2. Following addition of ferrous sulphate to the diet, and a simultaneous increase in its calcium content, already high, there was no recurrence of the outbreak.

3. Adult males or non-pregnant females showed few, if any, signs of reduction in red blood-cell count when they received the same diet as the slightly anaemic pregnant does and the markedly anaemic weanlings.

4. No animals, infant or adult, in a colony of piebald rats, kept alongside, under the same conditions and on the same diet as the albinos, showed any adverse effects of identical reduced iron intake and alteration of diet.

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Nutrition of Domestic Rabbits

3. Variations in Carcass Composition of Rabbits Reared for Meat

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(*Received* 15 *November* 1948)

It was shown by Hutchinson (1947*a*) that the fat content of rabbit carcasses cannot be predicted from their live weights or rates of increase in live weight because the fat content of the body or of the live-weight increase may be considerably influenced by the ration fed. This means that in experiments on rabbit-meat production the energy value of the meat for human consumption cannot be assessed even approximately from the increase in live weight. Since the chemical analysis of carcasses is laborious and expensive, an attempt has been made in this paper to find a method by which the fat content of the carcass may be predicted from anatomical data, in the hope that such a method would prove useful for field stations.

METHODS

To be of practical value a relationship between anatomical data and the fat content of the carcass should, so far as possible, be unaffected by environment, breeding and age. Therefore, in the attempt to work out a method of prediction, the material used was as heterogeneous as possible. The data available were the analyses of fifty-seven rabbit carcasses which were obtained from feeding experiments with substitute rations carried out during the war of 1939–45.

Rations

All the animals were fed on a stock ration till weaning at 7–8 weeks. Seven groups were then fed on the following rations for a further 7 weeks:

(1) Stock ration consisting of a pelleted concentrate mixture (see Hutchinson, 1947*a*), hay and cabbage or carrots all fed *ad lib.* The same stock ration was used up to weaning.

(2) Artichokes and hay *ad lib.* with 10 g. carrot/day.

(3) Artichokes and hay *ad lib.* with a protein supplement of 10–20 g. casein/day.

(4) Cooked potatoes and hay *ad lib.* with 10 g. carrot/day and in some cases 100 g. cabbage.

(5) Cooked potatoes and hay *ad lib.* with a protein supplement of 10–20 g. casein/day, and 10 g. carrot/day. Some animals received in addition 100 g. cabbage/day.

(6) Fresh weeds (mainly sow thistles) fed *ad lib.* The other species of weeds fed are listed in an earlier paper (Hutchinson, 1947*b*).

(7) Fresh weeds *ad lib.* with a supplement of cooked potatoes ranging from 100 to 200 g. daily.

The hay fed was poor quality meadow hay. All groups received supplements of sodium chloride, either incorporated in the rations (0·5 % on the dry-matter basis), or as blocks of salt put in the hutches. Water was always available.

Rations nos. 2 and 4 had a low protein content (9–12 % on the dry-matter basis). Ration no. 6 and, possibly, rations nos. 2 and 3 were low in energy.

Animals

Sex. There were twenty-nine males and twenty-eight females distributed fairly evenly among the groups.

Breed. The majority of the animals were the offspring of a sire of mixed Flemish-Giant and Belgian-Hare breeds and of does of the same breeding. There were, in addition, seven animals which were the progeny of a doe of a Dutch type crossed with a Chinchilla buck. All animals of the latter breeding received rations nos. 2 or 3. Owing to the fact that the animals were not all of the same breeding and that the parents of the majority were of mixed breeds, there was considerable variation in size and conformation. They were, however, all of a meat-producing type.

Age at slaughter. Six animals were slaughtered at 7–8 weeks at the time of weaning and the remaining animals at 14–15 weeks, the age at which animals of this breeding normally attain a suitable weight for slaughter for meat production.

Live weight and live-weight increase. Live weights at killing varied from 952 to 2731 g. for animals killed at 14–15 weeks and from 906 to 1205 g. for animals killed at 7–8 weeks. The growth of the animals during the 7 weeks' experimental feeding period varied from 9 g./week, a very slow rate of growth, to 227 g./week, a very rapid rate of growth.

Season of year

Rabbits were on experiment at all seasons of the year. Rations nos. 2 and 3 were fed only during the winter months and rations nos. 6 and 7 during the summer. Animals were fed on rations nos. 1, 4 and 5 in both winter and summer.

Carcass analysis

This was carried out as described by Hutchinson (1947*a*). The dressed carcass in this paper means the carcass after removal of the pelt, feet and both edible and inedible offal. 'Dissected fatty tissue' is the total of that round the kidneys and that over the shoulders and the pubic region. Fat, where referred to, means fat estimated chemically. Thus 'dissected fat' means the chemical fat of the 'dissected fatty tissue'.

RESULTS

Relationship between the edible fat and the dressed-carcass weight

Fig. 1 shows the percentage of edible fat in the dressed carcass plotted against the dressed-carcass weight. In general as the carcass weight increases the percentage of edible fat also increases. This would be expected from the known laws of physiological

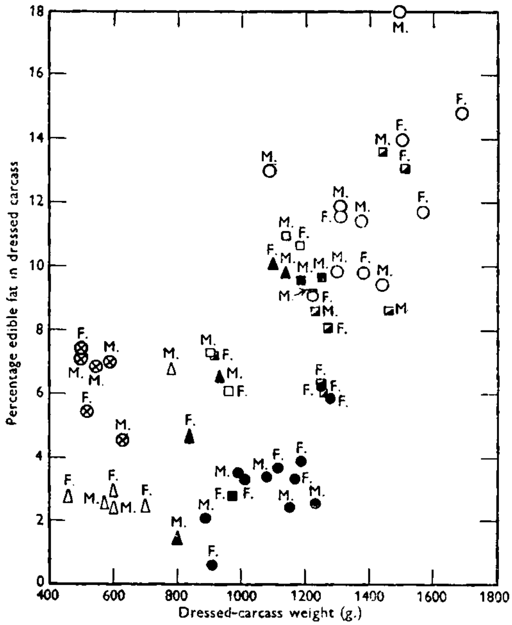

Fig. 1. Percentage edible fat in the dressed carcass plotted against the dressed-carcass weight. ○ ration 1; ⊗ ration 1, animals 7–8 weeks old; △ ration 2; ▲ ration 3; □ ration 4; ■ ration 5; ● ration 6; ◪ ration 7. F. = female, M. = male.

development since fat is laid down after bone and muscle, and heavy animals are generally at a later stage of development than light animals. The relationship between the percentage of edible fat and dressed-carcass weight is, however, affected by dietary treatment. Animals which received an adequate ration and were killed at 7–8 weeks contained considerably more fat than animals of the same carcass weight which had received an inadequate ration for a further 7 weeks. Moreover, the carcasses of the weed-fed group and, to a lesser degree, of the group fed on weeds and potatoes contained less edible fat than carcasses of the same weight from animals which had received the other rations for the experimental feeding period. Carcass weight is therefore not a suitable index for the prediction of edible fat content.

Relationship between the 'index of fat content' and the edible fat of the dressed carcass

The fatty tissue round the kidneys (perinephric) and that over the shoulders and the pubic region develops comparatively late. The amount is small at weaning but subsequently it develops rapidly. It occurred to the authors that, since this fatty tissue

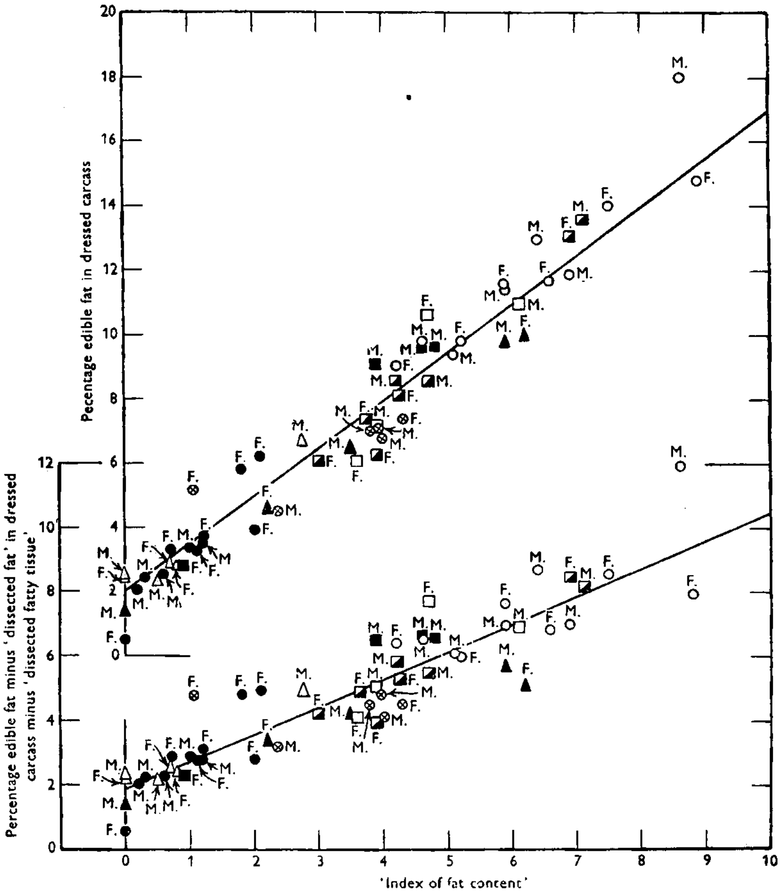

Fig. 2. *Upper diagram:* Percentage edible fat in the dressed carcass plotted against the percentage 'dissected fatty tissue' in the dressed carcass ('index of fat content'). *Lower diagram:* Percentage edible fat minus 'dissected fat' in the dressed carcass minus 'dissected fatty tissue' plotted against the 'index of fat content'. ○ ration 1; ⊗ ration 1, animals 7–8 weeks old; △ ration 2; ▲ ration 3; □ ration 4; ■ ration 5; ● ration 6; ◪ ration 7. F. = female, M. = male.

can be dissected out and weighed quite easily, it might be used as an index of the fat content of the dressed carcass. In order that this index might be independent of carcass size, the weight of fatty tissue was expressed as a percentage of the dressed-carcass weight, and the figure obtained is called the 'index of fat content' in the remainder of this paper.

Fig. 2 shows the percentage of edible fat in the dressed carcass plotted against the 'index of fat content'. The ordinate of the upper diagram includes the 'dissected fat' and is expressed as a percentage of the dressed-carcass weight; that of the lower diagram excludes the 'dissected fat' and is expressed as a percentage of the dressed-carcass weight minus the 'dissected fatty tissue'.

Both relationships are approximately linear and may be expressed as regressions having the equation $y=a+bx$, where y is percentage of edible fat, x is 'index of fat content', and a and b are constants.

The equation for the upper diagram is

$$y=1{\cdot}68+1{\cdot}59x. \qquad (1)$$

The variance about this regression line is $s^2_{y.x}=0{\cdot}7808$.

The equation for the lower diagram is

$$y=1{\cdot}92+0{\cdot}85x. \qquad (2)$$

The variance about this regression line is $s^2_{y.x}=0{\cdot}8199$.

The variance of the prediction of the percentage edible fat of an individual rabbit carcass is

$$s^2_y=s^2_{y.x}(1+1/N+(x-\bar{x})^2/S(x-\bar{x})^2)$$

(Snedecor, 1946), where N is the number of variates used in calculating the regression constants, x is the 'index of fat content' of the individual rabbit carcass, and $\bar{x}$ is the mean of the observations of x from which the regression is calculated.

For the upper diagram the standard deviation, s_y, varies from 0·90% edible fat when $x-\bar{x}=0$ ('index of fat content' = 3·52) to 0·94 % edible fat when $x-\bar{x}=5{\cdot}48$ ('index of fat content' = 9·00). The values for the lower diagram are 0·91 and 0·95 % edible fat respectively. s_y is nearly the same for both diagrams. For the prediction of edible fat the regression of the upper diagram only is of use because the ordinate gives the percentage of total edible fat, whereas that of the lower diagram relates to part only of the edible fat.

Since the variance of the regressions nos. 1 and 2 is, in each case, not unduly large, it is clear that the combined variations in nutrition, age, sex, breed, season of year, live weight and live-weight increase did not in general produce marked disturbing effects in the relationship between 'index of fat content' and percentage edible fat of the carcass. Where possible the data were examined for minor disturbing effects due to these factors separately, but in certain cases it was not possible to do so since some of the factors are interrelated.

Effect of nutrition. It is clear from Fig. 2 that, although the 'index of fat content' itself was dependent on the ration fed, the relationship between 'index of fat content' and percentage edible fat in the carcass was independent of nutrition within the range of nutritional treatment studied.

Effect of age and live weight. The animals killed at 7–8 weeks were naturally lighter than most of those killed at 14–15 weeks, so that the effect of age was confounded with that of live weight. Since the points representing the animals killed at 7–8 weeks lie close to the regression line of the older animals, it is clear that the combined effect of age and live weight did not disturb the relationship.

Effect of sex. There was little difference between the fat content of the carcasses of the male and female animals at this early age. The average percentage of edible fat of the dressed carcasses of the males was 7·58, whereas that of the females was 6·92. On the other hand, Wilson & Morris (1932) and Wilson & Botham (1933–4) have shown that in Havanas at 9 months, and in White Angoras at 11 and 24 months, the percentage of fat in the edible flesh is greater in females than in males. In adult animals, therefore, sex differences in fat content evidently develop.

In order to examine the effect of sex on the relationship between 'index of fat content' and percentage edible fat, regression constants were calculated separately for males and females. t was calculated for the difference between the adjusted sex means of y. This adjustment was carried out by multiplying the differences between $\bar{x}$ and the sex means of x by the average regression coefficient within sexes and adding or subtracting the results from the sex means of y. t was also calculated for the difference between the values of b appropriate to each sex. For the upper diagram (Fig. 2) the regression equation for males is

$$y = 1{\cdot}49 + 1{\cdot}65x, \quad (3)$$

and that for females is

$$y = 1{\cdot}83 + 1{\cdot}52x. \quad (4)$$

For the lower diagram the regression equation for males is

$$y = 1{\cdot}65 + 0{\cdot}94x, \quad (5)$$

and that for females is

$$y = 2{\cdot}14 + 0{\cdot}76x. \quad (6)$$

For the upper diagram the value of t for the difference between the adjusted sex means of y is 0·47, which corresponds to a probability of 0·6 and indicates that the difference is not significant. The value of t for the difference between the two values of b is 1·40, corresponding to a probability of 0·2, which again indicates that the difference is not significant. Similarly, for the lower diagram the value of t for the difference between the adjusted sex means of y is 0·59, representing a probability of 0·5–0·6, and the value of t for the difference between the two values of b is 1·83, representing a probability of 0·07, indicating that in each case the difference is not significant. For both diagrams, therefore, sex differences in the regressions are not significant in rabbits at the ages studied. In adult animals, on the other hand, when sex differences in the total fat content have developed, it is possible that there are also sex differences in the regressions.

Effect of breed. A close relationship was obtained between the 'index of fat content' and the percentage of edible fat, in spite of the fact that the animals were of somewhat heterogeneous genetical constitution. It does not follow, however, that the relationship would have been so close had animals of widely differing breeds been used.

Effect of the season of the year. The data were not sufficient for an analysis of the effect of the season of the year uncomplicated by other variables. The limited data available gave no indication of any seasonal effect.

Effect of the rate of growth. The effect of the rate of growth cannot be separated from the effect of nutrition and of genetical constitution on both of which it is dependent.

Other regressions relating 'dissected fatty tissue' to edible fat. The following regressions were calculated in the same way as those discussed above:

(1) Percentage edible fat in the dressed carcass on the percentage of perinephric fatty tissue in the dressed carcass:

$$y = 2{\cdot}31 + 2{\cdot}78x, \quad s^2_{y.x} = 2{\cdot}0885. \quad (7)$$

(2) Percentage edible fat in the dressed carcass, excluding 'dissected fat' and 'dissected fatty tissue', as in regression equation no. 2, on the percentage of perinephric fatty tissue in the dressed carcass:

$$y=2{\cdot}30+1{\cdot}46x, \quad s=^{2}_{y.x}1{\cdot}3122. \tag{8}$$

(3) Percentage edible fat in the dressed carcass on the percentage in the dressed carcass of fatty tissue over the shoulders and the pubic region:

$$y=2{\cdot}89+2{\cdot}51x, \quad s^2_{y.x}=4{\cdot}5678. \tag{9}$$

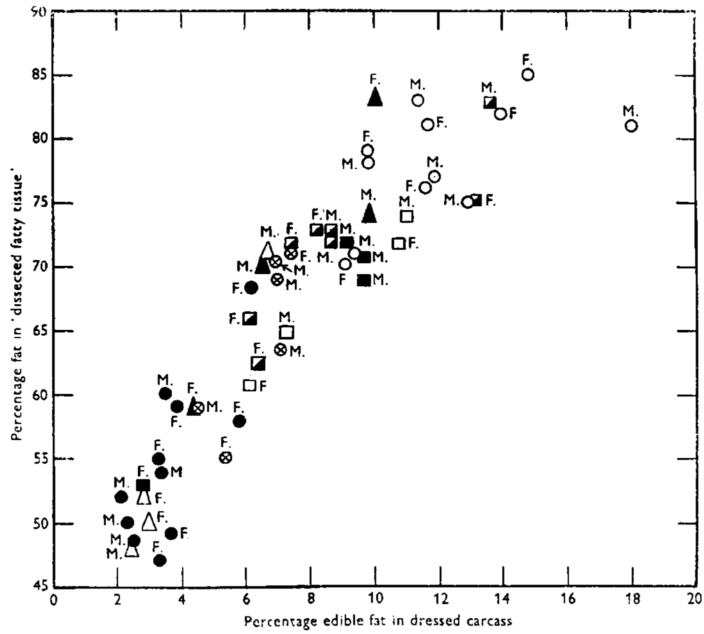

Fig. 3. Percentage fat in the 'dissected fatty tissue' plotted against the percentage edible fat in the dressed carcass. ○ ration 1; ⊗ ration 1, animals 7–8 weeks old; △ ration 2; ▲ ration 3; □ ration 4; ■ ration 5; ● ration 6; ◪ ration 7. F. = female, M. = male.

(4) Percentage edible fat in the dressed carcass, excluding 'dissected fat' and 'dissected fatty tissue', as in regression no. 2, on the percentage in the dressed carcass of fatty tissue over the shoulders and the pubic region:

$$y=2{\cdot}52+1{\cdot}37x, \quad s^2_{y.x}=1{\cdot}7699. \tag{10}$$

From these calculations it appears that the regression of the percentage edible fat in the dressed carcass on the 'index of fat content' (equation no. 1) has the smallest variance and, therefore, gives the most satisfactory prediction of the edible fat content of a dressed carcass. It is, on the other hand, easier to dissect out the perinephric fatty tissue in a standard manner than the fatty tissues over the shoulders and the pubic region, since the latter tissues are less sharply defined. If the weight of perinephric fatty tissue only is used as an index, equation no. 7 may be used for the prediction of the fat content. It should be observed that no difficulty was experienced in dissecting the fatty tissue from the dressed carcasses analysed in the experiments reported here, but all these dissections were made by the same worker.

Variations in the fat content of the 'dissected fatty tissue'

Fig. 3 shows the percentage of fat in the 'dissected fatty tissue' plotted against the percentage edible fat in the dressed carcass. This shows that the percentage of fat in the 'dissected fatty tissue' increases as the edible fat content of the carcass increases. Determination of the moisture of the fatty tissue showed that the fat content was inversely related to the water content. This finding is in agreement with Halnan's (1938) data for cockerels and Callow's (1947, 1948) data for cattle, sheep and pigs. Since the percentage of edible fat in the carcass varies with the 'index of fat content' it follows that the percentage of fat in the 'dissected fatty tissue' must also vary with the 'index of fat content'. This is illustrated in Fig. 4.

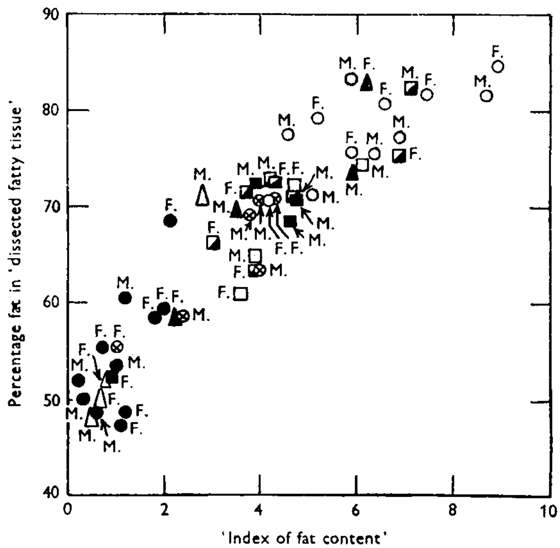

Fig. 4. Percentage fat in the 'dissected fatty tissue' plotted against the percentage 'dissected fatty tissue' in the dressed carcass ('index of fat content'). ○ ration 1; ⊗ ration 1, animals 7–8 weeks old; △ ration 2; ▲ ration 3; □ ration 4; ■ ration 5; ● ration 6; ◪ ration 7. F. = female, M. = male.

Deposition of fat as 'dissected fatty tissue' relative to that of total edible fat

The fat of the 'dissected fatty tissue' is often regarded as less palatable than the remainder of the edible fat; its quantitative relation to this latter is, therefore, of interest. Fig. 5 shows the 'dissected fat' as a percentage of the total edible fat plotted against the percentage fat in the dry matter of the dressed-carcass meat. Percentage fat in the meat dry matter is used in this case instead of percentage fat in the dressed carcass in order to avoid disturbing effects of the variable weight of bone in different animals. The diagram shows that in fat rabbits nearly half the edible fat is in the 'dissected fatty tissue', whereas in very lean animals almost all the edible fat is in the remainder of the carcass.

Fig. 6 shows the 'dissected fat'/100 g. meat dry matter plotted against the total edible fat/100 g. meat dry matter. The variates are expressed as percentages in order that the relationship may not be disturbed by variations in carcass weight. The regression equation is

$$y = 0{\cdot}54x - 5{\cdot}94, \quad s^2_{y.x} = 3{\cdot}7316. \tag{11}$$

The diagram shows that animals which are too lean to have laid down any 'dissected fat' may yet contain 11 % of fat in the meat dry matter. For each 1 % increment over 11 % of fat in meat dry matter there is an increment of 0·54 % 'dissected fat'. Thus 'dissected fat' appears to form a constant proportion of the fat laid down above 11 %. Fig. 6 refers to a number of animals, most of them 14–15 weeks old, the state of

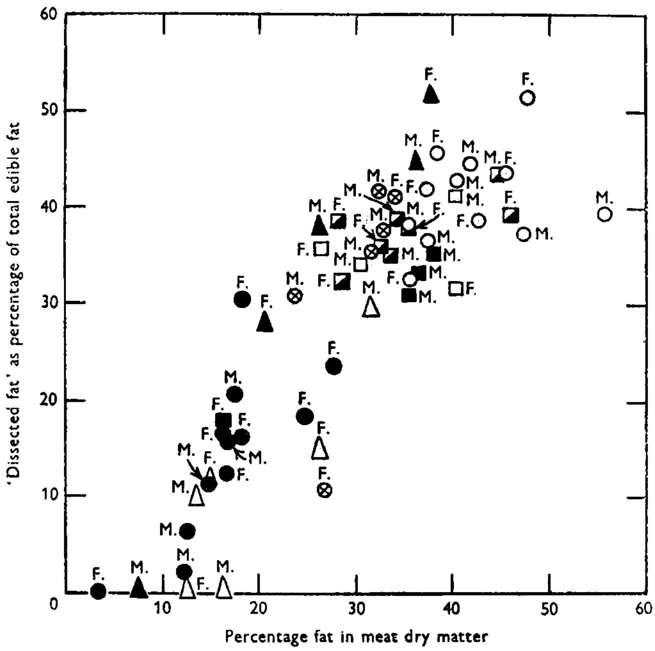

Fig. 5. 'Dissected fat' as a percentage of the total edible fat of the dressed carcass plotted against the percentage fat in the dry matter of the dressed-carcass meat. ○ ration 1; ⊗ ration 1, animals 7–8 weeks old; △ ration 2; ▲ ration 3; □ ration 4; ■ ration 5; ● ration 6; ◪ ration 7. F. = female, M. = male.

'maturity' of which depended on the ration fed. The same regression line would not necessarily be obtained from carcass analyses of animals fed on one ration only and slaughtered at different ages. Nevertheless, the fact that the points representing the six animals killed at 7–8 weeks fall reasonably close to this regression line suggests that the development of 'dissected fat' with increasing age may take place in a similar manner.

Relationship between the edible protein in the dressed carcass and the carcass weight

Table 1 shows the mean percentage of edible protein in the fat-free dressed carcasses for the various groups. The carcasses of the group killed at 7–8 weeks and of the group which received artichokes and hay without a casein supplement (ration no. 2) contained significantly smaller percentages of edible protein than those of any of the other groups. The probability (P) varied from 0·01 to $<0{\cdot}001$. The low content of edible protein of the carcasses of the animals killed at 7–8 weeks was presumably due to immaturity in muscular development. The 'index of fat content' of this group averaged 3·25 and the average for all the animals was 3·52, so that in fat deposition this group was not less

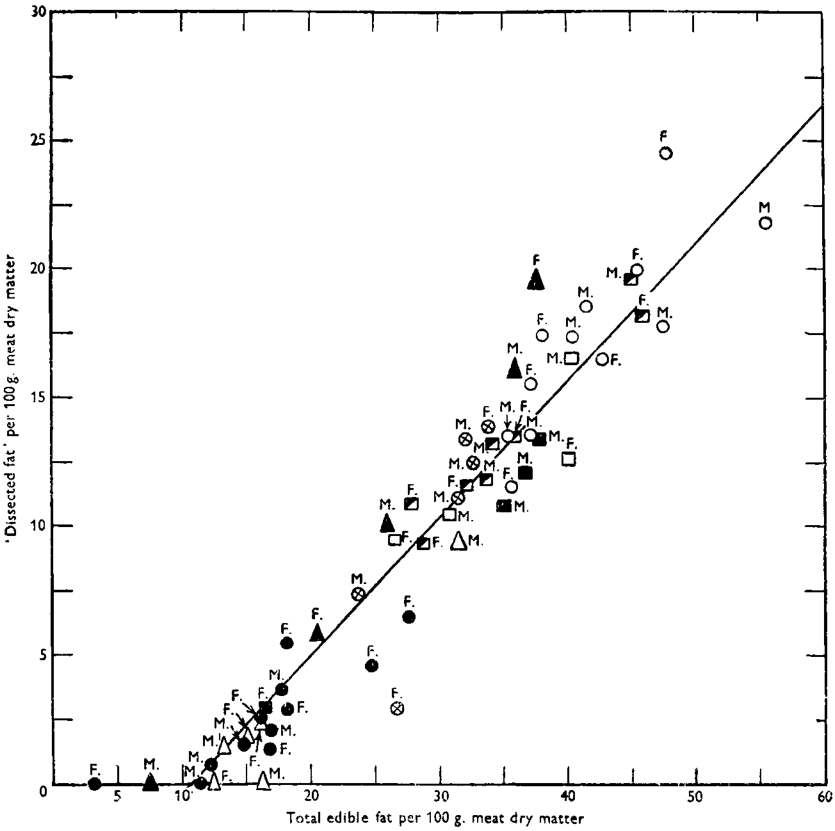

Fig. 6. 'Dissected fat'/100 g. meat dry matter plotted against the total edible fat/100 g. meat dry matter of the dressed carcass. ○ ration 1; ⊗ ration 1, animals 7–8 weeks old; △ ration 2; ▲ ration 3; □ ration 4; ■ ration 5; ● ration 6; ◪ ration 7. F. = female, M. = male.

Table 1. *Percentage edible protein in the fat-free dressed carcasses of rabbits*

			Mean percentage of edible protein	
Ration no.	Age at slaughter (weeks)	No. of animals	Value	Standard deviation of mean
1	7–8	6	14·72	0·23
1	14–15	12	17·66	0·21
2	14–15	6	14·73	0·50
3	14–15	5	17·48	0·37
4 and 5	14–15	8	16·97	0·40
6	14–15	12	16·51	0·24
7	14–15	8	16·89	0·43

mature than the average. It appears, therefore, that 'maturity' in muscle development does not necessarily run parallel with 'maturity' in fat development. The group fed ration no. 2 made very poor gains in live weight because the ration was deficient in protein. Artichokes contain only 10 % crude protein on the dry-matter basis, and of this only 45 % was found to be digested by rabbits. This deficiency of protein in the ration presumably hindered muscular development, so that the carcasses contained less edible protein than those of other animals of the same age.

Callow (1948) with cattle, sheep and pigs found an inverse relationship between the weight of protein from the boneless meat, expressed as a percentage of the carcass* weight, and the percentage of fatty tissue in the carcass*, provided that the latter was greater than 18 %; if the percentage of fatty tissue was less than 18 %, the relationship was quite irregular. In nearly all the rabbit carcasses analysed by us the edible fat content corresponded to less than 18 % of fatty tissue, so that a regular relationship

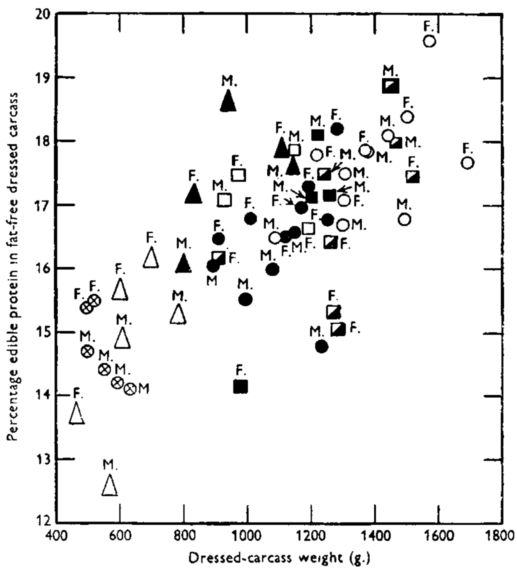

Fig. 7. Percentage edible protein in the fat-free dressed carcass plotted against the dressed-carcass weight. ○ ration 1; ⊗ ration 1, animals 7–8 weeks old; △ ration 2; ▲ ration 3; □ ration 4; ■ ration 5; ● ration 6; ◪ ration 7. F. = female, M. = male.

between percentage of edible protein and 'index of fat content' or percentage of edible fat would not be expected in these animals. It was found that, in fact, there was no regular relationship between the percentage of edible protein in either the dressed carcass or the fat-free dressed carcass and the 'index of fat content'.

Fig. 7 shows the percentage edible protein in the fat-free dressed carcass plotted against the dressed-carcass weight. On the whole, the heavier carcasses contained greater percentages of edible protein. The relationship is not, however, suitable for prediction of the edible protein content of a carcass because it depends upon the size of the breed of animal used. This is illustrated by the points representing animals receiving ration no. 3. All the animals of this group were of a Chinchilla × Dutch breeding and were genotypically smaller than those of the Flemish-Giant × Belgian-Hare breeding, and in consequence were more mature at the weight studied. The animals receiving ration no. 3, therefore, contained more edible protein in relation to their carcass weight than the animals of the other groups.

* Excluding the head.

DISCUSSION

These experiments show that it is possible to predict the percentage edible-fat content of a rabbit carcass from the weight of fatty tissue round the kidneys and over the shoulders and the pubic region with a standard deviation of about 1 % fat. This prediction is not affected by wide variations in nutritional treatment and live weight. It is, furthermore, not affected by age or sex between the ages of 7 and 15 weeks. The regression on which the prediction is based applies mainly to animals of one breeding, namely, the offspring of parents of mixed Flemish-Giant and Belgian-Hare breeds. Since the animals used varied rather widely in conformation owing to the fact that most of their parents were of this mixed breeding, it is possible, but not certain, that the regression would apply to rabbits of other breeds used for meat production. On the other hand, in species of farm animals which have been specially bred for meat production, there is a wide variation in the relative amounts of internal fatty tissue as compared with subcutaneous and intermuscular fatty tissue. For example, unimproved mountain breeds of sheep, such as Iceland and Blackfaced, lay down a greater proportion of their fatty tissue as perinephric fatty tissue than breeds or crosses improved for meat production (Pálsson, 1940). Such breed differences exist because animal breeders have consciously tried to produce carcasses with a definite type of fat distribution, in order to produce, for example, 'streaky' bacon or 'marbled' flesh in beef. Although certain breeds or crosses of rabbits are used in preference to others for meat production, rabbits have not been specially bred for carcass quality, so that differences in the anatomical sites of fat deposition between breeds are probably much smaller than with sheep.

The carcasses of rabbits tested for meat production at the Danish Rabbit Control Station at Favrholm are graded for fatness mainly on the appearance of the perinephric fatty tissue (Hoffman Hansen, 1947). The close relationship between perinephric fatty tissue as a percentage of dressed-carcass weight and percentage edible fat in the carcass (equation no. 7) shows that when carcasses of animals of the same breeding are compared with one another this grading system has a scientific basis. The grading could be made more exact by weighing the perinephric fatty tissue.

SUMMARY

1. A relationship was found to exist between the percentage edible fat of the dressed carcasses of rabbits and the weight of certain depot fatty tissue which can be easily dissected out. This 'dissected fatty tissue' comprised fatty tissue round the kidneys and that over the shoulders and the pubic region.

2. It is suggested that the relationship may be used for the prediction of the edible-fat content of dressed carcasses.

3. Between the ages of 7 and 15 weeks the relationship was independent of age, sex and live weight; it was also unaffected by wide variations in nutritional treatment.

4. The relationship held for the offspring of parents of mixed Flemish-Giant and Belgian-Hare breeds, and for the progeny of does of a Dutch type crossed with a

Chinchilla buck. No experiments were carried out to ascertain whether the relationship holds for other breeds.

5. A greater proportion of the edible fat of the dressed carcass was present in the 'dissected fatty tissue' of fat rabbits than of lean rabbits.

6. In general the percentage of edible protein of the fat-free dressed carcass increased as the dressed-carcass weight increased.

We are indebted for advice and criticism to Mr E. T. Halnan and to Mr M. S. Pease, at whose suggestion work on substitute rations for domestic rabbits was undertaken. Dr J. Wishart gave us considerable help in the statistical analyses. The animals were in the care of Miss M. Thompson. The expenses of this work were in part defrayed by a grant from the Agricultural Research Council.

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