock strain (C1) Flock 8, between 19 and 38 weeks of age

Farm collected data not available for week 24-25 timepoints.
Body weight below breed standard (Std).
Flock 45,000 birds.
N=100 birds to estimate body weight.

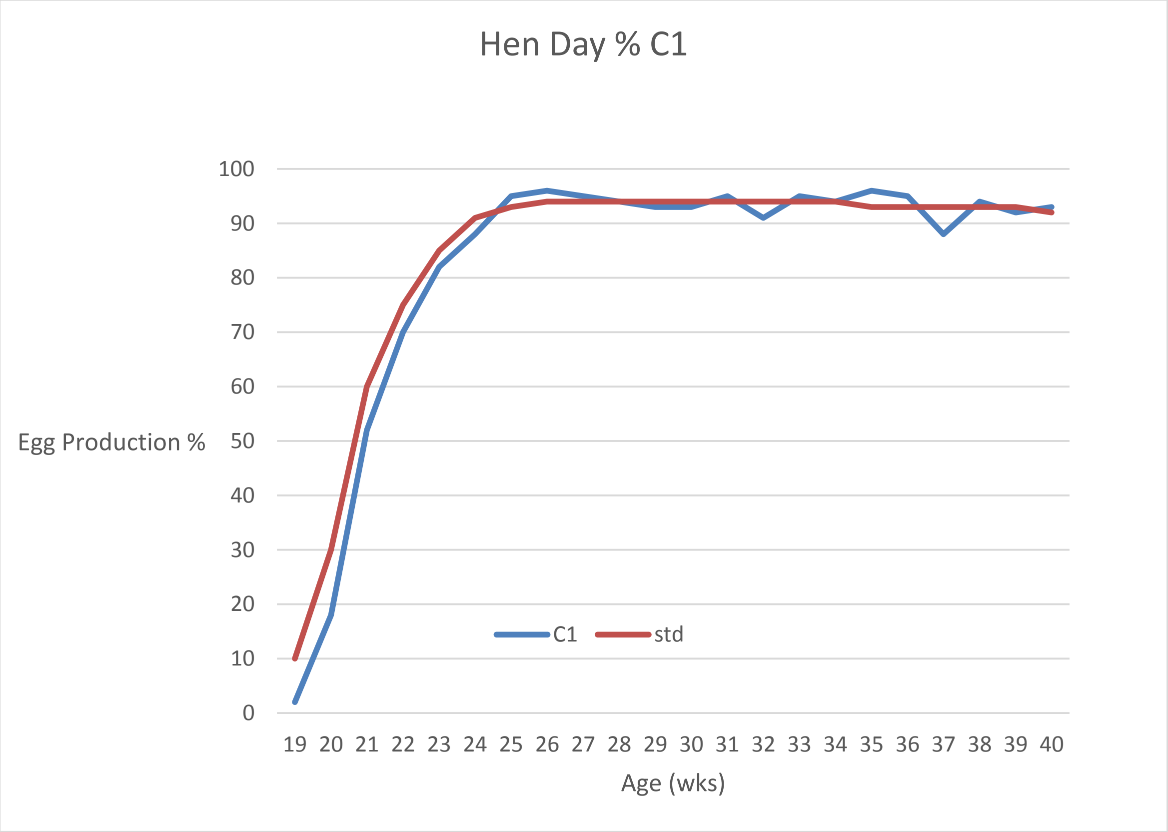


Figure 30 Egg production (Hen Day %) from elite free range flock (C1) Flock 8 that has average body weight below breed standard

N=20,000 birds.

The body weight pattern and production performance of the elite free range Flock C1 is similar to the patterns observed in the cage Flocks A1 and B1, in which the managerial intervention had aligned the flock average growth rates with the breed standards (Figures 17, 20, 21, 29, 30).

8 Communication and industry engagement

AECL workshops provided in Manly 2013 and Adelaide 2015

AECL Industry Consultative Committee meetings in 2013 and 2014

AECL Workshop in 2013

Seminars provided to Victorian Farmers Federation in 2012 and Southern Poultry Alliance in 2013

Hy-Line Australia Interactions and seminars in 2014 and 2015

Farm Pride Engagement in 2014

Farm visitation and seminars on six occasions at Happy Hens Egg Farms.

Farm visitation to DA Hall on three occasions

Farm visitation and seminar for Roger Adams (Darling Downs Fresh Eggs)

Farm visitation to Kinross Egg Farm on three occasions

Farm visits by Rowly Horn

AECL farmer training in Victoria in September 2015

Engagement with industry nutritionists G Richards, K Bruerton, D Meany, D Cadogan, P Scott, and R Horn

Article for Eggstra in September 2015

9 Conclusions

The intervention studies with flocks that closely aligned with the breed standards demonstrated not only a net improvement in efficiency by lowering average body weight, but a highly significant improvement in egg production performance that was not initially predicted. Improvements in persistency of production in the order of 10% were recorded, that seem likely to markedly alter the productive life of flocks.

The experimental models produced suggest that the moderation of the proportion of birds above 2.4 kg may be primarily responsible for this improvement in persistency of production. Birds that reach live weights of 2.5 kg and above seem likely to have compromised persistency of production and this is validated in the experiment described in Chapter 3.2.

For the elite commercial flocks with the body weights aligned to the breed standard, the gains appear to be twofold – a net reduction in daily feed intake produced by lowering body weight, and also improvements in egg mass output. Mathematical equations can precisely predict these shifts in feed efficiency for both commercial strains of brown egg layer (Chapter 5).

Clearly, many of the improvements recognised in these experiments are achieved by ensuring that the pullet weight is closely aligned to the prescribed breed standard and that initial point of lay uniformity is at 90% or above. Maintaining flock uniformity did not appear critical to maintaining persistency of production and a critical threshold weight principle appears more important at this stage (Chapters 3.2, 3.3 and 4).

The current industry practice of producing above standard pullet weights inevitably produces above weight flocks, fails to optimise egg production, lowers feed efficiency and compromises shell quality.

The sequential feeding experiment illustrated that the altered nutritional regimes can reduce the average weight of flocks, markedly improve flock uniformity and lower the proportion of heavier birds. Furthermore, very high peak production was able to be achieved in birds ranging in body weights from 1.75 to 1.80 kg, with uniformities above 90% at 27 weeks of age (Chapter 6).

The maximum physiological potential for caged birds able to be defined in these studies, appears to occur with body weights at or slightly below the breed standards, with high point of lay uniformities, and limited weight gain during egg production. Optimistically, this body weight standard could potentially achieve sustained peak production levels of 98-100%, with a persistency of production as high as 90% at 72 weeks of age.

For free range flocks, there are clear disparities in performance that involve poor uniformities at point of lay, with low growth rates compared to equivalent caged flocks. The most obvious explanation for these body weight problems is a feed intake gap (Net nutrient intake) between the prescribed levels of intake and the actual recorded intakes (Chapter 7). The performance of an elite free range flock with a low average body weight is associated with high feed intakes in the transition from point of lay to peak production, and is worthy of more systematic analysis.

These problems described for free range systems, are therefore not inevitable, because two of the eight flocks achieved acceptable performances, and one of the flocks achieved remarkably high egg production performance with a growth curves similar to the elite cage flocks and a body weight of 1.7 to 1.8 kg (30 to 40 weeks of age) (Chapters 4 and 7).

The elite outlying free range flocks need more in-depth analysis of pullet weights, uniformity patterns and feed intake patterns.

In summary, there appears to be great potential to undertake commercial egg production in lighter flocks than is currently practised and to achieve very significant improvements in persistency of production and feed efficiency. These ideas can be applied incrementally in cages, but more analysis and understanding of the production limitations on free range production is required. The preliminary findings on free range in this research suggest that a convergence of production performance with cages may be possible, if infectious disease can be controlled effectively.

Project design

The researchers have attempted to engage with elite producers around the concepts of lowering flock average weights, and were directed by the collaborating producers with regards to the experimental design, relevant to their concerns/constraints of adopting these ideas. One elite producer was very adventurous and the other interested but more constrained. Since completing this report, a third elite producer has been identified who has adopted the lighter average bird strategy with very good success, completely independent of these researchers.

10 Implications

- Many commercial caged flocks produce both pullet and mature weights well above breed standards (100-300 grams live weight) and this has not altered from the period 2005-2007.
- Intuitively, producers believe that they are reducing the proportion of underweight birds by increasing the average weight of the flock.
- There is a very wide variation in flock uniformity and/or coefficient of variation within many commercial flocks and some benchmark standards have been developed that indicate that the industry should uniformly achieve uniformities of 85-90% with coefficients of variation in the order of 8-9% in pullets at point of lay.
- Laboratory models suggest that point of lay flock uniformities can exceed 90% with coefficients of variation as low at 6-7%.
- There is evidence that the uniformity and coefficient of variation deteriorate during the egg production phase in most flocks after 33 weeks of age, and the correlation with persistency of production in not as strong as expected.
- The deterioration in uniformity occurring during lay in caged birds appears to result from an increase in the proportions of large or obese birds after 33 weeks of age.
- The current methods of estimating uniformity are based on the principles of a normal distribution and are designed to estimate one standard deviation from the mean or average weight. This approach may be inappropriate for modern egg production where 98% peaks are occurring and all birds appear capable of ovulating at a rate of 1 egg per 24 hours.
- High uniformities at between 19 and 25 weeks of age seem strongly correlated with peak production of 98-100% and high persistency of production (88-90% at 72 weeks of age).
- The challenge remains to be able to achieve the lowest possible body weight, tissue composition and nutrient turnover that will sustain these elite rates of ovulation and turnover between eggs.
- With these principles in mind, it seems likely that there will be threshold weights both below and above which egg production is compromised.
- The studies undertaken on caged birds on the commercial farm indicate that birds with very heavy pullet weights and heavy mature weights (2.5 kg) have a compromised peak production and lower persistency of production.
- The evidence from the intervention studies and the sequential feeding trial suggests that improved production performance can be achieved by lowering the average weights of flocks to the breed standard and slightly below.
- High peak production and persistency of production can be achieved in flocks with average body weights of 1.8-1.85 kg at 30-40 weeks of age.
- The caveats to these outcomes are high uniformity standards at point of lay and the appropriate nutrient intakes in the transition between point of lay and peak production.
- The two mathematical equations that predict feed intakes from an estimation of Metabolisable Energy Requirements (ME) and a knowledge of feed ME content seem quite precise.

- Different predictive equations seem to be required for the two different commercial strains (A and B).
- These equations accurately predict the impact of body weight changes on feed intake and can be used to estimate economic impacts.
- The majority of free range flocks have lower flock growth rates than equivalent cage flocks.
- The growth studies on free range flocks suggest that the heavier pullets may be associated with low or below prescribed growth rates.
- Two of eight free range flocks achieved high egg production that is similar to good cage performance.
- One of the free range flocks achieved elite egg production performance with a body weight well below the breed standard (C1), and this flock aligned closely with the performance of the elite cage flock (A1).
- The outlying superior free range flocks need more systematic analysis of growth rates, uniformities, feed intake patterns and nutrient intakes.
- Moderation of late egg size will improve overall shell quality, and this will be achieved by reducing flock average weights to breed standards and reducing the numbers of birds above 2.5 kg.

11 Recommendations

- The current findings on flock uniformity be developed into a seminar series for the national industry.
- Elite producers should be encouraged to undertake their own uniformity studies and reduce the average weights of pullets and flocks to more closely align with breed standards.
- Additional elite performing flocks should be identified for ongoing uniformity studies.
- Additional laboratory models of body weight thresholds and performance should be considered to establish clearer causal relationships, with productivity and shell quality, particularly in the lower weight range (1.5 to 1.7 kg at 50 weeks of age).
- If elite production performance is able to be achieved in the lighter birds (1.5 to 1.7 kg), more systematic analysis of the carcass characteristics should be undertaken using the CT scanning technology to define the tissue reserves required for elite sustained egg production.
- Simple standards for eggshell percentage and shell thickness should be established to create an elite category of eggs.

12 References

Balnave D. (1984). The influence of body weight at point of lay on the production responses of restricted reared pullets. Australian Journal of Agricultural Research. 35:845-849.

Connor, J.K. (1980a). Proceeding of Poultry Husbandry Research Foundation, Paper 10. University of Sydney.

Farrell, D.J. (1983). Feeding Standards for Australian Livestock-Poultry. Standing Committee of Agriculture, Technical Report Series-No. 12. pp. 29-31.

Fuller, M. F., Fowler, P. A., Mc Neill, G., and Foster, M. A. (1994). Symposium: Newer Techniques in Nutrition Research. Imaging Techniques for the Assessment of Body Composition. The Journal of Nutrition, 1546S-1550S.

Haynes, F. E. M., Greenwood, P. L., Siddell, J. P., McDonagh, M. B., and Oddy, V. H. (2010). Computer tomography software program'osirix'aids prediction of sheep body composition. Paper presented at the Proceedings of the Australian Society of Animal Production.

Hyline Layers. (1998-1999) Commercial Management Guide. 1/98. Page 13, West Des Moines, Iowa, USA, 50266

Hyline Layers. (2015) Brown Commercial Layers Management Guide. Retrieved from: http://www.hyline.com/UserDocs/Pages/BRN_COM_ENG.pdf

Li, X., Bryden, W.L., and Zhang, D. (2016) Available phosphorus requirement of laying hens. Australian Egg Corporation Limited. Project No 1UQ101

McEvoy, F. J. (2007). An application of image processing techniques in computed tomography image analysis. Veterinary Radiology and Ultrasound, 48(6), 528-534.

Parkinson, G. B., Cransberg, P. H. and Fadavi-firooz, R. (2007) Influence of flock uniformity on productivity, eggshell quality and bird welfare. Australian Egg Corporation Limited. Project: EPRID Project No. 1

Rosset, A., Spadola, L., and Ratib, O. (2004). OsiriX: an open-source software for navigating in multidimensional DICOM images. Journal of Digital Imaging, 17(3), 205-216.

ISA (2015) Layer Management Guide. 2015. Retrieved from: http://www.isapoultry.com/~/media/Files/ISA/ISA%20new/product%20information/Management_guide_cage_production_systems_vs1408a.pdf

Umar Faruk, M., Bouvarel, I., Mene, N., Rideau, N., Roffidal, L., H. Tukur, H.M., Bastianelli, D., Nys, Y. and Lescoat, P. (2010). Sequential feeding using whole wheat and a separate protein-mineral concentrate improved feed efficiency in laying hens. Poultry Science. 89:785-796.

13 Plain English Summary

Project Title:	**Pullet and layer flock uniformity, persistency and longevity: an epidemiological, industry-based approach to improve feed efficiency**
AECL Project No	1UN112
Researchers Involved	Greg Parkinson, Juliet Roberts, and Rowly Horn
Organisations Involved	Livorno Consulting, 86 Wilson St, Brunswick, VIC 3065 University of New England, Animal Science, Woolshed Building, Armidale, NSW 2351 Rowly Horn Services, 8 Ann Place, Bligh Park, NSW 2756
Phone	03 9387 8828; 02 6773 1995; 02 4572 0318 0417 506 574; 0408 968 473; 0409 772 045
Fax	02 6773 3922 02 4572 0328
Email	livornoconsulting@pacific.net.au jrobert2@une.edu.au rowly@rowlyhorn.com
Objectives	• To increase the economic longevity of first cycle flocks from the current 72 weeks until 80-85 weeks by sustaining egg production and shell quality. • To investigate the relationship between husbandry practices and body weight management (flock uniformity) on shell quality. • To review indicators and benchmarks for flock uniformity in rearing and production, to improve persistency and longevity in egg production • To provide guidelines on managing the genotype-phenotype interaction within production systems. • To improve standardisation of industry wide performance. • To establish an objective system for continuous improvement of feed efficiency by lowering body mass but maintaining egg mass output.
Background	Maintaining good flock uniformity, which means having all laying hens in a flock of very similar body weight, makes it much easier to manage the flock and to achieve the best production and egg quality. Previous research has shown that birds in commercial layer flocks have a higher body weight than is recommended by the breeder companies. This may be a risk management strategy to reduce the incidence of underweight birds in the flock. However, not only do heavier birds eat more, but they may also produce fewer eggs that are larger and are of inferior quality. It

	has been suggested that the range of body weights (upper and lower body weights within a flock) may be more important to flock performance than flock uniformity, as it is currently calculated. There have also been suggestions that maintaining uniformity is more difficult in free range flocks than it is for cage flocks.
Research	This project reviewed previously reported data and consulted extensively with industry – egg producers, breeder companies, nutritionists and hatchery managers. Workshops were held to facilitate discussion of the issues involved. Studies were conducted on cage flocks that were performing well ("elite" flocks) as well as on eight commercial free range flocks. An experiment was conducted at the University of New England to test the results obtained with commercial flocks. Mathematical modelling was used to determine the energy requirements of a typical flock of commercial laying hens. Another study was conducted on-farm to test the findings of a study conducted in Europe and published in 2010.
Outcomes	• Mechanisms to improve flock persistency and shell quality have begun to be identified but require ongoing extension of concepts to industry. • A relationship has been established between large body size, obesity and low shell percentage/thickness. • A comprehensive set of data has been generated that describes the uniformity standards across industry and has consolidated current industry best practice. • Elite production performance has been identified in some experimental models that exceeds current industry practice, and the causal environmental factors have been in part described. • The project has generated significant interest by elite producers in measurements of growth, uniformity, and feed intake patterns. • The biological and mathematical models described in this research provide a mechanism for significant and continuous improvements in feed efficiency in the medium-term.
Implications	Many commercial layer flocks have birds that are too heavy, 100-300 grams above the body weight recommended by the breeder company, and there is a very wide variation in flock uniformity in commercial flocks. An increased incidence of overweight, obese birds is occurring in many flocks after 33 weeks of age. High flock uniformity is correlated with improved performance in terms of production performance and persistency as well as egg quality. The results show that high peak production and good persistency of production can be achieved in flocks with average body weight of 1.8-1.85 kg at 30-40 weeks of age. The majority of free range flocks studied had lower growth rates than equivalent cage flocks. However, two free range flocks studied achieved high egg production that was as good as that found in cage flocks. Maintaining egg size relatively constant later in lay is essential to maintaining good shell quality.

Key Words	laying hens; flock uniformity; body weight; egg production; persistency of production; production performance; egg quality; hen age; layer production systems
Publications	Suawa, E. and Roberts, J.R. 2013. Effect of body weight uniformity on egg shell quality of free range laying hens. Proceedings of the XXI European Symposium on the Quality of Poultry Meat and the XV European Symposium on the Quality of Eggs and Egg Products, Bergamo, Italy September 15-19. Suawa, E. and Roberts, J.R. 2014. Body weight, flock uniformity and egg quality of flocks reared in two different rearing sheds. *Proceedings of the Australian Poultry Science Symposium (P. Selle, Ed).* **25:** 118-121. Suawa, E. and Roberts, J.R. 2014. Effect of body weight uniformity on eggshell and egg internal quality. Proceedings of the Asia Pacific Poultry Conference, Jeju, Korea, October 19-23. Suawa, E. and Roberts, J.R. 2015. Body weight at point of lay and the ultrastructural properties of eggshells. *Proceedings of the Australian Poultry Science Symposium (P. Selle, Ed).* **26:** 26. Suawa, E., and Roberts, J.R. 2015. Effect of body weight uniformity on eggshell ultrastructure of hens in a cage production system. Abstract XVI European Symposium on the Quality of Eggs and Egg Products, May 10-13, Nantes, France. World's Poultry Science Journal Vol. 71, Supplement 1: 10.