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The Detoxification of Cottonseed Meal for Hogs

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THE VALUE of cottonseed meal as a protein supplement has been the subject of numerous investigations. In the early investigations adverse results were obtained from feeding large amounts of this meal to hogs probably as a result of deficiences of the ration as well as from the toxic substance, gossypol, shown to exist in cottonseed meal by Withers and Carruth in 1915 (7). Evidence that a toxic substance is contained in meals produced by present milling practices is indicated in the ill effects observed by Robison (2) when cottonseed meal was fed to hogs in a well balanced ration. Cooking processes such as those employed in the manufacture of cottonseed meal change a portion of the gossypol contained in the kernels to a less toxic d-gossypol (8). The terms "bound" gossypol and "free" gossypol are often used to designate the changed and unchanged forms respectively. In 1926 Sherwood (3) analyzed 40 North Carolina meals and found that 75 per cent or more of the gossypol contained in the kernels is converted by the milling practices to the less toxic form. The amounts of the two forms of gossypol in cottonseed meal produced by present milling practices, and the relation of these to the effect of the meal on hogs, were the bases of the investigation reported here. The objectives were:

1. To study the range in toxicity of cottonseed meals produced by several mills in Alabama.

2. To study the relation of free and bound gossypol in these meals to their toxicity for rats and chicks.

3. To determine the effect of feeding meals containing various levels of free and bound gossypol to hogs.

4. To study the reduction or elimination of the toxic effect through various treatments of cottonseed meats and cottonseed meal.

EXPERIMENTAL PROCEDURE AND RESULTS

General Procedure

In this series of experiments meals were obtained from several mills, and analyzed chemically for their contents of both free and bound gossypol. The relative toxicity of the various

meals and the effect of moisture and heat treatments in reducing the toxicity were studied with rats and chicks. The results of these tests were made the basis of experiments with hogs. A final series of laboratory tests was conducted to determine more specifically some of the factors involved in the reduction of toxicity of cottonseed meal by treatments with moisture and heat.

The gossypol content of the meal was determined by the methods of Smith and Halverson (4,5). In the toxicity tests with rats and chicks cottonseed meal was included in a basal ration fortified with vitamin A. Animal sources of protein were used in limited amounts in the chick rations, but excluded from the other rations to avoid the protective influence this type of feed may have against the toxic effect of cottonseed meal (2).

Variation in Toxicity of Meals in Relation to Their Gossypol Contents

Experiments with rats.—Meals were obtained from 16 mills distributed uniformly over the state. While an effort was made to locate meals with a uniform percentage of protein, it was not possible to do so. The meals were obtained in one hundred pound bags and stored in tin cans. Insect infestation was prevented by placing small containers of carbon bisulphide in the cans at frequent intervals. Samples were taken for chemical analyses and sufficient meal removed from time to time to mix 1200 grams of ration.

The rat feeding experiments were conducted with male albino rats weighing approximately 90 grams per rat at the beginning of the experiment. The basal ration was as follows:

> Peanut meal (41% protein) 70.0%, yellow corn meal 27.5%, bone meal 1.5%, salt 1.0%, cod liver oil 0.25 cc, per rat mixed in the diet daily.

The test rations were prepared by substituting cottonseed meal for the peanut meal in the basal ration. Each ration was fed ad libitum to a group of four rats for nine weeks, at which time growth on the test rations had practically ceased. A summary of the results of these tests is presented in Table I.

The data are arranged in Table I according to the relative gains of the various groups of rats. Variation in the protein content of the meals from 36 to 41 per cent appears to have had no influence on the rat gains even though the same level of meal was used in all the rations. This result could be attributed to the fact that all of the rations contained more than the amount of protein normally required. It should be pointed out that gossypol is present in cottonseed hulls (1,6) with which the protein content of cottonseed meals is adjusted. Examination of the data

TABLE 1.—Variation in the Growth Rate of Rats in Relation to the Gossypol Content of Cottonseed Meals Used in the Diet.

Meal number	Mean Gain per rat[2]	Mean feed consumption per rat	Protein content	Gossypol content of meal[1]		
				Free	Bound	Total
	grams	grams	per cent	per cent	per cent	per cent
0[3]	156	875	41			
16	122	972	36	0.056	0.778	0.834
15	111	861	41	0.055	0.836	0.891
12	110	811	36	0.060	0.819	0.879
13	102	809	41	0.075	0.828	0.903
7	99	738	36	0.067	0.852	0.919
10	99	828	41	0.081	0.904	0.985
9	96	828	41	0.058	1.041	1.099
6	96	794	41	0.078	0.810	0.888
1	94	896	36	0.072	0.844	0.916
8	85	774	41	0.102	0.780	0.882
2	85	726	41	0.102	0.896	0.998
3	70	710	41	0.116	0.750	0.866
11	68	725	41	0.068	0.933	1.001
5	50	512	41	0.166	0.627	0.793
4	36	801	41	0.127	0.820	0.947
14	10	444	36	0.164	0.758	0.922

[1]Dry weight basis.

[2]Gain calculated at the end of a 9-week feeding period. Each value is the average of the gain of 4 rats except for meal No. 14, in which group two of the rats had died and the value shown is the average for the two remaining rats.

[3]Basal ration containing peanut meal.

reveals no apparent relationship between the protein content of each meal and its gossypol content or the amount of feed consumed by the rats. The total gossypol content ranged from 0.793 to 1.099 per cent; the bound gossypol content from 0.627 to 1.041 per cent; and the free gossypol content from 0.055 to 0.166 per cent. The mean gain per rat of 156 grams in the check group which was supplied peanut meal, was 34 grams in excess of the gain made by the highest gaining group fed cottonseed meal, indicating that even this cottonseed meal may have exerted some toxic effect. A cursory examination of the data reveals some decrease in feed consumption with decrease in gain and a definite inverse relationship between amount of gain and free gossypol content of the meal fed, but there is no apparent relationship between amount of gain and percentage of bound gossypol contained in the various meals. Statistical analysis of the data, however, shows that the amount of feed consumed had little or no influence on the gain of the rats, while the bound gossypol content of the different meals did influence the gains significantly. The fact that the major influence on the amount of gain was due to the free gossypol content of the meal was further confirmed by statistical analysis.

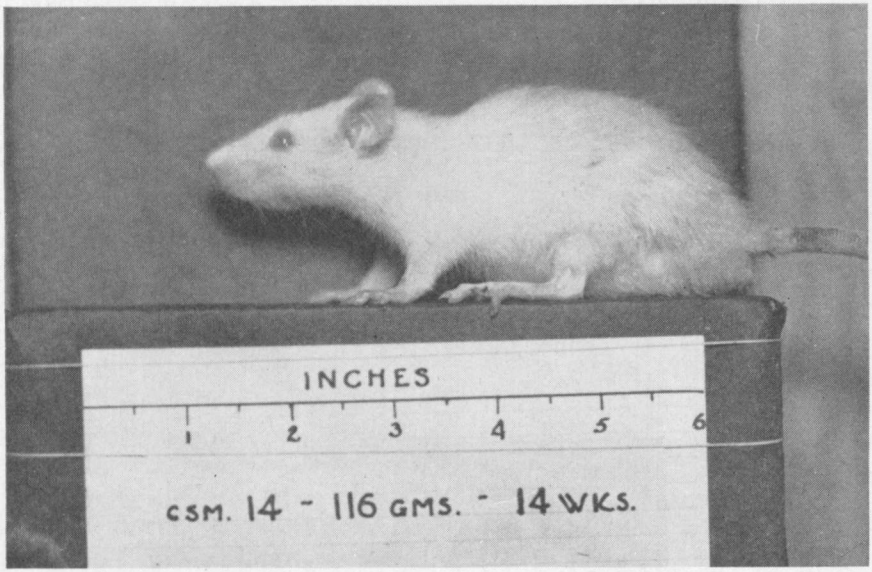

PLATE 1.—The diet fed this rat included a cottonseed meal containing 0.164% free gossypol.

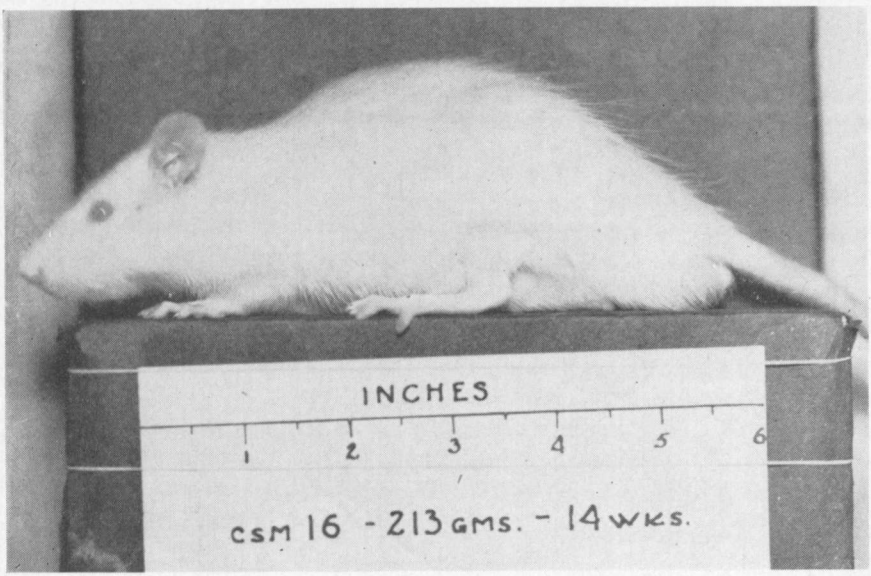

PLATE 2.—The diet fed this rat included a cottonseed meal containing 0.056% free gossypol.

Experiments with Chicks[1].—Following the experiments with rats, a ton of meal was purchased from each of the mills that had supplied the more toxic and the less toxic samples. Samples of these were composited from each of the twenty bags in the ton and analyzed for free and bound gossypol. Three of these ton lots were selected to represent meals of low, medium, and high free gossypol content and fed to White Leghorn chicks. The ration was as follows:

> Corn meal 55%, cottonseed meal 30%, dried buttermilk 5%, alfalfa leaf meal 5%, bone meal 2%, oyster shell 1%, salt 1%, cod liver oil 1%.

The chicks were placed on experiment when one day old and fed ad libitum in battery brooders for six weeks. The results are shown in Table 2.

TABLE 2—Variation in the Growth and Death Rate of White Leghorn Chicks in Relation to the Gossypol Content of Cottonseed Meal in the Ration.

Meal No.	Total gossypol content	Bound gossypol content	Free gossypol content	Av. gain per chick[3]	Chicks starting experiment	Chick deaths	
						Total	Last 4 weeks
	per cent[2]	per cent[2]	per cent[2]	grams	number	number	number
16C[1]	0.849	0.787	0.062	184	33	10	3
14C	0.805	0.704	0.101	173	33	7	3
5C	0.974	0.722	0.252	79	33	19	13

[1]The letter C designates meal obtained from the same mill from which original sample of this number came. The second order comprised a ton or more that was composited for both chemical analysis and feeding.

[2]Dry weight basis.

[3]Feeding period of six weeks.

The gains of the chicks, as shown in Table 2, were in inverse order to the free gossypol content of the meals fed. The detrimental effect of free gossypol is also indicated in the mortality data. Three more chicks died in the group receiving the low free gossypol meal than in the group receiving the meal of medium free gossypol content, but the excess deaths occurred during the first few days of the feeding period when the mortality of chicks is usually high. The low gain and high mortality in the group fed the meal containing the largest amount of free gossypol indicate the severe toxicity of this meal. Any influence the bound gossypol may have had is not indicated in the chick gains.

[1]The chick experiments were conducted in cooperation with Prof. D. F. King of the Poultry Department.

Elimination of Toxicity with Moisture and Heat

Experiments with rats.—In these experiments the effect of heat and moisture on some of the more toxic meals was studied in two series of tests. In the first series two treatments of the original sample of meal No. 14, which had proved very toxic in the earlier experiments, were compared with a mildly toxic cottonseed meal and with peanut meal. The two treatments applied to meal No. 14 consisted of stirring one batch of meal into cold water and another into boiling water followed by drying of each. Sufficient water was used to thoroughly wet the meal which was one and one-half times as much water as meal by weight. The meal was stirred into the water to form a wet dough and then dried in a forced draft oven at 70° C. Twelve hours were required for the drying process after which the meal was ground and mixed into the diets. In the second series of tests a highly toxic meal, which was obtained from the mill that had produced the original sample of meal No. 5[1], was given the hot water treatment and compared in rations for rats with cottonseed meal No. 16 of low toxicity and with peanut meal. The basal ration and general procedure was the same as in the previous rat experiments. Results of the two series of tests are shown in Table 3.

TABLE 3.—Comparison of the Effect of Raw and Heat Treated Cottonseed Meal on the Growth of Rats

SERIES 1	Peanut meal	Cottonseed meal			
		No. 16	No. 14	No. 14 heat treated	
				Cold H_2O	Hot H_2O
Free gossypol in raw meal, %		0.056	0.164		
No. rats per group	4	4	4	4	4
Duration of experiment, weeks	8	8	8	8	8
Mean initial wt. of rats, gms.	78	78	78	78	78
Mean gains, gms.	156	117	16[1]	109	113

SERIES 2	Peanut meal	Cottonseed meal		
		No. 16	No. 5C	No. 5C Heat treated
Free gossypol in raw meal, %		0.056	0.252	
No. rats per group	4	4	4	4
Duration of experiment, weeks	8	8	8	8
Mean initial wt. of rats, gms.	67	66	67	67
Mean gain, gms.	174	138	9[2]	125

[1]Average of three rats, one rat having died.
[2]Gain of one rat, the other three rats having died.

[1]This meal which was composited from each of 20 bags is referred to as No. 5C.

Examination of the results from the first series of tests shows that meal No. 14 proved very toxic when fed raw, one of the rats having died and the other three gaining an average of only 16 grams during the 8 week feeding period. Both the cold and hot water treatments resulted in marked improvement of this meal as a feed, producing mean gains of 109 grams and 113 grams respectively. These gains indicate some beneficial effect from the use of boiling water as compared with cold water but apparently the greatest influence was due to the application of heat during the drying process. The gains made as a result of the water and heat treatment were approximately equal to the mean gain of 117 grams made by the rats which received the mildly toxic meal No. 16 but were considerably below the mean gain of 156 grams produced by the rats that received peanut meal. Similar results were obtained in series 2. Meal No. 5C proved even more toxic than meal No. 14 since three of the rats died before the end of the feeding period and the fourth gained only 9 grams. Photographs of representative rats fed rations containing the treated and untreated meals in series 2 are shown in plates 3 and 4.

The condition of the rat shown in Plate 3 is typical of the rats fed for long periods on severely toxic meals. The other three rats in this group died. In addition to exhibiting diarrhea and an emaciated condition, they lost most of the hair around

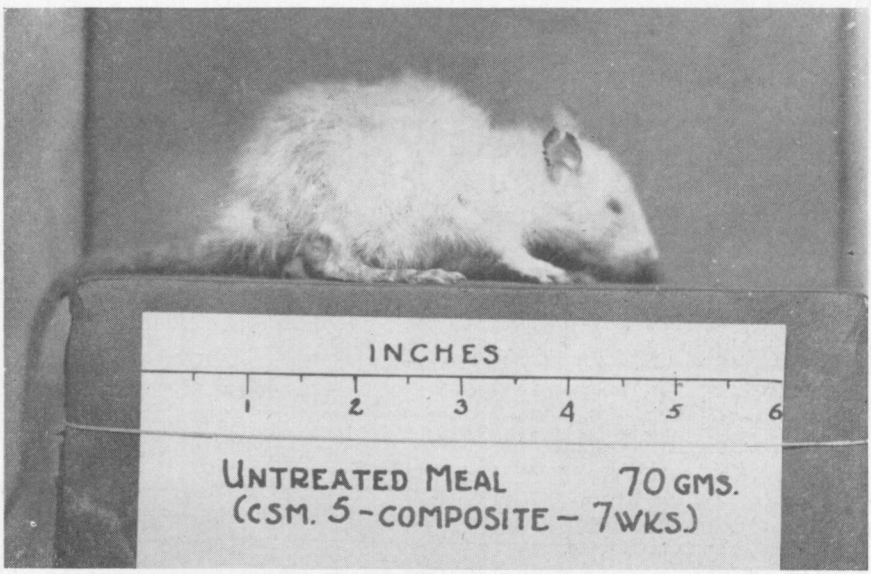

PLATE 3.—The diet of this rat included a cottonseed meal which contained 0.252% free gossypol.

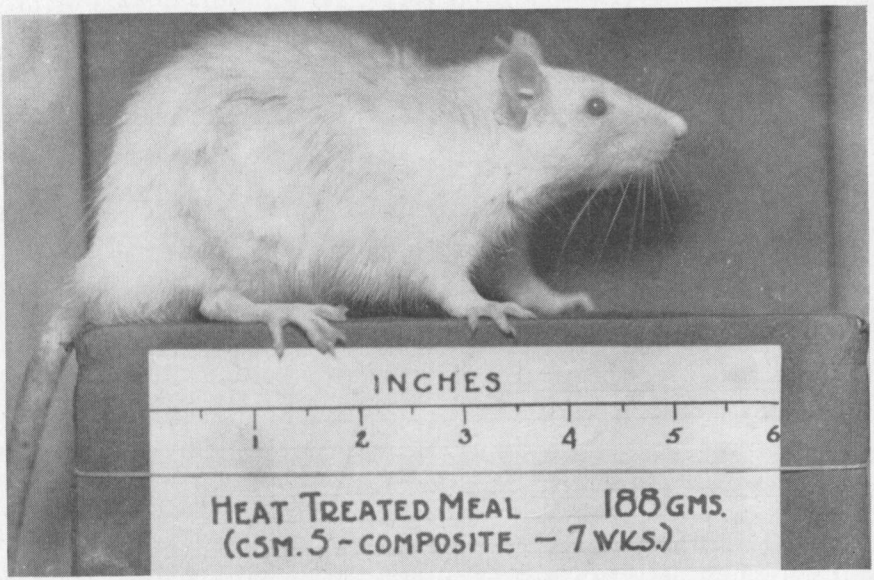

PLATE 4.—The diet of this rat included the same cottonseed meal as the diet fed the rat shown in Plate 3, except that the meal was treated with moisture and heat prior to feeding.

the head and neck. The groups of rats fed the wetted and heated meals appeared to be normal in every respect as illustrated by the rat shown in Plate 4.

Experiment with chicks.—Following the favorable results obtained in the reduction of toxicity of cottonseed meal by treatment with moisture and heat as indicated by the experiments with rats, a test was conducted to determine the response of chicks to meal similarly treated. The same ration and general procedure was used in this test as in the previous chick experiment. Cottonseed meal No. 5C was included in the ration for one group and meal from the same lot was boiled in two and one half times its weight of water, dried and included in the ration of a second group. A third or control group was fed the stock ration used by the Poultry Department of the Alabama Polytechnic Institute. It contained balanced proportions of animal and vegetable protein and was made up as follows:

Yellow corn (ground) 30 %, oats (ground) 16%, wheat bran 16%, wheat shorts 16%, meat scrap 10%, dried buttermilk 5%, alfalfa leaf meal 5%, cod liver oil 1%, salt 1%.

The results of this test are summarized in Table 4.

TABLE 4—Comparison of the Effect of Raw and Heat Treated Cottonseed Meal on the Growth and Mortality of White Leghorn Chicks.

Supplement	Cottonseed meal 5C raw	Cottonseed meal 5C heat-treated	Control ration[1]
Number of chicks beginning experiment	33	33	33
Mean initial weight, grams[2]	36	36	34
Mean gain, grams	167	224	351
Number deaths	8	3	0

[1]Stock ration given above.

[2]The experiment was begun when the chicks were one day old and continued six weeks.

It may be seen in Table 4 that the chicks fed the stock ration gained an average of 351 grams each during the six weeks period and no death losses occurred. During the same period the chicks fed the raw cottonseed meal gained an average of 167 grams with eight deaths while the chicks that received the heat treated meal gained an average of 224 grams with 3 deaths. These results show that the stock ration including a wider variety of grains and an animal source of protein was superior to the ration which included the heat treated cottonseed meal as the main source of protein. However, the treated meal was much more effective in producing growth and livability than was the raw meal. At the close of the experiment all the chicks that received the heat treated meal possessed a healthy appearance while seven of those that received the raw meal appeared to be near death.

The Toxicity of Cottonseed Meal for Hogs in Relation to the Gossypol Content and Heat Treatment of the Meal

When the studies with rats and chicks had progressed sufficiently to show that free gossypol was the major factor in the toxicity of cottonseed meal and that the toxicity can be reduced considerably or eliminated entirely by moisture and heat treatments, this information was used as the basis for an experiment with hogs. Six lots of 8 hogs each were fed rations containing the following: (1) peanut meal, (2) cottonseed meal of low free gossypol content, (3) cottonseed meal of medium free gossypol content, (4) cottonseed meal of high free gossypol content, (5) cottonseed meal of high free gossypol content heat treated in a crock with steam and (6) cottonseed meal of high free gossypol content boiled in a steel barrel over an open fire.

Each group of hogs had access to a quarter-acre dry lot and the basal concentrate mixture fed to the check group was as follows:

Yellow corn (ground) 70%, peanut meal (41% protein) 25 %, alfalfa leaf meal 5%.

The cottonseed meal to be tested was substituted for the peanut meal which furnished sufficient protein to balance corn for 30 pound pigs. This amount is excessive for older hogs but it was continued throughout the experiment to provide a margin of safety against variations in practical feeding. The hogs were fed all of the concentrate mixture they would consume, twice daily, and allowed access to the following mineral mixture:

Bone meal 38.80%, limestone 38.80%, salt 19.37%, iron oxide 2.80%, copper sulphate (anhydrous) 0.20%, potassium iodide 0.03%.

All of the meals except those that were heat treated were mixed with the basal ration in the dry form and sufficient amounts of each ration were prepared to last approximately two weeks. The heat treated meals were prepared by boiling in two and one half times their weights of water for 30 minutes. The steam heated meal was prepared daily and that which was boiled over an open fire was prepared twice weekly. Both meals were left in the containers in which they were cooked until just before feeding when portions of each were removed and mixed with the proper amount of basal ration.[1] Results of the test are shown in Table 5.

The relative influence of free and bound gossypol in causing cottonseed meal to be toxic to hogs is indicated by a comparison of the mortality data from Lots II, III, and IV. The number of deaths that occurred in each lot was closely related to the amount of free gossypol in the meal fed. The meal is fed in Lot II containing 0.062 per cent free gossypol resulted in one death; that in Lot III containing 0.107 per cent free gossypol resulted in two deaths; and that fed in Lot IV containing 0.252 per cent free gossypol caused six deaths. The number of days elapsing before the initial death occurred in each of these three lots was also in accordance with the free gossypol content of the meal. The influence of bound gossypol on the mortality rate and gains of these three lots was either non-existent or so slight that its effect was obscured by that of the free gossypol since the amount of bound gossypol in the three meals was not greatly different. Lot IV, in which most of the hogs died, was supplied a meal containing the least amount of bound gossypol.

Further evidence that the toxicity of cottonseed meal for hogs is due primarily to the free gossypol content and that the toxicity is considerably reduced or eliminated by heat and moisture treatments may be seen in a comparison of the results of Lots V and VI with those of the other lots. The meal fed to Lots V and VI was the same as that fed Lot IV except that it was

[1]The total feed the hogs were allowed, based on full feeding, was adjusted each day in the case of Lot V and twice weekly in the case of Lot VI and batches of dry meal representing 25 per cent of these amounts were weighed out for cooking. The prepared meal remained in the cooking container and the amount used at each feeding was approximated.

TABLE 5.—Effect of Feeding Hogs Cottonseed Meals Containing Various Levels of Gossypol and Cottonseed Meal Treated with Moisture and Heat.

Lot number	I	II	III	IV	V	VI[1]
		Cottonseed Meal				
Supplement	Peanut meal	No. 16C raw[2]	No. 4C raw[2]	No. 5C raw[2]	No. 5C heat treated[3]	No. 5C heat treated[4]
Duration of experiment, wks.	20	20	20	20	20	18
Free gossypol content, %		0.062	0.107	0.252	0.005	0.003
Bound gossypol content, %		0.788	0.961	0.722	0.761	
Number of pigs per lot	8	8	8	8	8	8
Mean initial weight, lbs.	34	33	34	34	34	44
Mean final weight, lbs.	202	172	154	105	211	213
Number deaths	0	1	2	6	0	0
Time on experiment prior to death, wks.		11	7, 17	5, 5, 6, 9, 11, 14		
Mean gain per pig, lbs.	168	139	120	71	177	169
Mean daily gain per pig, lbs.	1.19	1.05	.95	.90	1.26	1.34
Mean feed consumption per pig, lbs.	731	649	530	286	737	685
Mean feed consumption per cwt. gain, lbs.	435	466	443	400	416	405

[1]Pigs were not available to begin Lot VI until three weeks after the other lots were started.

[2]Gains and feed consumption of hogs that died were included up to the last weighing period before death.

[3]This treatment consisted of adding water to the meal and boiling it with steam in a crock churn for 30 minutes.

[4]This treatment consisted of adding water to the meal and boiling it in a steel barrel over an open fire for 30 minutes.

treated with water and heat previous to feeding. It may be seen that the free gossypol content of this meal was reduced from 0.252 to 0.005 per cent in the case of the meal treated for Lot V and to 0.003 per cent in that treated for Lot VI. Whereas, six of the hogs in Lot IV died, none of those in Lot V or VI died.

The average daily gain and feed required per unit of gain were more favorable in Lot V which was fed the steam heated meal than in Lot I which received peanut meal. The meal which was prepared by cooking in a barrel over an open fire and fed to Lot VI was included as a practical procedure that could be followed on farms. Pigs were not available to start this group with the others and it was necessary to begin it about three weeks later with pigs of larger initial weight. For these reasons it should be compared with the others in only a general way, but the results compare favorably with those from the steam heated cottonseed meal and peanut meal. The condition of all the hogs at the close of the experiment is shown in Plates 5 through 10.

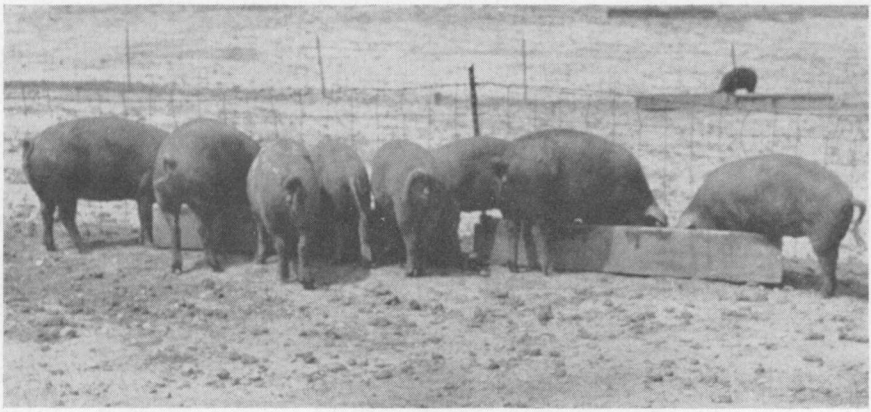

PLATE 5.—Lot I at the close of the experiment. These hogs were fed a ration supplemented with peanut meal. The average daily gain per hog was 1.19 pounds and the feed required per hundredweight of gain was 435 pounds. No deaths occurred in the lot.

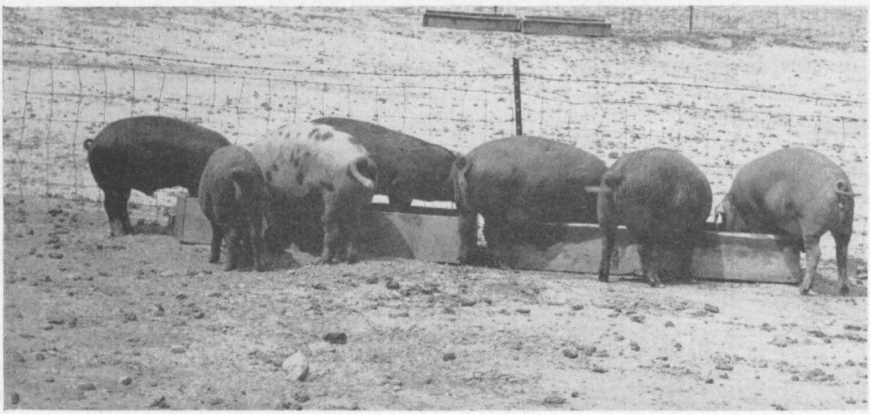

PLATE 6.—Lot II at the close of the experiment. These hogs were fed a ration supplemented with a cottonseed meal containing 0.062 per cent free gossypol and 0.788 per cent bound gossypol. The average daily gain per hog was 1.05 pounds and the feed required per hundred-weight of gain was 466 pounds. One death occurred in this lot.

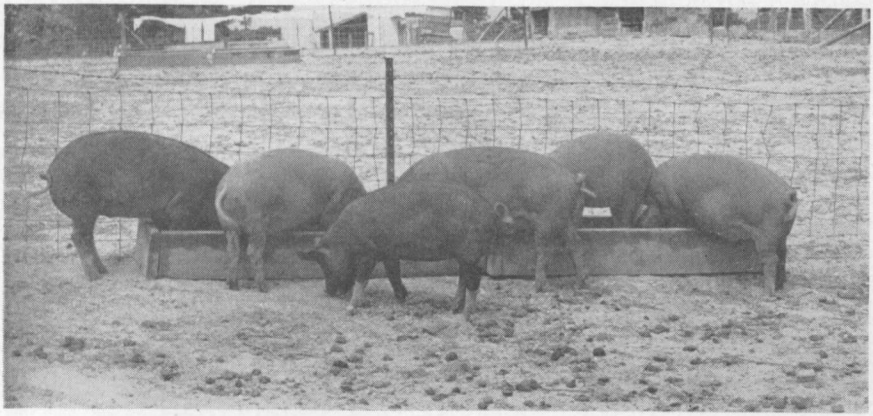

PLATE 7.—Lot III at the close of the experiment. These hogs were fed a ration supplemented with a cottonseed meal containing 0.107 per cent free gossypol and 0.961 per cent bound gossypol. The average daily gain per hog was 0.95 pounds and the feed required per hundred-weight of gain was 443 pounds. Two deaths occurred in this lot.

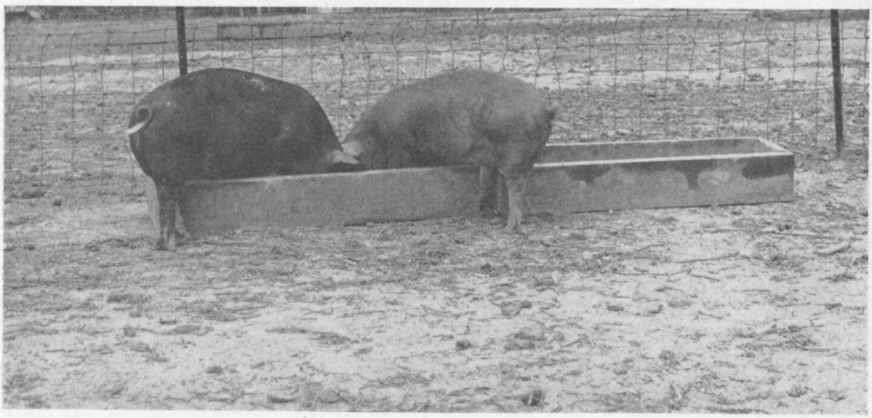

PLATE 8.—Lot IV at the close of the experiment. These hogs were fed a ration supplemented with cottonseed meal containing 0.252 per cent free gossypol and 0.722 per cent bound gossypol. The average daily gain per hog was 0.90 pounds and the feed required per hundred-weight of gain was 400 pounds. Six deaths occurred in this lot.

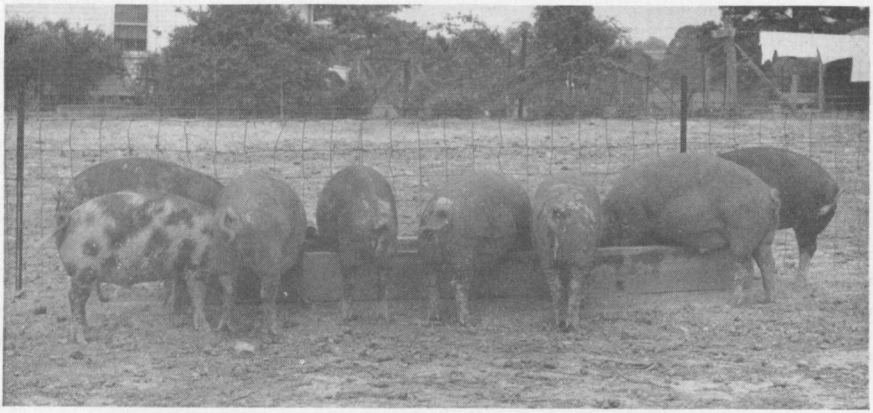

PLATE 9.—Lot V at the close of the experiment. These hogs were fed the same cottonseed meal as those shown in Plate 8 except that the meal was treated with water and heated with steam prior to feeding. The treated meal contained 0.005 per cent free gossypol and 0.761 per cent bound gossypol. The average daily gain was 1.26 pounds per hog and the feed required per hundredweight of gain was 416 pounds. No deaths occurred in this lot.

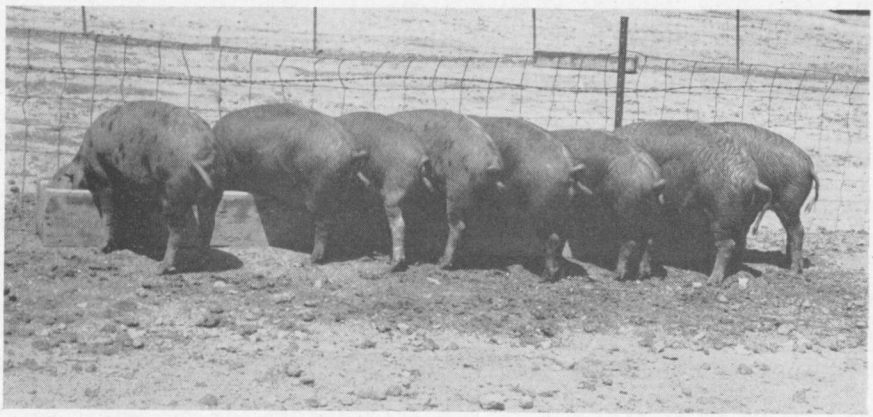

PLATE 10.—Lot VI at the close of the experiment. These hogs were fed the same cottonseed meal as those shown in Plate 8 except that meal was treated with water and cooked over an open fire prior to feeding. The treated meal contained 0.003 per cent free gossypol. The average daily gain was 1.34 pounds and the feed required per hundred-weight of gain was 405 pounds. No deaths occurred in this lot.

Laboratory and Oil Mill Studies of the Effect of Heat and Moisture on the Gossypol Content of Cottonseed Meal

Oil mill practices.—Processing data were obtained from the mills that had produced the original 16 samples of meals that were analyzed for free and bound gossypol. All of the mills use stack cookers except one, which uses a single compartment preheating cooker in connection with an expeller press. In general, the mill cookers are operated to raise the temperature of the incoming meats to a point between 212° F.[1] and 240° F. during the last 20 to 30 minutes, the entire process requiring from one to two hours. The degree of heat, time of heating and amount of moisture used varies not only from mill to mill, but also from time to time in the same mill. In general, the amount of water added to the cottonseed meats prior to cooking is based on the pressing condition and consequent degree of wetness of the meats issuing from the cooker. The latter condition is judged according to the appearance and feel of the cooked meats. In most of the mills the water is let into the meats from an ordinary faucet regulated by hand and as a result definite information regarding the amount of water used could not be obtained. Data concerning the degree of heat, time of heating and pressure used in the oil expelling process were obtained and are presented in Table 6 along with the gossypol analyses of the corresponding samples of meal.

In analyzing the data it should be remembered that the practices in each mill are changed from time to time, and that the amount of water used is a source of variation not disclosed by the table. The amount of pressure used in expelling the oil varies but little from mill to mill. Nine of the mills used 4000 pounds per square inch and the other five that furnished this information use either 4200 or 4500 pounds per square inch. The data indicate that the pressure applied to the cooked meats in expelling the oil has little or no influence on either the free or bound gossypol content of the meal. Examination of the data reveals no definite relationship between either the free or bound gossypol content of the meals and the maximum temperature at which the meats were cooked, but there is evidence of decrease in the free gossypol content of the meals as the cooking time is increased.

Meal No. 5 is particularly interesting in that the process of manufacture is distinctly different from the others. This meal had a bright greenish yellow color and a high protein content which by cottonseed meal standards would be rated the most desirable of all the meals for feeding livestock. As indicated in

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[1]The Fahrenheit scale is commonly used in the mills to express temperature readings and the temperature data concerning mill practices and the use of mill equipment are shown in degrees Fahrenheit.

TABLE 6.—Variation in the Gossypol Content of Cottonseed Meal With Relation to Oil Mill Processing Factors.

Meal No.	Free gossypol in meal	Bound gossypol in meal	Maximum cooking temperature	Total cooking time	Pressure used in expelling oil
	per cent[1]	per cent[1]	degrees F.	min.	lbs. sq. in.
15	0.055	0.836	230	130	4,000
16	0.056	0.778	240	96	4,000
9	0.058	1.041	230	130	4,000
12	0.060	0.819	233	105	4,000
7	0.067	0.852	240	60	4,000
11	0.068	0.933	220	105	not given
1	0.072	0.844	225	120	4,500
13	0.075	0.828	235	90	4,200
6	0.078	0.810	230	72	4,000
10	0.081	0.904	235	90	4,200
2	0.102	0.896	235	60	4,200
8	0.102	0.780	229	96	4,000
3	0.116	0.750	Information not given		
4	0.127	0.820	206	100	4,000
14	0.164	0.758	240	96	4,000
5	0.166	0.627	Estimated to be low	15 (est.)	not given (expeller process)

[1]Dry weight basis.

Table 6, the original sample had a free gossypol content of 0.166 per cent, the highest of all the samples tested, and additional lots purchased for feeding in the chick and hog experiments contained as much as 0.252 per cent free gossypol. Although exact information relative to the process used in making this meal could not be obtained, the cooker and press were observed in operation. It was estimated that the meats remained in the cooker about 15 minutes and the maximum temperature reached was considerably less than that in the other mills.

Laboratory Studies.—Information obtained from the mill data was used as a basis for laboratory studies to determine more specifically the effect of moisture and heat on the gossypol content of cottonseed meats and meal. Amounts of moisture and temperature ranges that have possibilities of use in present milling practices were studied with an oven and an autoclave. Samples of 100 grams of meats or meal were weighed into 800 ml. beakers and the percentage of moisture was adjusted to the desired levels. Heat and pressure treatments were then applied, after which the samples were dried under fans and gossypol analyses made. The interrelationship of amount of moisture, degree of heat, and duration of the heating period necessitated several series of tests.

The effects of pressure and moisture on gossypol in cottonseed meal are shown in Table 7.

TABLE 7.—Effect of Moisture With and Without Pressure on the Free Gossypol Content of Cottonseed Meats and Cottonseed Meal When the Degree of Heat is Held Constant

Series	Sample No.	Moisture content	Temperature of meats & meal[2]	Duration of temperature or pressure	Pressure	Free gossypol content[1]	
						Meats	Meal
		per cent	degrees C.	min.	lbs. per sq. in.	per cent	per cent
Raw meats and meal						0.641	0.219
Series I (oven treated)	1	7	105	60	None	0.555	0.059
	2	9	105	60	None	0.544	0.066
	3	13	105	60	None	0.396	0.044
	4	17	105	60	None	0.324	0.058
	5	21	105	60	None	0.298	0.032
Series II (oven treated)	6	30	105	15	None	0.216	0.036
	7	46	105	15	None	0.055	0.014
	8	63	105	15	None	0.013	0.015
Series III (autoclaved)	9	17	105	30	10	0.411	0.058
	10	30	105	30	10	0.200	0.027
	11	46	105	30	10	0.012	0.012
Series IV (autoclaved)	12	46	97	1	5	0.440	0.159
	13	46	97	15	5	0.255	0.100
	14	46	97	30	5	0.137	0.029
	15	46	105	1	10	0.289	0.130
	16	46	105	15	10	0.134	0.048

[1]Dry weight basis.

[2]Temperature of autoclave in series III and IV.

In these tests the temperature was regulated to approximately 105° C. which is intermediate in the range of temperatures employed by the mills. The length of time heat or pressure were applied was based on the milling practice of bringing cottonseed meats to the maximum temperature toward the latter part of the cooking period and holding them at that temperature for 20 to 30 minutes, as well as the length of time required to drive all the moisture from the material. As indicated in the table the free gossypol content of the raw meats and meal was 0.641 per cent and 0.219 per cent respectively.

Series I shows that the reduction of the free gossypol contents of both the meats and meal was accelerated by increasing the moisture content previous to heating. However, meats and meal containing 21 per cent moisture retained 0.298 and 0.032 per cent free gossypol respectively after heating at 105° C. for 60 minutes. The moisture was driven off and all the samples scorched before the cooking period was over indicating that no further reduction could be obtained by continued heating without the addition of moisture. In series II moisture levels of 30, 46 and 63 per cent were used. The meats and meal were heated to 105° C. as in series I but this temperature was held only 15 minutes, which was the time required to drive most of the water from the sample containing 30 per cent moisture. In this series, as in series I, the free gossypol content of both the meats and meal was reduced in proportion to the amount of moisture contained in the material treated. The free gossypol content was reduced to 0.014 per cent in the meal containing 46 per cent moisture and to 0.013 per cent in the meats containing 63 per cent moisture.

In series III are shown the results of constant pressure applied in an autoclave to meats and meals containing different amounts of moisture. In this series as in the previous ones the reduction of free gossypol content was in proportion to the moisture content. Practically all of the free gossypol was eliminated in both the meats and meal at the moisture level of 46 per cent.

Series IV shows the effect on the free gossypol content of meats and meal of high moisture content when pressures of 5 and 10 pounds were applied from 1 to 30 minutes. The free gossypol content of both the meats and meal was reduced in proportion to the amount of pressure and length of time it was applied but in none of the tests in these ranges was the free gossypol changed as completely as in Series III where 10 pounds of pressure was applied for 30 minutes.

The effects of temperature, time and method of heating on gossypol in cottonseed meal are shown in Table 8.

TABLE 8.—Effect of Temperature and Time and Method of Heating on the Free and Bound Gossypol Content of Cottonseed Meal and Meats of High Moisture Content.

Sample No.	Material treated	Moisture content	Treatment	Duration of treatment	Gossypol[2]	
					Free	Bound
		per cent		min.	per cent	per cent
1	Meal 5C		Raw		0.252	0.722
2	Meal 5C	53	Oven heated to 50° C.	30	0.116	0.835
3	Meal 5C	53	Oven heated to 75° C.	60	0.058	0.834
4	Meal 5C	53	Oven heated to 90° C.	90	0.025	0.787
5	Meal 5C	53	Oven heated to 97° C.	150	0.021	
6	Meal 5C	53	Oven heated to 102° C.	180	0.008	0.786
7	Meal 5C	67	Boiled in churn with steam	15	0.009	
8	Meal 5C	67	Boiled in churn with steam[1]	30	0.005	0.761
9	Meal 4, 5, 14C		Raw		0.125	
10	Meal 4, 5, 14C	67	Boiled in barrel over open fire[1]	1	0.009	
11	Meats		Raw		0.641	
12	Meats	46	Autoclaved at 10 lbs. pressure	30	0.012	0.423

[1]After treatment these samples were allowed to cool in the barrel before analyses were made. The cooling process required about five hours.

[2]Dry weight basis.

Meal No. 5C which contained 0.252 per cent free gossypol prior to heating was used in the series of oven treatments designated as samples 2, 3, 4, 5, and 6. These samples were heated simultaneously and one removed from the oven at each of the temperature levels shown in the table. The free gossypol content was reduced over half by the time the temperature of the meal reached 50° C. which required 30 minutes. Reduction continued with the increase in temperature and length of time the heat was applied. However, the rate of reduction became slower, particularly after the level of 0.058 per cent of free gossypol was reached, and at 97° C. after two and a half hours of cooking the meal still contained 0.021 per cent free gossypol. When the temperature was raised to 102° C., which required only 30 minutes additional heating, the free gossypol content was reduced to a trace. This indicates that the boiling point of water is a critical temperature for destruction or conversion of free gossypol. This is supported by the results of samples 10, 7 and 8, in which the free gossypol content was reduced to negligible amounts by boiling for 1 minute, 15 minutes, and 30 minutes respectively.

The bound gossypol content of the raw meal No. 5C was 0.722 per cent. The initial heat treatment of this meal increased its bound gossypol content, but not enough to account for the loss in free gossypol content. Continued treatment with heat lowered the bound gossypol slightly but after the temperature had reached 102° C. and the meal had been subjected to heat three hours, it still contained 0.786 per cent bound gossypol which was more than that in the raw meal. Resistance of bound gossypol to heat is further indicated in the amounts found in sample No. 8 and sample No. 12. Sample No. 8, boiled with steam for 30 minutes, contained 0.761 per cent bound gossypol, and the meats in sample No. 12, which were autoclaved 30 minutes at 10 pounds pressure, contained 0.423 per cent. In the latter case, however, as in the first treatment applied to meal No. 5C, considerable loss of either bound or free gossypol appears to have occurred. The raw meats contained 0.641 per cent free gossypol, but following autoclaving only 0.012 per cent free gossypol and 0.423 per cent bound gossypol were found.

Tests with oil mill equipment.—Following the laboratory studies of the effect of moisture and heat on the free gossypol content of cottonseed meal, oil mill equipment was used to prepare meals by processing cotton seed and expelling the oil as is regularly done in the oil mills and also by reprocessing commercial cottonseed meal.[1] In both cases a small pilot cooker was used first, followed by a larger cooker of approximately normal size. Both cookers were of the single compartment type with provision for cooking with or without steam pressure applied directly to the meats.

In the preparation of meal from cottonseed, delinted seed of the 1942 crop were obtained; the hulls were removed and the meats rolled for cooking. The meats were placed in the cooker and the desired amount of water was added. The cooker agitator was then started and the temperature of the meats raised to the desired level by letting steam into the jacket surrounding the cooker. The meats were cooked until the operator considered them dry enough for pressing, after which they were placed in a hydraulic press and pressure of 5000 lbs. per square inch applied. When the oil had been expelled, the cakes were removed from the press and ground into meal. The results of these tests are shown in Table 9.

When cottonseed meats containing 33.4 per cent moisture were cooked for 20 minutes at 270° F. in the pilot cooker, the

[1]The oil mill equipment used was made available by the Tennessee Agricultural Experiment Station and the meals prepared in cooperation with Mr. A. H. Morgan of that Station. Aid and advice was also received from Mr. J. O. Tankersley of the Tennessee Valley Authority.

TABLE 9.—Effect of Moisture and Length of Cooking Period on the Free Gossypol Content of Cottonseed Meals Prepared by Commercial Processes.

Meal sample	Type of cooker[1]	Cooking pressure	Cooking temperature	Moisture content	Cooking time	Free gossypol	Pressing condition
No.		lbs. sq. in.	degrees F.	per cent	minutes	per cent[2]	
1	Pilot	None	270	33.4	20	0.057	Crawled in press considerably.
2	Pilot	None	270	48.2	95	0.008	Crawled in press slightly.
3	Pilot	10 lbs. 20 min.	270	33.4	30	0.037	Crawled in press excessively.
4	Pilot	10 lbs. 20 min.	270	48.2	90	0.018	Crawled in press excessively.
5	Commercial	None	240	17.6	50	0.054	Pressed satisfactorily.
6	Commercial	None	240	24.5	70	0.038	Pressed satisfactorily.
7	Commercial	None	240	35.3	90	0.020	Crawled in press excessively.
8	Commercial	None	240	43.3	120	0.007	Crawled in press excessively.

[1]Both cookers were of the single compartment type that could be operated with or without pressure. The pilot cooker was a small experimental cooker which accommodated 25 pounds of meats and formed one press cake from each batch of meats. The commercial cooker approximated normal size and accommodated 300 pounds of meats which formed 12 press cakes.

[2]The raw meats used in preparing samples No. 1, 2, 3, and 4 contained 0.661 per cent free gossypol, and those used in preparing samples No. 5, 6, 7 and 8 contained 0.702 per cent free gossypol.

meal from these meats contained 0.057 per cent free gossypol. This is in contrast with the raw meats, which contained 0.661 per cent free gossypol, but the amount of free gossypol left is as much as that contained in some of the commercial meals. Sample No. 2, heated in the pilot cooker also and prepared from meats containing 48.2 per cent moisture had only a trace of free gossypol in it. The use of pressure along with heat and moisture appears to have been of little additional value as indicated by a comparison of samples 3 and 4 with samples 1 and 2.

Samples 5, 6, 7 and 8 were prepared in the large cooker at 240° F. All of these were heated with the cooker open, the differences being the moisture contents of the meats and the length of the cooking periods. The free gossypol contents of all the samples prepared in this large cooker ranged downward in proportion to the moisture content of the meat prior to cooking. In general, the reduction of free gossypol in the large cooker at 240° F. was greater than that in the pilot cooker at 270° F. This may be partially explained by the longer cooking period required to drive off the excess water at the lower temperature.

Examination of the column showing pressing condition reveals that only two of the samples pressed satisfactorily, Nos. 5 and 6 containing 17.6 and 24.5 per cent moisture respectively. Sample No. 8, the only sample prepared in the commercial cooker in which the free gossypol was reduced to a trace, was cooked at the highest temperature and for the longest period now employed by most of the mills. Since this treatment resulted in meats that crawled in the press, it is apparent that its use by the mills would necessitate further study. It was noted that some of the meats had a tendency to stick to the agitator and receive less of the cooking effect than the remainder of the material which suggests that improvement of the agitator methods may result in elimination of all the free gossypol by the use of an amount of moisture compatible with good pressing conditions. The results with sample 6, which pressed satisfactorily, indicate that sufficient moisture may be used with present mill equipment to produce cottonseed meal containing one half to two thirds as much free gossypol as the least amount found in any of the commercial meals that were analyzed. Changes in the milling procedure to allow the use of additional moisture and improvement of the agitator methods offer possibilities of further reduction in the free gossypol content of meals produced. Since the least toxic commercial meal analyzed in this investigation contained an amount of free gossypol that appeared to be near the toxicity threshhold for hogs when fed at a level of 25 per cent of the ration it seems likely that commercial meals may be produced that can be safely fed to hogs in sufficient amounts to balance corn or up to 20 per cent of the ration.

The reprocessed meal was prepared from raw commercial cottonseed meal containing 41 per cent protein. The raw meal was placed directly into the cookers and the water added. The agitator was then started and the wet meal raised to the temperature desired. Cooking was continued until, in the opinion of the operator, the moisture content of the meal was sufficiently low to prevent molding. The meal was then removed from the cooker, spread on the floor and allowed to dry several hours before sacking. The results of these tests are shown in Table 10.

TABLE 10.—Effect of Moisture, Heat and Length of Cooking Period on the Free Gossypol Content of Cottonseed Meal Reprocessed in Oil Mill Cookers.

Meal Sample number	Type of cooker[1]	Cooking temperature	Cooking time	Moisture content	Free gossypol content[2]
		degrees F.	minutes	per cent	
1	Pilot	240	10	23.8	0.042
2	Pilot	240	15	34.6	0.003
3	Pilot	240	20	49.4	0.003
4	Commercial	240	60	22.0	0.046
5	Commercial	240	79	33.2	0.033
6	Commercial	240	90	39.7	0.012

[1]Refer to foot notes Table 9.

[2]Dry weight basis. The meal reprocessed to produce samples 1, 2 and 3 contained 0.125 per cent free gossypol before treatment and that used to prepare samples 4, 5 and 6 contained 0.132 per cent free gossypol before treatment.

The raw meal reprocessed in the pilot cooker contained 0.125 per cent free gossypol prior to treatment. Raising the moisture content to 23.8 followed by cooking at 240° F. for 10 minutes, as was done with sample 1, reduced the free gossypol content to 0.042 per cent. Increasing the moisture content to 34.6 per cent, in the case of sample 2, followed by cooking at the same temperature for 15 minutes eliminated all but a trace of free gossypol. Samples containing similar moisture levels but cooked in the large cooker contained more free gossypol than those cooked in the pilot cooker even though the cooking period was considerably longer in the large cooker. This appears to be the result of higher heat efficiency in the small cooker. However, successive addition of moisture and lengthening of the cooking time in the large cooker resulted in further reduction in the amounts of free gossypol in the reprocessed meal. Practically all of the free gossypol was eliminated at 39.7 per cent moisture, as shown by sample No. 6. Further work is necessary before this method can be adopted commercially. More information is needed on the nutritive value of the reprocessed meal, particularly with regard to the effect of the heating process on the biological value of the meal proteins, as well as coordination

of the heat and moisture factors to avoid scorching or improper drying. Detoxification of meal by this method has certain advantages over that discussed above. It could be used during the idle season and therefore would involve very little if any change in the oil extraction procedure followed by the mills at present. Since cottonseed meal containing a low amount of free gossypol is of importance primarily for feeding hogs and chickens, it would be possible to produce reprocessed meals for these species and involve additional cost only in connection with the special meals.

SUMMARY

1. Cottonseed meals from 16 mills in Alabama were obtained and analyzed for their contents of free and bound gossypol. The free gossypol contents of the meals ranged from 0.055 to 0.252 per cent of the bound gossypol contents from 0.627 to 1.041 per cent.

2. Experiments with rats, chicks and hogs showed that the toxicity of these meals was due primarily to the free gossypol they contained.

3. The meal containing the least amount of free gossypol proved toxic to hogs when fed at a level of 25 per cent of the ration. Furthermore, the meal which contained the largest amount of free gossypol killed six out of eight hogs when fed in the commercial form, but showed no toxicity after the free gossypol was eliminated.

4. Oil mill and laboratory studies showed that the application of moisture and heat to cottonseed meats or meal reduces the amount of free gossypol they contain in proportion to the degree of heat, length of time the heat is applied and moisture content of the meats or meal. The most rapid elimination of free gossypol occurred at temperatures above 100° C. and moisture contents of the meats or meal ranging from 35 to 45 per cent. Free gossypol was practically eliminated from cottonseed meats and cottonseed meal by treatment at these levels of heat and moisture.

5. The effectiveness of present oil milling procedure in eliminating free gossypol from cottonseed meal may be greatly improved by the use of more moisture in the cooking process. The data indicate that the use of maximum temperatures and cooking time, as employed by the mills at present, with the addition of as much moisture as is compatible with satisfactory pressing conditions will produce meal containing considerably less free gossypol than any of the commercial meals analyzed. Additional changes in the cooking process may result in meal

that can be fed to hogs in sufficient amounts to supply the protein needed for balancing corn or up to 20 per cent of the ration.

6. Cottonseed meal containing little or no free gossypol was prepared by boiling commercial meal 30 minutes in approximately two and one half times its weight of water and leaving it in the container until cool. Meal treated in this manner was considerably improved for chicks and compared favorably with peanut meal as a protein supplement to corn for hogs at a level of 25 per cent of the ration.

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