

GROWTH, FOOD CONVERSION EFFICIENCY AND BODY COMPOSITION IN BROILERS :
GENETIC AND PHYSIOLOGICAL INTERRELATIONSHIPS

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SUMMARY

Direct and correlated responses were studied in three lines of broiler chickens selected for nine generations for either increased liveweight gain (line W), increased food consumption (line F) or improved food conversion efficiency (line E). A randomly selected control line (line C) was also maintained. The test period was from 35 to 63 d of age.

Growth rate was 35, 32 and 29 g/d, food consumption was 87, 99 and 69 g/d, FCR was 2.54, 3.18 and 2.38, total body fat was 12.7, 16.2 and 11.3%, abdominal fat was 2.91, 3.91 and 2.06%, metabolisability of dietary energy was 75.4, 73.8 and 77.0%, and daily maintenance energy requirement was 860, 937 and 796 kJ/kg W in lines W, F and E respectively. Average reproductive performance in terms of day-old chicks produced in the 6th and 7th generation, and expressed as a percentage of the control group was 53.8, 53.8 and 87.6% in the W, F and E lines respectively.

The desirable responses in the E line birds argue a strong case for selection for increased bodyweight in commercial breeding programmes to be combined with some form of direct selection either for improved feed efficiency or possibly for reduced body fat.

INTRODUCTION

Largely as a result of genetic selection for increased bodyweight at an early age, today's broiler chicken has a growth rate that is truly remarkable in comparison with its ancestors. In response to reduced maintenance requirements associated with a considerably shortened growth period to a given weight, food conversion efficiency has also improved markedly. There are, however, indications of considerable between-bird variation in food conversion efficiency which are not accounted for by differences in growth rate (Wilson 1969; Giull and Washburn 1974; Pym and Nicholls 1979). Since food conversion efficiency to a given weight is the major determinant of profitability in broiler production, there would seem to be good reason to combine selection for growth and efficiency in such a way as to optimise economic response.

Excessive fatness in broiler chickens is now recognised as a major world-wide problem. The present situation is considered by many to be largely due to continued selection for increased bodyweight by the commercial breeders, although the evidence is circumstantial and not conclusive.

Before attempting genetic solutions to these problems, it is important to have an understanding of the basic physiological interrelationships between the traits. This should enable desirable change to be made without the likelihood of further problems being created. There is little published information on genetic and phenotypic interrelationships between growth, food conversion efficiency and body composition in chickens and even less information is available on the underlying physiological control mechanisms.

SELECTION FOR IMPROVED FOOD CONVERSION EFFICIENCY

In an endeavour to provide more information on genetic and phenotypic parameters for food conversion and its components, a selection experiment was commenced at Seven Hills in 1970. Four lines were selected from a broiler base population.

- Line W - selected for increased 5 to 9-week weight gain
- Line F - selected for increased 5 to 9-week food consumption.
- Line E - selected for decreased 5 to 9-week food conversion ratio (FCR, i.e. food/gain)
- Line C - randomly selected control line.

Complete details of the selection experiment with responses in the performance traits to the fifth generation of selection are given by Pym and Nicholls (1979). Details of correlated response in body composition are given by Pym and Solvyns (1979) and a study of energy metabolism in the four lines at the third generation was reported by Pym and Farrell (1977).

Response in the performance traits

Direct and correlated responses in weight gain (WG), food consumption (FC) and food conversion ratio (FCR), to the seventh selected generation are shown in Fig. 1.

The main features of the responses are i) the complete lack of correlated response in food consumption in the E line which combined, with the moderate correlated increase in weight gain in this line resulted in a substantial decrease in FCR (i.e. improvement in efficiency), ii) the substantial direct response in FC in the F line combined with only moderate increase in WG in this line resulting in a considerable increase in FCR and iii) a moderate improvement in efficiency in the W line which was only about half that of the E line.

Realised heritability and genetic correlation estimates calculated to generation 7, are shown in Table 1.

TABLE 1 Realised heritability and genetic correlation estimates calculated from responses to generation 7

	WG	FC	Trait FCR
WG	0.32	+0.63	-0.54
FC		0.40	-0.04
FCR			0.22

The genetic correlation estimate of -0.54 between WG and FCR agrees with other published estimates (e.g. -0.51, Wilson 1969), and although of moderate size, indicates considerable variation in feed efficiency independent of weight gain. While selection for feed efficiency alone may not optimise response in body weight, there is a considerable saving in food.

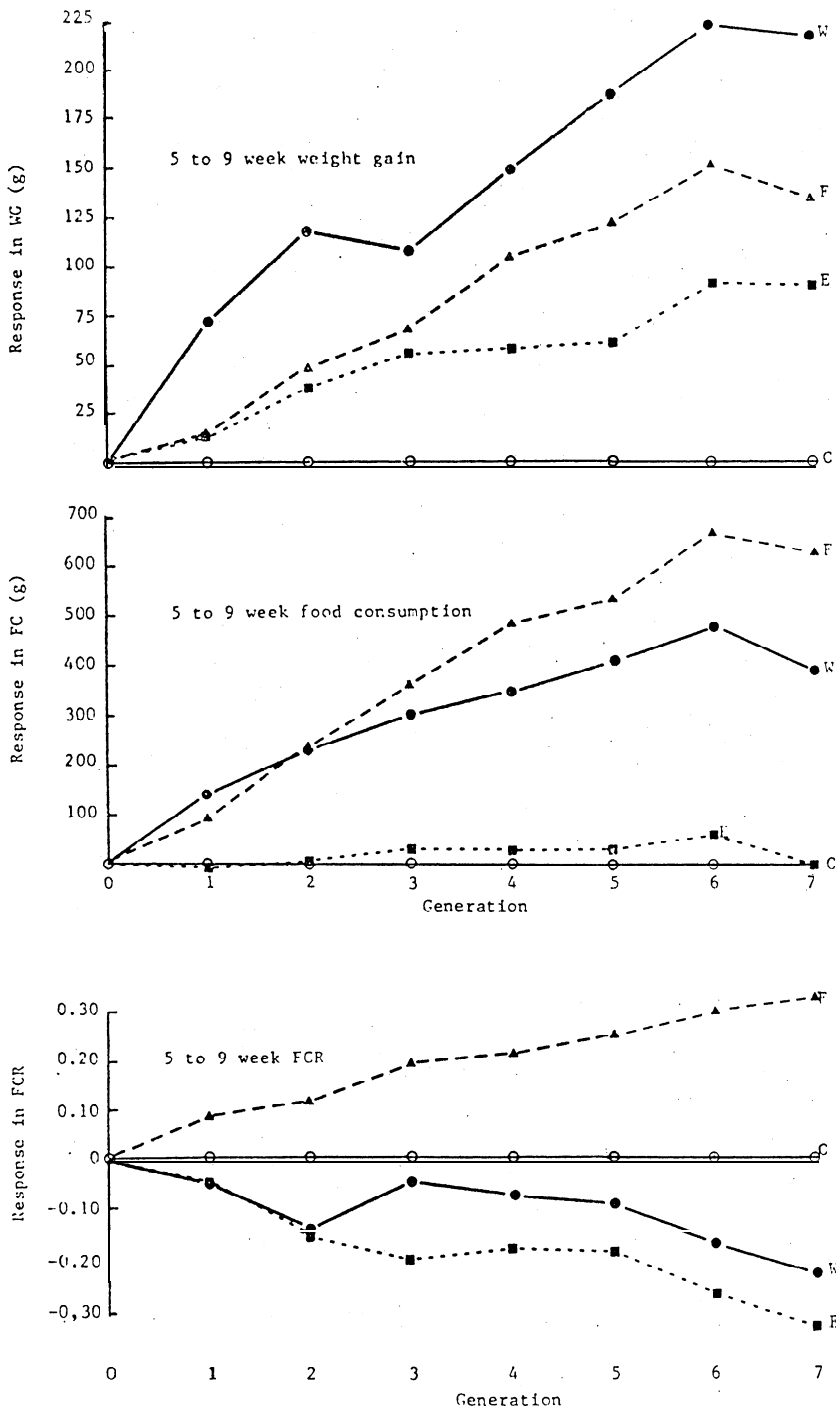


Fig. 1. Direct and correlated responses in WG, FC and FCR over 7 generations of selection in the W, F and E lines.

Selection for economic efficiency

As suggested earlier there would seem to be good reason to combine selection for growth rate and feed efficiency in such a way as to optimise economic response. Possible ways of achieving this were considered by Pym and James (1979). In that report, predicted responses to selection for i) body weight alone ii) an index incorporating individual bodyweight and food consumption and iii) an index incorporating individual bodyweight and sire family average food consumption, were compared. The assumptions made in predicting responses to selection were

given in that report.

The results indicated that sire family average food consumption record made little contribution to selection response. There was, however, an approximate 20% increase in predicted economic response when individual food consumption was used in the index. This was due to a slight reduction in growth response compared to selection for 9WW alone but with almost no response in food consumption. Relative responses in heavier commercial lines of broilers to selection at 7 weeks of age with food consumption measured from 3½ to 7 weeks of age should not be appreciably different.

Physiological aspects of feed efficiency

Variation in feed efficiency independent of growth rate can presumably be the result of variation in the following factors.

- i) Variation in external losses, i.e. food spillage
- ii) Variation in metabolisability of dietary energy
- iii) Variation in the availability of metabolisable energy
- iv) Variation in maintenance requirements
- v) Variation in the partitioning of body components (fat, protein and water).

With due care factor (i) can be eliminated from consideration by use of well designed and well managed feeders.

(i) Energy metabolism The contribution of factors (ii), (iii) and (iv) towards line differences in response to the performance traits was tested in a respiration calorimetry study in 1974 with male chickens sampled from the third selected generation. The design of and results from this study are reported in some detail by Pym and Farrell (1977). I will simply summarise the main findings.

- a) Metabolisability of dietary energy was 0.8 percentage points higher in the E line than in the three other lines.
- b) Fasting heat production and energy loss were higher in the F line than in the W, E and C lines.
- c) Nitrogen loss during starvation was greater in the F line than in the W and E lines.
- d) There was no significant difference between the lines in availability of metabolisable energy as measured by the slope of the regression of energy balance on ME intake (kJ/kgW/d).
- e) Daily maintenance energy requirements (kJ/kgW) for the four lines were calculated to be : W 860; F 937; E 796 and C 810..
- f) When only information above maintenance was considered there was a diminishing increment relationship between energy balance and ME intake.
- g) Using multiple regression analysis, the efficiency of utilisation of ME was calculated to be 64% for protein synthesis and 89% for fat synthesis.
- h) At zero nitrogen balance, daily ME intake (kJ/kgW) was higher in the F line (642) than in the W (566), E (525) and C (542) lines.
- i) When only information above maintenance was considered there was a diminishing increment relation between N balance and ME intake for lines W, F and C, but linear for line E.

- j) At zero energy balance the line average net synthesis of protein was 8.2 g/d and net loss of fat was 4.9 g/d while at an energy balance of 1384 kJ ME/d the average net synthesis of both fat and protein was 22.2 g/d.

Given the higher availability of ME for fat than protein synthesis and a greater rate of increase in fat than protein deposition with increasing ME intake, the diminishing increment relationship of energy balance on ME intake is unexpected. One possible explanation is that maintenance requirement may increase with increasing food intake. Under these circumstances energy retention would tend to decline with increasing level of intake.

The linear relationship between N retention and ME intake in the E line compared to the diminishing increment relationship in the other lines, indicates a special capacity of this line to maintain the rate of protein synthesis with increasing ME intake. There would thus seem to be scope for genetic manipulation to increase the rate of protein synthesis.

The results indicate that differences between the lines can be explained in part at least, by differences in metabolisability of dietary energy, in nitrogen retention and in maintenance energy requirements. No significant line differences in availability of metabolisable energy was observed.

In a recent study of metabolisability of dietary energy in the lines at the ninth selected generation, using an acid insoluble salts technique, line average values were: W 75.4, F 73.8, E 77.0 and C 76.0%. The superiority of the E line over the W and F lines has thus increased since the third selected generation. It is proposed that an open circuit respiration calorimetry study of the lines at the tenth selected generation be conducted later this year at the University of New England.

(ii) Body composition Chickens were sampled for body composition analysis at 9 weeks of age in generations 3 to 8. Details of the procedure and the results in generations 3, 4 and 5 are reported by Pym and Solvyns (1979). The sample each generation was one bird of each sex per sire family per line. Water, fat and protein were determined on samples of mince from each bird. Fat expressed as a percentage of whole body in female chickens sampled from the four lines in generations 3 to 8 is shown in Fig. 2. The picture in males was essentially similar with the difference that % fat was lower in all groups. The results show a substantial difference in fat between the F and E lines with the W and C lines similar and intermediate.

Thus to an age, selection for efficiency and its components has had a marked effect on body composition. However, broiler breeders are more concerned with comparisons at a given weight rather than at an age since broilers are marketed at predetermined weights. To obtain information on body composition comparisons at different weights, a special hatch was taken off at generation 7. Each week between 2 and 14 weeks of age, three birds of each sex per line were sacrificed for body composition analyses.

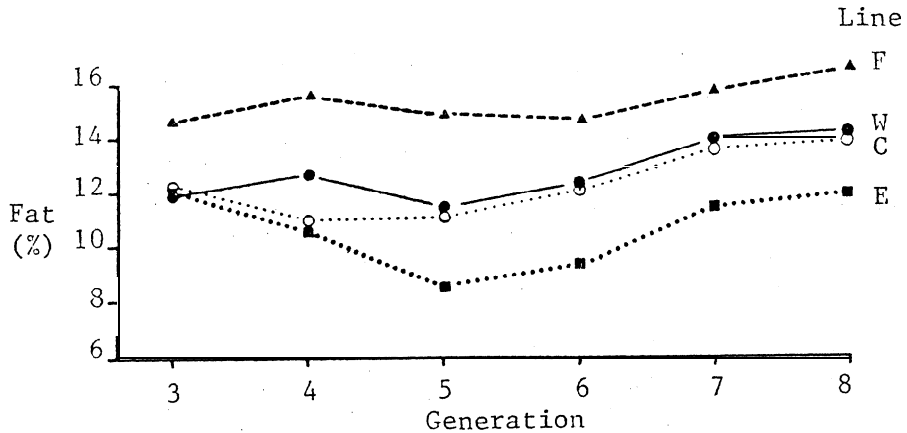


Fig 2. Fat expressed as a percentage of whole body in female chickens sampled from the four lines in generations 3 to 8 at 63 days of age.

Water, fat and protein were determined on each bird and expressed as percentages of the whole body. Regression equations relating the body composition components with bodyweight were calculated within each sex and line. Cubic, quadratic, and linear functions were tested.

Figure 3 shows the regression of % fat on bodyweight in male chickens sampled from the four lines. The picture with females was essentially similar but did show some variation. Differences between the lines varied with bodyweight. At a similar marketing bodyweight, line differences were essentially identical to the differences at 9 weeks of age. There was a rather dramatic reduction in fat between 2.0 and 2.5 kg body-weight in the W line chickens which may have been due to sampling error. Numbers were restricted in this line towards the conclusion and there may have been sampling bias. The coefficients of determination in all the lines were, however, similar and fairly high.

It seems logical that selection for improved feed efficiency would result in a decrease in the energy content of the gain since feed efficiency by definition is a weight ratio (gain/feed) and is not a measure of energetic efficiency. It is, however, erroneous to assume that fat is necessarily more energetically expensive to deposit than protein when considered on a dry weight basis. Although fat has a higher gross energy than protein (38.9 cf 23.4 MJ/kg, Zaniecka 1969), the efficiency of utilisation of ME for fat synthesis is considerably higher than that of protein, as discussed earlier, with the result that the two are deposited with roughly the same energy cost. However, since protein is associated in muscle with about 70% water compared to only about 10% water in fatty tissue, it is much less costly energetically to deposit muscle than fat. In this regard the results of the selection experiment are quite explicable. The E line, which is the most efficient, has more water and protein and less fat whereas the F line, which has very poor feed efficiency indeed, has less water and protein and more fat.

It has been suggested by some that selection for weight gain is simply a manipulation of appetite. It would certainly appear from the responses in weight gain and food consumption and from the correlated responses in body composition that this is not the case. In selecting

for weight gain there is obviously selection for appetite but this is tempered with concomitant selection for feed efficiency, with the result that body composition, as a result of the opposing effects, may be essentially unaltered.

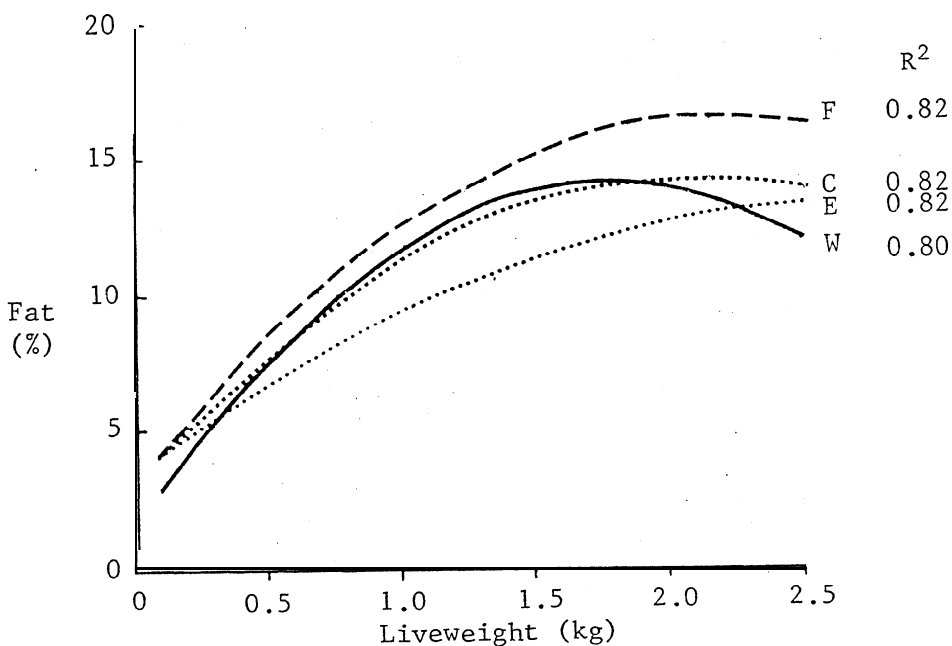


Fig. 3. The relationship between fat (% of whole body) and liveweight in male chickens sampled from the four lines at generation 7.

Although excessive total body fat is undesirable in that it represents a considerable energy cost, a certain amount of fatness is desirable as it provides the carcass with a good finished appearance. The size of the abdominal or retroperitoneal fat pad generally determines whether the carcass is regarded as acceptable or undesirably fat. There appears to be good agreement between abdominal and total fat. Griffiths *et al.* (1978) found moderately high correlations (ave. 0.66) between abdominal fat and total fat in four strains of broilers (range 0.41 to 0.88) and Becker *et al.* (1979) showed that abdominal fat was a good predictor of total fat ($r^2 = 0.82$) and suggested that selection for abdominal fat should decrease fat in other locations without changing the far free weight. In a recent study at the Poultry Research Station, Seven Hills using a strain of broiler chickens, the correlation coefficient between % total body fat and % abdominal fat was +0.86 in males and +0.88 in females.

Results from a recent study with the four selected lines described earlier, show that line differences in total body fat are reflected in differences in abdominal fat as shown in Table 2.

TABLE 2. The effect of selection for weight gain, food consumption and feed efficiency on total body fat and abdominal fat in chickens sampled at similar bodyweights in generation 8

Sex	Line	Selected for	Bodyweight (kg)	Trait	
				% Total body fat	% Abdominal fat
Male	W	↑Weight gain	1.83	11.6	2.84
	F	↑Food consumption	1.80	16.0	3.79
	E	↓FCR	1.75	10.7	1.93
	C	Control	1.60	12.4	2.71
Female	W	↑Weight gain	1.38	13.8	2.98
	F	↑Food consumption	1.38	16.4	4.03
	E	↓FCR	1.38	12.0	2.20
	C	Control	1.25	13.7	2.71

The fat pads contained about 6 to 7% water in all lines and approximately 99% of the remainder was fat.

In a recent study of lipogenesis and adipose tissue cellularity in the four lines at 9 weeks of age in generation 8 (Hood and Pym 1981), differences between the lines in fatness were due to the volume of the adipose tissue cells and not to differences in cell number. Average cell volume was 0.53 nl in the F line compared to 0.31 nl in the E line with the W and C lines intermediate. The number of adipose cells in the abdominal fat pad was higher in lines W and F than in lines E and C. The increased cell number was probably a consequence of more rapid growth rate and is not an important parameter in determining the size of the fat pad.

In vitro rates of lipogenesis were also measured on the chickens using the measurement of the incorporation of glucose-U-¹⁴C into radioactive lipid and the activity of 'malic enzyme', a key enzyme in the supply of NADPH for fatty acid synthesis, as indicators. For both these parameters, line F was the highest, line E the lowest and lines W and C similar and intermediate.

Irrespective of the contribution of genetics towards the presently recognised fat problem in broilers, in view of the sizeable correlated responses in body fat in the food consumption and feed efficiency lines, there is undoubtedly considerable scope for genetic manipulation of body composition by either direct or indirect means. The results suggest that selection incorporating a direct measure of feed efficiency such as the economic index discussed earlier, should go some way towards alleviating the current fat problem whatever its cause.

Feed efficiency and reproductive performance

Correlated response in reproductive performance appears to be quite different in lines selected for growth rate, food consumption and food conversion efficiency. Records were taken of egg production and chicks produced from the matings of the sixth and seventh generation selected parents which produced the seventh and eighth selected generations respectively. The results are shown in Table 3.

TABLE 3 Rate of lay, hatchability and chicks produced after 6 and 7 generations of selection for 5 to 9-week body weight gain, food consumption and feed efficiency

Generation	Line	Selected for	Trait		
			Rate of lay (%)	Hatchability (%)	Chicks produced (as % of control)
6	W	↑Weight gain	50.6	56.6	54.6
	F	↑Food consumption	40.7	62.1	48.2
	E	↓FCR	62.0	68.8	81.3
	C	Unselected control	67.6	77.6	100.0
7	W	↑Weight gain	49.2	46.3	52.9
	F	↑Food consumption	41.2	62.1	59.4
	E	↓FCR	58.6	69.0	93.8
	C	Unselected control	71.0	60.7	100.0

Notwithstanding the limitations imposed by the sampling and pre-selection of the parent birds, the general agreement of the data from the two generations and the magnitude of the line differences indicates that selection for improved feed efficiency, apart from other considerations, may have very real benefits in the relative effect upon reproductive performance.

A study of reproductive performance of birds in the four lines at the tenth selected generation is presently underway. The study will be completed in July 1982 when the birds are 66 weeks of age.

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