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Influence of the basal diet on the quality of pig fat

About 100 years ago it was thought that the depot fat in animal derives entirely from the fat ingested by the diet. The Rothamsted experiments in the 'sixties' showed, however, that pigs must convert considerable quantities of carbohydrates and, maybe, also proteins to fat. A complete investigation as to the ability of the pig to synthesize fat, both with regard to the quantity and the quality, was made in 1939 by Hilditch, Lea, and Pedelty [1]. By this examination it was demonstrated, that

1) an extensive biosynthesis of palmitic, stearic, and oleic acid occurs; besides, small amounts of hexadecenoic acid is formed;

2) the pig is unable to synthesize linoleic acid, present in most plant fats, and highly unsaturated C_{20-22}-acids, present in marine fats; consequently, when these acids are found as glycerides in the fatty tissue, feeds of the said origin must have been given to the pigs.

Thus, a piece of truth was present in the old opinion of the origin of the body fat. Generally the fat formed from the carbohydrates of the diet is, however, by far the most abundant and, moreover, the plant and marine fats do not contain the specific fatty acids mentioned only, but also various amounts of those being synthesized in the body, particularly oleic acid.

Now, from a practical point of view, the said specific fatty acids would be of no importance, unless they would contribute to the lowering of the quality of the pig fat with regard to consistency, keepability, and taste. In more serious cases also a yellow discolouration of the fat will occur. If the dietary fat (oil) has turned rancid, it may be unhealthy to the animals.

Addition of fat to the diet.

The effect of adding various plant fats or vegetable products rich in fat to the diet of pigs has been investigated repeatedly. In 1926 it was proved by Ellis and Isbell [2], that feeding pigs with soy beans or groundnuts alone will cause a marked increase of the content of linoleic acid in pig fat. In another experiment in 1931 Ellis, Rothwell and Pool [3] demonstrated the gradual rise of the linoleic acid content of the back fat by adding increasing amounts (4, 8, and 12 %) of cottonseed oil to the basal diet. Haagen-Petersen [4] in 1937 reported on the detrimental effect of oil cakes on the back fat, 15-17 % of this food stuff along with barley causing a rise of the iodine value of about 5 units as compared to feeding with barley alone together with skim milk. On the other hand, exchange of 20-40 % of the barley against tapioca revealed a lowering of the iodine value of the back fat of about 3 units.

The occurence of unsaturated fatty acids of the C_{20}- and C_{22}- series in the pig body fat on feeding menhaden oil can be concluded from a paper published in 1931 by Brown [5]. By feeding 7 % fish meal to pigs Banks and Hilditch (1932)[6] found 0,9-2,1 % (by weight) highly unsaturated C_{20}- and C_{22} - fatty acids deposited in the fat. Similarly, Haug (1938)[7] found highly unsaturated C_{20}-acids in fat from pigs fed herring meal. Garton, Hilditch, and Meara (1952)[8] fully examined the inner and outer back fat as well as the perinephric fat of a pig fed a diet including 50 % of whale oil. They found, that the whale oil glycerides had been assimilated and deposited in the depots without any chemical alteration. A relatively higher proportion of whale oil was deposited in the outer layers of the back fat. Garton and Duncan [9] in 1953 reported the composition of the inner and outer back fat from two pigs fed a diet containing i.a. equal parts of cod-liver oil and lard. 50 % of the diet was composed of this fat mixture after feeding 7 weeks, when the pigs were killed. It was concluded, that the cod-liver oil and the lard were absorbed essentially unchanged and deposited additively along with synthesized pig fat. Dahl [10,11] found higher iodine values and substantially increased susceptibility to oxidative rancidity of fats from pigs reared on fish meal instead of skim milk as protein source. This was true both for back fat, leaf fat, and mesenteric fat.

The fat in the cereal ration.

Apart from the above-mentioned, very informative investigations with purposely added fat or fat supplied along with the protein feeding, nothing is known about the fate of the cereal fat or oil in the pig body. Generally the content of the fat in cereal is low, that is true, and that is probably why it has not been regarded as yet. But, provided this fat would be continuously accumulated in the adipose tissue, the total quantity will not be negligible. This is evident from the following turnover, based on average analyses of barley, oats and wheat bran listed in table 1 and made on continuously drawn samples in experiments reported below on fats from pigs, reared on these food stuffs as the sole source of dietary fat.

Table 1: Analyses of barley, oats, and wheat bran oil

Determination of		Barley oil	Oats oil	Wheat bran oil
Content of crude oil in the grain, % [1]		1,7	5,5	3,5
Iodine value of oil		120,5	106,o	119,1
Composition of oil [2]:				
% by weight of total fatty acids	oleic acid [3]	7,5	33,o	18,7
	linoleic acid	54,5	33,6	46,7
	linolenic "	8,1	7,o	8,4
	saturated acids [4]	29,9	26,4	26,2

1) Excludes unsaponifiable matter.
2) Content of linoleic and linolenic acids were determined by alkaline isomerisation according to the method of Mitchell, Kraybill, and Zscheile [12] and by using the values of specific absorption given by Beadle and Kraybill [13]. No appreciably different result were obtained if the unsaponifiable matter was removed from the fatty acids or not, as is evident from the following figures on content of linoleic and linolenic acid determined without removing the unsaponifiable matter (results when freed from unsaponifiable matter are those in table 1): Barley oil: 54,1 and 8,5 %; oats oil: 32,o and 6,9 %; wheat bran oil: 47,9 and 8,1 %.
3) Computed from the iodine values 126.5; 111.o and 124.3 of the fatty acid mixtures after subtraction of iodine absorbed by the linoleic and linolenic acids (I.V. are 89.9; 181.0 and 273.5 for oleic, linoleic and linolenic acid respectively).
4) Remainder to 100 %.

About 170 kg of ground barley and 17 kg of wheat bran is consumed by a pig when growing from a live weight of 20 kg to 90 kg, that is 3.5 kg of cereal fat and 1.9 kg linoleic acid glyceride (2.1 kg linoleic + linolenic acid glycerides). The dressed weight amounts to 67 kg and the approximate fatty tissue content of the carcass is 40 % [14], i.e. about 34 % chemical fat. Thus, the carcass contains 23 kg fat and 8 % of the body fat will be linoleic acid glyceride (9 % linoleic + linolenic glycerides), provided this acid is quantitatively deposited in the adipose tissue. - If oats is used instead of barley about 230 kg are required together with 23 kg wheat bran, which means 13.5 kg of cereal fat and 4.6 kg linoleic acid glyceride (5.6 kg linoleic + linolenic acid glycerides). Then, with the same assumption as before, linoleic acid glyceride will constitute about 20 % (linoleic + Linolenic acid glycerides 24 %) of the body fat. Thus, barley and particularly oats, although not containing very much oil, may contribute to an appreciable degree to the character of the pig fat.

Now, oats is not an unusual substitute for barley in the pig's ration and, as a matter of fact, it is also used as a fixed and sometimes even sole ingredient in the basal diet. Furtheron, potatoes is fed to some extent in certain districts. In view of the practically complete absensce of fat in potatoes it is to be expected, that this ingredient will lower the content of linoleic and linolenic acid in the pig fat, when fed instead of cereal. Moderate quantities of swedes, turnips, sugar beets or tops of these plants are considered to have a benificial influence on the state of health and are therefore used to some extent in pig raising. When rearing pigs on diets containing fish meal the quality of the back fat, measured by iodine value and taste, is reported to be lower if the said root crops also are given than if the are not [15]. So the possible effect of tops of root crops in diets without fish meal ought to be known, too.

Experiments and results

In view of what has been argued the following four feeding experiments with pigs were undertaken:

I. Basal diet: barley.
II. " " : oats.
III. " " : barley and potatoes.
IV. " " : barley; besides sugar beet tops with crowns.

The barley and oats were ground. Primary data as to consumption, gain of weight etc. as well as killing data are collected in table 2.

Table 2: Feeds, weighings of the pigs, length of rearing periods, thickness of back fat etc.

The figures are means and standard deviations. They refer to one pig per day, unless otherwise stated. Weights are given in kg, time in days.

In addition to the food stuffs given in the table each pig in the groups I, III and IV had 5.1; 4.4; and 5.0 kg soy meal (containing 0.6 % oil) respectively. Besides, each pig in all groups had 2.0 kg yeast mixed with a fat free vitamin A and D preparation, 1.6 kg $CaCO_3$, 0.5 kg $CaHPO_4$, and 0.9 kg NaCl. The dry food stuffs were always given as a mixture. - The sugar beet tops had crowns. They were fed fresh from 1st Nov., when the experiment started, to 12th Dec., then as silage.

After splitting the carcass the thickness of the back fat was measured in the shoulder layer, where the fat is thickest, furtheron in the loin layer, where the fat is thinnest, and at last on the top and at each end of the M. Glutaeus medium ~~Piriformis~~. The mean of the latter three measurements was used along with the former two measurements to form the final mean given in the table.

	Group I	Group II	Group III	Group IV
Barley, total consumption per pig	170.5	-	144.9	166.2
Oats, " " " "	-	228.3	-	-
Wheat bran, total " " "	17.1	22.8	14.5	16.6
Raw Potatoes, " " " "	-	-	122.2	-
Sugar beet tops, total consumption per pig	-	-	-	237.1
Skim milk, " " " "	297.0	207.1	383.4	279.5
Scandinavian feed units, fe(sk), consumed	1.959	2.091	1.988	2.028
Grams of digestible true protein, "	209	198	213	210
" " " " " per fe(sk)	107	95	107	103
Digestible true milk protein, % of total digestible true protein	36.2	25.7	45.5	32.5
Crude fiber in dry feeding mixture, %	4.5	8.9	4.5	4.5
Crude fiber " roughage, %	-	-	0.6	1.5

table 2 - continued

Live weight at start	19.2 ± 2.4	18.9 ± 2.8	18.9 ± 2.2	19.0 ± 1.7
Age at start	62.9 ± 5.3	64.1 ± 6.4	63.5 ± 6.0	64.1 ± 6.4
Live weight at slaughter	89.6	71.4	89.5	89.7
Dressed weight	66.8 ± 2.7	67.8 ± 2.7	66.6 ± 1.4	66.9 ± 2.5
Rearing (experimental) period	111.8 ± 12.3	116.1 ± 6.9	112.6 ± 11.2	117.0 ± 13.0
Gain of weight	630	615	627	604
Fe (sk) per kg gain of weight	3.11	3.40	3.17	3.36
Thickness of back fat, mm	36.3 ± 5.0	36.1 ± 4.9	34.6 ± 6.2	34.9 ± 6.9
Grading (class)	1	1	1	1

Each group involved 8 pigs - 4 gilts and 4 hogs - of the Swedish Large White breed. The pigs were derived from 7 litters, the individuals of which were distributed as evenly as possible between the four groups. All the pigs were kept in the same stable and each group had equal space. All the trials were started simultaneously. The pigs were healthy and gained normally in weight during the whole rearing period.

From each carcass a strip of the back fat and the leaf fat were secured for analysis. The strip was cut out along the back from the atlas to the croup muscle. Special care was taken to get an overall equally wide section through the entire fat layer, since the character (iodine value etc.) of the back fat is markedly different in the outer and inner layers.

The back fat and leaf fat samples were examined with regard to iodine value, content of linoleic and linolenic acid, and resistance to oxidative rancidity (keepability). Each sample was analyzed separately.

For the latter examination the fat was minced and then heated for $1\frac{1}{2}$ hours in a water bath at 100°C, pressed and filtered. 50 ml were transferred in a 200 ml Erlenmeyer flash, protected against light by means of black paper, covered with a watch-glass, and placed in a thermostate at 55°C. At one day intervals samples of 1 ml (weighing) were analyzed for peroxide value according to Lea's simplified method [16]. The induction period (keeping time) was evaluated from a diagram. Sometimes, difficulties arises in drawing the asymptotes correctly, so an alternate method applied in estimating the keeping time was to fix a peroxide value of 100 mg active oxygen per kg fat as limit for the induction period. Then, generally two results were obtained, the mean of which was considered to be correct.

The iodine value was determined according to Hanuš' method. The method of analysis of linoleic and linolenic acid has been referred to previously (Table 1). For these investigations the minced samples of fat were treated with anhydrous Na_2SO_4 and then extracted with ethyl ether. Traces of the solvent were removed in vacuum.

The results are listed in table 3.

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Table 3: Analysis of back fat and leaf fat
8 pigs in each group. Means and standard deviations.

Analysis of	Group I (fed barley)	Group II (fed oats)	Group III (fed barley + potatoes)	Group IV (fed barley + sugar beet tops)
Back fat:				
Iodine value (pressed fat) 1)	57.2	66.9	57.1	57.8
Keepability, days at 55°C	14.9 ± 5.2	3.4 ± 1.5	12.8 ± 4.5	12.1 ± 3.4
Iodine value (extracted fat) 2)	57.7 ± 2.3	67.2 ± 2.1	57.8 ± 1.6	58.4 ± 1.8
Linoleic acid 3)	7.0 ± 0.7	15.6 ± 0.8	6.5 ± 0.6	7.4 ± 0.4
Leaf fat:				
Iodine value (pressed fat) 1)	48.9	56.8	48.1	49.5
Keepability, days at 55°C	20.1 ± 4.4	6.8 ± 1.4	20.0 ± 3.1	18.7 ± 1.7
Iodine value (extracted fat) 2)	49.0 ± 3.2	56.8 ± 2.1	48.2 ± 2.2	49.7 ± 2.1
Linoleic acid 3)	6.5 ± 0.6	13.2 ± 1.1	5.6 ± 0.5	6.5 ± 0.3

1) Samples used for the examination of keepability. To be compared with the iodine values of extracted fats used for the determination of the linoleic acid content. Means only; standard deviations not computed.

2) cf. foot note 1).

3) Per cent of total fatty acids.

Discussion

With the experiments of Hilditch, Lea and Pedelty 1) in mind, demonstrating that no synthesis of linoleic acid is likely to occur in the pig organism, it is evident from table 3, that appreciable amounts of cereal linoleic acid have been deposited in the adipose tissue of the pig. It can be stated, that even the fat supplied by so poor a source of fat as barley will be laid down and thus affect the quality of pig fat. In view of these findings and with regard to the higher fat content of oats it is to be expected, that the quality of the fat from pigs fed oats as a basal diet (group II) is widely different from that of pigs fed barley alone or barley together with potatoes or sugar beet tops. This is true, too, both for back fat and leaf fat. Not a single case was observed, where the data - iodine value, keepability, and content of linoleic acid - of the fats from pigs fed oats (group II), touched those of fats from pigs in the other groups. The iodine value of the back fat from pigs fed oats was about 10 units higher than that of the pigs belonging to the other groups, for leaf fat the difference was about 8 units. Accordingly, the keeping time of fat from pigs fed oats was but 1/4 (back fat) and 1/3 (leaf fat) of that of fats from pigs fed barley alone or barley along with potatoes or beet tops. The explanation of this is the substantially higher content of linoleic acid in fats from pigs fed oats than in fats from pigs fed barley etc. Thus, the content of linoleic acid is more than twice as high in the former fats than in the latter. This is true for back fat and leaf fat as well.

When comparing the content of linoleic acid found in these experiments with the introductory calculation, it seems probable, that part of the linoleic acid is used up by the pig organism and evidently to a greater extent in the case of group II. It is not possible, however, to make more far-reaching conclusions from such an approximate calculation. - Another thing worth mentioning is the almost complete absensce of linolenic

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acid in the pig fats investigated. Only between 0.0 and 0.2 % of this acid was found as compared to 1.4 % (groups I, III, IV) and 4.7 % (group II) required by theory, if the ingested fat had been deposited in the adipose tissue. A similar "disappearance" of linolenic acid was observed by Ellis and Isbell [2] when rearing pigs on soy beans. Now, linoleic and linolenic acid act as vitamins and, in addition, are common constituents in the phospholipids; so they may be absorbed somewhere else, e.g. in the liver and other organs, and only a surplus, if present, might be deposited in the adipose tissue in accordance with findings in experiments with rats 17,18,19).

From a practical point of view, the feeding of oats as the sole basal diet is not very common. Consequently, the detrimental effect on pig fat caused by oats generally will not appear so clearly as in these experiments. Yet the oats as a source of this effect should not be overlooked.

From table 2 it is to be seen, that the pigs in group II were 5 days older than those in group I at slaughter. According to Jarl [20] the iodine value is correlated to duration of life. The following equation was derived for back fat:

$i = 48.9 + 0.061a$ (i = iodine value, a = duration of life in days),

i.e. in 5 days the iodine number will increase by 0.3. In consequence, the difference between the data of the fats from pigs in group II and those of the fats from pigs in group I are slightly overestimated.

Although the data of the fats from the groups I, III, and IV are very similar a note on the results of some statistical investigations may be mentioned. No statistically significant differences exist between the iodine values or the keepabilities, although there is a tendency to higher iodine values and lower keepability of the fats from pigs in group IV (cf. influence of age above). The content of linoleic acid, however, was significantly different between the groups III and IV. This was true both for back fat and leaf fat, the probability of significance being 99.5 % and > 99.9 % respectively.[x] Furtheron, there was a significant difference between the means of the content of linoleic acid in leaf fat with regard to the groups I and III, the probability of significance being 99-99½%. Here again the difference of age (cf. table 2) may contribute to an explanation and, as was pointed out by Jespersen and Plesner[21] and also Haagen-Petersen[4], the injurious influence of certain roughages is due rather to a reduced rate of growth — smaller amounts of the firm fat deriving from carbohydrates will be formed — than to a specific influence of such food stuffs on the fat. However, the content of lipids in the appreciable amounts of sugar beet tops fed (table 2) cannot be completely disregarded. Assuming 3 % glycerides in the sugar beet tops on a dry weight basis (content of dry matter: 18.5 %) and 2/3 of the fatty acids being linoleic and linolenic acid, 237 kg sugar beet tops will supply 0.88 kg of these acids. Linoleic acid usually is the smaller fraction, say 0.3 kg. Then the content of linoleic acid (as glyceride) in the pig fat will be increased by 1.3 %, provided a quantitative deposition in the adipose tissue.

At last it may be mentioned, that the colour of the pig fats, measured spectrophotometrically[22], was affected by none of the diets used in these experiments.

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x) Secured by means of the t-test,

$$t = (\bar{x}_1-\bar{x}_2)\Big/\sqrt{\frac{(\sum \hat{x}_1^2 + \sum \hat{x}_2^2)\,(N_1+N_2)}{(N_1+N_2-2).N_1N_2}}$$, where $\bar{x}_1$ and $\bar{x}_2$ are the two means

regarded, $\sum \hat{x}_1^2 = \sum (x_1-\bar{x}_1)^2$, $\sum \hat{x}_2^2 = \sum (x_2-\bar{x}_2)^2$, N_1 and N_2 number of determinations.

Here $N_1 = N_2 = 8$; degrees of freedom = $N_1+N_2-2 = 14$.

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Summary

Even so poor a source of fat as barley affects the quality of pig fat by supplying unsaturated fatty acids, mainly linoleic acid, which is almost quantitatively deposited in the adipose tissue. Thus, 170 kg barley, containing 1.7 % oil, and 17 kg wheat bran, containing 3,5 % oil, - these feeds being the sole sources of dietary fat - contributed to a content of about 7 % linoleic acid (as glyceride) in the back fat of ordinary bacon pigs of 90 kg.

Feeding 228 kg oats (containing 5,5 % oil) as a subsitute for barley and 23 kg wheat bran, caused a content of about 16 % linoleic acid (as glyceride) in the back fat.

The iodine values of the back fats of pigs fed barley and oats were about 57 and 67 respectively.

The resistence of the back fat from pigs fed oats to oxidative rancidity was but 1/4 of that of back fat from pigs fed barley.

Similar differences as to content of linoleic acid, iodine value, and keepability of the fat also exist between leaf fats from pigs fed barley and oats respectively.

Potatoes showed a tendency to lower the content of linoleic acid in the pig fat, sugar beet tops caused a slight increase of the same. The reason for this has been mentioned.

Only traces of the linolenic acid supplied by the dietary fat were present in the pig depot fats. The probable reason for "disappearance" of this constituent is discussed.

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