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**Selecting Broilers for Low or High
Abdominal Fat: Genetic, Nutritional
and Environmental Aspects**

A. Cahaner, Z. Nitsan, I. Nir, H. Marks, K. Washburn

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Names of investigators:

Principal Investigator: Dr. A. Cahaner

Cooperating Investigators: Dr. Z. Nitsan
Dr. I. Nir
Dr. H.L. Marks
Dr. K.W. Washburn

Name and Address of Affiliated Institutions:

Principal Institution:

The Hebrew University of Jerusalem, Faculty of Agriculture,
P.O.Box 12, Rehovot, ISRAEL

Cooperating Institutions:

Agricultural Research Organization, The Volcani Center,
P.O.Box 6, Bet dagan, ISRAEL

U.S. Department of Agriculture, Southern Regional Poultry Breeding
Project, c/o UGA, Livestock-Poultry Bldg., Athens, GA 30602, USA

The University of Georgia, Athens, GA 30602, USA

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Principal Investigator

Institution's Authorizing Official

A. Cahaner

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ABSTRACT

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Excessive fat deposition in broilers is wasteful in terms of dietary energy input, processing yield and cooking losses. The primary objective of the presented research was to select lean and fat broilers, either directly by measuring abdominal fat, or indirectly by selection on feed efficiency or growth rate under altered water/feed ratio. Other topics related to fat deposition in broilers and especially to these lean and fat lines were: genetic control of abdominal fat deposition; juvenile response of lean and fat birds to various nutritional and environmental factors which are known to affect fat deposition; the potential advantage of leaner broilers in feed utilization, carcass composition and quality, and reproductivity.

There was a substantial response to the divergent selection on abdominal fat with no correlated effect on body weight. Similar responses were obtained in the dam (White Rock) and sire (Cornish) stocks. The total weight of the adipose tissues around the gizzard, neck and thighs was highly correlated and almost equal to abdominal fat. As a result of this association, and the equal live body weight of the divergent lines, the increase in the proportion of lean parts in the low-fat line was almost twice the reduction in the proportion of abdominal fat. The reproductivity of the low-fat line was somewhat superior to that of the high-fat line. Abdominal fat was found to be additively inherited; this was indicated by high heritability, high rate of response to selection, and the lack of heterotic effects in both within-stock and between-stocks crosses. It appears that selection against abdominal fat in broilers is very feasible. It would not interfere with selection for body weight, but actually increase meat yield.

Interaction between lines, diets and feeding status were found. An increase in dietary energy was accompanied with a substantial increase in weight of all adipose tissues in the HF but not in the LF line. Increasing dietary fat content by soybean oil supplementation reduced the weight of adipose tissues more in the HF than in the LF line. Similar trends were obtained in the fat concentration of the skin and carcass. When fed a low protein diet, body weight of the HF line was not affected but that of the LF line was depressed markedly. The poly-unsaturated fatty acids concentration in adipose tissues was related both to genetic and nutritional adiposity. Although dietary manipulations affected differently the amount of fat deposition in the HF and LF lines, the fatty acid profiles of the adipose tissues in the lines were affected similarly. The effect of food restriction on adiposity was more pronounced in the HF than in the LF line.

USA

Variation in lipogenic enzyme activity could not be clearly associated with the variation in degree of fatness in the stocks used. Growth hormone and T3 levels were negatively associated with fatness. Basic information was obtained concerning the genetic variation in feed efficiency. Preliminary evidence indicated that increased environmental temperatures result in a loss of the association of decreased carcass fat and improved efficiency.

Normal and dwarf chickens fed either regular (.4%) or high (1.6%) salt diets were selected four generations for high 8-week body weight. Selection differentials, gains, and heritabilities were greater in lines selected under the .4% salt environment. When tested females were fed .4% salt diets, those from lines selected after being fed 1.6% salt diets had from 13 to 29% less abdominal fat than contemporaries from the line selected after being fed .4% salt diets. Progeny of lines selected under the .4% salt environment tended to have higher body weights and consume more feed than progeny from lines selected under the 1.6% salt environment.

OBJECTIVES OF THE ORIGINAL RESEARCH PROPOSAL

ISRAEL

- #1 To select for low or high abdominal fat in female and male parent lines of broilers; to study the rate of genetic response and to evaluate selection limits.
- #2 To study the genetic control of abdominal fat: non-additive effects (heterosis), reciprocal differences (sex linkage and/or maternal effects) and correlated changes.
- #3 To study the juvenile response of the selected lines and their crosses to various nutritional and environmental factors which are known to affect fat deposition.
- #4 To study and quantify the potential advantage of leaner broilers in feed utilization, processing efficiency and carcass quality, and correlated responses in other economically important traits such as viability and reproductivity.
- #5 To obtain basic information on anatomical and physiological properties of low fat and high fat lines: feed utilization; optimal C/P ration; response to energy concentration in diet; response to feeding regimes: restriction and starvation; optimal environmental temperature; water/water ratio; behavior; adipose tissues distribution.

Most of these objectives were achieved during the course of the three and a half years of research. However, their presentation in the following report is arranged somewhat differently. A chapter is devoted to objective #1 and another one to objective #2. The chapter dealing with objective #3 covers also the nutritional aspects of objective #5. A paper on the reproductive performance of the selected lines (objective #4) is included in the report. Another paper which is part of the report deals with adipose tissues distribution (objective #5) and carcass quality (objective #4).

USA

- (a) To determine the effectiveness of selection on feed efficiency for decreasing abdominal fat in broilers.
- (b) To study the influence of environmental temperature on genetic variation in carcass fat achieved by selection for efficiency.
- (c) To select for increased 8-week body weight under high and normal water/feed ratio environments.
- (d) To determine the influence of different water/feed ratio environments on abdominal fat levels and on efficiency of feed utilization.

The actual research in the US followed a more basic approach to the subject than was detailed in the original objectives. This approach involved the study of various plasma hormones and lipogenic enzymes that might explain the reasons for differences in fatness. These studies included commercial broilers differing slightly in growth, dwarf vs. nondwarf commercial broilers, dwarf vs nondwarf randombreds and lines selected for divergence in oxygen consumption. It was not possible to carry out the longer term selection for efficiency because the broiler grandparent line used could not be reproduced in sufficient numbers. In the report, six chapters are related to objective (a), two to (b), one to (c) and one to (d).

DIRECT AND CORRELATED RESPONSES TO DIVERGENT SELECTION ON ABDOMINAL FAT IN BROILERS' DAM AND SIRE STRAINS

INTRODUCTION

Excessive fat deposition in broilers has been widely recognized as one of the industry's primary problems. This fat represents a waste product to consumers who are increasingly concerned about the nutritional and health aspects of their food. In response, processors have started recently to trim some of the fat from broilers, as well as from the further processed products and deboned meat. This means a loss to the producers or a price increase.

Abdominal fat has been regarded as the main source of waste, although several other adipose tissues cannot be ignored. Since abdominal fat is highly correlated with these tissues (Ricard et al., 1983; Cahaner et al., 1986a) and with total carcass lipids (Leclercq et al., 1980; Leclercq and Simon, 1982; Chambers and Fortin, 1984; Whitehead and Griffin, 1984), it is used as the main criterion of excessive fat deposition in broilers.

Although the amount of fat can be reduced by manipulation of nutrition and management, it is generally accepted that a genetic and breeding approach is a more feasible long term solution (Leenstra, 1986). The reported moderate to high heritability estimates for abdominal fat suggested that it could be reduced by breeding, although adverse effect on body weight gain had been expected due to the positive correlation between the two traits (Becker, 1978; Siegel, 1984).

Several studies were conducted to evaluate nondestructive methods for measuring fat, a necessity for mass selection programs. The amount of fat in spent parents under standard restricted feeding was not associated with the juvenile fat deposition of their offspring (Gyles et al., 1984). Skin-related measurements were impractical (Mirosh et al., 1980; 1981), and Pym's cloaca calipers (Pym and Thompson, 1980) were found inadequate by other researchers. The most successful nondestructive method was reported by Whitehead and Griffin (1984) who, after three cycles of divergent selection using blood VLDL, obtained lines that differed by 38% in total lipids and by 49% in abdominal fat. The realized heritability of the selection criterion was .4, but realized genetic correlation with abdominal fat was not reported.

In 1976, an experimental family selection for high or low abdominal fat was initiated in France (Leclercq et al., 1980). After seven generations, the fat line had four times more abdominal fat and 72% more total lipids than the lean line (Leclercq, 1983; 1984). The nutritional and physiological characteristics of these lines were studied intensively as well as some reproductive traits and meat quality. On the other hand, genetic aspects were given little attention: there were no line crosses, no replicated selection lines and no unselected control line in this program.

A selection program on abdominal fat was initiated in Israel in 1980 (Cahaner et al., 1985). Based on studies with a White Rock commercial stock, selection for low abdominal fat was expected to reduce fat deposition and increase meat yield of broilers (Cahaner and Nitsan, 1985). The selection

program was basically similar to that of Leclercq and his collaborators. Nutritional, environmental, physiological and reproduction aspects of the selected lines were intensively studied (Cahaner et al., 1985, 1986a, 1986b; Nitsan et al., 1986), but more emphasis was given to the genetic aspect. The latter is the topic of this section and the next one, while another section and two papers are devoted to the formers.

MATERIALS AND METHODS

Stocks

The sire-family divergent selection on abdominal fat was initiated in a 'White Rock' stock in 1980 (Cahaner et al., 1985). Similar selection was initiated in a 'Cornish' stock in 1984. The 'White Rock' base population was derived from a commercial female grandparent line in 1977 and was kept since then with minimal selection for body weight. The 'Cornish' base population was derived directly from a commercial male parent line. The same selection program has been applied to both stocks. It consists of a set of three lines from each stock: low fat (LF) and high fat (HF) selected lines, and an unselected control line (CF).

Selection procedure

The scheme planned for each cycle of the divergent sib-selection is presented in Table 1. Each of the 18 sires per selected line, and 10 sires per control line, is mated (by artificial insemination) to 4 dams and produces a total of 36 offspring, half males and half females, in two full-pedigreed hatches. Six males and 6 females per sire are obtained in the first hatch, accumulating to 216 chicks per selected line and to 552 chicks per three-line set of each stock. All these chicks are slaughtered when the flock reaches average marketing weight, usually around 7 weeks of age, and their body and abdominal fat weights are recorded. In the second hatch, two weeks later, 24 more offspring are obtained from each sire, a total of 1104 chicks for the entire three-line set. In both hatches, day-old chicks are wing-banded and raised intermingled in a conventional brooder/broiler house. Flock management follows the Israeli industry's standards with regard to nutrition, vaccination, etc.

Sire-families are ranked within each selected line according to the average relative weight of abdominal fat (% of body weight) of the first-hatch offspring. Males and females from the second-hatch are selected to reproduce the lines immediately when this information is available; they are about 6 weeks of age at that time. The heaviest males and all females from the six families with the lowest abdominal fat in the LF line, and from the six families with the highest abdominal fat in the HF line, are selected for reproduction. Three males and 4 females are saved for reproduction from each sire-family in the control line.

The breeding males from the control line are selected by body weight so that their selection differential is similar to that of the males selected in the LF and HF lines. It assures that similar low-intensity selection for growth rate is performed on males in all lines. The number of males kept at 6 weeks of age is two times larger than the number actually needed for reproduction, to accommodate for mortality and infertility. These problems

are less severe in females and therefore the families have no excess number of females. However, reserve females are kept from families ranked after the six top ones, and used when needed."

The selected males and females are immediately placed at random in individual battery cages in an open-air shed, where they are reared under a standard restricted feeding program with a commercial diet. There is a gradual increase from 60 g of feed/day/bird at 6 weeks to 100 g feed/day/bird at 20 weeks of age, followed by an accelerated increase up to 155 g/day at 26 weeks of age, when females start to lay, and thereafter. Matings within lines are performed when all the hens are laying, usually around 32 weeks of age. Four hens are assigned to each male at random, but half- and full-sib matings are avoided. Artificial insemination is performed for one month. About 20 and 40 eggs per sire-family are set for the first and second hatches, respectively. While the chicks from the first hatch are used to measure abdominal fat, the parents of the next generation are selected from the chicks hatched 2 weeks later. According to this scheme there is a 9-month interval between two consecutive generations.

RESULTS AND DISCUSSION

The base populations

The White Rock base population was evaluated in order to determine the optimal genetic approach to improve meat yield (Cahaner and Nitsan, 1985). The relative weights of the breast and abdominal fat were studied, since the former is the broiler's most valuable part while the latter is the most wasteful one. The relative weight of abdominal fat (% of body weight) was the most variable trait and had the highest heritability (.77), while breast relative weight had limited variation and intermediate (.45) heritability (Table 2). Since breast relative weight was highly correlated with body weight, and the latter had greater variation and heritability (Table 2), it was concluded that selection for % breast will have no advantage over selection for body weight. On the other hand, the genetic correlation between % abdominal fat and body weight was found to be less than .3, and therefore one can expect that genetic improvement in meat yield can be achieved by selection against abdominal fat, combined with selection for body weight. This expectation was indeed the basis for our selection experiment. The situation of the Cornish base population in regard to the genetic variation of body weight and abdominal fat was similar to that of the White Rock one: body weight with CV=8-9% and $h^2=.48$; % abdominal fat with CV=29-31% and $h^2=.92$ (Table 2). Although breast data was missing, one could expect the Cornish stock to be similar to the White Rock also in this aspect, and hence the same selection approach was taken with the male parent stock.

Actual vs. planned selection

So far, 7 cycles of selection were executed in the White Rock lines, and 3 in the Cornish lines. In each of these cycles, the actual numbers of families and individuals per line (Table 3) deviated to some extent from the selection scheme. Usually they were lower than planned due to accidental events during the life cycle of each generation, such as mortality prior to sexual maturity. In both stocks there were only 12 sire families per line in

the first generation (S1), but the number was increased up to about 18 in later generations. The control line (CF) of the White Rock stock was derived from the base population after two cycles of selection took place already. The CF line of the Cornish stock was derived from the same flock as the selected lines.

Generation intervals were 9-10 month long, as allowed by the sib-selection program, except in three cases (Table 4). In the S1 generation (White Rock), the limited facilities forced sire-evaluation rather than sib-selection. Only selected sires were supposed to produce offspring in the 2nd hatch, and hence matings were to start only after abdominal fat data were obtained from 1st hatch offspring. Such a program increases generation interval from 9 to 12 months, with the advantage of hatching and raising 2nd hatch offspring from proven sires only. However, by the time fat data were available, some of the top-ranked sires died or were infertile, and also the number of laying hens was reduced. As a result, the number of offspring did not allow for selection on abdominal fat but only for body weight among males (Cahaner et al., 1985). The longer interval and the loss of a generation resulted in a gap of almost two years between S1 and S2 of the White Rock lines. Following this experience, the sire-evaluation approach was abandoned. Offspring of all sires were obtained in the 2nd hatch, just two weeks after the 1st one (Table 1). More chicks were raised in each generation, but the time interval between generation was reduced and the entire program became less vulnerable to late mortality and infertility. As an additional safety, sires and dams were always kept up to the age of one year. The Cornish S3 and the White Rock S6 generations were reproduced from one-year old parents, overcoming technical problem in the former case, an a genetic one, which will be discussed later, in the latter.

The various generations of the two stocks were slaughtered at different ages, and reached different body weights and % abdominal fat (Table 4). Some of these differences are genetic, e.g. the higher growth rate of the Cornish stock compared to that of White Rock, which reflects the basic superiority of the Cornish breed and the higher commercial status of its S0 flock in the present study. However, the variation from generation to generation within stocks, especially from S2 to S6 of the White Rock lines, was mainly due to variation of environmental conditions. Generations S0 to S3 of the White Rock lines were kept in an old experimental farm. The housing there barely reduced the extreme climatic differences between seasons which affected growth rate and fat deposition. In 1984, the Cornish lines were initiated in a new farm with an improved housing. The new farm was kept free of Mycoplasma galisepticum. Therefore, in order to transfer the White Rock lines to the new farm, hatching eggs with S4 embryos had to be treated by heat and antibiotics to eradicate the MG. Egg treatments affected hatchability and hence reduced the size of the lines, mainly the HF one, to a degree that a significant inbreeding could not be avoided. The treatment also reduced growth rate of the chicks - the two sexes averaged only 1507g at 8 weeks of age (Table 4). While body weights of the Cornish lines in all generations, and of the White Rock's S6 and S7 were quite consistent, % abdominal fat of the control line fluctuated also in the new farm, probably as a result of an array of minor differences in environment, age, experimental procedure, etc. Therefore mean % abdominal fat of each selected line was related to its control line or to the divergent line.

Initial response to selection

In both stocks, the response to the first cycle of selection was very significant: % abdominal fat of the high fat (HF) line exceeded that of the low fat (LF) line by about one-half (51-57%) and one-third (33-38%) in the White Rock and Cornish stocks, respectively (Table 5). First cycle results also indicated that response of abdominal fat was similar in males and females, and that practically there was no correlated response in body weight. The similar response of the two sexes and lack of differences between lines in body weight characterized all generations in both stocks. Accordingly, results were averaged over sexes, and no separate attention was given to abdominal fat weight.

Calculation of selection differentials in a sib-selection program is troublesome, especially when matters are complicated by accidental faults, change of locations, etc. Therefore realized heritabilities are presented only for the first cycle of selection in both stocks, assuming symmetric divergent responses. The estimates (Table 6) were very high (.73 and .98 in White Rock and Cornish, respectively) and almost identical to those calculated by analyses of variance in the base populations (.77 and .92, Table 2). Although the former estimates are of half-sib means (h^2_{ms}) and the latter of individual (h^2), they have similar expectation when the coefficient of relationship (r) is .25 (half-sibs), intra-class correlation (t) is .2 (i.e. $h^2=.8$), and there are 16 sibs per family (n), since $h^2_{\text{ms}}=h^2nr/[1+(n-1)t]$ (Cahaner et al., 1985).

Long term responses

Since there were so far only 3 cycles of selection in the Cornish lines, their S3 generation was compared to the White Rock's S3 generation. Both stocks had control lines at that stage. Females' data were chosen to demonstrate the distribution of individuals within lines. Cornish females (Table 8) were much heavier than White Rock females (Table 7) at 7 weeks of age, and consequently had higher % abdominal fat. However, the relative distribution of % abdominal fat within lines, as well as the differences between line means, were similar in both stocks. The amount of abdominal fat in the HF lines was about twice that of the LF lines, but their phenotypic values overlap. The control lines (CF) had intermediate means and distribution. When compared to the CF lines which represent the base populations, it seems that 3 cycles of selection for low or high abdominal fat mainly eliminated the 'opposite' phenotypes from the selected lines (LF and HF), while individuals with lower (in LF) or higher (in HF) phenotypic values were scarce.

As for the genetic values, they are indicated by sire-family means. Their range and standard deviation in each selected line at each generation, averaged over sexes, are presented in Table 9. The genetic response of the selected lines, i.e. their deviations from CF at each generation, are also given in Table 9. However, since the CF lines were limited in size, their means could be affected by sampling error. Therefore the total differences between the selected lines (HF-LF) are also presented. The mean % abdominal fat of the CF lines markedly differed between generations and therefore differences between lines were expressed relative to the CF line mean in the corresponding generation (%CF).

There was a gradual response to selection in generations S1, S2 and S3 of the Cornish and the White Rock lines. When compared to CF, the reduction in abdominal fat in the White Rock LF line was larger than the increase in the HF line, while the opposite asymmetry was observed in the Cornish lines (Figure 1). However, while total divergence, relative to CF mean (%CF), between the White Rock selected lines was larger than that of the Cornish lines in S1, its increase in S2 and S3 was similar and linear in both stocks (Figure 2). The change in the range of sire-family means within lines was also similar in the two stocks. The LF and HF ranges overlapped in S1, matched top to bottom in S2 and were well separated in S3 (Table 9). In both stocks, a substantial reduction in between-family standard deviations (S.D.) was observed in the LF and HF lines from S1 to S2, and only in the LF line in later generations (Table 9).

After three generations of increased divergence, the difference between the White Rock selected lines decreased from S3 to S6. It seems to be associated with the transfer of the lines from one farm to another one. Anti-MG treatments of hatching eggs reduced hatchability substantially. Families were lost and S4 flocks were too small to allow for further selection on abdominal fat. In addition, a significant reduction in growth rate of all lines was observed (Table 4). Based on another study with the same stock (Cahaner, 1984), this reduction was attributed to the effect of inbreeding which is expected in lines with small effective population size, and could only be accelerated by the 'bottle neck' of the population reduction due to the change of farms.

To overcome a possible inbreeding, S5 females from all three White Rock lines were mated with males taken directly from a commercial grandparent line. This line was the source of the White Rock base population, but it has been continuously selected for growth rate. As expected, the introgression of foreign sires in S5 reduced the difference between the lines in abdominal fat in S6 (Figure 1), but improved growth rate and increased genetic variation of abdominal fat, as indicated by wider ranges and larger SD of sire-family means (Table 9). In S7, the difference between the LF and HF lines was increased for the first time since S3 (Figure 1) while growth rate further increased (Table 4), probably due to the additional genetic variation and the remove of inbreeding.

Association with body weight

The phenotypic correlations (r_F) between body weight and abdominal fat weight - absolute (g) and relative (%) - varied between lines, generations and stocks (Table 10). Most of this variation was probably random due to small sample size, mainly in the CF lines (Table 3). But it also seems that higher r_F were associated with lower mean body weight, such as White Rock's S3 and especially S4 generations. However, when averaged over generations, similar estimates of r_F were obtained from all lines. Regardless of stock, the average correlations of body weight with weight and % of abdominal fat weight were about .40 and .12, respectively (Table 10). Genetic correlations between abdominal fat and body weight were not calculated since data available were not sufficient for reliable estimates. However, the lack of significant and consistent difference in body weight between LF and HF lines in all generations of the two stocks indicates that there was no realized genetic correlation between these two traits. The low estimate of phenotypic correlation (.12) supports this conclusion.

Association with meat yield

The matter was tested in S3 generation of the White Rock and Cornish lines. In the two cases the proportion of the lean parts was higher in the low fat line than in the high fat line (Table 11). On the average, differences between lines in relative weight of the valuable lean parts (thighs, drumsticks and breast) were 1.8 times larger than differences in abdominal fat. In another study with the White Rock S3 lines, regression coefficient of gizzard+sartorial+mesenterial+neck adipose tissues on abdominal fat was .75% (Cahaner et al., 1986a) which means that a reduction by 1% in abdominal fat was associated with additional reduction of at least .75% in the other adipose tissues. Since all lines had similar body weights, a reduction of 1% of abdominal fat plus .75% of other adipose tissues in the low fat lines was expected to increase the proportion of the lean parts by 1.75% of body weight.

CONCLUSIONS

1. Based on the direct response to 3 cycles of divergent selection on abdominal fat with no effect on body weight, it appears that selection against abdominal fat in broilers is very feasible and should not interfere with selection for live body weight.
2. The correlated change in the proportion of lean parts was almost twice the change in the proportion of abdominal fat. It appears that selection against abdominal fat actually increased meat yield, as originally intended.
3. There was a close agreement between the White Rock and the Cornish results through three cycles of the experimental selection on abdominal fat. The similarity showed up in all aspects and phases of selection.

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Figure 1. Differences in abdominal fat between each selected line (LF or HF) and the control line as % of its mean (CF), in each generation of the White Rock and Cornish lines

Figure 2. Differences in abdominal fat between the divergent lines, expressed as % of the control line mean (CF), in each generation of the **White Rock** and **Cornish** lines

Table 1. The sire-family divergent selection scheme: number of male (M) and female (F) offspring per sire-family and per selected line at various stages.

Stage	Age (wks)	Sire family ¹⁾		Selected line		All 3 lines
		M	F	M	F	M+F
Chicks hatched ²⁾	0	18	18	324	324	1656
Abdominal fat tested	7	6	6	108	108	552
Available for selection	6	12	12	216	216	1104
Selected from top 6 fam.	6	6	12	36	72	276
Reproduction of lines	32	3	12	18	72	230

¹⁾ Eighteen sire-families in each of the two selected lines and 10 families in the control line.

²⁾ Two hatches per generation: chicks for abdominal fat test hatch first and those for selection hatch 2 weeks later

Table 2. The White Rock and Cornish base populations: means, coefficients of variation (CV), and heritabilities of body weight, % abdominal fat and % breast

Trait	Sex	Mean	CV (%)	Heritability
<u>White Rock (age - 9 wks; year - 1980)</u>				
Body weight (=bw, g)	M	2103	9	.55 ± .23
	F	1717	8	
Abdominal fat (% of bw)	M	1.71	34	.77 ± .27
	F	2.10	31	
Breast (% of bw)	M	16.2	5	.45 ± .21
	F	16.5	7	
<u>Cornish (age - 7 wks; year - 1984)</u>				
Body weight (=bw, g)	M	2200	9	.48 ± .19
	F	1750	8	
Abdominal fat (% of bw)	M	1.72	31	.92 ± .31
	F	2.13	29	

Table 3. Numbers, by stock (White Rock, Cornish), line (LF, CF, HF) and generation (Sn), of sire-families and chicks (males+females) slaughtered for abdominal fat measurement

Gener- ation	Sire-families				Slaughtered chicks			
	LF	CF	HF	Total	LF	CF	HF	Total
<u>White Rock</u>								
S1	12	--	12	24	183	---	125	308
S2	18	--	18	36	126	64	134	324
S3	22	9	19	50	214	85	155	454
S4	15	9	12	36	220	61	118	399
S5	18	10	17	45	166	76	154	396
S6	18	10	14	42	175	54	125	354
S7	20	10	20	50	226	95	226	547
<u>Cornish</u>								
S1	12	10	11	33	141	118	155	414
S2	16	10	16	42	250	123	241	614
S3	18	10	18	46	161	105	172	438

Table 4. Hatch date; and age, body weight (averaged over all lines and sexes), and % abdominal fat (mean of control line) at slaughter, by stock and generation

Stock and generation	Hatch date (m/y)	Slaughter age (d)	Body weight (g)	Abdominal fat (%)
<u>White Rock</u>				
S0	Aug. 80	63	1910	1.90
S1	June 81	61	1802	1.58
S2	May 83	61	1832	1.71
S3	Feb. 84	52	1703	1.35
S4	Oct. 84	56	1507	1.66
S5	July 85	56	1748	1.47
S6	July 86	53	1866	2.00
S7	Apr. 87	52	1898	1.72
<u>Cornish</u>				
S0	Apr. 84	49	1975	1.92
S1	Jan. 85	53	2035	1.84
S2	Nov. 85	52	2040	1.56
S3	Jan. 87	49	2005	1.71

Table 5. Mean body weight and % abdominal fat of males and females after one cycle of selection for low (LF) or high (HF) abdominal fat among White Rock and Cornish populations during 1980 and 1984, respectively

Trait	M a l e s			F e m a l e s		
	LF	HF	HF-LF	LF	HF	HF-LF
<u>White Rock lines (61 d)</u>						
Body wt, g	1897	1935	38 (2%) ¹⁾	1668	1708	40 (2%)
Ab. fat, %	1.07	1.68	.61 (57%)	1.42	2.15	.73 (51%)
<u>Cornish lines (53 d)</u>						
Body wt, g	2221	2241	20 (1%)	1859	1825	-34 (-2%)
Ab. fat, %	1.41	1.95	.54 (38%)	1.75	2.33	.58 (33%)

¹⁾ (HF-LF)x100/LF

Table 6. Calculation of realized heritability from the first cycle of divergent selection on abdominal fat in the Cornish and White Rock populations (averaged over sexes)

Population	Selected parents ¹⁾			S1 lines		
	LF	HF	S ²⁾	LF	HF	R ³⁾
<u>Means and differences (% abdominal fat)</u>						
White Rock	1.69	2.60	.91	1.25	1.91	.66
Cornish	1.68	2.25	.57	1.58	2.14	.56
<u>Realized heritability (R/S)</u>						
White Rock	.66 / .91 = .73					
Cornish	.56 / .57 = .98					

¹⁾ Calculated from sacrificed sibs

²⁾ Selection differential: S = HF-LF (parents)

³⁾ Response to selection: R = HF-LF (offspring)

Table 7. Mean and distribution of % abdominal fat of 7 weeks old White Rock females from the low fat (LF), high fat (HF) and control (CF) lines after 3 cycles of selection

Abdominal fat (%)

Line mean :	.93	1.61	1.96
Deviation from CF :	-.68 (42% of CF)	--	+.33 (22% of CF)
HF - LF :	1.03 (64% of CF)		
Mean body wt (g) :	1527	1542	1512

Table 8. Mean and distribution of % abdominal fat of 7 weeks old Cornish females from the low fat (LF), high fat (HF) and control (CF) lines after 3 cycles of selection

Abdominal fat (%)

Line mean :	1.36	1.91	2.48
Deviation from CF :	-.55 (29% of CF)	--	+.57 (30% of CF)
HF - LF :	1.12 (59% of CF)		
Mean body wt (g) :	1820	1862	1842

Table 9. Abdominal fat (% of bw): sire-family range and standard deviation (S.D.) of the LF and HF lines, and their deviations (L-C; H-C) from the control line (CF) mean.

Gener- ation	<u>Line differences</u>			<u>R a n g e s</u>		<u>S.D.</u>	
	L-C	H-C	H-L (%CF) ¹	LF	HF	LF	HF
<u>White Rock</u>							
S1	-.33	.33	.66 (42%)	.91-1.67	1.35-2.49	.24	.33
S2	-.54	.36	.90 (53%)	.77-1.72	1.71-2.48	.21	.21
S3	-.56	.37	.93 (69%)	.57-1.16	1.29-2.09	.16	.21
S4	-.59	.22	.81 (52%)	.56-1.22	1.33-2.22	.17	.26
S5	-.43	.24	.67 (46%)	.78-1.32	1.46-2.14	.15	.22
S6	-.44	.32	.76 (38%)	1.25-1.96	1.87-2.80	.23	.27
S7	-.43	.45	.88 (51%)	.85-1.65	1.75-2.57	.18	.25
<u>Cornish</u>							
S1	-.26	.28	.54 (29%)	1.19-1.91	1.53-2.44	.25	.28
S2	-.28	.44	.72 (46%)	.98-1.61	1.71-2.46	.18	.24
S3	-.45	.57	1.02 (60%)	.99-1.49	1.77-2.72	.16	.25

¹ %CF = (HF-LF)x100/CF

Table 10. Phenotypic correlations (averaged over sexes) between body weight (bw) and abdominal fat (weight and % of bw) in the low fat (LF), high fat (HF) and control (CF) lines in all generations of the two stocks

Gener- ation	<u>Ab. fat weight</u>			<u>Ab. fat (% of bw)</u>			Mean bw ¹⁾ (g.)
	LF	CF	HF	LF	CF	HF	
<u>White Rock</u>							
S1	.33	-	.44	.07	--	.15	1802
S2	.29	.33	.45	.04	.03	.23	1832
S3	.33	.60	.52	.10	.36	.24	1703
S4	.50	.76	.57	.30	.55	.31	1500
S5	.27	.17	.39	.02	-.28	.12	1748
S6	.39	.35	.30	.16	.01	.01	1866
S7	.29	.35	.36	.03	.07	.11	1898
Average	.34	.43	.43	.10	.12	.17	--
<u>Cornish</u>							
S1	.47	.55	.41	.20	.17	.10	2035
S2	.46	.34	.37	.21	.08	.03	2040
S3	.32	.28	.41	.06	.04	.14	2005
Average	.42	.39	.40	.16	.10	.09	--

¹⁾ Generation mean body weight averaged over lines and sexes

Table 11. Differences between the low fat (LF) and high fat (HF) lines in traits related to carcass quality

Trait	M a l e s			F e m a l e s		
	LF	HF	LF-HF (%) ¹	LF	HF	LF-HF (%)
	----- % of live body weight -----					
<u>White Rock</u>						
Abdominal fat	.6	1.2	-.6 (-67)	.8	1.6	-.8 (-67)
Breast	15.3	14.5	.8 (5.4)	15.8	15.1	.7 (4.5)
Lean carcass	75.9	74.5	1.4 (1.9)	71.9	69.9	2.0 (2.8)
<u>Cornish</u>						
Abdominal fat	1.1	2.2	-1.1 (-67)	1.8	3.1	-1.3 (-53)
Breast	16.4	15.9	.5 (3.1)	17.1	16.4	.7 (4.2)
Thighs+Drums	24.6	23.4	1.2 (5.0)	24.3	22.7	1.7 (7.2)
Th.+Dr.+Br.	41.2	39.5	1.7 (4.2)	41.4	38.9	2.5 (6.2)

¹ Difference as % of lines mean: $(LF-HF) \times 100 / .5 \times (LF+HF)$

CROSSES AMONG BROILERS' DAM AND SIRE LINES SELECTED FOR LOW OR HIGH ABDOMINAL FAT

INTRODUCTION

Fat deposition in broilers has been shown to be highly heritable and very responsive to selection. Lean broiler lines were established by selection against abdominal fat (Leclercq et al., 1980; Leclercq, 1984; Cahaner et al., 1985, 1986; Leenstra and Pit, 1987) and against plasma lipids (Whitehead and Griffin, 1984). The successful selection experiments indicate that fat deposition can be genetically reduced in broilers' parental lines. However, commercial broilers are hybrids and their performance may deviate from the mean additive genetic value of the dam and sire parental lines due to dominance. Therefore the planning of breeding program for leaner broilers, and the prediction of its results, rely on information regarding dominance control of fat deposition, and its direction. In Japanese quail, hybrid offspring had less abdominal fat than their parents (Wyatt et al., 1982). No similar study with the experimental lean and fat broiler lines has been reported, hence there is a lack of information regarding the genetic control of fat deposition in these lines. Leclercq et al. (1980) suggested that males and females may have different genes controlling fat deposition. A possible difference between dam and sire inheritance has not been studied.

In the present study, reciprocal crosses were made between low fat and high fat lines within sire strain and within dam strain, in order to examine dominance. Crosses were also made between males from the sire strain low fat or high fat lines and females from the dam strain low fat or high fat lines. It allowed to examine heterosis in fat deposition at the genetic level of commercial broilers, and also to compare sire and dam effects on their broiler offspring.

MATERIALS AND METHODS

Stocks and selected lines

The lines used in the various crosses were divergently selected on abdominal fat from dam strain (White Rock stock) and sire strain (Cornish stock) base populations. Base population parameters, selection procedures and the performance of the selected lines at various generations were reported in the first chapter of this report and elsewhere (Cahaner et al., 1985, 1986; Cahaner, 1987). Two types of crosses were performed:

- a. Within-stock crosses - reciprocal crosses between the two divergent lines, LF (low fat) and HF (high fat), of the same stock.
- b. Between-stocks crosses - crosses between LF and HF Cornish males and LF and HF White Rock females in all four combinations.

Within-stock crosses were performed twice with the dam (White Rock) lines, in generations S3 and S5, and once with the sire (Cornish) lines, in generation S3. The laying hens of each line were divided at random into two equal groups. The semen of the males of each line (LF or HF) was pooled and split to two parts. One part was used to inseminate hens from the same line (LFxLF and HFxHF) to produce the two "pure" lines. The other part of each line's semen was used to inseminate hens from the opposite line. These were the actual reciprocal crosses (LFxHF and HFxLF). There were 20 to 60 hens in each group, and 10 to 15 males, depends on stock and generation.

Between-stocks crosses were performed once with S2 Cornish males and S5 White Rock females, and once with S3 Cornish males and S6 White Rock females. Each sire line was represented by about 10 males; their semen was pooled and split to two parts. Each dam line was represented by two groups of 20 to 40 laying hens. One group was inseminated by semen of males of the same selection direction (i.e. LF Cornish x LF White Rock and HF Cornish x HF White Rock). The second group of hens from each White Rock line was inseminated by Cornish males of the opposite line (LFxHF and HFxLF).

Management and measurements of crosses' offspring were the same as those of the selected lines during the selection process (see previous chapter). There were 20 to 50 chicks per sex per cross combination or 'pure line' in each round of crosses, and they were raised intermingled in one litter pen until marketing age. Then their live body and abdominal fat pad weights were determined. Abdominal fat weight was related to the bird size, given as percent of its live body weight. Only in the crosses between S2 Cornish and S5 White Rock, bled and defeathered carcasses were weighed instead of live birds, and they were the basis for % abdominal fat.

RESULTS AND DISCUSSION

In all sets of crosses, data of females and males were analyzed separately. In contrast to reports suggesting different genetic control of abdominal fat in males and females (Leclercq et al., 1980; Leclercq, 1984), our results regarding differences between parental lines and their crosses were very similar in the two sexes, and therefore only their averages will be referred here. Mean % abdominal fat and mean live body weight of each parental line and each 'within-stock' reciprocal cross, and the number of birds (females+males) in these groups, are presented in Table 1. Mid-parent values and F_1 means are also given. While body weight means of the four groups (the two parental lines and two reciprocal crosses) were very similar in all three cases, the parental lines and the mean of their crosses differed in % abdominal fat. The differences between the parental groups in actual % abdominal fat varied from .92% to 1.40% (Table 2). However, when these differences were related to the corresponding generation mean, they were almost identical. While there were minor differences between reciprocal White Rock crosses, large difference (.52% abdominal fat) was obtained in the Cornish crosses. This difference did not indicate sex linkage, since it was similar in the two sexes. It was not due to maternal inheritance or effect either, but rather a result of the way the parents were picked. Dams were taken at random from each line while only top-ranked sires (by abdominal fat of their offspring) were used. Hence, sires and dams did not represent the same genetic level, and consequently the offspring of each reciprocal cross deviated from the mid-parent value towards the sire line value (Table 1). When % abdominal fat of the two reciprocal crosses was averaged, it was very close to the mid-parent value in all three cases (Table 2), indicating a complete additive genetic control with no sign for heterotic effects in this trait. The additive inheritance is in agreement with the very high estimates of heritability and the substantial responses to selection on % abdominal fat obtained in our studies as well as by other groups (Leclercq, 1984; Whitehead and Griffin, 1984; Leenstra and Pit, 1987).

Between-stocks crosses were performed twice, by mating S2 and S3 Cornish males with S5 and S6 White Rock females, respectively. The offspring produced by these crosses, about 50 males and 50 females per cross, resemble commercial broilers in their parental lines and growth rate. In both sets of crosses, mean % abdominal fat of the four groups of offspring formed a complete additive situation, with sire effect being independent of dam effect, and vice versa (Table 3). These crosses verify that additive genetic control of abdominal fat characterizes not only the parental lines but also their cross offspring, the broilers. The similarity between the two 'reciprocal' crosses, i.e. HF Cornish x LF White Rock on one hand, and LF Cornish x HF White Rock, indicates similar inheritance from the paternal and the maternal sides. This result, as well as the similarity between males and females in line and cross differences, rule out the possibility of sex linkage or maternal effect. This conclusion is very important for practical breeding.

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Table 1. Means of abdominal fat and body weight, and number of chicks (over sexes) in the LF and HF lines and their reciprocal crosses in the two stocks

Stock and generation	<u>Parental lines</u>			<u>Crosses (x)</u>		
	LF	HF	Mean	Mean	LFxHF	HFxLF
<hr/>						
----- % abdominal fat -----						
<u>White Rock (8 wks)</u>						
S3	.94	1.86	1.40	1.40	1.38	1.42
S5	1.28	2.52	1.90	1.94	1.87	2.01
<u>Cornish (7 wks)</u>						
S3	1.59	2.99	2.29	2.25	1.99	2.51
<hr/>						
----- Body weight (g) -----						
<u>White Rock (8 wks)</u>						
S3	1762	1766	1764	1780	1761	1800
S5	2030	2012	2021	2009	1995	2023
<u>Cornish (7 wks)</u>						
S3	1812	1873	1842	1858	1844	1872
<hr/>						
----- Number of birds -----						
<u>White Rock</u>						
S3	59	57			62	63
S5	47	48			91	86
<u>Cornish</u>						
S3	33	52			40	49

Table 2. Parental, reciprocal and heterotic differences of % abdominal fat calculated (over sexes) from the HF and LF lines and their reciprocal crosses within each of the two stocks; each difference is also expressed as % of total mean

		<u>White Rock</u>		<u>Cornish</u>
Differences		S3	S5	S3
Parental differences	HF-LF	.92 (65%)	1.24 (65%)	1.40 (63%)
Reciprocal differences	(HFxLF)-(LFxHF)	.04 (3%)	.14 (7%)	.52 (23%)
Heterotic differences	(HFxLF)+(LFxHF)-HF-LF	.00 (0%)	.04 (2%)	.04 (2%)

Table 3. Abdominal fat of crosses between White Rock dams and Cornish sires from the low fat (LF) and high fat (HF) lines in two generations; means of 7-week old offspring (males+females) and parental effects

Generation and stock of dams		Generation and stock of sires		Sire line effects
<u>A. % of carcass wt.</u>		S2 Cornish sires		
		<u>LF</u>	<u>HF</u>	<u>HF-LF (%)¹⁾</u>
S6 White Rock dams	<u>LF</u>	1.54	2.30	.76 (40%)
	<u>HF</u>	2.26	3.06	.80 (30%)
Dam line effect:	HF-LF (%)	.72 (38%)	.76 (28%)	HH-LL = 1.52 (66%)
<u>B. % of live body wt.</u>		S3 Cornish sires		
		<u>LF</u>	<u>HF</u>	<u>HF-LF (%)</u>
S7 White Rock dams	<u>LF</u>	1.46	2.27	.81 (43%)
	<u>HF</u>	2.11	2.92	.81 (32%)
Dam line effect:	HF-LF (%)	.65 (36%)	.65 (25%)	HH-LL = 1.46 (67%)

¹⁾ Parental effects (differences between means) expressed as % of total mean

The response of the HF and LF lines to diet composition and to food restriction

The possible existence of interaction between lines selected for high or low abdominal adipose tissue (AAT) in their response to feeding diets varying in energy, fat and protein content or to feeding level - restriction or overfeeding.

Effect of dietary energy and fat.

The experimental findings relating to the effects of various dietary levels of fat are inconsistent. The difficulties in interpreting these results are discussed comprehensively in the recent reviews of Fisher (1984) and Leenstra (1986). Diet x genotype interaction was reported by Scheele et al., (1981), who examined the response of various commercial lines to diets differing in fat concentration.

Materials and methods.

Four corn:soy diets were formulated to contain either 2.95 or 3.2 Mcal ME/kg and 3 levels of fat (Table 1). Energy:amino acid ratios were calculated according to NRC (1977). Dilution of energy was carried out with cellulose when needed. An excess of protein was provided in order to compensate for a possible "extra caloric effect" of the added fat (distilled soybean oil). The ME of the supplemented soybean oil was estimated to be 9.5 kcal/g. The ratio protein:energy was the same in all diets: 75g/Mcal and 65g/Mcal in diets provided on weeks 1 to 4 and 4 to 8, respectively.

Table 1. Calculated composition of the experimental diets.

Diet code	Energy (Mcal ME/kg)	Fat (%)	Protein (%)		Fat(g/Mcal)
			1-4wks	4-8wks	
2.95L	2.95	2.7	22.4	19.3	9.1
2.95M	2.95	6.7	22.4	19.3	22.7
3.2M	3.20	7.3	24.1	21.0	22.8
3.2H	3.20	11.0	24.1	21.0	34.3

Day old male chicks, from the S3 generation of selection (ANAK), 45 per line, were placed in electric brooder batteries, where they were kept for 3 weeks. At that age they were transferred to an open battery house. All chicks were kept in individual cages in both periods. At one week of age, 11 chicks per line were assigned to each of the 4 experimental diets (Table 1), and fed thereafter ad-libitum. Individual food intake was recorded.

At autopsy adipose and other tissues were removed, weighed and frozen for further examination.

Results and discussion.

No significant differences were found between the HF and the LF lines in body weight and food utilization at 8 weeks of age (Table 2). Food or energy intake was somewhat higher ($P < 0.1$) in the HF than in the LF line. Food or energy intake were depressed by fat supplementation of the low energy diet (2.95 ME) and were increased with the increase in dietary energy concentration from 2.95 to 3.2 ME when the level of fat supplementation was similar. Increasing the level of the oil of the high energy diet caused a further increase in energy intake in the HF line but not in the LF one.

Food utilization was improved in both lines when fed the high energy diets, the differences in energy utilization were smaller and less consistent.

Table 2. Body weight (g), food intake (g) and utilization of HF and LF 8-week old male chicks fed diets containing different levels of fat and/or metabolizable energy.

Diet code		2.95L	2.95M	3.2M	3.2H	Effects of:		
						Line	Diet	LXD
Body weight	HF	1823	1719	1899	1940	NS	NS	NS
	LF	1760	1732	1821	1830			
Food intake	HF	4273	3745	3823	4232	@	*	NS
	LF	4063	3748	3815	3704			
Energy intake	HF	12.60	11.05	12.23	13.54	@	**	NS
	LF	11.98	11.06	12.21	11.85			
Food:Gain	HF	2.47	2.31	2.14	2.32	NS	**	NS
	LF	2.45	2.30	2.22	2.16			
Energy:Gain	HF	7.30	6.83	6.85	7.43	NS	@	NS
	LF	7.23	6.78	7.12	6.92			

@, *, **, - Significant effect at 0.1, 0.05 and 0.01 level, respectively.

Table 3. The relative weight of abdominal (AAT), gizzard (GAT), sartorial (SAT), neck (NAT) and mesenterial (MAT) adipose tissues and of liver and skin (g/100g body weight) of Anak chicks, selected for 3 generations for high (HF) or low (LF) AAT at 8 weeks of age.

Diet code		2.95L	2.95M	3.2M	3.2H	Effects of (pF)		
						Line	Diet	LXD
AAT	HF	1.89 ^a	1.09 ^b	1.80 ^a	1.26 ^b	***	***	*
	LF	0.68 ^c	0.56 ^c	0.73 ^c	0.60 ^c			
GAT	HF	0.42 ^a	0.28 ^b	0.37 ^{ab}	0.30 ^b	***	**	NS
	LF	0.19 ^c	0.13 ^c	0.16 ^c	0.13 ^c			
SAT	HF	0.25	0.13	0.23	0.18	**	**	NS
	LF	0.11	0.10	0.09	0.08			
NAT	HF	0.47 ^a	0.32 ^b	0.47 ^a	0.30 ^b	**	*	NS
	LF	0.20 ^{bc}	0.13 ^c	0.21 ^{bc}	0.17 ^{bc}			
MAT	HF	0.59 ^{ab}	0.40 ^{cd}	0.63 ^a	0.49 ^{bc}	***	*	***
	LF	0.44 ^c	0.41 ^{cd}	0.30 ^d	0.35 ^{cd}			
Liver	HF	.2.50	2.55	2.09	2.29	NS	@	NS
	LF	.2.48	2.61	2.29	2.38			
Skin	HF	.6.32	5.86	6.60	5.95	NS	NS	NS
	LF	.6.17	6.04	5.80	5.79			

Different superscript letters indicate statistical significant difference between means ($p < 0.05$) within each adipose tissue of the two lines. For the effects of line, diet or the interaction linexdiet: @, *, **, *** - $p < 0.1$, 0.05, 0.01 and 0.001, respectively.

The increase in dietary energy from 2.95 to 3.2 Mcal ME/kg caused a substantial increase in all adipose tissues (AT) dissected in the HF but not in the LF line (Table 3). Increasing the level of dietary fat reduced the relative weight of all the adipose tissues, more in the HF than in the LF line.

Fat concentration in all adipose tissues (SAT excepted) was higher in the HF than in the LF line within all dietary treatments (Table 4). Increasing dietary energy was accompanied by a slight increase, and dietary fat supplementation by a slight decrease in fat concentration in adipose tissues in both lines, however this trend was not significant statistically. Fat content in breast muscle was low and ranged within lines and dietary treatments between 0.65% and 1.18%. Although the fat content was slightly higher in the HF than in the LF line in all treatments, the differences between the lines were not statistically significant.

The dietary treatments did not affect consistently fat concentration in the breast muscle. Fat concentration in the skin was higher in the HF than in the LF line in all dietary treatments. Levels of dietary energy and fat affected skin fat concentration as in adipose tissues: it increased with elevated energy and decreased with fat supplementation (NS).

The concentration of fat in the remaining carcass was higher, while the protein concentration was lower, in the HF than in the LF line. It should be pointed out that while the differences in adipose tissues weight were 2-3 fold higher in the HF than in the LF chicks, the difference in fat in the remaining carcass was about 10% only.

The dietary treatments affected carcass fat concentration in a similar way as adipose tissues and skin, and as for the latter the effect was not statistically significant.

No consistent differences were found in liver fat concentration within lines and diets.

Plasma total lipids and protein did not differ between lines. Fat supplementation was accompanied by a statistically significant depression of plasma total lipids and protein.

There are contradictory reports regarding the effect of dietary fat supplementation on body fat content. Many studies showed that if supplemental fat is added to the diet at the expense of carbohydrates, and if the energy:protein ratio remains constant, fat supplementation of the diet have no significant effect on carcass fat (Bartov, 1979; Laurin et al., 1985).

Deaton et al. (1981) reported that as supplemental dietary fat increases the amount of abdominal adipose tissue increases, while Whitehead and Griffin (1986) reported that supplemental dietary fat had no effect on AAT. The contradictory effects of fat supplementation could be due to the different ME values assigned to the added fat which may affect the energy:protein ratio and adiposity accordingly.

Table 4. Fat concentration (%) in various tissues and protein concentration in the carcass and blood plasma in HF and LF 8-week old chicks fed diets differing in levels of fat and/or energy (S3 generation).

Diet code		2.95L	2.95M	3.2M	3.2H	Effects of:		
						Line	Diet	LXD
<hr/>								
Fat concentration (%).								
AAT	HF	74.0	69.3	74.2	72.4	***	NS	NS
	LF	65.2	66.9	68.7	69.2			
GAT	HF	71.4	72.6	75.3	75.7	**	NS	NS
	LF	64.9	64.9	64.7	72.7			
SAT	HF	69.3	76.3	75.5	69.5	NS	**	*
	LF	70.8	65.9	77.3	67.9			
MAT	HF	65.6	57.6	64.7	61.8	***	NS	NS
	LF	52.4	50.5	51.2	55.2			
Liver	HF	6.99	5.77	5.66	5.98	NS	NS	NS
	LF	5.98	5.14	5.59	6.01			
Skin ¹	HF	37.6	33.8	37.5	35.3	*	NS	NS
	LF	30.9	29.9	33.2	34.6			
Breast muscle	HF	0.99	1.09	0.94	1.18	NS	NS	NS
	LF	0.93	0.79	0.65	1.16			
Tibia	HF	9.18	10.38	10.68	11.35	NS	NS	NS
	LF	10.62	10.35	12.11	9.59			
Carcass ²	HF	11.3	10.5	11.7	11.0	**	NS	NS
	LF	9.23	9.08	9.36	9.26			
Plasma (mg/ml)	HF	4.01	3.52	3.27	2.98	NS	**	NS
	LF	3.95	3.21	3.11	3.24			
<hr/>								
Protein ₂ concentration								
Carcass (%)	HF	17.6	17.4	17.6	17.4	**	NS	NS
	LF	18.3	17.5	18.0	18.1			
Plasma (mg/ml)	HF	40.1	35.2	32.7	29.8	NS	**	NS
	LF	39.5	32.1	31.1	32.4			

¹Skin from all body except wings and metacarpus.

²Carcass without all the dissected adipose tissues, skin, tibia and gastrointestinal content.

*, **, *** - P<0.05, 0.01, 0.001, respectively.

Effect of dietary protein concentration.

Diet composition may affect directly or indirectly growth and fat deposition. An important factor is the effect of energy:protein ratio of the diet; wide ratio is associated with high fat deposition (Bartov et al., 1974).

Dietary manipulations favouring energy intake, such as energy concentration, are accompanied by an increase in fatness (Fisher, 1984).

Materials and methods.

Three isocaloric (3.1 Mcal ME/kg) diets were formulated to contain: 1) 14% protein above that suggested by NRC (1977)-High protein diet (HP); 2) protein and essential amino acids according to NRC (1977) -Intermediate protein diet (IP); 3) 14% protein below NRC (1977) recommendations - Low protein diet (LP) (Table 5).

Table 5. Composition of the High (HP), intermediate (IP) and Low (LP) protein diets for the different ages.

Age (weeks)	2 - 3			3 - 6			6 - end.		
	HP	IP	LP	HP	IP	LP	HP	IP	LP
Energy Mcal/kg	3.00	3.00	3.00	3.05	3.05	3.05	3.06	3.05	3.05
Protein %	24.8	21.8	18.8	21.9	19.1	16.2	20.8	18.2	15.6
Fat %	3.5	3.5	3.5	4.0	3.6	3.2	3.6	3.6	3.6
Meth.+cystein %	1.05	0.90	0.76	0.79	0.69	0.58	0.67	0.61	0.54
Lysine %	1.4	1.3	1.2	1.20	1.00	0.81	1.10	0.95	0.79
Calory/protein	120	137	159	139	159	188	146	168	196

One week old male chicks, 125g $\pm$ 5 from S4 generation of Anak selection for high or low AAT, were kept individually as described previously. The birds were autopsied at 53d of age and the same tissues as in the previous experiment were removed and weighed.

Results and discussion.

No significant differences were found in the final body weight within lines and HP and IP diets. When fed the LP diet, the body weight of the HF line was not affected but that of the LF one was depressed consistently (Table 6). These results confirm those of Leclercq (1983) who suggested that although the lean lines utilize more efficiently dietary protein, the requirements are higher than those of the fat line and therefore low protein diets are more detrimental to lean than to fat birds.

Food intake was higher in the HF than in the LF line and was highest when the IP diet was fed in both lines. Food:gain ratio increased concurrently to the decrease in dietary protein concentration and was lower in LF than in HF line when the chicks were fed HP and IP diets, which allowed maximal growth. When fed the LP diet, the growth of the LF chicks was depressed and accordingly food utilization.

Table 6. Body weight, food intake and utilization of HF and LF chicks, fed diets containing High (HP), Intermediate (IP) and Low (LP) levels of protein, at 53 days of age (S4 generation of Anak selection for high or low AAT).

Diets		HP	IP	LP	Effects of:		
					Line	Diet	LXD
Final body wt. (g)	HF	2088 ^a	2068 ^a	2038 ^a	NS	**	NS
	LF	2083 ^a	2058 ^a	1883 ^b			
Food intake (g)	HF	4698 ^{bc}	4960 ^a	4879 ^{ab}	**	@	NS
	LF	4510 ^c	4651 ^{cb}	4539 ^c			
Food:gain	HF	2.39 ^a	2.56 ^b	2.55 ^b	@	**	@
	LF	2.29 ^a	2.40 ^a	2.60 ^b			

@, ** - $P < 0.1$, 0.01 , respectively.

The relative weight of the 5 adipose tissues dissected was lower in the LF than in the HF line (Table 7).

Table 7. The relative weight of abdominal (AAT), gizzard (GAT), sartorial (SAT), neck (NAT), mesenterial (MAT) adipose tissues and of the liver (g/100g body weight) in HF and LF - 53 days old chicks (S4 generation of ANAK selection).

Diets		HP	IP	LP	Effects of:		
					Line	Diet	LXD
AAT	HF	1.79	2.76	2.83	**	**	*
	LF	0.81	1.07	1.45			
GAT	HF	0.56	0.88	0.97	**	**	NS
	LF	0.30	0.48	0.30			
SAT	HF	0.22	0.34	0.33	**	**	NS
	LF	0.09	0.16	0.18			
NAT	HF	0.063	0.081	0.083	@	NS	NS
	LF	0.069	0.068	0.086			
MAT	HF	0.42	0.73	0.69	**	**	NS
	LF	0.27	0.37	0.44			
Liver	HF	4.69	4.86	4.35	@	NS	NS
	LF	4.56	4.42	4.24			

@, *, ** - $P < 0.1$, 0.05 , 0.01 , respectively.

The relative weight of the adipose tissues was negatively related to the dietary protein concentration in both lines. It seems that feeding HP vs. IP or LP diets was accompanied by a greater relative decrease in the AAT and GAT weight in the HF than in the LF line (Table 7). No line or diet effects were observed on liver weight.

Fat concentration was higher in the AAT, NAT and MAT of the HF line than of the LF one. It tended to decrease with the increase in dietary protein concentration, but a statistically significant decrease was found only for MAT (Table 8). Fat concentration of the liver was slightly higher in the HF than in the LF line ($P < 0.1$), no diet effect was observed in this respect.

Fat concentration in the skin was higher in the HF than in the LF line within all dietary protein levels and was negatively related to dietary protein concentration.

In contrast to the other tissues, the fat concentration in the tibia bone was higher in the LF than in the HF chicks. In the LF line it increased parallel to the decrease in dietary protein level while in the HF line the changes, due to diet composition, were small and inconsistent.

Lipid concentration in the breast muscle was not affected by diet or population.

Plasma total lipids was higher in the HF than in the LF line and increased slightly (NS) with the decrease in dietary protein level in both lines. Plasma glucose was higher in the LF line and was not affected by dietary protein level. Plasma protein was higher in the HF than in the LF line and decreased in both lines with the decrease in dietary protein level.

While the relative weight of the tibia bone was slightly higher in the HF than in the LF line ($P > 0.08$), no consistent difference was observed in its relative length. The slightly longer tibia in the LF line fed LP diet was probably due to the lower body weight of the birds fed this diet. A slight decrease was found in the relative length of the tibia bone as the dietary protein concentration increased. It is proposed that the relative weight and length of the tibia are inversely related to the lean body weight. This could explain the changes in the tibia relative length and weight occurring by feeding LP diet, which was accompanied by increased body fat and accordingly a reduced lean body weight.

Tibia ash concentration did not differ between the lines or diets.

The effect of energy:protein ratio on adiposity was described quite long ago by Fraps (1943) who concluded that a narrow energy:protein ratio was accompanied by a reduction in body fat deposition. This was subsequently confirmed by Guillaume and Summers (1970), Bartov, (1979) and Jackson et al., (1982).

Table 8. Fat concentration (%) in various tissues, blood plasma composition and tibia bone weight, length and composition, in HF and LF- 53 days old chicks fed diets containing High (HP), Intermediate (IP) and Low (LP) levels of protein. (S4 generation of ANAK selection).

Diets		HP	IP	LP	Effects of:		
					Line	Diet	LXD
AAT	HF	81.8	83.5	84.0	**	@	NS
	LF	78.7	78.2	80.1			
GAT	HF	67.5	73.2	76.7	NS	NS	*
	LF	73.6	70.0	72.0			
SAT	HF	75.4	78.4	77.0	NS	NS	NS
	LF	75.5	75.2	78.5			
NAT	HF	50.8	49.0	51.4	*	NS	NS
	LF	41.3	42.9	47.1			
MAT	HF	76.8	80.5	78.9	**	**	NS
	LF	70.0	73.5	76.0			
Liver	HF	7.51	7.80	7.63	@	NS	NS
	LF	6.76	6.90	7.19			
Back skin	HF	52.6	56.2	58.2	**	**	NS
	LF	46.8	49.8	53.8			
Breast muscle	HF	0.90	0.89	0.97	NS	NS	NS
	LF	0.96	0.98	0.98			
Blood plasma: Total lipids (mg/ml)	HF	4.18	4.29	4.43	*	NS	NS
	LF	3.84	4.13	4.20			
Glucose (mg/ml)	HF	2.22	2.43	2.29	*	NS	NS
	LF	2.31	2.46	2.43			
Protein (%)	HF	3.80	3.86	3.38	*	**	NS
	LF	3.68	3.50	3.28			
Tibia bone: Weight (g/kg)	HF	9.60	9.18	9.86	@	NS	NS
	LF	9.16	9.14	9.22			
Length (cm/kg)	HF	5.66	5.80	5.85	NS	@	NS
	LF	5.78	5.82	6.19			
Ash (%)	HF	20.1	20.3	20.2	NS	NS	NS
	LF	20.3	20.9	20.3			
Total lipids (%)	HF	9.91	11.0	10.2	*	NS	NS
	LF	10.5	11.7	12.5			

@, *, ** - $P < 0.1, 0.05, 0.01$, respectively.

The response of fatty acid profile to dietary composition.

The fatty acid pattern of the fat in adipose tissues and carcass is determined by the importance of lipogenesis and by dietary fat. Linoleic (18:2) and linolenic (18:3) acids are not synthesized and their presence in body fats depends on their presence in the diet.

Since no interactions were found between line and diets effects, results are presented for the main effects.

1). Effect of soybean oil supplementation of the diet and energy density (Fig. 1).

In the 3rd generation of selection for HF and LF chicks, there was no population differences in the fatty acid profile in all the tissues analysed.

Chicks fed diets containing 2.95 or 3.2 Mcal ME/kg with similar fat concentration (6.7% and 7.3%) did not differ in the fatty acid profile of the adipose and non adipose tissues.

The fatty acid profile was similar in the AAT and Skin fat except that the latter contained about 1.5% 20:4, which was not found in AAT. The level of 20:4 in the skin fat was slightly higher ($P < 0.05$) in the LF than in the HF birds.

In MAT, less 18:2 was observed than in AAT and skin. The muscle fat differed from the other adipose tissues and skin fat in it's higher level of 16:0, lower level of 18:2 and the presence of substantial amount of 20:4 (about 6%).

The increase in dietary fat content (soybean oil) was accompanied by an increase in 18:2 and 18:3 in all the tissues. This increase was greater when dietary fat content was elevated from 2.7 to 6.7 than from 7.3 to 11.0. This increase was on the expense of 16:0, 16:1 and 18:1, which concentration was reduced when fat concentration in the diet was increased.

2). Effect of dietary protein concentration (Fig. 2 & 3).

In the 4th generation of selection for HF and LF birds, unlike in the previous one, there were slight but statistically significant differences in the fatty acid profile between the lines.

In all adipose tissues (AAT, GAT, SAT, NAT, MAT) 18:2 was higher in the LF than in the HF line, on the expense of 16:0, 16:1 and 18:1, which were in most cases lower in the LF than in the HF line. In AAT 18:3 was also higher in the LF line than in the HF one.

In the breast muscle the differences between the lines were small; only 18:0 and 20:4 differed between the lines and were higher in the LF than in the HF birds ($P < 0.05$). In the liver, the only consistent difference between the lines was the higher level of 18:1 in the HF than in the LF line. Substantial amounts of 20:4 were found only in muscle and liver fat, traces in MAT and none in the other adipose tissues.

The decrease in dietary protein level was accompanied by an increase in 16:0, 16:1 and 18:1 and by a decrease in 18:2 and 18:3 in all adipose tissues (SAT, 16:0 excepted). In the liver fat the same trend was observed while in the muscle 18:2 and 18:3 were slightly reduced (NS) and 16:0 and 16:1 were not affected.

18:0 was reduced by low protein diet only in the GAT and liver fat.

Fig.1. The effect of dietary energy density and soyabean oil supplementation on fatty acid profile of abdominal (AAT), mesenteric (MAT) adipose tissues and breast muscle (MUF) and liver fat in lines of chickens selected for high (HF) or low (LF) abdominal fat for three generations. Effect of line, left, HF, ; LF, ; effect of diet, right.

Dietary energy and fat levels: 2.95, 2.7, ; 2.95, 6.7, ; 3.2, 7.3, ; 3.2, 11, , respectively.

The differences between the lines were NS. The effect of energy density was NS, the effect of soyabean oil supplementation was statistically significant for 16:0, 16:1, 18:1, 18:2, 18:3, ($P < 0.05$).

Fig.2. The effect of dietary protein level on fatty acid profile of various adipose tissues in lines of chickens selected for high (HF) or low (LF) abdominal fat for four generations. Effect of line, left, HF, ; LF, ; effect of diet, right. Level of dietary protein: high (HP), ; intermediate (IP), ; low (LP), . *, $P < 0.05$; **, $P < 0.01$.

It is suggested that 18:2 is negatively related both to genetic and nutritional adiposity. Since the source of 18:2 is only from the diet, its concentration is reduced by endogenous fatty acids and therefore a higher lipogenesis is accompanied by a reduced concentration of 18:2 in the fat of the various tissues. A negative correlation of $r=-0.84$ was found between the weight of the AAT and the concentration of 18:2. The higher monoenoic acids concentration found in the tissues of the HF line could be related to a higher desaturating activity found in fat birds as compared to lean ones (Legrand et al., 1987).

The differences in 18:2 concentration between the lines were more accentuated in the experiment in which the effects of dietary protein concentration were studied than in the study of the effect of dietary fat. This differences could be due to: 1). The protein study was carried out on S4, while the fat study was on S3 generation. 2). While in the protein study isocaloric diets were used, quite similar in fat concentration, the fat study was carried out with diets varying markedly in soybean oil content which is high in 18:2, and could mask the differences in this fatty acid between the lines.

It can be deduced from the present work that although dietary manipulations affect differently the amount of fat deposition in HF and LF birds, the fatty acid profile was affected in the same direction.

Fig.3. The effect of dietary protein level on fatty acid profile of breast muscle and liver fat in lines of chickens selected for high (HF) or low (LF) abdominal fat for four generations. Effect of line, left, HF, ; LF, ; effect of diet, right. Level of dietary protein: high (HP), ; intermediate (IP), ; low (LP), . *, $P<0.05$; **, $P<0.01$.

Effect of intermittent feeding on HF and LF chicks.

Pinchasov et al. (1985) found a marked reduction of AAT and body fat in meat -type chicks restricted to 80% of the ad libitum intake by exposing them to intermittent feeding from 12 days of age. In contrast, egg-type chicks are able to maintain a normal body composition when restricted up to 75-80% of ad libitum fed counterparts (Nir and Nitsan, 1979; Nitsan et al., 1984; Nir et al., 1987).

The response of female chicks from the 4th generation of selection to HF and LF lines to restricted feeding regime was studied.

Materials and methods.

Food restriction was carried out by feeding the chicks every other day (intermittent feeding). The feeding regime was applied from 2 weeks of age. A commercial diet was used; it contained 3000 kcal ME/kg and protein and amino acids according to NRC (1977). Control chicks from each line were fed ad libitum throughout the experimental period. Since the control birds grew faster, they were killed and processed at 7 weeks of age and the restricted ones at 9 weeks of age, to attain similar body weight at processing. About one half of the restricted birds were killed on the morning following a depletion day (Depleted) and the rest were killed on the next day, following a repletion day (Repleted). Management and processing methods were as described in the experiments with different dietary fat and protein contents. Feeding regimes were carried out as described by Pinchasov et al. (1985).

There were 21 restricted birds within each line. Nine HF and 12 LF birds were killed after 24h of food deprivation, and 12 HF and 9 LF birds were killed the next morning after 24h of food restoration.

Results and discussion.

The four groups of birds which were under restricted feeding had similar body weight after their last depletion day (Table 9). However, when killed the next day, the repleted birds of both lines weighed about 200g more. Approximately 110g out of the 200g weight gain accounted for the gut content, and the rest was actual body weight gain. To accomodate for differences in gut content, it was subtracted from the weight of each bird for further calculations. Although the restricted birds were killed 2 weeks after the control (ad libitum) birds, their mean body weight (except the repleted HF group) was lower than the controls by 100 to 150g (Table 9).

Table 9. Mean body weights of control and restricted HF and LF females, killed after 10h (Ad lib.) or 24h (Dep1) without food, or after 24h of food restoration (Repl).

	HF line			LF line		
	AD lib	Dep1	Repl	AD lib	Dep1	Repl
(Number of birds)	(20)	(9)	(12)	(19)	(12)	(9)
Age, days	49	63	64	49	63	64
Type of body weight (g)						
After last depletion	--	1200	1245	--	1265	1215
When killed	1370 ^a	1200 ^b	1446 ^a	1438 ^a	1265 ^b	1411 ^a
Without gut content	1327 ^a	1175 ^b	1338 ^a	1391 ^a	1243 ^b	1292 ^{ab}
Gut contents	43 ^b	25 ^c	108 ^a	47 ^b	22 ^c	119 ^a

The gut content of the repleted birds was about 3 fold that of the Ad libitum fed controls. Consistent amounts of chyme were found in the depleted birds after 24h of food removal.

The weight of several adipose tissues, relative to body weight (without gut contents), was compared between control, depleted and repleted birds within lines.

Table 10. The relative weight of the various adipose tissues and of liver and their fat concentration in HF and LF female chicks fed Ad libitum or intermittently, after 24h of food deprivation (Dep1) or restoration (Repl).

	HF line			LF line			Effects of:		
	Ad lib.	Dep1	Repl	Ad lib.	Dep1	Repl	Line	Diet	LXD
	Relative weight (%) ¹								
AAT	2.48	1.59	1.85	1.22	1.02	0.90	***	***	*
GAT	0.77	0.61	0.64	0.39	0.38	0.36	***	NS	NS
SAT	0.29	0.20	0.22	0.16	0.12	0.10	***	***	NS
NAT	0.81	0.22	0.65	0.49	0.20	0.36	***	***	*
MAT	0.45	0.30	0.33	0.39	0.19	0.24	***	***	NS
Sum of the above	4.76	2.92	3.69	3.31	1.91	1.96	***	***	*
Liver	2.61	2.82	4.60	2.58	2.86	4.20	NS	***	@
	Fat concentration (%)								
AAT	75.6	73.8	78.9	73.9	72.8	73.9	*	NS	NS
GAT	79.3	69.7	77.5	76.5	71.0	71.3	@	***	NS
NAT	75.1	71.3	67.8	68.7	75.6	64.7	NS	NS	NS
MAT	64.6	64.9	68.0	62.6	47.9	55.6	***	*	*
Liver	6.76	5.30	11.2	6.19	5.14	10.6	NS	***	NS

¹ Percent of body weight without gastrointestinal contents.

@, *, *** - P < 0.1, 0.05, 0.001, respectively.

Fig.4. Fat content in adipose tissues of chickens selected for high (HF) or low (LF) abdominal adipose tissue fed ad libitum (Control); after 24h of food deprivation (Depleted) or restoration (Repleted). Adipose tissues: AAT-abdominal; GAT-gizzard; NAT-neck; MAT-mesenterial.

Highly significant line differences were obtained for all adipose tissues relative weights. The ad libitum fed birds had bigger adipose tissues than the restricted ones. When compared to ad libitum fed birds, food restriction depressed the relative weight of adipose tissues more in the HF than in the LF line (MAT excepted) (Table 10).

Food restoration was accompanied by an increase of all adipose tissues in the HF line, while small and non consistent differences were observed in the LF line.

The changes in fat concentration following depletion were not consistent. Fat concentration increased after repletion in 3 adipose tissues (abdominal, gizzard and mesenterial) in the HF birds, and only in the mesenterial adipose tissue in the LF line.

Highly significant increase in liver weight and fat content in the repleted birds was observed in both lines. Although no line differences or line x treatment interaction was found in liver weight and fat concentration, it should be pointed out that in the HF line the increase in liver weight and fat concentration after repletion was more pronounced in the HF than in the LF line. The fat increment in the liver of the HF line during food restoration was 5.12g as compared to 3.93g in the LF line.

The interaction between line and feeding regime was significant for abdominal, neck and for the sum of all adipose tissues. The interaction could be partly explained by a different fat mobilization on day of food deprivation within adipose tissues and line. While in the HF line fat was mobilized to about the same extent, 9-19% from all the adipose tissues, in the LF line it was mobilized only from the neck and the mesenterial adipose tissues (Fig. 4). It is suggested that the rate of fat mobilization and deposition differ among adipose tissues and populations.

From the data obtained from the intermittently fed birds it may be concluded that the higher fat accumulation in the HF line is accompanied by higher fat turnover in adipose tissues and in liver.

The response to food restriction was more pronounced in the HF than in the LF line in accord to previous studies suggesting that under food restriction lean chickens are able to maintain body composition more efficiently than fat counterparts.

The response of HF and LF chicks to overfeeding glucose or soybean oil

The effect of overfeeding glucose or soybean oil on adiposity, hepatic malic enzyme (ME) activity, blood plasma free fatty acids (FFA), glucose and total lipids in HF and LF chicks were studied.

Materials and methods.

Four weeks old male chicks of HF and LF lines were assigned to 6 groups/line, 6-7 chicks/group.

Group 1 was fed ad libitum up to sacrifice; Groups 3-6 were given glucose or oil in addition to mash. In order to prevent the depressive effect of glucose or oil on food intake, the chicks were tube fed amount of mash equal or exceeding the amount consumed by the ad libitum counterparts during one or two days. 24h prior to the start of the experiments all the treated chicks were starved: groups 3 and 4 were forced-fed twice (at 13.00 and 21.00) with mash + oil or glucose (groups OIL1 and GLU1). On the next day, 24h prior to sacrifice (09.00) they were intubated once more with oil or glucose only. Groups 5 and 6 were forced-fed 5 times during 2 days (13.00, 21.00, 07.00, 13.00, 21.00) with mash and oil or glucose (groups OIL2 and GLU2). As in groups 3 and 4 they were intubated with oil or glucose 2h prior sacrifice on the 3rd day. Details on food intake are in Table 11.

Autopsies were carried out as described earlier (Nir et al., 1974). Blood samples were collected in heparinized syringes before autopsies. Adipose tissues and livers were removed, frozen in liquid nitrogen and were stored at -70°C .

Table 11. Food (g) and energy (kcal) consumption during the experiment.

	LF				HF			
	OIL1	GLU1	OIL2	GLU2	OIL1	GLU1	OIL2	GLU2
Initial body wt. (g) ¹	742	765	762	740	700	685	694	690
Ad lib. mash intake (g) ²	60	58	139	119	55	57	117	106
Intubated mash (g)	47	48	141	121	52	47	128	119
(kcal) ²	321	317	840	720	320	312	735	675
Intubated oil or glu. (kcal) ³	73	75	146	150	65	68	129	135
Total intake (kcal) ³	394	392	986	870	385	380	864	810
Mash energy/kg body wt.	80	461	1237	1096	512	505	1157	1080
Total energy/kg body wt.	590	569	1452	1324	616	615	1360	1296

1. Initial body wt. of control LF and HF chicks were 771g and 688g, respectively and their energy intake/kg body wt. was 393 and 366 kcal ME/day. The body wt. of the LF and HF chicks sacrificed after 24h of fast were 684g and 610g, respectively.

2. Ad libitum intake was measured for the whole group.

3. Calculated energy intake was done according to: 3 kcal/g mash; 3.4 kcal/g glucose and 9 kcal/g oil.

Results and discussion

Total daily food consumption per kg body weight was higher in the treated than in the ad libitum fed birds (Table 11). The amount of energy provided by the supplemented oil or glucose was about 20% of the total energy intake.

The effect of intubation of fat or glucose on the relative weight of adipose tissues was slight and not consistent (Table 12).

Table 12 Relative weight of adipose tissues

		AAT	SAT	MAT
TREAT				
Ad lib.	HF	9.78	2.59	2.63
	LF	5.73	1.18	2.14
FAST	HF	10.89	2.34	2.58
	LF	5.34	1.50	1.64
OIL1	HF	11.29	2.29	1.85
	LF	6.19	1.45	1.87
GLU1	HF	11.41	2.41	1.91
	LF	6.75	1.39	2.00
OIL2	HF	12.39	2.44	3.37
	LF	8.82	1.75	2.06
GLU2	HF	11.35	2.41	2.78
	LF	8.03	1.51	2.55
Effect of: Line		0.001	0.001	0.03
(P<)				
Treat.		0.25	0.97	0.008
LxT		0.9	0.9	0.17

Intubation of glucose for one day was accompanied by a consistent glycemia in both lines; after the second day the glucose levels resumed those of control chicks and total lipids level was increased (Table 13). Intubation of oil had no effect on glycemia, it was accompanied by a marked increase in total plasma lipids on both days. While no line differences were observed in glycemia and lipemia, a consistent line difference in plasma FFA level was observed. The LF line had considerably higher FFA level than HF line ($P < 0.01$). Fasting increased the level of FFA, administration of glucose for one day caused a consistent decrease in FFA, and after the 2nd day the FFA resumed the control level. Administration of oil increased the FFA level on the 2nd day in the HF but not in the LF line. Altogether, the fluctuations in FFA levels were much higher in the HF than in the LF line.

Relative liver weight was slightly but significantly higher in the HF than in the LF line. Its weight was almost doubled after the 1st day of glucose administration, and somewhat decreased after the 2nd day. The effect of oil administration was in the same direction but less pronounced. Fat concentration in the liver did not differ between the two lines; it was highest following 2 days of glucose administration and intermediate in the oil supplemented chicks.

Table 13 : Levels of free fatty acids (FFA), glucose and total lipids (fat) in the control and treated HF and LF chicks

		FFA	GLUCOSE	FAT
TREAT	LINE			
Ad lib.	HF	284	207	451
	LF	454	201	501
FAST	HF	479	204	472
	LF	591	204	511
OIL1	HF	348	216	566
	LF	480	218	530
GLU1	HF	186	260	458
	LF	286	251	459
OIL2	HF	427	197	539
	LF	459	212	547
GLU2	HF	336	236	582
	LF	455	217	660
Effects of: Line		0.002	0.75	0.14
(P<) Treatment		0.0009	0.007	0.0001
LxT		0.90	0.92	0.33

The percentage of PUFA (18:2+20:4) in the liver was higher in the LF than in the HF chicks (Table 14). LineXtreatment interaction was observed in this respect, since following starvation the PUFA was lower in the LF than in the HF line, and this lower level was maintained after 24h of refeeding with glucose supplementation. A consistent reduction of PUFA in the liver was observed in groups GLU1, GLU2 and OIL1 and OIL2. The percent of 18:2 in the AAT was higher in the LF than in the HF as was found also in the experiments described previously. It's concentration was lowest in GLU2 group.

Malic enzyme activity (units/g liver) was higher in the HF than in the LF line. It decreased after fasting and increased by glucose administration on the 2nd day. The lineXtreatment interaction was due to the enhanced activity in the LF line on the 2nd day of glucose or oil administration.

This experiment confirms the higher hepatic lipogenic activity in the HF line as compared to the LF line as suggested also by others (Sardoun and Leclercq, 1987).

It also shows that the LF line may have higher lipolytic capacity as shown by the higher levels of plasma FFA.

Oil did not depress lipogenic activity when supplemented in addition to a basic diet, rich in carbohydrates, in agreement with Shapira et al., (1978).

It seems that malic enzyme activity in the liver of the LF line responds to glucose administration slower than in the HF line.

Table 14: The weight, fat concentration, malic enzyme activity and PUFA concentration in the liver and the concentration of 18:2 in AAT.

		Liver				AAT
Treat		Weight g/kg body wt.	Fat %	Malic enzyme u/g	PUFA %	18:2 %
CON	HF	27.8	3.71	6.42	29.3	24.2
	LF	26.5	3.02	5.37	34.7	25.1
FAST	HF	27.0	3.12	5.01	30.1	22.3
	LF	26.0	3.37	3.76	28.2	26.1
OIL1	HF	44.1	6.85	5.83	16.9	24.9
	LF	35.3	4.97	5.03	22.3	27.0
GLU1	HF	49.0	5.23	8.33	16.6	23.4
	LF	50.7	5.73	5.66	13.4	25.4
OIL2	HF	33.3	5.02	7.66	21.6	27.7
	LF	32.3	4.41	9.08	26.8	26.5
GLU2	HF	37.7	8.54	10.69	12.0	20.2
	LF	37.5	8.60	10.89	13.6	21.0
Effects of (P<)						
Line		0.03	0.35	0.06	0.02	0.05
Treatment		0.001	0.001	0.001	0.001	0.001
LxT		0.79	0.62	0.02	0.002	0.40

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C.3.USA.a - Variation in GH, T₃ and Lipogenic Enzymes in Broilers
Differing in Growth and Fatness

The purpose of this study was to investigate several physiological parameters intrinsic to basic metabolism in three strains of broilers differing in growth rate and carcass fat. Developmental changes in body weight, lipid deposition, hormone (GH and T₃) concentration and enzyme (ME and CCE) activity from day one through 42 days of age were examined.

MATERIALS AND METHODS

At one day of age, male and female chicks from three experimental broiler strains were randomly distributed into 24 floor pens resulting in 4 replicates of each sex by strain combination. A conventional starter diet was fed from day 1 to 28 days and at 28 days the starter was replaced with a broiler finisher ration (Table 1). Birds were allowed feed and water ad libitum until termination of the experiment at 42 days of age. Three birds from each pen (n = 12 males and 12 females per strain) were randomly selected and weighed on days 3, 14, 28 and 42. Blood samples were then obtained by means of cardiac puncture using EDTA as an anticoagulant. Plasma was separated by centrifugation on the day of collection and stored at -20°C until used for hormone analysis. Chicks were sacrificed by dislocation of the neck to prevent blood loss, and the livers removed and frozen at -80°C. All carcasses were frozen at -20°C for subsequent determination of carcass lipid content.

The frozen carcasses, including feathers, were individually cut into sections, ground in a meat grinder, mixed and reground twice to obtain a homogenous mixture. Carcass lipid content was determined for duplicate one gram samples by a modification (Washburn and Nix, 1974) of the Folch method (Folch et al., 1957).

Liver homogenates for malic and citrate cleavage enzyme analysis were prepared in a 0.15M KCl and 20% ethanol solution. One gram samples of frozen liver were homogenized in a Sorvall Omni-Mixer (Dupont Instruments, Newtown, CN 06470), with 10 mls of the KCl-ethanol solution for approximately 1 minute. The 10% homogenates were then centrifuged for 60 minutes at 10,000 g and the resulting supernatants used for enzyme assays. All operations were carried out at 0° to 5°C. Assays were conducted at 25°C for malic enzyme (EC 1.1.1.40) by the method of Ochoa (1955) and for citrate cleavage enzyme (EC 4.1.3.8) by the procedure of Srere (1959). Enzyme activities were expressed on the basis of nanomoles of nucleotide (NADPH or NAD⁺) per milligram of protein. Protein concentration of the liver tissue extracts was determined utilizing the Bio-Rad protein assay (Bio-Rad Laboratories, Richmond, CA, 94804).

Plasma samples were assayed for growth hormone (GH) and triiodothyronine (T₃) using radioimmunoassays (RIA). For the T₃ assay, rabbit anti-T₃ serum was used in the general procedure described by May (1978), although a commercial (Antibodies, Inc., Davis, CA, 95616) goat anti-rabbit gamma globulin was used in a modification of the assay. The T₃ RIA was run over a 24 hour period. Barbital buffer (pH 8.6) was used to dilute 15 µl plasma samples to 50 µl while standards were dispensed in 50 µl quantities. Anti-T₃ serum was diluted 1:200 in barbital buffer and 37.5 µl of antiserum was added to the tubes. Fifty µl of tracer diluted to 0.1µCi/ml and 50 µl of a 1:5 dilution of goat anti-rabbit gamma globulin were then added. Finally, 312.5 µl of a barbital buffer solution containing 0.03 mg rabbit gamma globulin and 4.4 µg of 8-anilo-1-naphthalenesulfonic

acid (ANS) were added to the assay tubes. Tube contents were vortexed after each addition and after the final addition the tubes were kept at 5°C overnight. On the following day the tubes were centrifuged at 1400 g for 20 minutes and the resulting supernatants poured off. The tubes were then inverted and allowed to dry before being counted in a Beckman System 5500 gamma counter. Potency estimates of the samples were calculated using log-logit transformation and are expressed as ng per ml of plasma.

Proudman and Wentworth (1978) produced and characterized the anti-GH serum of the turkey GH radioimmunoassay used in this study. Turkey GH lot B166B (Burke and Papkoff, 1980) was used for the standard and a similar GH preparation (B181B) was used for iodination. The assay protocol used is described by Burke and Marks (1982).

The data were statistically analyzed using the Statistical Analysis System (Barr et al., 1979) as a repeated measures design. The model consisted of the whole plot units, strain and sex, and the split plot unit, time. Treatment effects involved the fixed order responses of the whole plot units in time. The split plot error term was used to test the whole plot error term and, if it was not found to be significant ($P \geq .25$), the terms were pooled before testing. Duncan's multiple range test (Duncan, 1955) was used to further test treatment differences. For clarity, where there were no strain by sex interactions (i.e. differences due to sex were similar between strains), the variables studied were presented and discussed by strain and by sex (pooled over strains).

RESULTS

Growth:

The patterns of growth observed for the three strains are shown in Figure 1. Day one body weights did not differ between strains, but by 14 days of age, strain 2 birds were significantly heavier than those in strains 1 and 3. At 28 days, body weights of strain 1 were intermediate to those of strains 2 and 3, and by 42 days they were heavier than strain 3. As expected, males had greater body weights than females (Figure 2), although this effect was not significant before 28 days of age.

Lipid:

Developmental changes in lipid deposition in the three strains are illustrated in Figure 1. Percent carcass fat did not differ significantly between strains before 28 days of age. At 28 and 42 days, strain 2 had a higher percent body fat than strains 1 and 3. Females deposited a greater amount of carcass fat than did males when expressed on a percentage basis, with significant differences in this trait apparent by 14 days of age (Figure 2).

T₃:

Although differing in growth and fattening, the strains showed no consistent differences in T₃ levels during the experimental period (Figure 3). However, at 42 days of age, T₃ levels of the faster growing strain were significantly higher than the slower growing strains. The larger, leaner male broilers had higher T₃ levels than the females, except at 14 days when no sex difference was detected (Figure 4). The age-related pattern of circulating T₃ was similar

between strains and sexes. Plasma T_3 levels were observed to increase from 3 to 14 days of age and to decrease in concentration thereafter.

GH:

A gradual decline in GH levels from 3 days was observed in the slowest growing strain 3. GH levels of strains 1 and 2, increased from 3 to 14 days and then declined (Figure 3). Although peak GH values did not differ between strains 1 and 2, the rate of GH decline was greater in the larger, faster growing strain 2. Therefore, with the exception of 14 days of age, the slow growing strain 3 had significantly elevated GH levels in comparison to the faster growing strain 2, and strain 1 had GH concentrations intermediate to the other strains. Male broilers had greater GH levels from 14 to 42 days of age than females (Figure 4). The age-related changes in GH levels in the male broilers were similar to those of the faster growing strains, while the pattern of circulating GH in the females was similar to that of the slow growing strain 3.

Both GH and T_3 levels were negatively associated with carcass fat in all strains and in both sexes (Table 2). The magnitude of the GH association was greater in the females, having a higher percent body fat, than in the males and also greater in the fatter strain 2. There were no consistent trends for a greater magnitude of T_3 association as the level of carcass fat increased.

Lipogenic enzymes:

There were no consistent strain differences in activity of malic enzyme (ME) or citrate cleavage enzyme (CCE) during the age period studied (Figure 5). However, at 3 days, ME activity of strain 2 was significantly higher than that of strain 1. There were also no

consistent sex differences in ME or CCE activity, although ME activity was higher in females at 3 and 28 days of age (Figure 6). The temporal patterns of enzyme activity were similar between strains and sexes. ME activity increased from 3 to 14 days of age and declined thereafter while CCE activity gradually decreased from 3 days of age.

DISCUSSION

Variation in growth between chickens has been related to differences in plasma concentrations of GH (Harvey et al., 1979; Scanes et al., 1980; Burke and Marks, 1983) and T_3 (Kühn et al., 1982; May and Marks, 1983). However, variable findings prevent definitive conclusions regarding the relationship between growth and hormone concentration. In agreement with the findings of Burke and Marks (1982), the slower growing broiler strain used in this study had higher GH levels than the faster growing broiler strain. Additionally, males had higher GH levels than females. The temporal pattern of circulating GH observed in 2 of the 3 strains in this study differed from that reported by Burke and Marks (1982). Whereas they found very little increase in GH between 1 and 2 weeks of age, levels in strains 1 and 2 increased. Harvey et al. (1979) reported similar age-related changes in GH concentration in male and female chickens.

The three broiler strains differed in growth rates and fattening but showed no difference in T_3 levels. While May and Marks (1983) did detect significant differences in T_3 levels between a commercial broiler line and a randombred line, the magnitude of body weight differences between their lines was much greater than in this study. Additionally, in contrast to Kühn et al. (1982), a significant sex effect in T_3 concentration was shown in this report. The elevated T_3

levels observed in males versus females may be attributable to differences in basal metabolic rate. The male broilers have an increased maintenance requirement to support their greater body weights and may thus exhibit greater thyroid activity for this reason. Age differences in plasma T_3 concentrations were similar to those reported by Bobek et al. (1977).

The high levels of ME and CCE activities observed in the post-hatching period is predictable since these enzymes have been shown to be linked to lipogenesis. The yolk on which the embryo is nourished has a high fat content and is essentially carbohydrate-free. Since high fat, low carbohydrate diets inhibit lipogenesis (White et al., 1978), it is not surprising to find a very low rate of fatty acid synthesis in embryonic liver. With the feeding of a conventional broiler starter ration, relatively high in carbohydrate and low in fat, the newly hatched chick exhibits a prompt increase in lipogenesis (Goodridge, 1968). The post-hatching patterns of ME and CCE activity observed in this study were similar to those shown by Goodridge (1968).

No consistent differences in ME and CCE activity between the strains differing in carcass fat were observed in this study. Shapira et al. (1978) and Hood and Pym (1982) did detect significant differences in lipogenic enzyme activity between selected lines of chickens. However, the magnitude of body fat differences between their lines was much greater than in this study.

Enzymes exhibit a great deal of variation from one physiological circumstance to another (Tepperman and Tepperman, 1964; Goodridge, 1968; Yeh and Levielle, 1969), and the actual rate of enzyme activity

is determined only by the concentration of substrate and the amount of enzyme present (White et al., 1978). Thus, while enzymes do not give direction to metabolism, they may be indicative of the state of metabolism.

The highly significant negative correlations between carcass fat and both GH and T_3 suggests the involvement of these hormones in growth and development in the chick. However, growth hormone and T_3 are but two of the numerous hormones giving direction to metabolism.

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Figure 1. Growth and lipid deposition in strains

Figure 2. Growth and lipid deposition in males and females

Figure 3. Changes in plasma T_3 and GH concentrations

Figure 4. Plasma T_3 and GH concentration in males and females

Figure 5. Variation in malic enzyme and citrate cleavage enzyme

Figure 6. Variation in malic enzyme and citrate cleavage enzyme in males and females

C.3.USA.a - Hormone and Lipogenic Enzyme Response of the Heterozygous dw Chick to Dietary Protein Level

The recessive sex-linked dwarfing gene (dw) in the chick, described by Hutt (1) in 1959, results in a reduction in body size. It has been shown that dwarf birds exhibit distinct pathways of protein and lipid metabolism. Protein turnover is accelerated in the dwarf (2-4) while lipolysis is inhibited (5,6). Blood glucose levels are lower in dwarf chicks (4) and liver glycogen storage is enhanced (7,8) as compared to non-dwarf chicks. These physiological differences are compatible with the reported differences in nutritional requirements between dwarf and normal birds. The dwarf requires higher dietary protein and lower dietary energy in comparison to the non-dwarf (6).

The dwarf chicken is also generally regarded as hypothyroidic (9-11). Although, decreased rates of ^{131}I uptake by the thyroid of dwarf chickens have been demonstrated, the rate of release of ^{131}I was shown to be identical for both dwarf and non-dwarf birds (12). Measurement of serum triiodothyronine (T_3) uptake by thyroid hormone binding protein and circulating thyroxine (T_4) levels demonstrated that the dwarf bird actually had higher levels of T_3 uptake and slightly greater serum T_4 levels than the non-dwarf controls (13). Scanes et al (14) and May and Marks (15) also reported circulating T_4 levels to be elevated in the dwarf, and additionally demonstrated circulating serum T_3 levels to be depressed. These authors hypothesized that the dwarf birds were deficient in the mono-deiodinase responsible for the conversion of T_4 to T_3 . Grandhi et al (16), however, reported that a greater proportion of T_4 was bound by serum proteins in the dwarf. Thus, Grandhi et al (16) felt abnormal binding of the thyroid hormones could prohibit their use at

the cellular level accounting for the apparent differences observed in thyroid function between dwarf and non-dwarf birds.

The dw gene is not entirely recessive. The heterozygous normal male progeny of dwarf dams exhibit a depressed (3 to 4 percent) eight week body weight while normal crossbred females from dwarf dams have a weight similar to their half-sib sisters from normal dams (6, 17). Further comparison of progeny from normal and dwarf dams crossed with normal males would provide more data concerning the degree of recessiveness of the dw gene and other pleiotropic effects it may have.

The purpose of this study was to examine the variation in hormone concentration and lipogenic enzyme function in phenotypically normal broiler progeny of normal and dwarf dams. Since the dwarfs require greater dietary protein than normal birds and since the rate of lipogenesis is also effected by dietary protein, the response of these broiler progeny to a high and low dietary protein regime was investigated.

MATERIALS AND METHODS

Strain and Diets: The experiment was initiated with 100 male (DwDw) and 100 female (Dw-) day old chicks descending from normal dams mated to normal males (Dw- x DwDw) and with 100 male (Dwdw) and 100 female (Dw-*) chicks descending from dwarf dams mated to normal males (dw- x DwDw). The progeny were the result of crosses within the same broiler strain and therefore differed only in the presence or absence of the sex-linked dw gene. At one day of age the chicks were sexed, wingbanded, weighed and randomly assigned to 16 floor pens of 25 birds

each. Treatments, consisting of a high and low protein regime (Table 1), were randomly assigned to the pens resulting in 4 replicates of each treatment by line by sex combination. The starter diet was fed from day one to 4 weeks of age and the finisher diet was then fed from 4 weeks to 8 weeks of age. Birds were allowed access to feed and water ad libitum until termination of the experiment at eight weeks. Food intake and body weights were recorded weekly. Initially and at bi-weekly intervals thereafter, three birds from each pen were randomly selected for analysis. Blood was collected by means of vena puncture using heparin as an anticoagulant. Plasma was separated by centrifugation on the day of collection and stored at -20°C until used for hormone analysis. Chicks were then sacrificed by dislocation of the neck to prevent blood loss, and the livers removed and frozen at -80°C . At 4, 6 and 8 weeks, abdominal fat pads were removed, weighed and returned to the carcasses. The carcasses were then frozen for subsequent determination of carcass composition.

Carcass Analysis: The carcasses were prepared for carcass analysis using the procedure of Stewart and Muir (18). Lypophilized carcass samples were assayed for nitrogen content utilizing the Kjeldahl method (19), and carcass fat was determined by a modification (20) of the Folch method (21). All carcass data are reported on a dry matter basis.

Enzyme Analysis: Liver homogenates for malic enzyme (NADP-malate dehydrogenase, EC 1.1.1.40) and citrate cleavage enzyme (ATP-citrate lyase, EC 4.1.3.8) analysis were prepared in 0.15M KCl and 20% ethanol. One gram samples of frozen liver were homogenized in a Sorvall Omni-Mixer (Dupont Instruments, Newtown, CN 06470), with 10

mls of the KCl-ethanol solution for approximately 1 minute. The 10% homogenates were then centrifuged at 10,000 x g for 60 minutes and the resulting supernatants used for enzyme assays. All operations were carried out at 0° to 5°C. Assays were conducted at 25°C for malic enzyme by the method of Ochoa (22) and for citrate cleavage enzyme by the procedure of Srere (23). Enzyme activities are expressed on the basis of nanomoles of nucleotide (NADPH or NAD⁺) per milligram of protein. Protein concentration of the liver tissue extracts was determined utilizing the Bio-Rad protein assay (Bio-Rad Laboratories, Richmond, CA, 94804).

Hormone Analysis: Plasma samples were assayed for growth hormone (GH), triiodothyronine (T₃), and thyroxine (T₄), using radioimmunoassays (RIA). A commercially purchased kit from Antibodies, Inc. (Davis, CA 95616) was utilized for the T₄ RIA. For the T₃ assay, rabbit anti-T₃ sera was used in the general procedure described by May (24), although a commercial goat anti-rabbit gamma globulin (Antibodies, Inc., Davis, CA 95616) was used in a modification of the assay. The T₃ RIA was run over a 24 hour period. Barbital buffer (pH 8.6) was used to dilute 15 µl plasma samples to 50 µl while standards were dispensed in 50 µl quantities. Anti-T₃ serum was diluted 1:200 in barbital buffer and 37.5 µl of antiserum was added to the tubes. Fifty µl of tracer diluted to 0.1µCi/ml and 50 µl of a 1:5 dilution of goat anti-rabbit gamma globulin were then added. Finally, 312.5 µl of a barbital buffer solution containing 0.03 mg rabbit gamma globulin and 4.4 µg of 8-anilino-1-naphthalenesulfonic acid (ANS) were added to the assay tubes. Tube contents were vortexed after each addition and after the final addition the tubes were kept

at 5°C overnight. On the following day the tubes were centrifuged at 1400 x g for 20 minutes and the resulting supernatants poured off. The tubes were then inverted and allowed to dry before being counted in a Beckman System 5500 gamma counter (Beckman Instruments, Palo Alto, CA). Potency estimates of the samples were calculated using log-logit transformation and are expressed as ng per ml of plasma.

Proudman and Wentworth (25) produced and characterized the anti-GH sera of the turkey GH radioimmunoassay used in this study. Turkey GH lot B166B (26) was used for the standard and a similar GH preparation (B181B) was used for iodination. The assay protocol is described by Burke and Marks (27).

Statistical Analysis: The data were statistically analyzed as a repeated measured design. The model consisted of the whole plot units, diet, line and sex, and the split plot unit, time. Treatment effects involved the fixed order responses of the whole plot units in time. The split plot error term was used to test the whole plot error and, if it was not found to be significant ($P \geq .25$), the terms were pooled before testing. Duncan's multiple range test (28) was used to further test treatment differences.

RESULTS AND DISCUSSION

Growth and carcass data: Growth rate (Figure 1) was significantly effected by genotype. The male progeny (DwDw) from normal dams exhibited greater ($P \leq .05$) weight gains from one to three weeks. There were no significant differences in gain between males of either genotype from 4 to 6 weeks, but from week 7 to 8 the Dwdw males had greater ($P \leq .05$) growth rates than the DwDw broilers. As a result of this increased growth rate of the Dwdw males, eight week body weights

were similar for the DwDw and Dwdw males, in contrast to the findings of Ricard and Conan (17) and Guillaume (6). These authors found that the heterozygous normal male progeny of dwarf dams had a slower growth rate than the homozygous normal males leading to a 3 to 4 percent depression in eight week body weight for the Dwdw broilers. However, the parental stock of the broilers used in this study have been selected for growth rate and Khan et al. (29) demonstrated that selection for growth rate in dwarf dams improved the performance of their normal crossbred progeny. In their study, there were no differences in weight gains between female progeny from either dwarf or normal dams after the first generation of selection, and by the third generation, growth rate between the male progeny also did not differ. Consistent with previous studies (6, 17, 29), growth rate was similar for female progeny regardless of dam type. As expected (30-32), the high protein regime resulted in improved gains.

Feed conversion ratios and percent carcass nitrogen were similar between progeny types, in agreement with previous reports (6, 17). Percent fat also was not significantly effected by genotype. While Ricard and Conan (17) reported that broilers from dwarf dams sometimes contain more abdominal fat, abdominal fat pad weights did not differ between broilers regardless of dam type in this study. Nor were genotypic differences detected if abdominal fat was expressed as a percent of body weight. Dietary protein did effect feed conversion ratios (Table 2), carcass nitrogen and fat content (Table 3) and abdominal fat deposition (Table 4). High dietary protein would be expected to improve feed to gain ratios (33-35), enhance carcass nitrogen content (36), decrease percent carcass fat (34, 37-40), and

reduce abdominal fat deposition (41-43), and all of these effects of high dietary protein were observed in this study.

No significant genotype by diet interactions were detected for growth rate or the carcass traits, indicating a similar response to protein level by all progeny. The expected poorer conversion of dietary protein typical of the homozygous dwarf was not evident in the phenotypically normal progeny of dwarf dams in this study. Thus, in terms of growth rate and carcass characteristics, there are no apparent differences in the dietary protein requirements of phenotypically normal broiler progeny from either dwarf or normal dams.

Hormone data: The presence of the dw gene and the growth differences associated with it were not reflected in hormonal differences between genotypes. Consistent with previous studies (15, 27, 44), males exhibited greater GH levels than females, and low dietary protein resulted in elevated plasma GH (Table 5). Neither sex nor diet effected T_4 levels (Table 6). Plasma T_3 levels (Table 7) did not differ between sexes, similar to the findings of Kühn et al. (45), and low dietary protein resulted in greater T_3 levels in male broilers. Variation in growth between strains of chickens has been related to differences in plasma GH (27, 46, 47) and T_3 (15, 45), but the magnitude of variation in body weight and carcass composition between such strains was greater than the genotypic differences observed in this study. The elevated T_4 levels and the depressed T_3 concentrations characteristic of the homozygous dwarf were not evident.

in the progeny of the dwarf dams although the males carried the dw gene.

Enzyme data: Although lipid deposition did not differ between progeny types, malic enzyme activity was significantly elevated in the DwDw broilers in comparison to the male broilers carrying the dw gene, regardless of dietary treatment (Table 8). The female progeny of the normal dams exhibited elevated enzyme activity in comparison to the Dw-* females only in response to low dietary protein (Table 9). A significant genotype by diet interaction for malic enzyme resulted from the marked elevation in enzyme activity in response to low dietary protein in the progeny of normal versus dwarf dams. Citrate cleavage enzyme was greater only in the female progeny of the dwarf dams in comparison to the Dw- females (Tables 10 and 11). Thus, both the level of enzyme activity and the dietary response in enzyme activity were affected by genotype. Malic enzyme has been demonstrated to play a major role in supplying reducing equivalents (NADPH) for the support of fatty acid biosynthesis in the chick (48, 49). Citrate cleavage enzyme is also associated with lipogenesis in the chick (50). Changes in the activities of these two lipogenic enzymes are preceded by a change in the rate of fatty acid synthesis (51, 52). Thus, since decreasing the dietary protein level increases fatty acid synthesis (53), the observed elevation in malic and citrate cleavage enzyme activities in response to low dietary protein was expected and was in agreement with the findings of Yeh and Leveille (48).

Although differences in lipogenic enzyme activity between lines of chickens differing in carcass fat have been demonstrated (54, 55),

the broiler progeny types used in this study differed in enzyme activity but not fat deposition. Mariash et al. (56) demonstrated that glucose is the factor responsible in the carbohydrate induction of malic enzyme, with T_3 acting as a multiplier of this glucose-induced signal. Dillman et al. (57) reported that the induction of malic enzyme in cultured rat hepatocytes was greatly inhibited by the loss of T_3 nuclear receptors. Therefore, if the introduction of the dw gene had effected the number of hepatic T_3 receptors, the elevated enzyme activity in the DwDw broilers in comparison to the males carrying the dw gene and the greater effect of low protein on the enzyme response of those progeny from normal dams would be understandable. Thus, since the actual thyroidal status of the dwarf bird is still unknown and since malic enzyme has been shown to be an excellent index of thyroid hormone action at the cellular level (58-60), regression analysis was used to investigate this relationship between hepatic enzyme activity and circulating T_3 levels in the progeny of normal versus dwarf dams. A significantly positive linear relationship between malic enzyme and plasma T_3 was found for all progeny except the males carrying the dw gene (Figure 2). This finding suggests that although circulating levels of thyroid hormones did not differ between genotypes, the cellular response to these hormones was effected by the presence of the dw gene. This difference in cellular response may be related to an effect of the dw gene on the number of T_3 receptors or on the affinity of the hormone for these receptors.

It is therefore apparent that the dw gene has more pleiotropic effects than its well documented influence on body weight. Further

investigation concerning the relationship between plasma hormone concentration and cellular response between normal and dwarf chicks is necessary to identify the extent of the physiological mechanisms influenced by the dw gene.

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Figure 1. Gain for progeny of normal and dwarf dams in response to dietary protein

Figure 2. Observed and predicted response of malic enzyme activity to plasma T_3 concentration

TABLE 1
Composition of high and low protein diets

Ingredients	Low Protein		High Protein	
	Starter	Finisher	Starter	Finisher
Corn	72.0	76.95	57.75	62.25
Soybean meal	18.75	9.67	31.00	22.50
Corn gluten meal	-	3.00	-	3.00
Poultry by product meal	5.0	5.00	5.00	5.00
Poultry fat	1.00	2.03	3.00	4.00
Limestone	0.65	0.65	0.65	0.65
Defluorinated phosphate	1.75	1.75	1.75	1.75
Salt	0.40	0.40	0.40	0.40
Methionine (DL)	0.15	0.15	0.15	0.15
Trace mineral ²	0.05	0.05	0.05	0.05
Vitamin premix ²	0.25	0.25	0.25	0.25
Protein (%)	18.4	16.3	23.0	21.2
Metabolizable energy (kcal/kg)	3120	3256	3120	3256

¹Trace mineral provides (ppm of diet): Mn, 60; Zn, 50; Fe, 20; Cu, 5; I, 1.05; Ca, 75 (min.) and 90 (max.).

²Vitamin premix provides (per kg of diet): vit. A, 5,500 IU, vit. D₃, 1100 ICU, vit. E, 11 IU; riboflavin 4.4 mg; Ca pantothenate, 12 mg; nicotinic acid, 44 mg; choline Cl, 220 mg, vit. B₁₂, 6.6 mcg; vit. B₆, 2.2 mg; menadione, 1.1 mg; folic acid, 0.55 mg; d-biotin, 0.11 mg; thiamine¹² mononitrate, 2.2 mg, ethoxyquin (125 mg).

TABLE 2
Feed conversion (feed/gain) means for sexes (pooled over genotype) in response to dietary protein level

Week	Male		Treatment Means	Female		Treatment Means
	Low Protein	High Protein		Low Protein	High Protein	
2	1.84 ± 0.04	1.52 ± 0.04	1.66 ± 0.03 ^a	1.80 ± 0.04	1.51 ± 0.04	1.67 ± 0.03 ^a
3	1.76 ± 0.05	1.66 ± 0.04	1.71 ± 0.03 ^a	1.84 ± 0.05	1.75 ± 0.05	1.80 ± 0.04 ^a
4	1.57 ± 0.29	1.63 ± 0.25	1.61 ± 0.19 ^a	2.27 ± 0.27	2.13 ± 0.29	2.21 ± 0.20 ^b
5	2.95 ± 0.13	1.83 ± 0.12	2.31 ± 0.09 ^a	2.90 ± 0.13	2.30 ± 0.14	2.62 ± 0.09 ^b
6	3.10 ± 0.09	1.84 ± 0.08	2.37 ± 0.06 ^a	3.00 ± 0.09	2.25 ± 0.09	2.65 ± 0.06 ^b
7	3.02 ± 0.28	2.57 ± 0.26	2.77 ± 0.19 ^a	2.68 ± 0.29	2.86 ± 0.30	2.77 ± 0.21 ^b
8	3.07 ± 0.22	2.74 ± 0.21	2.81 ± 0.15 ^a	3.35 ± 0.23	2.71 ± 0.24	3.03 ± 0.17 ^b
$\bar{x}$	2.47 ^x	1.97 ^y	2.21 ^a	2.55 ^x	2.22 ^y	2.39 ^b
SE	0.14	0.12	0.10	0.15	0.16	0.09

^{a,b}Means within week differ ($P \leq .05$) between male and female broilers if superscripts differ.

^{x,y}Means within sexes differ ($P \leq .001$) due to dietary treatment if superscripts differ.

TABLE 3

Percent nitrogen (nitrogen gain/DM wt.) and percent fat (fat gain/DM wt.) in response to dietary protein (pooled over genotype and sex)

Week	Percent Nitrogen Gain		Percent Fat Gain	
	Low Protein	High Protein	Low Protein	High Protein
2	7.56 $\pm$ 0.08	8.04 $\pm$ 0.09	24.84 $\pm$ 0.63	22.68 $\pm$.067
4	7.41 $\pm$ 0.08	8.11 $\pm$ 0.09	27.16 $\pm$ 0.62	22.14 $\pm$ 0.63
6	7.47 $\pm$ 0.08	8.00 $\pm$ 0.08	26.19 $\pm$ 0.67	24.32 $\pm$ 0.66
8	7.79 $\pm$ 0.08	8.39 $\pm$ 0.08	31.47 $\pm$ 0.64	28.84 $\pm$ 0.63
$\bar{x}$	7.56 ^a	8.14 ^b	27.44 ^a	24.50 ^b
SE	0.04	0.04	0.32	0.32

a,b Means differ ($P \leq .001$) due to dietary treatment is superscripts differ.

TABLE 4
Mean abdominal fat pad weights (g) for sexes in response to dietary protein

Week	Male		Treatment Mean	Female		Treatment Mean
	Low Protein	High Protein		Low Protein	High Protein	
2	—	—	—	—	—	—
4	8.69 ± 3.58	9.04 ± 2.97	8.89 ± 2.3	9.25 ± 2.77	8.07 ± 3.39	8.87 ± 2.1
6	26.61 ± 3.79	20.60 ± 2.97	22.89 ± 2.97	28.93 ± 2.97	26.13 ± 3.58	27.79 ± 2.3
8	43.82 ± 3.23	39.68 ± 2.87	41.50 ± 2.1	58.44 ± 3.23	42.44 ± 3.39	51.17 ± 2.3
$\bar{x}$	27.61 ^a	23.52 ^b	25.02 ^x	30.40 ^a	25.53 ^b	28.35 ^y
SE	2.03	1.70	1.30	1.70	1.99	1.29

^{a,b}Means differ ($P \leq .01$) due to dietary treatment if superscripts differ.

^{x,y}Means differ ($P \leq .05$) between sexes if superscripts differ.

TABLE 5

Mean plasma growth hormone (ng/ml) levels for sexes in response to dietary protein

Week	Male		Treatment Means	Female		Treatment Means
	Low Protein	High Protein		Low Protein	High Protein	
2	74.08 ± 9.42	82.81 ± 9.84	78.26 ± 6.8 ^a	99.16 ± 9.84	74.17 ± 9.42	86.12 ± 6.8 ^a
4	88.23 ± 10.88	72.16 ± 9.84	79.39 ± 7.3 ^a	54.99 ± 8.72	42.32 ± 9.84	49.42 ± 6.5 ^b
6	110.82 ± 12.34	55.26 ± 8.43	72.94 ± 6.9 ^a	60.21 ± 8.72	40.84 ± 11.54	53.16 ± 6.9 ^b
8	63.82 ± 9.84	30.57 ± 9.42	46.47 ± 6.8 ^b	27.77 ± 10.32	25.03 ± 10.88	26.47 ± 7.5 ^c
$\bar{x}$	81.05 ^x	59.19 ^y	68.88 ^a	60.84 ^x	47.69 ^y	54.93 ^b
SE	5.22	4.66	3.48	4.66	4.92	3.44

a,b Means differ ($P \leq .01$) between sexes if superscripts differ.

x,y Means within sexes differ ($P \leq .001$) due to dietary treatment if superscripts differ.

TABLE 6
Mean plasma T_4 (ng/ml) levels for sexes in response to dietary protein

Week	Male		Treatment Means	Female		Treatment Means
	Low Protein	High Protein		Low Protein	High Protein	
2	7.34 $\pm$ 0.78	9.33 $\pm$ 0.88	8.33 $\pm$ 0.58 ^a	7.74 $\pm$ 0.97	9.42 $\pm$ 0.81	8.73 $\pm$ 0.62 ^a
4	7.81 $\pm$ 0.97	8.19 $\pm$ 0.84	8.03 $\pm$ 0.64 ^a	6.02 $\pm$ 0.81	7.00 $\pm$ 0.92	6.45 $\pm$ 0.61 ^b
6	10.12 $\pm$ 1.10	7.17 $\pm$ 0.73	8.07 $\pm$ 0.61 ^a	7.53 $\pm$ 0.75	7.85 $\pm$ 0.92	7.66 $\pm$ 0.58 ^{ab}
8	9.19 $\pm$ 0.92	8.28 $\pm$ 0.84	8.69 $\pm$ 0.62 ^a	6.61 $\pm$ 0.84	8.41 $\pm$ 0.84	7.51 $\pm$ 0.60 ^{ab}
$\bar{x}$	8.40	8.14	8.25 ^a	6.94	8.26	7.58 ^a
SE	0.46	0.41	0.31	0.42	0.44	0.30

a,b Means differ ($P \leq .05$) between sexes if superscripts differ.

TABLE 7

Mean plasma T_3 (ng/ml) levels for sexes in response to dietary protein

Week	Male		Treatment Means	Female		Treatment Means
	Low Protein	High Protein		Low Protein	High Protein	
2	5.82 ± 0.31	5.47 ± 0.34	5.66 ± 0.23 ^a	5.40 ± 0.37	5.12 ± 0.32	5.24 ± 0.24 ^a
4	4.18 ± 0.37	3.74 ± 0.32	3.93 ± 0.24 ^{bc}	4.52 ± 0.30	4.10 ± 0.35	4.34 ± 0.23 ^b
6	5.13 ± 0.42	4.34 ± 0.28	4.58 ± 0.23 ^b	4.94 ± 0.30	4.75 ± 0.35	4.86 ± 0.23 ^a
8	3.91 ± 0.35	3.42 ± 0.32	3.64 ± 0.24 ^c	3.94 ± 0.32	3.53 ± 0.32	3.73 ± 0.23 ^c
$\bar{x}$	4.83 ^x	4.23 ^y	4.49 ^a	4.66 ^x	4.37 ^x	4.52 ^a
SE	0.18	0.16	0.12	0.16	0.17	0.11

^{a,b}Means differ ($P \leq .05$) between sexes if superscripts differ.^{x,y}Means differ within sexes ($P \leq .01$) due to dietary treatment if superscripts differ.

TABLE 8
Mean malic enzyme (nM NADPH/mg protein) activity for male broilers in response
to dietary protein

Week	DwDw		Treatment Means	Dwdw		Treatment Means
	Low Protein	High Protein		Low Protein	High Protein	
2	40.20 ± 2.2	21.04 ± 2.5	31.82 ± 1.5	29.92 ± 3.8	13.57 ± 3.3	20.58 ± 2.3
4	37.48 ± 3.3	16.30 ± 3.7	28.06 ± 2.1	28.64 ± 3.7	15.53 ± 2.8	20.29 ± 1.8
6	35.54 ± 3.2	14.94 ± 2.1	21.12 ± 1.6	23.81 ± 2.8	12.50 ± 1.9	16.26 ± 1.7
8	27.81 ± 1.8	11.50 ± 1.8	19.43 ± 1.7	23.47 ± 2.0	10.32 ± 1.7	15.80 ± 1.9
$\bar{x}$	35.77 ^x	15.93 ^y	25.66 ^a	26.05 ^x	12.89 ^y	17.90 ^b
SE	1.26	1.23	0.88	1.50	1.19	0.93

^{a,b}Means differ ($P \leq .001$) between genotypes if superscripts differ.

^{x,y}Means within genotypes differ ($P \leq .001$) due to dietary treatment if superscripts differ.

TABLE 9
Mean malic enzyme (nM NADPH/ng protein) activity for female broilers in response
to dietary protein

Week	Dw-		Treatment Means	Dw-*		Treatment Means
	Low Protein	High Protein		Low Protein	High Protein	
2	37.13 ± 3.8	21.15 ± 3.0	27.15 ± 2.1	33.77 ± 2.3	16.20 ± 2.5	25.57 ± 1.6
4	29.16 ± 2.8	14.74 ± 2.6	21.47 ± 1.9	33.53 ± 3.0	18.23 ± 4.3	28.71 ± 1.9
6	40.99 ± 1.9	19.35 ± 2.4	32.67 ± 1.7	28.16 ± 2.3	22.67 ± 2.4	25.11 ± 1.9
8	33.67 ± 2.0	12.33 ± 1.8	21.17 ± 1.9	27.48 ± 1.7	12.31 ± 2.2	21.96 ± 1.8
$\bar{x}$	35.51 ^x	16.43 ^y	25.55 ^a	30.85 ^x	16.64 ^y	25.29 ^a
SE	1.29	1.23	0.89	1.14	1.42	0.89

a,b Means differ ($P \leq .05$) between genotypes if superscripts differ.

x,y Means within genotypes differ ($P \leq .001$) due to dietary treatment if superscripts differ.

TABLE 10
Mean citrate cleavage enzyme (nM NAD⁺/mg protein) activity for male broilers in response to dietary protein

Week	Dwdw		Treatment Means	Dwdw		Treatment Means
	Low Protein	High Protein		Low Protein	High Protein	
2	17.14 ± 3.3	11.22 ± 3.6	14.38 ± 1.4	20.94 ± 5.4	22.98 ± 4.7	22.11 ± 2.1
4	13.94 ± 1.9	10.84 ± 2.4	12.77 ± 2.0	19.73 ± 2.1	9.73 ± 1.7	13.73 ± 1.7
6	8.61 ± 2.4	4.96 ± 1.6	6.05 ± 1.7	9.04 ± 2.1	7.06 ± 1.6	7.78 ± 1.7
8	8.96 ± 0.94	3.29 ± 0.86	5.87 ± 1.7	5.29 ± 1.0	4.31 ± 0.86	4.70 ± 1.7
$\bar{x}$	13.21 ^x	7.20 ^y	10.07 ^a	13.27 ^x	9.81 ^y	11.18 ^a
SE	1.21	1.16	0.84	1.43	1.16	0.90

a,b Means differ ($P \leq .05$) between genotypes if superscripts differ.

x,y Means within genotypes differ ($P \leq .001$) due to dietary treatment if superscripts differ.

TABLE 11
 Mean citrate cleavage enzyme (nM NAD⁺/mg protein) activity for female broilers in response
 to dietary protein

Week	Dw-		Treatment Means	Dw-x		Treatment Means
	Low Protein	High Protein		Low Protein	High Protein	
2	16.94 ± 5.4	12.74 ± 4.2	14.31 ± 2.0	27.49 ± 3.3	16.97 ± 3.8	22.98 ± 1.5
4	13.15 ± 1.6	12.88 ± 1.5	13.01 ± 1.4	17.93 ± 1.7	12.51 ± 2.4	16.08 ± 1.7
6	6.83 ± 1.6	3.64 ± 2.1	5.67 ± 1.7	5.93 ± 1.7	10.37 ± 1.9	7.18 ± 1.7
8	5.75 ± 1.21	3.50 ± 0.86	4.04 ± 2.0	6.23 ± 0.80	4.56 ± 1.0	5.62 ± 1.7
$\bar{x}$	10.63 ^x	8.79 ^y	9.63 ^a	15.08 ^x	11.40 ^y	13.69 ^b
SE	1.27	1.16	0.86	1.05	1.35	0.83

a,b Means differ ($P \leq .01$) between genotypes if superscripts differ.

x,y Means within genotypes differ ($P \leq .001$) due to dietary treatment if superscripts differ.

C.3.USA.a - Effect of the dw Gene on Growth, Plasma Hormone Concentration and Hepatic Enzyme Activity in a Randombred Population

INTRODUCTION

There have been numerous studies examining the effect of the recessive sex-linked dwarfing gene, dw, on growth and reproductive fitness in broiler population backgrounds since the gene was first described by Hutt (1959). More recently, the hormonal and biochemical explanations of the dwarfism phenomena have become the focus of much research.

Scanes et al. (1982) and May and Marks (1983) reported that circulating thyroxine (T_4) levels were elevated and that serum triiodothyronine (T_3) levels were depressed in dwarf versus non-dwarf chickens. These authors hypothesized that the sex-linked dwarf strain was deficient in the mono-deiodinase responsible for the conversion of T_4 to T_3 in the peripheral tissues. Hoshino and Yamamoto (1977) found dwarf male chickens to have a higher rate of growth hormone (GH) synthesis in the anterior pituitary and speculated that the sensitivity of the peripheral tissues to GH was lower in dwarf versus normal controls. Supporting the hypothesis of Hoshino and Yamamoto (1977), serum GH levels of dwarfs were similar to non-dwarfs but serum somatomedin activity was lower in the dwarfs in a study by Hoshino et al. (1982).

Numerous reports have demonstrated that the main difference in body composition between dwarfs and non-dwarfs is the greater amount of lipid deposited by the dwarf (Guillaume, 1976). However, the effects of the dw gene on lipogenic enzyme activity have not been reported. Malic enzyme (ME) plays a major role in supplying reducing equivalents (NADPH) for the support of fatty acid biosynthesis in the chick (Yeh and Leveille, 1969; Goodridge and Ball, 1966).

Additionally, citrate cleavage enzyme (CCE) is associated with lipogenesis in the chick (Goodridge, 1968). Investigation of differences in malic enzyme activity between dwarfs and non-dwarfs may be particularly significant since this enzyme has been shown to be an excellent index of thyroid hormone action at the cellular level (Oppenheimer *et al.*, 1978; Ruegamer *et al.*, 1965; Westerfield *et al.*, 1965).

The purpose of this study was to examine growth and lipid deposition in relationship to plasma hormone (GH, T_4 , T_3) concentrations and hepatic enzyme (ME, CCE) activities as effected by the dw gene in a broiler-type randombred population. In order to assess the degree of recessiveness of the gene the reciprocal crosses were examined as well as the purebred dwarf and normal populations.

MATERIALS AND METHODS

The development of normal and dwarf populations from the Athens-Canadian randombred base population is described by Marks (1983). The four mating combinations producing the chicks used in this study are shown in Table 1 and are referred to as cross 1, 2, 3 and 4. Cross 1 was the mating of a normal sire (DwDw) to a normal dam (Dw-) producing normal progeny. Cross 2 was the dwarf sire by dwarf dam mating. In cross 3 a dwarf sire (dwdw) was mated to a normal dam (Dw-) resulting in phenotypically normal male progeny heterozygous for the dw gene and dwarf female progeny. In cross 4 a normal sire (DwDw) was mated to a dwarf dam (dw-) to produce phenotypically normal male progeny carrying the dw gene and normal female progeny. Artificial insemination was used to produce all progeny.

At one day of age, chicks were sexed, wingbanded, and randomly assigned to 32 battery brooding pens of 12 birds each, resulting in 4 replicates of each sex by cross combination. From day 1 until termination of the experiment at 6 weeks, all birds were fed the University of Georgia conventional broiler starter diet (23% protein, 3120 kcal/kg metabolizable energy) on an ad libitum basis. Three birds from each pen (n = 12 males and 12 females per cross) were randomly selected for study at 0, 2, 4 and 6 weeks of age after weighing. Blood samples were then obtained by cardiac puncture using EDTA as an anticoagulant. Plasma was separated by centrifugation on the day of collection and stored at -20°C until analyzed. Chicks were sacrificed by dislocation of the neck to prevent blood loss, and the livers removed and frozen at -80°C. At 4 and 6 weeks, abdominal fat pads were removed, weighed and returned to the carcasses. All carcasses were frozen at -20°C for subsequent determination of carcass lipid content.

The frozen carcasses, including feathers, were individually cut into sections, ground in a meat grinder, mixed and reground twice to obtain a homogenous mixture. Carcass lipid content was determined for duplicate one gram samples by a modification (Washburn and Nix, 1974) of the Folch method (Folch et al., 1957).

Liver homogenates for malic enzyme and citrate cleavage enzyme analyses were prepared in a 0.15M KCl and 20% ethanol solution. One gram samples of frozen liver were homogenized in a Sorvall Omni-Mixer (Dupont Instruments, Newtown, CN 06470), with 10 mls of the KCl-ethanol solution for approximately 1 minute. The 10% homogenates were then centrifuged for 60 minutes at 10,000 X g and the resulting

supernatants used for enzyme assays. All operations were carried out at 0° to 5°C. Assays were conducted at 25°C for malic enzyme (EC 1.1.1.40) by the method of Ochoa (1955) and for citrate cleavage enzyme (EC 4.1.3.8) by the procedure of Srere (1959). Enzyme activities were expressed on the basis of nanomoles of nucleotide (NADPH or NAD⁺) per milligram of protein. Protein concentration of the liver tissue extracts was determined utilizing the Bio-Rad protein assay (Bio-Rad Laboratories, Richmond, CA 94804).

Plasma samples were assayed for growth hormone (GH), triiodothyronine (T₃) and thyroxine (T₄), using radioimmunoassays (RIA). A commercially purchased kit from Antibodies, Inc. (Davis, CA 95616) was utilized for the T₄ RIA. For the T₃ assay, rabbit anti-T₃ serum was used in the general procedure described by May (1978), although a commercial goat anti-rabbit gamma globulin (Antibodies, Inc., Davis, CA 95616) was used in a modification of the assay. The T₃ RIA was run over a 24 hour period. Barbital buffer (pH 8.6) was used to dilute 15 µl plasma samples to 50 µl while standards were dispensed in 50 µl quantities. Anti-T₃ serum was diluted 1:200 in barbital buffer and 37.5 µl of antiserum was added to the tubes. Fifty µl of tracer diluted to 0.1µCi/ml and 50 µl of a 1:5 dilution of goat anti-rabbit gamma globulin were then added. Finally, 312.5 µl of a barbital buffer solution containing 0.03 mg rabbit gamma globulin and 4.4 µg of 8-anilo-1-naphthalenesulfonic acid (ANS) were added to the assay tubes. Tube contents were vortexed after each addition and after the final addition the tubes were kept at 5°C overnight. On the following day the tubes were centrifuged at 1400 X g for 20 minutes and the resulting supernatants poured off. The tubes were than

inverted and allowed to dry before being counted in a Beckman System 5500 gamma counter (Beckman Instrument, Palo Alto, CA). Potency estimates of the samples were calculated using log-logit transformation and are expressed as ng per ml of plasma.

Proudman and Wentworth (1978) produced and characterized the anti-GH serum of the turkey GH RIA used in this study. Turkey GH lot B166B (Burke and Papkoff, 1980) was used for the standard and a similar GH preparation (B181B) was used for iodination. The assay protocol used is described by Burke and Marks (1983).

The data were statistically analyzed using the Statistical Analysis System (Barr et al., 1979) as a repeated measures design. The model consisted of the whole plot units, cross and sex, and the split plot unit, time. Treatment effects involved the fixed order responses of the whole plot units in time. The split plot error term was used to test the whole plot error term and, if it was not found to be significant ($P \geq .25$), the terms were pooled before testing. Duncan's multiple range test (Duncan, 1955) was used to further test treatment differences.

RESULTS and DISCUSSION

Growth and lipid deposition: The effect of the dw gene on body weight is a continuous process, progressively reducing the size of the growing dwarf bird as compared to the normal. Adult body size is gradually reduced by 30 percent (Hutt, 1959; Bernier and Arscott, 1972; Guillaume, 1969), although the relative reduction of body weight is not constant. The larger the potential adult size of the population in which the dw gene is introduced, the smaller the relative reduction in body weight (Mohammadian and Jaap, 1972). In

the present study, the body weights of the dwarf birds were significantly less than the phenotypically normal birds (Table 2). The reduction in body size between homozygous normal males and the dwdw males was approximately 17 percent, while the heterozygous males of crosses 3 and 4 had body weights about 27 percent greater than those of the dwarfs. Not only did the Dwdw males from crosses 3 and 4 have greater body weights than the dwdw males, they also exhibited significantly greater body weights than the homozygous normal males of cross 1. Typically the heterozygous male has a 3 to 4 percent depression in eight weeks body weight in comparison to the DwDw male (Ricard and Conan, 1974; Guillaume, 1976), although Khan et al. (1975) demonstrated that selection for growth rate in dwarf dams improved the performance of their normal crossbred progeny. The normal and dwarf populations developed from a randombred population and used to produce the four mating combinations of this study had undergone four generations of selection for increased body weight. Although selection had changed body weight only minimally in comparison to the base population in which the dw gene was originally introduced (Marks, 1983), the Dwdw males were the result of crossing two distinct populations. Thus "hybrid vigor" or heterosis may be the reason the Dwdw males were heavier than the DwDw males. The dw- females from crosses 2 and 3 exhibited a 25 percent reduction in body weight in comparison to the normal females from crosses 1 and 4. The observed reductions in body weights of the male and female progeny was progressive, with the greatest differences in body weight between the dwarfs and the non-dwarfs apparent at 6 weeks of age.

Percent carcass fat was greater in the dwdw males than the DwDw or Dwdw males, and similarly, the dw- females from crosses 2 and 3 exhibited greater carcass fat accumulation than the normal females from crosses 1 and 4 (Table 3). This finding is consistent with observations that the main difference in body composition between dwarfs and non-dwarfs is the greater amount of lipid deposited by dwarfs (Merat and Guillaume, 1969; Guillaume, 1969).

Ricard and Conan (1974) reported that broilers from dwarf dams sometimes contain more abdominal fat. In the present study, all male birds carry the dw gene (crosses 2, 3 and 4) had greater fat pad weights than homozygous normal birds from cross 1 (Table 4). There was no distinction between the males homozygous or heterozygous for the dw gene in the amount of abdominal fat deposited. In contrast, dwarf females of cross 3 had significantly less abdominal fat than Dw-females of cross 4, while dw-females from the dwarf parental mating (cross 2) had fat pad weights similar to normal females from either cross 1 or 4. There is a great deal of variation associated with both the amount of fat deposited in the abdominal area and in the recovery of that fat for weighing. Although, as stated previously, both cross 2 and cross 3 dwarf females had greater total carcass lipid deposition in comparison to normal females, it is apparent that this difference was not due to differences in accumulation of abdominal fat.

Hormone data: The presence of the dw gene and the growth and lipid differences associated with it were reflected in hormonal differences between genotypes. Plasma T_4 levels were greater in all males carrying the dw gene in comparison to DwDw males of cross 1 (Table 5). There was no distinction between males homozygous or heterozygous for

the dw gene in plasma T_4 concentrations. Dwarf females from dwarf parental matings (cross 2) exhibited greater T_4 levels than normal females from normal parental matings. Female progeny from crosses 3 and 4 had T_4 levels intermediate to, but not statistically different from progeny from either cross 1 or 2 (Table 5). The elevated plasma T_4 levels observed in this study for dwarf progeny are consistent with previous findings (Scanes et al., 1982; May and Marks, 1983) in other populations carrying the dw gene. The fact that the crossbred male progeny from crosses 3 and 4 also exhibited elevated T_4 levels versus DwDw males, and, although not significant statistically, the fact that both dw- and Dw- females from crosses 3 and 4 exhibited elevated plasma T_4 concentrations in comparisons to Dw- females from the normal parental mating, emphasizes the fact that the action of the dw gene is not entirely recessive, and suggests an influence of the residual genotype.

The dwdw males had significantly lower circulating T_3 concentrations than DwDw males. The heterozygous normal males of crosses 3 and 4 had levels lower than homozygous normal males, but greater than dwarf males (Table 6). Regardless of parental mating type or combination, dwarf females had lower circulating T_3 concentrations than normal females (Table 6). These findings of depressed T_3 levels in dwarf birds are consistent with previous reports by Scanes et al. (1982) in a White Leghorn population and May and Marks (1983) in a randombred population.

Mean plasma GH levels for male birds are shown in Table 7. Dwarf males had significantly greater GH concentrations than homozygous normal males from cross 1. The Dwdw males from crosses 3 and 4

exhibited GH levels intermediate to dwdw and DwDw males, although the difference between the cross 4 males and the cross 1 males was not significant. Dwarf females had significantly higher GH levels than normal females (Table 7). The sensitivity of the peripheral tissues to GH may be lower in dwarfs, the GH released by the pituitary of the dwarf may be biologically less active, or the degradation of the released GH may be more rapid in dwarfs than non-darwfs. Each of these suggestions could result in increased GH synthesis and, thus, in the elevated plasma GH concentrations observed in the slower growing, smaller dwarf progeny. The elevated GH concentrations of the dwarf progeny is in contrast to the reports of Hosino et al. (1982). These authors, using a rat-GH assay and relatively small numbers, found serum GH levels of White Leghorn dwarf chickens to be comparable to their non-dwarf counterparts.

Enzyme data: Malic enzyme activity was lower in all males carrying the dw gene, without distinction between the homozygote or the heterozygote, in comparison to the homozygous normal males (Table 8). Similarly, dwarf females had lower ME activity than normal females (Table 8). Citrate cleavage enzyme activity was similar between males and females from all crosses (Table 9).

Shapira et al. (1978) found ME and CCE activities were elevated in a heavy breed of chicken, containing greater carcass lipid, than in a leaner, light breed of chicken. Hood and Pym (1982) also found ME activity to be positively correlated with lipid deposition in chickens. In the present study, although dwarf males and females exhibited greater carcass fat content, ME activity was depressed in comparison to homozygous normal males and females. Additionally,

although Dwdw males did not differ in total carcass lipid in comparison to DwDw males, these males, heterozygous for the dw gene, also had lower ME activity than the homozygous normal males.

The lower ME activity may be a result of the lower plasma T_3 levels observed in the birds carrying the dw gene, or it may be the result of decreased sensitivity of the hepatocytes to plasma T_3 in these birds. A number of researchers (Oppenheimer et al., 1978; Ruegamer et al., 1965; Westerfield et al., 1965) have shown ME to be an excellent index of thyroid hormone action at the cellular level. Simat et al. (1980) observed a marked decrease in ME activity in thyroidectomized rats, with administration of physiological levels of T_4 restoring this activity to normal. Goodridge and Adelman (1976) reported that ME synthesis was induced by physiological levels of thyroid hormone in chicken liver cells in vitro, and they suggested that the regulation of ME activity by T_3 occurred at the nuclear receptor sites of the hormone. The loss of hepatic T_3 receptors has been demonstrated to inhibit the induction of ME in cultured rat hepatocytes by Dillman et al. (1978). The fact that the Dwdw males exhibited similar enzyme activities to the dwdw males, but had greater circulating T_3 levels suggests that the depressed ME activities associated with the dw gene are not simply attributable to the availability of plasma T_3 , but may be more related to the effect of the dw gene on the number of T_3 receptors or on the affinity of the hormone for these receptors.

Table 1. Genotypes of the parental matings and the genotypes of their progeny used in this study

Sire X Dam	Progeny	
	Male	Female
<u>Cross 1</u>		
<u>DwDw</u> X <u>Dw-</u>	<u>DwDw</u>	<u>Dw-</u>
<u>Cross 2</u>		
<u>dwdw</u> X <u>dw-</u>	<u>dwdw</u>	<u>dw-</u>
<u>Cross 3</u>		
<u>dwdw</u> X <u>Dw-</u>	<u>Dwdw</u>	<u>dw-</u>
<u>Cross 4</u>		
<u>DwDw</u> X <u>dw-</u>	<u>Dwdw</u>	<u>Dw-</u>

Table 2. Mean body weight (gms) for males and females

Week	Cross 1		Cross 2		Cross 3		Cross 4		Marginal means
	DwDw		dwdw		Dwdw		Dwdw		
0	40.24 ± 0.45 ^{ab}		39.25 ± 0.44 ^a		40.87 ± 0.46 ^b		39.05 ± 0.45 ^a		39.84 ± 2.21
2	133.79 ± 3.62 ^b		131.60 ± 3.58 ^b		164.29 ± 3.67 ^a		154.44 ± 3.62 ^a		145.81 ± 1.69
4	367.80 ± 9.43 ^a		331.49 ± 8.80 ^b		386.02 ± 9.24 ^a		369.26 ± 8.89 ^a		363.09 ± 4.71
6	690.45 ± 27.67 ^a		575.72 ± 26.59 ^b		795.33 ± 27.67 ^c		765.50 ± 24.75 ^{ac}		707.62 ± 12.74
Male means	176.57 ± 4.11 ^a		159.25 ± 4.00 ^b		200.34 ± 4.05 ^c		201.67 ± 3.87 ^c		205.45 ± 1.66
Week	Dw-		dw-		dw-		Dw		Marginal means
0	41.26 ± 0.40 ^a		39.03 ± 0.40 ^b		40.12 ± 0.41 ^{ab}		39.37 ± 0.40 ^b		39.94 ± 0.21
2	147.55 ± 3.24 ^a		129.96 ± 3.03 ^b		130.48 ± 3.70 ^b		156.46 ± 3.03 ^a		141.88 ± 1.77
4	357.90 ± 10.32 ^a		310.68 ± 9.53 ^b		285.67 ± 10.32 ^b		385.33 ± 9.71 ^a		335.45 ± 4.81
6	617.55 ± 27.59 ^a		485.21 ± 22.53 ^b		459.25 ± 30.85 ^b		655.23 ± 22.53 ^a		561.59 ± 13.26
Female means	183.65 ± 3.22 ^a		172.16 ± 3.03 ^b		148.22 ± 3.54 ^c		213.41 ± 3.04 ^d		180.89 ± 1.70

a,b Means within weeks differ ($P \leq .001$) between genotypes if superscripts differ.

Table 3. Percent carcass fat in males and females

Week	Cross 1		Cross 2		Cross 3		Cross 4		Marginal means
	DwDw		dwdw		Dwdw		Dwdw		
0	6.27 ± 0.21		7.01 ± 0.21		6.92 ± 0.37		6.10 ± 0.21		6.57 ± 0.18
2	6.45 ± 0.21		8.08 ± 0.21		7.02 ± 0.21		7.15 ± 0.37		7.18 ± 0.18
4	7.99 ± 0.33		9.39 ± 0.21		7.89 ± 0.37		7.54 ± 0.21		8.20 ± 0.17
6	7.90 ± 0.21		10.23 ± 0.37		8.04 ± 0.39		8.15 ± 0.21		8.57 ± 0.18
Male means	7.19 ± 0.17 ^a		8.65 ± 0.18 ^b		7.44 ± 0.18 ^a		7.24 ± 0.18 ^a		7.63 ± 0.09
Week	Dw-		dw-		dw-		Dw-		Marginal means
0	6.54 ± 0.36		7.25 ± 0.38		7.18 ± 0.38		7.01 ± 0.39		6.99 ± 0.19
2	7.37 ± 0.38		7.92 ± 0.38		8.63 ± 0.43		7.06 ± 0.39		7.70 ± 0.20
4	8.19 ± 0.38		9.12 ± 0.38		9.36 ± 0.49		8.08 ± 0.35		8.58 ± 0.19
6	8.34 ± 0.41		9.70 ± 0.39		8.24 ± 0.43		8.36 ± 0.39		8.69 ± 0.20
Female means	7.55 ± 0.19 ^a		8.47 ± 0.19 ^b		8.21 ± 0.21 ^b		7.66 ± 0.19 ^a		7.96 ± 0.09

a,b Genotype means differ ($P \leq .001$) if superscripts differ.

Table 4. Abdominal fat pad weight (gms) for males and females

Week	Cross 1	Cross 2	Cross 3	Cross 4	Marginal means
	DwDw	dwdw	Dwdw	Dwdw	
4	2.49 ± 0.61	4.70 ± 0.69	3.03 ± 0.65	2.67 ± 0.66	3.17 ± 0.33
6	6.41 ± 0.68	7.04 ± 0.65	8.71 ± 0.65	9.13 ± 0.65	7.85 ± 0.33
Male means	4.24 ± 0.45 ^a	5.92 ± 0.47 ^b	6.00 ± 0.47 ^b	5.90 ± 0.46 ^b	5.48 ± 0.23
Week	Dw-	dw-	dw-	Dw-	Marginal means
4	2.95 ± 0.67	3.96 ± 0.70	3.25 ± 0.78	3.47 ± 0.67	3.41 ± 0.36
6	6.52 ± 0.74	6.51 ± 0.70	4.85 ± 0.83	7.71 ± 0.67	6.54 ± 0.35
Female means	4.57 ± 0.50 ^{ab}	5.24 ± 0.50 ^{ab}	4.01 ± 0.50 ^b	5.59 ± 0.48 ^a	4.92 ± 0.25

a,b Means between genotypes differ ($P \leq .05$) is superscripts differ.

Table 5. Plasma T_4 (ng/ml) levels for males and females

Week	Cross 1 DwDw	Cross 2 dwdw	Cross 3 Dwdw	Cross 4 Dwdw	Marginal means
0	1.81 $\pm$ 0.31	1.31 $\pm$ 0.32	1.25 $\pm$ 0.31	1.45 $\pm$ 0.32	1.29 $\pm$ 0.16
2	1.25 $\pm$ 0.29	2.23 $\pm$ 0.31	1.79 $\pm$ 0.31	1.78 $\pm$ 0.33	1.73 $\pm$ 0.15
4	2.25 $\pm$ 0.31	2.47 $\pm$ 0.31	3.13 $\pm$ 0.31	1.62 $\pm$ 0.31	2.37 $\pm$ 0.15
6	2.24 $\pm$ 0.32	3.05 $\pm$ 0.32	2.73 $\pm$ 0.32	3.84 $\pm$ 0.31	2.98 $\pm$ 0.16
Male means	1.71 $\pm$ 0.15 ^a	2.24 $\pm$ 0.16 ^b	2.22 $\pm$ 0.15 ^b	2.20 $\pm$ 0.16 ^b	2.09 $\pm$ 0.08
Week	Dw-	dw-	dw-	Dw-	Marginal means
0	1.16 $\pm$ 0.27	1.40 $\pm$ 0.29	1.16 $\pm$ 0.30	1.42 $\pm$ 0.27	1.29 $\pm$ 0.14
2	1.79 $\pm$ 0.29	2.50 $\pm$ 0.29	2.20 $\pm$ 0.32	1.82 $\pm$ 0.27	2.07 $\pm$ 0.15
4	2.14 $\pm$ 0.27	2.25 $\pm$ 0.27	2.32 $\pm$ 0.32	2.02 $\pm$ 0.27	2.17 $\pm$ 0.14
6	2.30 $\pm$ 0.32	3.21 $\pm$ 0.27	2.91 $\pm$ 0.34	3.53 $\pm$ 0.27	3.05 $\pm$ 0.15
Female means	1.82 $\pm$ 0.14 ^a	2.36 $\pm$ 0.14 ^b	2.10 $\pm$ 0.16 ^{ab}	2.20 $\pm$ 0.13 ^{ab}	2.15 $\pm$ 0.07

^{a,b} Genotype means significantly differ ($P \leq .05$) if superscripts differ.

Table 6. Plasma T_3 (ng/ml) levels in males and females

Week	Cross 1 DwDw	Cross 2 dwdw	Cross 3 Dwdw	Cross 4 Dwdw	Marginal means
0	2.14 $\pm$ 0.35	1.09 $\pm$ 0.35	1.96 $\pm$ 0.35	2.26 $\pm$ 0.37	1.85 $\pm$ 0.17
2	3.24 $\pm$ 0.34	1.56 $\pm$ 0.35	3.25 $\pm$ 0.35	3.54 $\pm$ 0.39	2.88 $\pm$ 0.17
4	5.37 $\pm$ 0.35	1.69 $\pm$ 0.37	2.33 $\pm$ 0.35	2.10 $\pm$ 0.35	2.90 $\pm$ 0.17
6	2.39 $\pm$ 0.37	1.34 $\pm$ 0.37	1.91 $\pm$ 0.35	2.07 $\pm$ 0.37	1.93 $\pm$ 0.18
Male means	3.30 $\pm$ 0.17 ^a	1.42 $\pm$ 0.18 ^b	2.36 $\pm$ 0.17 ^b	2.46 $\pm$ 0.18 ^c	2.39 $\pm$ 0.09
Week	Dw-	dw-	dw-	Dw-	Marginal means
0	2.36 $\pm$ 0.28	1.12 $\pm$ 0.28	1.02 $\pm$ 0.31	2.59 $\pm$ 0.28	1.81 $\pm$ 0.14
2	3.82 $\pm$ 0.29	1.84 $\pm$ 0.29	1.73 $\pm$ 0.32	3.43 $\pm$ 0.28	2.77 $\pm$ 0.15
4	3.41 $\pm$ 0.28	1.70 $\pm$ 0.29	2.47 $\pm$ 0.32	4.01 $\pm$ 0.28	2.96 $\pm$ 0.14
6	2.04 $\pm$ 0.32	1.51 $\pm$ 0.29	1.47 $\pm$ 0.34	2.11 $\pm$ 0.28	1.80 $\pm$ 0.15
Female means	2.95 $\pm$ 0.14 ^a	1.53 $\pm$ 0.14 ^b	1.66 $\pm$ 0.16 ^b	3.03 $\pm$ 0.14 ^a	2.32 $\pm$ 0.07

^{a, b} Genotype means significantly differ ($P \leq .001$) if superscripts differ.

Table 7. Plasma GH levels (ng/ml) in males and females

Week	Cross 1		Cross 2		Cross 3		Cross 4		Marginal means
	DwDw		dwdw		Dwdw		Dwdw		
0	79.44 $\pm$ 42.8		144.68 $\pm$ 39.1		106.60 $\pm$ 37.6		97.32 $\pm$ 42.8		108.66 $\pm$ 20.2
2	173.49 $\pm$ 42.8		381.11 $\pm$ 60.9		251.43 $\pm$ 40.8		291.19 $\pm$ 42.8		258.84 $\pm$ 22.6
4	197.42 $\pm$ 40.8		362.12 $\pm$ 47.6		339.97 $\pm$ 42.8		270.66 $\pm$ 39.1		288.28 $\pm$ 20.7
6	196.38 $\pm$ 39.1		400.44 $\pm$ 42.8		225.15 $\pm$ 42.8		160.22 $\pm$ 40.8		241.28 $\pm$ 20.7
Male means	164.13 $\pm$ 20.66 ^a		301.23 $\pm$ 22.89 ^b		227.89 $\pm$ 19.97 ^c		206.87 $\pm$ 20.66 ^{ac}		221.43 $\pm$ 10.56
Week	Dw-		dw-		dw-		Dw-		Marginal means
0	107.09 $\pm$ 36.8		366.09 $\pm$ 38.2		226.4 $\pm$ 45.92		82.50 $\pm$ 39.8		166.38 $\pm$ 19.9
2	251.54 $\pm$ 41.5		399.67 $\pm$ 48.7		371.11 $\pm$ 79.5		204.32 $\pm$ 41.5		282.58 $\pm$ 24.0
4	124.38 $\pm$ 38.2		355.87 $\pm$ 41.5		351.31 $\pm$ 48.7		118.38 $\pm$ 41.5		224.28 $\pm$ 21.0
6	131.17 $\pm$ 56.2		389.67 $\pm$ 52.1		573.78 $\pm$ 79.5		110.27 $\pm$ 45.9		249.14 $\pm$ 27.6
Female means	151.60 $\pm$ 20.77 ^a		340.99 $\pm$ 22.06 ^b		334.03 $\pm$ 28.72 ^b		128.65 $\pm$ 21.00 ^a		222.71 $\pm$ 11.18

a,b Genotype means differ ($P \leq .001$) if superscripts differ.

Table 8. Malic enzyme (nM NADPH/mg protein) activity for males and females

Week	Cross 1		Cross 2		Cross 3		Cross 4		Marginal means
	DwDw		dwdw		Dwdw		Dwdw		
2	155.46 $\pm$ 10.8		111.97 $\pm$ 11.30		122.74 $\pm$ 11.3		98.47 $\pm$ 13.5		124.91 $\pm$ 5.8
4	108.12 $\pm$ 10.3		72.17 $\pm$ 10.3		69.67 $\pm$ 10.3		64.29 $\pm$ 10.3		78.56 $\pm$ 5.2
6	36.10 $\pm$ 10.8		38.10 $\pm$ 10.8		50.50 $\pm$ 10.3		45.02 $\pm$ 10.3		42.66 $\pm$ 5.2
Male means	100.14 $\pm$ 6.14 ^a		72.87 $\pm$ 6.20 ^b		78.51 $\pm$ 6.14 ^b		64.55 $\pm$ 6.40 ^b		79.02 $\pm$ 3.12
Week	Dw-		dw-		dw-		Dw-		Marginal means
2	162.71 $\pm$ 11.5		91.71 $\pm$ 12.6		118.22 $\pm$ 15.1		161.33 $\pm$ 12.6		136.17 $\pm$ 6.4
4	99.16 $\pm$ 11.5		72.25 $\pm$ 11.5		73.71 $\pm$ 13.3		97.69 $\pm$ 12.1		86.25 $\pm$ 6.0
6	68.74 $\pm$ 13.3		9.03 $\pm$ 12.6		28.64 $\pm$ 14.1		48.30 $\pm$ 11.5		46.42 $\pm$ 6.3
Female means	113.97 $\pm$ 6.97 ^a		67.07 $\pm$ 6.97 ^b		71.67 $\pm$ 8.17 ^b		99.02 $\pm$ 6.97 ^a		87.93 $\pm$ 3.61

a,b Genotype means significantly differ ($P \leq .001$). if superscripts differ.

Table 9. Citrate cleavage enzyme (nM NAD⁺/mg protein) activity in male and females

Week	Cross 1		Cross 2		Cross 3		Cross 4		Marginal means
	DwDw		dw dw		Dw dw		Dw dw		
2	11.88 ± 1.89		12.91 ± 2.00		14.24 ± 2.00		14.69 ± 2.12		13.35 ± 1.00
4	13.67 ± 1.73		10.50 ± 1.89		12.51 ± 1.73		12.35 ± 1.73		12.34 ± 0.88
6	9.92 ± 1.89		10.91 ± 1.89		8.38 ± 2.12		10.53 ± 1.73		9.96 ± 0.92
Male means	11.94 ± 1.06 ^a		11.39 ± 1.11 ^a		11.68 ± 1.07 ^a		12.25 ± 1.06 ^a		11.82 ± 0.54
Week	Dw-		dw-		dw-		Dw-		Marginal means
2	14.51 ± 1.27		9.10 ± 1.56		10.99 ± 1.67		11.65 ± 1.40		11.90 ± 0.72
4	9.79 ± 1.27		8.61 ± 1.33		9.23 ± 1.56		10.72 ± 1.33		9.62 ± 0.68 ^a
6	8.12 ± 1.40		8.70 ± 1.40		10.05 ± 1.67		9.83 ± 1.47		9.08 ± 0.74
Female means	10.97 ± 0.76 ^a		8.78 ± 0.82 ^a		10.05 ± 0.94 ^a		10.77 ± 0.81 ^a		10.14 ± 0.41

^{a,b} Genotype means do not differ significantly.

C.3.USA.a - Plasma Hormones and Lipogenic Enzymes in Chickens
Divergently Selected for Oxygen Consumption

Variation in metabolic rate would be expected to have a major influence on the growth and development of animals. Oxygen consumption is positively correlated to metabolic rate (Brody, 1945), and therefore, may be a useful selection criterion. Little (1958) used a modification of the apparatus of Strite and Yacowitz (1956) to measure oxygen consumption in a number of strains of chickens at 1, 2, 3 and 4 weeks of age. He found highly significant negative correlations between oxygen consumption at 3 and 4 weeks and body weight at 8 weeks. This finding prompted a long term two-way selection experiment for oxygen consumption by MacLaury and Johnson (1972). Selection was initiated in 1958, using 3-week-old chicks from a foundation stock of Athens Canadian Randombred birds, and was based on milliliters of oxygen consumed per 100 grams of body weight per minute. After 11 generations of selection, MacLaury and Johnson (1972) reported that the two lines differed an average of 1.53 milliliters of oxygen per 100 grams body weight per minute, and an average of 61 grams in 8 week body weight. They estimated realized heritability of oxygen (O_2) consumption to be 0.08.

Selection was relaxed in 1972, and a study investigating rate of gain and feed efficiency (gain/feed) of 4-week-old chicks from the two lines in response to varying levels of dietary protein was conducted in 1978. This study indicated that the birds from the low O_2 line gained at a significantly faster rate and were significantly more efficient in feed utilization than those from the high O_2 line at all dietary protein levels studied (Stewart et al., 1980). A subsequent experiment by Stewart and Muir (1982) examined the effect of dietary

protein on carcass composition and nutrient utilization in the two lines. They reported that feed efficiency and weight gains of the low O_2 line were greater than the high O_2 line at all protein levels studied, and that low O_2 birds gained more lean tissue and less fat tissue than high O_2 birds. Low O_2 birds were more efficient in the utilization of nitrogen, but there was no difference between the lines in efficiency of metabolizable energy utilization. In a later study investigating cholesterol metabolism, Sutton and Muir (1982) reported that high O_2 birds were significantly leaner than low O_2 birds, and that high O_2 birds had a greater rate of cholesterol turnover. The report of less carcass fat in high O_2 versus low O_2 birds was in contrast to earlier findings of Stewart and Muir (1982). In either case, however, although selection for oxygen consumption had been suspended, the two lines of birds still exhibited distinct differences in growth and metabolism of nutrients.

The present study was initiated to characterize differences in circulating plasma hormone levels and hepatic lipogenic enzyme function in the high and low O_2 lines. The Athens Canadian randombred population, the stock from which the high and low O_2 lines originated, was used as an unselected control.

MATERIALS AND METHODS

Two trials were conducted to examine the physiological differences resulting from selection for O_2 consumption in 3-week-old chicks. In trial 1, criteria were measured at 0, 1, 2 and 3 weeks of age. In trial 2, sampling occurred at 0, 3 and 6 weeks. The variables measured and the sampling procedures used were the same in both trials. Laboratory analyses of hormone levels, enzyme activities

and carcass fat content were conducted at the same time for the two trials using the same reagents to minimize the variation between trials.

In both trials, one-day-old chicks were wingbanded and randomly assigned to 12 battery brooding pens of 20 chicks each, resulting in 4 replicate pens of each of the three lines. From day one until termination of each trial, all birds were fed the conventional University of Georgia broiler starter diet (23% protein, 3120 kcal/kg metabolizable energy) ad libitum. Five birds from each pen ($n = 20$ chicks per line) were randomly selected and weighed at each of the sampling periods specified for the two trials. Blood samples were then obtained using EDTA as an anticoagulant. Plasma was separated on the day of collection and stored at -20°C until analyzed. Chicks were sacrificed by cervical dislocation of the neck to prevent blood loss, and the liver removed and frozen at -80°C . All carcasses were frozen at -20°C for subsequent determination of carcass lipid content.

The frozen carcasses, including feathers, were individually cut into sections, ground in a meat grinder, mixed and reground twice to obtain a homogeneous mixture. Carcass lipid content was determined for duplicate one gram samples by a modification (Washburn and Nix, 1974) of the Folch method (Folch et al., 1957).

Liver homogenates for malic enzyme and citrate cleavage enzyme analyses were prepared in a 0.15M KCl and 20% ethanol solution. One gram samples of frozen liver were homogenized in a Sorvall Omni-Mixer (Dupont Instruments, Newton, CN 06470), with 10 mls of the KCl-ethanol solution for approximately 1 minute. The 10% homogenates were then centrifuged for 60 minutes at $10,000 \times g$ and the resulting

supernatants used for enzyme assays. All operations were carried out at 0° to 5°C. Assays were conducted at 25°C for malic enzyme (EC 1.1.1.40) by the method of Ochoa (1955) and for citrate cleavage enzyme (EC 4.1.3.8) by the procedure of Srere (1959). Enzyme activities were expressed on the basis of nanomoles of nucleotide (NADPH or NAD⁺) per milligram of protein. Protein concentration of the liver tissue extracts was determined utilizing the Bio-Rad protein assay (Bio-Rad Laboratories, Richmond, CA 94904).

Plasma samples were assayed for growth hormone (GH), triiodothyronine (T₃) and thyroxine (T₄) using radioimmunoassay (RIA). A commercially purchased kit from Antibodies, Inc. (Davis, CA 95616) was utilized for the T₄ RIA. For the T₃ assay, rabbit anti-T₃ serum was used in the general procedure described by May (1978), although a commercial goat anti-rabbit gamma globulin (Antibodies, Inc., Davis, Ca 95616) was used in a modification of the assay. The T₃ RIA was run over a 24 hour period. Barbital buffer (pH 8.6) was used to dilute 15 µl plasma samples to 50 µl while standards were dispensed in 50 µl quantities. Anti-T₃ serum was diluted 1:200 in barbital buffer and 37.5 µl of antiserum was added to the tubes. Fifty µl of tracer diluted to 0.1µCi/ml and 50 µl of a 1:5 dilution of goat anti-rabbit gamma globulin were then added. Finally, 312.5 µl of a barbital buffer solution containing 0.03 mg rabbit gamma globulin and 4.4 µg of 8-anilo-1-naphthalenesulfonic acid (ANS) were added to the assay tubes. Tube contents were vortexed after each addition and after the final addition the tubes were kept at 5°C overnight. On the following day the tubes were centrifuged at 1400 X g for 20 minutes and the resulting supernatants poured off. The tubes were then inverted and

allowed to dry before being counted in a Beckman System 5500 gamma counter (Beckman Instrument, Palo Alto, CA). Potency estimates of the samples were calculated using log-logit transformation and are expressed as ng per ml of plasma.

Proudman and Wentworth (1978) produced and characterized the anti-GH serum of the turkey GH RIA used in this study. Turkey GH lot B166B (Burke and Papkoff, 1980) was used for the standard and a similar GH preparation (B181B) was used for iodination. The assay protocol used is described by Burke and Marks (1982).

Since the two trials had the sampling periods of week 0 and week 3 in common, the data from the two trials were pooled and tested for a significant trial effect. Differences between trials were not significant ($P \geq .25$) and therefore, for clarity, the data at week 0 and week 3 from trial 2 was pooled with the corresponding data from trial 1. This new data set containing all of the data in trial 1 and the 0 and 3 week data in trial 2 was statistically analyzed as a repeated measures design. The model consisted of the whole plot unit, line and the split plot unit, time. The treatment effect was the fixed order response of the whole plot unit in time. The split plot error term was used to test the whole plot error term and, if it was not found to be significant ($P \geq .25$), the terms were pooled before testing. Duncan's multiple range test (Duncan, 1955) was used to further test treatment differences. The remaining data from the 6 week sampling period in trial 2 was analyzed as a completely randomized design. The 6 week data is presented separately in Table 1, from the combined data from 0 to 3 weeks of trials 1 and 2 which is presented in Figures 1 through 4.

RESULTS AND DISCUSSION

The early growth of birds from the low O₂ line was greater than birds from the high O₂ line. At three weeks of age, low O₂ birds were significantly heavier (192 ± 9 g) than high O₂ birds (165 ± 8 g), while the average body weight of the Athens Canadian (AC) randombreds (177 ± 7 g) was intermediate to, but not statistically different from the weights of the two O₂ lines. The overall weight gain from 0 to 3 weeks was also significantly greater for low O₂ line in comparison to high O₂ line, but as seen in Figure 1, the greatest difference in gain was from 2 to 3 weeks of age. Weight gain of AC control birds did not differ significantly from either the high or low O₂ line. These early differences in growth and body weight are consistent with previous findings (Stewart and Muir, 1982; Stewart *et al.*, 1980). Gain from 3 to 6 weeks of age, however, did not differ among the three lines, and by 6 weeks of age, although low O₂ birds were numerically heavier than high O₂ birds, the body weights of the O₂ lines were not significantly different (Table 1). This lack of body weight difference at 6 weeks was unexpected since MacLaury and Johnson (1972) had reported a significant difference of 61 grams between the lines in 8-week body weights, and Sutton (1982) had found highly significant 7-week body weight differences.

The age-related pattern of lipid deposition was similar between low O₂ chicks and AC birds (Figure 1). However, carcass lipid as a percent of body weight was relatively less in high O₂ chicks than the other two lines at 1 and 2 weeks of age. At 3 weeks, high O₂ birds exhibited significantly more carcass fat than low O₂ birds, and numerically greater fat levels than AC chicks. At 6 weeks (Table 1)

the three lines did not significantly differ in percent fat but the high O_2 line still exhibited numerically greater carcass lipid content than either the low O_2 line or the AC control. Stewart and Muir (1982) also found the high O_2 line to have a greater percent carcass fat on a dry matter basis than the low O_2 line. However, in the study of Sutton and Muir (1982) the low O_2 line exhibited 4 percent greater carcass fat than the high O_2 .

Previous findings had suggested that selection for O_2 consumption had resulted in differences in metabolic rate between the lines, or more specifically, in differences in thyroid activity (Stewart and Muir, 1982). Similar conclusions were presented by Sutton and Muir (1982) in their study investigating differences in cholesterol metabolism. They found that high O_2 birds had a higher rate of cholesterol turnover, which is consistent with greater thyroid activity (Takeuchi et al., 1975; Lakshmanan et al., 1975). Scott and Washburn (1983), in a study examining the effect of cool temperature brooding on thyroid activity in neonate chicks, demonstrated that high O_2 chicks had the greatest concentrations of serum T_4 at 1 and 2 days of age in comparison to either low O_2 birds or AC randombred chicks. In the present study, no significant differences in circulating T_4 levels were detected after day 1 of age (Figure 2). At day 1, in contrast to the findings of Scott and Washburn (1983), it was the AC birds which exhibited the greatest T_4 levels in comparison to high or low O_2 chicks, and the two lines selected for O_2 consumption did not differ significantly from one another. Additionally, there was no consistent trend for lower T_4 levels in the low O_2 line. Plasma T_3 levels (Figure 2) were significantly lower in high O_2 birds in

comparison to AC chicks at 0, 1 and 2 weeks of age. The T_3 levels of low O_2 birds were intermediate to but not different from those of the other two lines. No statistical differences in circulating T_3 levels were detected among the lines at 3 weeks or at 6 weeks (Table 1). The temporal patterns of circulating T_4 and T_3 levels were very similar for the three lines.

Variation in growth between strains of chickens has been related to differences in plasma concentrations of GH (Harvey et al., 1979; Scanes et al., 1980; Burke and Marks, 1982), but without definitive associations of increased GH levels with greater growth. In the present study, it appears that divergent selection for O_2 consumption has altered the growth rate of high and low O_2 birds to the extent that plasma GH levels differ significantly between the two lines, but not to the extent that they differ statistically from the foundation stock from which they originated (Figure 3). During the early growth phase from 1 to 3 weeks, low O_2 birds had significantly greater GH levels than high O_2 birds, while plasma GH in AC chicks was intermediate to, but not statistically different from the two O_2 lines. By 6 weeks of age, the high and low O_2 lines had similar GH levels, but these levels were significantly lower than those found in the AC birds (Table 1). The age-related pattern of circulating GH levels was similar between the O_2 lines but differed from the AC control line, further suggesting selection may have altered GH secretion or utilization.

Malic enzyme and citrate cleavage enzyme have both been associated with lipogenesis in the chick (Goodridge, 1968a; Tanaka et al., 1983). The high fat diet provided by the yolk on which the

embryo, as well as the newly hatched chick, is nourished inhibits lipogenesis. Not until the feeding of a conventional broiler starter ration, high in carbohydrate and low in fat, will the chick exhibit an increase in fatty acid synthesis. For this reason, lipogenic enzyme activity was not determined for the day-old chicks.

Malic enzyme activity from 1 to 3 weeks is illustrated in Figure 4. The enzyme activities of the low and high O_2 lines were not significantly different from one another, but were less than the AC chicks at 2 weeks and significantly greater than the AC birds at 3 weeks. Citrate cleavage enzyme activity did not differ between high O_2 birds and AC chicks, but low O_2 birds had greater citrate cleavage enzyme activity at 1 and 3 weeks in comparison to the other lines (Figure 4). Neither malic enzyme or citrate cleavage enzyme activities differed among the lines at 6 weeks (Table 1). These observed differences in lipogenic enzyme activity can not be attributed to differences in lipid deposition since the lines did not significantly differ in percent carcass fat. Nor were the temporal patterns of enzyme activity and carcass lipid accumulation similar. However, these enzymes exhibit a great deal of variation from one physiological circumstance to another (Yeh and Leveille, 1969; Goodridge, 1968b; Tepperman and Tepperman, 1964) and the actual rate of enzyme activity is determined by the rate of substrate fluctuation (Tanaka et al., 1983; Leveille, 1970; Yeh and Leveille, 1970). Therefore it appears that the observed differences in lipogenic enzyme activities among the lines may be more attributable to environmental influences (i.e.: time of feeding in relation to sampling, levels of

feed intake) rather than genetic differences resulting from selection for O_2 consumption.

After 11 generations of selection for O_2 consumption MacLaury and Johnson (1972) reported the establishment of two distinct populations of birds. Oxygen consumption is positively correlated to metabolic rate (Brody, 1945), and thus the study of the differences in growth and of the physiological mechanisms altered by their selection was of interest. Understanding the effects of altering metabolic rate could be of great benefit in the further improvement of poultry production efficiency as well as in the elucidation of several human pathological conditions. However, it is evident that the distinct population differences reported by MacLaury and Johnson (1972), have diminished. The birds no longer differ in growth rate by 6 weeks of age. The differences in carcass fat fluctuate from generation to generation indicating a high degree of environmental influence on this phenotypic trait. There are some early differences in thyroid activity in the two O_2 lines in comparison to the AC line but not in comparison to one another. Additionally, some differences in plasma GH levels are evident among the three lines, but only until 6 weeks when the O_2 lines no longer differ.

No new genetic material has been introduced into the O_2 lines since 1958 and only a small population size has been maintained. This would then lead one to believe that the lines are fairly highly inbred. However, selection for O_2 consumption has been relaxed for 10 years, and without selection pressure a gradual change, or random drift, of the genotypes toward the heterozygote state is favored.

Table 1. Six week means for the three lines

	Low O ₂ Line	High O ₂ Line	AC
Body weight (gms)	481.29 ± 17.6 ^a	444.30 ± 16.3 ^{ab}	425.06 ± 17.6 ^b
Weight gain (gm wt. 6 -gm wt. 3)	305.76 ± 11.0 ^a	290.06 ± 10.4 ^a	277.20 ± 10.9 ^a
Percent carcass fat	6.04 ± 0.28 ^a	6.29 ± 0.30 ^a	5.97 ± 0.29 ^a
Plasma T ₄ (ng/ml)	2.19 ± 0.16 ^a	2.15 ± 0.17 ^a	2.65 ± 0.18 ^a
Plasma T ₃ (ng/ml)	4.49 ± 0.25 ^a	4.37 ± 0.26 ^a	4.44 ± 0.27 ^a
Plasma GH (ng/ml)	156.96 ± 39.5 ^a	177.21 ± 33.2 ^a	334.33 ± 34.2 ^b
Malic enzyme (nM NADPH/mg protein)	38.14 ± 2.6 ^a	35.95 ± 2.7 ^a	37.71 ± 2.9 ^a
Citrate cleavage enzyme (nM NAD /mg protein)	16.19 ± 1.2 ^a	17.67 ± 1.2 ^a	13.85 ± 1.4 ^a

a,b Means differ ($P \leq .05$) due to line if superscripts differ.

Figure 1. Body weight gains (gms) and percent carcass fat of lines

Figure 2. T_4 (ng/ml) and T_3 (ng/ml) levels for the AC lines

Figure 3. GH levels (ng/ml) for the lines

Figure 4. Malic enzyme (nM NADPH/mg protein) and citrate cleavage enzyme activity (nM NAD⁺/mg protein) for the lines

C.3.USA.a - Variation in feed conversion and abdominal fat of a broiler grandparent line

Methods

A commercial grandparent line was evaluated for variation in efficiency of feed utilization, abdominal fat, and growth hormone (GH). In two hatches progeny from 33 and 35 sire families were placed in individual cages for determination of feed consumption, weight gain, and feed conversion ratio from 4-7 weeks of age. In hatch 2, GH levels were determined at 25 days and % abdominal fat at 50 days of age.

The individuals in hatch 1 will be used as the parental population of a selection project involving selection for efficiency and associated changes in abdominal fat.

Results

Hatch differences (Table 1). The birds in hatch 2 were significantly heavier and consumed more feed than in hatch 1. Differences in FCR between hatches were not significant. The birds were similar in body weight when placed in the cages at 4 weeks. It is interesting to note that the range in 7-week body weight was similar for both hatches (473g and 512g) but that the minimum and maximum values in hatch 1 were about 200g less than in hatch 2. Although hatch 2 grew better than hatch 1, this was not reflected in FCR differences.

There were two major differences in the hatches. In hatch 1, the birds did not adjust well to the move from the floor pens to the individual cages and there was some evidence of Gumboro. Approximately 20% of the hatch 1 birds placed in the cages died within 2

weeks. Another 10% had such poor growth that they were discarded. In hatch 2, the birds were vaccinated for Gumboro and water fountains similar to the ones used in the cages were placed in the floor pens for a week prior to placing birds in the cages.

TABLE 1

Hatch and sire family differences in weight gain, consumption and feed conversion of broiler grandparent line

	Hatch 1 (284)				Hatch 2 (353)				* Hatch
	$\bar{X}$	Range	P > F	C.V.	$\bar{X}$	Range	P > F	C.V.	P > F
WT 4	748	628-848	.01	13	744	643-837	.16	15	.35
WT 7	1808	1487-1960	.36	11	1897	1677-2189	.82	13	.02
Gain	1060	859-1162	.69	14	1153	968-1445	.56	16	.0001
Cons	2145	1918-2399	.26	12	2292	2115-2713	.83	12	.0001
FCR	2.05	1.90-2.38	.04	10	2.01	1.89-2.20	.01	9	.11

Sire family differences in FCR. The FCR of the sire families ranged from 1.90-2.38 in hatch 1 and 1.89 to 2.20 in hatch 2. The differences between sire families in FCR were significant in both hatches. However, differences between the sire families in 7-week weight, gain or consumption were not significant. When the five families with the highest FCR (2.15) were compared to the five families with the lowest FCR (1.91), the consumption of the L-FCR families as a % of the H-FCR families was 98% and the gain was 108%. This comparison suggests that the differences in FCR were primarily achieved by increased gain.

ASSOCIATION OF GROWTH HORMONE AND ABDOMINAL FAT TO FEED CONVERSION

Methods

In trial 2, blood was obtained for growth hormone (GH) and triiodothyronone analysis.

Blood was obtained at 4 weeks of age, prior to obtaining body weights of the birds in individual cages. The phenotypic correlations between these 4-week GH and T_3 values and the 4-7 week conversion and gain were calculated separately for males and females.

Results

The GH, FCR, gain and abdominal fat means, variation and correlations are presented in Table 5.

The abdominal fat was relatively low for a broiler line and was significantly higher in the females. The C.V. for abdominal fat was high with a very wide range between the high and low individuals. Differences between families were statistically significant.

The GH levels were higher in the males than in the females and differences between families were significant. Growth hormone values were extremely variable. Individual values ranged from 18-1250 and the C.V. from 125 to 190 for males and females.

The correlations between GH and abdominal fat followed the expected trend of a negative relationship between the two variables, but the magnitude of the correlations was low and statistically significant only for males. The association of decreased abdominal fat with improved efficiency of feed utilization (lower FCR) was observed, but the magnitude of the correlations were low and non-significant in the males.

C.3.USA.a - Relationship of serum triglycerides and glucose to amount of abdominal fat

Methods

Three commercial grandparent broiler lines which were known to differ slightly in growth and fatness were used. Pen body weights and feed conversion ratios (FCR) were obtained thru 49 days of age. At 50 days, 60 birds of each sex and strain were bled for determination of serum triglycerides and glucose which were correlated with abdominal fat.

Results

Glucose levels of the strains were different (Table 1). The fatter S_2 strain had higher serum glucose levels than the S_1 strain, but they were similar to that of the S_3 strain which had the least amount of abdominal fat. The correlations between glucose level and abdominal fat were very low. Thus, the differences between strains in glucose levels may not be associated with differences in degree of fatness.

There was an association between triglyceride level and abdominal fat in the females, but not in the males (Table 1). In females, the fatter S_2 strain had triglyceride levels significantly higher than the S_1 or S_3 strains. In addition, there was a significant correlation between triglyceride level and abdominal fat in the females. In the males there was no correlation and the level of triglycerides was not associated with differences between strains in abdominal fat.

TABLE 1

Relationship of serum glucose and triglyceride levels to gain, efficiency, and fatness

		0-7 wk gain	FCR	Abdominal fat (%)		Glucose mg/100 ml	Serum triglycerides M moles/L
				Live wt.	Carcass wt.		
S ₁	♂	1874	1.76	2.1 ^x	3.2 ^x	183	.954 ^x
	♀	1651	1.78	2.5 ^m	3.9 ^m	188	.833 ^m
	X	1762 ^a	1.77 ^a	2.3	3.5	186 ^a	.893
S ₂	♂	1960	1.73	2.3 ^y	3.6 ^y	188	.918 ^x
	♀	1710	1.82	3.1 ⁿ	4.7 ⁿ	212	1.020 ⁿ
	X	1835 ^b	1.77 ^a	2.7	4.1	199 ^b	.969
S ₃	♂	1908	174	1.9 ^x	2.9 ^x	189	.962 ^x
	♀	1938	176	2.3 ^m	3.4 ^o	201	.905 ^m
	X	1773 ^a	175 ^a	2.1	3.1	194 ^b	.933
						♂ X 187 ^a	♂ X .945
						♀ X 201 ^b	♀ X .919
Correlation with Abdominal Fat			♂			-.07	-.03
			♀			.11	.27*

S₁, S₂, S₃ = strains; FCR = units of feed required/unit of gain.
 abc = significant differences ($P < .05$) in strain or sex means.
 xy = significant differences ($P < .05$) between males of strains.
 mno = significant differences ($P < .05$) between females of strains.

C.3.USA.b - Effect of environmental temperature on the relationship between efficiency and fatness

Methods

Commercial broiler males were placed in individual cages at three weeks of age for a week adjustment period. During this period the temperature of one room was increased to 90° and the other room decreased to 70°. Because of the arrangement of the heat source and ventilation, there was a top to bottom temperature gradient of the 4 tier cage system arrangement. In the "90° room", the top 2 rows were approximately 90° while the 2 bottom rows were approximately 80°.

In the "70° room" the bottom 2 rows were 70° while the top 2 rows were 80°. When the fan motor in this room was destroyed and unoperative for a part of an evening, most of the birds in the top 2 rows died. Thus, there was left a 90° and 80° group in 1 room and a 70° group in the other room.

Gain, consumption and feed conversion ratios were measured from 4-7 weeks. At 7 weeks of age the abdominal leaf fat was measured and expressed as % of live body weight.

Results

Increasing temperature resulted in a decreased gain, decreased consumption and poorer efficiency of feed utilization. However, the % abdominal fat was not significantly affected by the growing temperature (Table 1).

There was a distinct association between the growing temperature and the relationship between efficiency and fatness. At 90°, there was no correlation of % abdominal fat and feed conversion, while at 70° this correlation was .46.

C.3.USA.a - Relationship of carcass fat and heat stress survival time

Methods

Sixty 7-week-old males of two commercial broiler strains known to differ in degree of fatness were subjected to heat stress of 120°F for 240 minutes. The first 20 of each strain which showed heat prostration were considered as heat intolerant and the last 20 of each strain to show heat prostration were considered as heat tolerant. The abdominal fat, as a percentage of live body weight of the heat tolerant and heat intolerant strains, was determined.

Results

Although the strains showed the expected differences in abdominal fat, there were no differences in abdominal fat of the heat tolerant and heat intolerant groups in either strain (Table 1).

TABLE 1

Abdominal fat in broilers with high or low heat stress tolerance

			HSST (min.)	B.W. (g)	A.F. (%)
S ₁	-	HI	70 ^a	2312 ^a	1.66 ^b
	-	HT	124 ^b	2233 ^a	1.83 ^b
S ₂	-	HI	71 ^a	2255 ^a	2.28 ^a
	-	HT	158 ^b	2281 ^a	2.22 ^a

HSST = heat stress survival time; B.W. = body weight;
 A.F. = abdominal fat weight as a % of live body weight;
 S₁ = lean commercial broiler; S₂ = fat commercial broiler;
 HI = heat intolerant; HT = heat tolerant.
 ab = Significant differences between treatment groups ($P \leq .05$).

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C.3.USA.c - To select for increased 8-week body weight under high and normal water/feed ratio environments.

INTRODUCTION

Selection for reduced abdominal fat levels in chickens is complicated by the inability to detect actual fat levels in live birds. Although it is possible to measure abdominal fat in slaughtered birds and select sibs to produce subsequent generations (Becker, et al 1982, 1984; Leclercq, et al, 1980; and Cahaner et al 1985), this procedure is both time consuming and costly. Two indirect techniques: the abdominal fat probe (Pym and Thompson 1980), and very low density lipoproteins (Griffin and Whitehead, 1982) appear to have some merit, however, these techniques have not been totally successful in the hands of other researchers.

The inverse relationship between carcass lipid and carcass moisture is well documented (Donaldson et al., 1956, Twining et al., 1978). In an attempt to increase carcass moisture and thereby decrease carcass lipid, Marks and Washburn (1983) fed broilers diets containing up to 2.4% dietary salt. Abdominal fat weights were significantly reduced (17 to 28%) in two commercial stocks receiving the higher salt diet. These data indicated that high water/feed ratios may be associated with a reduction in abdominal fat. The purpose of this study was to determine if providing a high water:feed selection environment, while selecting for increased body weight, would have a favorable effect on abdominal fat levels.

MATERIALS AND METHODS

Two sets of replicate normal (N1 and N2) and dwarf (DW1 and DW2) lines (Marks, 1983) originating from the Athens-Canadian (AC) population (Hess, 1962)

served as the base populations for this study. The N1 and N2 lines and the DW1 and DW2 lines were reciprocally crossed to establish two new base populations. Chicks from each new base population were divided within full-sib family into two groups. One group from each genotype was placed on a regular .4% salt diet, whereas, the second group from each genotype was placed on a high 1.6% salt diet. Thus, two lines (one normal and one dwarf) were selected on a .4% salt diet, while two lines (one normal and one dwarf) were selected on a 1.6% salt diet.

Individual phenotypic selection was practiced within each line for high 8-week body weight for four generations. Approximately 100 progeny from the AC population were intermingled with the selected lines each generation to measure environmental variation. Within each of the four selected lines, 10 males and 40 females were selected each generation to produce four selected generations (S_1 , S_2 , S_3 , and S_4). Adult birds were maintained in individual cages and artificial insemination was used to produce about 200 progeny per line in each generation. From 0 to 8 weeks of age, birds were fed a 23% protein broiler starter diet containing 3120 kcal/kg of metabolizable energy with either .4 or 1.6% salt levels. Following selection at 8 weeks of age, potential breeders were fed a 15% protein grower diet (.4% salt) from 8 to 20 weeks, and a 16% protein layer-breeder diet starting at 20 weeks of age. Birds received natural daylight prior to 20 weeks. All laying birds were maintained in individual cages and received a 16-hr photoperiod starting at 20 weeks of age.

Realized heritabilities ($h^2 = R/S$) for 8-week body weight were obtained by dividing cumulative gains by cumulative selection differentials; the nonselected controls were used to correct for environmental variation across generations.

Realized heritabilities were also obtained by regressing corrected population means on cumulative selection differentials.

To compare growth and abdominal fat levels, female chicks from S_3 breeders were reared intermingled in a floor pen and fed the .4% salt diet from 0 to 42 d and a broiler finisher diet from 43 to 66 d. Birds were weighed at 66 d and 15 birds per line were slaughtered to obtain abdominal fat weights. The 10 males and 10 females with body weights closest to the population mean at 8-weeks of age in the S_4 generation were slaughtered at 58 d to obtain abdominal fat weights under the respective selection environments.

Since the primary objective was to compare responses under the 1.6% salt environment as opposed to the .4% salt environment within genotype, a completely randomized design instead of a 2x2 factorial was utilized. Therefore each genotype, sex, environment was considered as separate treatments. Data were analyzed by the GLM procedure of the SAS User's Guide: Statistics, 1982 edition with mean separation according to Duncan.

RESULTS AND DISCUSSION

Selection Responses. Mean 8-week body weights of normal and dwarf birds under the .4% and 1.6% salt environments increased across the four generations of selection (Table 1). Selection progress was greater for males than for females, however, on a percentage basis, progress was similar for both sexes. Environmental effects were small as evidenced by maximum variation of only 21 and 18 g in 8-week body weights of males and females from the control population across the four generations. Body weights were greater under the

.4% salt environment than under the 1.6% salt environment (Table 1). Ratios (dwarf weights:normal weights) were similar (.67 to .69) across sexes and selection environments in the S_0 generation (Table 1). Ratios, however, increased across generations under both selection environments indicating greater responses in body weight in dwarf genotypes. Similar changes in ratios for males and females were observed across generations and environments. When expressed as percentage deviation from the base generation following correction for environmental variation, the increase in body weight was greater in dwarf lines than in normal lines (Fig. 1). Percentage deviations (21% and 16%) of birds selected under the .4% salt environment were greater than deviations (18% and 9%) of birds selected under the 1.6% salt environment following four generations of selection. The greater selection gains in the dwarf lines (Fig. 1) were unexpected since a previous report indicated that selection gains were similar in background populations from which these lines were derived (Marks, 1983).

Selection differentials were approximately 15 to 24% greater for lines selected under the .4% salt environment than for lines selected under the 1.6% salt environment. Expected and effective selection differentials were similar (Table 2) within line across generations, indicating that natural selection had exerted little influence on the response to artificial selection in these lines.

Due to absolute differences in body weight between normal and dwarf genotypes, the intensity of selection (i) obtained by dividing the effective selection differential by the phenotypic standard deviation p provided a more appropriate measure for comparing selection pressure (Table 2). Selection intensities were numerically greater under the .4% salt environment than under the 1.6% salt environment and greater in dwarf lines than in normal lines (Table 2).

Realized heritabilities for 8-week body weight obtained by dividing the cumulative gains by cumulative selection differentials and by regressing the population means on the cumulative selection differentials are presented in Table 3. Heritabilities were consistently higher under the .4% than the 1.6% salt environment and for the dwarf than the normal genotype. The higher heritabilities for dwarf than normal genotypes in this study differed from a previous report which suggested that normal lines had slightly higher heritabilities for 8-week body weight than dwarf lines (Marks, 1983). The lower heritabilities observed in this study as opposed to earlier estimates in these lines are in agreement with the concept of diminishing selection gains and heritability estimates with advancing generations of selection (Marks, 1978). Heritability estimates for 8-week body weight in these lines fall within published limits for this trait (Siegel, 1962; Kinney, 1969).

Abdominal Fat: When all lines were evaluated on the .4% salt diet, the body weights of normal females were significantly greater than body weights of dwarf females at 66 d of age (Table 4). Body weights of normal females selected under the .4% salt environment were also greater than contemporaries selected under the 1.6% salt environment. Body weight differences were not significant, however, for dwarf line females selected under the two environments. Abdominal fat (leaf and gizzard) weights of normal females selected under the 1.6% salt environments were significantly smaller (28 g vs. 39 g) than weights of normal females selected under the .4% salt environment (Table 4). Abdominal fat weights of dwarf lines selected under both environments were essentially the same as abdominal fat weights of normal females selected under the .4% salt environment. Smaller body weights of dwarf females resulted in higher percentage abdominal fat levels than in normal lines (Table 4). The lower fat weights of normal females selected

under the 1.6% salt environment than for females selected under the .4% salt environment was not solely due to lower body weights, since percent fat of these females was also less (27%) than percent fat of normal females selected on the .4% salt environment. These data suggest that selection under a high water:feed ratio may result in less abdominal fat in normal females, but has little effect in dwarf genotypes.

Body weights of birds used to determine abdominal fat levels of the four lines under their respective selection environments are shown in (Table 5). Abdominal fat weights and percentages of males of normal lines were significantly smaller than corresponding weights of dwarf lines when comparisons were made under their respective selection environments (Table 5). Within genotype, however, abdominal fat weights of males were similar (Table 5). Mean fat weights of males and females were not significantly different. Expression of abdominal fat on a percentage basis resulted in generally higher values in dwarf lines than in normal lines due to the smaller body size of dwarfs except in females fed the .4% salt diet (Table 5). The normal females on the 1.6% salt environment had approximately 35% less fat on a percentage basis than normal females on the .4% salt environment. These data indicate that the high salt selection environment resulted in normal females having lower abdominal fat levels, while male contemporaries were unaffected by the high water:feed environment when evaluated under their given selection environment. This raises a question as to whether males selected under the high salt environment, when placed under the normal salt environment (.4%) will have lower abdominal fat levels as was demonstrated by normal females.

TABLE 1. Mean 8-week body weights by sex, genotype, selection environment and generation

Gen	Selection environment				Ratio ¹	
	0.4%		1.6%		.4%	1.6%
	N	dw	N	dw		
-----Male-----						
S ₀	1226±16 ^b	852±10 ^c	1272±13 ^a	876±7 ^c	.69	.69
S ₁	1332±17 ^a	965±16 ^b	1294±22 ^a	949±14 ^b	.72	.73
S ₂	1330±19 ^a	1014±13 ^b	1328±18 ^a	998±16 ^b	.76	.75
S ₃	1413±15 ^a	1094±13 ^c	1349±14 ^b	1032±14 ^d	.77	.77
S ₄	1454±14 ^a	1116±14 ^b	1423±14 ^a	1059±12 ^c	.77	.74
-----Female-----						
S ₀	1023±17 ^b	699±9 ^c	1057±13 ^a	712±8 ^c	.68	.67
S ₁	1091±13 ^a	800±7 ^b	1088±17 ^a	790±11 ^b	.73	.73
S ₂	1135±14 ^a	865±10 ^c	1064±19 ^b	867±15 ^c	.76	.81
S ₃	1160±12 ^a	923±9 ^c	1109±13 ^b	872±9 ^d	.80	.79
S ₄	1215±14 ^a	905±10 ^c	1131±11 ^b	892±11 ^c	.74	.79

¹Dwarf weights divided by normal weights

a,b,c,d, means within row with the same superscript are not significantly different (P < .05)

TABLE 2. Selection differentials and selection intensity (i) values by genotype, selection environment and generation

Genotype	Gen	Selection environment					
		0.4%			1.6%		
		Exp.	Eff.	i	Exp.	Eff.	i
Normal	S ₀	144 ¹	157	.82 ²	128	114	.80
	S ₁	76	77	.45	79	82	.47
	S ₂	141	142	.73	103	86	.53
	S ₃	142	130	.75	98	99	.52
	$\bar{x}$	126	127	.69	102	95	.58
Dwarf	S ₀	91	92	.74	94	101	.84
	S ₁	122	122	.84	106	106	.72
	S ₂	92	90	.68	62	64	.50
	S ₃	128	124	.90	114	114	.78
	$\bar{x}$	108	107	.79	94	96	.71

Exp = Expected; Eff = Effective

¹g

²SD/ σ_p

TABLE 3. Realized heritabilities by genotype and selection environment

<u>Genotype</u>	<u>Method</u>	<u>Selection environment</u>	
		<u>.4%</u>	<u>1.6%</u>
Normal	1*	.42	.32
	2**	.38±.09	.28±.06
Dwarf	1	.56	.49
	2	.66±.07	.56±.10

*1 - h^2 = cumulative gain/cumulative selection differential

**2 - h^2 = regression of population means on cumulative selection differentials.

TABLE 4. Female body weight (g), abdominal fat weight (g) and percent abdominal fat by line at 66 d (evaluations under .4% salt environment)

Trait	Environment				Ratio (.4%:1.6%)	
	.4% salt		1.6% salt			
	Normal	Dwarf	Normal	Dwarf	Normal	Dwarf
BW (g)	1472 ^a	1204 ^c	1381 ^b	1158 ^c	107	104
Fat wt (g)	38.7 ^a	38.1 ^a	28.5 ^b	38.8 ^a	136	98
% fat	2.61 ^b	3.16 ^a	2.06 ^c	3.37 ^a	127	94

a,b,c,d Means within row with different superscripts significantly different at P < .05 level.

TABLE 5. Body weight (g), abdominal fat weight (g) and percent abdominal fat by sex and line at 58 d (evaluations under respective selection environments)

Sex	Trait	Environment				Ratio (.4%:1.6%)	
		.4% salt		1.6% salt			
		Normal	Dwarf	Normal	Dwarf	Normal	Dwarf
Male	BW (g)	1490 ^a	1156 ^c	1437 ^b	1050 ^d	1.04	1.10
	Fat wt. (g)	15.1 ^b	22.9 ^a	16.2 ^b	22.1 ^a	.93	1.04
	% fat	1.01 ^b	1.98 ^a	1.13 ^b	2.10 ^a	.89	.94
Female	BW (g)	1190 ^a	909 ^c	1125 ^b	900 ^c	1.06	1.01
	Fat wt. (g)	20.3 ^{ab}	19.3 ^{ab}	14.2 ^b	23.4 ^a	1.43	.82
	% fat	1.71 ^{bc}	2.11 ^{ab}	1.27 ^c	2.59 ^a	1.35	.81

a,b,c,d means within row with different superscripts significantly different at $P < .05$ level.

FIG. 1. Percent deviation from base populations by generation for normal and dwarf genotypes selected under .4 and 1.6% salt environments.

C.3.USA.d - To determine the influence of different water/feed ratio selection environments on abdominal fat levels and on efficiency of feed utilization.

INTRODUCTION

Although numerous workers have explored ways to genetically alter abdominal or carcass fat levels (Leclercq et al., 1980; Becker et al., 1984; Whitehead and Griffin, 1984; Cahaner, et al 1985) little is known regarding accompanying changes that may be related to alterations in abdominal fat level. Marks (1987) reported that selection for 8-week body weight in dwarf and normal genotypes under regular (.4%) and high (1.6%) dietary salt environments resulted in differential abdominal fat responses. There was evidence that selection under the high salt environment resulted in normal females having lower abdominal fat levels under both normal and high salt environments. Normal males, and dwarf males and females, however, failed to demonstrate lower fat levels following selection under the high salt environment.

The purpose of this study was to investigate possible changes in early water and feed intake, and feed efficiency to determine if these parameters were related to changes observed in abdominal fat levels.

MATERIALS AND METHODS

Two experiments were conducted utilizing progeny from two dwarf and two normal lines selected for high 8-week body weight under different dietary salt environments (Marks, 1987). Experiment 1 utilized progeny from S_3 generation breeders while experiment 2 utilized progeny from S_4 generation breeders. Chicks from the four lines were hatched in the same incubator and vent-sexed at hatching. The experimental design for evaluation of progeny from the S_3 and S_4 breeders from 0-16 d was identical. Six replicates of each line - sex subclass (with 8 birds per subclass) were placed in separate pens of

electrically heated battery brooders at hatching. From 0-6 weeks all birds were fed a 23% protein broiler starter diet containing 3120 kcal/kg of metabolizable energy with the regular (.4%) salt level. All birds were moved to a single floor pen at 16 days of age and remained intermingled until 66 and 63 d of age in experiments 1 and 2, respectively. At six weeks all birds received a finisher diet containing 19% protein and 3200 kcal/kg of metabolizable energy. Individual body weights were obtained at hatching, at 2 d intervals through 16 d, and at 66 d of age in experiment 1 and 63 d in experiment 2. Feed and water were measured at 2 d intervals from 0 - 16 d. Water disappearance was corrected for evaporative losses from waterers atop the battery to calculate water intake (Marks, 1981).

In experiment 1 (S_3 progeny) 20 birds from each line/sex were randomly chosen at 66 d for slaughter to determine body and abdominal fat (leaf and gizzard) weights. In experiment 2 (S_4 progeny) approximately 22 birds from each line/sex subclass were slaughtered at 63 d of age to obtain body and abdominal fat weights.

Statistical Analysis: A 2x2 factorial analyses of variance was initially utilized in a fixed model on a within generation bases to compare the effects of genotype (normal vs dwarf), selection environments (.4% and 1.6% salt) and determine if genotype x environment interactions were present. The following model describes the effect of each of the variables studied: model 1:

$Y_{ijk} = u + G_i + E_j + (GE)_{ij} + c_{ijk}$ where Y_{ijk} is the observation of the k^{th} individual in the i^{th} genotype (G) and j^{th} environment (E). The mean is represented by u and c_{ijk} represents random variation. These initial analyses indicated significant differences between genotypes (normal and dwarf) for essentially all traits analyzed and the presence of some genotype x

environment interactions. Therefore, data were analyzed on a within genotype basis using the following model:

$Y_{ijk} = u + E_i + S_j + (ES)_{ij} + e_{ijk}$ where Y_{ijk} is the observation of the k^{th} individual in the i^{th} selection environment (E) and j^{th} sex (S). The mean is represented by u and e_{ijk} represents random variation. The selection environment x sex interactions were significant in only four of 66 analyses which is close to expectations assuming ($P > .05$). The GLM procedure of the SAS User's Guide, Statistics, 1982, edition was utilized for the analyses with means compared by using Duncan's multiple range test.

RESULTS AND DISCUSSION

Early growth and response patterns for body weights, feed and water intake, and feed efficiencies were similar in data collected in experiment 1 (generation 3) and experiment 2 (generation 4). Therefore, only experiment 2 early growth data will be presented for purposes of brevity.

Early Growth Data:

The influence of selection environment had only a minor influence on body weights from 0 to 16 d (Table 1). However, there was a tendency for birds selected on the .4% salt diet to have higher body weights than those from the 1.6% salt diet as evidenced by significant differences on a within sex basis in 9 of 20 comparisons. It is of interest to note that normal males from both selection environments had similar body weights (205 and 207 g) at 16 d, however, significant differences were observed between males from the different selection environments at 16 d in the dwarf genotypes. Body weights were similar for females at 16 days within genotype in the S_4 generation (Table 1), however, in S_3 data, females from the .4% salt environment were significantly larger at 16 d than females from the 1.6% salt

environment. Early body weights within selected environments (0 d) of normal males and females were similar, however, male body weights increased more rapidly than female body weights across the 16 day period (Table 1). This pattern was in agreement with previous reports on body weight deviations between sexes (Marks, 1985). Sex differences in body weights of dwarfs were not as pronounced as in normal birds, especially in the birds from the 1.6% salt environment.

There was evidence that feed intake on a within genotype - sex basis was higher for birds from the .4% salt environment than for birds from the 1.6% salt environment for 0 to 6 d, however, differences were not significant except for dwarf males (Table 2). Although there was considerable variation among subgroup means (Table 2) feed intake patterns generally followed body weight patterns (Table 1). Normal genotype males consumed more feed than normal females, however, differences were small initially and not significantly ($P < .05$) different until 15 - 16 d. Sex differences in feed intake of dwarf birds were smaller than differences observed in normal birds and not significantly ($P < .05$) different (Table 2).

Differences in water intake between selection environments were erratic. In the dwarf genotype, birds from the .4% salt selection environment appeared to consume more water than contemporaries from the 1.6% salt selection environment. However, normal birds from the 1.6% selection environment consumed an equal or greater amount of water than birds from the .4% salt selection environment (Table 2). Consistent sex differences in water intake did not appear until later ages.

Because feed and water intake values are shown in Table 2 corresponding water:feed ratio values are not presented. There was evidence in generation 3

data that early (0-4 d) water:feed ratios were greater in normal birds from the 1.6% salt selection environment than from the .4% salt environment. When expressed as a ratio (1.6% salt environment water:feed ratio/ .4% salt environment water:feed) values for males ranged from 1.04 to 1.06 and values for females from 1.02 to 1.15. In the dwarf birds there were no differences observed between water:feed ratios between birds from the two selection environments. Water:feed ratios were substantially higher for normal birds from the 1.6% selection environment than for normal birds from the .4% selection environment in generation 4. There was evidence that the differences in initial ratios (0-6 d) were greater than differences at later ages and that initial differences were greater between females than males (Fig. 1). There was no evidence of differences in water:feed ratios between selection environments for dwarf birds in generation 4 which was in agreement with corresponding data in generation 3.

Feed efficiencies of both normal and dwarf birds were similar within genotype across selection environments with the exception of the low feed efficiency for dwarf males (1-4 d) in the 1.6% salt environment (Table 1). Feed efficiency of males tended to be superior to that of females, however, differences were not always significant. Although significant ($P < .05$) only for certain observation periods (days 5-8), early feed efficiency of dwarf birds was superior to that of normal birds. These observations are supported by the summary of feed efficiencies (across sexes and selection environments) shown in Table 3. Ratios of dwarf:normal feed efficiencies indicated that dwarf birds were more efficient from 0 to 8 d, whereas normal birds had superior feed efficiency after 8 d of age. The ratio for 0-4 d of 1.00 for generation 3 was low due to the unusually low feed efficiency of dwarf females for days 1-2 under the 1.6% salt environment.

Abdominal Fat Data:

Body weights at 66 d in generation 3 and 63 d in generation 4 were significantly ($P < .05$) greater for normal than dwarf birds (Table 4). Body weights at these ages were also significantly ($P < .05$) greater for birds from the .4% salt environment than for those from the 1.6% salt environment except for normal birds in generation 4. Abdominal fat weights of dwarf birds were significantly ($P < .05$) greater than fat weights of normal birds in generation 4, but not in generation 3. Percent fat (abdominal fat weight/body weight $\times 100$) values were significantly ($P < .05$) larger in dwarf birds than in normal birds in both generations (Table 4). Review of the data within genotype indicated no differences between dwarf birds selected on the .4% salt environment and the 1.6% salt environment in abdominal fat levels, however, there was evidence that normal birds selected under the 1.6% salt environment had less abdominal fat than those selected under the .4% salt environment (Table 4). These data support earlier observations regarding lower abdominal fat levels in birds selected under a high salt environment (Marks, 1987). Earlier studies had also suggested that the reduction in fat level was greater in females than males (Marks, 1987). Separation of the data for the normal birds by sex in Table 5 supports the observation of a greater reduction in abdominal fat in females than males. On a percent fat basis, males from the .4% salt environment had from 5 to 7 percent more fat than males from the 1.6% salt environment, whereas, differences for females ranged from 13 to 29 percent. These data indicate that selection for body weight under a high salt environment which leads to a high water:feed ratio may have a favorable effect on abdominal fat levels in normal females, but not in normal males or dwarfs. However, the expression of lower abdominal fat levels under a normal environment does not appear to be related to changes in water and feed intake patterns. Further

research appears warranted to determine if these results can be repeated with other high water:feed ratio selection environments and determine why the favorable response is only expressed in females.

TABLE 1. Mean body weights and feed efficiencies ($\pm$ standard deviations) by genotype, sex, and selection environment (Sel. Env.) from 0 to 16 days of age.

Trait	Age (Day)	Genotype:				Dwarf			
		Normal							
		Sel. Env.:		1.6%		.4%		1.6%	
		Male	Female	Male	Female	Male	Female	Male	Female
Body Wt. (g)	0	35 ^a $\pm$ 3	35 ^a $\pm$ 2	33 ^b $\pm$ 3	33 ^b $\pm$ 2	32 ^a $\pm$ 2	31 ^a $\pm$ 2	33 ^b $\pm$ 3	32 ^a $\pm$ 2
	4	54 ^a $\pm$ 7	53 ^{ab} $\pm$ 5	51 ^{bc} $\pm$ 6	49 ^c $\pm$ 5	49 ^a $\pm$ 6	48 ^a $\pm$ 6	44 ^b $\pm$ 5	47 ^a $\pm$ 6
	8	88 ^a $\pm$ 10	83 ^b $\pm$ 8	83 ^b $\pm$ 11	82 ^b $\pm$ 8	81 ^a $\pm$ 12	79 ^a $\pm$ 12	70 ^b $\pm$ 12	76 ^a $\pm$ 11
	12	136 ^a $\pm$ 18	126 ^c $\pm$ 16	134 ^{ab} $\pm$ 18	128 ^{bc} $\pm$ 14	127 ^a $\pm$ 20	121 ^a $\pm$ 20	112 ^b $\pm$ 20	120 ^{ab} $\pm$ 19
	16	207 ^a $\pm$ 24	188 ^b $\pm$ 21	205 ^a $\pm$ 27	187 ^b $\pm$ 31	184 ^a $\pm$ 29	173 ^{ab} $\pm$ 27	171 ^b $\pm$ 30	173 ^{ab} $\pm$ 28
Feed Efficiency	1-4	.83 ^a $\pm$.02	.77 ^b $\pm$.07	.82 ^{ab} $\pm$.04	.78 ^{ab} $\pm$.04	.86 ^a $\pm$.04	.84 ^a $\pm$.03	.76 ^b $\pm$.08	.80 ^{ab} $\pm$.04
	5-8	.62 ^a $\pm$.02	.60 ^a $\pm$.05	.63 ^a $\pm$.01	.61 ^a $\pm$.04	.69 ^a $\pm$.02	.65 ^a $\pm$.04	.67 ^a $\pm$.05	.66 ^a $\pm$.01
	9-12	.67 ^a $\pm$.04	.64 ^a $\pm$.04	.68 ^a $\pm$.04	.64 ^a $\pm$.05	.68 ^a $\pm$.02	.64 ^a $\pm$.04	.69 ^a $\pm$.10	.65 ^a $\pm$.02
	13-16	.69 ^{ab} $\pm$.03	.66 ^{bc} $\pm$.02	.70 ^a $\pm$.03	.64 ^c $\pm$.04	.61 ^{ab} $\pm$.03	.59 ^b $\pm$.04	.60 ^a $\pm$.04	.58 ^b $\pm$.06

a, b, c, d Means within genotype and age group with different superscripts are significantly ($P < .05$) different from each other.

TABLE 2. Mean feed and water intake¹ and standard deviation by genotype, sex, and selection environment (Sel. Env.) from 0 to 16 days.

Trait	Age (Days)	Genotype:					
		Normal			Dwarf		
		Sel. Env.: Age (Days)		Sel. Env.: Age (Days)		Sel. Env.: Age (Days)	
		Male	Female	Male	Female	Male	Female
		.4%		1.6%		.4%	
						1.6%	
Feed Intake	1-2	3.9 ^a ± .6	3.8 ^a ± .7	3.4 ^a ± .7	3.3 ^a ± .7	3.8 ^a ± .4	3.8 ^a ± .4
	3-4	7.9 ^a ± .4	8.0 ^a ± .8	7.1 ^a ± .9	7.1 ^a ± .5	6.0 ^a ± .4	6.0 ^a ± .5
	5-6	13.1 ^a ± .8	12.3 ^{ab} ± .9	11.6 ^{ab} ± .9	12.1 ^{ab} ± .4	10.7 ^a ± .7	10.6 ^a ± .8
	7-8	14.0 ^a ± .9	13.3 ^a ± .8	13.9 ^a ± 1.0	13.6 ^a ± .6	12.5 ^a ± 1.1	12.2 ^a ± .8
	9-10	16.1 ^a ± 1.1	15.7 ^a ± 1.7	16.9 ^a ± 1.0	15.9 ^a ± .7	15.7 ^a ± 1.4	14.8 ^{ab} ± .7
	11-12	20.0 ^{ab} ± 1.3	18.8 ^b ± 1.7	21.1 ^{ab} ± 1.9	19.1 ^b ± .9	18.9 ^a ± .6	17.9 ^a ± 1.1
	13-14	24.5 ^a ± .9	22.6 ^{ab} ± 1.6	23.0 ^{ab} ± 2.3	21.8 ^b ± 1.0	21.7 ^a ± .9	19.9 ^a ± 1.0
	15-16	27.3 ^a ± 1.0	25.1 ^b ± 1.2	27.4 ^a ± 1.1	25.6 ^b ± 1.3	24.7 ^a ± 1.2	23.2 ^a ± .6
	1-2	9.3 ^a ± 1.7	9.9 ^a ± 1.9	9.6 ^a ± 2.5	10.3 ^a ± 1.7	9.7 ^a ± 1.5	10.5 ^a ± 1.8
	3-4	20.3 ^a ± 1.7	18.3 ^a ± 2.2	19.4 ^a ± 2.3	18.8 ^a ± 2.3	15.4 ^a ± 1.2	15.9 ^a ± 1.8
Water Intake	5-6	27.3 ^a ± 1.6	25.7 ^a ± 1.8	26.1 ^a ± 2.9	27.7 ^a ± 4.1	22.0 ^{ab} ± 1.4	23.1 ^a ± 2.8
	7-8	28.9 ^a ± 2.3	28.6 ^a ± 2.2	29.9 ^a ± 1.1	30.2 ^a ± 4.8	26.2 ^a ± 1.4	27.0 ^a ± 3.3
	9-10	31.1 ^a ± 2.1	31.5 ^a ± 3.8	33.9 ^a ± 1.0	31.9 ^a ± 3.9	30.9 ^a ± 3.0	29.7 ^{ab} ± 2.5
	11-12	37.5 ^a ± 1.8	36.8 ^a ± 5.4	41.0 ^a ± 2.6	38.9 ^a ± 5.3	36.7 ^a ± 1.8	36.3 ^a ± 3.1
	13-14	45.9 ^a ± 2.1	44.2 ^b ± 2.5	46.5 ^a ± 3.1	43.7 ^b ± 3.8	41.0 ^a ± 2.6	39.2 ^a ± 2.2
	15-16	51.1 ^{ab} ± 2.4	47.8 ^b ± 2.4	53.7 ^a ± 3.2	50.1 ^b ± 2.9	46.1 ^a ± 3.1	43.9 ^a ± 3.8
	1-2	3.1 ^b ± .5	3.1 ^b ± .5	4.9 ^b ± .7	4.9 ^b ± .7	3.1 ^b ± .5	3.1 ^b ± .5
	3-4	4.9 ^b ± .7	4.9 ^b ± .7	10.5 ^b ± 2.0	10.5 ^b ± 2.0	9.0 ^b ± 1.6	9.0 ^b ± 1.6
	5-6	10.3 ^a ± 1.0	10.3 ^a ± 1.0	12.2 ^a ± .9	12.2 ^a ± .9	10.3 ^a ± 1.0	10.3 ^a ± 1.0
	7-8	12.2 ^a ± .9	12.2 ^a ± .9	14.7 ^a ± 1.4	14.7 ^a ± 1.4	12.2 ^a ± .9	12.2 ^a ± .9
	9-10	14.7 ^a ± 1.4	14.7 ^a ± 1.4	18.6 ^a ± 1.4	18.6 ^a ± 1.4	14.7 ^a ± 1.4	14.7 ^a ± 1.4
	11-12	18.6 ^a ± 1.4	18.6 ^a ± 1.4	21.0 ^a ± 1.8	21.0 ^a ± 1.8	18.6 ^a ± 1.4	18.6 ^a ± 1.4
	13-14	21.4 ^a ± 1.5	21.4 ^a ± 1.5	24.9 ^a ± 1.9	24.9 ^a ± 1.9	21.4 ^a ± 1.5	21.4 ^a ± 1.5
	15-16	24.8 ^a ± 1.6	24.8 ^a ± 1.6	27.2 ^a ± 1.8	27.2 ^a ± 1.8	24.8 ^a ± 1.6	24.8 ^a ± 1.6

¹g/bird/day.

a,b,c,d,e Means within genotype and age group with different superscripts are significantly (P<.05) different from each other.

TABLE 3. Mean feed efficiency (across sex and selection environment) by generation, genotype and age.

Age (d)	Gen. 3		Ratio ¹	Gen. 4		Ratio ¹
	Genotype			Genotype		
	Normal	Dwarf		Normal	Dwarf	
0-4	.740	.740	1.00	.800	.815	1.02
5-8	.603	.663	1.10	.615	.668	1.09
9-12	.651	.636	.98	.658	.665	1.01
13-16	.690	.658	.96	.672	.610	.91

¹Ratio = dwarf/normal.

TABLE 4. Body weight, abdominal fat weight and percent abdominal fat by generation, genotype and selection environment (Sel. Env.).

Gen.	Genotype: Sel. Env.: Trait	Normal		Dwarf	
		.4%	1.6%	.4%	1.6%
S ₃	Body Weight (66 d)	1356 ^a	1246 ^b	996 ^c	926 ^d
	Fat Weight(g)	21.0 ^a	16.3 ^b	19.0 ^{ab}	18.2 ^{ab}
	% Fat	1.55 ^b	1.30 ^c	1.89 ^a	1.92 ^a
S ₄	Body Weight (63 d)	1254 ^a	1258 ^a	1037 ^b	954 ^c
	Fat Weight (g)	17.4 ^b	15.8 ^b	21.0 ^a	20.6 ^a
	% Fat	1.40 ^b	1.28 ^b	2.03 ^a	2.19 ^a

^{a,b,c} Means within generation and age group with different superscripts are significantly ($P < .05$) different from each other.

TABLE 5. Body weight, abdominal fat and percent abdominal fat by generation, sex and selection environment (Sel. Env.) for normal birds.

Gen.	Sex: Sel. Env.: Trait	Male		Ratio ¹	Female		Ratio ¹
		.4%	1.6%		.4%	1.6%	
S ₃	Body Weight (66 d)	1491	1361	-	1221	1129	-
	Fat Weight	19.3	16.5	1.17	22.7	16.1	1.41
	% Fat	1.27	1.19	1.07	1.83	1.42	1.29
S ₄	Body Weight (63 d)	1395	1392	-	1106	1105	-
	Fat Weight	17.3	16.5	1.05	17.6	15.0	1.18
	% Fat	1.24	1.19	1.05	1.56	1.38	1.13

¹Ratio = .4%:1.6%.

FIG.1. Ratios of water : feed ratios from 1.6% salt environment birds to water : feed ratios from 0.4% salt environment birds by sex and age.

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DESCRIPTION OF COOPERATION

The cooperating investigators met several times in the course of the research. Some of these meetings took place during international scientific congresses, and they were used to coordinate research topics and procedures. The principal investigator (A.C.) visited Athens twice, in 1985 and 1986. Mid-way results of the American and the Israeli teams were evaluated and conclusions were drawn regarding the last phases of the research. An American investigator (K.W.) visited Israel in 1987, to discuss the overall project and prepare the final report.

The American investigator followed the Israeli ones in using commercial broiler stocks rather than only randombred lines in their studies. Blood plasma of chickens from the Israeli low-fat and high-fat lines was sent to Georgia for growth hormone determination. Results obtained from these samples suggested that GH and abdominal fat were hardly associated, and they supported K.W. previous findings.

RESEARCH ACHIEVEMENTS AND BENEFIT TO AGRICULTURE

The main achievement of the reported research was the successful selection against fat deposition in broilers. Moreover, the substantial response to the selection on abdominal fat was not associated with reduction in live body weight. The practical importance of these findings was emphasised by the similar responses which were obtained in the dam (White Rock) and sire (Cornish) stocks. Fat deposition was found to be additively inherited, which means that breeders can design the selection programs of their parental lines and accurately predict the expected genetic gain, i.e. reduction of fatness, in the commercial broilers. The reported research proved that selection against abdominal fat in broilers is very feasible; it will increase meat yield without interfering with selection for improved growth rate and reproduction.

As for the economic importance, American producers started recently to remove the abdominal fat from some of their broilers, and charge 10 to 20% more for them, to compensate for the extra labor costs and weight lose. Our research indicates that lean poultry products can be obtained without the extra labor and weight lose, and probably with improved feed efficiency.

Another achievement of this cooperative research is the integrated approach to fatness of broilers. Important information was obtained regarding physiological and nutritional aspects of growth, feed utilization and fat deposition. This information, although not completed yet, will provide guidelines for farmers and breeders of meat-type chickens, to assure maximal expression of the genetic potential of their stocks.

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