SOFT PORK STUDIES.

I. FORMATION OF FAT IN THE PIG ON A RATION MODERATELY LOW IN FAT.

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The difference in the firmness of the chilled carcasses of young, immature, pigs and fully developed, mature, hogs when fed a ration of corn and non-softening[1] protein supplement has been one of the outstanding developments of the cooperative soft pork investigations being conducted by the U. S. Department of Agriculture and a number of the State Experiment Stations.[2]

Although variations in the composition and firmness of the fat in hogs of different ages have been reported, the conditions of experimentation were not strictly comparable to those existing in the type of feeding under question. In a study of the Canadian soft bacon problem, Schutt[3] found that most of the bacon classed as soft came from immature or underfed pigs which had received poorly balanced rations such as corn alone or beans alone. The softness was eliminated in the well grown and well finished

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[1] The term non-softening refers to those protein supplements such as tankage, wheat middlings, fish-meal, and skim milk which when fed do not have a tendency to produce a soft fat.

[2] The following were the cooperating stations when the work reported in connection with this paper was under way: Alabama, Arkansas, Georgia, Indiana, Kentucky, Mississippi, North Carolina, Oklahoma, South Carolina, Tennessee, Texas, Coastal Plains Experiment Station, and Iberia Livestock Experiment Farm.

[3] Schutt, F. T., Composition and properties of fat in firm and soft pork, *Canada Exp. Station, Bull. 38*, 1901.

animals after feeding mixed feeds composed of corn, barley, peas, skim milk, and other feeds.

König and Schluckebier[4] observed that as pigs grow older, the melting point of the body fat is raised and that the iodine number is lowered. The weights of the pigs studied as well as the feeds compared do not, however, furnish data strictly comparable with our studies.

Moulton and Trowbridge[5] found in the beef animal that the iodine number of the fat increased and the melting point decreased with age and fatness. The ration fed was composed, in most instances, of corn, linseed meal, and hay. These results seem to indicate that the behavior of the fat in this animal is the reverse of that in the hog when the latter is fed corn and non-softening supplement.

The direct relation between immaturity and softness was first observed in check pigs selected from experimental lots at the start of feeding tests in the soft pork work. These pigs weighed approximately 100 pounds and had received corn with some protein supplement as their main feed. They were usually graded soft or medium soft by the grading committee.[6] The fat of these animals showed rather high iodine numbers and refractive indexes. Control lots fed to a market weight of 200 to 250 pounds on the same ration as the check pigs were graded hard or medium hard with few exceptions and the fat constants were lowered appreciably.

The two experiments reported in this paper were conducted in order to study the question in greater detail. In these experiments, the feed consumption, the composition of the animal body, and the composition of the fat were studied. Periodic killings were made to compare pigs at different stages of development.

[4] König, J., and Schluckebier, J., On the influence of food fat on body fat of swine with special reference to the final location of phytosterin, *Z. Untersuch. Nahrungs- u. Genussmittel*, 1908, xv, 641.

[5] Moulton, C. R., and Trowbridge, P. F., Composition of the fat of beef animals on different planes of nutrition., *J. Ind. and Eng. Chem.*, 1909, i, 761.

[6] Chilled carcasses of all hogs in soft pork experiments are graded by an official committee into five grades; namely, hard, medium hard, medium soft, soft, and oily.

The results of this work along with a summary[7] embracing 371 hogs, on the check and control lots in connection with 4 years of cooperative soft pork experiments, show very strikingly the direct relation of softness to immaturity and also the progressive hardening of the fat of pigs fed on corn and tankage or similar non-softening supplement. The data from the two experiments reported here give an explanation of this behavior. These data show that as the pigs became fatter and better finished, more of the body fat necessarily was derived, through synthesis, from the carbohydrate and protein of the ration and proportionally less from the fat of the ration. The synthetic fat was firm while the ingested fat used for deposition was (soft) oily, and was apparently stored without material change in character.

The present paper records in detail the results of two experiments which deal with the formation of fat in the pig on a ration of corn and skim milk (Experiment A); and corn and tankage with and without alfalfa meal (Experiment B). Special attention is given, in respect to both quantity and quality, to the relationships of the ingested fat and the synthesized fat to the resulting body fat. These relationships are considered to afford a satisfactory explanation of the progressive hardening observed.

EXPERIMENTAL.

The work, begun in April, 1922, was conducted at the U. S. Experiment Farm, Beltsville, Maryland, as a supplement to the cooperative soft pork investigations. In Experiment A, litters from four sows were used. Of the 34 pigs in the four litters, 27 were actually used in the slaughter tests. Their dams were fed a ration of corn, wheat middlings, and alfalfa hay during the gestation period and after farrowing received a mixed ration of corn, 8 parts; middlings, 4 parts; and fish-meal, 1 part. At the age of 6 weeks, pigs from each litter were killed for analysis. The individual hand feeding of the remaining pigs was started at this point; the ration was corn-meal, 1 part, and skim milk, 3 parts. The pigs continued to suckle their dams until weaned at 10 to 12 weeks of age, when the second killing was made. The

[7] Given in a bulletin, entitled: Some results of soft pork investigations, which is in the course of publication by the cooperating agencies.

ration of corn-meal, 1 part, and skim milk, 3 parts, was fed throughout the test. All of the pigs were fed individually for 2 months after weaning. From that point two litters were lot-fed while the other two continued on individual feeding. Additional killings were made at the approximate weights and ages indicated, as follows: the third at 70 pounds (5 months); the fourth at 100 pounds (6 months); the fifth at 170 pounds (7 months); and the sixth at 225 pounds (8 months).

In Experiment B three litters, numbering 19 pigs, farrowed in October, 1922, were used. The three dams were self-fed corn and wheat middlings on a mixed pasture of sudan grass, soy beans, cow-peas, field-peas, oats, and rape during the gestation period and a mixture of corn-meal, 8 parts; wheat middlings, 4 parts; and fish-meal, 1 part, on rye pasture during the suckling period. At about 4 weeks of age the pigs from two litters were given access to a mixture of corn-meal, 100 parts, and tankage, 15 parts, in a self-feeder in a creep. After weaning at the age of 11 weeks, they received the same mixture in a self-feeder. The total amount of feed consumed by all the pigs was determined by growth stages and the average amount consumed per individual was calculated. In this way any differences in feed utilization due to stage of growth were accounted for and expressed in the feed consumption per unit of gain. The pigs in the third litter were handled in a similar manner, excepting that they were fed individually, on a ration of corn, 100 parts; tankage 14.5 parts; and alfalfa meal, 6 parts. Six killings were made as in the first test.

The composition of the feeds used in the experiments are contained in Table I.

The growth and feeding results as shown by individual pigs are reported in Table II. The pigs are grouped by experiment and by stages of growth. The gains from birth weight to final weight, and the consumption of feed per pound of gain show that the pigs, generally speaking, made satisfactory growth.

Slaughter.

In the first and second killings of each experiment, the pigs were taken directly from the feed lot and slaughtered. In the remaining four killings the pigs were restricted to water for 24 hours prior to slaughter.

All parts of the animal, with the exception of the hair and the contents of the stomach and intestines, were saved for analysis. Weighings were made of live weight, dressed weight, individual and total organs, and blood. A sample of blood was saved for analysis, and the cleaned empty organs were ground and sampled. With the exception of the first two killings, the carcasses were chilled for 48 to 72 hours and graded for firmness.

Back and leaf fat samples were cut out and prepared for fat analysis, after which the carcasses were cut up and separated into three fractions; skin, bone, and meat. The skin and meat were finely ground in a sausage mill and the bones were put through a

TABLE I.

Composition of Feeds.

	Moisture.	Ash.	Protein.	Fat.	Crude Fiber.	Nitrogen-free extract.
Experiment A.						
Corn....................	13.25	1.55	8.85	2.90	2.04	71.41
Skim milk...............	89.97	0.62	3.78	0.30	—	5.35
Experiment B.						
Corn....................	14.90	1.31	8.46	3.57	1.90	69.86
Tankage.................	7.40	22.90	57.12	5.70	3.24	3.64
Alfalfa.................	9.11	6.95	13.60	1.75	30.00	38.59

bone cutter. The entire body was thus divided into five fractions; namely, blood, organs, skin, bone, and meat. The sum of these fractions plus the water lost in evaporation from the carcass made up the total analyzed weight. The slaughter weight and the total analyzed weight for each animal are given in Table II. The per cent analyzed weight of the live weight expresses the portion of the animal which was analyzed. This value is less than the live weight by the amount represented by the contents of the digestive tract and the hair.

Composition of the Animals.

The percentage composition of moisture, protein, fat, and ash was determined in each of the fractions referred to above. Com-

TABLE II.

Growth, Feed Consumption, Slaughter Yield, and Composition of Individual Pigs.

Period.	Hog No. and breed.*	Age at slaughter.	Total gain.	Feed consumed per pound gain.†	Slaughter weight.	Total analyzed weight.	Analyzed weight of live weight.	Analyzed weight.				Total weight of fat.
								Water.	Protein.	Fat.	Ash.	
						Experiment A.						
		days	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*lbs.*
1	1 H.	26	8.2	(Weaning	9.9	9.3	93.08	65.99	14.34	16.68	2.91	1.56
	2 H.	26	9.7	to close	11.4	10.3	90.68	65.17	15.13	16.63	3.01	1.72
	3 C.	30	9.2	of feed-	12.4	11.8	94.94	65.26	13.75	18.09	2.91	2.12
	4 B.	41	14.4	ing)	16.6	15.3	92.46	62.63	15.02	19.15	3.25	2.94
	5 C.	39	17.0	—	19.1	18.3	95.75	61.44	14.30	20.68	3.64	3.78
2	6 H.	68	19.0	—	21.1	19.1	90.80	69.65	14.76	12.36	3.22	2.37
	7 C.	72	25.5	—	27.9	25.3	90.60	69.04	15.78	11.64	3.76	2.94
	8 B.	83	28.1	—	30.4	27.3	89.72	71.44	16.02	9.04	3.70	2.47
	9 C.	81	29 3	—	32.5	29.6	90.96	69.24	14.76	12.13	3.97	3.59
3	10 B.	173	50.8	4.27	52.5	47.0	89.53	69.93	16.39	10.94	3.04	5.12
	11 H.	158	71.0	2.77	65.5	60.8	92.82	66.48	16.43	14.28	3.00	8.72
	12 C.	162	78.5	2.85	72.0	66.4	92.26	64.06	15.68	17.29	2.94	11.50
	13 C.	171	78.0	2.90	77.0	71.1	92.32	66.07	16.04	14.48	3.35	10.28
4	14 B.	201	107.0	3.76	101.0	93.9	92.94	61.40	16.51	18.74	3.15	17.59
	15 C.	199	108.8	3.25	109.0	100.4	92.10	54.32	14.53	27.85	3.10	27.94
	16 H.	186	107.5	3.20	109.0	101.4	93.00	58.41	15.70	22.72	2.87	23.00
	17 C.	190	125.0	3.57	116.0	111.0	95.70	55.28	14.68	26.95	2.74	29.91

5	18 H.	222	155.7	3.75	152.0	143.3	94.30	52.98	14.77	29.52	2.71	42.32
	19 H.	222	166.7	3.49	160.0	151.7	94.84	50.38	14.20	32.68	2.63	49.56
	20 C.	226	169.5	3.99	162.0	152.3	94.02	51.37	14.16	31.81	2.67	48.44
	21 C.	235	178.3	3.38	170.0	163.4	96.15	47.44	12.91	37.31	2.57	61.00
6	22 H.	246	204.5	3.64	193.0	185.8	96.27	46.03	13.31	38.42	2.37	71.37
	23 B.	261	226.0	4.20	213.0	204.6	96.08	45.44	12.96	39.21	2.35	80.25
	24 C.	226	234.3	2.91	225.0	217.4	96.60	43.77	11.85	42.41	2.15	92.19
	25 C.	297	228.5	4.78	228.0	217.3	95.30	40.06	11.23	46.74	2.28	101.56
	26 C.	250	255.5	3.55	240.0	230.3	95.96	43.20	12.21	42.37	2.20	97.56
	27 H.	284	221.2	4.31	218.0	207.3	95.06	43.92	12.34	41.56	2.28	86.12

Experiment B.

1	28 C.	36	14.6	—	16.4	15.8	96.60	62.06	14.18	20.62	3.14	3.26
	29 D.	39	15.8	—	17.8	16.9	95.30	66.34	15.05	15.30	3.39	2.60
2	30 C.	78	33.7	—	36.0	31.7	88.00	64.93	17.18	14.47	3.88	4.58
	31 D.	81	43.7	—	46.0	41.8	90.90	60.30	16.28	19.96	3.83	8.34
	32 H.	77	36.3	—	38.3	35.0	91.52	60.00	15.88	20.65	3.70	7.23
3	33 C.	119	74.5	2.95	73.3	69.4	94.70	60.75	14.90	21.25	3.22	14.77
	34 D.	122	63.2	4.50	61.8	55.0	89.07	62.67	15.98	17.63	3.85	9.70
	35 H.	118	67.2	3.38	64.5	61.5	95.34	60.75	14.86	21.10	3.24	12.98
4	36 C.	144	115.0	2.82	110.5	104.6	94.58	53.68	13.84	29.54	2.90	30.88
	37 C.	144	111.5	2.40	104.5	100.6	96.18	52.20	13.60	31.16	3.04	31.32
	38 D	147	103.2	2.52	98.5	90.3	91.65	58.53	15.08	22.60	3.74	20.41

TABLE II—*Concluded.*

Period.	Hog No. and breed.*	Age at slaughter.	Total gain.	Feed consumed per pound gain.†	Slaughter weight.	Total analyzed weight.	Analyzed weight of live weight.	Analyzed weight.				Total weight of fat.
								Water.	Protein.	Fat.	Ash.	
Experiment B—*Concluded.*												
		days	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*lbs.*
5	39 C.	216	172.5	4.19	159.5	154.9	97.14	49.39	13.80	33.70	3.04	52.26
	40 C.	216	168.2	5.14	161.5	157.4	97.43	47.49	13.39	36.00	2.99	56.65
	41 D.	253	180.5	3.85	172.5	160.8	93.18	47.20	12.85	36.50	3.21	57.34
	42 D.	253	159.5	4.50	155.5	146.9	94.45	50.21	13.75	32.82	3.14	48.20
	43 H.	192	167.5	3.77	162.5	158.6	97.63	46.03	13.34	37.59	3.01	59.64
6	44 C.	250	230.0	3.44	225.0	218.6	97.14	43.78	12.59	40.94	2.75	89.47
	45 D.	219	222.0	3.03	210.0	201.6	96.02	49.21	14.26	33.25	3.25	67.04
	46 H.	249	180.0	5.10	180.0	177.3	98.48	38.00	11.04	48.02	2.78	85.12

* The letters attached to the numbers refer to the breed as follows: H., Hampshire; C., Chester White; B., Berkshire; D., Duroc Jersey.

† Skim milk fed in Experiment A is calculated to a grain basis—6 pounds skim milk were considered to be equivalent to one pound of grain.

TABLE III.

Average Composition of Hogs at Certain Stages of Growth.

Stage of growth.	1	2	3	4	5	6
Experiment A.						
No. of pigs analyzed	5	4	4	4	4	6
Live weight at close of experimental period (lbs.)	13.9	28.1	70.6	114.2	170.0	231.0
Live weight at slaughter (lbs.)	13.9	28.1	66.7	108.7	161.0	219.5
Total weight of parts analyzed (lbs.)	13.2	25.3	61.3	101.6	152.8	210.4
Percentage of analyzed weight.*						
Water	64.12	69.84	66.64	57.40	50.54	43.74
Protein	14.64	15.33	16.14	15.36	14.01	12.32
Fat	18.25	11.29	14.25	24.07	32.83	41.78
Ash	3.15	3.66	3.08	2.96	2.65	2.27
Weight (lbs.).						
Water	8.46	17.68	40.86	58.35	77.25	92.08
Protein	1.93	3.88	9.90	15.62	21.41	25.90
Fat	2.41	2.86	8.74	24.47	50.20	87.95
Ash	0.42	0.93	1.89	3.01	4.05	4.77
Weight of fat gained, by periods (lbs.)		0.45	5.88	15.73	25.73	37.75
Percentage fat gained, by periods		3.16	13.19	36.06	46.15	61.88
Experiment B.						
No. of pigs analyzed	2	3	3	3	5	3
Live weight at close of experimental period (lbs.)	17.1	40.1	70.8	112.2	171.8	212.8
Live weight at slaughter (lbs.)	17.1	40.1	66.5	104.7	162.3	205.0
Total weight of parts analyzed (lbs.)	16.3	36.2	61.8	98.4	155.7	199.2
Percentage of analyzed weight.*						
Water	64.20	61.74	61.39	54.80	48.06	43.66
Protein	14.62	16.45	15.25	14.17	13.43	12.63
Fat	17.96	18.36	20.00	27.77	35.33	40.74
Ash	3.26	3.80	3.44	3.23	3.08	2.93
Weight (lbs.).						
Water	10.50	22.28	40.42	57.85	79.30	90.25
Protein	2.39	5.94	10.03	14.95	22.17	26.13
Fat	2.93	6.72	12.48	27.54	54.82	80.54
Ash	0.54	1.38	2.25	3.41	5.07	6.05
Weight of fat gained, by periods (lbs.)		3.79	5.76	15.06	27.28	25.72
Percentage fat gained, by periods		16.48	18.73	36.40	45.75	62.70

* Based on the combined results obtained from the separate analyses of blood, organs, meat, bone, and skin.

posite samples of blood were made for hogs of the same size. In several cases the organ and skin samples were handled in the same way. In the analysis of the blood and bones, 300 to 400 gm. samples were given a preliminary drying, weighed, and then ground in a pulverizing mill. Whenever the organ and skin samples were found to be too coarsely ground, they were treated

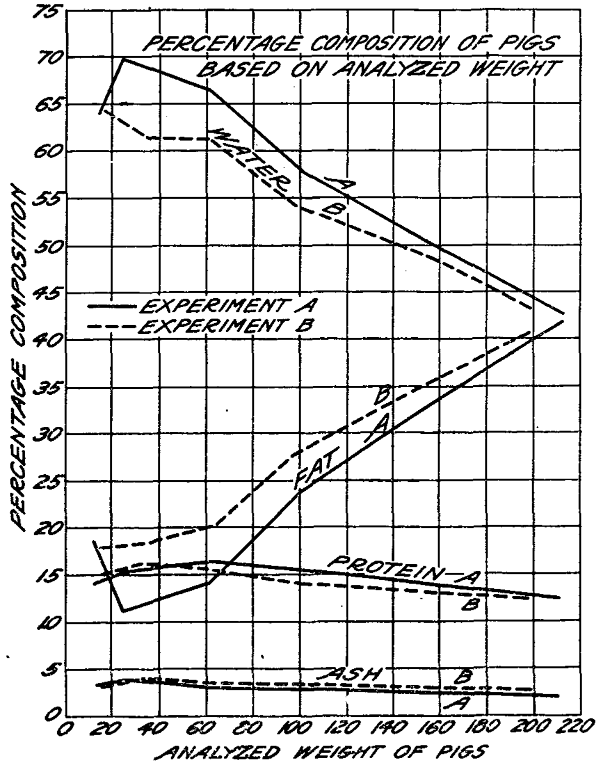

CHART 1.

in a similar manner. The methods of analysis of the Association of Official Agricultural Chemists were followed throughout. Triplicate determinations were made on sufficiently large samples to insure reliable results. From these analyses, the composition of each animal was calculated back to the total analyzed weight The per cent of water, protein, fat, and ash based upon the analyzed weight and also the total weight of fat are given in Table

II. There was some variation within a group of animals, on the other hand, with the number of animals used, and with one experiment a check on the other, the average figures given in Table III can be taken as representative of the conditions in the experiments.

Chart 1 shows the change in percentage composition of the pigs on the analyzed weight basis. The most noteworthy point in this chart is the rise in fat content. The pigs in Experiment B were fatter throughout the trial than those in Experiment A although the latter reached a heavier weight and consequently a fatter condition at the close of the experiment.

Composition of the Fat.

Fat samples were prepared from the meat fractions of each pig in addition to the back and leaf samples previously mentioned. These were usually prepared by rendering the meats on the steam bath, then decanting and filtering the fat. This sample, which was termed the meat fat, represented 80 to 90 per cent of all the fat in the animal. The general analysis on the back, leaf, and meat fat samples from the individual pigs consisted in the determination of the refractive index, iodine number, and melting point as shown in Table IV. Included are the Soft Pork Committee[6] grades. The change in these fat constants, indicating a decrease in the degree of unsaturation of the fat, was accompanied by the change in carcass grades from soft to hard. The small pigs under 100 pounds were soft, while the 165 to 225 pound pigs were hard. It will be noted that in Experiment B, the weanling pigs of the second killing were the softest. Otherwise all show the progressive hardening step by step. The corn and skim milk ration in the first trial resulted in the formation of a slightly harder fat than the corn and tankage ration of Experiment B. The features of these results are shown in Chart 2 in which the changes in the refractive index and iodine number of the meat fat are plotted. These results on fat constants and committee grades confirm the conclusions previously referred to, that as hogs take on weight and finish they become progressively harder.

After completing the analyses on the fat samples of the individual pigs, aliquot samples of meat fat for each stage of growth

TABLE IV.

Grades and Fat Constants of Individual Pigs.

Stages of growth.	Hog No.	Grade.	Refractive index—40°C.			Iodine No.		Melting point.	
			Meat.	Back.	Leaf.	Meat.	Back.	Meat.	Back.
				Experiment A.					
1	1	—	1.4602	—	—	73.7	—	25.5	—
	2	—	1.4598	—	—	72.4	—	26.1	—
	3	—	1.4606	—	—	73.6	—	26.9	—
	4	—	1.4609	—	—	72.4	—	27.7	—
	5	—	1.4604	—	—	73.0	—	27.5	—
2	6	—	1.4604	—	—	71.5	—	27.3	—
	7	—	1.4603	—	—	70.9	—	27.3	—
	8	—	1.4606	—	—	73.5	—	27.7	—
	9	—	1.4604	—	—	71.5	—	26.7	—
3	10	Soft.	1.4604	1.4602	—	69.6	73.9	27.8	28.0
	11	"	1.4600	1.4594	—	68.4	69.9	28.0	28.6
	12	"	1.4597	1.4592	—	65.9	66.0	29.0	31.0
	13	"	1.4596	1.4594	—	64.0	65.6	33.2	35.8
4	14	"	1.4597	1.4601	—	65.9	68.0	31.0	31.6
	15	"	1.4591	1.4592	—	61.6	61.5	31.4	31.4
	16	"	1.4594	1.4595	—	63.0	65.2	29.4	30.8
	17	"	1.4592	1.4592	—	62.1	61.8	30.8	32.4
5	18	Med. hard.	1.4590	1.4590	1.4580	61.0	60.6	34.0	37.0
	19	Hard.	1.4591	1.4588	1.4579	60.8	60.5	34.2	38.2
	20	"	1.4589	1.4586	1.4579	60.1	57.1	36.0	39.8
	21	"	1.4585	1.4585	1.4577	56.3	56.3	37.6	40.2
6	22	"	1.4586	1.4584	1.4577	60.0	59.4	30.8	37.4
	23	"	1.4584	1.4584	1.4576	58.9	58.6	33.0	36.4
	24	"	1.4586	1.4584	1.4580	57.4	56.3	36.2	38.6
	25	"	1.4589	1.4589	1.4580	59.0	59.1	38.5	38.5
	26	"	1.4584	1.4582	1.4575	57.7	58.0	39.2	39.2
	27	"	1.4590	1.4589	1.4583	60.1	61.2	36.1	36.1
				Experiment B.					
1	28	—	1.4605	—	—	73.9	—	26.1	—
	29	—	1.4600	—	—	69.8	—	30.1	—
2	30	—	1.4609	—	—	80.4	—	21.7	—
	31	—	1.4604	—	—	75.7	—	26.9	—
	32	—	1.4605	—	—	76.9	—	25.1	—

TABLE IV—*Concluded.*

Stages of growth.	Hog No.	Grade.	Refractive index—40°C.			Iodine No.		Melting point.	
			Meat.	Back.	Leaf.	Meat.	Back.	Meat.	Back.
Experiment B—*Concluded.*									
3	33	Soft.	1.4600	—	—	70.3	—	35.9	—
	34	"	1.4610	—	—	78.2	—	27.7	—
	35	"	1.4602	—	—	73.0	—	30.4	—
4	36	Med. hard.	1.4596	1.4598	1.4590	67.7	—	30.1	—
	37	" soft.	1.4591	1.4593	1.4582	63.2	—	37.5	—
	38	Soft.	1.4599	1.4602	1.4590	69.7	—	38.1	—
5	39	Hard.	1.4593	1.4593	1.4586	64.6	—	36.4	—
	40	"	1.4591	1.4591	1.4581	63.2	—	40.0	—
	41	Med. Hard.	1.4589	1.4590	1.4581	61.8	—	40.0	—
	42	Hard.	1.4589	1.4590	1.4583	60.7	—	39.9	—
	43	"	1.4594	—	—	64.8	—	37.6	—
6	44	Med. hard.	1.4589	1.4589	1.4580	61.3	—	39.6	—
	45	Hard.	1.4591	1.4592	1.4584	63.3	—	39.4	—
	46	"	1.4589	1.4591	1.4584	62.2	—	39.4	—

in each feeding test were combined in a composite sample which was used for a detailed study of the fat composition. Most of the fat constants, Table V, were included in this study along with the separation of the fatty acids by the lead salt-ether method. For the fat constants, the methods of the Association of Official Agricultural Chemists[8] were followed, while for the lead salt-ether method the directions given by Lewkowitsch[9] and by Jamieson and Baughman[10] were used. In addition to determining the percentage of saturated and unsaturated acids present, the percentage composition of the individual unsaturated acids was also determined. The unsaturated fraction was brominated and the ether-insoluble bromides separated from the ether-soluble. The former yielded no hexabromide (linolenic acid)

[8] Official and tentative methods of analysis, *Assn. Off. Agric. Chem.*, Washington, 1920.

[9] Lewkowitsch, J., Chemical technology and analysis of oils, fats, and waxes, London, 6th edition, 1921–23, iii.

[10] Jamieson, G. S., and Baughman, W. F., *Cotton Oil Press*, 1922, vi, 41.

but was insoluble in boiling benzene and did not melt at 180°C., thus indicating an octabromide, which probably belonged to the clupanodonic acid series. The ether-soluble material was further tested to demonstrate the presence of both linolic and oleic acids. The actual percentages of these acids were calculated from the iodine number of the mixture of these two acids.

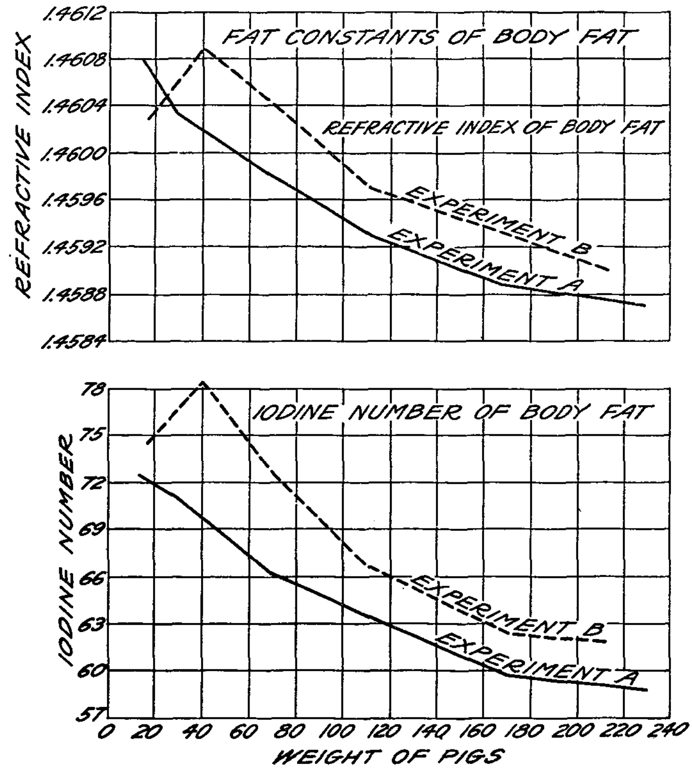

CHART 2.

The results of the fat analysis of the composite samples are shown in Table V. The refractive index, iodine number, and melting point values, already indicated, show increasing hardness with increasing size, with the exceptions noted. The refractive index and iodine number are shown in Chart 2. The specific gravity, saponification number, the proportion of insoluble acids, the Reichert-Meissl number, the Polenske number, and the titer

TABLE V.

Results Obtained from the Analysis of Composite Meat Fats, Giving the Composition of the Average Fat at Definite Stages of Growth.

Stage of growth.	1	2	3	4	5	6
Experiment A.						
Refractive index	1.4608	1.4603	1.4598	1.4593	1.4589	1.4587
Iodine No	72.5	71.0	66.1	63.2	59.7	58.8
Melting point	25.5	26.7	35.1	37.1	38.7	37.5
Specific gravity	0.9043	0.9053	0.8980	0.8970	0.8956	0.8957
Saponification No	200.0	199.4	194.6	196.1	196.0	195.0
Insoluble acids, per cent	94.36	92.65	94.30	95.51	95.85	95.61
Reichert-Meissl No	0.58	1.46	0.94	1.22	1.10	1.03
Polenske No	1.25	1.37	2.56	4.31	4.90	5.19
Titer test	37.0	37.5	37.8	37.9	39.2	39.1
Unsaturated acids, per cent	62.0	63.5	59.3	59.8	58.7	58.8
Saturated acids, per cent	30.7	29.0	34.6	35.6	36.5	36.9
Total acids, per cent	92.7	92.5	93.9	95.4	95.2	95.7
Iodine No.—unsaturated acids	107.7	109.3	107.5	103.1	101.0	100.8
Oleic acid, per cent	50.4	50.5	48.2	51.3	51.7	52.0
Linolic acid, per cent	11.3	12.7	10.9	8.4	6.9	6.7
Octabromide acid, per cent	0.25	0.23	0.16	0.09	0.06	0.07
Experiment B.						
Refractive index	1.4603	1.4609	1.4604	1.4597	1.4593	1.4590
Iodine No	74.6	78.5	72.8	67.0	62.7	62.2
Melting point	27.2	23.8	30.4	36.6	39.4	39.8
Specific gravity	0.8983	0.8986	0.8984	0.8961	0.8960	0.8963
Saponification No	198.2	197.1	196.6	196.6	197.2	195.8
Insoluble acids, per cent	95.75	95.50	95.49	95.50	95.57	95.49
Reichert-Meissl No	0.90	1.42	2.29	1.26	0.67	0.82
Polenske No	3.25	4.65	4.97	4.52	3.96	3.53
Titer test	37.0	34.0	36.4	37.9	38.9	39.3
Unsaturated acids, per cent	63.8	67.7	63.4	61.8	58.7	58.9
Saturated acids, per cent	32.0	27.9	31.7	33.7	36.7	36.6
Total acids, per cent	95.8	95.6	95.1	95.5	95.4	95.5
Iodine No.—unsaturated acids	111.4	112.7	113.7	105.6	104.8	104.3
Oleic acid, per cent	49.2	51.2	47.2	51.4	49.4	49.8
Linolic acid, per cent	14.4	16.2	16.1	10.3	9.3	9.1
Octabromide acid, per cent	0.21	0.24	0.14	0.09	0.07	0.07

test show only slight fluctuations with the other fat constants. It could hardly be expected that these values would show much change under the conditions of this experiment. There is a slight drop in specific gravity and saponification number. The Reichert-Meissl number is constant (within experimental error) throughout. The Polenske number shows some fluctuation; in Experiment A it increases as the animal increased in size while in the second experiment it is at a maximum in the 70 pound size. The titer test shows a slight rise in Experiment A and a more decided

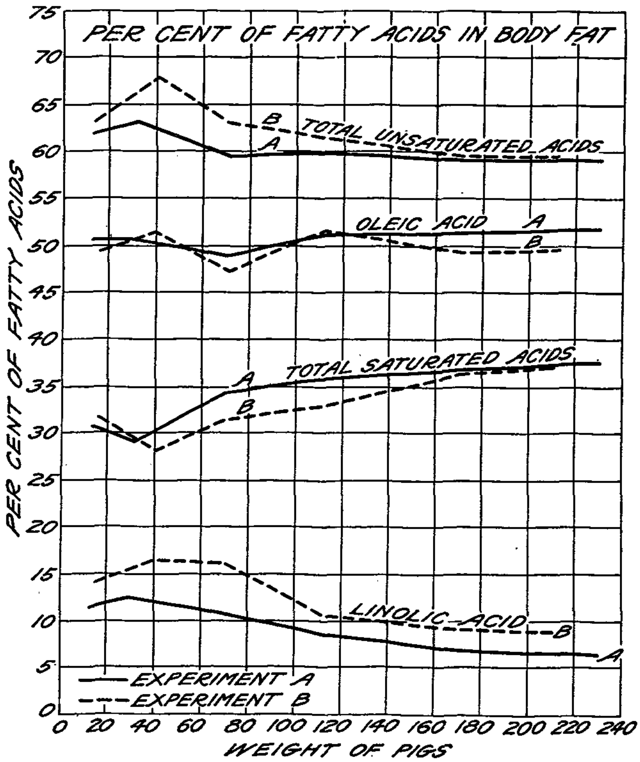

CHART 3.

change in Experiment B. As is to be expected this determination gives values which are comparable with the changes in the refractive index, iodine number, and melting point.

The total saturated and the unsaturated fatty acids (see Chart 3) are of particular interest. In both trials, the lowest per cent of saturated acids occurred at the weanling stage and the highest per cent at the fifth and sixth stages which were very close; the total unsaturated acids were the reverse of this. Of the individual unsaturated acids the oleic acid was surprisingly constant at about 50 per cent of the fat. Linolic acid, however, decreased as the saturated acids increased; in the first trial it declined from a high point of 12.7 per cent in the second killing to 6.7 per cent in the last killing, while in the second trial the percentages were 16.2 and 9.1, respectively. These declines, amounting to nearly

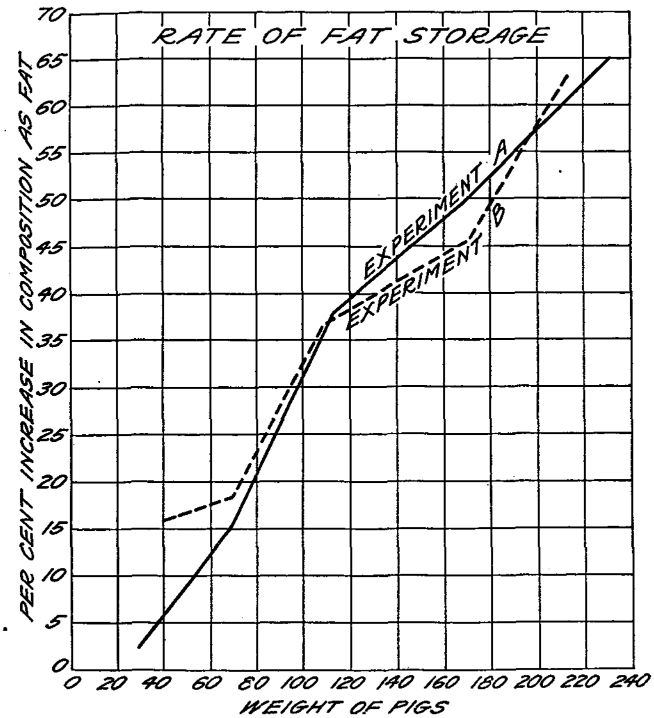

CHART 4.

50 per cent in each case, were considered very significant, particularly since they paralleled the change from soft to hard in the body fat. No attempt was made to separate or to determine quantitatively the different saturated acids of these twelve samples. Certain saturated acid fractions were, however, examined and found to consist of palmitic, stearic, and myristic acids; occurring in decreasing amounts in the order named, the latter being relatively small.

It has long been known that in a fattening animal the gain in fat makes up a much higher proportion of the total gain than it does in a growing animal. From the average composition of

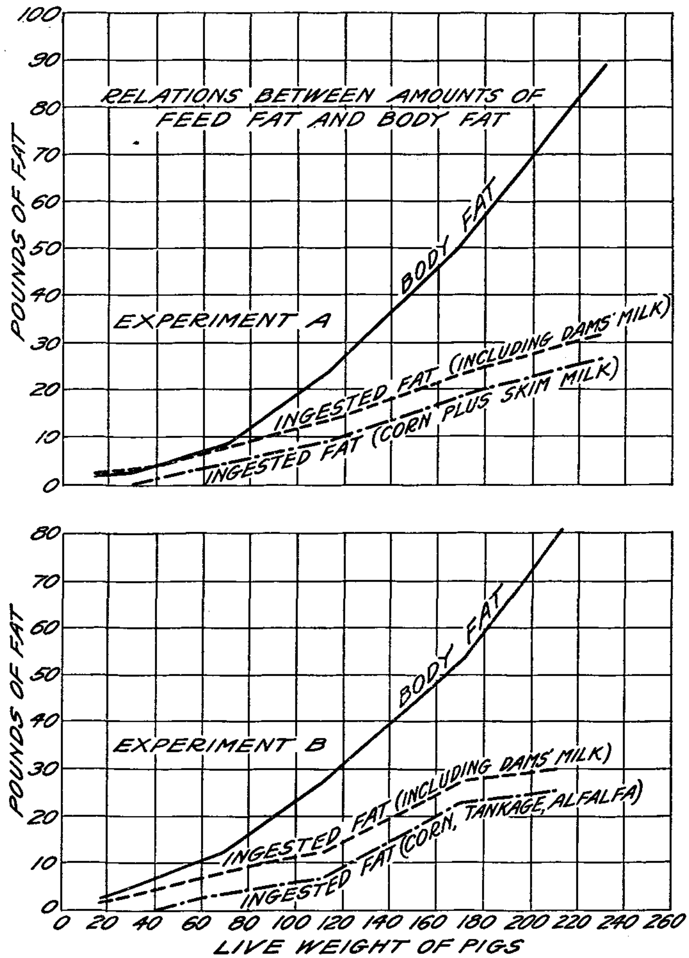

CHART 5.

the hogs (see Table III), the percentage of fat increase by periods has been calculated for both trials. This value was obtained by dividing the gain in fat between two given periods by the gain in live weight for the same interval. In the first experiment there was an increase from 3.16 to 61.88 per cent while in the second experiment the increase was from 16.48 to 62.70 per cent. These figures are shown graphically in Chart 4. Knowing that the feed fat, when the supply of total nutrients is in excess of the maintenance requirements, will be utilized for the formation of body fat, it is easy to see that there will be a wide variation in the ratio of feed fat consumed to body fat deposited per pound of gain. A 30 pound pig will consume about 3 pounds of feed, while a 225 pound pig will consume about 5 pounds of feed for each pound of gain. If this feed contained 4 per cent of fat, the amount of ingested fat would be in the one case 0.12 pounds and in the other 0.20 pounds. However, on the basis of the percentages of fat increases given above, the 30 pound pigs deposited only 0.03 to 0.17 pounds of fat for a gain of one pound and the 225 pound pigs deposited 0.61 to 0.63 pounds of fat. Thus, on a moderate amount of fat in the diet, the body fat in the small pig may be derived very largely from the ingested fat. In the larger animal, the amount of feed fat supplied makes up a much smaller percentage of the body fat deposited.

It is apparent that the conditions outlined above existed in the experiments under discussion. The actual amounts of the feed fat consumed have been calculated for the six groups in each of the two experiments. These figures together with the amounts of body fat as given in Table III were plotted (see Chart 5) to show the relationship between the feed fat and the body fat. Although no actual figures were available to show the amount of fat derived from the dam's milk, it was estimated that the average weight of milk fat consumed per pig from birth to weaning was 4 pounds in Experiment A, and 4.5 pounds in Experiment B.[11] These amounts were added to the total ingested fat and the resulting figures plotted to show the total fat consumption.

The curves clearly show the widening of the ratio between ingested fat and body fat. Thus with the growth of the animal, more and more of the body fat necessarily was synthesized. The only time when the feed fat could have met the demands of the body was during the suckling period. Of course, not all of the ingested fat was assimilated and used for fat storage but the

[11] Henry, W. A., and Morrison, F. B., Feeds and feeding, Madison, 18th edition, 1923, 698.

percentage was probably quite constant throughout so that the relative change in ratio was likewise constant.

These changes immediately suggest a close relationship to the change in firmness of the fat. It is common knowledge, fully borne out by results obtained in the soft pork work, that ingested fat is deposited in the animal with but slight modification of the fatty acid make-up. Corn oil is composed largely of the unsaturated acids, oleic and linolic, and since this is the predominating fat (oil) in the rations in question, the acids mentioned would predominate in the ingested fat and would be expected to result in the formation of a soft, oily fat. Since the fat formed in the animal body from carbohydrate and protein (that is synthetic fat) is usually hard, the character of the fat present in the adipose tissues of the pig at a particular stage of development would be dependent, other things being equal, on the ratio of body fat

TABLE VI.

Composition of Feed Fat Expressed as the Per Cent Fatty Acids of Total Fat.

	Saturated.	Oleic.	Linolic.
Corn oil.[12]	11.2	43.4	39.1
Butter fat.[9]	55.0	35.0	—
Tankage	27.0	59.5	6.0

derived from ingested fat to that derived synthetically. Some information on this point is furnished by the following study of the fatty acid content of the feed fat and the body fat.

A Comparison of the Fatty Acids Ingested with Those Deposited.

The comparison of the amounts of fatty acids ingested with the total fatty acids deposited was next made. Since no figures on the composition of the fat of sow's milk were available, the comparison was based on the results from weaning to slaughter. In the case of the fatty acids in the body fat, the amount of each present at weaning was subtracted from that present at each following stage.[13]

[12] Baughman, W. F., and Jamieson, G. S., *J. Am. Chem. Soc.*, 1921, xliii, 2696.

[13] The formation of fat during the suckling period will be given further study.

The three fractions of the fat considered were the total saturated acids, oleic acid, and linolic acid. The figures used for calculating the composition of the feed fat are given in Table VI. Al-

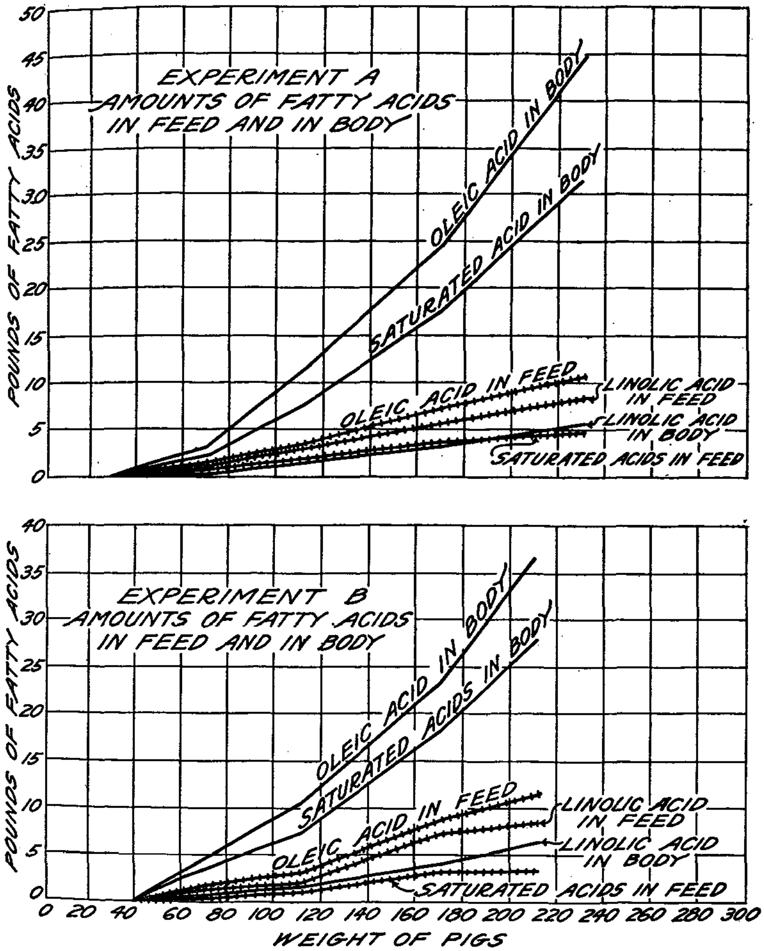

CHART 6.

falfa was omitted from consideration because of its small fat content.

The total saturated acids and the oleic acid ingested and deposited were comparable to the whole fats (see Chart 5) in that the amounts in the body were in excess of the supply in the feed. The linolic acid, however, presents a strikingly different situation since the total amount ingested was in excess of that in the body in late as well as early growth. From unpublished data on the composition of hog fats on various rations, it has been observed that the linolic acid in the body follows the supply in the feed very closely. The actual percentage of this acid has been found to vary through extremely wide limits. Apparently linolic acid is not as essential a factor in adipose tissue as is oleic acid, since the amount appears to be controlled by the amount furnished in the feed. The drop in the per cent of linolic acid in the fat with a corresponding rise in the per cent of saturated acids explains the hardening of the fats in the experiments reported. Linolic acid has an extreme softening influence and the saturated acids, of course, have the opposite effect.

SUMMARY.

The progressive hardening of hogs on a ration containing a moderately low amount of softening fat such as is found in corn is accounted for as follows:

1. The change from a soft fat as found in young, immature hogs to a hard fat in older, mature hogs was accompanied by an increased rate of fat deposition.

2. This increased rate of fat deposition caused a widening of the ratio of body fat derived from carbohydrate and protein (hard) to that derived from ingested fat (soft).

3. The change in the composition of the body fat resulted in a decrease in the iodine number and refractive index and an increase in the melting point.

4. The effect on the proportions of the fatty acids were: an increase in the per cent of total saturated acids and a decrease in the per cent of linolic acid with the per cent of oleic acid remaining nearly constant.

SOFT PORK STUDIES.

II THE INFLUENCE OF THE CHARACTER OF THE RATION UPON THE COMPOSITION OF THE BODY FAT OF HOGS.

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The intimate relationship between the firmness of the body fat of hogs and the character and quantity of the ingested fat has been an important field of study during the course of investigations on soft pork.[1] Rations low in fat have produced firm body fats while those high in unsaturated oils have produced fats with the characteristics of the ingested fat. The evidence indicates that the animal body tends to deposit ingested fat in preference to synthesizing new fat when there is a surplus of food materials and the ingested fat is not needed for energy requirements.

The hog is exceptionally well suited for the study of the general problem of fat formation because of the rapid rate at which the process proceeds and the noticeable effect of small differences in the supply of feed fat at the lower levels of intake. In addition, the supply of fat available for study is always sufficient to meet all needs.

The refractive index, iodine number, and melting point determinations have been found of great value for the purpose of showing differences in the firmness of the fat in the general routine

[1] Work on the soft pork problem is being conducted jointly by State Experiment Stations and the United States Department of Agriculture. The data in this paper were obtained from animals fed by the following cooperating stations: Alabama, Arkansas, Georgia, Indiana, Kentucky, Mississippi, North Carolina, Oklahoma, South Carolina, Tennessee, Coastal Plains Experiment Station, Iberia Livestock Farm, and the U. S. Experiment Farm, Beltsville, Md.

examination of fat samples from individual hogs. Lately, the first named test has been relied upon almost solely for the routine laboratory examination where a quick reliable test is essential. The primary purpose of this routine examination has been to measure differences in the fat for use in conjunction with the grading of carcasses according to physical standards of firmness.[2] The differences in the body fat as shown by these tests suggested the need of further data on the physical and chemical properties of the fat. Therefore additional analyses including fat constants and fatty acid separations have been made on representative samples for the purpose of tracing the effect of the feed on the body fat.

Experimental Rations.

The data given in this article relate to a number of feeds and feed combinations which have been used in soft pork experiments by the cooperating agencies and the results have been discussed in a recent bulletin (1). The rations are as follows:

1. Brewers' rice with tankage. The basal feed in this case is very low in fat and produces a very hard lard, especially low in linolic acid.

2. Corn with tankage or fish-meal. This is the common hog ration of the country. Corn contains sufficient oil to exert an influence on the body fat. However, well grown hogs have the desired firm fat.

3. 2 parts corn-meal mixed with 1 part peanut meal. The latter feed is a by product of the oil milling industry. It usually contains from 6 to 10 per cent oil and in this particular combination with corn the quantity of oil (corn plus peanut) is sufficient to soften the body fat to an appreciable extent.

4. Rice polish and tankage. This basal feed is also a by product used to a considerable extent in hog feeding. It contains sufficient oil to cause marked softening of the fat.

5. Soy beans grazed plus a 2 to 2.5 per cent ration of shelled corn. This is a less softening ration than soy beans alone due to the lowered oil content.

[2] The chilled carcasses of all hogs in soft pork experiments are graded by an official committee into five grades; namely, hard, medium hard, medium soft, scft, and oily.

6. Peanuts grazed or self-fed in dry lot. Approximately one-third of the whole peanut is oil which more than supplies the bodily fat requirements of the pig. The carcasses of pigs fed on peanuts for 2 months or more are oily and blubbery.

7. Soy beans grazed. The ripe soy bean contains considerably less oil than the peanut but the oil is more highly unsaturated. The adipose tissue of soy bean-fed hogs may become softer than that of peanut-fed animals.

8. Corn with tankage plus (*a*) peanut oil, (*b*) soy bean oil, (*c*) cottonseed oil, (*d*) corn oil. In one series comparison was made of these oils fed at the same level. The addition of a moderately high amount of corn oil to one lot produced oily carcasses.

9. Peanuts followed by corn with protein supplement. This is the usual practice in attempts to harden hogs whose fat has become soft on peanuts.

10. Soy beans followed by corn with protein supplement. This system of feeding parallels that just mentioned. However, experiments show that the softness developed by soy bean feeding is more easily overcome than that of peanut.

These rations represent a wide range in fat content.[3] Study of the body fats produced on them show considerable variation in relative firmness which is related to the amount and the degree of unsaturation of the fat in the feed. Peanut feeding results in the formation of fat which approaches the characteristics of peanut oil. On the other hand, the fat resulting from the feeding of brewers' rice and tankage is essentially the product of synthesis from a non-fat ration. From the standpoint of the body fat, the variations in the relative firmness are chiefly associated with the changes in the linolic acid content. The occurrence of this acid in the adipose tissue can be more directly traced to the ingested fat than can any other fatty acid. This is true not only of the increase in unsaturation of the fat on a softening feed but to the decrease in unsaturation with subsequent feeding of corn, a hardening feed.

[3] The fat content of the feeds, together with iodine and refractive index values on the extracted oils, are given in Table IV. A more detailed table on the fatty acid composition of the oils is included in another paper (2).

Fat Samples.

The samples of lard given special study were usually composites of back fat samples from three or more hogs of a particular experiment under identical feeding conditions. The experiments drawn on for samples were those showing results typical of the feeds in question and by no means include all the hogs which have been fed the rations listed.

The back fat has been used for laboratory study because it is representative of the entire body fat of the hog and has proved to be more reliable as an index of firmness of the carcass than the leaf fat which has often been studied.[4] The fact that it is representative of the entire adipose tissue is well illustrated in

TABLE I.

Comparison of "Meat," Back, and Leaf Fats As Measured by the Refractive Index.

Lot No.	No. of hogs sampled.	Average weight of hogs.	Basic feed of hogs.	Meat fat.	Back fat.	Leaf fat.
				Refractive index at 40°C.		
1	2	110	Brewers' rice.	1.4583	1.4582	1.4576
2	3	98	Corn.	1.4601	1.4602	1.4591
3	7	180	"	1.4590	1.4590	1.4583
4	3	151	Peanuts.	1.4617	1.4618	1.4612
5	3	201	"	1.4633	1.4631	1.4525

Table I in which are compared the refractive index values on meat, back, and leaf fats. These data were obtained in the course of studies on the total composition of the animal body. The meat fat was rendered from a small portion of the meat fraction resulting from the separation of the entire dressed carcass into bone, skin, and meat fractions. It actually represented approximately 90 per cent of the total fat of the body. The back fat was rendered from a cross section strip of adipose tissue taken along the middle of the back between the kidney and the shoulder.

[4] In the early investigations on soft pork in this country, much of the data reported on the composition of the fat was on the kidney or leaf fat. Since the leaf fat is usually considerably harder than the back fat, due allowance must be made for differences in standards of firmness in comparison of results.

Examination of the results in Table I shows that the refractive index values of the meat and back fats are almost identical, lying within the experimental error. The range from hard fat (Lots 1 and 3) to oily fat (Lot 5) causes no variation between the two. The leaf fat values lie considerably below those of the other samples. This difference between the leaf fat and the meat or back fat is not always a uniform one, as evidenced by the values in Table I. Frequently the differences are abnormal when judged by the agreement of back fat values with the committee grades.

DISCUSSION OF RESULTS.

The data reported in this paper embrace the results of the examination of 36 samples representing 196 hogs. The samples are grouped into classes according to the ten feeds or feed combinations already mentioned. The methods of analysis of the Association of Official Agricultural Chemists (3) were followed in the determination of the saponification number, specific gravity (at 100°C.), insoluble acids, iodine number (Wijs method), refractive index (at 40°C.), melting point, and titer test. The saturated acids were separated from the unsaturated acids by the well known lead salt-ether method. The unsaturated acids were usually further separated by the differential solubility of the bromides of the acids. The fraction yielding hexabromide and octabromide was separated from that containing the dibromide and tetrabromide. The acids in the former fraction were identified and weighed and then the percentages of oleic acid and linolic acid were calculated from iodine numbers.

Only two samples yielded hexabromides (linolenic acid), while all samples in which bromides were prepared yielded an octabromide fraction. Arachidonic acid was identified in the octabromide. It occurred in small amounts ranging from 0.02 per cent to 0.21 per cent.[5]

The results of the analyses are given in Tables II and III. Since increase in gain during experiment is usually accompanied by progressive hardening or softening, dependent upon the nature of the ration, the samples within a group are arranged according

[5] A more complete discussion of the method followed for isolation and determination of the bromides is contained in another paper (2).

TABLE II.

Composition of Body Fat Showing the Effect of Variation in Oil Content of the Ration.

Sample No.*	Slaughter weight.	Gains on experiment.	Grade.	Saponification No.	Specific gravity 100°C.	Insoluble acids.	Iodine No.	Refractive index 40°C.	Melting point.	Titer.	Iodine No. Unsaturated acids.	Per cent of fat as: Oleic acid.	Linolic acid.	Arachidonic acid.	Saturated acids.
Group 1. Brewers' rice with protein supplement.															
	lbs.	*lbs.*				*per cent*			*°C.*	*°C.*		*per cent*	*per cent*	*per cent*	*per cent*
1 (3)	69		Hard.	197.2	0.8960	95.6	58.0	1.4586	29.6	36.8	93.8	58.0	2.4	0.04	35.2
2 (11)	242	176	"	195.3	0.8942	96.0	52.6	1.4582	39.7	41.4	92.0	55.9	1.2	0.02	38.5
3 (9)	234	178	"	197.3	0.8955	95.3	56.8	1.4588	34.8	38.5	94.0	56.2	2.5	0.03	36.4
Average of Samples 2 and 3......	238	177		196.3	0.8949	95.7	54.7	1.4585	37.3	40.0	93.0	56.1	1.9	0.03	37.5
Group 2. Corn with protein supplement.															
4 (3)	98		Medium soft.	197.5	0.8972	95.9	70.2	1.4601	28.3	37.1	111.1	48.0	14.0	0.14	34.0
5 (12)	216	149	Hard.	194.6	0.8950	95.9	60.3	1.4590	38.7	40.8	101.8	49.5	9.0		37.5
6 (3)	205	174	"	195.8	0.8963	95.5	62.2	1.4590	39.3	39.3	104.3	49.8	7.4	0.07	36.8
7 (1)	248	169	"			95.6	61.1	1.4589	38.3		102.4	51.7	8.1		35.8
8 (1)	276	204	"	195.1	0.8950	95.9	58.8	1.4591	39.6	40.8	103.6	46.9	8.2		39.5
Average.....	236	174		195.2	0.8954	95.7	60.8	1.4590	39.1	40.3	103.0	49.5	8.2		37.4

Group 3. Peanut meal 1 part, mixed with corn-meal 2 parts.															
9 (25)	182	112	Soft.	194.5	0.8957	95.3	72.6	1.4602	28.7	34.9	108.6	52.6	13.0	0.12	30.2
Group 4. Rice polish with protein supplement.															
10 (16)	134	63	Soft.	193.8	0.8984	95.4	80.0	1.4610	27.6	33.2	108.0	56.4	13.5	0.15	25.5
11 (11)	201	140	"	194.7	0.8963	95.8	73.7	1.4605	29.6	35.8	109.4	51.8	13.8	0.06	30.5
Average.....	168	102		194.3	0.8974	95.6	76.9	1.4608	28.6	34.5	108.7	54.1	13.7	0.11	28.0
Group 5. Soy beans with 2.5 per cent corn.															
12 (6)†	175	63	Soft.	195.5	0.8975	95.5	78.3	1.4610	27.6	36.5	118.9	44.1	20.0	0.02	30.8
Group 6. Peanuts.															
13 (3)	151	58	Oily.	194.2	0.8979	95.8	84.1	1.4619	22.5	30.7	113.7	54.3	18.5	0.18	22.6
14 (1)	133	64	"	195.5	0.8994	95.2	86.3	1.4618	25.5	30.6	113.5	54.2	18.8		20.8
15 (3)	153	81	"	193.7	0.8992	95.2	90.4	1.4624	21.0	28.6	114.0	57.3	20.1	0.07	19.2
16 (3)	178	92	"	193.2	0.8999	96.3	93.3	1.4630	22.3	24.5	119.5	50.8	24.1		20.0
17 (3)	201	149	"	194.4	0.9000	94.6	91.8	1.4633	5.0	24.5	111.5	61.0	18.5	0.05	14.9
18 (3)	213	160	"				91.5	1.4627	20.3	29.7	116.7	52.6	21.6	0.07	19.4
Average.....	171	101		194.2	0.8993	95.4	89.6	1.4625	19.4	28.1	114.9	55.0	20.3	0.09	19.5

TABLE II—*Concluded.*

Sample No.*	Slaughter weight.	Gains on experiment.	Grade.	Saponification No.	Specific gravity 100°C.	Insoluble acids.	Iodine No.	Refractive index 40°C.	Melting point.	Titer.	Iodine No. Unsaturated acids.	Per cent of fat as: Oleic acid.	Linolic acid.	Arachidonic acid.	Saturated acids.
Group 7. Soy beans.															
	lbs.	*lbs.*				*per cent*			°*C.*	°*C.*		*per cent*	*per cent*	*per cent*	*per cent*
19 (6)‡	157	57	Oily.	199.3	0.9019	95.1	87.6	1.4625	30.4	35.5	125.5	42.2	25.9	0.08	27.6
20 (9)	152	65	"	195.3	0.9000	95.1	90.7	1.4628	22.0	34.2	130.6	38.7	30.6	0.08	26.3
21 (4)	171	84	"	195.6	0.9015	94.8	101.4	1.4638	25.6	32.1	135.6	36.3	35.4	0.12	24.2
Average.....	160	69		196.7	0.9011	95.0	93.2	1.4630	26.0	33.9	130.6	39.1	30.6	0.09	26.0

* The numbers in parentheses indicate the number of hogs represented by the sample.

† Contained 0.02 per cent linolenic acid.

‡ Contained 0.14 per cent linolenic acid.

to gain. The seven groups in Table II cover an equal number of rations and are listed in order of increasing softness. In all of these groups, the hogs were started on experiment at weights of 50 to 100 pounds and received the ration designated until slaughtered.

Fig. 1 shows the influence of the feeds listed in Table II on the body fat as measured by the several values selected from the table. The increasing softness shown in the steady rise in the iodine and refractive index values is accompanied by a similar rise in the per cent of linolic acid. Oleic acid and the softness of the fat are not so directly related as is the case with the linolic acid. The highest proportion of oleic acid was in the firm lard of the hogs fed brewers' rice, whereas the next highest was in the soft "peanut lard," while the lowest was from the "soy bean lard." In the latter case there was almost as much linolic acid as oleic acid. The peanut lard shows a close approach to peanut oil in the content of oleic and linolic acids. The soy bean lard, on the other hand, does not show such a close approach to the oil. However, the high degree of unsaturation of soy bean oil is reflected in the low oleic acid and high linolic acid content of the lards. Except in the case of soy bean feeding, the percentage of saturated acids declines with increase in softness.

The titer and melting point values are much less indicative of the change in softness of the fat than the refractive index and iodine number. The specific gravity, which is usually associated with the degree of unsaturation of the fat, shows a gradual rise with increasing softness. The saponification value varies within a small range; peanut oil and rice oil cause a slight lowering while soy bean does not have any effect. The percentages of insoluble acids indicate that the lards consist almost entirely of glycerides of the high molecular weight acids.

Consideration of the results on the individual groups of samples show numerous noteworthy points of interest. The three samples in Group 1 given in Table II illustrate the effect of a high carbohydrate and low fat ration; brewers' rice, the basal feed, contains only 0.8 per cent fat (see Table IV). The ration of brewers' rice with protein supplement produces the firmest carcasses and consequently the firmest fat obained thus far in the present investigations. Sample 1 came from young pigs slaughtered at a weight

TABLE III.

Composition of Body Fat Showing Effects of Added Oils and of Change from a Softening to a Hardening Ration.

Sample No.*	Slaughter weight.	Gains on experiment.†	Grade.‡	Saponification No.	Specific gravity 100°C.	Insoluble acids.	Iodine No.	Refractive index 40°C.	Melting point.	Titer.	Iodine No. Unsaturated acids.	Per cent of fat as: Oleic acid.	Linolic acid.	Octabromide acid.	Saturated acids.
Group 8. Corn with tankage plus added oils.															
	lbs.	*lbs.*				*per cent*			°C	°C		*per cent*	*per cent*	*per cent*	*per cent*
22P (4)	215	118	M.S.	195.5	0.8988	94.5	72.4	1.4603	34.3	38.0	110.4	47.9	13.8		32.5
23SB (3)	222	135	"	194.1	0.8968	95.2	75.7	1.4608	31.2	37.5	117.9	43.3	18.6		33.8
24CS (4)	222	129	H.	197.6	0.8987	95.2	64.4	1.4600	45.3	42.7	117.8	35.9	15.7		43.0
25C1 (4)	226	131	M.S.	195.0	0.9007	96.0	76.3	1.4610	33.6	37.6	115.0	45.0	16.8		33.0
26C2 (3)	174	115	O.	194.4	0.9001	94.6	97.2	1.4633	24.5	24.5	129.7	41.4	31.4		23.1
Group 9. Peanuts followed by corn with supplement. Series A.															
27 (3)	200	75–59	O.	194.0	0.8967	95.2	78.2	1.4606	28.0	33.7	110.0	54.8	14.5	0.23	26.6
28 (3)	244	75–116	H.	194.3	0.8962	95.2	68.8	1.4601	28.4	37.1	106.2	52.1	11.0	0.09	31.9
29 (3)	286	79–129	M.H.	195.7			69.6	1.4602	28.7	36.1	104.5	54.4	9.6		31.3
30 (3)	325	67–211	"	194.0	0.8967	95.6	69.3	1.4598	30.0	37.4	103.1	52.9	8.7	0.09	34.3
Peanuts followed by corn with supplement. Series B.															
31 (7)	219	46–76	O.	194.0	0.8964	95.3	78.4	1.4612	28.0	34.3	108.0	55.6	13.3	0.14	25.5
32 (7)	282	49–140	M.S.	194.2	0.8973	95.2	74.2	1.4606	27.8	34.9	102.3	54.9	12.3	0.15	26.8
33 (7)	342	53–193	M.H.	194.1	0.8937	95.2	69.5	1.4598	28.0	36.1	104.8	55.0	10.1	0.21	30.9

Group 10. Soy beans followed by corn with supplement.

34	(4)	233	66–139	M.S.	195.5	0.8958	95.4	70.9	1.4602	30.2	36.6	110.8	49.4	13.5	0.04	32.6
35	(3)	251	46–115	M.H.	197.4	0.8973	96.0	69.5	1.4603	32.2	37.4	105.9	52.7	10.9	0.04	32.6
36	(4)	282	46–133	M.S.	196.1	0.8937	95.8	69.2	1.4600	35.0	37.2	110.0	48.5	13.0	0.07	34.1

* Letters refer to added oil as follows: P, 4.1 per cent peanut oil; SB, 4.1 per cent soy bean oil; CS, 4.1 per cent cottonseed oil; C1, 4.1 per cent corn oil; C2, 11.5 per cent corn oil. The naturally contained corn oil amounted to about 3 per cent in each case. The numbers in parentheses indicate the number of hogs represented by the sample.

† In the cases of double numbers, the first refers to gain on softening feed (peanuts or soy beans) and the second to gain on hardening feed.

‡ The grades are: H, hard; M.H., medium hard; M.S., medium soft; S., soft; O., oily.

of 69 pounds. The fat was only slightly softer than that of mature hogs on the same ration such as those of Samples 2 and 3. This result is different than that obtained on a basal feed of corn (4) where the fat of young pigs is soft. It is believed that the low amount of oil in the brewer's rice prevented the development of softness in the pigs represented by Sample 1.

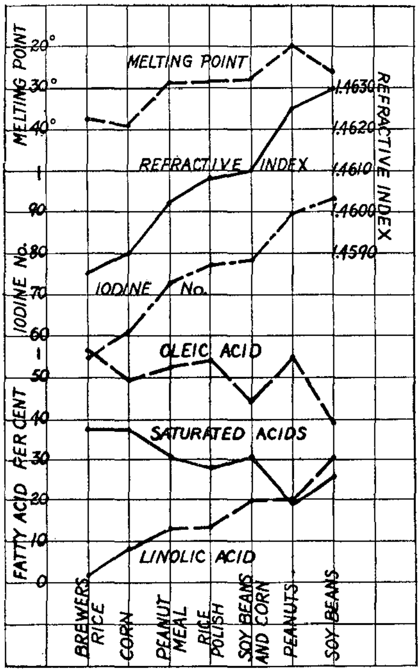

FIG. 1. This figure contains the averages of certain of the results listed in Table II. The abscissæ are in the order of increasing softness of the groups as listed in Table II, while the scales for melting point, refractive index, iodine number, and percentage of oleic, linolic, and total saturated acids are arranged as ordinates.

The iodine values of the brewers' rice lards were the lowest obtained. Albert (5), Henriques and Hansen (6), Klein (7), Vinson (8), and Popowitsch (9) found iodine values comparable to these, ranging from 50 to 58 on the back fat of hogs fed rations made up of potatoes, barley, skim milk, meat meal, and other low fat feeds. Gibbs and Agcaoili (10) fed a ration containing coconut cake (copra) and obtained a minimum iodine number of 32.5 on the leaf lard. Likewise, Konig and Schluckebier (11) in feeding coconut cake obtained an iodine number of 43.9 on the back fat. The coconut fat (iodine number 8.5) was evidently responsible for the depression in the iodine value below that obtained on rations with a minimum of fat. It is therefore safe to conclude that the fat formed on a carbohydrate and protein ration is of a composition approximated by the samples of Group 1, particularly Sample 3.

Results of the separation of the saturated and unsaturated acids of the brewers' rice group show that the per cent of saturated acids was almost identical to that in corn-fed hogs. The difference in firmness of the fat as indicated by the iodine number and other values is accounted for by the lower percentage of linolic acid in the "brewer's rice" lard. The amount of this acid is the

TABLE IV.

Fat Composition of Feeds.

	Per cent fat.	Iodine No.	Refactive index at 40° C.
Brewers' rice	0.8	100.0	1.4645
Corn	4.3	126.0	1.4673
Rice polish	9.7	100.0	1.4645
Soy beans	17.5	128.0	1.4648
Whole peanuts	33.1	93.7	1.4625
Peanut meal (unshelled nuts)	9.0	93.7	1.4625
Cottonseed oil		107.4	1.4620

lowest found. Calculations on the fat ingested indicate that all the linolic acid can be accounted for in this way although it does not follow that no new linolic acid was synthesized. However, the oleic acid as well as the saturated acids were evidently very largely supplied by synthesis from carbohydrate and protein.

The slightly softer fat of the hogs fed corn and protein supplement is attributed to the effects of the corn oil as described in a previous paper (4). The presence of a higher per cent of linolic acid explains the rise in iodine number and refractive index. Sample 4 was obtained from a lot of hogs slaughtered at an average weight of 98 pounds. It shows the moderate softness developed in hogs of such size on a ration of corn and protein supplement. Samples 5 to 8 are typical for well grown hogs and the analyses are considered typical for normal, firm, body fat. The iodine numbers compare favorably with those given by Lewkowitsch (12) for back fat. The change in firmness from the soft fat of the 98 pound hogs to the firm fat of the hogs weighing over 200 pounds is representative of the normal course of progressive hardening.

One sample from a lot of hogs weighing 182 pounds, and fed a ration of 2 parts of corn-meal mixed with 1 part of peanut meal was analyzed. The composition is quite similar in degree of softness to that of 98 pound hogs fed on corn and tankage. Extensive study of results on the corn-meal and peanut meal ration has shown that hogs started on the ration at weights around 100 pounds develop a maximum softness after making a moderate gain and then slowly harden, but at weights of 175 to 200 pounds (as Sample 9) are still no firmer than at the start of feeding, whereas hogs on a ration of corn and tankage become progressively harder and reach the desired degree of hardness at a weight of about 170 pounds. The failure to harden to the same extent as on a corn and tankage ration must be attributed to the small increase in the total oil of the mixture. The corn fed to these hogs contained 3.6 per cent oil, while the peanut meal contained 7.8 per cent oil (average given in Table II is 9.0 per cent) making the composition of the mixture 5 per cent. Thus the effect of small changes in the oil content at the lower levels as here indicated is decidedly noteworthy in changing the course of fat formation from a desired firm fat to an undesirable medium soft fat.

The two samples which represent two lots of hogs fed rice polish and tankage are moderately soft lards. The rice polish which was fed contained in one case 12.4 per cent oil and in the other 12.3 per cent.[6] It will be noted that fat Sample 10 was softer than Sample 11. In the first case the hogs were slaughtered at an average weight of 134 pounds and in the second case at 201 pounds. The development of a maximum softness followed by subsequent hardening on the same feed as evidenced in these results is analagous to the condition in the corn-meal-peanut meal ration. The higher oil content of the rice polish did not cause the formation of as soft a fat as might have been expected. As will be discussed later, rice oil does not appear to be as softening as corn or soy bean oils but is more like peanut oil.

[6] These quantities are decidedly higher than those given in Table IV. However, the average fat content of seven samples of rice polish used in soft pork experiments is 12.7 per cent.

Aside from the difference in the iodine and refractive index values, the chief difference in these two samples is the higher oleic acid and correspondingly lower saturated acids in Sample 10 as compared to Sample 11. The linolic acid, which usually furnishes a fairly accurate measure of relative firmness, was practically the same for the two samples.

The next group in order of increasing softness of fat is represented by one sample (No. 12) obtained from a lot of hogs which grazed on soy beans with a supplementary ration of corn amounting to 2.5 per cent of the weight of the animal, the equivalent of half a full feed. Such a ration contains approximately the same oil content as the rice polish and tankage combination. The results indicate that the soy bean oil is slightly more softening than rice oil. The fat constants and the fatty acid percentages lie about midway between those of soy beans alone and corn with supplement.

The six samples in the peanut group were taken from hogs which either grazed peanuts in the field or had eaten the nuts from a self-feeder in a feed lot. The average gains of the group ranged from 58 to 160 pounds, and with certain exceptions, the feeding period was 2 months. All samples came from oily carcasses. A characteristic feature of the lard was the tendency on standing in the refrigerator to separate into a clear light yellow oily layer and a precipitate of solid glycerides. The iodine number, refractive index, and percentages of fatty acids are all very similar to the values on peanut oil. There is little doubt but that the ingested peanut oil is deposited with but little change in the proportions of fatty acids. In fact, the ration of whole peanuts is the most effective feed of those studied in respect to similiarity of body fat to ingested fat. Analyses reported by Richardson and Farey (13) on oily lard show values which are similar yet not quite so high in degree of unsaturation as the present samples.

The samples of lard in Group 7 from hogs grazed on soy beans are comparable in oiliness to the peanut samples. In fact, the iodine and refractive index values show that the fat of the former is more unsaturated than the latter.

Although the quantity of oil in the soy bean is considerably lower (see Table IV) than in the peanut, soy bean oil is more highly unsaturated and thus causes a slightly greater softening of the body fat. However the full effect of the soy bean oil was probably not attained, judging by the steady increase in softness along with gains, in any of the lots which are represented by fat samples. This difference from the condition prevailing in the peanut feeding was probably due to a combination of circumstances among which the relatively low gain, the oil content of the soy bean, and a possible difference in the utilization of the feed for growth and fattening were contributing factors.

Sample 21 is the most unsaturated of the three lards in Group 7. It has approximately equal quantities of oleic and linolic acids. A total of 0.14 per cent linolenic acid was obtained from Sample 20 and no measureable amount from the other two.

Soy bean oil is reported to contain 2.3 per cent of linolenic acid glyceride (14). Judging by the close parallel between the linolic acid in the feed and in the adipose fat, it is surprising to find the near absence of linolenic acid. The linolenic acid because of its high degree of unsaturation was evidently either metabolized or converted to a more saturated acid and then deposited.

The first group in Table III is made up of a series of experiments in which oils were added to a basal ration of corn and tankage. Similar quantities of peanut, soy bean, cottonseed, and corn oils were added to the rations in the first four lots to determine if moderate amounts of oil would materially affect the composition of the fat and also to compare the softening effect of the various oils. The added oil made up 4 per cent and the naturally contained corn oil approximately 3 per cent of the total ration.

With the exception of cottonseed oil, the addition of 4 per cent added oil caused a definite softening of the fat. On the basis of iodine and refractive index values, the greatest softening was obtained with corn oil (Sample 25), closely followed by soy bean oil (Sample 23), while the least effect was obtained with peanut oil (Sample 22). The latter sample had a composition similar to that of the corn-meal-peanut meal ration. The fatty acid content of the three samples shows the effect of the particular oil especially the increases in the amount of linolic acid. The fat of the cottonseed oil lot was nearly as firm as that in pigs of similar weight fed on a ration of corn and tankage. There are, however, abnormalities in composition which suggest a peculiar behavior of the cottonseed oil in metabolism when fed in the amounts used in this experiment. The iodine-number, refractive index, and melting point values do not show a comparable firmness. The iodine number is probably the most nearly correct value for the firmness of the fat. The melting point is excessively high. The oleic acid is considered abnormally low and the total saturated acids abnormally high. Cottonseed meal is sometimes used as a protein supplement to corn in hog rations. The meal usually contains in the neighborhood of 8 to 10 per cent fat. Hare (15) reported fats produced on a ration of corn-meal 2 parts and cottonseed meal 1 part as firm as those obtained with a ration of corn and tankage. This result is in accord with the data reported here on cottonseed oil. Peanut meal in place of the cottonseed meal produces a moderately soft lard, a result which points to a wide difference in the effect of cottonseed oil and peanut oil at low levels of intake.

The last sample came from hogs which had received a ration containing 11.5 per cent of added corn oil. The total corn oil content was over 14 per cent and was sufficient to produce oily carcasses. The data indicate that the ingested corn oil was not altered very materially for deposition in the adipose tissues. The fat constants and the percentages of fatty acids indicate a highly unsaturated fat. Here, as in the case of the soy bean feeding, a still more unsaturated body fat would possibly have resulted with greater length of the feeding or an increase in the quantity of added oil.

The variation in the softening properties of the plant oils is a matter of considerable practical importance. The order of the oils as to softening properties appears to depend largely on the degree of unsaturation as measured by the iodine number (see Table IV). Soy bean and corn oils head the list while rice and peanut oils rank somewhat below these two. On the basis of the data reported here, cottonseed oil must be classed separately because of its peculiar behavior. The reason for this remains to be determined. Jackson (16) classified a large number of feeding stuffs as to the softening power of the oil contained in them. With the exception of cottonseed oil his arrangement agrees with the data reported in this article.

The effect of feeding corn and tankage to hogs whose fat has become soft during a feeding period on peanuts is illustrated in

Group 9 in Table III. The pigs in Series A and B were fed peanuts for 8 weeks and were then changed to a ration of corn with protein supplement. At monthly intervals a certain number of animals were slaughtered for grading as well as for laboratory analysis of the fat. The samples in each series thus represent increasing length of feeding period along with increasing gain on the corn ration. In Series A the gain on peanuts averaged

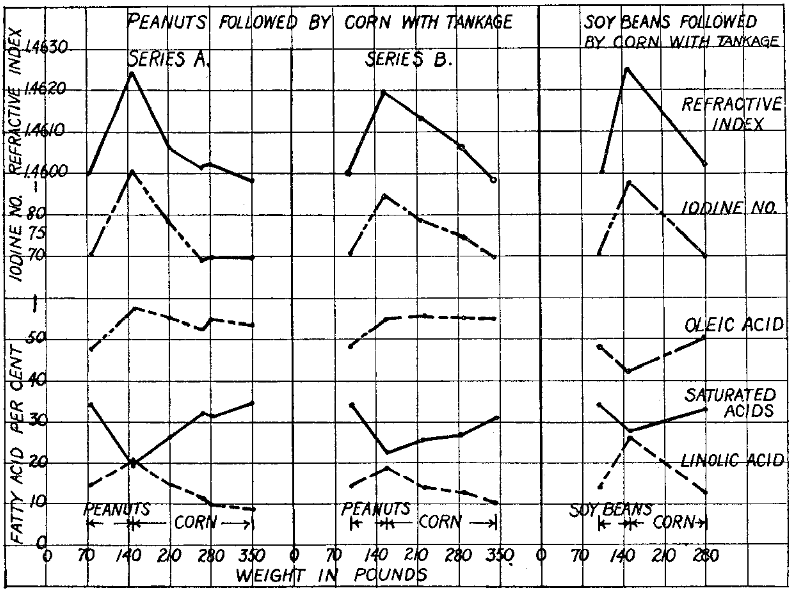

FIG. 2. The curves in this figure show the changes in refractive index, iodine number, and percentages of fatty acids when corn with tankage is fed subsequent to both peanuts and soy beans. The composition of the fat at the beginning and at the close of the peanut or soy bean feeding period is shown along with that during the corn with tankage feeding.

slightly over 70 pounds and the gain on the hardening ration increased from 59 to 211 pounds. In Series B the gain on the softening feed was approximately 50 pounds while that on the hardening feed reached 193 pounds in the final period.

The changes occurring in the fat as shown by certain of the analyses are illustrated in Fig. 2. The composition at the start and at the close of peanut feeding as taken from data in Table II is given along with the results during the corn feeding period. A pronounced change in the direction of greater saturation of the fat occurs with the progress of the second feeding period. The fat constants show a steady change toward a harder fat, but they by no means reach the level found in the lards of the corn with supplement ration discussed earlier in this article.

Although there is a pronounced decline in the percentage of linolic acid, the oleic acid remains at a rather high level especially in Series B. In spite of the high gain on corn in the last lot of each group the carcasses are still only medium hard. The unsaturated fat deposited during the peanut feeding evidently has a prolonged and lasting effect on the composition of the lard even though a hardening ration is fed for a long period. The fat at any of the stages of these series appears to be simply a blend of the fat produced during the several feeding periods. Since the fat formed on a corn and tankage ration is not an extremely hard fat, the great difficulty of hardening peanut-fed hogs is quite apparent.

Corn and tankage following soy beans formed the feeding combination of the lots in the last group of Table III. The three samples do not form a regular series from the standpoint of increasing gains on the hardening feed; yet considering the ratio of gain on soy beans to that on corn, the results show the usual marked change in degree of saturation observed in the two previous groups. The decided drop in the percentage of linolic acid largely accounts for the increase in hardness due to the admixture of fat synthesized on the corn with tankage ration.

SUMMARY.

The physical and chemical properties as well as the percentages of total saturated acids and the various unsaturated acids were determined on lards obtained from hogs fed various rations. The oils contained in the rations have very materially influenced the composition of the body fat. The iodine and refractive index values were an excellent measure of firmness of the adipose tissue. Other fat constants showed less correlation.

The percentages of saturated acids, oleic acid, and linolic acid of lard from peanut- and soy bean-fed hogs were similar to the content in peanut and soy bean oils. The linolic acid showed the most striking change, increasing from 1.9 per cent in the hard fat from hogs fed brewers' rice to 30.6 per cent in oily fat from hogs fed soy beans.

Small amounts of arachidonic acid were found in lard samples representing all types of feeds.

A decrease in the unsaturation of the fat results from a change in the ration from peanuts or soy beans, softening feeds, to corn and tankage, a ration which produces hard fat. However, after long periods on the latter ration, the body fat was still less saturated than that of hogs grown on corn and tankage.

Corn and soy bean oils result in greater softening of the fat than peanut and rice oils.

BIBLIOGRAPHY.

1. Hankins, O. G., and Ellis, N. R., *U. S. Dept. Agric., Bull. 1407*, 1926.
2. Ellis, N. R., and Isbell, H. S., *J. Biol. Chem.*, 1926, lxix, 239.
3. Official and tentative methods of analysis, *Assn. Off. Agric. Chem. Washington*, 1920.
4. Ellis, N. R., and Hankins, O. G., *J. Biol. Chem* , 1925, lxvi, 101.
5. Albert, F., *Landw. Jahrb.*, 1899, xxviii, 943.
6. Henriques, V., and Hansen, C., *Skand. Arch. Physiol.*, 1901, xi, 151.
7. Klein, J., *Milch-Ztg.*, 1897, xxvi, 807;*Milchwirtsch. Zentr.*, 1905, i, 345; 1909, v, 281.
8. Vinson, A. E., Inaugural dissertation, University of Göttingen, 1904.
9. Popowitsch, K., Inaugural dissertation, University of Halle, 1908.
10. Gibbs, H. D., and Agcaoili, F., *Philippine J. Sc., Section A*, 1910, v, 33.
11. Konig, J., and Schluckebier, J., *Z. Untersuch. Nahrungs- u. Genussmittel*, 1908, xv, 641.
12. Lewkowitsch, J., and Warburton, G. H., Chemical technology and analysis of oils, fats and waxes, London, 6th edition, 1922, ii, chapter xiv.
13. Richardson, W. D., and Farey, F. O., *J. Am. Chem. Soc.*, 1908, xxx, 1191.
14. Baughman, W. F., and Jamieson, G. S., *J. Am. Chem. Soc.*, 1922, xliv, 2947.
15. Hare, C. L., *J. Ind. and Eng. Chem.*, 1912, v, 410.
16. Jackson, F. W., *J. Ministry Agric.*, 1923, xxx, 261.

SOFT PORK STUDIES.

III. THE EFFECT OF FOOD FAT UPON BODY FAT, AS SHOWN BY THE SEPARATION OF THE INDIVIDUAL FATTY ACIDS OF THE BODY FAT.

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In a previous paper (1) the writers reported data on the effects of widely different rations on the composition of the body fat of the hog. The characteristic differences in the composition of the lard suggested the need of a more complete analysis on a few typical samples. This study has been made on six samples including certain ones already briefly reported, as a further contribution to the information on fat formation in the hog. The types subjected for complete analysis were obtained from well matured and fattened hogs fed on rations (1) very low in fat, (2) moderately low in fat, and (3) high in fat.

The feeds used to obtain the desired results were from different sources and were, respectively, (*a*) brewers' rice and tankage, (*b*) corn and skim milk, (*c*) soy beans alone, and peanuts alone, both represented by two samples each. Where necessary, the rations were supplemented with mineral mixtures. In the case of the first two rations, the hogs were also allowed access to green feed. Table I gives the weights, gains, carcass grades, and other data on the six lots. The length of the feeding periods and the gains were all of sufficient duration and size to make the fat samples typical for the feed used. This is particularly true of Samples 1, 2, 4, and 6. Sample 3 is representative of the 2 months feeding period used in practice for grazing the peanut crop to be later followed by a hardening period on corn. Likewise Sample 5 is representative of the system of grazing soy beans.

TABLE I.

Weights, Gains, and Carcass Grades of Hogs.

	Sample No. and basic feed.					
	1 Brewers' rice.	2 Corn.	3 Peanuts.	4 Peanuts.	5 Soy beans.	6 Soy beans.
No. of hogs in lot..........	11	6	3	3	9	1
Days on experiment........	84	188	80	277	52	53
Average weight at start of experiment, *lbs*...........	59	30	99	52	100	83
Total gain on experiment, *lbs*.......................	178	201	58	149	65	98
Slaughter weight, *lbs*.......	242	231	151	201	152	175
Carcass grade..............	Hard.	Hard.	Oily.	Oily.	Oily.	Oily.

TABLE II.

Chemical and Physical Characteristics of the Fat.

	Sample No. and basic feed.					
	1 Brewers' rice.	2 Corn.	3 Peanuts.	4 Peanuts.	5 Soy beans.	6 Soy beans.
Saponification value.	195.3	195.9	194.2	194.4	195.3	194.3
Iodine No............	52.6	58.8	84.1	91.8	90.7	100.6
Refractive index, 40°C...............	1.4582	1.4587	1.4619	1.4633	1.4628	1.4636
Melting point, °C....	39.7	37.5	22.5	Liquid at 5°	22.0	28.1
Acetyl value.........	3.8	4.1	12.1	16.3	7.7	7.6
Acid value...........	1.0	0.9		0.7	0.8	5.2
Polenske No.........	3.7	5.2		0.3	0.5	0.6
Reichert-Meissl No.	3.3	1.0		0.1	1.5	0.2
Specific gravity, 100°C..............	0.8942	0.8957	0.8979	0.9007	0.9000	0.9003
Unsaponifiable matter, *per cent*.......		0.02		0.03		0.33
Insoluble acids, *per cent*................	96.0	95.6	95.8	94.5	95.1	95.4

Analyses were made on the meat fat of the corn-fed lot and the two peanut-fed lots and on the back fat of the remaining three lots. In addition to the fat constants determined in the previous study, the acetyl value, acid value, Polenske number, Reichert-Meissl number, and per cent of unsaponifiable matter were determined. The chemical and physical characteristics of the fat are given in Table II.[1]

From 200 to 300 gm. of fat from each sample were separated by the lead salt-ether method into saturated and unsaturated fractions for use in determining the individual fatty acids.[2] The percentages of total saturated and total unsaturated acids were always checked by duplicate determinations using smaller quantities of fat, and, in certain cases, duplicate separations of large quantities were made for duplicate distillations of the saturated acid esters. In calculating the percentages of the fractions, corrections of the unsaturated acids contained in the saturated acids were always made.

Procedure for Separation of the Unsaturated Acids.

2 to 3 gm. of the liquid acids were weighed into a previously carefully dried and weighed test-tube and 20 cc. of a 10 per cent solution of glacial acetic acid in absolute ether added. The solution was cooled in an ice bath, and, while stirring the solution, bromine was slowly added to a decided red tint. After standing overnight in the ice box, the precipitated bromides were separated by centrifugation, washed three times with 10 cc. portions of chilled ether, after which they were extracted three times with 10, then 5 and 5 cc. portions of hot benzene. This benzene was then evaporated off and the residue reextracted with 3, then 2 and 2 cc. portions of hot benzene in order to recover any octabromide which may have dissolved in the first treatment with the larger volumes of benzene. After evaporating off the benzene, the bromide fractions were dried in a vacuum oven to constant weight, and melting points and per cents of bromine determined.

The ether-soluble bromides were washed with a dilute solution of sodium thiosulfate followed by water to remove the excess

[1] The analytical procedures followed in the determination of the chemical and physical characteristics of the fat were the same as those used in previous work (1): namely, the Official and provisional methods of analysis, *Assn. Off. Agric. Chem., Washington, 1920.*

[2] In the separation of the fatty acids, the technique described by Jamieson and Baughman (2) has been generally followed. The authors wish to express their thanks to Dr. G. S. Jamieson of the Bureau of Chemistry for helpful suggestions in technique.

bromine. After evaporation of the ether and acetic acid, the mixture of bromides was dried and weighed. They were then dissolved in 25 cc. of petroleum ether and the solution allowed to stand in the ice box for a week. In case the tetrabromide failed to start crystallizing, the sides of the flask were scratched or part of the petroleum ether was evaporated and the solution seeded with a trace of tetrabromide crystals.

The crystallized bromides were filtered in the cold, washed with chilled petroleum ether, dried, and weighed. The melting points and per cent of bromine were then determined. The method used throughout this work for the determination of bromine was that of Drogin and Rosanoff (3).

The bromide contents of the various fractions indicated a fairly clean cut separation in most cases. The bromine in the octabromide averaged 67.1 per cent and was interpreted as corresponding to a compound of the formula $C_{20}H_{32}O_2Br_8$ which has a bromine content of 67.76 per cent. The theoretical per cents of acid in the octabromide (32.24), the hexabromide (37.67), and the tetrabromide (46.67) were used in calculating the respective acids. The soluble residue usually contained appreciable quantities of tetrabromide along with the dibromide so the proportionate amounts of the linolic and oleic acids were calculated, using 63.82 per cent as the per cent of oleic acid in a pure dibromide.

The percentages of each acid were further checked by calculations from the iodine numbers of the fat and the total unsaturated acids. In previous work, only the octa- and hexabromides were isolated leaving the oleic and linolic acids to be calculated from iodine numbers.

Procedure for the Separation of the Saturated Acids.

The saturated acids were separated by the vacuum distillation of their methyl esters according to the following procedure.

The acids were dissolved in twice their weight of purified methyl alcohol. The solution was kept warm on the steam bath and a current of washed and dried hydrochloric acid gas was bubbled through the mixture for 12 hours. After washing the esters with water followed by a dilute solution of sodium bicarbonate, about 75 gm. were filtered (to remove traces of water) into a distilling flask. The esters were then subjected to fractional distillation at a pressure of 1 to 2 mm. The fractions were cut at points where abrupt rises in temperature occurred or where convenient volumes of distillate were obtained. After weighing the fractions, iodine and saponification values were determined. Wherever the saponification value indicated a possibility of three saturated acids occurring in a single fraction a further separation was made to insure having not more than two saturated acids to a fraction. The mean molecular weights were calculated and from these values and the iodine numbers the per cent of each saturated acid was determined.

The acids were also further identified by fractional crystallizations from alcohol and the determination of the melting point. Although the errors in the determinations may sometimes be large, the duplicate runs checked very satisfactorily. One great chance of error lies in the possibility of having three saturated acids in one fraction. This possibility was tested by making duplicate distillations on one of the samples in which the distillate in one case was cut into ten fractions and in the other into three fractions. It was thought that the former procedure would eliminate the chances of three acids occurring together and the latter procedure would favor such a possibility. However, the results of the two distillations checked surprisingly well. All other samples were separated into six to eight fractions.

The general differences in the characteristics of the various fats shown in Table II are further illustrated by the titer, refractive index of insoluble acids, and per cents of saturated and unsaturated acids given in Table III. While not all of these characteristics show variations for the different types of lard, they do indicate the ranges likely to be encountered in lards produced on the rations outlined.

It will be noted in Table III that oleic, linolic, linolenic, arachidonic, myristic, palmitic, stearic, and arachidic acids were isolated. The occurrence of oleic, linolic, palmitic, and stearic acids has been commonly accepted but the presence of the other acids has either not been noted or has been questioned.

The linolenic acid was found in lards from hogs fed soy beans. In the case of Sample 5, there was a loss when isolating the bromide so that the amount actually recovered was little more than a trace; the 0.5 per cent found in Sample 6 was easily identified by melting point and bromine content. The acid yielding an octabromide and thought to be arachidonic acid occurred in all samples in small amounts.

Arachidic acid was identified in the two samples from peanut

TABLE III.

Characteristics and Percentage Composition of the Fatty Acids.

	Sample No. and basic feed.					
	1 Brewers' rice.	2 Corn.	3 Peanuts.	4 Peanuts.	5 Soy beans.	6 Soy beans.
Titer	41.4	39.1	30.7	24.5	34.2	32.2
Refractive index of insoluble acids, 40°C.	1.4420	1.4424	1.4452	1.4465	1.4472	
Unsaturated acids, per cent of fat (corrected)	57.0	58.8	73.0	79.6	69.2	72.3
Saturated acids, per cent of fat (corrected)	38.6	36.9	22.6	14.9	26.3	20.8
Iodine No. of unsaturated acids	92.0	100.8	113.7	111.5	130.6	136.2
Iodine No. of saturated acids as separated	4.8	5.3	13.4	12.4	4.8	11.2
Acids in fat:	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*
Oleic	55.9	52.0	54.3	61.7	38.7	36.1
Linolic	1.2	6.7	18.6	18.8	30.5	35.6
Linolenic	0.0	0.0	0.0	0.0	0.2	0.5
Arachidonic	0.02	0.06	0.12	0.05	0.08	0.05
Myristic	1.7	0.6	0.4	0.1	0.7	0.3
Palmitic	25.2	24.1	14.8	9.9	16.6	13.1
Stearic	11.6	12.2	7.1	4.7	9.0	7.4
Arachidic	0.0	0.0	0.2	0.3	0.0	0.0
Glycerides in fat:						
Oleic	58.4	54.3	56.7	64.6	40.4	39.8
Linolic	1.2	7.1	19.5	19.7	31.9	38.3
Linolenic	0.0	0.0	0.0	0.0	0.02	0.5
Arachidonic	0.02	0.06	0.12	0.05	0.08	0.05
Myristic	1.8	0.7	0.4	0.1	0.8	0.3
Palmitic	26.5	25.2	15.5	10.4	17.4	14.5
Stearic	12.2	12.8	7.5	4.9	9.4	8.0
Arachidic	0.0	0.0	0.2	0.3	0.0	0.0

feeding. The melting point of pure arachidic acid is reported as 77°C. but repeated crystallization of the fractions failed to raise the melting point to this figure. However, a mixed melting point with an impure arachidic acid obtained for the purpose was 73.6 indicating the presence of the acid in the lard. It is probable that there was lignoceric acid mixed with the arachidic acid although none could be separated by fractional crystallization from alcohol.

Although the occurrence of myristic acid has been questioned by Amberger and Wiesehahn (4) it was satisfactorily identified in all the six samples. Its presence was proved by mixed melting point determinations in which mixtures containing myristic acid melted at 45–46°C. This is lower than for any mixture of palmitic and stearic acids and higher than for any mixture of lauric and myristic acids. Lauric acid was not found although its presence in lard has been reported by Lewkowitsch (5) and others. It may, of course, occur when the feed contains the acid.

In comparing the fatty acid composition of the various samples, that of Sample 1 is particularly noteworthy since it is largely the product of synthesis from carbohydrate. The hogs had access to brewers' rice and tankage in separate compartments of a self-feeder and ate only 4 pounds of tankage to 333 pounds of rice for each 100 pounds of gain. The result was a low protein intake with a surplus of carbohydrate for fat synthesis. The small amount of oil ingested may have supplied some linolic and oleic acid to the adipose tissue but the fatty acids are almost entirely the result of synthesis. Oleic acid predominates and occurs in an amount comparable to that in corn and in peanut-fed hogs. The low amount of linolic acid and absence of linolenic acid accounts for the hardness of the lard. Myristic acid was present in greater amounts than in any other sample while palmitic and stearic acids occurred in amounts comparable to that in the second sample.

The course of fattening in corn-fed hogs which has already been reported (6) needs little further mention. The increase in linolic acid, probably derived from corn oil, was evidently responsible for the slightly softer fat over that of rice-fed hogs.

The close resemblance in the composition of lards from peanut- and soybean-fed hogs to the respective plant oils was mentioned in a previous paper (1). With more complete data available, a better comparison between the plant oils and the lards is now possible. The data compiled in Table IV show the composition of peanut, soy bean, and also corn oils. The small differences in the peanut oils derived from the Virginia variety as compared to the Spanish variety of peanuts are unlikely to be reflected in the lards to any appreciable extent since the supply of ingested peanut oil from the feeding of whole peanuts is greatly in excess of body demands for storage. Virginia peanuts were fed the pigs of Lot 3 for 80 days while Spanish peanuts were fed Lot 4 for 277 days. In addition, due to the lighter starting weight, the latter lot derived a much greater proportion of the total adipose fat from peanuts than the

TABLE IV.

Composition of Plant Oils.

	Peanut oil.*		Soy bean oil.†	Corn oil.‡
	Virginia.	Spanish.		
Saponification value	187.8	182.2	189.5	187.3
Iodine No.	94.8	90.1	128.0	117.2
Acetyl value	9.5	8.7	17.0	10.0
Refractive index, 40°C.§	1.4625	1.4625	1.4660	1.4642
Unsaturated acids, *per cent*	78.7	74.6	83.5	82.5
Saturated " " "	16.4	20.6	11.5	11.2
Oleic glyceride	60.6	52.9	33.4	45.4
Linolic "	21.6	24.7	51.6	40.9
Linolenic "			2.3	
Myristic "				
Palmitic "	6.3	8.2	6.8	7.7
Stearic "	4.9	6.2	4.4	3.5
Arachidic "	3.3	4.0	?	?
Lignoceric "	2.6	3.1	?	?

*See bibliography (7).
†See bibliography (8).
‡See bibliography (9).
§The refractive index for peanut oil is taken from Table IV in the preceding article (1). The values on the other oils were calculated to 40°C. from values quoted in the original reference at 20°C.

Lot 3 pigs. It is thought that this is the explanation of the higher percentage of oleic acid and the lower percentage of saturated acids in Sample 4 over that in Sample 3. Compared to the composition of the oil of the Spanish variety of peanuts, the lard (Sample 4) shows a higher percentage of the oleic acid glyceride, a lower percentage of linolic acid glyceride, and a slightly wider ratio of palmitic to stearic acid glyceride. The most significant difference noted in the peanut lards is the low amount of arachidic acid present, especially when the supply of arachidic acid plus lignoceric acid in the oil was greater than that of stearic acid. These high melting point saturated acids evidently failed to be absorbed or were changed to other acids in the animal body. The small amounts of myristic acid were evidently products of synthesis or of transformation from other fatty acids in the peanut lards as well as in the other samples since none are reported in any of the oils. The full amounts of all the other fatty acids can be accounted for in the ingested peanut oil.

The composition of the lard in soy bean feeding is also largely controlled by the composition of soy bean oil. The most apparent difference between the lard and the oil seems to lie in the lower proportion of linolic acid in the lard. The samples actually show a much higher per cent of glycerides of the saturated acids and only a few per cent more oleic acid glyceride than the oil. Sample 5 is little different from peanut lard in degree of unsaturation but Sample 6 shows the effect of the increase in linolic acid and may be classed as a more oily lard than is obtained in peanut feeding.

Although 2.3 per cent linolenic glyceride is reported in soy bean oil, only 0.5 per cent was recovered in the lard of Sample 6. There is little doubt but that this acid is readily absorbed by the intestinal tract but since it is also easily oxidized, the low amount found may be due to different reasons than in the case of arachidic acid with its high melting point.

The proportions between the various saturated acids are much more constant for the six samples than between the unsaturated acids. Indeed, it appears significant that the proportion of palmitic acid to stearic acid was approximately the ratio of 2:1 for all samples. Even in the case of the peanut and soy bean lards there was some selective action in favor of palmitic acid, while with the low fat rations, the ratio was very evidently controlled by the synthetic powers of the body.

The high amount of oleic acid in all samples, not only in Samples 1 and 2 where it had to be synthesized but in the others as well, indicates that it ranks ahead of palmitic and stearic acids as a normal constituent of lard.

The rise in the linolic acid from 1.2 per cent to 18.8 per cent in Samples 1 to 4 furnished a close measure of increasing softness of these samples. However, in the case of Samples 5 and 6 the decided increase in the linolic acid content is partly offset by the decrease in oleic acid.

SUMMARY.

A complete separation of the fatty acids was made on six samples of fat obtained from as many lots of hogs fed rations varying in fat content.

The fatty acids occurring in all samples were oleic, linolic, arachidonic, myristic, palmitic, and stearic. Palmitic acid and stearic acid occurred in a ratio of 2:1.

The feeding of soy beans caused the deposition of small quantities of linolenic acid, while the feeding of peanuts led to the deposition of arachidic acid. The oils of these two feeds have a pronounced effect on the composition of the lard. A greater likeness was noted between peanut oil and "peanut lard" than between soy bean oil and "soy bean lard."

The fat formed on a ration of brewers' rice and tankage which contained less than 1 per cent fat was very hard. The glycerides of oleic, palmitic, and stearic acids composed over 97 per cent of the fat.

BIBLIOGRAPHY.

1. Ellis, N. R., and Isbell, H. S., *J. Biol. Chem.*, 1926, lxix, 219.
2. Jamieson, G S., and Baughman, W. F., *J. Am. Chem. Soc.*, 1920, xlii, 1197.
3. Drogin, I., and Rosanoff, M. A., *J. Am. Chem. Soc.*, 1916, xxxviii, 711.
4. Amberger, C., and Wiesehahn, A., *Z. Untersuch. Nahrungs- u. Genussmittel*, 1924, xlvi, 276.
5. Lewkowitsch, J., and Warburton, G. H., Chemical technology and analysis of oils, fats and waxes, London, 6th edition, 1922, ii, 709.
6. Ellis, N. R., and Hankins, O. G., *J. Biol. Chem.*, 1925, lxvi, 101.
7. Jamieson, G. S., Baughman, W. F., and Brauns, D. H., *J. Am. Chem. Soc.*, 1921, xliii, 1372.
8. Baughman, W. F., and Jamieson, G. S., *J. Am. Chem. Soc.*, 1922, xliv, 2947.
9. Baughman, W. F., and Jamieson, G. S., *J. Am. Chem. Soc.*, 1921, xliii, 2696.

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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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.							
	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.	Feed consumed per lb. of gain by weight intervals. 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.

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BIBLIOGRAPHY.

1. Ellis, N. R., and Isbell, H. S., *J. Biol. Chem.*, **69**, 219 (1926).
2. Anderson, W. E., and Mendel, L. B., *J. Biol. Chem.*, **76**, 729 (1928).
3. Eckstein, H. C., *J. Biol. Chem.*, **81**, 613 (1929).
4. Ellis, N. R., and Hankins, O. G., *J. Biol. Chem.*, **66**, 101 (1925).
5. Gibbs, H. D., and Agcaoili, F., *Philippine J. Sc.*, *Sect. A*, **5**, 33 (1910).
6. Wierzuchowski, M., and Ling, S. M., *J. Biol. Chem.*, **64**, 697 (1925).
7. Eckstein, H. C., *J. Biol. Chem.*, **64**, 797 (1925).
8. Wesson, L. G., *J. Biol. Chem.*, **65**, 235 (1925).
9. Jamieson, G. S., *J. Oil Fat Ind.*, **3**, 256 (1926).
10. Leathes, J. B., and Raper, H. S., The fats, London (1925).