PHYSIOLOGICAL AND NUTRITIONAL ASPECTS OF RESTRICTED FEEDING OF POULTRY

A thesis submitted for the degree of Doctor of Philosophy of the University of New England

by

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PREFACE

The studies presented in this dissertation are original and were completed by the author in the Department of Biochemistry and Nutrition, Faculty of Rural Science, University of New England, Armidale, New South Wales, Australia. Assistance given by other persons is indicated in the text or in the list of acknowledgements. All references cited are included in a bibliography.

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I certify that the substance of this thesis has not already been submitted for any degree and is not being currently submitted for any other degree.

I certify that any help received in preparing this thesis, and all sources used, have been acknowledged in this thesis.

December 1981 *R.J. Johnson*

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LIST OF GENERAL ABBREVIATIONS AND TERMS

kg	kilogram
g	gram
mg	milligram
h	hour
d	day(s)
C	degrees centigrade
m	metre
cm	centimetre
mm	millimetre
l	litre
ml	millitre
J	joule(s)
kJ	kilojoule (4.184 kJ = 1 kcal)
min	minute(s)
s	second(s)
µ	micro-
%	percentage
/	per
<	"less than"
>	"more than"
±	plus or minus
viz.	(namely)
i.e.	(that is)
e.g.	(for example)
R^2	coefficient of determination
RSD	residual standard deviation
hen d	one day per bird (hen)
IU	International Unit
c	Currie (1c = 3.7 x 10^{10} disintegrations/s)
c.	approximately
N	number of observations
SD	standard deviation
inter alia	among other things
pro rata	on a shared basis

Realimentation is used in this thesis to signify the allowance of *ad libitum* feed intake after prior nutritional restriction.

Layer-type birds are those which are used primarily for the production of eggs for human consumption.

Broiler breeder birds are those which are used to produce fertile eggs to be hatched for the production of fast-growing meat chickens (broilers).

SUMMARY

1. The biological effects of feed restriction were investigated in experiments with both layer-type and broiler breeder hens. Major emphasis was placed on the elucidation and clarification of alterations in (a) the important production characteristics, (b) body and liver composition, and (c) energy metabolism, primarily from the aspect of the effects due to feed restriction during rearing.

2. Two experiments which examined in detail the influence of feed restriction during rearing on the production of layer-type birds were carried out. Both experiments used commercially available stock (Experiment 1, WL x A; Experiment 2, WL x NH) and under conditions of increasing daylength and temperature during rearing. The three treatments (N = 50 birds/treatment) applied during rearing (*c.* 42-154 d of age) were (i) *ad libitum* feed intake, (ii) limited-time feed restriction (*c.* 24 h feed/72 h) and (iii) quantitative feed restriction (*c.* 60-70% of (i)). Restriction programmes were regulated to give a liveweight reduction at cessation of restriction of about 20% relative to birds allowed *ad libitum* feed intake. The results were as follows:

   (a) alterations in the production characteristics of birds due to feed restriction could be accurately assessed only with consideration of physiological rather than chronological age;

   (b) analyses on a physiological age basis with stage of egg production as the criterion (10 eggs/100 hen d, 50 eggs/100 hen d and peak production) over equal periods for each treatment showed that in Experiment 1 the birds which were on the limited-time restriction treatment during rearing produced a significantly greater number of eggs compared to the other two treatments ((i) and (iii) in 2 above). However, because of their greater egg weights, birds which were on the two restriction treatments had a significantly greater egg mass output. For example, for equal periods after the attainment of 50 eggs/100 hen d in each

treatment, egg mass output was 40.1, 46.5 and 42.4 in Experiment 1, and 47.5, 52.4 and 53.5 b/gird d^{-1} in Experiment 2 for birds which were on the *ad libitum*, limited-time and quantitative treatments respectively;

(c) the production of abnormal eggs was high in birds which were allowed *ad libitum* feed intake during rearing, particularly up to the period after peak of egg production. During the first two 28 d periods after each treatment had reached 10 eggs/100 hen d, total abnormal egg production was 10.3% and 5.5% in Experiment 1, and 18.1% and 9.2% in Experiment 2, for birds on the *ad libitum* treatment. The majority (*c.* 70%) of the abnormal eggs produced during these periods were eggs with shell formation defects (*viz.* shell-less and partially weak shells). Production of abnormal eggs for birds which were on the restriction treatments was negligible;

(d) since all eggs were weighed individually for each bird throughout each experiment, the effect of feed restriction could be accurately identified. The pattern of development of egg weight showed that egg weight was increased for birds previously on the feed restriction treatments. Arguments were put forward that this was crucial to the overall effects of feed restriction, and that it was dependent on the observed hyperphagia associated with the cessation of feed restriction which was associated with a greater intake of linoleic acid at time of commencement of egg production.

3. Body composition studies were designed to:

(i) determine the changes in the major body components due to feed restriction during rearing, both during the period of restriction and after the cessation of restriction;

(ii) estimate the influence of body fat content *per se* on egg production as a possible reason for the observed increases in egg production due to feed restriction during rearing; and

(iii) investigate certain facets of liver metabolism.

During the serial slaughter of birds to determine body composition, experiments were carried out to enable the prediction of body compo-

sition in poultry. Isotope dilution techniques, using the radioactive tritiated water and non-radioactive deuterium oxide, were used to obtain an accurate estimation of total body water. The main factors found to contribute to the observed overestimation (*c.* 10%) of total body water by isotope dilution space were insufficient recovery of isotope from blood using vacuum sublimation and loss of isotope in urine prior to equilibrium. The relationships between the major body components in layer-type birds (age 39-476 d, mean liveweight 429-2000 g) and broiler breeders (age 126-476 d, mean liveweight 2887-3581 g) were investigated to allow prediction of body composition. These relationships were found to be dynamic in that they were influenced by age, type of bird, liveweight or stage of egg production. However, prediction equations which included all birds and based on tritiated water space (N = 169) or deuterium oxide space (N = 115) and liveweight were shown to have good accuracy. Some examples of the most suitable regression models for the relationship between total body water (TBW, g), tritiated water space (T, g), deuterium oxide space (D, g), liveweight (W, g), protein (P, g) and fat (F, g) were:

$$\begin{aligned} TBW &= 46.7 + 0.483T + 0.483T \\ P &= 29.8 + 0.084W + 0.160T \\ F &= -80.2 + 0.604W - 0.606T \end{aligned}$$

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$$\begin{aligned} TBW &= 51.3 + 0.315W + 0.361D \\ P &= 47.4 + 0.093W + 0.137D \\ F &= -109.1 + 0.484W - 0.403D \end{aligned}$$

The main results of the slaughter and prediction studies carried out with the aims as specified and on the layer-type birds described (see (2)) were:

(a) both limited-time and quantitative feed restriction during rearing resulted in significantly lower body fat and higher water content of the fat-free mass at or near cessation of restriction relative to birds allowed *ad libitum* feed intake during rearing. In Experiment 1 liveweight at cessation of restriction (162 d of age) was 1817, 1540 and 1404 g, body fat was 155, 129 and 130 g/kgW and water content of the fat-free mass was 66.3, 67.8 and

67.2 g/100 g for brids on the *ad libitum*, limited-time and quantitative treatments for each component respectively. Corresponding values for Experiment 2 at 120 d of age were 1494, 1309 and 1234 g for liveweight, 100, 70 and 42 g/kgW for body fat, and 67.6, 69.8 and 69.1 for water content of the fat-free mass for the three treatments respectively.

(b) body composition predicted with the equations described and using deuterium oxide showed that there was no demonstrable relationship between body fat content at sexual maturity and subsequent rate of egg production under the conditions of the experiment. This was verified in subsequent studies on broiler breeders, but it was concluded that under certain conditions, such as high temperature and humidity, such an effect may become evident.

(c) liver composition studies clearly showed that the stage of the feed cycle influenced the results due to the extremely dynamic nature of chemical reserves in this organ. *De novo* lipogenesis, measured *in vivo* with U-C^{14}-acetate, illustrated this effect, particularly with the limited-time restriction treatment.

4. Energy metabolism studies were as follows:

(i) serial measurement of starvation heat production of layer-type birds prior to and during egg production in closed-circuit respiration chambers;

(ii) analysis of the detailed production data, obtained in the two experiments on layer-type birds, by regression techniques which attempted to partition the dietary metabolisable energy between the processes of maintenance and production; and

(iii) energy and nitrogen metabolism studies on broiler breeders which were on commercially based feed restriction programmes. These studies required the construction of large open-circuit respiration chambers to minimise the known influences of calorimetric measurement *per se* and to allow techniques to be implemented which did not rely on manipulation of dietary intake for calorimetric measurement *per se*. The chambers operated on

the indirect principles of measurement of gaseous exchange (CO_2 and O_2) and were designed to house groups of birds. In each of the three chambers there was a tiered cage arrangement which was hermatically sealed during measurement. Equipment function was measured by carbon dioxide infusion and recovery studies and ethyl alcohol combustion tests. The mean recovery of carbon dioxide was 98.4, 99.2 and 98.8% for chambers 1, 2 and 3 respectively, while the mean (± SD) quotient of carbon dioxide produced to oxygen consumed (CO_2/O_2) was 0.670 (± 0.019). A preliminary experiment on groups of broiler breeder birds (N = 16/chamber) showed that consecutive measurements of heat production at a set feeding level gave acceptable coefficients of variation (*c.* 3%) and reasonable estimates of starvation heat production (352 $kJ/kgW^{0.75}\ d^{-1}$), maintenance energy requirement (366 $kJ\ ME/kgW^{0.75}\ d^{-1}$) and efficiency of utilization of metabolisable energy for production (70%).

The main results from these studies were found to be the following:

(a) there were no alterations in starvation heat production in layer-type birds measured under conditions which minimized physical activity. Results of other studies were used to suggest that under normal production conditions starvation heat production may be increased due to increased physical activity;

(b) the partition of dietary metabolisable energy by laying hens appeared to be altered due to prior feed restriction but analysis of the production data by regression techniques without certain constraints in the regression model resulted in unrealistic estimates of the efficiency of utilization of metabolisable energy for production. Setting the efficiency of utilization of energy for production at 60 or 70%, irrespective of the type of production (eggs or liveweight gain), showed that there were differences between treatments in maintenance energy requirements, but the relative changes were dependent upon the experiment (Experiment 1 or 2) and level of efficiency which was used in the regression model. In Experiment 1, the metabolisable energy required for maintenance at an assumed efficiency of 70% was 578,

560 and 555 kJ/kgW$^{0.75}$ d^{-1}, and in Experiment 2 was 500, 505 and 539 kJ/kgW$^{0.75}$ d^{-1} for birds on the *ad libitum*, limited-time and quantitative treatments respectively. The lower energy requirements for maintenance of birds on Experiment 2 partially explained the observed higher gross energetic efficiency of these birds, but the results concerning the effects of feed restriction during rearing were inconclusive;

(c) the energy and nitrogen metabolism of broiler breeders was dynamic due to the apparent influence of age, liveweight and stage of egg production. The effect of feed restriction, primarily during rearing (to 154 d of age), was also apparent. Analyses during rearing (112-154 d of age) proved difficult because of the high metabolisable energy intake and the small number of observations, but the energy required for maintenance and/or the energetic efficiency of production of birds on the feed restriction treatments was apparently altered during this period. During the major portion of the egg production period for each treatment, the energy required for maintenance was apparently increased for birds on the restriction treatments; this was counterbalanced by a slightly higher energetic efficiency of production for birds on one of the restriction treatments (Treatment 2, liveweight reduction at 154 d of 38% relative to birds allowed *ad libitum* feed intake) but not for birds on the other restriction treatment (Treatment 3, liveweight reduction at 154 d of 43% relative to birds allowed *ad libitum* feed intake). Values were 410, 486 and 466 kJ/kgW$^{0.75}$ d^{-1} for the maintenance energy requirement (MEm) with corresponding efficiencies (kp) of 73, 85, 73% during the major portion of the egg production periods for birds on Treatments 1 (*ad libitum*), 2 and 3 respectively. The quantity of nitrogen required for maintenance during egg production was 679 and 1200 mg/kgW$^{0.75}$ d^{-1} for birds allowed *ad libitum* feed intake or which were restricted respectively, while the energy required for nitrogen balance was 362 and 407 kJ/kgW$^{0.75}$ d^{-1} for birds allowed *ad libitum* feed intake or which were restricted, respectively. There were little real differences in total egg production or output due to feed restriction, but apparent production and output

were considerably greater for birds on the restriction treatments due to the large contribution of abnormal eggs, particularly shell-less and weak shelled eggs, to the production of birds which were allowed *ad libitum* feed intake and which matured earlier.

5. The studies presented in this thesis have clarified the effects of feed restriction on the production characteristics of poultry, and have found that biological alterations may occur due to appropriate restriction programmes. Although certain alterations in energy and nitrogen metabolism were illustrated, these may play only a minor role in the overall production effects observed due to restriction, and may be manifestations of an altered production *per se*. It was postulated that simple time-scaled relationships may determine the production response to a feed restriction programme.