THE CHEMICAL COMPOSITION OF ANIMAL BODIES

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(With 1 Text-figure.)

IN a previous communication (1) the author pointed out that the chemical composition of the bodies of farm animals is determined when the percentage of fat is known; for the composition of the non-fatty matter is practically the same in all, it is not affected by the "condition" (fatness) and it varies only to a slight extent with the age of the animals. The averages, in round numbers, deduced from Lawes and Gilbert's analyses (2) were as follows:

	Ash	Protein	Water
Young (growing) animals ...	4	20	76 %
Adults	6	22	72 %

These conclusions were necessarily more or less tentative in character because the data referred to only ten animals in all, viz., two pigs, three cattle and five sheep. More extensive data, recently to hand, afford a striking confirmation of the general thesis and enable us to determine the influence of age and the individual variation with greater precision.

Haecker (3) records separate analyses of the whole bodies of 49 individuals (cattle) ranging from about 100 lb. to 1500 lb. live weight and from 3·5 per cent. to 35 per cent. of body fat. Swanson (4) records separate analyses of the whole bodies of 36 individuals (pigs) ranging from about 20 lb. to 400 lb. live weight and from 5 per cent. to 60 per cent. of body fat.

In Haecker's experiments the animals were arranged in groups according to size with intervals of about 100 lb. average live weight between them. The mean values for each group are shown in Table I below.

The empty body weight is, of course, the live weight minus the refuse, i.e. the contents of stomach, intestines and urinary bladder. The fat-free empty weight is the weight of non-fatty matter in the actual body. It is found from the empty body weight by

$$m = M(100 - F)/100$$

or, directly from the live weight, by

$$m = M'(100 - F - R)/100,$$

Table I. *Composition of Whole Bodies* (Cattle).

No. in group	Live weight	Empty body weight	Fat-free empty weight	Fat in empty body	Composition of non-fatty matter			
					Ash	Protein	Water	*P/A*
	lb.	lb.	lb.	%	%	%	%	
5	107	90·0	86·4	4·00	4·44	20·72	74·84	4·69
4	207	163·2	153·5	6·01	4·71	20·36	74·93	4·33
4	301	246·1	218·5	11·19	4·83	21·13	74·03	4·37
5	416	339·5	303·8	10·55	4·86	21·59	73·55	4·45
5	504	418·1	360·7	13·73	4·89	22·19	72·91	4·55
3	614	493·7	424·5	13·97	5 33	22·58	72·08	4·46
4	708	587·8	490·2	16·57	5·36	22·31	72·33	4·15
3	815	692·1	563·8	18·52	5·20	23·08	71·72	4·43
3	905	774·5	587·6	24·08	5·48	23·27	71·25	4·24
4	1008	880·7	643·6	26·91	5·41	23·41	71·18	4·31
3	1108	976·3	663·8	32·03	5·62	24·13	70·25	4·29
3	1204	1077·0	728·8	32·32	5·46	23·66	70·88	4·33
1	1302	1150·5	776·6	32·50	5·60	23·40	71·00	4·18
1	1413	1237·0	834·1	32·58	5·21	23·95	70·84	4·60
1	1508	1352·9	843·9	37·59	5·14	25·19	69·66	4·90

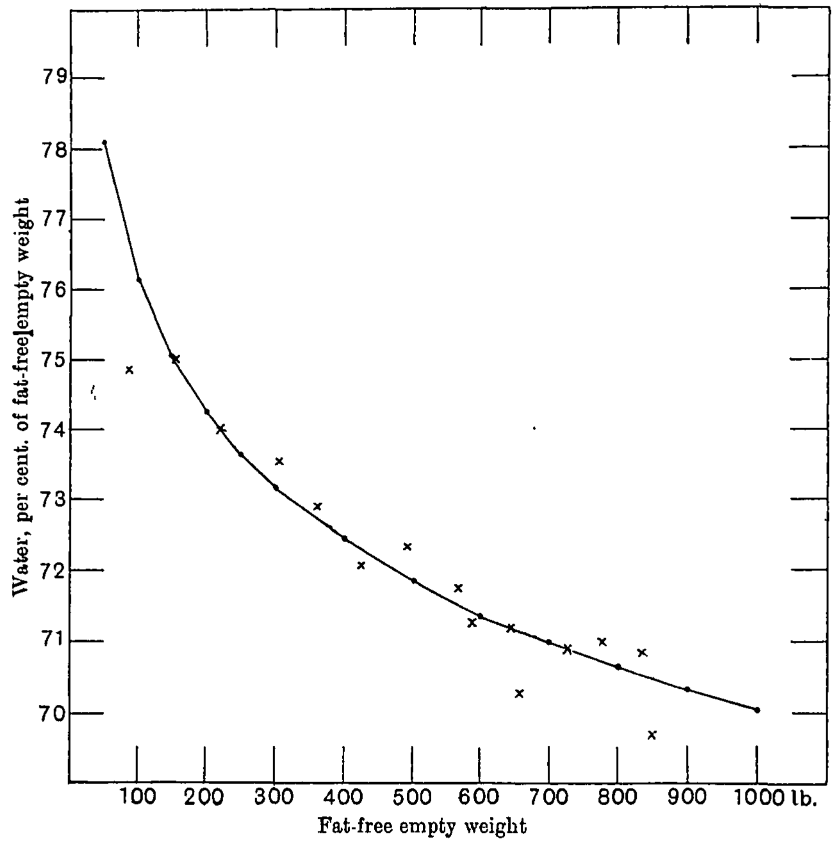

Fig. 1

where F and R are respectively the percentages of fat and refuse in the empty weight M and in the live weight M' respectively and m is the fat-free empty weight.

It will be seen, on reference to the table, that the percentage of water in the non-fatty matter diminishes progressively as age (weight) increases, and the percentages of ash and protein are correspondingly increased. There appears to be no consistent relationship between the ratio of protein to ash and the age of the animal; the variation observed must therefore be ascribed to individuality, i.e. to unknown causes. The mean value of the ratio P/A is $4{\cdot}392 \pm 0{\cdot}215$*. In other words, protein forms from 79 per cent. to 84 per cent. of the dry substance of the non-fatty matter and ash the remaining 16 per cent. to 21 per cent. The mean percentages of these ingredients may therefore be found by the formulae

$$P = 0{\cdot}815\,(100 - W);\;\; A = 0{\cdot}185\,(100 - W)$$

where P, A and W are the percentages of protein, ash and water respectively in the non-fatty matter.

It only remains therefore to find an expression for determination of w. It is obvious that the relationship of water to weight is not one of simple proportion; but when the points are plotted out a definite order can be clearly discerned. The smooth curve in the diagram (Fig. 1) corresponds to the formula $w = 90m^{-{\cdot}03624}$, where m is the fat-free body weight (lb.) and w is the percentage of water in the same. The points corresponding to the mean values of the observed data are indicated by $\times$ and it will be seen that the curve passes through or near to most of them. The mean deviation, $\frac{1}{N}\Sigma\,(d)$, (of all the individual cases) from the curve is 0·71.

In order to test these conclusions the composition of the three cattle analysed by Lawes and Gilbert was calculated from the live weight and percentage of fat and the results are given for comparison with the observed data in the table below.

The discrepancies between the observed and calculated results do not exceed the limits of individual variation in Haecker's data. In the case of the two oxen they are attributable mainly to deviation from the mean ratio of protein to ash. In the case of the calf they are attributable mainly to deviation from the curve of relationship of water to weight.

* $\sqrt{\frac{1}{N}\Sigma\,(d^2)} = 0{\cdot}319$.

Table II. *Composition of Actual Bodies.*

	Fat calf		Half-fat ox		Fat ox	
	Calculated	Observed	Calculated	Observed	Calculated	Observed
	%	%	%	%	%	%
Water	62·79	65·16	55·71	56·10	47·79	48·40
Protein... ...	17·86	15·70	19·14	18·08	16·45	15·42
Ash	4·06	3·92	4·35	5·08	3·74	4·17
Fat	(15·29)	15·29	(20·80)	20·80	(32·02)	32·02
	100·00	100·07	100·00	100·06	100·00	100·01
Refuse	—	3·2	—	8·2	—	6·0
Fasted live weight (lb.)		259		1232		1419

The composition of the fattening increase (oxen) calculated from the data actually recorded by Lawes and Gilbert is as follows:

Fat 94·54 %, Water 5·49 %, Protein 0·6 %, Ash – 0·84 %.

The percentages of water and protein in the increase might be regarded as an indication of growth, but as the animals were four years old it is improbable that any increase in size occurred, or that such increase, if it did occur, would be accompanied by a loss of 1·71 lb. of ash ingredients. Further, as the ratio of water to protein in the increase is 9/1 whereas in the whole body it is only 3/1 it is more reasonable to attribute the apparent increase in non-fatty constituents to difference in composition of the two animals. The individual variations revealed by Haecker's data are more than sufficient to justify this assumption. The inference therefore is that, in fully grown animals the fattening increase consists entirely of fat. This, of course, is acceptable on other grounds, but those who have maintained it have had to do so in the face of numerical data which could be quoted against it and of which, hitherto, no satisfactory explanation was forthcoming.

It is to be expected that in other animals the composition of the non-fatty matter will alter with age in much the same manner as in cattle, and the author anticipated no difficulty in tracing this relationship in pigs from Swanson's data. A preliminary survey, however, indicated that these results might be affected by the differences in feeding as well as by the age and individuality of the animals, and that the variations due to these combined causes would make it difficult clearly to distinguish the influence of any one. The best that could be done, it seemed, was to divide the data into three groups as shown in the table below.

It appears that the ratio of protein to ash in pigs is higher than in cattle, but the percentage of water in the non-fatty matter alters with age not only in the same manner but even in the same degree. The latter inference, however, must be to a large extent discounted in view of the magnitude of the probable errors. It could not have been deduced from Swanson's data alone and until confirmed by further evidence it must be regarded as hypothetical.

Table III. *Influence of Age* (Pigs).

Fat-free empty weight	No. of animals	Composition of non-fatty matter: Ash	Protein	Water	P/A
Under 60 lb.	10	4·15±0·87	19·03±2·55	76·83±3·12	4·60
60–100 „	10	3·91±0·36	19·89±1·35	76·02±1·41	5·09
100–170 „	11	4·01±0·30	20·90±0·96	75·09±1·04	5·21

The test of comparison with Lawes and Gilbert's data is not conclusive, but, so far as it goes, it indicates that the inference is perhaps more reliable than might be supposed. For this purpose the percentage of water in the non-fatty matter was calculated, as before, by the formula $w = 90m^{-.03624}$; but owing to the difference in the ratio of protein to ash different coefficients must be used for these ingredients, thus

$$P = 0{\cdot}8\dot{3}\,(100 - W);\ A = 0{\cdot}1\dot{6}\,(100 - W).$$

The results are as follows:

	Store pig: Calculated	Observed	Fat pig: Calculated	Observed
Water	58·28	58·15	42·71	43·01
Protein	14·28	14·45	11·13	11·35
Ash	2·86	2·82	2·22	1·72
Fat	(24·59)	24·59	(43·94)	43·94
Live weight (lb.)	—	94	—	185

In the following table the data are grouped according to the kind of food consumed by the animals.

Table IV. *Influence of Food* (Pigs).

Food	No. of animals	Empty weight	Fat-free empty weight	Fat in live weight	Composition of non-fatty matter: Ash	Protein	Water	P/A
		lb.	lb.	%	%	%	%	
Corn alone ...	5	80·27	47·45	36·69	3·56	17·93	78·51	6·03
Corn and ash ...	5	130·74	68·25	37·03	4·16	17·39	78·45	4·17
Corn and protein	10	217·94	109·31	48·01	3·54	21·34	75·12	6·07
Corn, ash and protein ...	5	226·74	118·57	45·55	4·41	21·17	74·42	4·82

In order to interpret these results correctly it is necessary to make allowance for the difference in size, i.e. to compare them with data calculated for animals of the same size by means of the formula above, as follows:

	Corn alone		Corn and ash		Corn and protein		Corn, ash and protein	
	Cal'd	Obser'd	Cal'd	Obser'd	Cal'd	Obser'd	Cal'd	Obser'd
	%	%	%	%	%	%	%	%
Water... ...	78·25	78·51	77·21	78·45	75·91	75·12	75·68	74·42
Protein ...	18·12	17·93	18·98	17·39	20·07	21·34	20·26	21·17
Ash	3·63	3·56	3·81	4·16	4·02	3·54	4·06	4·41

The correspondence between the observed and calculated data is, throughout, as close as could be expected in any circumstances. The inference therefore is that the differences which do occur should be attributed to individual variation and that the effect of the additions to the food was nil. It is to be observed, however (Table IV), that the addition of ash to the corn has reduced the ratio of protein to ash whereas the addition of protein has produced no appreciable alteration in that ratio. When ash and protein are added together the ratio is reduced only about half as much as by addition of ash alone. When the results are stated as percentages of the several ingredients these effects are obscured by the large amount of water present. Swanson remarks that the addition of protein and ash accelerates the growth of the animal but does not affect its composition.

The only data relating to sheep at present available are those of Lawes and Gilbert and, as these refer to only five individuals, they are inadequate for purposes of the present investigation. They may, however, be used to test the applicability of the formula deduced for cattle. Thus it is found that the ratio of protein to ash (4·3) is practically the same but the coefficient in the formula for water must be reduced, i.e. $w = 87m^{-\cdot 03624}$. Calculated on this basis the results are as follows:

Fat-free live weight (lb.)		50·63	70·82	73·84	74·20	123·80
Fat (per cent. of live weight) ...		28·50	23·50	18·70	35·60	45·80
Ratio of protein to ash		4·43	4·34	4·67	4·34	3·75
Water (per cent. of non-fatty matter) ...	observed	75·91	74·42	76·10	74·63	71·80
	calculated	75·46	74·56	74·46	74·42	73·07

Amount of Body Fat.

In farm animals generally the ratio of fat to non-fatty matter varies within wide limits. It depends largely upon the quantity and quality of the food and, to that extent, it can be controlled. Elsewhere (1) the author has inferred that the maximum amount of body-fat is about

60 per cent. of the live weight. This estimate was based on the increase in basal katabolism, determined by Armsby (5), in an ox. Pigs probably have a smaller capacity for food than ruminants of the same size; but, on the other hand, the food which is customary and suitable for them has a much higher productive index (ratio of dynamic to total energy). It was recognised that the result depends upon these factors and that any animal would require an indefinite time to attain the maximum degree of fatness of which it is capable under any given conditions. The fact that over 60 per cent. of body fat was recorded in two cases in Swanson's data indicates that the theoretical maximum is probably higher for pigs than for ruminants. At any rate it disposes of the objection that the estimated maximum (60 per cent.) is far beyond what had hitherto been recorded. The theoretical minimum of body fat is zero. The lowest recorded in the data under consideration is 5·27 per cent. in the pigs and 3·64 per cent. in the ruminants. There is no reason to believe that these records are the lowest attainable in living animals.

Attention may be called to the fact that the diminishing percentage of water in the non-fatty matter coincides with diminishing rate of growth and to the possible connection between these phenomena. The biological significance of the constants in the formula for water may also prove a matter of interest to physiologists.

SUMMARY.

Animal bodies are composed of fat and non-fatty matter. The relative proportions of these two ingredients vary within wide limits but can be controlled by food. The non-fatty matter consists of water, protein and ash. The percentage of water varies with the age of the animal in a definite manner. This has been determined with tolerable certainty for cattle. The available evidence indicates that the same formula is applicable to pigs and, with slight modification, also to sheep, but these inferences require confirmation. The ratio of protein to ash is the same in sheep as in cattle but in pigs it is higher. In any case it does not alter with the age of the animal but it may be influenced to a certain extent by the food. Individual variation is wider in pigs than in ruminants. The average composition of the whole body at any stage can be calculated when the live weight and percentage of fat in it are known.

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