SOFT PORK STUDIES.

IV. THE INFLUENCE OF A RATION LOW IN FAT UPON THE COMPOSITION OF THE BODY FAT OF HOGS.

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(Received for publication, August 11, 1930.)

It is generally recognized that the fattening animal stores a more saturated type of body fat when the feed is low in ether-soluble substances than when oils such as corn, peanut, and soy bean are present even in moderate quantities. Recent work with hogs (1) has shown that the wide variations in composition of the body fat are in general closely related to the quantity and degree of unsaturation of the oil ingested in the feed. The most saturated fat was found in hogs fattened on the ration lowest in ether extract. Anderson and Mendel (2) and Eckstein (3) found that the addition of fatty substances to an otherwise fat-free ration altered the composition of the body fat of rats. In general the body fats resembled the ingested oils or other fatty substances as judged by the iodine numbers. Fat-free rations, high in carbohydrates as well as in proteins, produced body fats in rats with iodine numbers of 60 to 70. These values correspond to those found in the fat of hogs fed on rations moderately low in ether extract such as corn with tankage (4).

The firm body fat which occurs in hogs, cattle, sheep, and other animals when feed fat is not an important constituent in the ration is made up largely of oleic, stearic, and palmitic acids combined in various glyceride combinations. Other fatty acids occur in relatively small amounts in the usual case. Contrary to statements frequently noted in articles and books on fats, lards may show a wide range in saturation, usually the result of the ingestion and utilization of feed oils. The iodine numbers may vary from approximately 30 to 100 and over. These extremes are the result of widely different rations such as copra cake (5) on the one hand and peanuts or soy beans on the other. In the case of the oily feeds such as peanuts or soy beans, linolic acid is known (1) to rank in importance with the three acids previously named. It is noteworthy that a vegetable fat such as that in copra meal should produce a more saturated fat than a ration low in fat where the iodine numbers usually range from 50 to 60. Such values have been reported in German and Danish investigations in which the rations fed were composed of potatoes, barley, skim milk, and other feeds low in fat as well as in the present investigations when brewers' rice was used as the basal feed.

Shortly after the soft pork investigations were undertaken 10 years ago, by the United States Department of Agriculture and coöperating state experiment stations, the production of extremely firm carcasses on a rice by-product feed known as brewers' rice was noted. This feed has consistently produced firmer carcasses (1) than have other materials, including corn, which contained more oil (ether extract). The fact that other feeds low in oil such as sweet potatoes, hominy, and barley (unpublished results) have produced similar although less striking results supports the view that the lack of oil in the feed is the principal influence toward production of firm body fat on these foodstuffs.

Following the experiments previously reported (4) on the progressive hardening of hogs on rations of corn with non-softening supplements in which the probable influence on firmness of the oil contained in the corn was pointed out, the present experiment with brewers' rice as the basal feed was undertaken. Attention has been directed in this experiment to a study of the quantity and composition of the body fat of hogs at successive stages of growth. The hogs were reared on a ration containing approximately 0.5 per cent of ether extract. Not only were the experimental animals grown from weaning on this ration but their dams received a similar ration during the periods of pregnancy and suckling. Body fat was produced at a normal rate varying in composition only to a small extent from weaning to market weight. As compared to the results on corn rations, which contained approximately 4 per cent of ether extract, the progressive hardening was much less pronounced and the fat more saturated in the present experiments. The predominating fatty acids were oleic, palmitic, and stearic. Linolic acid was present in small amounts, but the quantity apparently bore no relation to the increase in total fat. During the late stages of growth, the conversion of non-fatty constituents, mainly carbohydrates, into fat was remarkably high although it should not be inferred that it was more rapid than normally occurs on a properly balanced ration.

Plan and Procedure of the Experiment.

Two pregnant sows, one a Chester white and the other a Duroc-Jersey, were placed on a ration of brewers' rice, alfalfa meal, and blood meal balanced to an appropriate nutritive ratio. The sows were purposely selected because of their thin condition in order to insure a preponderance of firm fat in the tissues during the suckling period. Evidence that this was accomplished was obtained later when one of the sows was slaughtered after the pigs had been weaned. The carcass was found to have a firmness grade of "hard," and an iodine number analysis on the back fat gave a value of 52.9. The two sows made rapid gains in weight and in fatness. They farrowed large, normal litters. From the seventeen pigs alive at the age of 6 weeks, thirteen were used in the experiment. The pigs were allowed access to the feed mixture given the dams during the suckling period and no attempt was made to obtain feed consumption records until after weaning.

Two pigs were killed at the midway point of the suckling period and two more at weaning time. Beginning shortly after weaning the remaining nine pigs were hand fed in individual feeding compartments twice daily. The ration, consisting of brewers' rice, blood meal, alfalfa meal, and mineral mixture, was weighed out at each feeding. It was the intention to change the proportion of rice and blood meal at intervals to adjust the nutritive ratio according to requirements of the hogs. The alfalfa meal was kept at 8.5 per cent and the mineral mixture at 1.5 per cent of the total mixture. From weaning until 110 pound weight was reached, the nutritive ratio was approximately 1:4.7. When the mixture was changed at the 110 pound weight the amount of blood meal was inadvertently increased so that the nutritive ratio was approximately 1:4. This was corrected within a few weeks and the nutritive ratio fed until the end of the experiment was 1:5.7.

After the slaughter of the four pigs as mentioned, the remainder were slaughtered in pairs at weights of approximately 75, 110, 170, and 240 pounds. The remaining one was slaughtered at a weight of 300 pounds.

The same general plan of slaughter and analysis as used in earlier work of similar nature (4) was followed. The entire body was analyzed for protein, water, fat, and ash in five fractions, namely, blood, cleaned organs and alimentary tract, skin, bone, and meat. After calculating the constituents in each fraction they were totaled and the loss in shrinkage from "hot" to "cold" carcass weight added to the moisture total. Calculation of constituents was thus made on the total empty weight minus hair and scurf. The weight of hair was obtained in a number of cases. The analysis of one composite sample showed 87 per cent protein. The protein in the hair was found to be approximately 4.5 per cent of the total protein in the body.

The carcasses of all hogs killed subsequent to weaning were chilled for 2 to 3 days and then graded for firmness according to the grading system used in the cooperative soft pork investigations. Samples of back and leaf fats were rendered, filtered, and analyzed for fat constants. Special composite fat samples representative of the entire body were prepared by heating 5 pound lots of ground meat on the steam bath for 2 to 3 hours, then, after expressing the fat and water liquid from the meat residue by draining and pressure, the melted fat was separated in a separatory funnel and filtered. The detailed work on fatty acid separations was made on these composite fat samples.

Experimental Results. Growth and Feed Consumption.

A record of the feed consumption was kept on the nine hogs continued on experiment subsequent to weaning. These animals were slaughtered at the weight intervals chosen for study as indicated in Table I. The increase in rate of gain with increase in weight is in keeping with the usual progressive increase in rate of gain for hogs of this weight range. It will be noted that the feed consumption for unit gain is given by weight intervals as well as for the entire period of the experiment. There was an increase in the amount of feed consumed per pound of gain during the interval of growth from 110 to 170 pounds, when the protein content of the

TABLE I.

Growth and Feed Consumption of Individual Hogs.

Hog No. and breed.*	Period I, group feeding.				Period II, on individual feeding test.							
								Feed consumed per lb. of gain by weight intervals.				
	Birth weight.	Weight at close of period.	Days on test period.	Average daily gain.	Weight at close of feeding.	Days on test period.	Average daily gain.	Beginning of period to 75 lbs.	75-110 lbs.	110-170 lbs.	170 to close of test.	Entire period.
	lbs.	*lbs.*		*lbs.*	*lbs.*		*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*
1 C.	2.75	18.5†	35	0.45								
2 D.	2.50	22.7†	46	0.44								
3 C.	2.75	31	61	0.46								
4 D.	3.00	44	72	0.57								
5 "	3.25	61	85	0.68	75	25	0.56	3.28				3.28
6 C.	3.25	42	74	0.52	75	37	0.89	2.64				2.64
7 "	3.00	47	74	0.60	110	60	1.05	2.36	2.90			2.66
8 D.	3.25	52	85	0.57	110	60	0.97	2.87	2.90			2.89
9 "	3.25	58	85	0.64	170	114	0.98	3.53	2.62	4.47		3.75
10 C.	3.00	35	74	0.43	166	131	1.00	2.96	3.41	4.94		3.97
11 "	2.75	39	74	0.49	253	171	1.25	3.11	2.77	5.08	3.48	3.72
12 "	3.00	37	74	0.46	246	171	1.22	2.95	2.77	5.04	3.82	3.83
13 D.	2.25	56	85	0.63	299	171	1.42	2.89	2.40	4.71	3.00	3.31
Average..................................								2.96	2.82	4.85	3.34	3.34

* The letters attached to the numbers refer to the breed as follows: C., Chester white; D., Duroc-Jersey.

† Slaughtered before the close of Period I.

TABLE II.

Composition of the Feeds.

Feed.	Moisture.	Protein.	Ash.	Ether extract.	Crude fiber.	N-free extract.
	per cent	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*
Brewers' rice.....................	13.7	7.2	0.7	0.5	0.5	77.4
Blood meal........................	15.0	79.0	6.4	0.3		
Alfalfa meal......................	9.2	9.3	10.1	1.2	30.2	39.9

ration was high. However, the daily feed intake did not show an abnormal increase.

The composition of the feeds is given in Table II. As already stated these feeds were mixed to give a certain nutritive ratio at a given period in the growth of the animals. On a percentage basis the protein content ranged from 12 to 17, the carbohydrates from 66 to 68, while the ether extract was approximately 0.5 throughout the experiment. These figures at once indicate that only a small proportion of the body fat could have been derived from the

TABLE III.

Composition of the Entire Body.

Hog No.	Age at slaughter.	Weight at slaughter.	Total analyzed weight.	Composition.				Total weight of fat.
				Water.	Protein.	Fat.	Ash.	
	days	*lbs.*	*lbs.*	*per cent*	*per cent*	*per cent*	*per cent*	*lbs.*
1	35	18.5	17.7	67.61	15.35	13.60	3.44	2.41
2	46	22.7	20.8	64.95	14.71	17.02	3.52	3.53
3	61	29	26.7	66.82	15.78	14.16	3.24	3.78
4	72	41	38.0	62.15	14.42	20.62	2.81	7.83
5	110	73	65.7	57.29	14.77	25.05	2.89	16.44
6	111	73	66.5	60.30	15.54	21.63	2.53	14.34
7	134	110	100.1	57.25	14.68	25.57	2.50	25.60
8	145	110	100.1	54.42	14.05	28.86	2.67	28.90
9	199	170	159.3	46.50	12.78	38.24	2.50	60.87
10	205	166	154.8	45.20	12.97	39.52	2.29	61.14
11	246	243	236.4	45.76	12.32	39.35	2.57	92.91
12	246	244	231.9	46.41	13.49	37.66	2.44	87.43
13	257	282	275.8	40.82	11.76	44.92	2.50	123.90

ingested fat and that much of it necessarily must have been synthesized from the carbohydrates.

The analyses given in Table III on the composition of the entire body give the per cent of water, protein, fat, and ash in the entire body, hair excepted. The total protein including the hair may be calculated, since it was found, as previously mentioned, that the protein in the hair constituted approximately 4.5 per cent of all other protein in the body. The fat content of these hogs was somewhat above the average for the corn-fed hogs in the earlier experiment up through the 170 pound group. Indeed at this weight the rice-fed hogs were much above the average. At heavier weights the animals herein reported were somewhat below the average. However, it was not enough to be significant. Indeed, observations on carcasses of hogs similarly fed have frequently indicated excessive fattening. The results on Hog 13 are of particular interest in illustrating the rapid synthesis of fat which can take place. This animal made the most rapid gain and most efficient feed utilization (see Table I) for the entire experimental period. When slaughtered at the age of 257 days it had

TABLE IV.

Grades and Fat Constants of Individual Hogs.

Hog No.	Carcass grade.	Refractive index, – 40°.	Iodine No.	Melting point.	Titer test.	Saponification No.	Reichert-Meissl No.	Polenske No.
				degrees				
1		1.4591	63.6	25.6	37.2	201.9	1.00	
2		1.4593	65.7	26.0	36.4	200.0	1.00	2.00
3		1.4591	66.1	24.6	35.6	200.0		2.05
4		1.4591	64.9	25.8	35.7	201.3		1.25
5	Medium soft.	1.4590	61.2	34.8	37.5	201.2	0.35	0.80
6	" "	1.4588	56.5	37.4	38.7	199.4		0.80
7	" hard.	1.4584	57.4	35.8	37.9	199.8		0.85
8	Hard.	1.4582	54.3	39.7	39.3	200.1		1.00
9	"	1.4589	57.6	32.8	37.4	195.5	0.30	0.50
10	"	1.4583	55.6	35.4	37.5	195.1	0.18	0.42
11	"	1.4584	53.3	32.8	38.0	195.8	0.51	0.54
12	"	1.4587	57.4	33.0	37.1	194.6	0.36	0.42
13	"	1.4584	55.1	37.6	38.1	195.0	0.18	0.81
Chester white dam.		1.4580	52.9					

stored 123.9 pounds of fat or at the average rate of 0.49 pound (220 gm.) per day. Wierzuchowski and Ling (6) in a calorimetric study of fat production found a daily average production of 98 gm. of fat in a pig weighing 13.5 kilos (30 pounds). Their animal was on test for 47 days (from the 70th to 117th day of its life) and during this time grew from a weight of 8.5 to 18.1 kilos (19 to 40 pounds).

Litter mates of Hog 13 which were killed at weights of 22.7 and 41 pounds (10.3 and 18.6 kilos) showed a difference in fat content of 4.30 pounds. With this as a basis for calculation, Hog 13 which increased in weight from 20 to 40 pounds between the 36th and 56th days of its life stored fat at the average daily rate of 0.22 pound (101 gm.), which is 3 gm. higher than that reported by Wierzuchowski and Ling. During the last 15 days of the experimental feeding period this animal gained 46 pounds, and, according to estimate, stored approximately 1.85 pounds (840 gm.) of fat daily.

Composition of Body Fat.

The fat constants determined on the individual samples of lard rendered from the composite meat samples are given in Table IV. The gradings for firmness of the chilled carcass are also given for the nine hogs killed subsequent to weaning. Hogs 5 and 6 were graded medium soft. Experience in the grading of animals of light weight such as these has shown that the grading does not follow the composition of the fat so closely as it does in heavier animals where a greater proportion of the carcass is adipose tissue. Hog 7 graded medium hard and the remainder all graded hard. The refractive index, iodine number, and titer test indicate a hard fat even in the young pigs. The melting point values show little if any correlation with the other analyses.

There was a tendency for the fat to increase in firmness with increasing weight of the animal. However the maximum firmness was apparently reached in Hogs 7 and 8. As compared with earlier results on hogs fed a basal ration of corn, the fat constants as given in Table IV show that the fat of the rice-fed hogs was not only more saturated at all weights but particularly so at the lighter weights. There was also a shorter and less abrupt course in the progressive hardening of the hogs in the present experiment than in the former. It is believed that this can safely be attributed to the low amount of ether extract in the feed. At the same time it lends additional support to the idea previously expressed in connection with the progressive hardening of hogs fed on a corn ration relative to the indirect rôle of the ingested fat in determining this increase in firmness with increase in the rate of fattening. The saponification, Reichert-Meissl, and Polenske values are indicative of a greater proportion of lower molecular weight acids in the young animals than in the older ones.

Perhaps the most important question raised in connection with the experiment was that of the distribution of the various fatty acids occurring in the adipose tissues. Lead salt-ether separations of the saturated and unsaturated acids were made on the fat samples from the individual hogs. The unsaturated fractions were brominated and small quantities of an octabromide recovered. This amounted to 0.11 per cent in the fat of Hog 2, while the other hogs, particularly those toward the end of the experiment, contained considerably less. On the basis of previous analyses (1) this octabromide was assumed to be arachidonic acid. Eckstein

TABLE V.

Fatty Acid Distribution in Body Fat.

Hog No.	Unsaturated acids.				Saturated acids.			
	Total.	Oleic.	Linolic.	Arachidonic.	Total.	Myristic.	Palmitic.	Stearic.
	per cent	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*
1	64.0	57.9	6.9	0.05	31.2			
2	63.0	53.9	9.0	0.11	32.1			
3	65.0	57.4	7.5	0.07	29.8			
4	63.5	55.5	7.9	0.07	31.6			
5	61.2	54.9	6.2	0.07	33.3	1.1	24.2	8.0
6	58.7	55.1	3.6	0.03	36.4			
7	60.2	53.9	4.3	0.05	35.3	0.7	26.1	8.5
8	57.6	55.2	2.4	0.06	37.4			
9	60.1	58.0	2.1	0.04	35.1			
10	60.7	59.7	1.0	0.02	34.6			
11	58.6	57.8	0.8	0.03	37.0	1.0	25.0	11.0
12	62.0	59.4	2.6	0.04	33.6			
13	60.2	58.9	1.3	0.02	35.3	0.7	24.3	10.3

(7) as well as Wesson (8) have reported its presence in body fat. With the exception of this small amount of arachidonic acid the unsaturated fraction consisted of oleic and linolic acids. The proportions were calculated from the iodine numbers and are given in Table IV as per cent of the total fat.

It will be noted in Table V that the oleic acid varied from 53.9 to 59.7 per cent. However, there was no consistent change except a tendency to increase with increasing weight of animal. The linolic acid shows a pronounced decline from 9.0 per cent for Hog 2 to 0.8 per cent for Hog 11. The low values found in Hogs 8 to 13 correspond to those previously reported (1) for hogs fed a similar ration of brewers' rice and supplements. The minimum content reported was 1.2 per cent, which occurred in a composite sample of back fat taken from hogs fed brewers' rice, tankage, and skim milk. It was suggested that the quantity occurring in the body fat was less than that ingested in the feed consumed by the animals and could have been derived from this source instead of direct synthesis. Results from various feeding experiments support the view that linolic acid is not synthesized and deposited to any great extent in the fattening hog but can generally be traced to the ingested fat.

The fact that a relatively greater proportion occurred in the young animals in the present experiment seems to indicate that synthesis of linolic acid or conversion of other ingested fatty acids to this acid followed by deposition does take place to a certain extent at least in young animals. The calculated amounts in Hogs 4, 5, and 6 (from Tables III and IV) range from 0.5 to 1.0 pound. This quantity was not greatly exceeded in the remaining animals except Hogs 12 and 13, which show approximately 2.25 and 1.60 pounds, respectively. These figures indicate that little if any synthetic linolic acid was deposited after the hog reached a weight of 75 pounds. The calculated amount of ether extract in the feed consumed from weaning to slaughter was approximately 4.5 pounds for Hogs 11, 12, and 13. Analyses on this ether extract gave an iodine number of 80.3 and a saponifiable matter content of 72.6 per cent. Since this was derived for the most part from the brewers' rice, the composition of this fatty acid material was assumed to be similar to that in rice oil as given by Jamieson (9). Thus estimated, the oleic and linolic acid content was 32 and 29 per cent, respectively. Calculation of the quantities of linolic and oleic acids ingested by Hogs 11, 12, and 13 gives 1.4 and 1.3 pounds, respectively. This amount of linolic acid was sufficient to account for that deposited in the body subsequent to weaning.

In considering the possible explanation of the relatively high proportion of linolic acid in the small animals, one possible source was the sow's milk. Milk fat normally contains little or no unsaturated acids other than oleic. A small sample of milk was obtained from one of the dams at the close of the suckling period when she was slaughtered. The iodine number of the fat was 51.6, which is much higher than normally found in sow's milk. However, an attempt at determination of unsaturated acids did not reveal any linolic acid nor the probability of any appreciable quantity being present. The sample was too limited to admit of extended analysis. It has been frequently noted that the outermost adipose tissue lying directly under the skin as well as the fat in the skin is more unsaturated than the fat further removed from the external surface of the body. This fat near the surface acting as a protective covering may carry a more or less constant amount of the liquid, unsaturated acids. Mayer, Schaeffer, and Terroine, as quoted by Leathes (10), have termed the fat found in the organs and muscles which is largely in complex lipid combination and extracted with some difficulty as the "element constant," as distinguished from that in the adipose tissue which they term the "element variable." The element constant, frequently spoken of as metabolic fat, is more unsaturated than stored fat. It is reasonable to believe that a relatively higher proportion of the total body fat would consist of the surface fat and the metabolic fat in the young, thin animal than in the older, fat animal. It is, of course, impossible to preclude ingested linolic acid as the precursor of that found in the young animals, yet its presence in the amounts found may be the result of synthesis to meet certain demands of the tissues.

The total saturated acids were lowest in the first four animals. The increase in per cent following these was not only small but without uniformity. Indeed it is unusual to find such a low saturated acid content in the well fattened, mature animals. The carcass grading has shown an unusually hard adipose tissue, which at first sight is difficult to reconcile with the relatively low content of saturated acids. The absence of an appreciable amount of linolic acid would seem to be an important factor. The oleic acid on the other hand must be so combined with the palmitic and stearic acids into mixed glycerides as to lose much of its softening properties.

Four samples were chosen for fractionation of the saturated acids in order to determine the proportions of stearic, palmitic, and myristic acids occurring in the body fat. Saturated acid fractions of the fat from Hogs 5, 7, 11, and 13 were prepared, the methyl esters formed, and fractionally distilled under low pressure. After determining the saponification numbers on these fractions the acids were identified and the proportions of each calculated. The results of this rather laborious method are given in Table V. Myristic acid constituted 0.7 to 1.1 per cent of the fat. Palmitic acid predominated among the three saturated acids present although the quantity was less than half that of oleic acid. Stearic acid on the other hand was comparatively low. In Hogs 5 and 7 it was approximately 33 per cent, while in Hogs 11 and 13 it approached to 50 per cent that of palmitic acid.

These results of fatty acid separations, reflecting as they do the results of fat anabolism in the hog when fed on a ration low in fat, show through their changes from the young suckling to the grown fattened animal some shifting in the type of fat deposited. They are interpreted as representing a close approximation of the normal body fat of hogs when the influence of ingested fat is at a minimum and other factors of nutrition are normal.

SUMMARY.

The changes in the quantity and composition of the body fat of hogs at successive intervals of growth and reared on a ration low in fat were found to be as follows:

1. The animals synthesized and stored fat at a normal rate. The lack of fat in the ration did not appear to exert material influence on the degree of fatness.
2. Hard, saturated fat was formed even in the young pigs. A gradual increase in saturation occurred up to a weight of approximately 100 pounds, above which extremely hard body fat was produced.
3. The principal fatty acids found in the fat were oleic, palmitic, and stearic. Others which occurred in small amounts were linolic, myristic, and arachidonic.
4. The principal change occurred in the linolic acid content. From a maximum content in the suckling pigs a steady decrease occurred up to a weight of 170 pounds. This change appeared to account for the increase in saturation of the fat which accompanied increase in weight.

The authors wish to express their gratitude to K. F. Warner for assistance in preparation of the samples for analysis, and to O. G. Hankins and Paul E. Howe for helpful criticism.

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