Fat deposition in a broiler sire strain

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STELLINGEN

1. Selektie tegen vetaanzet via de vaderlijn is bij braadkuikens uitvoerbaar en verantwoord.
   Dit proefschrift.

2. Individuele selektie op een gunstige voederconversie in de vaderlijn van braadkuikens is door direkte en gecorreleerde effekten méér dan de moeite waard.
   Dit proefschrift.

3. Selektie op gewicht, bereikt bij beperkte voedering en groepshuisvesting, is niet bruikbaar om kuikens te verkrijgen, die bij ad libitum voedering minder vet zijn, dan wel hun voer efficiënter benutten.
   Sørensen, P., 1986. Study of the effects of selection for growth in meat type chickens. Thesis, Kopenhagen.
   Dit proefschrift.

4. De kennis over de wijze waarop kuiken en kip hun voeropname regelen, is niet toereikend om bij ad libitum voedering de resultaten van voedings- en klimaatsonderzoek in modellen te beschrijven.

5. Voedernormen zijn afhankelijk van het genetisch potentieel van de populatie waarvoor ze worden gebruikt.
   Emmans, G., 1986. Proc. 27th British Poultry Breeders Roundtable Conference, Edinburgh.

6. Selektieëxperimenten moeten worden uitgevoerd met diermateriaal, dat wat produktieniveau betreft, vergelijkbaar is met het materiaal waarvoor de onderzoeksresultaten moeten gelden.

7. De wensen van de consument ten aanzien van de vetheid van kip zijn onbekend en alleen al daarom ondergeschikt aan de belangen, die kuikenmester en slachterij bij de produktie van minder vette kuikens hebben.

8. Het is te betreuren, dat in de humane voedingsvoorlichting de nadruk eenzijdig op het cholesterolgehalte van eieren wordt gelegd, terwijl een ei wat betreft overige nutriënten en de verteerbaarheid daarvan een vrijwel ideaal voedingsmiddel is en tevens uitstekende culinaire eigenschappen heeft.

Moore, J.H., 1987. pp. 27-56 in: Egg quality - current problems and recent advances. Wells, R.G. and C.G. Belyavin, eds., Butterworth, Londen.

9. Gezien de interne belangentegenstellingen kan de Nederlandse landbouw niet meer als één bedrijfstak beschouwd worden.

10. De neiging van de Nederlandse overheid te bezuinigen op onderzoek en tegelijkertijd strukturele financiering te vervangen door programmatische, miskent de waarde van onderzoek als fundamenteel onderdeel van onze cultuur en als investering in de toekomst.

11. Het onderzoeksmanagement houdt te weinig rekening met het feit, dat bij onderzoekers de drang tot het beter willen weten meestal niet bij de grenzen van het eigen vakgebied ophoudt.

12. Het begrip "bedrijfssynthese" is een voorbeeld van Ambtelijk Beleids Nederlands: voor diegenen, die slechts het Algemeen Beschaafd Nederlands machtig zijn, volstrekt onbegrijpelijk.

13. Denken aan stellingen leidt tot het denken in stellingen.

Proefschrift "Fat deposition in a broiler sire strain"
van F.R. Leenstra.
Wageningen, 26 mei 1987.

VOORWOORD

Een proefschrift kan veelal alleen tot stand komen met de medewerking van veel mensen. Dat geldt zeker voor dit proefschrift, waarin de resultaten beschreven worden van een selektieëxperiment bij pluimvee. Het onderzoek werd uitgevoerd op het Centrum voor Onderzoek en Voorlichting voor de Pluimveehouderij "Het Spelderholt". De direktie en het bestuur van Het Spelderholt ben ik zeer erkentelijk voor alle ruimte (ook letterlijk) en de vrijheid, die ik heb gekregen om het onderzoek en dit proefschrift af te ronden.

De werkzaamheden, die voor het onderzoek noodzakelijk waren, varieerden zeer. Zo werd individuele huisvesting voor jonge kuikens gecreëerd, moesten hokken vaak in recordtempo worden schoongemaakt, werden duizenden kuikens en volwassen dieren verzorgd, broederij- en plaatsingsgegevens ingevoerd, selektieoverzichten gedraaid, hanen gemolken, hennen geïnsemineerd, kuikens geknopt en slachtrendementen en chemische samenstelling van kuikens bepaald. Er zijn dan ook maar weinig Spelderholt medewerkers die niet direkt of indirekt bij het onderzoek betrokken zijn geweest. Al die mensen wil ik graag bedanken voor hun medewerking, ideeën en steun.

Pieter Vereijken, van ITI-TNO, de discussies met jou over proefopzet, modelkeuze en toetsen en de hulp bij de uitvoering daarvan, heb ik zeer op prijs gesteld.

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Bij de opzet en het verloop van het gehele onderzoek heeft Reint Pit een grote rol gespeeld. Reint, door jouw meedenken, inzet en organisatorisch vermogen werd het mogelijk het projekt Vetaanzet bij slachtkuikens tegelijk met de andere fokkerijprojekten uit te voeren en tot een goed einde te brengen. Heel hartelijk bedankt voor de plezierige samenwerking gedurende de afgelopen jaren.

Ferry Leenstra

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INTRODUCTION

Poultry meat production is a relatively new branch in agriculture. Before 1950 poultry meat was not much more than a byproduct of egg production. It was produced from culled and spent hens and roosters. On a small scale, chickens of the breeds Mechelse Koekoek, Breda Hoen and Noord Hollandse Blauwe were "fattened" by skilled farmers in the Netherlands on a diet of barley and skimmed milk. This diet often had to be forced fed. One considered these chickens a delicacy. Incidentally, dual-purpose hens were mated to cocks of a heavy breed to produce chickens suited better for meat production. The low importance of poultry meat production in the first half of this century is illustrated by Hutt (1949). In his chapter "Genetics in practice" selection methods for egg production and disease resistance are mentioned, but not those for meat production.
The demand for poultry meat increased, however, at a fast and constant rate (Figure 1). Therefore, from 1950 onwards specific meat strains were developed to improve poultry meat production. These strains were also available in the Netherlands. In 1958, however, the Dutch Commodity Board for Poultry and Eggs (PPE) still had to warn that dual purpose hens were not suited as

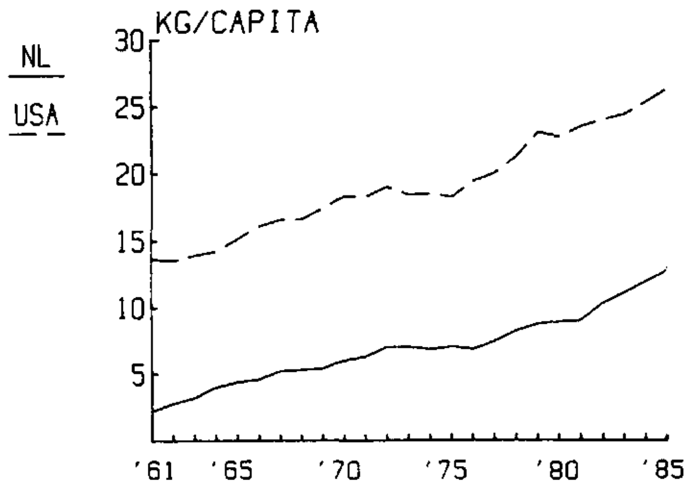

Figure 1: Annual poultry meat consumption in the Netherlands and the USA. (source: Annual reports PPE and Trade et al., 1986).

dam stock for meat-type chickens. More research to develop specialized meat strains was required. In 1959, separate registration of meat- and egg-type stock was started. Since that time, poultry meat production has developed rapidly. The number of chickens reared for meat production and the total weight slaughtered of broiler-type birds increased greatly (Figure 2). The same developments occurred in other countries. In the United States, for instance, the total production/year of ready-to-cook poultry meat increased with more than 300% from 672 million kg between 1955 and 1959 to 2881 million kg between 1980 and 1985.

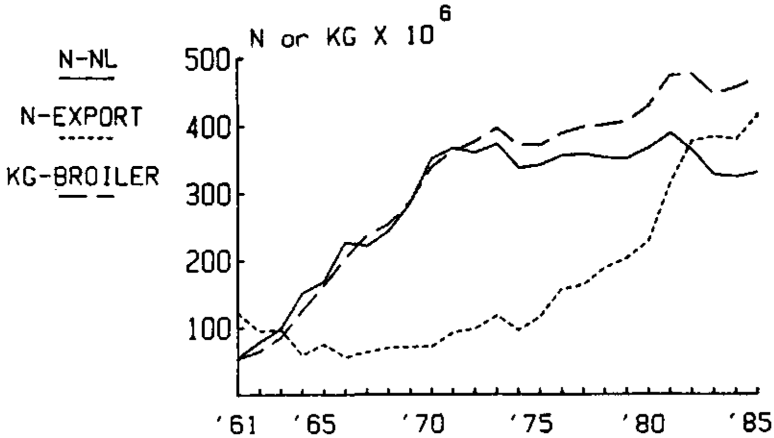

Figure 2: Number of eggs set/year for broilers reared in the Netherlands (N-NL); number of hatching eggs exported + number of eggs set for exportation of one-day-old chickens/year (N-EXPORT); broiler production in kilogram live weight/year (KG-BROILER). (Source: Annual reports PPE).

In the sixties most broilers were processed to whole frozen carcasses. From the seventies onwards processing and consumption changed from frozen to fresh and from whole birds to parts (Table 1). These trends can be expected to continue. The consumption figures are based on the data of poultry slaughterplants. Retailers often process whole birds further themselve. Because of this the proportion of chicken consumed as parts is in reality higher, and is aproaching 80% in 1986 (AGB Rapportage, 1986).

Table 1: Production and consumption of poultry meat in the Netherlands. (source: Annual reports PPE).

	Production				Consumption			
	Frozen	Fresh	Whole	Parts	Frozen	Fresh	Whole	Parts
1978	55%	45%	71%	29%	30%	70%	69%	31%
1985	40%	60%	56%	44%	18%	82%	52%	48%

The development in poultry meat production and consumption causes changes in the type of broiler demanded. At the onset of specialized broiler production, most improvements were made by intensive selection for weight-gain, whereas little attention was given to carcass composition or quality, other than the shape of the whole carcass. Between 1961 and 1985 weight-gain/day increased from about 20g to more than 40g. Slaughter age reduced from 12 weeks to about 6 weeks in 1985. These developments made the frozen whole carcass a cheap product in which quality was subordinate to cost price.

The increasing quality awareness of consumers and their increasing demand for chicken parts and further processed products require properties of the broiler other than fast weight-gain only. For further processing, the anatomical composition of chickens determines for a large part the yield for the slaughterplant. The proportion of offal is of more importance when parts are produced than when whole carcasses are the endproduct. Fat depots are anatomical parts that are considered as offal nowadays, the more so as consumers are advised to diminish their fat consumption. Processing yields worsen when fat depots are removed from the carcass. When not removed, they can affect the healthy and low-in-fat-content image of poultry meat. The low fat content is a main reason why poultry meat is preferred above red meat. The main fat depot in broilers is the abdominal fat. It extends from the cloaca over the intestines and around the gizzard. The abdominal fat forms about 2.5% of the total live weight of a broiler. This implies that in the Netherlands more than 10000 tons of abdominal fat are produced per year.

Against this background, in 1980 a research program was started at the Spelderholt Centre aimed at reducing fatness in broilers. The purpose of the program was to examine the possibilities and the consequences of selection against fatness. The results of the research program are set forth in this thesis. In Chapter 1 the literature on the subject is reviewed. Selection appeared to be most promising in the long term to reduce fatness, but little was known about the relative efficiency of different selection methods. Therefore, a selection experiment was started. The Chapters 2, 3 and 4 describe the basic material, the methods and the results of this selection experiment in which different selection characteristics are tested on their usefulness to reduce fatness. Chapter 5 gives the results of an experiment in which the established selection lines are used as sire strain in a broiler cross. In Chapter 6 phenotypic and genetic parameters estimated from the selection experiment are used to predict the consequences of application of different selection methods in a commercial broiler breeding program.

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CHAPTER 1

EFFECT OF AGE, SEX, GENOTYPE AND ENVIRONMENT ON FAT DEPOSITION IN BROILER CHICKENS.

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ABSTRACT

The possibilities of preventing excessive fat deposition in broiler chickens are reviewed. Both the total amount of fat deposited and the ratio between abdominal fat and total fat can be changed by nutritional and genetic means. The effects of environmental factors like housing design, temperature and lighting regimes on fat deposition are too small to be useful for preventing excessive fat deposition.

Most important among nutritional factors is the ratio between energy and protein in the diet. Several other dietary factors and their interactions also have a marked influence on fat deposition. Information on the effects of interactions between dietary components among each other and between nutrition and sex, age and genotype of the broiler is however far from complete.

Selection can solve the problem of excessive fat deposition in the longer term in an effective way, although more research is needed on the effects of selection against fatness on growth rate, feed conversion, slaughter yields and the quality of the broiler from a consumer's point of view.

INTRODUCTION

The problem of defining the most desirable amount of fat in broilers is complex. On the one hand there are undesirable, even wasteful, fat depots like abdominal and crop fat. On the other hand there is physiologically necessary fat and - from a consumer's point of view - desirable fat. A certain amount of subcutaneous fat gives the broiler a good appearance and a moderate amount of fat in the meat increases its palatability.

On average, about 2 to 3% of the live body weight of broilers is abdominal fat. This implies that in the Netherlands about 10.000 tons of abdominal fat are produced each year by broilers alone. About half of this quantity is deposited in other, smaller depots (crop, intestines, etc.). Part of the depot fat is lost from the carcass during processing, thus reducing processing yields and increasing the amount of offal and the fat content of waste water (Heath et al., 1980). Part of the fat stays in the ready-to-cook bird and can give poultry meat a fatty image.

Although the unprofitable effects of depot fat are well known to all involved in broiler production, there is still no reliable method of evaluating total broiler flocks for carcass quality. In general, broilers are paid for on the amount of live weight delivered at the slaughter plant and not on a combination of weight and quality, as is usual in cattle, sheep and swine.

Until methods, of evaluating broiler carcass quality on a large scale, are available and used, methods for changing fat deposition are valuable only if they reduce, or at least do not increase, the costs of production of live weight. Production costs of broilers are dependent mainly on growth rate and feed costs. Feed conversion, the ratio between feed consumption and body weight gain, is an important factor here.

Fat tissue has a high energy content compared with lean meat. The amount of energy needed to deposit 1 gram of protein or 1 gram of fat is about the same (Pullar and Webster, 1977). The correlation between feed conversion (feed/gain) and fat deposition can be expected to be positive, as deposition of protein is accompanied by deposition of three times as much water. A broiler converting its feed to lean tissue instead of fat, will therefore gain more per unit of feed consumed. Consequently if the lean and fat birds metabolize their feed with equal efficiency, are equally active, subject to the same heat loss, etc., the lean ones will show a favourable feed conversion (Brody, 1935; Thomas et al., 1958).

In this article genetic and environmental influences on fat deposition and, where available, correlated effects on growth rate and feed conversion, are reviewed. General aspects of fat deposition, the effects of sex and age, genotype, nutrition, other environmental factors and their interactions, are discussed.

GENERAL ASPECTS OF FAT DEPOSITION

The main biological purpose of fat deposition in poultry is to store energy in times of abundant feed supply against times when the feed supply is limited. In broilers it is not unusual for fat to constitute 15-20% of the total body weight (Scheele et al., 1981; Griffin and Whitehead, 1982; Leenstra, 1982). Evans (1977) stated that over 85% of total body fat is stored in adipose tissue (subcutaneous, intermuscular, abdominal fat, etc.) as an energy supply. Thus, a maximum of 2 to 2.5% of the total body weight is fat that is present in the blood and other tissues as physiologically necessary fat. This is compatible with the results of Yoshida and Morimoto (1970), who found that at least 0.9% of the total weight should be fat for normal body functioning.

In broilers, fat is the most variable body component (Lohman, 1973). The amount of fat deposited in the abdominal cavity is far more variable than that deposited inter- and intra-muscularly (Ricard, 1975; Håkansson et al., 1978; Becker et al., 1979; Leenstra, 1982). The coefficient of variation of amount of abdominal fat is 25 to 30%, while the coefficient of variation of the total fat content (abdominal fat included) varies between 15 and 20% (Leenstra, 1984). The coefficient of variation of total fat content is in its turn large compared to the coefficients of variation of water content (approx. 2%), protein content (approx. 4%) and ash content (approx. 8%) (Leenstra, 1982).

The size of the different fat depots in the body are positively correlated. Changes in one depot will be accompanied by changes in other depots (Becker et al., 1979; Cherry et al., 1984). The danger that, due to diminution in abdominal fat, broiler meat will become too lean is however small. As abdominal fat is far more variable than total fat and thus than the fat content of meat, considerable changes in abdominal fat are possible without large changes in inter- and intra-muscular fat content (Becker et al., 1984; Ricard et al., 1983).

Fat is stored as triglycerides in fat cells. In contrast to mammals, avian fat cells cannot synthesize triglycerides, but have only a storage function (Evans, 1977). The triglycerides are transported by the blood and are derived directly from the feed, or from the liver and to a lesser extent from the skeleton where the triclycerides are synthesized from fatty acids (Leveille et al., 1975; Pfaff and Austic, 1976; Nir and Lin, 1982). Both the number and size of the fat cells are variable and related to the amount of fat deposited (March and Hansen, 1977). The amount of fat that can be stored depends on energy intake, the amount of energy needed for maintenance including activity and for the growth of non-fat tissues. If the energy intake exceeds these requirements fat will be deposited (Lin, 1981).

Appetite is thus a main factor in determining the amount of fat deposited (Van Gils et al., 1977).
Layer-type chickens and broilers differ in the regulation of feed intake. Layer-type chickens can be forced fed to about 50% above ad libitum intake; broilers can hardly be forced to take more than 10% above ad libitum intake (Shapira et al., 1978). The same phenomenon was found by Barbato et al. (1984): chickens from lines selected bidirectionally for high and for low body weight differed considerably in the extent to which they could be overfed (high body weight line 10%, low body weight line 23%). Overfeeding had hardly any effect on growth rate in the high body weight line, but gave a 40% increase in body weight in the low body weight line.
In broilers the capacity of the gastro-intestinal tract seems to be the limiting factor for ad libitum feed intake, while in layer-type birds regulation by hypothalamic hormones is more important (McCarthy and Siegel, 1983; Fisher, 1984). This is supported by the findings of Fisher and Wilson (1974), who concluded that, in 95% of the cases examined, an increase in dietary density enhanced the growth rate of broilers.
Unfortunately, most basic research on the regulation of appetite and its relation to fat deposition in poultry is carried out with layer-type chickens. As fat deposition is dependent on appetite and appetite has a specific regulation mechanism in broilers, fat deposition should be examined in broiler-type birds.

THE INFLUENCE OF SEX AND AGE OF THE CHICKEN ON FAT DEPOSITION

Both sex and age of the broiler have a distinct effect on fat deposition. Females tend to be fatter than males and older birds have a higher fat content than younger birds. Changes in percentage of fat with age are larger than changes in percentage of protein and ash (Lin, 1981; Leenstra, 1982). Cöp (1974) reported that in swine with increasing body weights (age) the percentage of fat increased at the cost of the percentage of water. Percentage of protein and ash were constant over a large range of body weights.
Fat depots grow by an increase in the number of fat cells (hyperplasia) and/or by an increase in the size of the fat cells (hypertrophy). The number of fat cells in layer- and broiler-type chickens increases until

about 14 weeks of age (Pfaff and Austic, 1976; March and Hansen, 1977). After 14 weeks of age the number of fat cells per fat pad is constant (Hood, 1982). Up to 14 weeks of age Hood (1984) found only a slight increase in the size of the fat cells in broilers but, when cell multiplication stopped, a rapid increase in cell size occurred. March et al. (1984) found, that in broilers from 5 weeks of age onwards two populations of fat cells could be distinguished: a population of small cells, that increased in number, but not in size, until after 12 weeks of age and a population of large fat cells that only increased in size. Cherry et al. (1984) reported that in broilers the amount of abdominal fat increased until four weeks of age mainly by hyperplastic growth. Until about 6 weeks of age the number of fat cells per gram of fat tissue was constant, after 6 weeks of age the number of fat cells per gram of fat tissue declined, indicating that from 6 weeks of age hypertrophic growth is more important. Hood (1984) however stated, that in young birds also cell size is the dominant factor in determining the amount of abdominal fat. Simon and Leclercq (1982) found that up to 90% of the differences in the amount of abdominal fat could be attributed to differences in cell size.

In females the increase in percentage of total body fat and abdominal fat exceeds greatly that in males (Edwards et al., 1973; Fisher, 1980.). Leenstra (1982) found, that between 3 and 10 weeks of age the total percentage of fat in females increased from 10 to 19%; in males, in the same age period, from 10 to 13%. In males the percentage of fat showed only minor increases from 6 weeks of age onwards. In females there is no indication of fat deposition reaching a plateau before the adult age (Ricard, 1977). Ehinger and Seemann (1982) found for commercial broilers slaughtered between 35 and 53 days of age, a clear effect of sex and age on the percentage of fat, but no differences between the sexes in the rate of change due to age. Males had on average a total of 12.7% fat, females 14.5%. Birds of 35 days of age had 12.3% fat, those of 53 days 14.7%. The similarity in increase in fat content in males and females in this material could be due to the relative short period studied. It would be interesting to see whether studies of fat cells could give more insight into the interactions between age and sex.

In general, the allometric coefficient for the growth of fat in relation to body weight is greater than unity for all species; indicating, that fat tissue is growing at a faster rate than total body weight (Walstra, 1980; Taylor, 1981; Fisher, 1984). Among fat depots in different parts of the body abdominal fat has the highest allometric coefficient (Simon and Leclercq, 1982; Fisher, 1984).

Griffith et al. (1978) found between 4 and 8 weeks of age an increase of about 12% in the fat content of the ready-to-cook bird, while the amount of abdominal fat increased by 40%. Between 6 and 12 weeks of age depot fat increased, but the percentage of fat in meat was constant from 6 weeks of age onwards (Ricard, 1983). Grey et al. (1983) found no clear increase in fat content of meat (breast and thigh) between 3 and 11 weeks of age, while the fat content of skin increased significantly. The effect of sex was not significant if the fat content of meat only was considered, but for fat content of skin, females showed a greater increase than males, resulting in a sex x age interaction.

In females the amount of abdominal fat is a larger part of the total fat than in males (Håkansson et al., 1978). As both total and abdominal fat content are higher in females than in males of the same age, excessive fat deposition can be prevented to some extent by slaughtering females at earlier ages and thus lower body weights, than males.

INFLUENCE OF GENOTYPE ON FAT DEPOSITION

Differences in fat deposition between breeds (Edwards and Denman, 1975) and strains within breeds (Ricard, 1975; Van Middelkoop et al., 1979; Cherry et al., 1978; Twining et al., 1978; Ehinger and Seemann, 1982) indicate the importance of genetic factors in fat deposition.

A genetic variation within strain in the total amount of fat was found by Friars et al. (1983). They estimated the heritability of total percentage body fat to be 0.48. More information is available on the heritability of the amount of abdominal fat (Table 1). The values of 0.3 to 1.80 found for the heritability of abdominal fat relative to body weight correspond well with the heritability of 0.4 to 0.6 found for backfat thickness in swine (Berg, 1982; Tess et al., 1983). In the experiments of Becker et al.(1984), Friars et al. (1983) and Leenstra (1982) the degree of heritability estimated from the dam component of variance is higher than that estimated from the sire component. This could be a maternal effect. It is possible, that egg size or egg composition influences fat deposition in the chicken hatched from that egg. Experimental proof for this hypothesis is not yet available.

Table 1. Heritability, estimated from full and half sib analysis, of the absolute amount of abdominal fat and of abdominal fat as percentage of body weight of chickens between 44 and 77 days of age.

	Abdominal fat (g)		Abdominal fat (%)		
Sex	h^2_{sire}	h^2_{dam}	h^2_{sire}	h^2_{dam}	Author
Females	0.32	0.70	0.42	0.81	Friars et al., 1983
Both	0.59	1.12	0.38	1.24	Becker et al., 1984
Males	0.67	-	0.72	-	Gyles et al., 1984
Females	0.24	-	0.23	-	Gyles et al., 1984
Males	1.80	0.31	1.70	0.26	Leclercq et al., 1980
Both	0.21	1.25	0.38	1.22	Leenstra, 1982
Males	0.79	0.29	0.65	0.30	Ricard and Rouvier, 1967
Both	0.70	0.53	0.75	0.68	Ricard and Rouvier, 1969

In the French work (Ricard and Rouvier, 1967 and 1969; Leclerq et al., 1980) the heritability estimated from the sire component of variance is considerably higher than that estimated from the dam component. An explanation for these results is not easy to find. Sex-linked inheritance cannot be the cause as the high h^2_{sire} is found in groups consisting only of males and in a material consisting of both sexes.

It is supposed that broilers are fat because of intensive selection for body weight at a fixed age under ad libitum feeding conditions (Lin, 1981). Such a selection system favours the birds with a large appetite that are capable of over-eating to such an extent that feed intake exceeds the birds capacity for lean tissue growth and thus they become fat (Summers and Leeson, 1979). Lilburn et al. (1982) found, while selecting for and against abdominal fat in adult chickens, that selection had resulted in differences in appetite. At 14 weeks of age the fat line ate 25% more than the lean line and had about twice as much abdominal fat. If the fat line was restricted to the feed intake of the lean line, there were no differences in body weight or body composition. Leclercq and Saadoun (1982) found, however, that in their lines selected for a high or low amount of abdominal fat at 9 weeks of age, the fat line deposited more fat than the lean line if both were restricted to the same feed intake.

Layer-type chickens tend to have less than half the relative amount of abdominal fat of broiler-type chickens of the same age (March, 1984). The broilers have about twice as many fat cells as the layer-type chickens (March and Hansen, 1977). Hood and Pym (1982) found that chickens of faster growing lines had more and larger fat cells than lines growing at a slower rate. Nir and Lin (1982) found with in vitro tests, that chickens of heavy strains tended to show more lipogenic activity than leaner lines.

Within strains and generations, the correlation between body weight and relative amount of fat is weak, often not significantly different from zero, but in nearly all cases positive (Table 2).

The amount of abdominal fat relative to body weight can be reduced by selection through progeny testing or sib selection (Leclercq et al., 1980; Leenstra, 1982), selection for feed efficiency (Pym and Solvyns, 1979) and selection based on the concentration of triclycerides in blood plasma (Griffin and Whitehead, 1982). In these cases there were no differences in body weight between selected and non-selected chickens. This indicates that the genetic correlation between the relative amount of abdominal fat and body weight is close to zero.

The correlation between the relative amount of abdominal fat and feed conversion within generations is generally positive in poultry (Table 3), and of the same magnitude as that between abdominal fat and body weight. In other species (mice, rat, swine) the correlation between fat deposition and feed conversion has also been found to be positive, although the results are more variable than with poultry (Eisen, 1982; Dickerson, 1982; Tess et al., 1983).

Selection for a low feed conversion results in less carcass fat whether compared at the same age or the same body weight with selection for high body weight or an unselected control line (Washburn et al., 1975; Pym and

Table 2. Phenotypic correlation coefficients between live body weight and abdominal or total amount of fat within strains.

Sex	Abdominal fat(g)	Abdominal fat(%)	Total fat(%)
Males	0.49[b]	0.29[b]	0.10[b]
Females	0.53[b]	0.36[b]	0.28[b]
Females	0.55[e]	0.18[e]	0.20[e]
Males	0.29[i]	0.40[a]	0.43[a]
Females	0.41[i]	0.18[a]	0.20[a]
Males	0.50[g]	0.33[h]	0.35[h]
Females	0.42[g]	0.24[h]	0.33[h]
Males	0.31[d]		0.20[f]
Females	0.28[d]		0.33[f]
Males	0.44[d]		0.01[f]
Males	0.29[d]		0.48[f]
Males	0.49[c]		0.20[c]
Males	0.60[c]		-0.04[c]

[a] Becker et al.(1979)
[b] Becker et al.(1981)
[c] Burgener et al.(1981)
[d] Cherry et al.(1978)
[e] Friars et al.(1983)
[f] Griffin et al.(1982)
[g] Griffith et al. (1978)
[h] Leenstra (1982)
[i] Ricard et al.(1969)

Table 3. Phenotypic correlation coefficients between feed conversion and amount of abdominal or total fat relative to body weight within strains.

Sex	Abdominal fat(%)	Sex	Total fat(%)
Males	0.12[b]	Males/females	-0.10[d]
Males	0.12[b]	Males/females	-0.07[d]
Males	0.45[b]	Males/females	0.65[e]
Males	0.28[b]	Males/females	0.36[e]
Females	0.22[a]	Females	0.24[a]
Males/females	0.13[c]		

[a] Friars et al. (1983)
[b] Griffiths et al. (1978)
[c] Leenstra (1982)
[d] Pym and Solvyns (1979)
[e] Washburn et al. (1975)

Solvyns, 1979). Lines selected for low fat deposition have a more favourable feed conversion than lines selected for the opposite characteristic (Griffin and Whitehead, 1982; Leclerq and Saadoun, 1982).
Ricard et al. (1982) found, in comparing lines selected for a high or low amount of abdominal fat relative to body weight, a favourable effect of selection for leanness on processing yields and meat content of the carcass. Selection against abdominal fat had reduced the total fat content of the bird, but while differences in abdominal fat between the lines were fourfold, the fat line had only 1.3 times as much fat in the meat of the legs (Ricard et al., 1983).
In the rather short term experiments reported on selection against fat deposition the results are favourable. There is a clear response in the amount of abdominal fat, no effect on growth rate, and favourable effects on feed conversion and processing yields. The main problem in selection against fatness is, that it is extremely laborious, whether performed via sib or progeny testing, selection on feed conversion or concentration of triglycerides in blood plasma. This inhibits the extensive use of these methods as a means of selection.

THE INFLUENCE OF NUTRITION ON FAT DEPOSITION

Nutritional factors do have significant effects on body composition in broilers (Lin et al., 1980; McLeod, 1982; Fisher, 1984). Even with commercial diets nearly twofold differences in total body fat content (10.7 to 18.1%) can be found (Neupert and Hartfiel, 1978). In general, high energy diets have advantages if body weight gain and feed conversion are considered. If carcass quality is taken into account, the benefits of high energy diets are less (Freeman, 1983). Using different dietary compositions and restricted feeding for 10 days before slaughter Arafa et al. (1983) obtained a reduction in energy intake, while the intake of protein and minerals was not below that of ad libitum feeding. An energy allowance of 80% of the ad libitum intake reduced full fed live body weight to 94% of the ad libitum fed control group, percentage of abdominal fat to 79% and slaughtered weight to 95%, while there were no differences in weight of the cooked broilers.

Fraps (1943) found more than 40 years ago, that diets with a small energy to protein ratio caused less fat deposition than diets with a large energy to protein ratio. This has been confirmed more recently by several authors (Bartov et al., 1974; Farrell, 1974; Kirchgessner et al., 1979). Guillaume and Summers (1970) and Jackson et al. (1982) found, that the degree to which dietary energy was utilized, was dependent on the energy to protein ratio of the diet. In diets relatively high in protein, energy is utilized less efficiently than in diets low in protein. These findings could explain, why diets with a small ratio between energy and protein give less fat deposition than those with a large ratio, independent of the quality of the protein (Griffith et al., 1977).

Although much has been learned about the effects of dietary factors on carcass composition, it is as yet not possible to predict carcass composition accurately from the available knowledge of dietary factors. This is due mainly to the fact, that many factors and their interactions influence carcass composition. Factors as widely differing as amino acids, crude fibre, fat, or salt content of the diet have significant effect on carcass fat deposition (Lipstein et al., 1975; Ten Have and Scheele, 1981; Marks and Washburn, 1983). In addition, the physical form of the feed (crumbs or meal) has a significant effect on fat deposition (Marks and Pesti, 1984).

Pesti et al. (1983) found, that crumbling a low density diet increased abdominal fat by 23%, while with a high density diet the form of the feed had no effect on the amount of fat deposited. Chickens fed mash diets need more time to consume the same amount of feed than chickens fed pellets or crumbs (Jensen et al., 1962). Thus especially with low density diets, mash feeding implies some feed restriction.

An illustration of the interaction between dietary factors is the influence of the ratio between energy and lysine on the effect of dietary fat on fat deposition (Ten Have and Scheele, 1981). Dietary fat had significantly more effect on fat deposition at low levels of lysine per unit of dietary energy than at relatively high lysine levels.

Another complicating factor in research on the effects of nutrition on fat deposition is, that most dietary factors do not have the same effect on the deposition of abdominal fat and the deposition of fat in the rest of the body. The effects of diet on abdominal fat content are greater than its effects on the total amount of carcass fat (Elwinger, 1980; Jackson et al., 1982; Ehinger and Seemann, 1982). Scheele et al. (1981) found that regression formulas, developed by stepwise regression to predict abdominal fat from dietary factors, differed significantly from those to predict total fat minus abdominal fat. Energy and crude fibre content of the diet were important in explaining the percentage of abdominal fat, while lysine content was the main factor in predicting total fat minus abdominal fat.

If more information on the effects of dietary factors and their interactions becomes available, it should be possible to manipulate the total amount of carcass fat and the ratio between abdominal and total fat by dietary means. Because of the marked effect of interactions between dietary components on fat deposition, factorial designs, in which more dietary factors are examined simultaneously, should be preferred to research in which only a single dietary component is varied.

THE INFLUENCE OF OTHER ENVIRONMENTAL FACTORS ON FAT DEPOSITION

Environmental factors, that influence maintenance requirements or activity, can also influence the fat content of broilers. Such factors are ambient temperature, housing systems and lighting regimes.

At moderate temperature levels the correlation between temperature and total body fat content is positive (Kubena et al., 1972). Over several experiments, Fisher (1984) found a linear increase of 0.19% total body fat per degree increase in temperature between 10 and 30°C. For abdominal fat Kubena et al. (1974) could find only a non-significant tendency for a positive correlation with rearing temperature. In general, however, lower temperatures increase feed conversion.

Broilers housed in cages show less activity than broilers reared on litter (Haye and Simons, 1978). This could be the reason that broilers reared in cages tend to deposit more abdominal and total body fat than broilers reared on litter (Deaton et al., 1974). Evans et al. (1976) found, however, no differences in the fat content of breast and thigh meat between birds reared in cages or on litter. The influence of lighting systems on body composition is not consistent. Van Es (1981) found, that intermittent light gave less fat deposition, while Simons (pers.comm.) could find no significant effect of lighting systems on total carcass or abdominal fat. Most prominent among environmental factors is the effect of rearing temperature on fat deposition. But the effect of temperature is small compared with the influence genetic or nutritional factors have on fat deposition. The influence of environmental factors on fat deposition is therefore too small to be of interest in preventing excessive fat deposition.

THE INFLUENCE OF INTERACTIONS ON FAT DEPOSITION

Interactions between sex, age, genotype and nutrition can have an effect on fat deposition. The interaction between sex and age, the difference between males and females in fat content becoming more pronounced with increasing age, has already been mentioned.

Males and females react differently to changes in dietary protein. Males show a linear decline in percentage of abdominal fat with increasing protein levels in the diet. Females react more strongly with less fat deposition on an increase in protein at low dietary protein levels than at high dietary protein levels (Mabray and Waldroup, 1983). The same authors did not find any interaction between sex and dietary energy content if fat deposition is considered.

A significant interaction between age of the broiler and dietary composition on fat deposition was found by Have and Scheele (1981) and Van Gils et al. (1977). Have and Scheele compared fat deposition in 6- and 8-week old broilers that were fed with diets of a constant energy to protein ratio, but that differed in concentration. The 6-week old chickens on a feed of 12 MJ metabolizable energy/kg had less than 80% of the fat content of chickens given a feed with 15MJ ME/kg, while at 8 weeks of age there was no difference in fat content between the groups whether fed 12 or 15 MJ ME/kg.

Interactions clearly exist between genotype and nutrition. Cherry et al. (1978) and Have and Scheele (1981) found that the influence of dietary factors on fat deposition was not the same for different commercial broiler strains. In particular the effect of the ratio between dietary energy and protein on fat deposition showed considerable strain differences.

Leclercq (1983) compared lines selected for a high and a low amount of abdominal fat relative to body weight on diets differing in protein content. The lean line had a lower body weight on low protein diets than the fat line, while on high protein diets body weight of the lines was the same. Differences in fat deposition were more pronounced on the diet lowest in protein (8.1% fat in the lean line and 16.9% for the fat line) than on the diet highest in protein (6.8% vs 11.7%). Plucinski et al. (1984) found in genetically obese mice, a more pronounced effect on fat deposition of dietary composition and frequency with which meals were offered, than in unselected control mice.

Ehinger and Seemann (1982) studied the importance of different factors and their interactions on fat deposition in a very interesting way. They used males and females of four commercial broiler strains, four diets differing in protein (19% and 24%) and energy (12.14 MJ and 14.23 MJ metabolizable energy per kg) and four slaughter ages (35, 41, 47 and 53 days). Among other characteristics the percentage of abdominal fat was measured. Age was responsible for about 7% of the total variation, dietary composition for 14%, strain for 4% and sex for 16%. Interactions had a significant effect on body weight and absolute amount of abdominal fat, but not on percentage of abdominal fat. Interactions were, however, never responsible for more than 2% of the total variation. This illustrates, that although interactions should be taken into consideration, their absolute effect is rather small.

CONCLUSIONS AND PROSPECTS

There is no doubt, that all involved in the broiler industry are concerned about fat deposition and know that by both nutritional and genetic means fat deposition can be reduced.

The main point in the discussion about fatness in broilers is not if the problem can be solved, but how it can be solved in an efficient way. The fact that there is still no method by which complete broiler flocks can be evaluated for carcass quality on a commercial scale, considerably delays a practical solution.

The feed intake of a broiler provides for maintenance, non-fat growth in which a physiologically required amount of fat is included, and fat growth.

Within the fat growth desired fat (for palatability and appearance of the broiler) and waste fat can be distinguished. The desired amount of fat and the variation in this from a consumer's point of view is not known. More knowledge about the optimal quantity of fat in the various broiler parts is required.

In the current situation of overfat broilers the deposition of waste fat, has to be minimized. This implies that the ratios between maintenance, non-fat growth and desired fat growth on the one hand and growth of waste fat on the other at a certain level of feed intake, have to change.

There is substantial information, that the ratio between non-fat growth and total fat growth is dependent on age, sex and genotype of the chicken, and level and composition of the diet. Environmental factors like temperature and housing design can also influence the ratio between non-fat and total fat growth, but their effect is too small to be of practical value. There are indications, that changes in the ratio between non-fat and total fat growth are mainly dependent on changes in the growth of waste fat.

Slaughter age alone is not a solution to the fat problem, but the difference between males and females in growth rate and fat deposition is worth considering. At greater ages, or at higher body weights, the increase of fat content in females exceeds by far that in males. Broilers can be divided roughly into two groups on the basis of their slaughter weights: heavy birds for cutting up purposes and lighter chickens for the production of whole carcasses. If broilers were sexed at hatching and reared separately, the females could be used for the production of whole birds and thus be slaughtered at relatively early ages. The males could be slaughtered at higher weights to produce broiler parts. If the sexes are reared separately, the effect of the interaction between sex and dietary composition on body composition could also be used.

Females reach maximum non-fat growth at lower dietary protein levels than males (Holsheimer, 1975). Using this interaction will not reduce fat deposition, but more likely feed costs. In this respect, knowledge about the overall effects of autosexing genes on broiler production is lacking.

Of all the factors affecting fat deposition in broilers it is the nutritional one that has been studied most intensively. In broiler production ad libitum feeding is standard. Restricted feeding reduces fat deposition, but increases, in general, the rearing period. It requires more feeding equipment and a lower housing density as all birds should be able to eat at the same time. Restricted feeding therefore causes higher production costs.

Dietary composition can have an influence on feed intake, and thus on the ratio between non-fat and fat growth. More interesting however, are the effects of dietary composition on the ratio between non-fat and fat growth independent of feed intake. It is possible to produce by dietary means broilers with a wide variation in fat content. Changes in fat deposition by dietary means can be realized almost immediately, but will only be applied if the generally increased feed costs are balanced by an increased value of the broiler carcass.

Selection can solve the fat problem in the longer term in an effective way. Indications that the ratio between non-fat and fat growth, and between desired fat and waste fat are heritable are clear enough. Less is known about the effects of selection against fat deposition on growth rate, feed conversion and yields in the longer term. To gather this information and more insight into selection methods to reduce fatness, further experiments are necessary. Lines differing in fat content, that can be obtained by selection experiments, are also useful in studying the effects of interactions between genotype and nutrition.

The direct costs of a selection program against fat deposition will be high, as all methods to measure fat deposition, directly or indirectly, are laborious. Selection against fatness can be used in a practical breeding program only as one of the last steps in a multi-stage selection program, since only a limited number of animals can be tested because of the labour involved. Selection intensity will thus be low, but due to the high heritability and the large variation in fatness, selection response can still be considerable.

Based on results of selection experiments and estimates of genetic correlations it can be expected that the correlated effects of selection against fatness are in general favourable. There will be no changes in body weight, while feed conversion and slaughter yields will improve.

Broiler sire strains offer the best possibilities for selection against fat deposition. In dam strains selection is on both growth rate and egg production. Selection against fat deposition could interfere with selection for egg production, as a certain amount of total and abdominal fat appears to be necessary for high egg production (Brody et al., 1984; Gyles et al., 1982).

Because of the high reproductive rate of poultry the costs per broiler of an extra selection criterion are low. Still selection against fatness can only be implemented in a commercial selection programme if there are adequate returns.

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CHAPTER 2

PHENOTYPIC AND GENETIC VARIATION IN, AND CORRELATIONS BETWEEN, ABDOMINAL FAT, BODY WEIGHT AND FEED CONVERSION.

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FAT DEPOSITION IN A BROILER SIRE STRAIN. I. Phenotypic and genetic variation in, and correlations between, abdominal fat, body weight and feed conversion.

ABSTRACT

Variability in body composition was examined weekly from 3 to 10 weeks of age in chickens from a broiler sire strain. Genetic aspects of body weight, quantity of abdominal fat, and feed conversion were examined in pedigree birds of the same strain at 6 weeks of age.

Variability in abdominal fat relative to body weight (RAF), total percentage of carcass fat, and body weight (BW) was not influenced by sex or age. The phenotypic correlation (r_p) between RAF and BW was generally positive, but low (between .20 and .68); that between RAF and total percentage of carcass fat was invariably positive and higher.

The heritability estimated from sib analyses for body weight after ad libitum feeding was 0 (h^2_{sires}) and 1 (h^2_{dams}), for RAF .41 (h^2_{sires}) and 1 (h^2_{dams}), for feed conversion .39 (h^2_{sires}) and .53 (h^2_{dams}) and for body weight after restricted feeding .31 (h^2_{sires}) and .57 (h^2_{dams}).

The genetic correlations were estimated as correlations between mean performance of progeny of each sire (r_{sires}) or dam (r_{dams}). The correlation between family mean of RAF and BW was -.01 (r_{sires}) or .04 (r_{dams}), between RAF and feed conversion .19 (r_{sires}) and .29 (r_{dams}), and between RAF and body weight after restricted feeding -.12(r_{sires}) and -.24 (r_{dams}).

The heritability indicates that selection against RAF is possible. The genetic correlations indicate that selection based on feed conversion or on body weight after restricted feeding could result in less fat deposition under ad libitum feeding conditions.

INTRODUCTION

One of the main problems in broiler production is excessive fat deposited in the abdominal cavity. This fat is clearly visible and gives an unappetizing appearance. When removed from the carcass, processing yield is reduced.

In broiler sire strains the main selection criterion is body weight at a fixed age after ad libitum feeding. This method increases feed intake and, indirectly, the fat content of the bird (McCarthy, 1977; Lilburn, 1981; McCarthy and Siegel, 1983). Several authors have reported differences between commercial broiler strains in total and abdominal fat content independent of body weight (Van Middelkoop et al., 1977; Griffith et al., 1978; Scheele et al., 1981). Also within strains, genetic variation in abdominal fat content exists. Estimates of the heritability of the amount of abdominal fat relative to body weight vary from .3 to more than 1 (Ricard and Rouvier, 1967; Becker et al., 1981, 1984; Leclercq et al., 1980).

To predict the efficiency and the consequences of selection against abdominal fat, information is needed on variation in abdominal fat content and on correlations between abdominal fat and other traits important in broiler production. A major difficulty is that the amount of abdominal fat cannot, as yet, be measured accurately on the live bird. Sib testing is effective (Leclercq et al, 1980), but laborious. Therefore characteristics correlated with fat deposition are of interest for selection purposes. Of these, feed conversion is important because of a favorable feed conversion in leaner birds (Pym and Solvyns, 1979; Washburn, 1980; Griffin and Whitehead, 1982).

Although genetic aspects of both abdominal fat and feed conversion are being studied intensively, additional research is needed, particularly with current broiler stock. The reason is that in broilers, which have a high growth rate, the physiological regulation of feed intake is different from the regulation in slower growing nonbroiler strains (McCarthy and Siegel, 1983).

In two experiments reported here, a broiler sire line comparable with commercial broiler sire material was used. The purpose of the first experiment was to investigate whether the coefficients of variation of, and the correlations between, abdominal fat, other body composition traits and body weight changed with age.

In the second experiment genetic aspects of body weight, amount of abdominal fat and feed conversion after ad libitum feeding, and body weight after restricted feeding were examined. In restricted feeding, appetite is less important and growth efficiency more so than in ad libitum feeding. Body weight after restricted feeding can be negatively correlated with the amount of abdominal fat under ad libitum feeding conditions (Whittemore, 1978; Sørensen 1980).

The results of the experiments have been used to study the possibilities and to predict the consequences of direct and indirect selection for less abdominal fat.

For further studies, the chickens of Experiment 2 were also used to select the first generation of an experiment in which the effects of sib selection against abdominal fat and individual selection for feed conversion and body weight after restricted feeding were compared. The results of these studies will be reported later.

MATERIAL AND METHODS

Chickens. For both experiments, chickens of the third generation of the Spelderholt White Cornish, a line comparable to commercial broiler sire strains, were used. The Spelderholt White Cornish line was obtained by two generations of crossing between three commercial broiler sire strains. The line was further selected for two generations for 6-week body weight under ad libitum feeding. All chickens were sexed and wingbanded at hatching. In both experiments the chickens recieved a pelleted broiler diet with 13.4 MJ metabolizable energy and 21.5% crude protein.

Experiment 1. One thousand chickens, from 50 families, each consisting of one sire mated to four dams, were hatched. The chickens were reared in one pen under continuous light and fed ad libitum. At 14 days of age the birds were individually weighed. In each sex the chickens with the highest and lowest body weights were discarded until 400 remained. These were divided into 20 body weight classes. Each week from 20 to 69 days of age, 20 birds per sex, one from each body weight class, were taken at random, weighed and killed by CO_2 suffocation. For each chicken the amount of abdominal fat, including that surrounding gizzard and proventriculus, was determined (Leenstra, 1983). The whole birds were then ground and analyzed individually for water, fat and protein content according to a procedure described by Scheele and Janssen (1971). Body composition data were expressed as percentages of live body weight.

Experiment 2. For the estimation of genetic parameters 50 families of one sire and two to four dams each provided, in six hatches, fully pedigreed chickens. The properties, that were measured were divided into three groups (Table 1).

Table 1. Traits measured on an individual basis in the abdominal fat (AF) group (group housing on litter, ad libitum feeding), the feed conversion (FC) group (individual housing in cages from 21 tot 42 days of age, ad libitum feeding) and the growth restricted (GR) group (group housing on litter, restricted feed).

Trait	AF group Hatches 1 and 2	FC group Hatches 3 and 4	GR group Hatches 5 and 6
Body weight at 21 days		+	
Body weight at 42 days		+	+
Body weight at 46,47 days	+		
Feed consumption 21-42 days		+	
Feed conversion 21-42 days		+	
Abdominal fat	+		

The abdominal fat (AF) group consisted of two hatches of about 500 chickens each. Each hatch was reared on litter with continuous light and fed ad libitum. At 41 days of age males and females were separated by a wire mesh fence. At 46 and 47 days of age, females and males, respectively, were fasted for 12 hours, weighed, and slaughtered. After bleeding and plucking the chickens were chilled in an air tunnel for 30 minutes at -10°C and stored at 0°C. Each bird was eviscerated by hand on the day of slaughter. Abdominal fat and the fat surrounding gizzard and proventriculus was removed and weighed (Leenstra et al., 1981).

The live weight of the females of Hatch 2, because of a failure in the electronic weighing equipment, averaged about 10% too low. Because the exact error could not be determined, it was decided to delete these data and not include them in the statistical analyses.

The feed conversion (FC) group consisted of two hatches of about 500 chickens each. Until 21 days of age, the birds were reared on litter. At 21 days of age, 144 males and 144 females from each hatch (chosen at random, but approximately equal numbers per half sib family) were weighed and transferred to individual battery cages with individual feeders (Leenstra et al., 1982). The chickens were fed ad libitum and received 14 hr light and 10 hr darkness alternating. Individual 21- and 42-day live weights were obtained after the birds were fasted for about 12 hours. From 21 to 42 days of age weight gain and feed consumption were measured.

The growth restricted (GR) group consisted of one hatch of about 350 chickens and one of about 700 chickens, maintained in sex-separated flocks. Rearing was on litter with a 14-hr light and 10-hr darkness regimen. The chickens were fed restricted from 4 days of age onwards. They received about 70% of the ad libitum intake of chickens of the same strain, sex and age. A weighed amount of feed was provided daily. Feeder space was sufficient to allow all chickens to eat simultaneously. Throughout the whole rearing period the chickens needed about 4 hr to consume the daily feed allowance. Until 42 days of age, the males received 2350 g, and the females 2150 g/bird. At 42 days of age the chickens were weighed before being fed.

Data analysis in Experiment 1. Means and coefficients of variation of each variable were calculated for each sex and age group. Variation coefficients were used to compare the variability of the traits examined. Simple product-moment correlations were calculated between body weight and abdominal fat as a percentage of body weight, between body weight and total percentage of fat and between percentage of abdominal fat and total fat percentage for each sex and age group.

Data analysis in Experiment 2. Analyses of variance and covariance were carried out on the data collected in Experiment 2, using the Harvey LSML76 program (Harvey, 1977). The models initially used are given in Table 2. Sire and dam within sire effects were considered random and sex and hatch effects fixed. Because of the unbalanced data, Satterthwaite's (1946) procedure was used to test the sire effect. Phenotypic and genetic correlations between traits measured on the same bird were calculated from variance and covariance components.

The presence or absence of a genetic correlation between body weight, feed conversion and relative amount of abdominal fat measured on different birds in different environments was also examined. This was done by calculating product-moment correlations between the mean performance of progeny from each dam (dam family mean, full sibs) or the mean performance of progeny from each sire (sire family mean, a mixture of full and half sibs). The family means were based on data adjusted for sex and hatch effects and for heterogenity of variance.

Table 2. Main effects, interactions and covariates included in the models initially used for analyses of variance (see Table 1 for abbreviations).

	AF group			FC group			GR group
	Body weight	Abd. fat (g)	Abd. fat (%)	Body weight (42 d)	Weight gain	Feed conversion	Body weight
Sires	+	+	+	+	+	+	+
Dams within sire	+	+	+	+	+	+	+
Sex	+	+	+	+	+	+	+
Hatch	+	+	+	+	+	+	+
Sex x Hatch				+	+	+	+
b_1 x (body weight)		+					
b_2 x (body weight)^2		+					

The data on live weight and feed conversion by sex and hatch were, therefore, expressed as deviations from the mean of the sex and hatch combination. Regression equations were derived with abdominal fat as dependent and body weight and the square of body weight as independent variate. The residuals of these regression equations were used for further calculations. The deviations and the residuals were expressed in units of standard deviation of their own sex and hatch combination. These values were obtained from birds in different environments and at different times. The eventual influence of an environmental correlation between family means was therefore neglected.

RESULTS

Experiment 1. Figures 1 and 2 show the conventional picture of males growing faster, but changing less in body composition with age than females. For females the increase in both percentage of abdominal fat and total percentage of fat was large. Ten-week-old females had more than twice the relative amount of abdominal fat and nearly twice as much in total fat percentage as 3-week-old females.

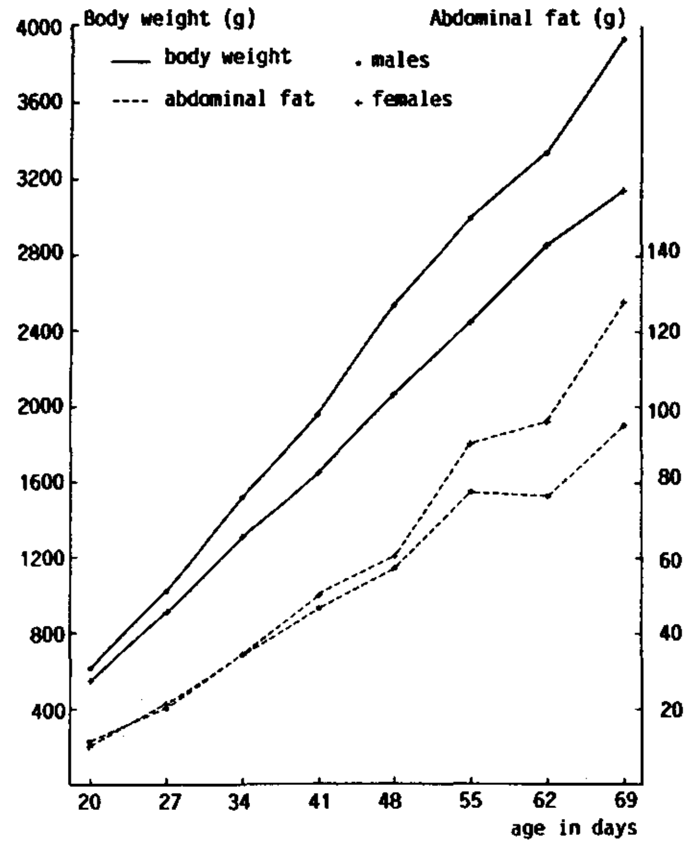

Fig. 1. Body weight and amount of abdominal fat of male and female chickens between 20 and 69 days of age.

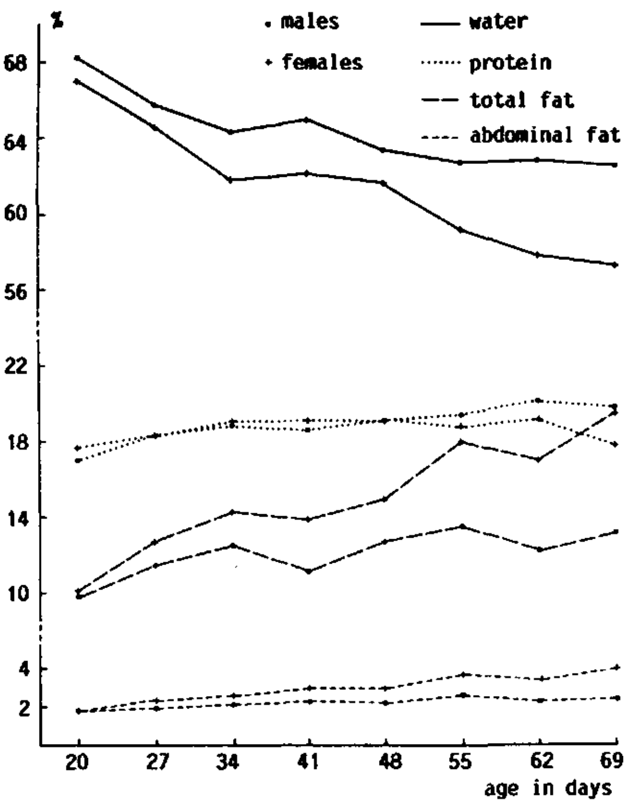

Fig. 2. Body composition data of male and female chickens between 20 and 69 days of age.

For selection purposes variation is more interesting than the absolute level of any characteristic. The coefficients of variation of the various traits for males and females are plotted against age in Figure 3. The coefficients of variation for males and females were similar. Neither did age influence the coefficients of variation to any considerable extent. Within sex and age groups abdominal fat as a percentage of body weight was highly variable, as variation coefficients of 17 to 36% indicate. Variability in body weight and total percentage of fat was less, while protein percentages showed the lowest coefficient of variation.

The correlation coefficients between body weight and percentage of abdominal fat, between body weight and total percentage of fat, and between percentage of abdominal fat and total percentage of fat are given in Table 3.

Table 3. Correlation coefficients for sex and age group between body weight and percentage of abdominal fat, body weight and total percentage of fat and total percentage of fat and percentage of abdominal fat[1] (Experiment 1).

	Body weight and % abdominal fat		Body weight and % total fat		% total fat and % abdominal fat	
Age	Males	Females	Males	Females	Males	Females
(days)						
20	.40	.30	.52*	.18	.74**	.61**
27	- .15	- .20	.34	- .08	.68**	.69**
34	.68**	.43	.55*	.41	.85**	.77**
41	.59**	.07	.38	.30	.65**	.82**
48	.06	.05	- .06	.18	.80**	.75**
55	.48*	.44	.41	.61**	.88**	.83**
62	.27	.16	.30	.43	.80**	.83**
69	.32	.64**	.35	.57**	.91**	.94**

1) 20 birds/group. *: $P<.05$. **: $P<.01$.

Correlations between body weight and percentage of abdominal fat or total fat were positive within an age group, but in most cases not significantly different from zero. Correlations of total percentage of fat and percentage

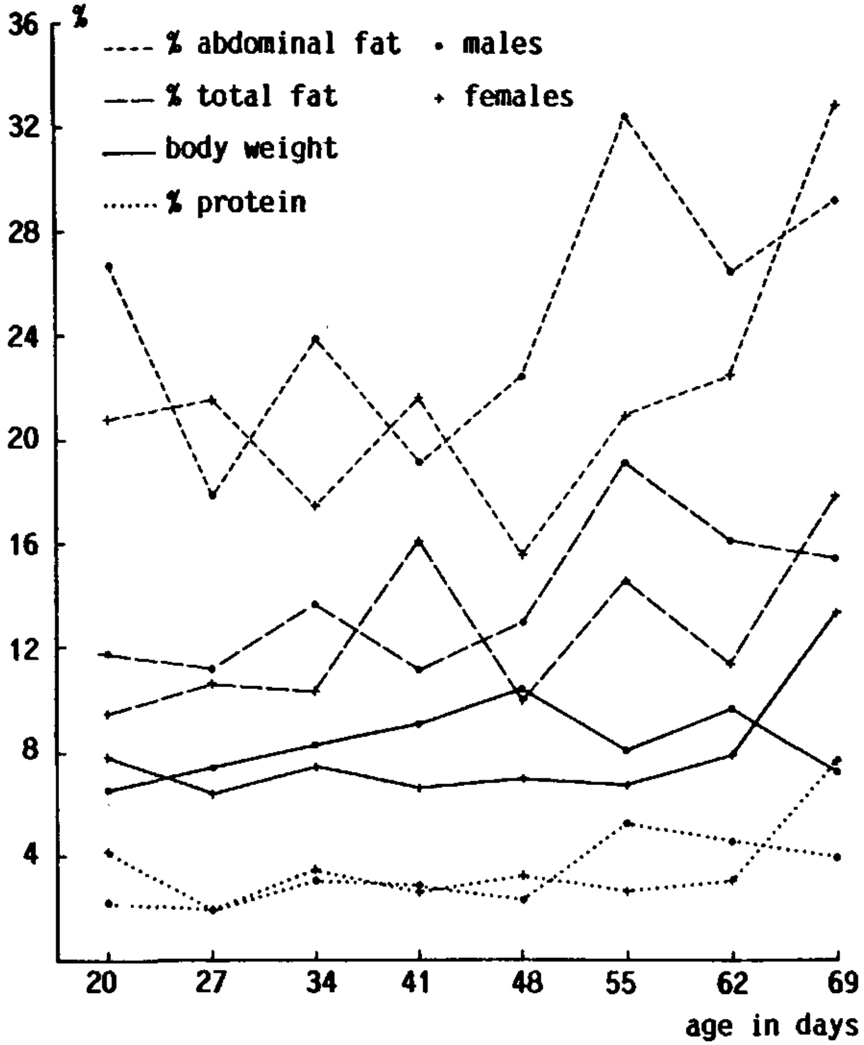

Fig. 3. Coefficients of variation of body weight and percent of abdominal fat, total fat, and protein of male and female chickens between 20 and 69 days of age.

of abdominal fat were significant and positive. This high correlation is probably partly due to abdominal fat being an important part of the total body fat content.

Experiment 2. Means and standard deviations of the properties measured in Experiment 2 are given in Table 4 by sex and hatch. As in Experiment 1, abdominal fat had relatively more variation than body weight. Feed conversion had, compared with body weight, a very low coefficient of variation.

Table 4. Mean and standard deviation of the traits measured in Experiment 2 for sex and hatch.

	Males		Females	
AF[1])group				
Body weight (males 47 days	Hatch 1		Hatch 2	
and females 46 days)	2229±193	2409±191	1893±168	...[2])
Abdominal fat (g)	46±15	58±15	48±13	...[2])
Abdominal fat (%)	2.0±.6	2.4±.6	2.6±.7	...[2])
FC[1])group	Hatch 3		Hatch 4	
Body weight (42 d)	1852±142	1943±148	1572±125	1609±116
Weight gain (21 to 42 d)	1316±113	1333±125	1086± 96	1066±116
Feed consumption(21 to 42 d)	2555±207	2555±217	2227±227	2214±182
Feed conversion(21 to 42 d)	1.94±.09	1.92±.11	2.05±.15	2.08±.10
GR[1])group	Hatch 5		Hatch 6	
Body weight (42 d)	1456±132	1430±144	1311±113	1261±121

1) AF = Abdominal fat; FC = Feed conversion; GR = Growth restricted.

2) Omitted because of a failure in the body weight data.

The results of the analyses of variance with the final models are given in Table 5. The regression coefficients of abdominal fat on body weight were significant for both sexes and hatches. Body weight squared proved not to have a significant effect on abdominal fat. The quadratic term was dropped from the model. Because the interaction between sex and hatch was not

Table 5. Analysis of variance with the final models[1)].

Source of variation	AF[2)] group						FC[3)] group					GR[4)] group	
	d.f.	Body weight	Abdominal fat(g)	Abdominal fat(%)	d.f.	Abdominal fat (g)	d.f.	Body weight	Gain 21-42 d.	Feed consumption	Feed conversion	d.f.	Body weight
Sires	49	80	97	195*	49	895°	51	32	22	72	33*	46	73*
Dams within sires	48	75**	53**	100**	48	418**	76	33**	16**	66**	17**	87	37**
Sex	1	18348**	44	3543**	1	15633**	1	11614**	7542**	3860**	2140**	1	4860**
Hatch	1	3621**	1751**	1538**	1	3488**	1	437**	1	11	0	1	215**
Sex x Hatch												1	23**
Body weight					1	24902**							
Remainder	693	28	13	21	692	91	444	14	9	36	10	928	12

1) df = Degrees of freedom, k_1 and k_2 = the coefficients of the dam component of variance in the mean squares for dams and sires, k_3 = the coefficient of the sire component in the mean square for sires.

2) AF = abdominal fat; $k_1 = 6.6$, $k_2 = 9.5$, $k_3 = 15.8$.

3) FC = Feed conversion; $k_1 = 3.9$, $k_2 = 5.3$, $k_3 = 11.0$.

4) GR = Growth restricted; $k_1 = 7.1$, $k_2 = 9.3$, $k_3 = 22.5$.

° $P<.1$

* $P<.05$

** $P<.01$

significant for the traits in the FC group this term also was dropped from the model.

The influence of the sires on body weight in the AF and FC groups (ad libitum feeding) was not significant nor was their influence on the absolute amount of abdominal fat (AF group) or feed consumption (FC group). This applied whether the chickens were reared on litter or in cages. However, in the amount of abdominal fat relative to body weight, feed conversion and body weight after restricted feeding, the influence of the sires was significant. The effect of the dam was highly significant in all the characteristics examined.

Table 6 shows the heritabilities estimated from the sire and the dam component of variance. The estimates based on the sire component of variance varied from 0 for body weight after ad libitum feeding, to moderately high for abdominal fat relative to body weight, feed conversion and body weight after restricted feeding. The estimates of the heritability from the dam component of variance were high, especially for the abdominal fat traits and to a lesser extent for body weight.

Table 6. Estimates of the heritabilities and the standard errors (between brackets) based on the sire component of variance (h^2_s) and on the dam component of variance (h^2_d).

	Trait	h^2_s	h^2_d
AF[1] group	Body weight	< 0	.83 (.15)
	Abdominal fat (g)	.31 (.11)	> 1
	Abdominal fat (%)	.41 (.12)	> 1
	Abdominal fat[2]	.52 (.14)	> 1
FC[1] group	Body weight	< 0	> 1
	Gain 21-42 days	.10 (.10)	.67 (.17)
	Feed consumption	< 0	.72 (.17)
	Feed conversion	.39 (.15)	.53 (.16)
GR[1] group	Body weight	.31 (.10)	.57 (.08)

1) AF = Abdominal fat; FC = Feed conversion; GR = Growth restricted.

2) Abdominal fat (g) corrected for body weight by linear regression on body weight.

Phenotypic correlations and genetic correlations estimated from the dam component in the analyses of covariance are given in Table 7. Because of negative estimates of the sire component of variance for body weight, genetic correlations between body weight and the other traits could not be calculated on a paternal half sib basis.

Table 7. Estimates of the phenotypic (r_p) and the genetic correlations based on the dam component of covariance ($r_{g\ dam}$) between the traits of the AF and the FC group. The estimates of the standard errors of the genetic correlations are given in brackets.

	Traits	r_p	$r_{g\ dam}$
AF[1] group	Body weight - abdominal fat (g)	.46	.45(.17)
	Body weight - abdominal fat (%)	.18	.21(.20)
FC[1] group	Body weight - gain 21-42 days	.93	.99(.02)
	Body weight - feed consumption	.79	.85(.07)
	Body weight - feed conversion	- .25	- .23(.26)
	Gain 21-42 days - feed consumption	.79	.85(.08)
	Gain 21-42 days - feed conversion	- .36	- .26(.32)
	Feed consumption - feed conversion	.29	.30(.25)

1) AF = Abdominal fat; FC = Feed conversion.

The estimates of the genetic correlations based on correlation coefficients between family means of the standardized residuals of the traits are given in Table 8. The amount of abdominal fat regressed on body weight was not significantly correlated with body weight after ad libitum feeding, if the family means were considered. The regression coefficient was positively correlated with feed conversion, indicating a more favourable feed conversion for the leaner bird. Although the correlation between body weight after restricted feeding and amount of abdominal fat after regression on body weight was weak, both the correlation based on dam and on sire family means were negative. This suggests that families with a high body weight after restricted feeding, had a low amount of abdominal fat after ad libitum feeding.

Table 8. Estimates of the correlation coefficient between dam family means (70-120 families) (upper triangle) and 48-50 sire family means (lower triangle).

	Trait		1	2	3	4	5
AF[1] group	Body weight	1		.04	.35	- .10	.34
	Abdominal fat[2]	2	- .01		- .22	.29	- .24
FC[1] group	Body weight	3	.09	.04		- .25	.42
	Feed conversion	4	- .04	.19	- .29		- .07
GR[1] group	Body weight	5	.15	- .12	.24	.17	

1) AF = Abdominal fat; FC = Feed conversion; GR = Growth restricted.

2) Abdominal fat (g) corrected for body weight by linear regression on body weight.

DISCUSSION

The large variation in the relative amount of abdominal fat, combined with a heritability estimated from the sire component of variance of about .4, offers favorable prospects for selection against abdominal fat.

Coefficients of variation of 20 to 30% for the amount of abdominal fat, both absolute and relative to body weight, were found in nearly all cases in which variability in amount of abdominal fat was examined (Becker et al., 1984; Leenstra, 1984).

As the coefficients of variation of abdominal fat content, as well as the correlations between abdominal fat content and body weight and between abdominal fat content and total fat content, were scarcely influenced by the age of the chicken, the normal broiler slaughter age is the most appropriate age for selection against fatness. The difference in variability between abdominal fat content (coefficient of variation more than 20%) and total fat content (coefficient of variation around 10%), indicates that considerable changes in abdominal fat content are possible without large changes in fat content in other parts of the broiler. The positive correlation coefficient between percentage of abdominal fat and total fat indicates that the total fat percentage will decrease if the amount of abdominal fat decreases. However, Ricard et al. (1983) found no differences in tenderness, juiciness, or flavour between chickens of lines selected for a low or a high abdominal fat content. The danger that, with selection against percentage of abdominal fat, broiler meat will become too lean for consumers preference is thus small.

The estimate of .41 to .52 for the heritability of the relative amount of abdominal fat in this study, agrees well with estimates of Becker et al. (1984), Ricard (1975), Leclercq et al. (1980) and Griffin and Whitehead (1982).

The absence of a significant sire effect on body weight and feed consumption after ad libitum feeding is noteworthy. In the parental stock the dams were selected less intensively than the sires for body weight. This is the normal situation in broiler parent stock but could have caused a relatively low variance between sires and a relatively high variance between dams for body weight under ad libitum feeding conditions compared to the situation where variance components are estimated from data on progeny of parents that were not selected.

Analysis by sex showed the same results. In the AF-group was the h^2_{sire}, estimated from the data on males only, also below zero. The h^2_{dam} was .97, slightly higher than that estimated from the data on both sexes (.83). As another explanation for the difference between the sire and dam component of variance, a large influence of maternal or dominance effects remains. It is most likely that maternal effects are present (McCarthy and Siegel, 1983), although the absence of additive genetic variance in our line cannot be excluded.

The estimated heritability of body weight after restricted feeding is high compared with that for body weight after ad libitum feeding. Abdou and Kolstad (1980) and Sørensen (1977) found more additive genetic variation in weight in an environment with limited feed resources than in an environment in which feed supply was not limited.

Body weight of chickens fed ad libitum is largely a function of feed intake (McCarthy and Siegel, 1983), whereas in circumstances where feed is restricted, it depends more on the efficiency of feed conversion. As broiler sire strains have been selected for more than thirty generations on body weight after ad libitum feeding, genetic variation in appetite could have disappeared in our material. This is supported by the absence of a significant sire component of variance in feed consumption in the FC group.

Although live weight gain and feed consumption from 21 to 42 days of age in the FC group were not significantly influenced by a sire effect, their ratio, feed conversion, was. The heritabilities of .39 (sire component estimate) and .53 (dam component estimate) found in this study, agree well with the values of about .4 found by Pym and Nicholls (1979). How the absence of a significant sire component of variance for body weight gain and feed consumption from 21 to 42 days can be consistent with a significant sire component of variance for feed conversion, will be a subject for further investigation.

The phenotypic correlation between body weight and relative amount of abdominal fat tends to be positive. The genetic correlation between the relative amount of abdominal fat and body weight is close to 0 (Table 7, Leclercq et al., 1980; Griffin et al., 1982). Selection against excessive fat deposition should thus be possible without large losses in growth rate. The estimated genetic correlations between feed conversion and relative amount of abdominal fat are positive (.19 if based on sire family means and .29 if based on dam family means). This confirms the results of Pym and Solvyns (1979), Washburn (1980) and Chambers et al. (1983), that selection on feed conversion is in favour of the leaner bird.

Body weight after restricted feeding and relative amount of abdominal fat after ad libitum feeding tend to a negative correlation (-.12 if based on sire families and -.24 if based on dam families). Whittemore (1978) and Sørensen (1980) found a negative genetic correlation between body weight in an environment in which feed was a limiting factor and fat deposition under ad libitum feeding conditions.

In spite of the weak correlations between feed conversion and body weight after restricted feeding on the one hand and fat deposition on the other, both traits are interesting enough to justify further examination of their suitability for selection of broiler sire material.

Feed conversion itself is an important trait in broiler production, while body weight after restricted feeding has the advantage, that it can be measured easily on large numbers of chickens.

To examine the traits relative amount of abdominal fat, feed conversion and body weight after restricted feeding as selection criteria for broiler sires, all three are compared simultaneously in an experiment with selection for body weight after ad libitum feeding.

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CHAPTER 3

COMPARISONS AMONG LINES SELECTED FOR LESS ABDOMINAL FAT, LOWER FEED CONVERSION RATIO, AND HIGHER BODY WEIGHT AFTER RESTRICTED AND AD LIBITUM FEEDING.

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FAT DEPOSITION IN A BROILER SIRE STRAIN. II. Comparisons among lines selected for less abdominal fat, lower feed conversion ratio, and higher body weight after restricted and ad libitum feeding.

ABSTRACT

Four lines were selected from a broiler sire strain. Selection criteria were sib selection for a low amount of abdominal fat relative to body weight (AF line), individual selection for feed conversion (feed consumed/weight-gain) from 21 to 42 days of age (FC line), individual selection for body weight after restricted feeding (GR line), and individual selection for body weight after ad libitum feeding (GL line).
In the fifth generation lines were compared at 6 weeks of age for body weight, percent abdominal fat, feed conversion, slaughter yield, and chemical composition. Rankings of lines reared in groups on litter and in individual cages were the same for all traits examined. Lines GR and GL hardly differed, whereas lines AF and FC, compared with line GL, had respectively, significantly lower body weights (-293g and -228g), less abdominal fat (-1.45% and -1.00%), better feed conversions (-.11 and -.17), and higher slaughter yields (+.50% and +.70%).
Selection for body weight after restricted feeding was not effective in reducing fat deposition. When compared at the same age with the line selected for body weight after ad libitum feeding, sib selection against abdominal fat and selection for a better feed conversion reduced abdominal fat, improved feed conversion and increased slaughter yields.

INTRODUCTION

In the long term, selection may be the best solution to the problem of excessive abdominal fat deposition in broilers (Leclercq et al., 1980, Griffin and Whitehead, 1982, Leenstra, 1986). Selection for lower fat deposition is generally accompanied by improved feed conversion and slaughter yield. At fixed ages the genetic correlation between body weight and amount of abdominal fat relative to body weight appears to be close to zero (Leenstra, 1986; Cahaner et al.,1986). Although the effects on feed conversion and slaughter yield of selection against fat deposition can be expected to be positive, selection against fatness has not yet been applied on a large scale in commercial broiler breeding programs.
The main problem in selecting against fatness is that abdominal fat can not

be measured accurately in live chickens. Traits significantly correlated with fat deposition that can be measured in a live chicken are feed conversion ratio and triglyceride content of blood plasma (Whitehead and Griffin, 1984). However, measurement of both characteristics is laborious and individual selection for feed conversion requires individual cages (Pym and James, 1979). Eitan et al. (1982) and Leenstra et al. (1986) found negative genetic correlations between body weight gain with restricted feeding and amount of abdominal fat deposited with ad libitum feeding. Eitan et al. (1982) used individual housing, while Leenstra et al. (1986) housed the chickens in groups. Selection for body weight among group housed chickens, which are fed restricted, can be applied easily to large numbers of chickens. It is therefore worthwhile to test whether selection for body weight after restricted feeding can be used to select leaner chickens.

In a commercial broiler breeding program, selection against fatness will probably be carried out in the sire strains. This is because there is a greater opportunity for an extra selection criterion in sire strains than in dam strains, since they are more intensively selected for egg production. A substantial part of the information available on the effects of direct and indirect selection against fat deposition is, however, from chickens with growth rates lower than that of current broilers.

In this paper the results of four generations of sib selection against abdominal fat are compared with individual selection for feed conversion, for body weight after restricted feeding and for body weight after ad libitum feeding in a broiler sire strain.

MATERIAL AND METHODS

Selected lines. The Spelderholt White Cornish strain was used as a foundation stock. It descends from and is similar to commercial broiler sire material (Leenstra et al., 1986). We developed four lines.

The abdominal fat (AF) line was selected for a low amount of abdominal fat relative to body weight. The AF line chickens were housed on litter and fed ad libitum. Abdominal fat was weighed in grams at about 6 weeks of age in slaughtered chickens (Leenstra et al., 1981) and for each hatch it was regressed on body weight and body weight squared for males and females separately. For each chicken the residual of this regression equation was expressed in units of standard deviation of the residual. Full sib families were selected on a low standardized residual averaged over sexes and hatches. An average of ten, but at least three, chickens were tested from each family. A maximum of four sons and six daughters per full sib family was used for breeding.

The feed conversion (FC) line was selected individually for a low feed conversion ratio (feed consumption/body weight-gain) from 21 to 42 days of age. Chickens were reared on litter until 21 days of age, when they were housed in individual cages with individual feeders (Leenstra et al., 1982). During the period from 21 to 42 days, ad libitum feed consumption and body weight gain were measured. Numbers of chickens tested from each full sib family were about equal.

The body weight after restricted feeding (GR) line was individually selected for a high 6-week body weight after restricted feeding. Restricted feed intake was about 70% of the ad libitum intake of chickens of the same sex and age from 4 days of age onward. Chickens were housed by sex on litter.

The body weight after ad libitum feeding (GL) line was individually selected for body weight at 6 weeks of age after ad libitum feeding. The chickens were housed on litter.

The first generation of all four lines was derived from the same 50 sires and 200 dams. Dams were divided at random into two groups of 100 hens. Each sire was mated to two hens from each group. The AF and FC lines descended from one group of hens and the GL line from the other. Line GR, which had to be hatched for practical reasons at the end of the reproductive period, was obtained from both groups of hens. For subsequent generations 25 to 50 sires and 100 dams by line were used as breeders. As selection methods and environments differed considerably, no attempt was made to keep selection intensity at the same level for the four lines. Table 1 shows the number of families (AF line) or chickens (FC, GR and GL line) tested and selected by generation. Percentage of families (AF line) or chickens (FC, GR and GL line) selected and selection differentials are shown in Table 2.

Comparison of lines. In the fifth generation, chickens from each line were tested in two environments. The first was group housing on litter

Table 1: Number of full sib families (AF line) or chickens (FC, GR and GL lines) tested and selected by generation[1].

Line	Sex	Generation 1 Tested	Generation 1 Selected	Generation 2 Tested	Generation 2 Selected	Generation 3 Tested	Generation 3 Selected	Generation 4 Tested	Generation 4 Selected
AF	♂	98	17	95	10	98	13	100	8
	♀	98	30	95	21	98	24	100	25
FC	♂	288	25	288	25	288	25	288	25
	♀	288	100	288	100	288	100	288	100
GR	♂	555	25	354	25	190	25	655	25
	♀	562	100	358	100	195	70	671	100
GL	♂	467	50	467	50	373	50	468	25
	♀	465	100	458	100	354	100	470	100

Table 2: Percentage of the flock selected and selection differentials for body weight, percent abdominal fat and feed conversion by line in Generations 1 to 4[1].

Line	Generation 1 ♂	Generation 1 ♀	Generation 2 ♂	Generation 2 ♀	Generation 3 ♂	Generation 3 ♀	Generation 4 ♂	Generation 4 ♀
	% selected							
AF	26	41	20	42	15	29	10	29
FC	16	43	15	42	18	42	14	42
GR	10	22	10	34	15	38	6	18
GL	27	26	19	29	21	47	9	33
	Selection differential							
	Body weight(g)							
AF	- 11	+ 9	+ 2	+ 19	+ 16	+ 17	- 8	- 18
FC	+ 42	+ 14	- 14	+ 11	+ 6	+ 15	+ 3	- 6
GR	+238	+151	+256	+105	+224	+141	+256	+150
GL	+204	+146	+255	+135	+210	+103	+282	+135
	Percent abdominal fat							
AF	-.48	-.31	-.45	-.31	-.40	-.32	-.33	-.22
	Feed conversion							
FC	-.09	-.09	-.11	-.09	-.11	-.08	-.10	-.05

[1]Lines are: AF:sib selection against abdominal fat, ad libitum feeding; FC: individual selection for feed conversion, ad libitum feeding; GR: individual selection for body weight, restricted feeding; GL: individual selection for body weight, ad libitum feeding.

(designated as litter housing). This was the selection environment of Lines AF, GR and GL. The second environment was group housing on litter followed by individual housing in cages (designated as cage housing). This was the selection environment of Line FC. Chicks from three hatches were sexed, wingbanded and started in both environments. Chickens were fed, ad libitum, a pelleted broiler diet containing 13.4 MJ metabolizable energy per kilogram and 21.5% crude protein. To reduce leg disorders a system of 1 hr of light alternating with 3 hr of darkness was used (Simons, 1982). At 7 days of age the chickens were vaccinated against Newcastle disease.
Chickens in litter housing were reared in three groups of eight 12 m^2 pens (2 pens per line per hatch) located along both sides of a corridor. Within hatches each line was randomly assigned a pen on the left and one on the right side of the corridor. There were 75 males and 75 females started in each pen. Chickens in individual cage housing were reared in one pen with lines intermingled until 21 days of age when 36 chickens per sex, line, and hatch were taken at random and transferred to individual cages with individual feeders. A total of 288 cages was arranged in eight rows of 36 each. Nine chickens of each of the lines (4 or 5 per sex) were placed at random in each row.
Measurements. Traits that were measured are summarized in Table 3. Litter-housed chickens were weighed at 22 and 41 days of age, while on full feed. At 41 days of age 10 chickens were selected from each hatch, sex, and line and killed with CO_2 after being fasted for about 5 hours. Birds were analyzed as a group for water and fat content of the whole bird - feathers, intestines and gastrointestinal contents included (Scheele and Janssen, 1971).
For the determination of abdominal fat, chickens were fasted for 12 hr, weighed, and slaughtered. Abdominal fat, including that surrounding the gizzard and proventriculus, was removed and weighed. The empty carcass, without neck, neck-skin and abdominal fat (griller), was also weighed. Retail cut distribution was determined as described by Uijttenboogaart and Gerrits (1982). Cage housed chickens were weighed at 21 and 42 days of age after a period of 12 hr without feed.
Slaughter data and those of the chemical analysis of whole chicken were expressed as percentages of live body weight. Data on fat and water content

Table 3: Traits measured on litter-housed chickens and on chickens housed in individual cages.

	LITTER			CAGES		
Trait	Age(days)	Measured by	n. sex	Age(days)	Measured by	n. sex
Body weight	22	Pen	900	21	Individual	108 ♂,108 ♀
	41	Individual	900	42	Individual	108 ♂,108 ♀
	43(♂),44(♀)	Individual	300 ♂,300 ♀			
Feed consumption	0 to 22	Pen	900	21 to 42	Individual	108 ♂,108 ♀
	0 to 41	Pen	900			
Mortality	0 to 41	Sex, Hatch	450 ♂,450 ♀			
Abdominal fat	43(♂),44(♀)	Individual	300 ♂,300 ♀	42	Individual	108 ♂,108 ♀
Griller weight	43(♂),44(♀)	Individual	300 ♂,300 ♀	42	Individual	108 ♂,108 ♀
Retail cuts distribution	43(♂),44(♀)	Individual	30 ♂, 30 ♀			
Water and fat content:						
whole bird	41	Sex, Hatch	30 ♂, 30 ♀			
griller	43(♂),44(♀)	Sex, Hatch	15 ♂, 15 ♀			
breast meat	43(♂),44(♀)	Sex, Hatch	15 ♂, 15 ♀			
thigh meat	43(♂),44(♀)	Sex, Hatch	15 ♂, 15 ♀			

of griller, breast and thigh meat were expressed as a percentage of wet weight.

Statistical analysis. All data except those for mortality were subjected to analysis of variance by the Genstat program (Genstat Manual, 1977). For body weight, abdominal fat, and griller weight of the litter-housed chickens means by pen and sex were analyzed using the model:

$$y_{ijkl}=U+h_i+C_j+hC_{ij}+L_k+hL_{ik}+CL_{jk}+hCL_{ijk}+S_l+hS_{il}+CS_{jl}+LS_{kl}+e \quad [1].$$

In this model U represents the general mean, h_i the random hatch effect (i=1,2,3), C_j the fixed effect of corridor side (j=1,2), L_k the fixed line effect (k=1,2,3,4), and S_l the fixed sex effect (l=1,2). CL_{jk}, CS_{jl} and LS_{kl} are the fixed interactions between corridor side, line and sex and hC_{ij}, hL_{ik}, hS_{il}, and hCL_{ijk} are the interactions between the random effect of hatch and the fixed effects of corridor side, line and sex. The term e_{ijkl} contains all remaining interactions.

Feed conversion of litter-housed chickens was analyzed by pen with the model:

$$y_{ijk}=U+h_i+C_j+hC_{ij}+L_k+hL_{ik}+CL_{jk}+hCL_{ijk} \quad [2]$$

Symbols have the same meaning as in model 1.

Chemical composition and retail cuts distribution data means by hatch, line, and sex were analyzed using the model:

$$y_{ikl}=U+h_i+L_k+hL_{ik}+S_l+hS_{il}+LS_{kl}+hLS_{ikl} \quad [3]$$

Symbols have the same meaning as in model 1

Cage-housed chickens data means by line, sex, and row of cages were analyzed with the model:

$$y_{ijkl}=U+h_i+C_j+hC_{ij}+L_k+S_l+hL_{ik}+hS_{il}+CL_{jk}+CS_{jl}+LS_{kl}+e \quad [4]$$

Symbols have the same meaning as in the preceding models, except that C_j now represents the effect of row of cages (j=1,..,8).

Mortality data were analyzed by χ^2-statistics.

Effects with $P < .05$ were considered significant.

RESULTS

All data are presented as the average for hatches and pens of the litter-housed chickens or hatches and rows of the cage-housed chickens. Significant effects of these factors and of their interactions with line and sex

were present for several traits. Because the ranking of the lines was not influenced by interactions with hatch or location of the pen or row of cages, and because the effects of hatch and location are specific to the experiment reported here, they will not be discussed.
Table 4 summarizes body weight, percentage of abdominal fat, and percentage of griller weight for the litter-housed chickens. Differences between the lines in body weight at 41 days of age were equal to those at 43 and 44 days of age. Therefore data for only the latter ages are presented.

Table 4: Means and standard errors of difference for body weight, percent abdominal fat and percent griller weight for litter-housed chickens at 43(♂) or 44(♀) days of age; standard errors of difference are calculated from analyses of variance according to Model 1.

Line[1)]	Body weight(g) ♂	Body weight(g) ♀	Abdominal fat(%) ♂	Abdominal fat(%) ♀	Griller weight(%) ♂	Griller weight(%) ♀
AF	1887	1676	1.04	1.42	64.06	64.05
FC	1967	1730	1.47	1.90	64.43	64.08
GR	2113	1895	2.25	3.09	64.35	64.05
GL	2193	1956	2.28	3.12	63.64	63.40
	Standard error of difference of two means for					
Line	10.4		.025		.084	
Line x sex	16.7		.033		.145	

[1)]Lines are: AF:sib selection against abdominal fat, ad libitum feeding; FC: individual selection for feed conversion, ad libitum feeding; GR: individual selection for body weight, restricted feeding; GL: individual selection for body weight, ad libitum feeding.

Data on body weight, percent abdominal fat, griller weight, and feed conversion of the cage-housed chickens are given in Table 5, and feed conversion of the litter housed chickens is shown in Table 6. Male chickens were heavier, and had less abdominal fat, generally higher griller yield, and better feed conversion than females ($P < .01$). In both environments line

Table 5: Means and standard errors of difference for body weight, percent abdominal fat and percent griller weight at 42 days of age and feed conversion from 21 to 42 days of age of individually housed chickens; standard errors of difference are calculated from analyses of variance according to Model 4.

	Body weight(g)		Abdominal fat(%)		Griller weight(%)		Feed conversion	
Line[1)]	♂	♀	♂	♀	♂	♀	♂	♀
AF	1862	1599	1.02	1.31	62.60	62.20	1.92	2.04
FC	1898	1643	1.34	1.70	63.28	62.55	1.85	1.95
GR	2061	1808	1.95	2.71	62.38	61.98	2.10	2.24
GL	2146	1875	2.04	2.80	62.41	61.70	2.03	2.21
	Standard error of difference of two means for							
Line	14.6		.050		.136		.011	
Line x sex	20.7		.070		.192		.016	

Table 6: Means and standard errors of difference for feed conversion ratios based on full fed body weight from 0 to 22 and from 0 to 41 days of age of litter-housed chickens; standard errors of difference are calculated from analyses of variance according to Model 2.

Line[1)]	0 to 22 days	0 to 41 days
AF	1.398	1.728
FC	1.366	1.665
GR	1.447	1.859
GL	1.444	1.844
	Standard error of difference of two means for	
Line	.011	.008

[1)]Lines are: AF:sib selection against abdominal fat, ad libitum feeding; FC: individual selection for feed conversion, ad libitum feeding; GR: individual selection for body weight, restricted feeding; GL: individual selection for body weight, ad libitum feeding.

effects were significant(P<.01) for these traits. Although the two housing systems cannot be compared statistically, there is no indication of an interaction between lines and rearing environment. In both environments all four lines differed significantly from each other in body weight. Line GL chickens were heaviest, followed in descending order by Lines GR, FC and AF. On litter and in cages AF chickens had the least abdominal fat, followed by Line FC and Lines GR and GL, which were similar. There was a significant interaction between line and sex (P<.01) for percentage of abdominal fat, because males and females differed less in Lines AF and FC than in Lines GR and GL. The GL line tended to have a lower slaughter yield than the other three lines. On litter the difference between Line GL and Lines AF, FC and GR was significant. In cages, GL chickens had a significantly lower percentage of griller than Lines AF and FC, but not lower than that of Line GR. Feed conversion, whether determined in individuals or in groups, was best in Line FC, followed by Line AF; Lines GR and GL did not differ. Differences in feed conversion between males and females were smaller in Lines AF and FC than in Lines GR and GL, resulting in a significant interaction between line and sex (P < .01) for the cage-housed chickens.

Mortality of the litter housed-chickens as a percentage of chickens started is shown in Table 7. Effects of hatch and of the interaction between hatch and line or sex were not significant. Data were therefore pooled over hatches. Line and sex both had a significant effect on mortality. Mortality among FC chickens was relatively low; among GR chickens it was relatively high. Differences in mortality between the lines can be ascribed to differences in the frequency of leg disorders in general and in dyschondroplasia in particular. Because of the relatively high mortality among male and the low mortality among female GL chickens, there was a significant interaction for mortality between line and sex. Mortality of cage housed chickens was not analyzed because only 18 chickens died.

Retail cuts as a percentage of live body weight are given in Table 8. Females had more skin, fat and tail than males (P<.01). Male chickens had heavier legs and a higher weight of the remainder of the carcass relative to body weight. Line effects were significant for percentage of breast meat (P<.05) and of skin, fat and tail (P<.01). Compared to the other lines, Line FC had a significantly higher percentage of breast meat, while Lines AF and FC had less skin, fat, and tail than Lines GR and GL. There were no significant differences between the lines in percentage of wings, legs, or remainder of the carcass.

Table 7: Mortality as percentage of chickens started.

Line[1)]	♂	♀
AF	5.1[ab][2)]	4.7[a]
FC	4.0[a]	2.7[b]
GR	6.9[ab]	5.6[a]
GL	7.8[b]	2.0[b]

[1)] Lines are: AF:sib selection against abdominal fat, ad libitum feeding; FC: individual selection for feed conversion, ad libitum feeding; GR: individual selection for body weight, restricted feeding; GL: individual selection for body weight, ad libitum feeding.

[2)] Within sex percentages indicated with different letters differ significantly ($P<.05$).

Water and fat content of whole chicken, griller, thigh, and breast meat were significantly influenced by line (Table 9). The GR and GL line chickens contained less water and more fat than chickens or meat of the AF and FC lines. For whole chicken and griller, females were fatter than males. There was, however, no significant sex effect for fat content of breast or thigh meat. In contrast to findings for abdominal fat, for chemically determined fat no interactions were found between line and sex.

DISCUSSION

The experiment reported here demonstrates that, in a broiler sire strain, feed conversion and fat deposition can be modified by artificial selection. Selection for less abdominal fat (AF line) gave results similar to selection for feed conversion (FC line), while responses to selection for body weight were similar for restricted feeding (GR line) and for ad libitum

Table 8: Means and standard errors of difference of retail cuts as percentage of live body weight at 43(♂) or 44(♀) days of age of litter-housed chickens; standard errors of difference are calculated from analysis of variance according to Model 3.

Line[1]	Wings		Breast meat		Legs		Skin,fat,tail		Remainder	
	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀
AF	8.7	8.5	13.9	14.5	24.4	23.8	3.0	3.5	13.7	13.2
FC	8.4	8.5	14.4	14.8	24.2	23.6	3.0	3.5	13.9	13.2
GR	8.5	8.2	14.0	13.8	24.3	23.7	3.7	4.8	13.5	13.2
GL	8.4	8.1	13.8	14.0	23.9	23.3	3.7	4.4	13.4	13.1
Standard error of difference of two means for										
Line	.10		.18		.23		.15		.14	
Line x sex	.15		.22		.28		.20		.19	

[1]Lines are: AF:sib selection against abdominal fat, ad libitum feeding; FC: individual selection for feed conversion, ad libitum feeding; GR: individual selection for body weight, restricted feeding; GL: individual selection for body weight, ad libitum feeding.

Table 9: Percent water and fat of whole bird at 41 days of age and of griller, breast, and thigh meat at 43(♂) or 44(♀) days of age of litter-housed chickens (means and standard errors of difference); standard errors of difference are calculated from analyses of variance according to Model 3.

	Whole bird				Griller				Thigh meat				Breast meat			
	% water		% fat		% water		% fat		% water		% fat		% water		% fat	
Line[1)]	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀
AF	67.3	65.9	9.3	10.4	67.3	66.9	10.4	11.0	72.9	72.9	7.6	7.6	74.9	74.7	1.6	1.8
FC	66.5	65.3	10.3	12.2	67.3	66.0	10.2	12.5	73.0	72.9	8.2	7.9	74.8	74.8	1.9	2.0
GR	63.7	62.2	13.9	16.3	64.5	63.7	14.2	15.3	71.9	69.4	9.4	12.4	74.6	74.6	2.5	2.2
GL	64.3	62.3	12.9	15.6	64.8	62.9	13.4	15.9	70.1	69.9	11.7	11.8	74.8	74.3	2.2	2.4
	Standard error of difference of two means for															
Line	.16		.21		.43		.57		.47		.66		.21		.15	
Line x sex	.22		.34		.54		.68		.53		.72		.23		.16	

1)Lines are: AF:sib selection against abdominal fat, ad libitum feeding; FC: individual selection for feed conversion, ad libitum feeding; GR: individual selection for body weight, restricted feeding; GL: individual selection for body weight, ad libitum feeding.

feeding (GL line). The differences between the lines in body weight, feed conversion, fat deposition and slaughter yields will be discussed in that order.

Body weight. It is not surprising, that Lines GR and GL have higher body weights than Lines AF and FC, since Lines AF and FC have not been selected for body weight for four generations. According to the correlated selection differentials for body weight (per generation and cumulative) shown in Table 2, few differences in body weight between Lines AF and FC would be expected. Genetic correlations between body weight and feed conversion estimated in the zero generation of this experiment (Leenstra et al., 1986) and elsewhere (Pym and Nicholls, 1979; Washburn, 1980) indicate, however, that a correlated response toward a higher body weight can be expected from selection for feed conversion. Another explanation for the higher body weight of Line FC could be the low incidence of leg disorders among this line. Probably natural selection against leg disorders was more intense in Line FC than in the lines housed on litter. Housing in cages causes a higher incidence of leg disorders than housing on litter (Haye and Simons, 1978). Line GR chickens were not as heavy as those of Line GL, although selection pressure on body weight was higher in Line GR. In the zero generation the genetic correlation between body weight with ad libitum and with restricted feeding was estimated as .20 (Leenstra et al., 1986). This indicates that the two types of body weight have only a part of the genetic variation in common. Lower body weight of the GR line could also be caused by high incidence of tibial dyschondroplasia among GR chickens. This is probably the result of a lack of natural selection against leg disorders. With restricted feeding hardly any leg problems were seen, whereas among chickens fed ad libitum during selection several chickens died or had to be culled because of leg disorders.

Feed conversion. Individual selection for feed conversion between 3 and 6 weeks of age, as carried out in Line FC, gave a significant response in feed conversion of chickens housed in groups. Selection also improved feed conversion in the first 3 weeks of the rearing period. The feed conversion ratio of Line AF is intermediate between that of Line FC and Lines GR and GL. This confirms the genetic correlation of about .5 found between feed conversion and fat deposition (Leenstra, 1986). The growth pattern of Line

FC differs from that of Line AF. At 3 weeks of age AF and FC chickens had the same body weight in both environments. At 6 weeks of age FC line chickens were, over sexes and hatches, an average of 68g (litter) and 42g (cages) heavier than AF chickens. Pasternak and Shalev (1983) found in a simulation study that chickens with a relatively slow growth rate in the first part of the rearing period, followed by a relatively high growth rate in the second part, have a favorable feed conversion ratio because of overall lower maintenance requirements. Probably both changes in body composition and in growth pattern contribute to the favorable feed conversion ratio of Line FC.

Fat deposition. Selection against abdominal fat and for feed conversion have both resulted in less fat deposition than selection for body weight. Direct selection against abdominal fat (Line AF), resulted in a lower percentage of abdominal fat than selection for feed conversion. Body weight after restricted feeding was not effective in reducing the amount of abdominal fat under ad libitum feeding conditions.

Selection also affected chemical composition of whole chicken and chicken meat but relatively less than it affected abdominal fat content. Differences between lines in fat content of griller, thigh and breast meat were of the same order as those in whole chicken. Consequently, selection against abdominal fat will diminish the fat content of chicken meat.

Slaughter yields. Differences in griller yield are partly due to differences in abdominal fat content. Abdominal fat was not included in the griller weight. Line GL had about 1% more abdominal fat than Lines AF and FC. This is more than the difference in griller yields. Ricard et al. (1983) compared a fat with a lean line and found differences in percentage of griller weight that were in favour of the lean line, but smaller than differences in percentage of abdominal fat. No measurements were made of the weight of slaughter offals; thus it is speculation that the high griller yield of Line GR is the result of an altered relative weight of the intestinal tract due to selection for body weight after restricted feeding.

The high percentage of breast meat of Line FC compared with the other lines is very interesting. Chickens with a favorable feed conversion ratio tend in general to deposit less fat and more water than birds with a higher feed conversion ratio, as reported here and by Washburn et al. (1975),

Washburn (1980), and Pym and Solvyns (1979). It could be that in chickens with a high proportion of breast meat - the muscles lowest in fat and highest in water content - are favored by selection for feed conversion.
It can be concluded from the data of the AF and FC lines on fat deposition and feed conversion that a lower rate of fat deposition causes a more favorable feed conversion and vice versa. Each trait, however, accounts for only a part of the variation in the other. If only diminished fat deposition is the selection goal, selection should be for fat deposition. Feed conversion is, however, so important in broiler production that a lower response to reduction in abdominal fat can be worthwhile in exchange for the direct and correlated responses to selection for feed conversion.

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CHAPTER 4

HERITABILITY OF AND GENETIC CORRELATIONS BETWEEN BODY WEIGHT, ABDOMINAL FAT AND FEED CONVERSION RATIO.

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ABSTRACT

Genetic parameters of body weight, abdominal fat and feed conversion were estimated in ad libitum fed pedigree chickens of four lines selected from a broiler sire strain. The lines were selected for four generations for a low amount of abdominal fat (AF), a favourable feed conversion (FC), a high body weight after restricted feeding (GR) and a high body weight after ad libitum feeding (GL). A total of 2400 chickens were reared by line in groups on litter and of 864 chickens in individual cages.
The h^2_{sire} for the four lines combined was for body weight .27 (litter) and .22 (cages), for weight of abdominal fat .54 (litter) and .40 (cages), for percentage abdominal fat .53 (litter) and .45 (cages) and for feed conversion .44 (cages).
The genetic correlation (sire estimate) for the four lines combined between body weight and weight of abdominal fat was .58 (litter) and .55 (cages), between body weight and percentage abdominal fat .36 (litter) and .47 (cages), between body weight and feed conversion .16 (cages), between weight of abdominal fat and feed conversion .43 (cages) and between percentage abdominal fat and feed conversion .44 (cages).
Analysis within line and sex indicated, that in the relatively fat GR and GL lines sex-linked inheritance could be involved for abdominal fat. In the leaner AF and FC lines this was not the case.
Genetic correlations did not differ significantly between sexes, but in the AF and FC lines the genetic correlation between body weight and abdominal fat was higher (AF: .80, FC:.76) than in the GR (.14) and GL (.68) line.

INTRODUCTION

Excessive fat deposition in the abdominal cavity in broilers can be prevented by direct and indirect selection (Leclercq et al., 1980; Whitehead and Griffin, 1984; Cahaner et al., 1986; Leenstra and Pit, 1987). Leenstra and Pit (1987) found, that four generations of sib selection against abdominal fat resulted in chickens with 1.2% abdominal fat, compared to 2.7% in chickens of a weight selected line from the same base population. Leclercq (1983) selected lines for a high and a low percentage of abdominal fat and observed that in the 8^{th} generation male chickens of the fat line had a five to six times higher percentage of abdominal fat than males of the lean line. After only two generations of divergent selection for abdominal fat, Cahaner et al. (1986) found twice as much abdominal fat in the fat line than in the lean line.

Selection on the concentration of very low density lipoproteins (VLDL) in blood plasma gives a correlated response in percentage of abdominal fat (Whitehead and Griffin, 1984). After three generations of selection the line selected for low VLDL had .5% less and the line selected for high VLDL .6% more abdominal fat than a commercially selected line from the same base population.

A genetically lower percentage of abdominal fat is generally accompanied by a favourable feed conversion (Whitehead and Griffin, 1984; Leenstra and Pit, 1987) and higher slaughter yields (Ricard et al., 1982; Leenstra and Pit, 1987). The genetic correlation between body weight and relative amount of abdominal fat is low (Leenstra, 1986). However, including direct or indirect selection against abdominal fat in a broiler selection program will imply less selection pressure on body weight and thus diminished genetic progress in body weight, unless total selection intensity is increased.

For decisions about an optimal selection program in broiler production, ample information is required on the heritability of the amount of abdominal fat and its genetic correlation with body weight and feed conversion, as important characteristics in broiler production. The objective of this research is, to present estimates of these parameters in lines differing in body weight, fat deposition and feed conversion.

MATERIAL AND METHODS

Chickens and experimental procedures. Phenotypic and genetic parameters were estimated from analysis of variance and covariance of data of chickens of the fifth generation of four selection lines. The lines originated from a strain comparable to commercial broiler sire material. The lines and their selection criteria are:

AF line: sib selection for a low amount of abdominal fat adjusted for body at 6 weeks of age.

FC line: individual selection for a favourable feed conversion between 3 and 6 weeks of age;

GR line: individual selection for body weight at 6 weeks of age after restricted feeding (about 70% of the ad libitum intake);

GL line: individual selection for body weight at 6 weeks of age after ad libitum feeding, as is usual in broiler sire material.

In the four generations of selection, AF, FC and GL line chickens were fed ad libitum until 6 weeks of age and GR line chickens restricted. The AF, GR and GL line were housed on litter and the FC line in cages. After 6 weeks of age, the selected chickens of all four lines were treated in the same way.

The fifth generation of the lines was bred from 100 sires (25/line) each mated to 4 dams of the same line. In three hatches, 2400 pedigreed chickens (on average 3 ♂♂ and 3 ♀♀/dam) were reared in litter pens and weighed and slaughtered at 43(♂♂) or 44(♀♀) days of age. The number of chickens of which feed consumption could be recorded individually was restricted by the number of cages available. Divided over three hatches 864 chickens (on average 1 ♂ and 1 ♀/dam) were kept in individual cages from 21 to 42 days of age. During this period body weight gain and feed consumption were determined. The cage housed chickens were slaughtered at 42 days of age.

In all slaughtered chickens the amount of abdominal fat was determined (Leenstra et al., 1981).

The history of the lines, the experimental conditions and the differences in performance between the lines in the fifth generation are described by Leenstra and Pit (1987). Table 1 gives mean and standard deviation by line and for the four lines combined of body weight, weight of abdominal fat and abdominal fat as percentage of body weight for the litter and cage housed chickens and for feed conversion of the cage housed chickens.

Statistical analysis. For the analyses of variance and covariance, Harvey's LSML76 program (Harvey, 1977) was used. Heritabilities of and genetic correlations between the characteristics examined were calculated from the sire and from the dam component of variance or covariance.

The traits measured on litter housed chickens were analyzed by line and sex, by line, by sex and with the data on all chickens combined.

The sampling variance of the estimates of genetic parameters from sib

Table 1: Number of chickens (n) and mean and standard deviation (s.d.) for body weight and weight and percentage of abdominal fat for litter and cage housed chickens and for feed conversion from 21 to 42 days of age of cage housed chickens (litter housed chickens 43(♂♂) or 44(♀♀), cage housed chickens 42 days of age).

	AF line[1]		FC line		GR line		GL line		All lines	
	mean	s.d.	mean	s.d.	mean	s.d.	mean	s.d.	mean	s.d.
LITTER	n=556		n=577		n=596		n=597		n=2326	
Body weight(g)	1780	188	1845	217	2005	211	2074	231	1929	198
Abd. fat(g)	22.0	7.7	31.1	9.4	53.6	12.9	55.5	14.9	41.0	10.4
Abd. fat(%)	1.23	.41	1.68	.47	2.69	.66	2.69	.72	2.09	.54
CAGES	n=206		n=207		n=200		n=209		n=822	
Body weight(g)	1750	191	1772	191	1938	214	2002	203	1860	229
Abd. fat(g)	20.3	6.9	27.1	7.9	44.9	13.8	48.8	12.2	35.2	16.2
Abd. fat(%)	1.18	.39	1.53	.44	2.32	.69	2.45	.65	1.87	.78
Feed conversion	1.98	.11	1.90	.10	2.16	.16	2.12	.14	2.04	.17

[1]AF: sib selection for a low amount of abdominal fat relative to body weight.

FC: individual selection for feed conversion.

GR: individual selection for body weight after restricted feeding.

GL: individual selection for body weight after ad libitum feeding.

analysis is dependent on the number of families and the number of progeny per family (Falconer, 1981). For the cage housed chickens, the number of chickens per family was rather small (on average 2/dam and 8/sire). It was therefore decided, to maximize the number of families in the analyses. This implied, that the data of the cage housed chickens were not analyzed by line, but only by sex and with all data combined.

In the first instance, besides sire and dam effects, the appropriate main effects (line, sex, hatch and/or location of the pen or cage in the house) and their two-way interactions were included in the model. Interactions and main effects that were not shown to be significant at the 5% level were dropped from the model. All models for the statistical analyses had the same structure. Therefore, only the most extended ones with data on lines and sexes combined are given. The model for chickens housed on litter was:

$y_{ijklmnq}=U+L_k+s_{ki}+d_{kij}+S_l+H_m+P_n+LS_{kl}+LH_{km}+LP_{kn}+HP_{mn}+e_{ijklmnq}$

The statistical model for analysis of data on cage housed chickens was:

$y_{ijklmopq}=U+L_k+s_{ki}+d_{kij}+S_l+H_m+T_o+C_p+LS_{kl}+SH_{lm}+HC_{mp}+TC_{op}+e_{ijklmopq}$

In these models letters represent:

$y_{i..q}$ the observation on the q^{th} individual,

U the general mean,

L_k the effect of the k^{th} line (k=1, 2, 3, 4),

s_{ki} the effect of the i^{th} sire of line k (i=1,....,25); sires are nested within line,

d_{kij} the effect of dam j mated to the ki^{th} sire (j=1, 2, 3, 4); dams are nested within sires,

S_l the effect of the l^{th} sex (l=1, 2),

H_m the effect of the m^{th} hatch (m=1, 2, 3),

P_n the effect of location of the litter pen on the west or the east side of the poultry house (n=1, 2),

T_o the effect of location of the cage on the upper or lower tier of the battery (o=1, 2),

C_p the effect of location of the cage along the wall or along the corridor side of the house (p=1, 2),

LS_{kl}, LH_{km}, LP_{kn}, SH_{lm}, HP_{mn}, HC_{mp}, TC_{op} are interactions between main effects,

$e_{i..q}$ the error term.

s_{ki}, d_{kij} and $e_{i..q}$ are considered random and all other effects as fixed. The coefficient (k-value) for the dam component in the expected mean square for dams is smaller than the coefficient for the dam component in the expected mean squares for sires. The significance of the sire component of variance was therefore tested according to Satterthwaite (1946).

RESULTS

Analyses of variance. The results of the analysis of variance of body weight, weight of abdominal fat and abdominal fat as percentage of body weight of litter housed chickens with lines and sexes combined are given in Table 2. Table 3 shows mean squares and levels of significance from the analysis of body weight, absolute and relative amount of abdominal fat and feed conversion of the cage housed chickens with sexes and lines combined.

Table 2: Results of analysis of variance (mean squares[1]) of body weight (BW), weight of abdominal fat (AFg) and abdominal fat as percentage of body weight (AF%) of litter housed chickens.

Effect	df	BW	AFg	AF%
Line	3	10768***	158101***	30873***
Sire/line	95	114***	564***	109***
Dam/sire/line	271	56***	178***	35***
Sex	1	26423***	30728***	20457***
Hatch	2	124**	133	88**
Location	1	15	69	12
Line x Sex	3	12	2309***	916***
Line x Hatch	6	66*	207*	35*
Line x Location	3	27	266*	75***
Hatch x Location	2	356***	483***	52*
Residual	1936	25	87	17

1) $MS_{sire} = \hat{\sigma}^2{}_e + 7.1\hat{\sigma}^2{}_d + 23.4\hat{\sigma}^2{}_s$; $MS_{dam} = \hat{\sigma}^2{}_e + 5.9\hat{\sigma}^2{}_d$

*: P<.05; **: P<.01; ***: P<.005

The influence of line and sex was highly significant (P <.005) in both environments for all traits examined. The effects of hatch, location of the pen or cage and of interactions between the fixed effects were less consistent. However, the interaction between line and sex was highly significant for weight and percentage of abdominal fat of litter and cage housed chickens. This is probably a scale effect. Only in absolute sense is the difference between males and females in the fat GR and GL lines greater than in the lean AF and FC lines.

Sire and dam influences were clearly present (P<.005) for the three traits measured on litter housed chickens and for abdominal fat of the cage housed chickens. Body weight of the cage housed chickens was significantly influenced by both sire and dam (P<.05), but for feed conversion only the sire effect was significant (P<.005).

Table 3: Results of analysis of variance (mean squares[1]) of body weight (BW), weight of abdominal fat (AFg), abdominal fat as percentage of body weight (AF%) and feed conversion (FC) of cage housed chickens.

Effect	df	BW	AFg	AF%	FC
Line	3	36310***	38465***	7681***	3036***
Sire/line	100	323*	212***	50***	22***
Dam/sire/line	228	222*	120***	27***	11
Sex	1	90631***	2868***	3282***	2149***
Hatch	2	2384***	1393***	260***	343***
Tier	1	18	689***	182***	77***
Row	1	131	160	32	2
Line x Sex	3	257	424***	176***	29
Sex x Hatch	2	64	245*	70*	7
Hatch x Row	2	485	318*	54*	15
Tier x Row	1	37	392*	108*	12
Residual	452	175	75	16	10

1) $MS_{sire} = \hat{\sigma}^2_e + 2.8\hat{\sigma}^2_d + 7.6\hat{\sigma}^2_s$; $MS_{dam} = \hat{\sigma}^2_e + 2.2\hat{\sigma}^2_d$

*: P<.05; ***: P<.005

Pooled estimates of genetic parameters. Heritabilities and genetic correlations were estimated from sire and dam components of variance and covariance calculated from the analyses by housing system with lines and sexes combined (Table 4). The estimates from the two housing systems agree well. In abdominal fat and feed conversion more additive genetic variance appeared to be present than in body weight. The heritability estimated from the dam component of variance for body weight is of the same magnitude as that for abdominal fat, while the h^2_{dam} for feed conversion neither differed significantly from zero or from the h^2_{sire} for feed conversion.

Table 4: Heritability of (diagonal) and phenotypic (below diagonal) and genetic (above diagonal) correlations between body weight, abdominal fat (g) and abdominal fat (%) of litter and cage housed chickens and between these traits and feed conversion for cage housed chickens, estimated from the sire and from the dam component of variance or covariance.

Trait		Body weight		Abdominal fat(g)		Abdominal fat(%)		Feed conversion	
	Housing	Sire	Dam	Sire	Dam	Sire	Dam	Sire	Dam
Body weight(g)	litter	.27(.06)	.64(.08)[1]	.58(.10)	.54(.09)	.36(.13)	.24(.11)	-	-
	cages	.22(.13)	.41(.18)	.55(.19)	.30(.22)	.47(.22)	.09(.24)	.16(.27)	.56(.74)
Abdominal fat(g)	litter	.56		.54(.09)	.52(.08)	.97(.01)	.94(.02)	-	-
	cages	.51		.40(.15)	.77(.18)	.99(.01)	.97(.01)	.43(.19)	.58(.46)
Abdominal fat(%)	litter	.26		.93		.53(.09)	.53(.08)	-	-
	cages	.28		.96		.45(.15)	.84(.18)	.44(.18)	.47(.39)
Feed conversion	litter	-		-		-		-	-
	cages	-.18		.18		.27		.44(.15)	.14(.18)

[1]Between brackets: the standard error of heritability or genetic correlation.

Although the correlation between weight and percentage of abdominal fat was almost one in both environments, the correlation between body weight and absolute amount of abdominal fat appeared to be higher than the correlation between body weight and percentage of abdominal fat. The abdominal fat traits showed a low, but positive phenotypic correlation with feed conversion. The genetic correlations were considerably higher, both for the absolute and relative amount of abdominal fat.

The phenotypic correlation between feed conversion and body weight was negative, while the genetic correlation was positive, but not significantly different from zero.

Genetic parameters estimated within sex. To investigate the presence of sex-linked inheritance for body weight, abdominal fat and feed conversion, the data were analyzed by sex. Figure 1 gives the h^2_{sire} and the h^2_{dam} for males and females by housing system.

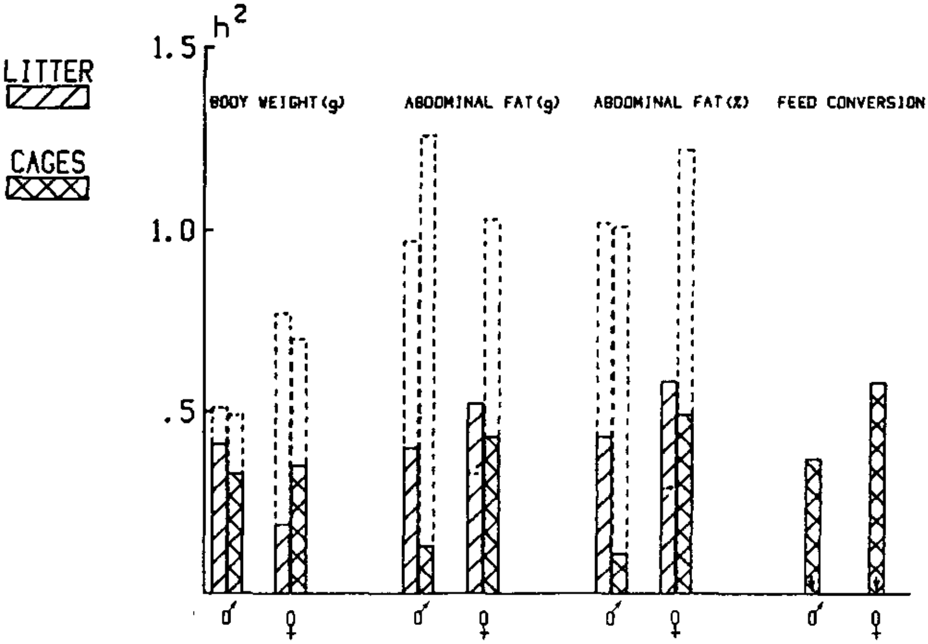

Figure 1: Heritabiltity estimated from the sire (solid line) and from the dam (broken line) component of variance of body weight, weight of abdominal fat, abdominal fat as percentage of body weight and feed conversion by sex for litter and cage housed chickens. (▾ : $h^2_{dam} < 0$).

The phenotypic and genetic correlations within sex did not differ from the ones estimated in the combined analyses. Only for the abdominal fat traits of the litter housed chickens significant differences between heritability estimates in males and females were present, indicating the importance of sex-linked inheritance. This was, however, not reflected by the cage housed chickens.

The h^2_{dam} for feed conversion from the analyses within sex was estimated as negative in both sexes.

Genetic parameters estimated within line and sex. Figure 2 gives the estimates of the heritability of body weight and weight and percentage of abdominal fat by line and sex for the litter housed chickens. In general, the h^2_{sire} for body weight of females was lower than the h^2_{sire} for body weight

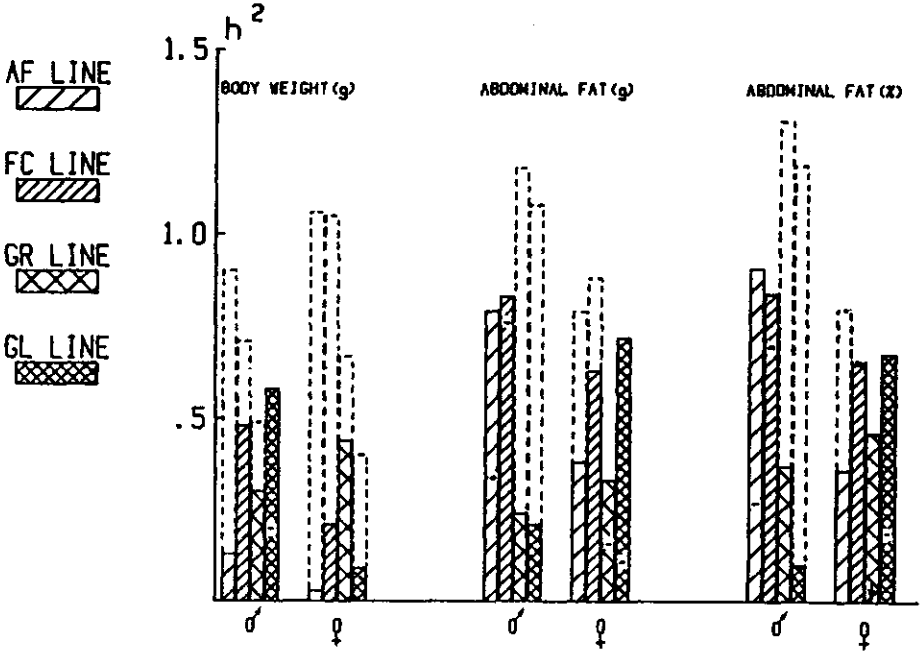

Figure 2: Heritability etimated from the sire (solid line) and from the dam (broken line) component of variance of body weight, and absolute and relative amount of abdominal fat by line and sex for litter housed chickens. (AF line: sib selection for a low amount of abdominal fat; FC line: selection for feed conversion; GR line: selection for body weight after restricted feeding; GL line: selection for body weight after ad libitum feeding).
(↑: $h^2_{dam} < 0$).

of males, while the estimate of the h^2_{dam} was higher for females than for males. The differences in the heritability of body weight between males and females were, however, only significant ($P<.05$) for the h^2_{sire} of the GL line. In the AF and FC lines, maternal and/or dominance effects on body weight seemed to be more important than in the heavier GR and GL lines.

In the estimates of the heritability of abdominal fat, two groups can be distinguished: the leaner and lighter AF and FC lines and the heavier and fatter GR and GL lines. In the fat and heavy lines, the h^2_{sire} is relatively low in males and high in females, while the h^2_{dam} is high in males and low in females. This tendency is reversed in the AF and FC lines. For weight of abdominal fat the difference between the h^2_{sire} for males and females was significant in the GL line and between the h^2_{dam}'s in the AF, GR and GL lines. For percentage of abdominal fat, the differences between the heritability estimates in males and females were significant in the AF and GL lines (h^2_{sire}) and AF, GR and GL lines (h^2_{dam}).

The phenotypic and genetic correlations by line for the litter housed chickens are summarized in Table 5. The estimates of correlations within sex were not clearly different from the ones with sexes combined and are thus not shown. The phenotypic and genetic correlation between body weight and abdominal fat tended to be higher in the AF and FC lines compared with the weight selected lines (GR and GL). In the GR and GL lines, the genetic correlation between percentage of abdominal fat and body weight is lower than the r_g between absolute amount of abdominal fat and body weight.

DISCUSSION

Heritability estimates pooled over lines. In the four lines examined, a significant part of the variation in body weight, abdominal fat and feed conversion was of genetic origin. Estimates of the pooled h^2_{sire} (Table 4) of body weight and the abdominal fat traits indicate, that abdominal fat was more dependent on additive genetic variance than body weight. In both housing systems, the h^2_{sire} of weight and percentage of abdominal fat were about twice as high as that for body weight. The h^2_{dam}'s of body weight and abdominal fat were about equal. The same was found by Ricard and Rouvier (1969), Leclercq et al. (1980), Chambers and Gavora (1982) and Cahaner and

Table 5: Phenotypic(r_p) and genetic($r_{g_{sire}}$ and $r_{g_{dam}}$) correlations between body weight and weight and percentage of abdominal fat by line of litter housed chickens.

	Body weight x Abd.fat(g)			Body weight x Abd.fat(%)			Abd.fat(g) x Abd.fat(%)		
Line[1)]	r_p	$r_{g_{sire}}$	$r_{g_{dam}}$	r_p	$r_{g_{sire}}$	$r_{g_{dam}}$	r_p	$r_{g_{sire}}$	$r_{g_{dam}}$
AF	.64	.80(.20)	.80(.11)[2)]	.46	.71(.25)	.56(.18)	.97	.99(.01)	.95(.03)
FC	.65	.76(.13)	.67(.12)	.40	.64(.18)	.36(.19)	.95	.99(.01)	.93(.03)
GR	.48	.14(.29)	.46(.21)	.12	-.23(.28)	.11(.27)	.92	.93(.04)	.94(.03)
GL	.55	.68(.16)	.44(.23)	.21	.49(.24)	.10(.27)	.92	.97(.02)	.94(.03)

1)AF line: sib selection for a low amount of abdominal fat; FC line: selection for feed conversion; GR line: selection for body weight after restricted feeding; GL line: selection for body weight after ad libitum feeding).

2)Between brackets: standard error of the genetic correlation.

Nitsan (1985). Ricard and Rouvier (1967) and Becker et al. (1984) found however a higher h^2_{sire} and a lower h^2_{dam} for body weight compared to those for abdominal fat. In most cases, maternal and/or dominance effects and/or cytoplasmatic inheritance are thus more important for body weight than for abdominal fat. Cytoplasmatic or mitochondrial inheritance of body weight is an interesting subject for further research (Boursot and Bonhomme, 1986).

In the zero generation of the selection lines heritabilities were also estimated (Leenstra et al., 1986). The h^2_{sire} for body weight was in that generation estimated as negative, that for weight of abdominal fat as .31 and that for percentage of abdominal fat as .41. For all traits, the estimate of the h^2_{dam} was larger than one. The h^2_{sire} for feed conversion found in this experiment agrees well with the one found in the zero generation of .39 reported by Leenstra et al. (1986). Both are slightly higher than most estimates reported in the literature, which vary between .11 and .42 (Thomas et al., 1958; Pym and Nicholls, 1979; Marahrens and Flock, 1980; Washburn, 1980; Chambers and Gavora, 1982; Friars et al., 1983).

Analysis within sex (Figure 1) could not explain the low h^2_{dam} (.14) found for feed conversion. In both sexes, the h^2_{dam} was negative, but not significantly different from the h^2_{sire}. The influence of sex-linked inheritance on feed conversion found by Pym and Nicholls (1979) was thus not found in our material.

Heritability estimates within sex and line. Sex-linked inheritance could be involved in determining the amount of abdominal fat in the litter housed chickens of the GR and GL lines. In males of these lines, the h^2_{sire} was lower than the h^2_{dam}, while in females the h^2_{sire} was higher than the h^2_{dam} (Figure 2). In the lean AF and FC lines, this was completely reversed. In the analysis with the lines combined, but within sex, the picture of the GR and GL lines was present. These lines thus had a strong influence on the estimates of the variance components in the pooled data. Becker et al. (1984) found in broiler parent stock for abdominal fat also in males a lower h^2_{sire} and a higher h^2_{dam} than in females.

In a selection experiment concerning abdominal fat reported by Leclercq et al. (1980), only males were used to estimate genetic parameters. Their work indicated, that in the lean line the h^2_{sire} was higher and in the fat line lower than the h^2_{dam}.

The differences between heritabilities of abdominal fat for males and females in lean and fat lines could be caused by a major gene located on the sex chromosome. This gene may be fixed in the lean lines due to the selection. The high h^2_{sire} and h^2_{dam} in both males and females of the AF and FC lines indicate, that also normal autosomal genes influence the amount of abdominal fat deposited. Further research on the existence of a major gene on the sex chromosome influencing fat deposition is required.

Genetic correlations. From the genetic correlations estimated from the combined data (Table 4), it can be concluded, that in the lines used in this experiment a high body weight was accompanied by a high amount of abdominal fat. Still only 30%(cage) and 34%(litter) of the additive genetic variance in abdominal fat was explained by variation in body weight.

The genetic correlation between body weight and percentage of abdominal fat was equal to the genetic correlation between percentage of abdominal fat and feed conversion. About 20% of the variation in percentage of abdominal fat was explained by genetic variation in body weight or feed conversion. Feed conversion was not significantly correlated with body weight. The genetic correlations are in accordance with the selection responses found in the lines (Leenstra and Pit, 1987) and in other selection experiments on fat deposition or feed conversion (Pym and Solvyns, 1979; Leclercq et al., 1980; Washburn, 1980; Whitehead and Griffin, 1984). Selection for feed conversion gives a leaner bird and selection for less fat deposition provides a favorable feed conversion.

Between the lines, marked differences in the genetic correlations between body weight and abdominal fat were present (Table 5). In the lean AF and FC lines, this correlation was considerably higher than in the fatter and heavier GR and GL lines. Selection against abdominal fat in relatively fat lines will thus hardly influence body weight, while in lean lines more than half of the variation in abdominal fat is dependent on the variation in body weight.

Both, abdominal fat and feed conversion can be used as selection traits to reduce excessive fatness. Because of the high correlation between body weight and abdominal fat in the lean lines, it is not feasible to strive for a minimum amount of abdominal fat. Sire strains are a better choice than dam strains for selection against fatness in broilers, as sex-linked inheritance could be important in relatively fat strains.

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CHAPTER 5

PERFORMANCE OF BROILER PROGENY OF FOUR DIFFERENTLY SELECTED SIRE LINES.

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ABSTRACT

Cocks of four lines selected for a low amount of abdominal fat (AF), a favourable feed conversion (FC), and a high body weight after restricted (GR) and after ad libitum (GL) feeding were mated to commercial broiler breeder hens. A total of 3600 progeny resulting from these matings were reared by line in litter pens.

At 41 days of age GR and GL line progeny had a significantly higher body weight, a poorer feed conversion and a higher percentage of abdominal fat than that observed from the AF and FC line progeny. At a comparable body weight (AF 1893g, FC 1918g, GR 1848g, GL 1897g) feed conversion was most favourable for FC line progeny (1.72); AF and GL line progeny did not differ (1.77) and GR line progeny had the poorest feed conversion (1.79). AF line progeny had the lowest percentage abdominal fat (1.88%), followed by FC line progeny (2.20%), GL line progeny (2.91%) and GR line progeny (3.10%).

As in the pure lines, selection for body weight after restricted feeding was not effective in obtaining leaner and more efficient chickens. When compared to the differences between the pure lines, the results of the broiler progeny indicate, that body weight, feed conversion and percentage abdominal fat are inherited in an additive way.

INTRODUCTION

Significant changes in fat deposition can be achieved in chickens by means of selection. Besides sibselection for a low amount of abdominal fat relative to body weight (Leclercq et al., 1980, Cahaner et al., 1985), also selection for a favourable feed conversion (Pym, 1985; Leenstra and Pit, 1987a) and selection for a low triglyceride content of bloodplasma (Whitehead and Griffin, 1984) are effective in developing leaner chickens.

Only a few generations of selection against fatness with moderate selection intensity are sufficient to obtain chickens with about half the amount of abdominal fat of chickens of the same age but selected for body weight (Leenstra and Pit, 1987a).

In practical broiler breeding programs it is not likely, that both sire and dam lines will be selected for a low fat content. Selection for less fat deposition only in sire lines is more probable. Therefore, it is interesting to compare lines differing in fat deposition as sires in a broiler cross. In this paper data are presented on body weight, abdominal fat and feed conversion of progeny of commercial broiler breeder hens and sires of lines selected for a low amount of abdominal fat, a favourable feed conversion, and a high body weight after restricted and ad libitum feeding.

MATERIAL AND METHODS

Chickens and management. The chickens used in this experiment descended from sires of the fifth generation of four selection lines and commercially available broiler breeder hens. The four sire lines and their selection criteria are:

AF line: sibselection for a low amount of abdominal fat relative to body weight at about 6 weeks of age;

FC line: individual selection for a favourable feed conversion between 3 and 6 weeks of age;

GR line: individual selection for a high body weight at 6 weeks of age after restricted feeding (about 70% of ad libitum intake);

GL line: individual selection for a high body weight at 6 weeks of age after ad libitum feeding.

The selection procedures and the results of comparisons of the pure line chickens of the fifth generation on body weight, fat deposition and feed conversion are described by Leenstra and Pit (1987a).

In the fifth generation, the best 18% (AF, FC and GL lines) or 27% (GR line) of the cockerels were selected according to the selection criterion of each line. Fifteen males of each line, taken at random from the selected group, were naturally mated to 150 hens of the commercial dam stock. During three periods of about one week, hatching eggs were collected. The eggs of the four sire groups were set simultaneously and the chickens were sexed at hatching. In each hatch 1200 chickens, 300 per sire line, were started.

Each line was housed in litter pens of about 12m^2 with 75 male and 75 female chickens per pen (2 pens per sire line per hatch). The pens were located along both sides of a corridor. In all hatches progeny of each sire line was housed on both sides of the corridor.

The chickens were fed, ad libitum, a pelleted broiler diet containing 13.4 MJ metabolizable energy/kg and 21.5% crude protein. A system of 1 hr light alternating with 3 hr darkness was used to prevent leg disorders. At 1 day of age the chickens were vaccinated against infectious bronchitis and at 7 days of age against Newcastle Disease.

Measurements. At 41 days of age, the chickens from each pen were weighed full fed and feed consumption per pen was also recorded. Twentyfive males and 25 females were taken at random from each pen, starved for about 16 hr and weighed individually at 42 days of age. Immediately after weighing the chickens were slaughtered. The abdominal fat, fat surrounding the gizzard and proventriculus included, was removed and weighed. The weight of the griller (the eviscerated carcass, without neck, neckskin and abdominal fat) was also determined.

To compare the broiler progeny at about equal body weight, the remaining chickens of the slower growing AF and FC groups were weighed again at 44 days of age. At that age, they were at least as heavy as GR and GL sired chickens at 41 days of age. Feed consumption of the AF and FC line progeny between 41 and 44 days of age was also recorded.

In the second hatch at 45 and in the third hatch at 46 days of age 25 males and 25 females from the pens with AF and FC line progeny were weighed and slaughtered in the same way as was done with progeny of all four lines at 42 days of age.

Statistical analyses. The influence of sire line on full fed body weight and feed conversion was examined by analysis of variance. Pen mean was taken as experimental unit:

$$y_{ijk}=U+h_i+C_j+hC_{ij}+L_k+hL_{ik}+CL_{jk}+hCL_{ijk} \qquad [1]$$

In Model 1 U represents the general mean, h_i the random hatch effect (i=1,2,3), C_j the fixed effect of location of the pen on the west or east side of the corridor (j=1,2) and L_k the fixed effect of sire line (k=1,2,3,4). hC_{ij}, hL_{ik}, CL_{jk} and hCL_{ijk} are interactions between the main effects.

Body weight prior to slaughter and abdominal fat and griller weight as percentage of that body weight were examined with mean per sex within pen as experimental unit:

$$y_{ijkl}=U+h_i+C_j+hC_{ij}+L_k+hL_{ik}+CL_{jk}+hCL_{ijk}+S_l+hS_{il}+CS_{jl}+LS_{kl}+e \quad [2]$$

In Model 2 the symbols have the same meaning as in Model 1. S_l represents the fixed sex effect (l=1,2) and e all remaining interactions. In both models the data measured at the same age and the data measured at similar body weight were used as dependent variables. This implied, that in the analyses at about the same body weight with Model 2 only 2 hatches instead of 3 were involved.

With Model 1, the standard error of differences between lines and with Model 2 the standard error of differences between lines within sex were calculated. For all statistical analyses the Genstat program (1977) was used. Main effects, interactions and differences between lines were considered significant if $P<.05$.

RESULTS

Comparisons at equal age. Mean full fed body weight and feed conversion at 41 days of age per sire line are given in Table 1. At 41 days of age, progeny of the GL line was significantly heavier than progeny of the GR line and the GR line progeny was significantly heavier than FC and AF line progeny. Besides a significant line effect ($P<.001$), a significant interaction between line and location of the pen was present ($P=.01$). This interaction did not change the ranking of the lines. Feed conversion at the same age was only influenced by sire line ($P<.001$). Feed conversion was most favorable for the FC line progeny. AF line progeny had a better feed conversion than GR and GL sired chickens.

Table 2 gives body weight prior to slaughter, percentage abdominal fat and percentage griller weight by sex and sire line at 42 days of age. Males were in all lines heavier ($P<.001$), had less abdominal fat ($P<.001$) and tended to have a higher griller yield ($P<.001$). Line effect was significant for body weight ($P=.001$) and percentage abdominal fat ($P<.001$). There were no significant differences in percentage griller weight between the progeny groups.

Table 1: Full fed body weight and feed conversion of progeny of four sire lines and a commercial dam strain at the same age and at about the same body weight.

Sire line[1)]	Age(days)	Body weight(g)	SED[2)]	Feed conversion	SED[2)]
AF	41	1727		1.71	
FC	41	1737		1.68	
GR	41	1848	11.0	1.79	.004
GL	41	1897		1.77	
AF	44	1893	10.6	1.77	.007
FC	44	1918		1.72	

Table 2: Body weight and weight of griller and abdominal fat as percentage of body weight at 42 days of age of progeny of four sire lines and a commercial dam strain.

	Body weight (g)		Griller weight (%)		Abdominal fat (%)	
Sire line[1)]	♂	♀	♂	♀	♂	♀
AF	1743	1476	62.6	62.4	1.68	2.07
FC	1771	1503	62.7	62.1	1.94	2.45
GR	1866	1594	62.7	62.2	2.64	3.55
GL	1919	1638	62.4	62.0	2.50	3.32
SED[2)]	24.6		.25		.081	

[1)] Lines are: AF:sib selection against abdominal fat, ad libitum feeding; FC: individual selection for feed conversion, ad libitum feeding; GR: individual selection for body weight, restricted feeding; GL: individual selection for body weight, ad libitum feeding.

[2)] Standard error of difference between lines (Table 1) or between lines within sex (Table 2).

AF progeny had less abdominal fat than FC progeny, while FC sired chickens had less abdominal fat than GR and GL sired chickens.

Only body weight showed a hatch x sex interaction (P=.03). The significant interaction between line and sex for percentage abdominal fat (P<.001) is probably a scale effect. In the leaner AF and FC progeny, the difference in percentage abdominal fat between males and females is in absolute sense smaller than in the fatter GR and GL line sired chickens.

Comparisons at similar body weight. Comparisons between the lines at about equal body weight are summarized in Table 1 (body weight and feed conversion per pen) and Table 3 (body weight before slaughter, percentage abdominal fat and percentage griller weight per pen and sex). The data in Table 3 are the mean results of two hatches instead of three.

Table 3: Body weight and weight of griller and abdominal fat as percentage of body weight of progeny of four sire lines and a commercial dam strain at similar body weight.

Sire line[1]	Age in days	Body weight(g) ♂	Body weight(g) ♀	Griller weight(%) ♂	Griller weight(%) ♀	Abdominal fat(%) ♂	Abdominal fat(%) ♀
AF	45/46	1946	1618	62.5	62.5	1.55	1.96
FC	45/46	1990	1651	62.9	62.8	2.00	2.46
GR	42	1836	1571	62.5	62.1	2.68	3.56
GL	42	1884	1603	62.2	61.9	2.51	3.27
SED[2]		23.3		.25		.081	

[1] Lines are: AF:sib selection against abdominal fat, ad libitum feeding; FC: individual selection for feed conversion, ad libitum feeding; GR: individual selection for body weight, restricted feeding; GL: individual selection for body weight, ad libitum feeding.

[2] Standard error of difference between lines within sex.

At similar body weight line significantly influenced body weight (P<.05), feed conversion (P<.001) and percentage abdominal fat (P<.001). Males were heavier and had a lower percentage abdominal fat (P<.001). The differences between males and females in body weight increased with increasing age.

This resulted in a significant interaction (P=.02) between line and sex for body weight. There was also a significant interaction between line and sex for percentage abdominal fat at similar body weight (P<.01).
Table 1 indicates, that body weight at 44 days of age of AF and FC sired chickens was not significantly different from the weight of GL sired chickens at 41 days of age. AF and FC line progeny were significantly heavier at 44 days of age than GR line progeny at 41 days of age.
Feed conversion at a similar body weight was most favourable for FC line progeny, although these chickens needed a three day longer rearing period than GR and GL line progeny. At a similar body weight, AF progeny had a better feed conversion than GR progeny, but not than GL progeny. Also, at about similar weight AF progeny had less abdominal fat than FC progeny, which in turn had less abdominal fat than GR and GL sired chickens. FC line progeny had a higher percentage griller weight than GL line progeny, while the other lines did not differ.

DISCUSSION

The differences between the sire lines tested as pure line in the 5th generation are shown in Table 4. The differences between the sire lines in body weight, percentage abdominal fat and feed conversion are clearly reflected in their broiler progeny. As in pure line stock, AF and FC line progeny had a lower body weight, a better feed conversion and less abdominal fat than progeny of the weight selected lines.
Among the pure lines, significant differences in percentage griller weight were present (Leenstra and Pit, 1987a). This was not the case for the broiler progeny of the four lines, although for percentage griller weight the same ranking as in the pure lines could be recognized.
The data on the broiler progeny groups are compared with pure line data to evaluate the effects of selection in the sire line only on their broiler progeny (Table 5). The observations on the AF, FC and GR lines were expressed as deviations from the GL line data, as the selection trait of the GL line, selection for body weight at a fixed age after ad libitum feeding, is comparable to selection procedures in commercial broiler sire material.

Table 4: Body weight, percentage abdominal fat and feed conversion of chickens of pure sire lines (from Leenstra and Pit, 1987a).

Line[1)]	Body weight (g) ♂	Body weight (g) ♀	Abdominal fat (%) ♂	Abdominal fat (%) ♀	Feed conversion
AF	1887	1676	1.04	1.42	1.73
FC	1967	1730	1.47	1.90	1.67
GR	2113	1895	2.25	3.09	1.86
GL	2193	1956	2.28	3.12	1.84

[1)]Lines are: AF:sib selection against abdominal fat, ad libitum feeding; FC: individual selection for feed conversion, ad libitum feeding; GR: individual selection for body weight, restricted feeding; GL: individual selection for body weight, ad libitum feeding.

Table 5: Performance of pure line chickens and broiler progeny of the lines expressed as deviation from the performance of pure GL line chickens and GL line broiler progeny.

	Body weight (g)				Abdominal fat (%)				Feed conversion	
	♂		♀		♂		♀			
Line[1)]	Pure	Broiler	Pure	Broiler	Pure	Broiler	Pure	Broiler	Pure	Broiler
AF	-383	-181	-350	-167	-1.55	-.82	-2.13	-1.25	-.14	-.06
FC	-283	-148	-283	-148	-1.01	-.56	-1.53	- .87	-.21	-.09
GR	-100	- 61	- 76	- 45	- .04	+.14	- .04	+ .23	+.02	+.02

[1)]Lines are: AF:sib selection against abdominal fat, ad libitum feeding; FC: individual selection for feed conversion, ad libitum feeding; GR: individual selection for body weight, restricted feeding; GL: individual selection for body weight, ad libitum feeding.

The pure lines were compared in the 5^{th} generation, while the broiler progeny descended from selected males of the 5^{th} generation. No data were available on pure line chickens of the 6^{th} generation. Therefore these data were estimated from data of the 5^{th} generation. The selection intensity for the males in the 5^{th} generation was about equal to the average selection intensity in generation 1 to 4 (Leenstra and Pit, 1987a). The differences in body weight, percentage abdominal fat and feed conversion between the pure lines were thus multiplied by 5/4. The so obtained expected differences between the pure lines in generation 6 and the observed differences between the broiler progeny groups are compared in Table 5.

It is remarkable, that the differences between the broiler groups are almost exactly 50% of the differences between the pure lines, although the GR line data fit not as good as those of the AF and FC lines in this pattern. This can be caused by the high incidence of dyschondroplasia in the pure GR line (Sørensen and Leenstra, 1986), while in GR broiler progeny the incidence of dyschondroplasia was not abnormal.

The differences between the pure lines and the broiler progeny groups indicate, that differences in body weight, percentage abdominal fat and feed conversion inherite in an additive way. From Table 5 no conclusion can be drawn about the influence of heterosis on body weight, percentage abdominal fat and feed conversion, as no data are available on performance of the dam stock used to produce the broiler progeny groups. Leclercq (1985) in comparing a fat and a lean line and their reciprocal crosses found indications of an effect of heterosis on body weight, but not on abdominal fat.

In a sibanalysis of the pure line data we found indications, that genes located on the sex chromosome might be involved in the inheritance of the amount of abdominal fat (Leenstra and Pit, 1987b). This is however not supported by the observations on the broiler progeny groups. If sex-linked inheritance is important in determining percentage abdominal fat, the differences between the female broilers would be of a greater magnitude than the differences between the male broilers.

The results of the broiler progeny demonstrate, that, although selection for less abdominal fat or feed conversion gives a slower growth rate than selection for body weight, both are successfull in obtaining a leaner chicken. In the case of selection for less abdominal fat feed conversion is not worse, and in the case of selection for feed conversion it is even better than feed conversion of weight selected progeny, all determined at the same body weight. Thus, although the genetic correlation between body weight and percentage abdominal fat is positive (a.o. Leclercq et al.,1980, Becker et al., 1984, Leenstra, 1986), the negative effects of selection for less abdominal fat or feed conversion on growth rate may be compensated for by positive effects on feed conversion.

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CHAPTER 6

COMPARISONS OF ECONOMIC EFFICIENCY OF DIRECT AND INDIRECT SELECTION AGAINST FATNESS.

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ABSTRACT

In a simulation study, selection for weight-gain in a broiler sire strain is compared with one- and two-stage index selection for weight-gain and feed conversion or for weight-gain, slaughter yield and percentage of abdominal fat. Weight-gain is assigned an economic value of 1.138ct/g; feed conversion, -138.18ct; slaughter yield, zero or 7.55ct/%; and percentage abdominal fat, zero or -10ct/%. When selection is completely or almost completely (as in two-stage selection) on weight-gain, percentage abdominal fat increases, otherwise it decreases. Weight-gain, feed conversion and slaughter yield improve with all selection methods examined. Due to the high positive correlation between feed conversion and percentage abdominal fat, selection for an index of weight-gain and feed conversion gives about the same reduction in percentage abdominal fat as selection for an index of weight-gain, slaughter yield and percentage abdominal fat.

Selection response in the four traits is more dependent on selection methods than on sets of economic values. Selection for an index of weight-gain and feed conversion gives 1.70 to 3.35 times the financial gain of selection for weight-gain only, depending on economic values. Selection for an index of weight-gain, slaughter yield and percentage abdominal fat gives 1.15 to 3.12 times the financial gain of selection for weight-gain, depending on economic values.

The extra financial gains of all selection methods exceed by far the estimated extra costs of the index selection methods.

INTRODUCTION

The breeding goal for broiler sire stock is not well defined quantitatively but body weight-gain per day is predominantly used in commercial broiler breeding programs. Selection for this breeding goal is carried out generally by selection for body weight at a fixed age with ad libitum feeding. However, weight-gain per day is not the only trait that determines the value of a broiler. The traits that determine the value of a broiler are not the same for producers of broilers, slaughter plants and consumers. For producers of broilers, weight-gain and feed conversion are important, for slaughter plants especially slaughter yields, whereas consumers can be interested in the fat content of broilers. It is therefore worthwhile to define the breeding goal for broiler sire stock more precisely.

The selection characteristic most commonly used, body weight at a fixed age with ad libitum feeding, is becoming less attractive because of two trends: the law of diminishing returns and the accumulating negative impact of traits correlated with body weight. Sørensen and Leenstra (1986) reported that the reduction in production costs obtained by selection for body weight is now 78% of what it used to be ten years ago. The correlation between weight-gain and fat deposition is low, but positive. The increasing amount of fat, especially fat deposited in the abdomen, is, therefore, one of the pronounced negative consequences of selection for body weight. Both trends justify the search for selection traits that can be used in addition to, or instead of, selection for body weight at a fixed age.

Alternative selection characteristics might be feed conversion, percentage abdominal fat and slaughter yield (Shalev and Pasternak, 1983, Leenstra, 1986). Abdominal fat and slaughter yield will be determined simultaneously. If one is measured, the other can be determined practically without extra costs. Among others, Pym and Nicholls (1979), Chambers et al. (1983) and Leenstra and Pit (1987a) indicated, that individual selection for feed conversion is effective. Leclercq et al. (1980), Cahaner et al. (1985) and Leenstra and Pit (1987a) found the same for sib selection for a low amount of abdominal fat. The genetic correlation between feed conversion and percentage abdominal fat is positive (r=0.5, Leenstra, 1987b). Therefore, feed conversion can be used to select a leaner broiler, while sib selection for a low percentage of abdominal fat improves feed conversion (Pym and Solvyns, 1979, Leclercq et al., 1980, Sørensen and Leenstra, 1986, Leenstra and Pit, 1987a).

Application of selection against fatness in a practical breeding program depends on costs and returns of the selection program. The costs of selection are mainly determined by the amount of labour required. The returns depend on the number of broiler progeny of selected stock and on the system by which breeding stock and broilers are marketed. In a integrated system, the returns at the level of the endproduct will be divided over all elements of the production chain. In a non-integrated system a breeding company will only increase the costs of selection more than its competitors, if breeding stock or one-day old broilers differ in price. One-day old broilers can differ in price primarily if differences in costs of rearing (mainly determined by weight-gain and feed conversion) or value of the slaughter ready broiler are present. The latter will occur primarily if differences in slaughter yield or carcass value due to consumers preference exist between groups of broilers.

In the current market situation fatness in general or abdominal fat in particular does not have a positive or negative economic value. As soon as a rapid method is available to judge a flock accurately on the fat content, it can be expected that fatness will be assigned a negative economic value. When expected developments in the determination of the value of broilers for a slaughter plant are taken into consideration, also in the non-integrated broiler production system, it can be advantageous to add feed conversion, slaughter yield and percentage of abdominal fat to weight-gain as breeding goal characteristics.

Cahaner and Nitsan (1985), in a simulation study, compared results of simultaneous selection (independent culling) for abdominal fat and body weight with single-trait selection. They assigned to one gram of abdominal fat a negative economic value that was five or ten times as high as that of one gram body weight. These values were based only on expected improvements in feed conversion due to the reduced fat content. With these values independent culling for body weight and abdominal fat gave theoretically higher economic gains than single trait selection for each of the characteristics. Cahaner and Nitsan (1985) assumed, however, that selection for abdominal fat could be carried out on an individuals own performance. The more realistic situation, in which abdominal fat is measured in sibs or indirectly in the chicken itself, was not discussed.

In the study reported here, slaughter yield and percentage abdominal fat are added to weight-gain and feed conversion as breeding goal characteristics. Own performance for body weight and feed conversion and full sib performance for slaughter yield and percentage of abdominal fat are used as selection characteristics. Based on phenotypic and genetic parameters reported by Leenstra (1985) and Leenstra and Pit (1987b), single- and two-stage index selection for combinations of the traits weight-gain, feed conversion, slaughter yield and percentage of abdominal fat are simulated.

The results of this selection are compared with those of selection for weight-gain only.

ASSUMPTIONS AND METHODS

Assumptions. Selection for the traits considered here is only carried out in sire lines. All traits inherite additively (Leenstra and Pit, 1987c). Effects of sex-linked inheritance and dominance and epistatic effects are assumed to be non-existent to keep the model for simulation simple. The generation interval with mass selection is 300 days. For sib testing, ten chickens per full sib family are used (Cunningham, 1969). It takes 28 days to collect hatching eggs for these ten chickens. Environmental covariances between sibs are zero.

For comparisons of financial results of selection methods, it is assumed that the selected sire stock (grantparent stock) is multiplied once before the broiler parent level: each selected female gives at least twenty male progeny. Each of these twenty cockerels is mated randomly to ten broiler dams and gives 1300 broilers. Every broiler shows half of the genetic merit of the sire stock. Selection response in the sire stock is multiplied by 20 x 1300 x .5 = 13000 at the broiler level, but for simplicity 10000 will be used.

Total selection intensity for the selection methods considered here is 2.419 (2%) for males and 1.755 (10%) for females (Flock, 1980).

Breeding goal and economic values. Broilers are in general slaughtered at a predetermined fixed weight. The characteristics included in the breeding goal are therefore weight-gain/day to a fixed body weight of 2014g, feed conversion for the entire rearing period and slaughter yield and abdominal fat as percentage of that fixed body weight.

Three different sets of economic values are assigned to these traits (Table 1). The economic values are in Dutch cents and based on the market situation in the Netherlands of December 1986. The values are calculated for a "standard" chicken of 2014 g. This chicken gains 47g/day between hatching and 42 days of age (1974g in total). It has a feed conversion of 1.90, a slaughter yield of 65% (abdominal fat not included) and 2.40% abdominal fat. An increase in gain/day to a fixed weight implies a reduction in slaughter age. Costs for housing and labour/day/chicken are 1.3ct. An increase in gain/day of one gram reduces slaughter age by .875 day. This has an economic value of 1.138ct.

A reduction in feed conversion of .1 implies 197.4g of feed used less. At a feed price of 70ct/kg, the economic value of feed cnversion is thus 138.18ct. The value of slaughtered chickens is 375ct/kg. Slaughter yield as percentage of live body weight is assigned a value of zero (only live weight has an economic value) or 7.55ct/% (.01 x 2014 x .375ct). Abdominal fat is given a value of either zero or -10ct/%. In the present situation, fatness has no clear economic value. A good estimate of the correlation between fat content and value of the carcass is not available. A decrease in abdominal fat implies a decrease in the size of other fat depots (Leenstra and Pit, 1987a) and can thus imply an increase in meat yield. The economic value of -10ct/% for abdominal fat is based on the assumption that meat yield increases with 2% if abdominal fat decreases with 1% and an average price of broiler meat of 500ct/kg.

Table 1: Sets of economic values assigned to the characteristics in the breeding goal in ct/unit/chicken at a fixed weight of 2014g.

Characteristic	Set 1	Set 2	Set 3
Gain/day (g)	1.138	1.138	1.138
Feed conversion	-138.18	-138.18	-138.18
Slaughter yield (%)	0	7.55	7.55
abdominal fat (%)	0	0	-10.00

Selection methods. The traits in the breeding goal, determined at a fixed weight, are not suited for a selection index. For selection, data collected at or until a fixed age are used. In this study it is assumed that body weight, slaughter yield and percentage of abdominal fat, determined at 42 days of age, provide accurate estimates for gain/day to, and for slaughter yield and percentage abdominal fat at the weight of 2014g. Genetic and phenotypic correlations between these traits determined at a fixed age are also assumed to be equal to parameters estimated from data determined at a fixed body weight. The genetic and phenotypic parameters used in this study are based on data of Leenstra (1985) and Leenstra and Pit (1987b) and are given in Table 2.

Table 2: Mean, standard deviation (s.d.), heritability (diagonal), phenotypic (above diagonal) and genetic correlations (below diagonal) for body weight at 3 weeks, gain/day to a body weight of 2014g at 6 weeks, slaughter yield (%) and percentage of abdominal fat, and feed conversion between 3 and 6 weeks.[1)]

			Traits				
Traits	Mean	s.d.	BW3wk	G/day	%Sl.y	%Ab.f	FC
Body weight 3wk (g)	500	50	.35	.60	.20	.20	.35
Gain/day (g)	47	4.70	.60	.25	.25	.25	-.25[2)]
Slaughter yield (%)	65.00	1.65	.10	.25	.40	-.10	0
Abdominal fat (%)	2.40	.60	.25	.25	-.20	.40	.20
Feed conversion	1.90	.10	.70	-.25[2)]	-.25	.50	.40

1) Source: Leenstra (1985) and Leenstra and Pit (1987b).

2) Besides a phenotypic and genetic correlation between weight gain and feed conversion of -.25 also a value of -.50 is used.

Individual feed conversion between 21 and 42 days of age can be used to estimate feed conversion from hatch to 42 days of age (Leenstra and Pit, 1987a). Estimates of the phenotypic and genetic correlations between weight-gain and feed conversion to a fixed weight are not available. The rearing period to a fixed weight is prolonged if weight-gain/day is lower. This increases the amount of feed required for maintenance. Thus, it can be expected, that the correlation between weight-gain and feed conversion to a fixed weight is higher (i.e. closer to -1) than the correlation between these characteristics measured to a fixed age. Therefore it was decided to calculate selection responses with a genetic and phenotypic correlation of -.25 (estimated from data at a fixed age) and with an arbitrarily chosen value of -.50.

Three single-stage (Method 1, 2 and 4) and two two-stage (Method 3 and 5) selection methods are compared (Table 3). With Method 1, selection is on weight-gain/day only. For Methods 2 and 3 slaughter data of ten full sibs are included in the selection index. With Method 2 (single-stage) all chickens are selected on an index of weight-gain/day, slaughter yield and percentage abdominal fat. For Method 2, the chickens that are slaughtered have to be hatched before the chickens that are selected. Otherwise all chickens have to be kept and reared until slaughter data are available. With Method 2 the generation interval is, therefore, prolonged with 28 days.

Table 3: Characteristics used (+) as selection index traits for the five selection methods.

	Index characteristics				
Method	Body weight 3 wk (g)	Gain/day (g)	Slaughter yield (%)	Abdominal fat (%)	Feed conversion 3 to 6 wks
1, single-stage		+			
2, single-stage		+	+	+	
3, first stage		+			
second stage		+	+	+	
4, single-stage		+			+
5, first stage	+				
second stage	+	+			+

With selection Method 3, the chickens are selected in two stages. In the first stage selection is for weight-gain/day; in the second stage for an index of weight-gain/day, slaughter yield and percentage abdominal fat. Now only full sibs of chickens selected in the first stage have to be slaughtered. With Method 3, the generation interval is not prolonged; the slaughter data are collected after selection in the first stage is completed.

Feed conversion between three and six weeks of age is added to weight-gain/day for single-stage selection Method 4. All chickens are between three and six weeks of age housed in individual cages to determine feed conversion. With Method 5 the number of chickens that is tested for feed conversion is restricted. In the first stage of selection chickens are selected on a low three-week body weight. Chickens with a low three-week body weight have, on average, a better feed conversion than chickens with a high three-week body weight. This results in a genetic correlation between three-week body weight and feed conversion of + .70 (Leenstra, 1985). Only chickens selected on a low three-week body weight are tested for feed conversion in the second stage of selection with Method 5. In this second stage chickens are selected for an index of three-week body weight, weight-gain/day from 0 to 42 days of age, and feed conversion between 21 and 42 days of age.

For the two-stage selection methods (3 and 5), only a proportion of all families or chickens are tested for slaughter yield and percentage abdominal fat or feed conversion. Methods 3 and 5 are thus less laborious than Methods 2 and 4. To save labour, selection of males with Method 3, 4 or 5 can be combined with selection of females with Method 1. With Method 2 this is not the case as males and females are selected on the same set of slaughter data. With Method 3 selection of 4, 8 or 15% of the males in the first stage of selection is simulated. In these cases, females are selected with Method 1. Selection of males and females with Method 3 with 20% of the males and females selected in the first stage is also tested. With this option at least part of the sib data required in the second stage to select one sex are the same data as required to select the other sex.

For measurement of individual feed conversion, the number of cages and the amount of labour required are directly proportional to the number of chickens tested. Selection of males with Method 4 and females with Method 1 saves labour and requires less individual cages. Therefore, this option is tested besides selection of both males and females with Method 4. As Method 5 is meant to minimize labour, it is assumed that only 4, 8 or 15% of the males is tested in the second stage of selection for feed conversion, whereas females are selected on weight-gain (Method 1).

The different combinations of selection methods tested and estimates of the costs of labour are in Table 4. The costs for individual weighing are set at 40ct/chicken (300 chickens/hr with three people and salary costs of hfl 40/person/hr). For Method 2 it is assumed that from each full sib family, fifty chickens are hatched for selection. Ten additional chicks from each family will be slaughtered. This implies that for each chicken tested 0.2 chickens are slaughtered. Determination of slaughter yield and percentage abdominal fat takes for each chicken about 15 times as much labour as individual weighing. Applying Method 3 thus takes .2 x 15 = 3 times more labour than individual weighing. For Method 3 only sibs of chickens selected in the first stage are slaughtered. Applying Method 3 will never be more laborious than Method 2. More precise estimates cannot be made as the exact number of full sib families represented among the chickens selected in the first stage is not known.

For determination of feed conversion chickens and feed have to be weighed twice. Caging and management of the individually housed chickens also takes extra time. Determination of feed conversion will take approximately five times more labour than individual weighing.

Table 4: Estimated amount of labour required for selection relative to labour required for selection on body weight gain and costs of labour for selection per chicken (Method 1 = 100%).

Selection method[1]		Labour as percentage of method 1			Labour in cents/chick
♂	♀	♂	♀	Total	
1	1	100	100	100	40
2	2	400	400	400	160
3(4%)[2]	1	100 < x < 400	100	100 < x < 250	40 < x < 100
3(8%)	1	100 < x < 400	100	100 < x < 250	40 < x < 100
3(15%)	1	100 < x < 400	100	100 < x < 250	40 < x < 100
3(20%)	3(20%)	100 < x < 400	100 < x < 400	100 < x < 400	40 < x < 160
4	1	600	100	350	140
4	4	600	600	600	240
5(4%)	1	120	100	110	44
5(8%)	1	140	100	120	48
5(15%)	1	175	100	138	55

1) See Table 3.

2) Percentage selected in the first stage of selection.

Calculations. For calculations of selection responses per characteristic in the breeding goal and for the total financial gain per generation the formula's of Cunningham (1969 and 1975) and Brascamp (1984) are used. The response to selection with Method 2 is corrected for the increased generation interval.

RESULTS

The selection response per generation in each of the four characteristics in the breeding goal is illustrated in Figure 1. For simplification, not all combinations of selection methods are shown. The selection responses are dependent on selection methods, economic value of the traits and the correlation between weight-gain and feed conversion (r=-.25 or -.50). Highest response in weight-gain is obtained by selection with Method 1. Selection method 2 gives highest responses in slaughter yield, while Method 4 gives most improvement in feed conversion. Selection on an index of weight-gain and feed conversion (Method 4) is almost as effective or even more effective in reducing percentage abdominal fat as selection on an index including abdominal fat (Method 2).

Weight-gain, feed conversion and slaughter yield improve in all cases examined. The selection response in percentage abdominal fat is more variable. If selection is completely on weight-gain (Method 1) or almost completely on weight-gain (Method 3 with 4% selected in the first stage for males and Method 1 for females), the percentage of abdominal fat will increase. Selection Method 5 in males and 1 in females also can give an increase in abdominal fat percentage. In all other cases percentage abdominal fat reduces due to selection.

The effect of sets of economic values on selection response in weight-gain, slaughter yield and percentage of abdominal fat is greater than the effect of economic values on response in feed conversion.

The increase in the genetic and phenotypic correlation between weight-gain and feed conversion from -.25 to -.50 has a marked influence on the selection response in the four traits. In nearly all cases, the selection response in weight-gain and feed conversion is higher with the high correlation. When data on slaughter yield and abdominal fat are used for selection (Methods 2 and 3), the response in slaughter yield and percentage abdominal fat is generally reduced by the high correlation. The response in slaughter yield and abdominal fat increases due to the high correlation if selection is with Method 4 (index of weight-gain and feed conversion). With the correlation of -.50 and the two-stage selection Method 5, the response in slaughter yield and percentage abdominal fat depends very much on the economic value of the breeding goal traits.

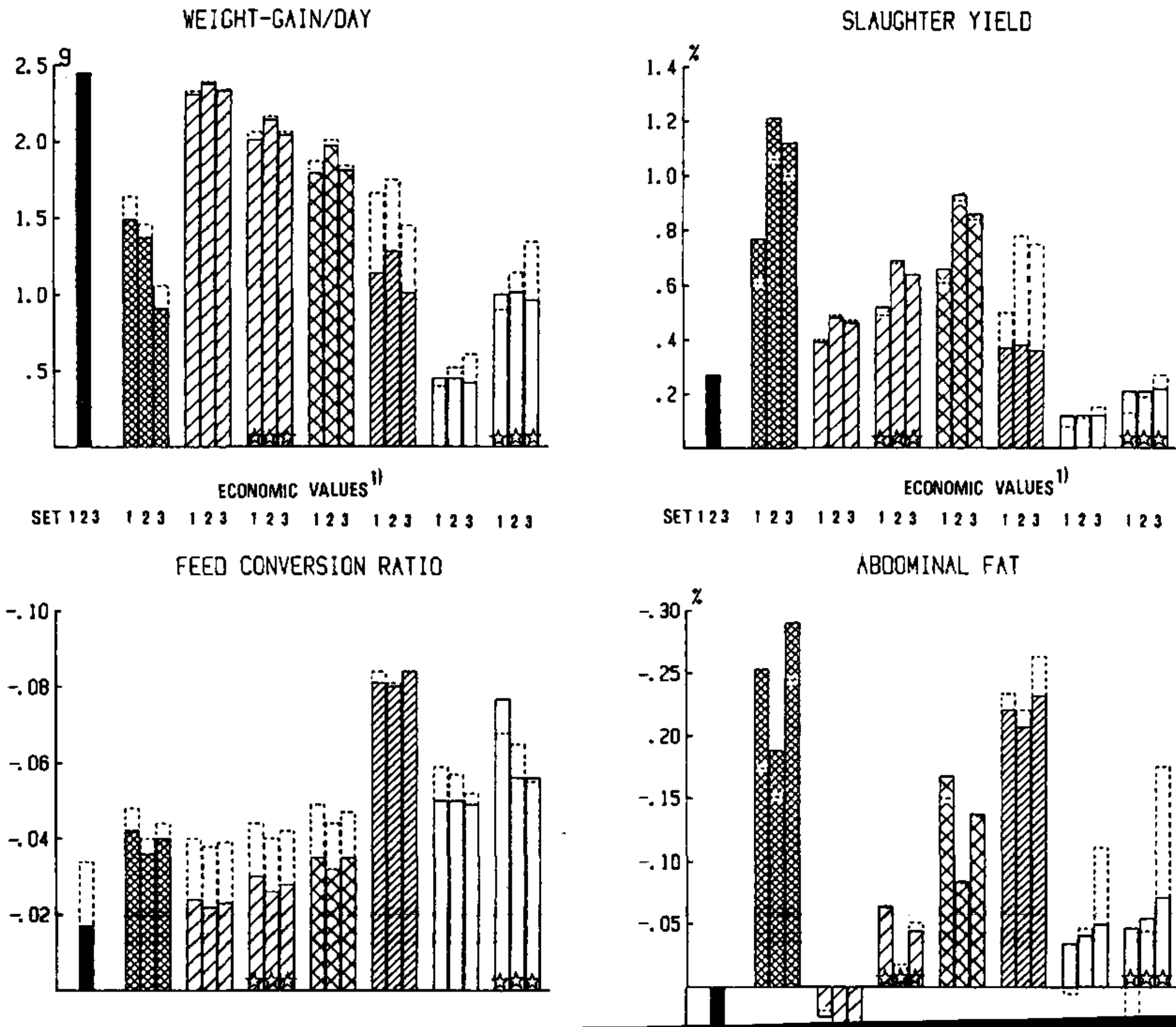
Table 5: Absolute financial gain in cents per generation if in total 2% of the males and 10% of the females are selected for a genetic and phenotypic correlation between weight gain and feed conversion (r) of -.25 and of -.50.

Selection method[2]		Economic values[1] Set 1		Set 2		Set 3	
♂	♀	r=-.25	r=-.50	r=-.25	r=-.50	r=-.25	r=-.50
1	1	5.05	7.33	7.10	9.37	6.09	8.39
2	2	7.94	8.44	16.42	15.17	18.99	17.19
3(4%)[3]	1	5.85	8.05	9.32	11.47	8.96	11.13
3(8%)	1	6.16	8.26	10.42	12.42	10.45	12.48
3(15%)	1	6.31	8.31	11.09	12.95	11.43	13.31
3(20%)	3(20%)	7.07	8.94	13.42	15.07	14.54	16.19
4	1	9.41	10.80	11.90	13.20	12.76	14.20
4	4	14.56	13.32	17.83	15.97	20.39	18.41
5(4%)	1	7.35	8.57	8.25	9.79	8.76	10.03
5(8%)	1	8.35	9.72	9.64	10.72	10.26	11.70
5(15%)	1	8.98	10.46	10.56	11.67	11.25	12.82

1) Set 1: Weight gain/day 1.138ct/g, feed conversion -138.18ct.
Set 2: Weight gain/day 1.138ct/g, feed conversion -138.18ct, slaughter yield 7.55ct.
Set 3: Weight gain/day 1.138ct/g, feed conversion -138.18ct, slaughter yield 7.55ct/%, abdominal fat -10ct/%.

2) See Table 2.

3) Percentage selected in the first stage of selection.



WEIGHT-GAIN/DAY
2.5 g
2.0
1.5
1.0
.5
ECONOMIC VALUES 1)
SET 1 2 3 1 2 3 1 2 3 1 2 3 1 2 3 1 2 3 1 2 3 1 2 3
SLAUGHTER YIELD
1.4 %
1.2
1.0
.8
.6
.4
.2
ECONOMIC VALUES 1)
SET 1 2 3 1 2 3 1 2 3 1 2 3 1 2 3 1 2 3 1 2 3 1 2 3
FEED CONVERSION RATIO
-.10
-.08
-.06
-.04
-.02
ABDOMINAL FAT
-.30 %
-.25
.20
-.15
-.10
-.05

Figure 1: Selection response per generation dependent on selection method, economic values and genetic correlation between weight-gain and feed conversion (solid line: r=-.25, broken line: r=-.50).

Selection methods	
Males	Females
Weight-gain = 1	1
Index of weight-gain, slaughter yield and abdominal fat = 2	2
Two stage: 1^{st} stage weight-gain; 2^{nd} stage index of weight gain, slaughter yield and abdominal fat = 3(4%[2)])	1
3(15%)	1
3(20%)	3(20%)
Index of weight-gain and feed conversion = 4	4
Two stage: 1^{st} stage 3-week body weight; 2^{nd} stage index of 3-week weight, weight-gain and feed conversion = 5(4%)	1
5(15%)	1

1) Set 1: Weight gain/day 1.138ct/g, feed conversion -138.18ct.
Set 2: Weight gain/day 1.138ct/g, feed conversion -138.18ct, slaughter yield 7.55ct/%.
Set 3: Weight gain/day 1.138ct/g, feed conversion -138.18ct, slaughter yield 7.55ct/%, abdominal fat -10ct/%.

2) Percentage selected in the first stage of selection.

Table 5 gives the total financial gain in cents/generation/chicken in the sire stock for combinations of selection methods, sets of economic values and correlations between weight gain and feed conversion. In Table 6 the financial gain is expressed relative to the financial gain obtained by selection Method 1. Adding selection characteristics to weight-gain improves financial gain for the three sets of economic values and both sets of correlations. Method 4 always gives the highest financial gain per generation. Financial gain per generation increases when the number of traits with an economic value different from zero increases.

Table 6: Financial gain relative to selection method 1 (selection for weight gain only) for a genetic and phenotypic correlation between weight gain and feed conversion (r) of -.25 and of -.50.

Selection method[2]		Economic values[1] Set 1		Set 2		Set 3	
♂	♀	r=-.25	r=-.50	r=-.25	r=-.50	r=-.25	r=-.50
1	1	100	100	100	100	100	100
2	2	157	115	231	162	312	205
3(4%)[3]	1	116	110	131	122	147	133
3(8%)	1	122	113	147	133	172	149
3(15%)	1	125	113	156	138	188	159
3(20%)	3(20%)	140	122	189	161	239	193
4	1	186	147	168	141	210	169
4	4	288	182	251	170	335	219
5(4%)	1	146	117	116	104	144	119
5(8%)	1	165	133	136	114	168	139
5(15%)	1	178	143	149	125	185	153

[1] Set 1: Weight gain/day 1.138ct/g, feed conversion -138.18ct.

Set 2: Weight gain/day 1.138ct/g, feed conversion -138.18ct, slaughter yield 7.55ct/%.

Set 3: Weight gain/day 1.138ct/g, feed conversion -138.18ct, slaughter yield 7.55ct/%, abdominal fat -10ct/%.

[2] See Table 2.

[3] Percentage selected in the first stage of selection.

Table 7: Percentage reduction in financial gain for multiple trait selection methods if a characteristic is deleted from the index for a genetic correlation between body weight and feed conversion (r) of -.25 or -.50.

Characteristic deleted	Selection method 2[1]						2nd stage selection method 3					
	r=-.25			r=-.50			r=-.25			r=-.50		
	Set 1	Set 2	Set 3[2]	Set 1	Set 2	Set 3	Set 1	Set 2	Set 3	Set 1	Set 2	Set 3
Gain/day (g)	27.7	9.3	5.5	41.3	15.4	10.0	7.4	2.0	1.1	13.6	3.7	2.1
Slaughter yield (%)	5.1	35.1	25.8	2.8	28.4	22.2	8.2	45.0	29.1	5.8	41.5	27.3
Abdominal fat (%)	20.4	5.4	15.5	14.2	5.1	14.6	35.2	6.5	17.3	32.2	6.9	17.7
	Selection method 4						2nd stage selection method 5					
Body weight 3wk (g)	-	-	-	-	-	-	2.4	.7	.2	7.3	.6	3.2
Gain/day (g)	1.3	2.6	.5	.2	.5	.1	7.3	4.6	1.0	9.8	1.2	4.3
Feed conversion	59.8	53.9	65.3	44.9	41.2	54.4	12.5	17.3	27.5	.8	1.4	18.4

1) See Table 2.

2) Set 1: Weight gain/day 1.138ct/g, feed conversion -138.18ct.

Set 2: Weight gain/day 1.138ct/g, feed conversion -138.18ct, slaughter yield 7.55ct/%.

Set 3: Weight gain/day 1.138ct/g, feed conversion -138.18ct, slaughter yield 7.55ct/%, abdominal fat -10ct/%.

The correlation between weight-gain and feed conversion (-.25 or -.50) has a large influence on absolute and relative financial gains. The financial gains due to selection Methods 1, 3 and 5 are higher and those due to Methods 2 and 4 lower when the correlation between weight gain and feed conversion is -.50 instead of -.25. Adding selection characteristics to weight-gain has relatively more effect if the correlation between weight-gain and feed conversion is low than when it is high.
The index traits differ in their relative contribution to the total financial gain. Table 7 gives the percentage reduction in financial gain when a characteristic is deleted from the multiple trait selection methods (Methods 2 and 4, and the second stage of Methods 3 and 5). If slaughter yield has an economic value of 7.55ct/%, it is far more important as index trait in Methods 2 and 3 than weight-gain or abdominal fat. If the slaughter data have an economic value of zero percentage abdominal fat is important because of its positive correlation with feed conversion.
Financial gain due to selection with an index of weight-gain and feed conversion (Method 4) is hardly reduced if weight-gain is deleted as index trait. In the second stage of selection Method 5, however, weight-gain is valuable as index characteristic.

DISCUSSION

The three sets of economic values used in this study are only one choice out of numerous possibilities. The values for slaughter yield (0 and 7.55) and percentage of abdominal fat (0 and -10), however, are quite extreme. Analysis of the response obtained for each characteristic with the three sets of economic values can provide indications about the applicability of the results for various market situations. The financial gain per generation for the different economic values in relation to estimates of the amount of labour, indicates whether selection methods other than for weight-gain only, are beneficial and whether a reduction in percentage abdominal fat by selection is economically feasible.
Response per trait. The response in each of the characteristics appears to depend more on selection methods than on economic values assigned to the traits (Figure 1). The effect of set of economic values on selection

response is small in nearly all cases. The response in percentage abdominal fat due to selection Method 5, with a correlation between weight-gain and feed conversion of -.50, is the only exception. This implies that the results of the simulated selection carried out here are valid for a wider range of market situations. This agrees with studies of Rønningen (1971), Vandepitte and Hazel (1977) and Smith (1983), that the results of index selection are rather independent of variations in economic values of the traits in the breeding goal.

The responses in body weight vary less with selection methods than the responses in the other traits. The difference between the highest and the lowest response in each of the traits expressed in units of their standard deviation (Table 2) is for weight-gain .43σ (r=-.25) or .44σ (r=-.50); for feed conversion, .67σ (r=-.25) or .46σ (r=-.50); and for slaughter yield and percentage abdominal fat it varies between .57σ and .65σ for each correlation. The relatively low variability in response in weight-gain is because weight-gain is present in each selection index examined.

Relative to the mean value of the traits, the maximum response in percentage abdominal fat is large (12.1% of the mean). The maximum response in weight-gain is 5.1% of the mean, that in feed conversion 4.4% and that in slaughter yield only 1.9% of the average slaughter yield.

Two-stage selection method 3 in males only gives a minor decrase or an increase in percentage abdominal fat. The positive correlation between weight-gain and percentage of abdominal fat and the selection for weight-gain in the first stage of Selection method 3 prevent a large decrease in amount of abdominal fat. If males and females are selected with Method 3 and selection intensity in the first stage is low, Method 3 can be used to reduce percentage abdominal fat. In relatively lean chickens, the genetic correlation between weight-gain and percentage of abdominal fat is higher than the one used in this study (Leenstra and Pit, 1987b). It can be expected, therefore, that the reduction in percentage abdominal fat due to selection Method 3 will decrease as selection proceeds.

Noteworthy is the response in feed conversion if selection is by Method 5. In the first stage of selection, chickens with a low three-week body weight are selected. Due to their lower maintenance requirements in the second part of the rearing period these chickens have a favorable feed conversion

(Pasternak and Shalev, 1983) but also a low six-week body weight. It is questionable whether selection for a low three-week body weight has positive results under practical circumstances. It is likely that more subclinically diseased chickens are present among those selected for a low three-week body weight than among a random sample. The phenotypic and genetic correlations between three-week body weight and feed conversion used here are estimated in data from a random sample of chickens. Whether these are valid for chickens selected on a low three-week body weight is a point for further examination.

The arbitrarily chosen increase in the phenotypic and genetic correlation between weight-gain and feed conversion from -.25 to -.50 increases considerably the selection response in weight-gain and feed conversion with most selection methods. Estimates of the phenotypic and genetic correlation between weight-gain and feed conversion to a fixed body weight are required for a more accurate prediction of selection response in feed conversion and weight-gain.

Financial gain. Selection on an index of weight-gain and feed conversion gives about two (r=-.50) to three (r=-.25) times as much financial gain as selection for body weight only. Adding slaughter data to the selection index gives minor improvements in total financial gain if only weight-gain and feed conversion have an economic value (Economic data set 1) and the correlation between weight-gain and feed conversion is -.50. If, however, slaughter yield and/or percentage abdominal fat are used to determine the value of a broiler (Set 2 and 3), including these traits in the index gives almost the same results as adding feed conversion to weight-gain as an index characteristic.

Pym and James (1979) found an increase of only 20% in financial gain when five- to nine-week feed consumption was added to nine-week body weight as a selection criterion. Shalev and Pasternak (1983) predicted from a simulation study, that single-trait selection for feed conversion or growth rate had the same financial result. In each study the heritability of body weight was high compared to that of feed conversion whereas the economic value of feed consumption was relatively low in the study of Pym and James. In the study reported here, estimates of genetic parameters are based on data of chickens intensively selected for weight-gain. In this stock, genetic variation in weight-gain appeared to be smaller than that in feed conversion. The relatively low heritability of weight-gain increases the relative value of feed conversion as a selection characteristic.

It is surprising to note that the two-stage selection Methods 3 and 5 differ not much in financial gain from Methods 2 and 4. For Methods 2 and 3, this is largely due to the difference in generation interval between these methods (300 vs. 328 days). It is questionable if Method 3 can be carried out with less labour than Method 2. If 20% of the individuals is selected in the first stage on weight-gain, a large proportion of all families will be represented in the selected group. The number of chickens that has to be tested for slaughter data will not be much smaller than the number that has to be tested for selection with Method 3. For Method 5, the relatively high efficiency can be explained by the addition of three-week body weight to the selection characteristics. Selection on an index of low weight-gain in the first part of the rearing period and high weight-gain in the second part might be an interesting option for further examination.

Costs and returns of selection. The extra returns of selection methods other than that for weight-gain have to be compared with the costs of adding criteria to the selection index. Weight-gain is the only trait that can be deleted from the indices without great losses in financial gain (Table 7). However, weight-gain has to be known to determine slaughter yield, percentage abdominal fat and feed conversion and thus cannot be deleted.

The financial gain is expressed per chicken in the grantparent stock. The differences in financial gain at the broiler level are at least 10000 times as large, because of multiplication. Even the smallest increase in financial gain (Table 5, Method 5 for males, with 4% selected in the first stage and the economic values of Set 2) gives hfl 42 more financial gain per generation at the broiler level than selection for weight-gain only. The highest increase in financial gain (Method 4) at the broiler level is hfl 559, hfl 660 and hfl 1002 for economic data Sets 1, 2 and 3, respectively, per generation and per selected chicken for the higher correlation between weight-gain and feed conversion. For the lower correlation between weight-gain and feed conversion these values are hfl 951, hfl 1073 and hfl 1430. The extra costs of labour for selection other than with Method 1, varying between 4 and 200ct/chicken, are negligible compared to the extra returns. Thus, whether alternative selection methods are applied is not a matter of costs and returns of selection per se. An important factor in this respect is the availability of individual cages for measurement of feed consumption and/or a small-scale slaughter plant that can be used to determine slaughter data in pedigree chickens. Considering the expected results of selection at least one of these facilities should belong to the standard equipment for commercial broiler breeding. More knowledge about the physiological basis of differences between chickens in feed conversion and slaughter yield could provide selection criteria that are easier to apply than individual determination of feed conversion or slaughter data.

Most interesting as a selection characteristic is feed conversion. In every market situation, feed costs determine the majority of the production costs of broiler meat. Selection for a low three-week body weight, followed by selection for an index of three-week body weight, weight-gain and feed conversion is the most attractive selection method for practical application. The positive results of Selection method 5 are, however, not yet confirmed by experimental selection, whereas single-stage selection for feed conversion already has proven to be worthwhile in selection experiments (Pym, 1985, Leenstra and Pit, 1987a).

Adding slaughter data as a selection characteristic is especially advantageous if slaughter quality has an economic value. Until now, fatness is mentioned by everyone involved in poultry meat production as a main problem. Still, little is known about the relations between fatness, the quality of broilers for further processing and sensory characteristics of broilers. This and the lack of methods for grading broilers for fatness fast and objectively has not allowed a generally accepted economic value for broiler fat content to be used. Even the effects of amount of depot fat on slaughter yield are not well known. The economic value of -10ct/% abdominal fat, based on an increase in meat yield of 2% per percent reduction in abdominal fat (Set 3), causes only minor extra responses in percentage abdominal fat compared to selection for Economic data set 1. The main effect of an index in which slaughter data are included is on slaughter yield and not on abdominal fat. To reduce fatness by selection it is not necessary to assign an economic value to abdominal fat. The economic importance of feed conversion and the high positive correlation between feed conversion and fat content can guarantee a large reduction in percentage of abdominal fat by selection on feed conversion.

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SUMMARY

Low fat content is one of the favourable properties of poultry meat. Chickens, however, deposit also fat in depots, of which the abdominal fat is the largest and most wasteful one. Abdominal fat reduces slaughter yields or when not removed it can give poultry meat a fatty image.
In Chapter 1, the literature on fat deposition in young chickens is reviewed. The total amount of fat deposited and the ratio between total fat and abdominal fat can be changed by nutritional and genetic means. The effects of environmental factors such as housing design, temperature and lighting regimes on fat deposition are too small to be useful for preventing excessive fat deposition. Most important among nutritional factors is the ratio between energy and protein in the diet. In the long term, selection appears to be an appropriate solution to the problem of excessive fat. The possibilities and the consequences of selection against abdominal fat are the subject of the experimental work reported here. We used a broiler sire strain for the selection experiment, as under practical circumstances selection against fatness will be applied in sire material rather than in dam strains.

In Chapter 2, the population from which selection started is described. In the broiler sire strain chosen for the project, percentage abdominal fat does show genetic variation (h^2=.41). Percentage abdominal fat (coefficient of variation 25%) is phenotypically far more variable than total fat content (c.v. 12%), protein content (c.v. 4%), or live body weight (c.v. 8%). The percentage of abdominal fat is dependent on sex and age. Females are fatter than males; older chickens are fatter than younger ones. The variability in body composition is, however, not influenced by sex or age.
The genetic correlation between percent abdominal fat and body weight with ad libitum feeding is positive, but close to zero (r=-.01 or .04 if the genetic correlation is estimated as the correlation between family means, and .21 when estimated from analysis of covariance). Percentage abdominal fat is negatively correlated with body weight after restricted feeding (r=-.12 or -.24 when estimated from family means) and positively with feed

conversion (feed consumed/ weight gained, r=.19 or .29 when estimated from family means).
Based on these data, four lines were selected from a broiler sire strain. The lines and their selection criteria are:

- -sib performance for amount of abdominal fat relative to body weight at six weeks of age with group-housing and ad libitum feeding (AF line);
- -feed conversion between three and six weeks of age of individually housed and ad libitum fed chickens (FC line);
- -body weight at six weeks of age with group-housing and restricted feeding (GR line);
- -body weight at six weeks of age with group-housing and ad libitum feeding (GL line).

The results of the selection experiment are described in Chapter 3. After four generations of selection the lines are compared at equal age on body weight, percentage of abdominal fat, feed conversion, slaughter yield and chemical composition. The lines are for the comparison reared in groups on litter as well as individually in cages. Ranking of the lines is the same for both environments for all traits examined. Lines GR and GL hardly differ, whereas lines AF and FC have significantly lower body weights (respectively -293g and -228g), less abdominal fat (-1.45% and -1.00%), better feed conversion (-.11 and -.17) and higher slaughter yields (.50% and .70%). AF and FC chickens tend to have a higher percentage of breast meat (.30% and .70%) and heavier legs (.50% and .30%) than GL chickens.
AF and FC chickens contain more water and less fat in whole and ready-to-cook chickens and in thigh and breast meat. The differences in fat content in the edible parts between the lines are smaller than those in abdominal fat content, but significant. Fat content is an important factor in determining sensory properties of meat. Research on the relation between fat content of poultry meat, sensory characteristics and consumers attitude is required to establish if the differences in fat content of meat due to the reduced abdominal fat content affect palatibility of poultry meat and consumers preference.

The data of the litter and cage housed chickens of the four lines are determined in pedigreed individual chickens. The data are therefore suitable to examine if selection has influenced genetic parameters of body weight, feed conversion and percent abdominal fat. The results of this analysis are described in Chapter 4. The estimates of genetic parameters for the four lines combined are of the same magnitude for litter and cage housed chickens. The heritability of percent abdominal fat (litter: .53; cages: .45) and feed conversion (cages: .44) is relatively high compared to the heritability of body weight (litter: .27; cages: .22).
Analysis within line and sex indicates that in the fatter GR and GL lines, sex-linked inheritance can be involved for abdominal fat. In the leaner AF and FC birds this is not the case. Genetic correlations did not differ between sexes. In the AF and FC line the genetic correlation between body weight and percent abdominal fat is higher (AF: .80; FC: .76) than in the GR (.14) and GL line (.68).

In Chapter 5 the performance of broiler progeny of sires of the selection lines and commercial broiler breeder dam stock is discussed. The broiler progeny shows differences that are about half as large as the differences that were found between the pure lines, when compared at six weeks of age. At a comparable body weight (AF progeny 1893g, FC progeny 1918g, GR progeny 1848g and GL progeny 1897g) the percentage of abdominal fat is lowest among AF progeny (1.76%), followed by FC progeny (2.23%), GL progeny (2.91%) and GR progeny (3.10%). Feed conversion is most favourable for FC progeny (1.72); AF and GL progeny do not differ (1.77) and GR progeny has the poorest feed conversion (1.79). Slaughter yield is, as in the pure lines, higher among AF and FC progeny (respectively 62.5% and 62.9%) than among GR and GL progeny (62.3% and 62.1%). In the data of the broiler progeny there are no indications that selection affects male and female chickens in a different way.
From the results of the comparisons among the pure lines and their broiler progeny it is concluded that body weight after restricted feeding is not useful as selection characteristic to obtain chickens with less abdominal fat. Feed conversion and amount of abdominal fat determined in slaughtered chickens can be interesting traits to add to weight gain as selection

characteristics. This is further examined with simulated selection. The results of the simulation study are reported in Chapter 6.

In the simulation study phenotypic and genetic parameters based on estimates from the selection experiment are used. One set of heritabilities of and correlations between weight gain, feed conversion, slaughter yield and percentage of abdominal fat is chosen, but the correlation between weight gain and feed conversion is varied. Only estimates of this correlation to a fixed age are available, while for simulation for a commercial breeding goal this correlation to a fixed body weight is required. Besides the correlation between weight gain and feed conversion to a fixed age of -.25 the arbitrarily chosen value of -.50 is used. The genetic correlation between weight-gain and percent abdominal fat depends on the mean fat content of the chickens examined. For this study the lower correlation of the fat GR and GL line is taken. Further research on the variability that exists in genetic parameters between genetically different groups of chickens should however be carried out.
Three sets of economic values are assigned to the traits that form the breeding goal in this study (weight-gain, feed conversion, slaughter yield and percentage of abdominal fat). The economic values of weight-gain and feed conversion are not varied, while slaughter yield has a positive or zero value and percent abdominal fat a negative or zero value.
When selection is completely or almost completely (two stage selection with weight-gain as first stage characteristic and an index of weight-gain, slaughter yield and abdominal fat as second stage) on weight-gain, percentage of abdominal fat increases. If selection is on an index of weight-gain, slaughter yield and abdominal fat or of weight-gain and feed conversion, percent abdominal fat decreases. Weight-gain, feed conversion and slaughter yield improve with all selection methods examined. Due to the positive correlation between feed conversion and percentage of abdominal fat, index selection for weight-gain and feed conversion gives the same reduction in percent abdominal fat as index selection for weight-gain, slaughter yield and abdominal fat.
Selection response in the four traits is more dependent on selection methods than on economic values. Selection on an index of weight-gain and

feed conversion gives 1.70 to 3.35 times the financial gain of selection for weight-gain only, dependent on economic values. Selection on an index of weight-gain, slaughter yield and percentage of abdominal fat gives 1.15 to 3.12 times the financial gain of selection for weight-gain.
The extra financial gains of the index selection methods at the broiler level (varying between hfl 42 and hfl 1430 per generation and chicken in the selected grantparent stock) by far exceed the estimated extra costs of measuring more selection characteristics than weight-gain only (maximally hfl 2.00 per chicken in the selected stock).

To reduce fatness by selection it is not necessary to assign a negative economic value to percentage of abdominal fat. Due to its high economic value, feed conversion is worthwhile to add to weight-gain as selection characteristic in broiler sire stock. As soon as feed conversion is used as selection characteristic, a decrease in percentage of abdominal fat is guaranteed by the high positive correlation between feed conversion and percentage of abdominal fat.

SAMENVATTING

Een gunstige eigenschap van pluimveevlees is het lage vetgehalte. Slachtkuikens zetten echter ook vet aan in aparte depots, waarvan buikvet het grootste en meest hinderlijke is. Buikvet verlaagt het slachtrendement en het kan pluimvee vlees een vet image geven, als het niet verwijderd wordt.
In Hoofdstuk 1 wordt de literatuur over vetaanzet bij kuikens samengevat. De totale hoeveelheid vet in een kuiken en de verhouding tussen totaal vet en buikvet kan worden beïnvloed door voeding en fokkerij. De invloed van omgevingsfaktoren op overmatige vetaanzet, zoals stalinrichting, temperatuur en lichtschema is te gering om van praktisch nut te zijn bij het voorkomen ervan. De belangrijkste voedingsfaktor in relatie tot vetaanzet is de verhouding tussen energie en eiwit. Op langere termijn is echter selektie de meest aangewezen weg om het probleem op te lossen van overmatige vetaanzet bij slachtkuikens. De mogelijkheden en de konskwenties van selektie tegen buikvet zijn nader onderzocht in een selektieexperiment. Voor het onderzoek werd slachtkuikenvadermateriaal gekozen, omdat onder praktijkomstandigheden selektie tegen vetaanzet ook in vadermateriaal uitgevoerd zal worden.

Hoofdstuk 2 beschrijft het uitgangsmateriaal voor het selektieexperiment. In het gebruikte slachtkuikenvader materiaal komt erfelijke variatie voor in het percentage buikvet (h^2 = 0,41). De hoeveelheid buikvet (variatiecoëfficiënt 25%) vertoont fenotypisch aanzienlijk meer spreiding dan de totale hoeveelheid vet (v.c. 12%), de hoeveelheid eiwit (v.c. 4%) of het levend gewicht (v.c. 8%). Het percentage buikvet is afhankelijk van leeftijd en sexe van de kuikens. Hennen zijn vetter dan hanen en oudere dieren zijn vetter dan jonge. De variatiecoëfficiënten voor lichaamssamenstelling zijn niet afhankelijk van leeftijd of geslacht.
De genetische correlatie tussen percentage buikvet en levend gewicht bij volop voedering is positief, maar nauwelijks afwijkend van nul (r=-0,01 of 0,04 als de genetische correlatie geschat wordt als de correlatie tussen gemiddelde waarden per familie en 0,21 als de correlatie uit covariantie analyse geschat wordt). Het percentage buikvet is negatief gecorreleerd met

levend gewicht na beperkte voedering (r=-0,12 of -0,24, berekend uit familiegemiddelden) en positief met voederconversie (=voederconsumptie/ gewichtstoename, r=0,19 of 0,29, berekend uit familiegemiddelden).
Op grond van deze gegevens zijn uit een slachtkuikenvaderlijn vier selektielijnen gevormd. De lijnen en hun selektiekenmerken zijn:

- percentage buikvet per volle broer zuster familie op zes weken leeftijd bij groepshuisvesting en volop voedering (AF lijn);
- voederconversie van drie tot zes weken leeftijd bij individuele huisvesting en volop voedering (FC lijn);
- levend gewicht op zes weken leeftijd bij groepshuisvesting en beperkte voedering (GR lijn);
- levend gewicht op zes weken leeftijd bij groepshuisvesting en volop voedering (GL lijn).

In Hoofdstuk 3 worden de resultaten van de selektie besproken. Na vier generaties selektie zijn de lijnen bij gelijke leeftijd vergeleken op levend gewicht, percentage buikvet, voederconversie, slachtrendement en chemische samenstelling. De kuikens zijn in die vergelijking zowel in groepen op strooisel, als individueel in kooien opgefokt. De rangorde van de lijnen is identiek voor alle onderzochte kenmerken in beide opfokmilieus. Uit de resultaten blijkt, dat de GR en GL lijn nauwelijks verschillen, terwijl de AF en FC lijn significant lichter zijn (resp. -293g en -228g), minder buikvet hebben(-1,45% en -1,00%), een gunstiger voederconversie (-0,11 en -0,17) en hogere slachtrendementen (0,50% en 0,70%). AF en FC kuikens lijken relatief meer borstvlees te hebben (0,30% en 0,70%) en zwaardere poten (0,50% en 0,30%) te hebben dan GL kuikens.
AF en FC kuikens bevatten meer water en minder vet, zowel in heel en grillklaar kuiken als in borst- en dijvlees. De verschillen tussen de selektielijnen in vetgehalte in het eetbare deel van het kuiken zijn relatief kleiner dan die in percentage buikvet, maar wel significant. Het vetgehalte is een bepalende faktor als sensorische eigenschappen van vlees beschouwd worden. Onderzoek is nodig naar de relatie tussen vetgehalte van pluimveevlees, sensorische eigenschappen en de houding van de consument om vast te stellen of verschillen in vetgehalte van het vlees, ontstaan door selektie tegen buikvet, van invloed zijn op de waardering door de consument.

De gegevens van de op strooisel en in kooien gehuisveste kuikens van de vier lijnen zijn per dier verzameld. De gegevens kunnen daardoor ook worden gebruikt om na te gaan of selektie de erfelijkheidsgraad van - en de genetische correlaties tussen - gewicht, percentage buikvet en voederconversie beïnvloedt. De resultaten van deze analyse zijn beschreven in Hoofdstuk 4. De schattingen van de erfelijkheidsgraden op basis van de gecombineerde gegevens van de vier lijnen zijn van gelijke grootte voor op kooien en op strooisel gehuisveste kuikens. De h^2 voor percentage buikvet (strooisel: 0,53; kooien: 0,45) en voederconversie (kooien: 0,44) is relatief hoger dan die voor gewicht (strooisel: 0,27; kooien: 0,22).
Analyse binnen lijn en sexe laat zien, dat bij de vettere GR en GL lijn geslachtsgebonden vererving een rol kan spelen bij buikvet. Bij de minder vette AF en FC lijn is dat niet het geval. Sexe is niet van invloed op de genetische correlaties. Bij de AF en FC lijn is de genetische correlatie tussen gewicht en percentage buikvet hoger (AF: 0,80; FC: 0,76) dan bij de GR en GL lijn (GR: 0,14; GL: 0,68).

In Hoofdstuk 5 worden de resultaten van een vergelijking van kuikens uit een kruising van hanen van de selektielijnen met commerciële slachtkuikenmoederdieren gegeven. Nakomelingen uit deze kruising vertonen, indien vergeleken op zes weken leeftijd, verschillen, die ca. half zo groot zijn als de verschillen, die tussen de zuivere lijnen gevonden worden. Bij een vergelijkbaar gewicht (AF nakomelingen 1893g, FC nakomelingen 1918g, GR nakomelingen 1848g en GL nakomelingen 1897g) is het percentage buikvet het laagst bij AF nakomelingen (1,76%), gevolgd door FC kuikens (2,23%), GL kuikens (2,91%) en GR kuikens (3,10%). Voederconversie is het gunstigst voor de FC nakomelingen (1,72); AF en GL nakomelingen verschillen niet (1,77), terwijl de GR nakomelingen de slechtste voederconversie hebben (1,79). Net als bij de zuivere lijnen, is het slachtrendement hoger bij AF en FC nakomelingen (resp. 62,5% en 62,9%) dan bij GR en GL nakomelingen (62,3% en 62,1%). De gegevens van de slachtkuikennakomelingen geven geen aanleiding te vermoeden, dat selektie tegen vetaanzet verschillende resultaten geeft voor hanen en hennen.
Uit de resultaten van de vergelijkingen van de zuivere lijnen en hun nakomelingen is geconcludeerd, dat het kenmerk gewicht bereikt met beperkte

voedering niet bruikbaar is om kuikens met een geringere vetaanzet te selekteren. De kenmerken voederconversie en percentage buikvet bepaald in geslachte dieren zijn wel interessant om naast gewicht voor selektie te gebruiken. Met behulp van gesimuleerde selektie werd dit verder onderzocht. De resultaten van de gesimuleerde selektie worden in Hoofdstuk 6 besproken.

In het simulatie onderzoek zijn fenotypische en genetische parameters gebruikt, die gebaseerd zijn op schattingen uit het selektieexperiment. Eén set van erfelijkheidsgraden van en correlaties tussen groei, voederconversie, slachtrendement en percentage buikvet is gekozen. Alleen de correlatie tussen groei en voederconversie is gevariëerd. Slechts schattingen op een vaste leeftijd zijn beschikbaar, terwijl voor simulatie voor een commercieel fokdoel de correlatie bij een vast eindgewicht interessanter is. Naast de correlatie tussen groei en voederconversie op een vaste leeftijd van -0,25 is daarom ook als alternatief de arbitrair gekozen waarde van -0,50 gebruikt. De genetische correlatie tussen het percentage buikvet en het levend gewicht blijkt afhankelijk te zijn van het gemiddelde vetgehalte van de kuikens. In dit onderzoek is de lagere correlatie op basis van de vettere GR en GL kuikens gebruikt. Meer onderzoek naar het voorkomen van spreiding in genetische parameters tussen genetisch verschillende groepen is echter gewenst om tot duidelijker uitspraken te komen.
De kenmerken groei, voederconversie, slachtrendement en percentage buikvet vormen het fokdoel in dit onderzoek. Drie series van economische waarden zijn aan de kenmerken toegekend. De economische waarde voor groei en voederconversie zijn niet gevarieerd. Aan het slachtrendement is een positieve of geen waarde toegekend en aan het percentage buikvet een negatieve of geen waarde.
Als selektie volledig of vrijwel volledig (twee fase selektie, met als eerste fase selektie op groei en als tweede fase selektie op een index van groei, slachtrendement en buikvet) gebeurt op basis van groei, neemt het percentage buikvet toe. Als geselekteerd wordt op een index van groei, slachtrendement en buikvet, danwel van groei en voederconversie, neemt het percentage buikvet af. Groei, voederconversie en slachtrendement verbeteren bij alle onderzochte selektiemethoden. Door de positieve correlatie tussen

buikvet en voederconversie geeft indexselektie voor groei, slachtrendement en buikvet dezelfde afname in het percentage buikvet als selektie op een index van groei en voederconversie.
De selektie respons in de vier kenmerken is meer afhankelijk van de toegepaste selektiemethoden dan van de series economische waarden. Selektie op een index van groei en voederconversie geeft, afhankelijk van de economische waarden, 1,70 tot 3,35 keer zoveel financiële vooruitgang als selektie op groei alleen. Selektie op een index van groei, slachtrendement en percentage buikvet geeft, afhankelijk van de economische waarden, 1,15 tot 3,12 keer zoveel financiële vooruitgang als selektie op groei. Als de financiële vooruitgang berekend wordt op slachtkuiken niveau, dus na vermenigvuldiging van het geselekteerde materiaal, zijn de geschatte extra kosten van de indexselektie (hooguit enkele guldens per dier in de te selekteren populatie) te verwaarlozen vergeleken bij de extra financiële vooruitgang als gevolg van de index selektie (varierend van 42 tot 1430 gulden per dier per generatie in het geselekteerde grootoudermateriaal).

Om de hoeveelheid buikvet via een selektieprogramma te verminderen is het niet noodzakelijk in het fokdoel een negatieve economische waarde aan percentage buikvet toe te kennen. Het is evenmin noodzakelijk de hoeveelheid buikvet in het fokmateriaal te bepalen. Het opnemen van voederconversie als selektiekenmerk voor slachtkuikenvaderlijnen is, door het economisch belang van een gunstige voederconversie, meer dan verantwoord. De positieve correlatie tussen voederconversie en het percentage buikvet garandeert dat, zodra direkt op voederconversie geselekteerd wordt, het percentage buikvet afneemt.

CURRICULUM VITAE

Fetsje Rieme Leenstra werd geboren op 14 augustus 1954 te Drachten (Fr.). In 1972 behaalde zij het diploma HBS-B aan de Rijks Scholen Gemeenschap te Leeuwarden. In datzelfde jaar begon zij met haar studie Zoötechniek aan de Landbouwhogeschool te Wageningen. Deze studie werd in januari 1979 afgesloten met als hoofdvakken de Veeteelt en de Gezondheids- en Ziekteleer der Huisdieren en als bijvak de Erfelijkheidsleer. Sinds december 1978 is zij in dienst van het Ministerie van Landbouw en Visserij als wetenschappelijk medewerker op het gebied van de fokkerij bij het Centrum voor Onderzoek en Voorlichting voor de Pluimveehouderij "Het Spelderholt" te Beekbergen.