RANCIDITY OF PORK

A study of the influence of different feeding and cold storage on the development of rancidity in fatty tissue of pork.

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Introduction and General Consideration.

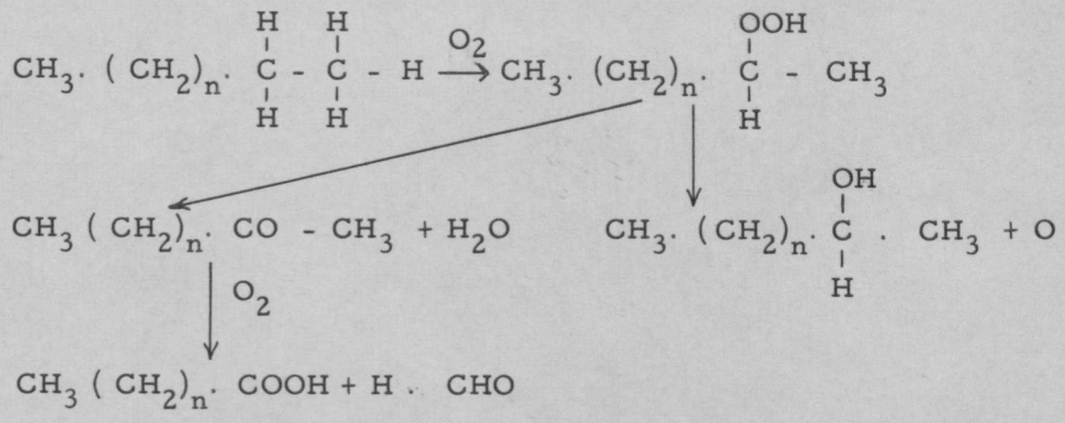
It is a well known fact that certain materials, like fish silage, fish meal, cod liver oil, and vegetable products containing easily oxidized fats may cause off-flavour as well as discoloration of pork, when used as pigs feed. The influence of different feeding on fatty acid composition of pork fat was very early recognized. For early data see e.g. HALDEN-GRÜN (1929). More recent work in this field has been published by BEADLE & al. (1948 a & b).

The off-flavour of pork and bacon may have different causes. Hydrolysis may, for instance, play a rôle in cases where original or microbiologically produced lipatic enzymes are present. As a rule the dominating cause of rancidity of pork is oxidation reactions. Enzymes, particularly Lipoxydase, seem to be able to accelerate oxidation reactions in pork fat, just as has earlier been shown in other fats by BERGSTRÖM & HOLMAN (1948), HOLMAN & BERGSTRÖM (1951), FRANKE (1951) and FREDHOLM (1955). Sometimes off-flavours of different origin may be present, which will make the organoleptic trials difficult to interpret.

There seems to be little difference between the oxidation reactions occurring, for instance, in butter, as studied by FREDHOLM (1955) and others, and the corresponding reactions in pork fat. Principally, there is no difference whether the pork fat is isolated or occurs in natural tissue. The velocity of reaction is very much influenced, though. In the tissue and, to some extent, in molten lard, too, occurring substances with antioxidative properties play a rôle as well as the ratio surface volume and the quantity of absorbed and adsorbed oxygen. Temperature has, of course, a great influence on reactions of the kind in question.

The reactions of pork fat, which have in common that hydroperoxides are formed as intermediate products, are of greatest interest, because they will

result in off-flavours of the type often described as oily or fishy. Principally, all fatty acids of pork fat may undergo oxidation, beginning with the formation of hydroperoxy-compounds. The reactions of the saturated fatty acids are of the same type as the autoxidation of hydrocarbons:



i. e. the β-oxidation is the dominating reaction here, too. The velocity of this reaction in lard or pork fat in natural tissue, as compared to the oxidation reactions of unsaturated compounds of the fat, is so slow that the reaction will play a rôle only in very highly oxidized products.

The oxidation of monoetenoide compounds like oleic acid has been studied by FARMER (1942), FARMER & al. (1942), HOLMAN & al. (1954), ROSS & al. (1949), KHAN & al. (1951), MAX & DEATHERAGE (1951), SWIFT & al. (1946), SWIFT & DOLLEAR (1948) and SWIFT & al. (1948). The rate of oxidation of oleic acid without catalyzer at 37° C is 0, 08 mol 0_2 per mol oleic in 100 h according to HOLMAN & ELMER (1947). In molten lard the velocity of the corresponding oxidation reaction seems to be somewhat greater and in natural fat tissue of pork slower. The part of this work which concerns reaction velocities in question is not yet finished. The reactions seem to follow the general scheme: (1) Formation of hydroperoxyoleic acid glycerol esters from oleic ester and molecular oxygen; (2) The hydroperoxyoleic esters are decomposed with formation of α,β-unsaturated carbonyl-compounds, amongst which 2-undecenal has been found.

The oxidation of conjugated as well as non-conjugated polyetenoide fatty acid compounds play a much more important rôle in the studies at hand. HOLMAN & ELMER (1947) found the following oxidation rates for free fatty acids with one, two or three non-conjugated double bounds without catalyzing agent.

Table 1.

Acid	Oxygen absorbed per mol acid at 37°C in mol 0_2/h
Oleic	0.0008
Linoleic	0.0220
Linolenic	0.0618

The main reaction involved the formation of hydroperoxy compounds.

When the double bounds are conjugated the reaction velocity will normally grow. Conjugated triene-esters oxidize faster than do non-conjugated triene-esters, as was first shown by MYERS & al. (1941). As far as pork fat is concerned, there are exceptions from this rule of the same type as described by ANDERSSON (1950) in a study of methyl linoleate.

Free fatty acids are faster oxidized than their glycerol esters. The rate of oxidation seems to be between 1, 5 and 2 times higher for the free fatty acids of pork fat than for their glycerol esters, or in the same order as found by HOLMAN & ELMER (1947) in a study of the oxidation of unsaturated fatty acids and some of their simple esters.

Pigs are able to deposit glycerol esters of fatty acids, which do not normally occur in pork fat. Even fatty acids of the peculiar type occurring in fish fat and oils of vegetable origin may be deposited in the fatty tissue of pork and remain there for a considerable time. In this way very highly unsaturated and, therefore, easily oxidized fatty acids are incorporated with the pork fat. There is reason to believe that even small amounts of such fatty acids may strongly alter the keeping qualities of pork, as far as rancidity is concerned. During the course of this work we have also found that such, as pork fat components abnormal, highly unsaturated and easily oxidized fatty acids, once incorporated into the fat tissue of the pig, may remain there for more than four months, maybe considerably longer. Detailed results of chromatographic studies in this respect will be published elsewhere.

Materials and Methods

This report deals with results obtained with 1. 631 pigs, delivered for slaughter at the abattoirs of the Stockholm-Gävle Slakteriförening. The work

has been carried out during the years 1953-1960. Some preliminary results have been reported, FREDHOLM (1957). All of the pigs have been followed in regard to feeding stuffs used. Some reservation must be made as to the reliability of the feeding stuff control. In any case no objection can be raised against 1. 112 cases, i. e. 70 % of the material, and in most of the remaining cases ev. objections are restricted to details of feeding which are likely to be without importance.

The pigs were divided into four groups. The feeding of each group was carefully controlled. A close connection to practical feeding was pursued. Since the influence of fish fat is well known and has been described many times, e. g. HALDEN & GRÜN (1929), LANDØKONOMISK FORSØGSLABORATORIUM (1951, 1952), GARTON & al. (1952), ASKÖE & MADSEN (1954) and HELLBERG & al. (1956) no special fish diet group was included.

In most western countries the kind of pigs feed is of importance which is produced by privately or municipally owned plants which sterilize food-waste from households, restaurants and alike on a big scale by cooking. Because the food-waste comes from many sources it has a remarkably constant composition. Here this kind of feed is called Västberga feed from the name of the most important plant of this kind in Sweden. One of the groups, group I, of the pigs were fed Västberga feed together with grain, skimmilk and vitamins.

Group II was fed food - waste directly delivered from big commercial kitchens and fish-shops together with commercial dry pigs feed mixtures but no Västberga feed.

Group III was given grain, skimmilk, potatoes and food-waste from farm household.

Group IV was fed grain, skimmilk and potatoes. No kind of food-waste was used in this group.

Details of feed composition will be given below in cases where they might be of special interest.

Most samples belonging to group I emanated from big pigs farms. 15 breeders have given full particulars concerning the composition of the pigs feed used. In this group 752 samples from as many hogs have been examined. " Västberga" pigs feed has been given in varying quantities. Young pigs have been fed 0, 5 to 5 kgs per day, and this ration was raised to 1 to 9 kgs during

the fattening period. During the last four weeks before slaughter 1 to 8 kgs per day were given. Besides "Västberga" pigs feed the pigs were given grain, skimmilk, small quantities of dried herring powder or dried tankage, ordinary pigs feed mixtures and so called pigs feed concentrates consisting of mineral components, vitamin A and tocopherols. Table 2 below illustrates in detail the composition of a typical feed for pigs belonging to group I.

Table 2.

Feed used in a big pigs farm belonging to group I.

	Young pig period	Fattening period	Time immediately before slaughter (approx. 4 weeks)
Feed	Kg/day and pig	Kg/day and pig	Kg/day and pig
Grain	1	1,5	2
Skimmilk	0,5		
Fish-or herring powder	1 table spoon	1 table spoon	
"Västberga" pigs feed	2 - 3	4	5
Pigs feed concentrates containing A-vitamins and tocopherols	0,2	0,4	

Group II contains 240 pigs, i.e.21, 6% of the total number of pigs included in the experiments. The kinds of feed mentioned in table 2 were used in group II too except the Västberga-feed which was exchanged to the abovementioned food-waste.

Since there was no need to have a big material in the groups III and IV because these two groups served to give a comparison material in the first hand, and could very easily be completed, only 71 pigs (6, 4% of total) were used in group III and 49 pigs (4, 4% of total) in group IV.

After slaughter and sampling as described below 900 carcasses were frozen and kept cold stored at -25°C for up to 23 months. During cold storage samples have been taken after 1 week, 2-3 weeks, 2 months, 6- 7, 10 -11 and 22 - 23 months.

Immediately after slaughter and at intervals during storage a sample, 2 - 3 cm wide, is carved from the tail root toward the croup through the layer of depot fat. The samples were frozen at once and kept at -23°C. This sampling differs only in details from the one used by ASKÖE & MADSEN (1954). Laboratory work was then carried out as described below.

The thiobarbituric acid method originally deviced by KOHN & LIVERSEDGE (1944) and studied by BERNHEIM & al. (1947, 1948), WILBUR & al. (1949), GLAVIND & HARTMANN (1951) and ASKÖE & MADSEN (1954) was found to be suitable for the purpose of this work. A modification of the method described by ASKÖE & MADSEN (1954) was used to get a colorimetrically measurable aldehyde test. In details the test was carried out as follows:

Two hours after the samples had been frozen a cylindrical roll, 6 mm diameter, of fat was bored out. With a two-blades knife 4 pieces, 7,5 mm long, were cut from the cylindrical roll. The pieces were placed in Pyrex test tubes. 10 ml freshly made reagent, consisting of equal parts of 0,04 - m Na- thiobarbiturate and 0,065 - m HCl with pH = 2,0 was added. The tubes were equipped with condensing bulbs and kept for one hour in a boiling water bath. Then the liquid was poured into cylindrical cuvettes and centrifuged for 10 min. at 3200 rev. per minute. After cooling to 20°C the transmission of light of 5350 Å was measured in a Bausch & Lomb Spectronic photometer.

The organoleptic tests were carried out as follows. One mm thick slices were carved from the frozen samples of fatty tissue. The slices were dipped into a saturated sodium chloride solution for 15 min. Then they were roasted in an electric oven at 200 - 225°C. The taste was tested by at least two, as a rule 5 people, accustomed to tests of this kind. In order to diminish the uncertainty of tasting only 3 classes were used, namely:

1. Distinctly oily or fishy off-flavour
2. Slightly " " " " "
3. No " " " " "

730 tests for taste were carried out on the 1631 samples mentioned above.

Determination of the quantity of active oxygen, i. e, hydroperoxides, was performed in the following way.

About 1 g finely cut fatty tissue was exactly weighed and shaken for two minutes with an acetic acid - chloroform mixture (2:1). Then 1 g of potassium iodide was added. The mixture was heated to boiling, then immediately cooled

to room temperature and titrated with 0,01 - n $Na_2S_2O_3$. Then hydroperoxide content of the samples is expressed as mgs of active oxygen per 1000 g of fatty tissue.

Iodine numbers were determined according to generally accepted method.

Results

In order to judge the possibility of comparing directly the results of the light transmission measurements with those of the taste-testing which are fewer, the results have been divided into groups, each group comprising results within 5 units of the transmission, according to the photometer scale, table 3.

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Table 3.

Distribution of values

of transmission and taste in %

Light Transmission % groups	Number of light transmission measurements in each group %		Tests for taste %		Diff.
1 - 5	1,7		3,6		+ 0,7
6 - 10	11,7	46,1	12,8	45,4	
11 - 15	16,0		15,2		
16 - 20	16,7		13,8		
21 - 25	14,1		12,2		
26 - 30	10,5	38,9	7,7	35,4	+ 3,5
31 - 35	7,5		8,5		
36 - 40	6,8		7,0		
41 - 45	6,2		7,2		
46 - 50	4,1	13,7	4,5	17,1	- 3,4
51 - 55	2,2		3,8		
56 - 60	1,2		1,6		
61 - 65	0,5		1,1		
66 - 70	0,4	1,3	0,5	2,1	- 0,8
71 - 75	0,4		0,5		
76 - 80	-		-		

The tests for taste are considered to be representative of the total quantity of samples in regard to the subjectivity of the tests for taste.

All carcasses of the four groups have within each group been collected in clusters each of which comprising 5 units of light transmission. Table 4 and the curves fig. 1 show details.

All pigs carcasses which have been taste tested have been collected into clusters too according to light transmission of samples, fig. 2 and. table 5.

Table 4.

Distribution of light transmission values in feeding groups I to IV of pigs.

Transmission of light %	1 - 5	6 - 10	11 - 15	16 - 20	21 - 25	26 - 30	31 - 35	36 - 40	41 - 45	46 - 50	51 - 55	56 - 60	61 - 65	66 - 70	71 - 75	Totals Nr	Totals %	%
Group I																		
Number	17	118	157	174	124	81	38	27	12	3	1					752		
% of total	1,5	10,6	14,1	15,6	11,2	7,3	3,4	2,4	1,1	0,3	0,1						67,6	
% of group	2,3	15,7	20,9	23,1	16,5	10,8	5,1	3,6	1,5	0,4	0,1							100,0
Group II																		
Number	2	12	21	12	29	30	32	34	38	21	4	4	1			240		
% of total	0,2	1,1	1,9	1,1	2,6	2,7	2,9	3,1	3,4	1,9	0,3	0,3	0,1				21,6	
% of group	0,8	5,0	8,7	5,0	12,0	12,5	13,3	14,1	15,8	8,8	1,6	1,6	0,8					100,0
Group III																		
Number					1	5	12	12	9	12	11	5	1	3		71		
% of total					0,1	0,4	1,1	1,1	0,8	1,1	1,0	0,4	0,1	0,3			6,4	
% of group					1,4	7,0	16,9	16,9	12,7	16,9	15,6	7,0	1,4	4,2				100,0
Group IV																		
Number					2	1	1	2	10	9	9	6	4	1	4	49		
% of total					0,2	0,1	0,1	0,2	0,9	0,8	0,8	0,5	0,3	0,1	0,3		4,4	
% of group					4,1	2,0	2,0	4,1	20,4	18,4	18,4	12,2	8,2	2,0	8,2			100,0
Group III and IV																		
Number					3	6	13	14	19	21	20	11	5	4	4	120		
% of total					0,3	0,5	1,2	1,2	1,7	1,9	1,8	1,0	0,4	0,4	0,4		10,8	
% of group					2,5	5,0	10,8	11,7	15,8	17,5	16,7	9,2	4,2	3,3	3,3			100,0
Total, Number	19	130	178	186	156	117	83	75	69	45	25	15	6	4	4	1.112		
Total, %	1,7	11,7	16,0	16,7	14,1	10,5	7,5	6,8	6,2	4,1	2,2	1,2	0,5	0,4	0,4		100,0	

Fig. 1. Distribution of light transmission values within different feeding groups and within the total material.

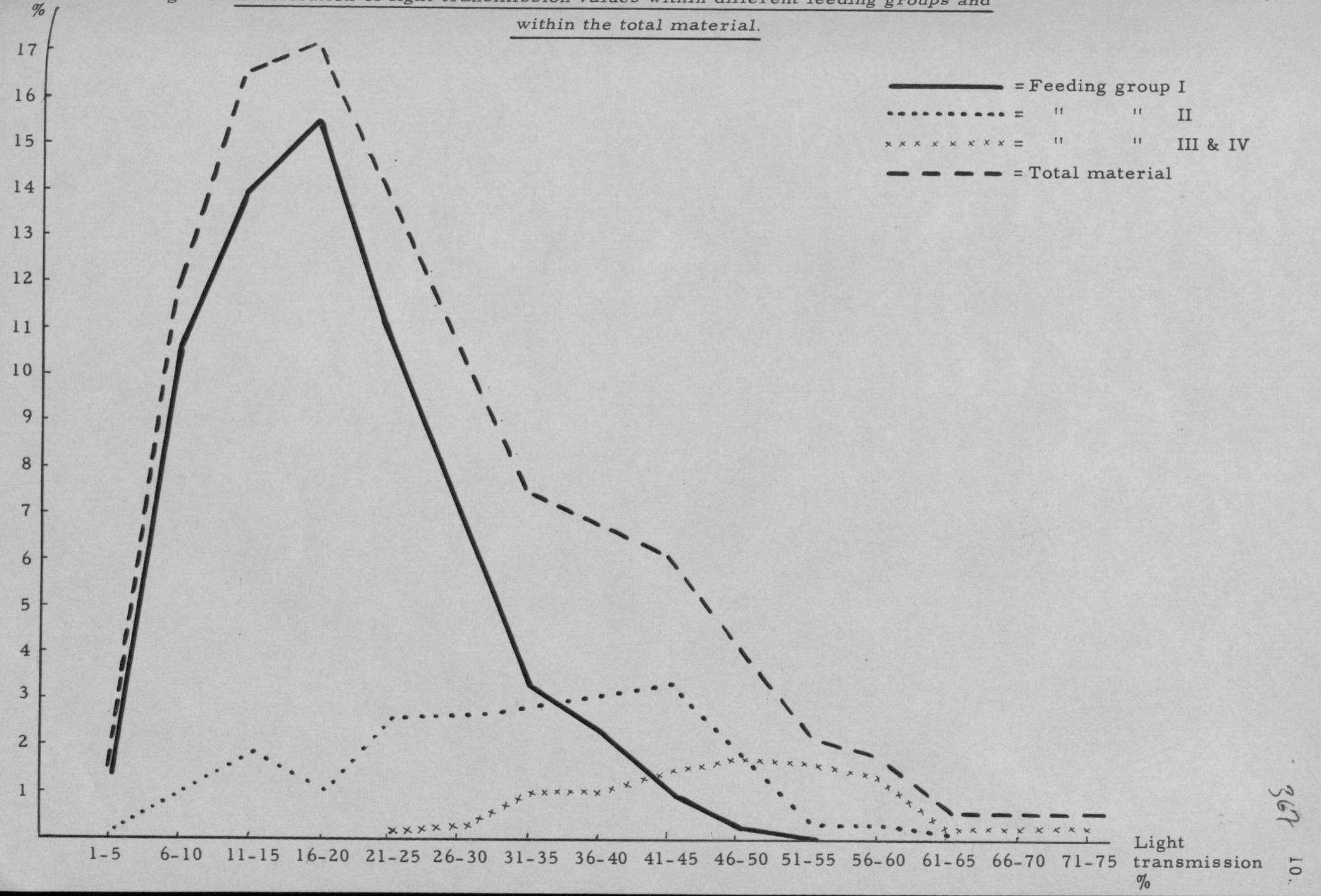

Table 5.

Distribution of taste tests on different light transmission clusters.

Light transmission %	1 - 5	6 - 10	11 - 15	16 - 20	21 - 25	26 - 30	31 - 35	36 - 40	41 - 45	46 - 50	51 - 55	56 - 60	61 - 65	66 - 70	71 - 75	Totals Nr	Totals %	Totals %
Distinctly oily or fishy off-flavour	26	66	50	24	17	2	1									186		
% of total	3,6	9,1	6,8	3,3	2,3	0,3	0,1										25,5	
% of group	14,0	35,5	26,9	12,9	9,1	1,1	0,5											100,0
Slightly oily or fishy off-flavour		27	56	68	48	24	9	13	4	2						251		
% of total		3,7	7,7	9,3	6,6	3,3	1,2	1,8	0,5	0,3							34,4	
% of group		10,7	22,3	27,1	19,1	9,6	3,6	5,2	1,6	0,8								100,0
No oily or fishy off-flavour			5	9	24	30	52	38	48	31	28	12	8	4	4	293		
% of total			0,7	1,2	3,3	4,1	7,2	5,2	6,7	4,2	3,8	1,6	1,1	0,5	0,5		40,1	
% of group			1,7	3,1	8,2	10,2	17,7	13,0	16,4	10,6	9,5	4,1	2,7	1,4	1,4			100,0
Total, Nr	26	93	111	101	89	56	62	51	52	33	28	12	8	4	4	730		
Total, %	3,6	12,8	15,2	13,8	12,2	7,7	8,5	7,0	7,2	4,5	3,8	1,6	1,1	0,5	0,5		100,0	

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Fig. 2.

Distribution of light transmission values on taste test clusters.

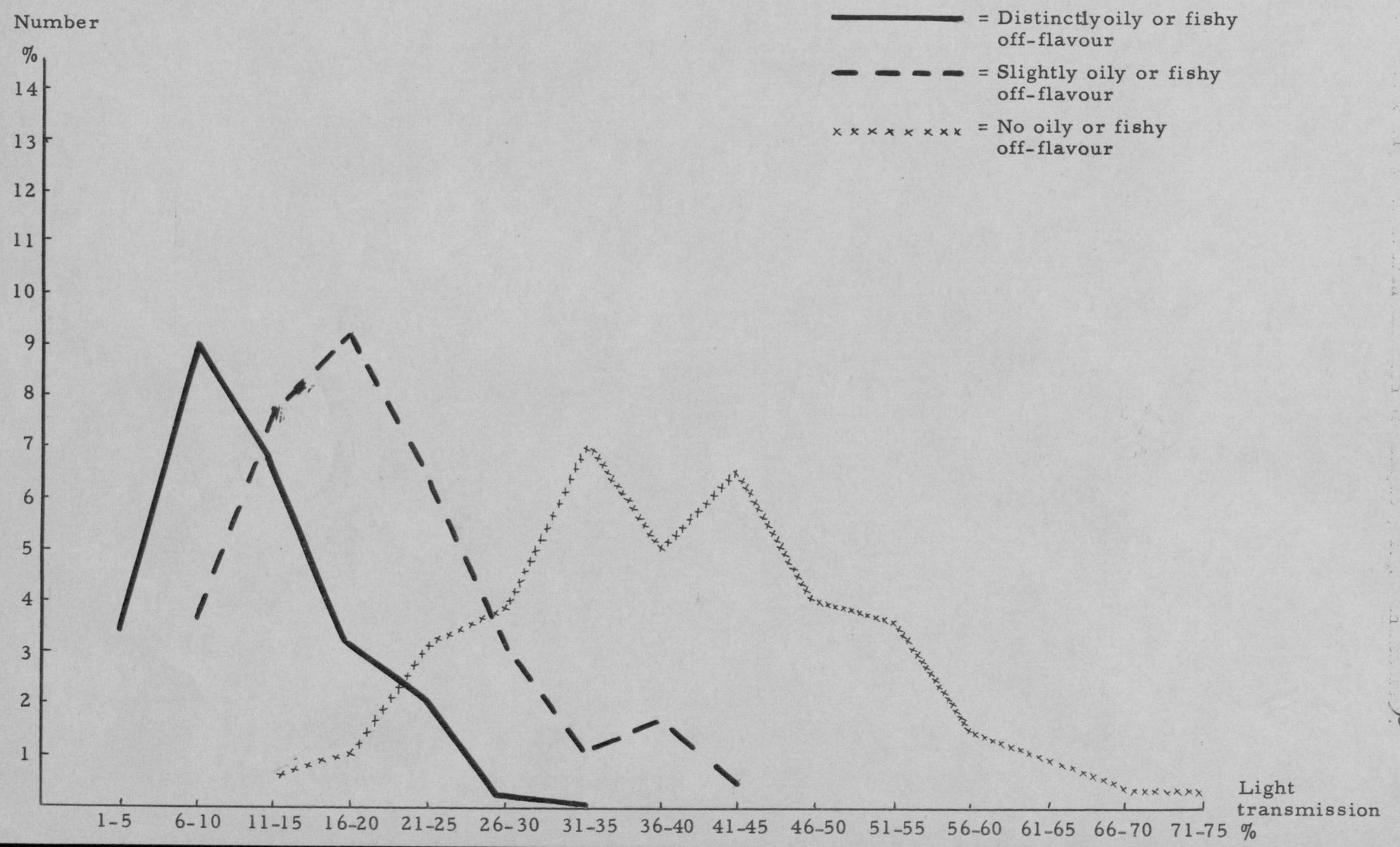
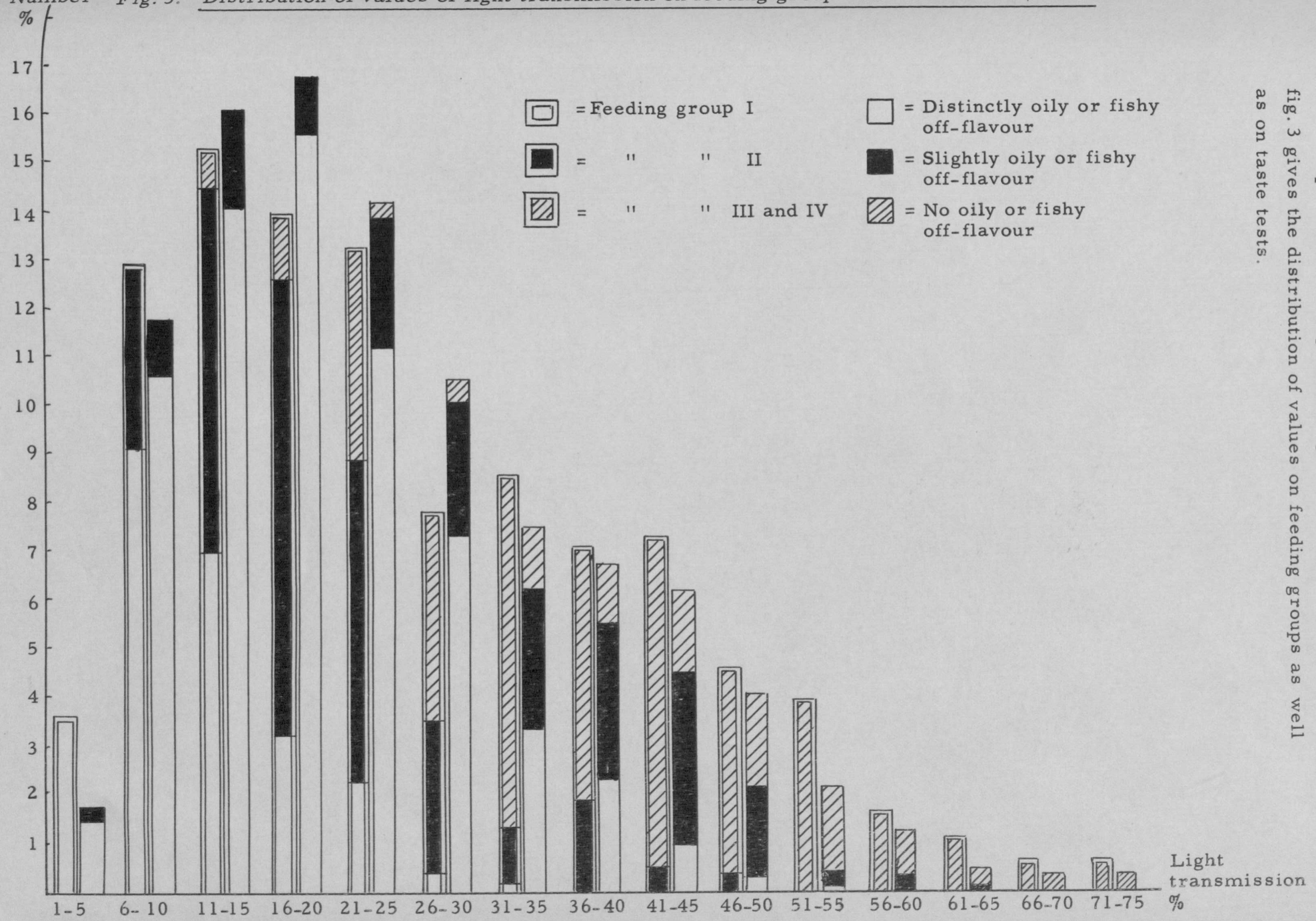


Fig. 3. Distribution of values of light transmission on feeding groups and taste test clusters.



For comparison of both parts of light transmission distribution fig. 3 gives the distribution of values on feeding groups as well as on taste tests.

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Detailed examination of material from separate swineries has been carried out. A typical feeding scheme used at a swinery belonging to group I is given in table 6.

Table 6.

Feeding scheme breeder A, group I, 52 pigs.

Feed	Young pigs period	Fattening period	Four weeks before slaughter
	Kg/day and pig	Kg/day and pig	Kg/day and pig
1. Grain	1	1, 5	2
2. Skim milk	0, 5	None	None
3. Whey	None	None	None
4. Potatoes	"	"	"
5. Root crops	"	"	"
6. Meat or blood powder	"	"	"
7. Fish powder	1 table-spoon	1 table-spoon	"
8. Fish silage or fresh fish	None	None	"
9. Farm food-waste	"	"	"
10. Cod liver oil	"	"	"
11. Västberga pigs feed	2-3	4	5
12. Commercial pigs feed	None	None	None
13. Commercial pigs feed concentrates, consisting of mineral components, vitamin A and tocopherols	0, 2	0, 4	"

Table 7 gives the results of light transmission measurements and taste tests from this particular material, in the table called A, as well as from 3 other swineries of the same kind, in the table called B, C and D.

Table 7.

Light transmission and taste of material from separate swineries, group I.

Swinery	Number	Transmission of light %											Taste tests		
													Fishy or oily off- flavour		
		1-5	6-10	11-15	16-20	21-25	26-30	31-35	36-40	41-45	46-50	Mv	Number	Distinct	Slight No
A	9		6	2		1						10	9	9	
B	13		6	3		4						12	15	4	11
C	258	4	21	70	94	35	17	10	5	1	1	18	141	52	89
D	85		3	6	9	22	21	15	6	2	1	26	46	5	33

For swineries belonging to group II a typical feeding scheme is given in table 8, and the corresponding results of light transmission measurements and taste tests are collected in table 9.

Table 8.

Feeding scheme breeder J, group II, 100 pigs.

Feed	Young pigs period	Fattening period	Four weeks before slaughter
	Kg/day and pig	Kg/day and pig	Kg/day and pig
1. Grain	1	2	2
2. Skim milk	2	1	1
3. Whey	None	None	None
4. Potatoes	1	2	3
5. Root crops	1	2	None
6. Meat or blood powder	None	None	None
7. Fish powder	"	"	"
8. Fish silage or fresh fish	"	"	"
9. Food-waste	2	4	4
10. Cod liver oil	0,01	0,015	None
11. Västberga pigs feed	None	None	"
12. Commercial pigs feed	"	"	"
13. Pigs feed concentrates	0,20	0,20	0,20
14. Wheat bran	0,10	0,10	0,10
15. Mineral mixture (80 % $CaCO_3$ + 20 % tocopherol oil)	0,02	0,04	0,04

Table 9.

Light transmission and taste of material from separate swineries, group II.

Swinery	Number	Transmission of light %											Taste tests			
		1-5	6-10	11-15	16-20	21-25	26-30	31-35	36-40	41 - 45	46-50	Mv	Fishy or oily off - flavour			
													Number	Distinct	Slight	No
E	14	2	6	5	1							9				
F	13		3	6			2	2				17				
G	19		3	4	2	2	6	2				20				
H	26			2	4	2	4	2	4	5	3	32	24		3	21
I	16					1	3	8	4			32	17		4	13
K	28					7	1	6	8	4	2	35	6		3	3
L	16							4	6	4	2	39				4

The same detailed examination of material from separate swineries has been carried out in the groups III and IV. As has been pointed out already these two groups have much in common, and with few exceptions show high light transmission and no off-flavour in fatty tissue from carcasses. The exceptions are connected to cases where pigs have been incorporated into the groups at a late date corresponding to live weights of 20 kgs or more. It is interesting to see that in all such cases reported (in group II, 5 pigs) light transmission of fat is below the mean value, which is 44 %. The two lowest light transmission values of group II (27 and 29 % resp.) are two of these cases. The statistical mean value of group IV is 52 %.

All determinations of hydroperoxides carried out on samples collected immediately after slaughter gave quantities below 1 mg of active oxygen per kg of fatty tissue or less than 0,001 mg of active oxygen per gram fatty tissue.

The study of the changes occurring during cold storage of pork was performed as follows. From the 900 pigs carcasses frozen and kept at -25° C for up to 23 months, as reported above, 2.148 samples were collected during storage.

In table 10 the results of determinations of light transmission during cold storage are collected. The table shows the number of samples with increased or decreased light transmission and gives the mean values of the increase or decrease compared to the values found immediately after slaughter. Unchanged values are not included, i. e. all cases where light transmission was found to be the same during cold storage as immediately after slaughter. The number of these cases was 79 or scant 4 %. Fig. 4 represents the statistical mean value of changes of light transmission to original light transmission.

Table 11 gives the corresponding distribution in number per cent of the product of mean value of light transmission change into number of samples. The double setting encloses those light transmission clusters which represent 10 samples or more.

Table 10.

Light transmission changes during cold storage.

Transmission %	1 - 5		6 - 10		11 - 15		16 - 20		21 - 25		26 - 30		31 - 35		36 - 40		41 - 45		46 - 50		51 - 55		56 - 60		61 - 65		66 - 70	
	+	-	+	-	+	-	+	-	+	-	+	-	+	-	+	-	+	-	+	-	+	-	+	-	+	-	+	-
1 week																												
Number of samples	-	-	39	6	44	16	30	17	11	23	5	17	5	10	3	10	5	3	-	1	4	3	1	-	-	1	-	-
Mean variation			7	2	10	4	10	5	7	7	12	6	11	10	7	11	9	9		24	8	10	2			5		
2-3 weeks																												
Number of samples	3	-	49	13	69	20	42	47	25	60	16	50	11	39	4	27	4	17	2	9	1	7	-	6	-	1	-	1
Mean variation	2		7	3	7	4	8	8	8	10	6	10	5	11	6	12	7	13	13	22	2	15		21		14		35
2 months																												
Number of samples	31	1	25	8	52	20	61	30	42	39	32	47	26	27	18	22	19	18	8	16	4	15	2	8	-	4	-	5
Mean variation	13	7	11	4	9	4	9	6	11	7	11	9	14	8	9	12	10	8	11	10	8	10	4	14		6		10
6 - 7 months																												
Number of samples	31	-	38	1	55	5	53	11	40	19	39	14	31	21	26	13	25	11	8	15	4	8	2	7	1	4	-	3
Mean variation	17		13	1	10	4	10	3	13	5	12	8	14	7	9	8	10	7	11	8	10	12	2	15	1	12		12
10-11 months																												
Number of samples	-	-	5	-	13	5	12	22	10	28	2	41	5	13	1	10	2	9	1	5	1	7	-	3	-	1	-	1
Mean variation			10		7	3	5	4	8	7	3	10	2	11	11	12	10	11	3	19	9	10		10		8		20

Number of samples after: 1 week 254; 2 - 3 weeks 523; 2 months 610; 6-7 months 485; 10 - 11 months 197

Thereof unchanged (not included): 12; 20; 22; 16; 9

Total number of samples: 2.148

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Fig. 4
Light transmission changes during cold storage at - 25°C.

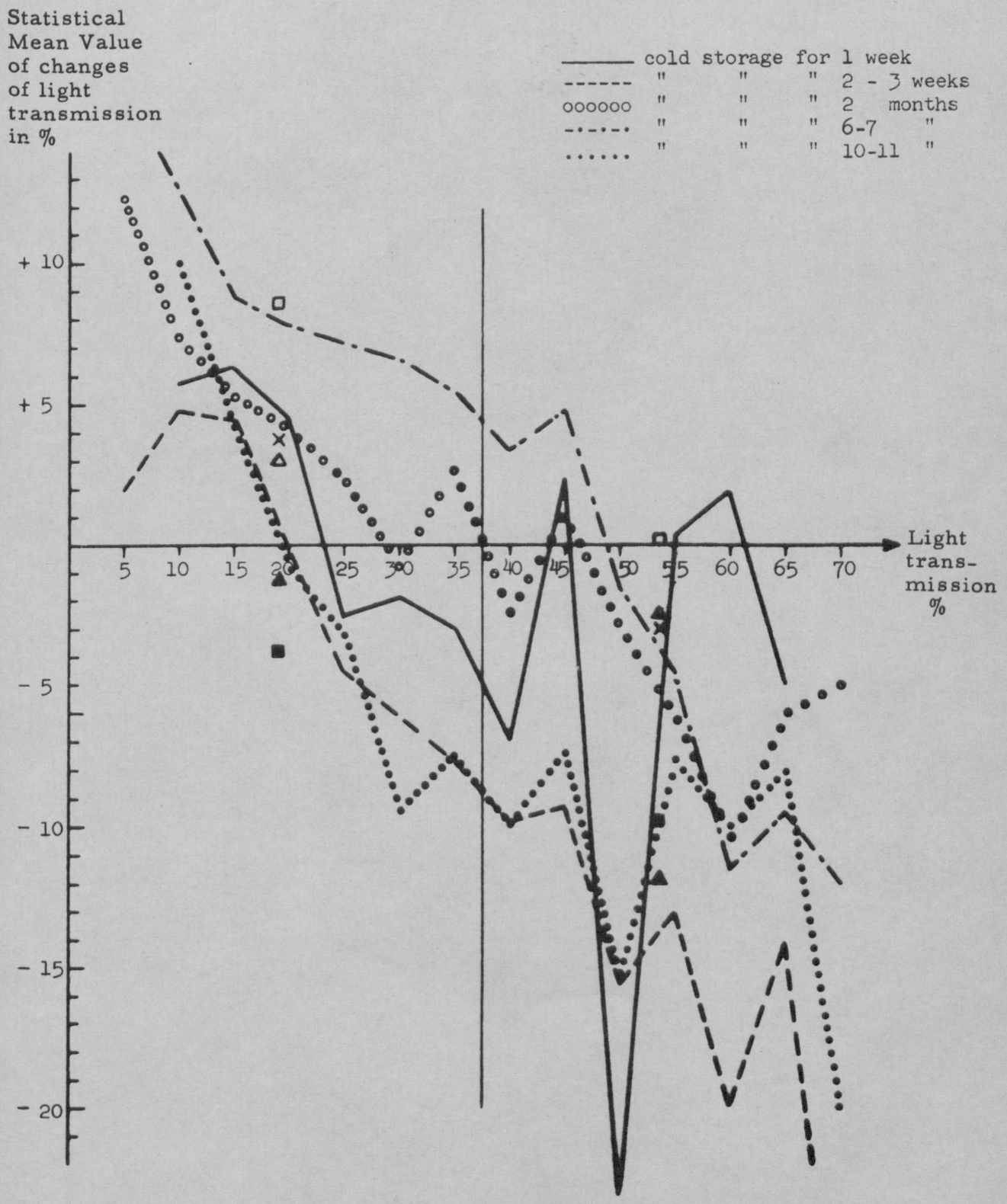

Table 11.

Changes of light transmission of fatty pork tissue during cold storage.

The column % contains the product of mean value of light transmission change into number of samples.

Striated field contains clusters showing greater increase than decrease of light transmission values .

Light transmission %	1 - 5		6 - 10		11 - 15		16 - 20		21 - 25		26 - 30		31 - 35		36 - 40		41 - 45		46 - 50		51 - 55		56 - 60		61 - 65		66 - 70	
	+	-	+	-	+	-	+	-	+	-	+	-	+	-	+	-	+	-	+	-	+	-	+	-	+	-	+	-
1 week	-	-	273	12	440	64	300	85	77	161	60	102	55	100	21	110	45	27	-	24	32	30	2	-	-	5	-	-
%			95,8	4,2	87,3	12,7	77,9	22,1	32,4	67,6	37,0	63,0	35,5	64,5	16,0	84,0	62,5	37,5	0	100	51,6	48,4	100	0	0	100		
2 - 3 weeks	6	-	343	39	483	80	336	376	200	600	96	500	55	429	24	324	28	221	26	198	2	105	-	126	-	14	-	35
%	100	0	89,8	10,2	85,8	14,2	47,2	52,8	25,0	75,0	16,1	83,9	11,4	88,6	6,9	93,1	11,2	88,8	11,6	88,4	1,9	98,1	0	100	0	100	0	100
2 months	403	7	272	32	468	80	549	180	462	273	352	423	364	216	162	264	190	144	88	160	32	150	8	112	-	24	-	50
%	98,3	1,7	89,6	10,4	85,4	14,6	75,3	24,7	62,9	37,1	45,4	54,6	62,8	37,2	38,0	62,0	56,9	43,1	35,5	64,5	17,6	82,4	6,7	93,3	0	100	0	100
6 - 7 months	527	-	494	1	550	20	530	33	520	95	468	112	434	147	234	104	250	77	88	120	40	96	4	105	1	48	-	36
%	100	0	99,8	0,2	96,5	3,5	94,1	5,9	84,6	15,4	80,7	19,3	74,7	25,3	69,2	30,8	76,5	23,5	42,3	57,7	29,4	70,6	3,7	96,3	2,0	98,0	0	100
10-11 months	-	-	50	-	91	15	60	88	80	196	6	410	10	143	11	120	20	99	3	95	9	70	-	30	-	8	-	20
%			100	0	85,8	14,2	40,5	59,5	29,0	71,0	1,4	98,6	6,5	93,5	8,4	91,6	16,8	83,2	3,1	96,9	11,4	88,6	0	100	0	100	0	100

It might be of some interest to show the changes of light transmission in fatty tissue from pigs belonging to separate swineries within a certain feeding group. From the most interesting feeding group I table 12 gives the light transmission values obtained during cold storage for 11 months, of pork deriving from some separate swineries.

Table 12.

Light transmission changes in pork from separate swineries belonging to feeding group I. Cold storage -25° C.

	0 days	2-3 weeks	2 months	6-7 months	10-11 months
Breeder S					
Number of samples	119	48	89	94	21
Mean value of light transmission	19	9	19	21	17
Breeder D					
Number of samples	18	18	18	-	18
Mean value of light transmission	28	17	28	-	20
Breeder M					
Number of samples	23	16	23	23	-
Mean value of light transmission	11	6	12	11	-
Breeder N					
Number of samples	38	24	47	11	23
Mean value of light transmission	17	20	19	22	24
Breeder O					
Number of samples	21	17	21	26	6
Mean value of light transmission	28	20	28	30	26

During cold storage of pork hydroperoxides are formed. Table 13 contains some values of active oxygen determined during cold storage at -25°C of pork for up to 23 months. In every here reported case the initial value (immediately after slaughter) of hydroperoxides was lower than corresponding to 0,001 mg of active oxygen per g of fatty tissue. In the table the values of hydroperoxides content are distributed to light transmission values obtained immediately after slaughter.

Table 13.

Hydroperoxides content of pork wich has been cold stored for 23 months.

Original light transmission %	< 1	1-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-110
	Hydroperoxides as active oxygen in mg per kg of fatty tissue											
1 - 5	2	1		1		1	1					
6 - 10	3	2	3	2			1			2		
11 - 15	4	4	9	4	2	1	2	1		1		
16 - 20	9	5	5	1	4	1						
21 - 25	11	10	5	3		1		1			1	1
26 - 30	4	8	5	6	2	2						
31 - 35	3	2	9	2	1	2						
36 - 40	4	2	6	4	3	1		1				
41 - 45	3	1	2	1	1							
46 - 50	3	5	2	2				1				
51 - 55			2	1	1							
56 - 60		1	1	1	2			1				
61 - 65		2			1							
66 - 70		1		1			1					

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Table 14 contains found hydroperoxide quantities distributed on light transmission measured at the same time as hydroperoxides.

Table 14.

Quantities of hydroperoxides as active oxygen in mg/1000 g after 23 months of cold storage in relation to light transmission measured at the same time.

Light transmission %	1	1-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	101-110
	Hydroperoxides as active oxygen in mg per 1000 g of fatty tissue											
1 - 5		3	2	1						1		
6 - 10	6	4	5	5	1		2	2		1	1	
11 - 15	14	2	3	5	3	6	1			1		1
16 - 20	7	4	6	3	1	1	1					
21 - 25	10	5	6	2	2							
26 - 30	5	7	9	5	4	2		2				
31 - 35		7	3	1	2							
36 - 40		3	6	1	3		1	1				
41 - 45	1	1	8	1	1							
46 - 50	2	5	1	1								
51 - 55		2		3								
56 - 60												
61 - 65	1	1		1								
66 - 70												

In table 15 the increase or decrease of light transmission, determined after 23 months of cold storage, is given. For comparison the values of light transmission determined immediately after slaughter are contained in the table too.

Table 15.

Increase or decrease of light transmission after 23 months of cold storage, in relation to light transmission immediately after slaughter.

Original light transmission %	Increase	Decrease	Unchanged
1 - 5	6		
6 - 10	10	3	
11 - 15	12	16	1
16 - 20	15	8	2
21 - 25	10	20	
26 - 30	7	18	2
31 - 35	5	14	
36 - 40	6	14	1
41 - 45	3	6	
46 - 50	2	11	
51 - 55	1	3	
56 - 60		6	
61 - 65		3	
66 - 70		3	

Table 16.

Iodine numbers of pork fatty tissue in relation to transmission of light of 5350 Å according to modified thiobarbituric acid method.

Iodine Number	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	Arithm. mean value	Max.	Min.	Samples Number
Light transmission %																							
1 - 5											1			1	1	1	1		1	72,3	76	68	6
6 - 10												1			1					71,5	72	69	2
11 - 15				1		1		1	1	2		1							1	66,8	76	61	8
16 - 20				1	1			1	1		1	1				1				66,3	73	61	7
21 - 25				2		1	2		1	1		1				1				65,3	73	61	9
26 - 30	1		1	1	2	3		2		1			1							63,3	70	58	12
31 - 35					1		1	1	1				1	1						66,3	71	62	6
36 - 40							1	1	1											65,0	66	64	3
41 - 45				1	1		1		1											63,3	66	61	4
46 - 50		2							1											61,3	66	59	3
51 - 55					2															62,0	62	62	2
56 - 60																							-
61 - 65																							-
66 - 70	1					1														60,5	63	58	2

Iodine numbers are given in table 16 distributed on light transmission clusters.

DISCUSSION.

The data reported have been statistically treated in order to state whether statistically significant differences exist between.

1 Light transmission and feeding
2 Taste and light transmission
3 Cold storage and light transmission
4 Hydroperoxide content and light transmission, and
5 Iodine values and light transmission.

All under the conditions given. For securing, the well-known tests were used i.e.

1. Light transmission and feeding:

$$\bar{x} = \frac{1}{n} \sum x ;$$

$$\bar{\bar{x}} = \frac{n_1 \bar{x}_1 + n_2 \bar{x}_2 + \ldots.}{n_1 + n_2 + \ldots.}$$

$$s^2 = \frac{1}{n} \sum (x ; - \bar{x})^2$$

$$Q_1 = n_1 (\bar{x}_1 - \bar{\bar{x}})^2 + n_2 (\bar{x}_2 - \bar{\bar{x}})^2 + \ldots.$$

$$Q_2 = n_1 s_1^2 + n_2 s_2^2 + \ldots.$$

$$F = \frac{\frac{1}{r - 1} Q_1}{\frac{1}{n - r} Q_2}$$

$$\lambda = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{\frac{s^2 x_1}{n_{x_1} - 1} + \frac{s^2 x_2}{n_{x_2} - 1}}}$$

$$t = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{\frac{n_{x_1} s^2 x_1 + n_{x_2} s^2 x_2}{n_{x_1} + n_{x_2} - 2} \left(\frac{1}{n_{x_1}} + \frac{1}{n_{x_2}} \right)}}$$

where

r = groups

n = observations

F, λ, t, = tests.

For every group the following data have been calculated:

Group	I	II	III	IV
	$n_1 = 752$	$n_2 = 240$	$n_3 = 71$	$n_4 = 49$
	$\sum x_1 = 15810$	$\sum x_2 = 8075$	$\sum x_3 = 3260$	$\sum x_4 = 2580$
	$\bar{x}_1 = 21,0$	$\bar{x}_2 = 33,6$	$\bar{x}_3 = 45,9$	$\bar{x}_4 = 52,1$
	$s_1^2 = 80,83$	$s_2^2 = 158,21$	$s_3^2 = 126,63$	$s_4^2 = 134,80$

$\bar{\bar{x}} = 26,70$

$Q_1 = 95155$

$Q_2 = 114363$

F-test variation analysis over all data gives:

Hypothesis H_o : $\bar{x}_1 = \bar{x}_2 = \bar{x}_3 = \bar{x}_4$

$F = 307$

$F\alpha$ for α = 0,005 and 3 degrees of freedom in numerates and 1108 degrees of freedom in denominator = 4, 35 i. e.
$P (F > 4, 35) = 0,005$

$\therefore$ F-test gives a strong significant difference between the groups

The λ -method of statistical analysis shows:

Hypothesis H_o : $\bar{x}_1 = \bar{x}_2$

$\lambda_1 = 14,3$

$\lambda_\alpha = \pm 2,56$ for $\alpha = 0,01$ $\therefore$ significant difference between $\bar{x}_1$ och $\bar{x}_2$

Hypothesis H_o: $\bar{x}_2 = \bar{x}_3$

$\lambda_2 = -7,9$ $\therefore$ significant difference

Hypothesis H_o: $= \bar{x}_3 = \bar{x}_4$

$\lambda_3 = -3,16$ $\therefore$ significant difference

Conclusion 1) :

Statistically significant differences exist between the four groups as to transmission of light.

2. Taste and light transmission:

Statistical investigations.

Distinct oily or fishy off- flavour	Slight oily or fishy off - flavour	No oily or fishy off - flavour
$n_1 = 186$	$n_2 = 251$	$n_3 = 293$
$\bar{x}_1 = 13,7$	$\bar{x}_2 = 21,9$	$\bar{x}_3 = 41,5$
$s_1^2 = 37,98$	$s_2^2 = 72,86$	$s_3^2 = 152,39$
$\sum x_1 = 2540$	$\sum x_2 = 5505$	$\sum x_3 = 12165$

$Q_1 = 100698$ $\qquad \bar{\bar{x}} = \frac{20204}{730} = 27,68$

$Q_2 = 70002$

The F-test gives:

Hypothesis: $H_o : \bar{x}_1 = \bar{x}_2 = \bar{x}_3$ $\qquad F_\alpha = 0,005 = 5,40$

$F = 522$ $\qquad$ fgt = 2
fgn = 729

The F-test gives a strong significant difference between the light trans - missions of the three taste categories.

The λ -test gives:

Hypothesis $H_o : \bar{x}_1 = \bar{x}_2$

$\lambda_1 = 11,7$ $\qquad \lambda_{\alpha = 0,01} = \pm 2,58$ $\qquad \therefore$ significant difference between $\bar{x}_1$ och $\bar{x}_2$

$\lambda_2 = 23,0$ $\qquad \therefore$ sign.

Conclusion 2) :

Statistically significant differences exist between the taste categories as to transmission of light.

3. Cold storage and light transmission:

A similar statistical investigation carried out on data from measurements during cold storage shows:

Cold storage time	Light transmission	
	1 - 35	36 - 70
1 week	no sign. diff.	no sign. diff.
2 - 3 weeks	no sign. diff.	sign. diff.
2 months	no sign. diff.	no sign. diff
6 - 7 months	sign. diff. +	no sign. diff.
10 - 11 months	no sign. diff.	sign. diff.

Conclusion 3:

There is a significant increase in light transmission values after 6 to 7 months of cold storage of fatty tissue of pork which has an original light transmission lower than 35 %.

Fatty tissue of pork having a higher light transmission than 35 % (35 to 70 %) shows a significant decrease of light transmission after 2 to 3 weeks and 10 to 11 months of cold storage.

4. Hydroperoxide content and light transmission:

The data used for statistical investigation have been divided into two categories, namely those consisting of light transmission values between 1 and 35 and those between 36 and 70.

Calculations:

I	II
$n_1 = 151$	$n_{II} = 58$
$\bar{x}_1 = 21,6$	$\bar{x}_{II} = 20,5$
$s_1^2 = 458$	$s_{II}^2 = 325$

Hypothesis H_o: $\bar{x}_1 = \bar{x}_{II}$, t - test :

$t = 0,35$ $\quad t_{\alpha = 0,01} = 2,58$

" no statistically significant difference.

Conclusion 4:

No statistically significant differences exist between the hydroperoxide content of the different categories of light transmission data, i. e. between fatty tissue of pork with high or low light transmission.

5. Iodine values and light transmission:

A thorough statistical investigation of iodine and light transmission values shows that there are probable differences of iodine values in different groups of light transmission values, but the differences are not great enough to give statistically significant differences between every group.

SUMMARY.

Results obtained with 1631 pigs, all of which have been followed in regard to feeding stuffs used, then slaughtered and cold stored, are reported. An account of chemical reactions involved in rancidity of pork is given. A special interest is devoted to food waste as a feeding stuff for pigs, and to the influence of food waste from different sources on quality of pork.

Organoleptic and chemical testing is carried out and details as to taste and chemical composition are given, and put into relation to feeding. A modification of the thiobarbituric acid method originally deviced by KOHN & LIVERSIDE (1944) and described by ASKÖE & MADSEN (1954) is worked out and used to get a measurable aldehyde test. Monochromatic light of the wavelength of 5350 Å is used for measuring the transmission of light. Determinations of the quantity of active oxygen, i. e. hydroperoxydes, are carried out, as well as measurements of iodine numbers.

In the different feeding groups there is a consistency of light transmission with taste, though not a few samples of pork have no off-flavour but a low percentage of light transmission. If there is an off-taste of an oily or fishy character, light transmission is low. The upper limit of light transmission for off-flavour seems to be about 25 to 30 %.

It is stated that commercial feed mixtures containing 3 or 4 % of not defatted fishmeal, as a rule give low values of the transmission of light, even if they are only used to some 0, 2 kgs per day and pig.

The kind of pigs feed produced from food waste collected and cooked by special plants will practically always cause off-flavour and low values of light transmission but not necessarily high values of hydroperoxide content or high iodine values.

Even food waste from one household or restaurant often gives off - taste and low values of light transmission.

Cold storage of pork has a most interesting influence on off-flavour and light transmission. This influence is up till now unknown. As a rule there is a limit at 20% transmission of light. When pork of a light transmission below 20 % is cold stored there is an increase, whilst pork with a light transmission above 20 % as a rule will show a decrease during cold storage. After 2 to 3 weeks of cold storage this limit is moved lower, but later a higher light transmission value, as high as 45%, is obtained. This higher value will remain

for 6 to 7 months. After this time light transmission will be lower, and revert to the original value after one year of cold storage.

Statistical investigations show that there are significant differences between light transmission values of the different feeding groups as well as between light transmission and off-taste. The statistical investigations also give as a result that there is a significant increase of light transmission after 6 to 7 months of cold storage of pork, if the pork has a low light transmission (1 to 35 %). Fatty tissue of pork which has a higher light transmission (36 to 70 %) shows a significant decrease of light transmission after 2 to 3 weeks and 10 to 11 months of cold storage.

On the other hand there is no significant difference between hydroperoxides and light transmission, nor are there statistically significant differences between iodine values of every feeding group studied.

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