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DIVISION OF CHEMISTRY

The Hardness of Cottonseed Cake as Related to its Suitability for Feeding

AGRICULTURAL AND MECHANICAL COLLEGE OF TEXAS
T. O. WALTON, President

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The best of the methods tested for determining the hardness of cottonseed cake as related to feeding of animals was considered to be the force required to crush it between flat surfaces. The average crushing strengths of the commercial cracked cake tested ranged from 127 lbs. to 3698 lbs., and those of samples of slab cake ranged from 710 lbs. to 3427 lbs. The average splitting or ball tests for the cracked cake varied from 92 lbs. to 607 lbs., and those for the slab cake varied from 186 lbs. to 493 lbs. The force required to break the molar teeth of cows was 1080 lbs. to 4550 lbs. with an average of 2165 lbs.; that required to break sheep teeth was from 420 lbs. to 1430 lbs. with an average of 1108 lbs.

Large specimens required more force than small ones. The shape of the specimen also affected the results. Cottonseed cake crushed by the "boot heel" had a crushing strength of less than 450 lbs. Moistening the cake with saliva during mastication no doubt reduces the force required to chew the cake, since soaking of specimens five minutes decreased the force required to crush them about one-third, while soaking them 20 minutes decreased the force required to about one-half. Feeding tests with cows and sheep showed that while the size, shape, and hardness of the cottonseed cake seemed to affect its consumption, some animals would eat the hard cake, while others might not eat relatively soft cake.

A tentative classification of cracked cottonseed cake with respect to its crushing strength was made upon the basis of the data presented. If the crushing strength is less than 400 lbs. the cake is classed as soft. If the crushing strength is between 401 and 1500 lbs. the cake is classed as medium hard. If the crushing strength is between 1501 lbs. and 2500 lbs. the cake is classed as hard. If the crushing strength is over 2500 lbs. the cake is classed as very hard.

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THE HARDNESS OF COTTONSEED CAKE AS RELATED TO ITS SUITABILITY FOR FEEDING.

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Cracked cottonseed cake is extensively used for the feeding of range animals in Texas and in other states. Its form enables it to be fed directly upon the ground, from which it is picked up by the animals. Both cows and sheep are fed in this way. It is used as a supplementary feed when pastures are not sufficiently good, especially in winter or in times of drouth.

Complaints are occasionally received by the Division of Feed Control Service that cracked cottonseed cake sold for feeding purposes is too hard for the animals to eat. There are differences of opinion as to what constitutes hardness in cake, and what kind of cake is best suited for feeding purposes. Some believe that the cake should be so soft that it can be crushed by the heel of a boot. Others think the cake should be so hard that an old cow may hold it in her mouth and suck it for a long time. Very soft cake may crumble when exposed to weather, or it may partly fall to pieces in the sack, resulting in a loss of the small particles. Hard cake may be entirely refused by some animals. Some feeders have complained of cake so hard it broke the teeth of the animals so that the feeding trough had a number of broken teeth in it.

Some cottonseed crushers claim that a soft cake can be made only at the expense of a reduced production of oil. In other words, the soft cake contains more oil than the hard cake. Some millers find it difficult to make a cake as soft as their customers desire and at the same time to do efficient milling in the extraction of the oil.

The term "hardness" as used in this publication is applied only to the suitability of the cake as food for the animal. The object of the work here reported was to study the hardness of cottonseed cake, to devise methods for measuring it, to ascertain the factors which affect it, and in other respects to contribute to a solution of the problem of hardness of cottonseed cake as related to its suitability for feeding purposes.

This publication is restricted to a study of the hardness of cottonseed cake as related to feeding. Data regarding other tests and experiments relating to the hardness of cottonseed cake from the manufacturing or technical point of view are to be presented in a subsequent publication.

MANUFACTURE OF COTTONSEED CAKE

In the manufacture of cottonseed cake, the cotton seed are first cleaned in order to remove as much as possible of the sand, dirt, bolls, leaves, and other foreign matter present. After the seeds have been reginned in order to remove part of the lint, they are cut open with as

little crushing as possible by a machine called a huller. The kernels are separated from the outside coat or hull by shakers and hull-beaters. Since the kernels vary in protein content, a sufficient amount of hulls is allowed to remain with the kernels to secure the desired protein content of the final product. The kernels are crushed between several sets of smooth steel rolls under high pressure and are then cooked at 212° to 235° F for approximately 1 hour. The kernels are formed into layers which are enclosed in woven hair press cloths and subjected to a pressure of approximately 4000 lbs. per square inch in order to expel as much oil as possible. The resulting press cakes are about 14x26 inches, ¾ inch thick, and weigh from 20 to 50 pounds. The cakes may be stored, exported, ground to a meal, or broken to form cracked cake. Cubes or cake made from cottonseed meal or other feed are also now on the market.

The quality of the cake is determined by its odor, color, and texture. The odor and color of the cake depend upon the quality of the seed and the proper control of the cooking process. Off-quality or sour seed will give cake which is off-quality in odor or color; excessive temperatures in the cooker may give a cake which is off-quality in color.

The sizes of cracked cottonseed cake as agreed on by the National Cottonseed Products Association, are as follows:

Nut-size cake should pass through 1½ inch round perforations and pass over ⅞ inch round perforations. It should be free from meal and from pea-size and pebble-size cake, and it should not contain in excess of 10 per cent of sheep-size cake.

Sheep-size cake should pass through ⅞ inch round perforations, and over ⅝ inch round perforations. It should be free from meal and pebble-size cake and should not contain in excess of 10 per cent of nut-size and pea-size cake.

Pea-size cake should pass through ⅝ inch round perforations, and over ⅜ inch round perforations. It should be free from meal and from nut-size and pebble-size cake, and it should not contain in excess of 10 per cent of sheep-size cake.

Pebble-size cake should consist of fine particles and small pieces of cottonseed cake capable of passing through ⅜ inch round perforations.

MASTICATION BY COWS AND SHEEP

It was thought possible that a consideration of the shape of the teeth, their strength, the manner in which the food is crushed and divided, and other similar processes of mastication by the animals which consume cracked cottonseed cake, might aid in deciding what constitutes hardness in cottonseed cake, and what kind of cake is suitable for feeding purposes.

Both sheep and cows are ruminants and have similar methods of mastication. The front teeth are sharp-edged cutting teeth while the

back teeth are wide, corrugated grinding teeth, often badly worn in older animals. The lower jaw is narrower than the upper jaw, so that the teeth on both sides never meet at the same time (Fig. 1). In mastication, the lower jaw is alternately pulled up and lowered. In pulling up the lower jaw the lower teeth are pressed against the upper

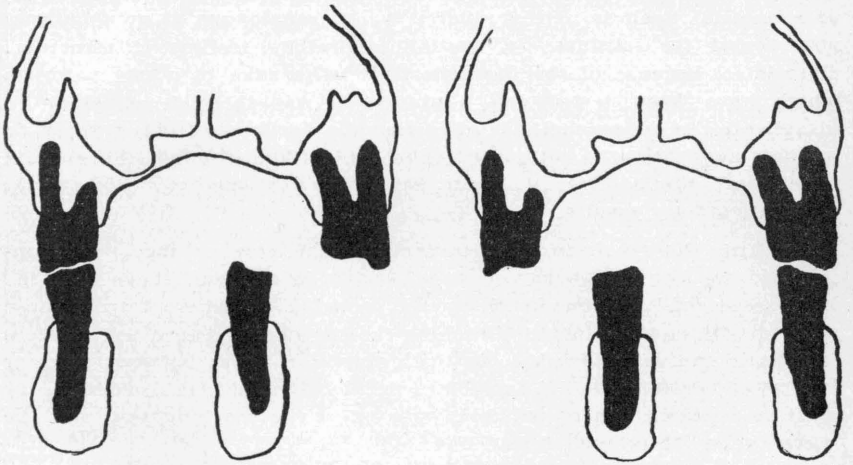

Figure 1. Position of the teeth of the cow in the jaw.

ones. This crushes the food. But at the same time the lower jaw moves laterally, which causes the food to be torn apart by attrition. The cheeks and the tongue prevent the food from escaping and also push the food back between the masticatory surfaces of the teeth. The food is moistened with saliva.

The strength and form of the lower jaw, the pattern and composition of the teeth and lower jaw, and the manner of movement of the lower jaw are closely related to the kind of natural food of the animal and to its manner of mastication.

While eating, the cow moves its lower jaw from 15 to 20 times in from 15 to 25 seconds, and the sheep moves its lower jaw from 5 to 12 times in from 15 to 25 seconds. The lateral movement of the lower jaw is more nearly described as a rotary motion with the center of motion the hinge of the jaw on that side in which mastication is taking place. (Figure 1). The food is not ground alternately upon one side of the jaws and then the other, but is usually ground upon one side for several minutes and then shifted to the other side. After the food is moistened, it goes to the first stomach. After a time, it is returned to the mouth and masticated some more.

METHODS USED IN THE TESTING OF THE CAKE

A number of methods are in use for testing the crushing strength, hardness, or similar properties of structural materials, such as concrete,

steel, and bricks. These methods have been considered in selecting a method which might be related to the hardness of cottonseed cake, as concerns its suitability for use by animals. The development of a method for testing the hardness of cottonseed cake involves several factors which are not met with in the ordinary routine testing of materials. The material itself is neither similar to nor analogous to any material now tested for hardness in routine laboratory testing of structural materials. Because of the dissimilarity of the cake to other materials which have been tested for hardness, it was thought necessary to investigate the known methods of testing the hardness of other materials in their application to cottonseed cake, and either to adopt the method which gave the best results or to develop a new method which would give satisfactory results.

Crushing the specimen between teeth of the cow or sheep was considered, but the teeth vary so considerably in size and shape that the results secured with one tooth would probably be different from those secured with another tooth. Crushing the specimen between flat surfaces is open to the objection that the teeth abrade or crush between more or less irregular surfaces. After some consideration, it was decided to try out two methods, one of which is here called the crushing test, and the other the splitting test, or ball test.

Crushing Test.

The crushing test is made by crushing the material between two plane surfaces which are parallel to each other and which move toward each other in such a manner that there is no rotary or twisting motion of the surfaces during the movement. It gives the value of the ultimate load a material will bear when no forces are involved which will induce bending or torsional stresses in the material. The crushing tests are made by machines of two types which give the same result.

The Olsen 60,000 lb.-testing machine was used on the initial tests in this study. This machine is so constructed that a movable platform is brought down upon a stationary weighing platform by means of screws operated by a gear. The stationary platform is connected to a graduated scale beam by means of a suitable system of levers. A movable counterweight on the scale beam is used to balance the applied load, and the amount of the load is determined by the position of the counterweight on the scale beam. The counterweight is moved along the scale beam by means of a long screw working in a half nut and turned by a crank and a system of pulleys. The beam and one of the pulleys of this system are graduated so that the loads can be measured in 10 lb. intervals.

The other machine used for making the crushing tests is the Southwark-Emery Hydraulic Testing machine. This machine has a movable piston which is operated by oil pressure from a rotary pump. The piston moves upward toward an adjustable weighing head. The force on this head is transferred to a diaphragm acting on oil in a closed

chamber. The pressure on the oil is measured by suitable gauges which are graduated at 20 lb. intervals. The Southwark-Emery machine is speedy and has been used in the great majority of the tests made.

Both of these machines are so designed that no torsional stresses are induced in the specimen being tested, and that, if the specimen is of the correct size and shape, no bending moment is applied to the specimen.

The Splitting, or Ball Test.

In the splitting, or ball test, a steel ball 15/32 inches in diameter is forced into the specimen of cake until the specimen fails by splitting. The force necessary to split the specimen is measured by the pressure recorded on the gauge of the Southwark-Emery testing machine. The ball used is set in a short section of steel shafting. This ball is imbedded in the shaft until just slightly less than ½ of the diameter of the ball is above the surface of the mounting. The mounting is then crimped in around the ball so that it is firmly held. The splitting test is made with the mounted ball in the testing machine and with the specimen to be tested placed on top of the ball so that the ball is approximately in the center of the specimen. The specimen is forced against the plane crushing surface of the weighing head of the testing machine until it fails and the pressure necessary to cause failure is recorded. The splitting test should give results that measure both the crushing strength of the cake and the cohesion of the particles along the weakest section. A test similar in many respects to the splitting test has been used for some time in making hardness tests of timber.

PREPARATION OF SAMPLE TO BE TESTED

Individual pieces of cracked cottonseed cake vary in size and shape. The specimens to be tested may be selected so as to represent either the average or hardest specimens. Since the hardest specimens are the ones most likely to be rejected by the cattle and are therefore most apparent to the purchaser, it is probably best to select for testing those pieces which appear to be the hardest.

Some of the work was done upon slab cake. At first, the specimens were sawed to the desired size. Later on, they were taken by means of a core drill. The same slab varies in hardness in different parts of its area. In comparative tests, therefore, a number of cores were taken from each slab and only the averages were used.

CRUSHING STRENGTH OF TEETH OF THE SHEEP AND THE COW

Apparently the hardness of the feed should not be greater than that of the teeth which are to be used to crush it. For this reason, it is desirable to have information regarding the crushing strength of the teeth of the sheep and of the cow.

A number of cow teeth and sheep teeth were secured from Armour and Company and from Swift and Company of Fort Worth. The back,

or crushing teeth were the only teeth tested. The cow teeth were mounted singly in short sections of 2-inch pipe by means of a mixture of equal parts of Portland cement and sand. These mountings were covered with moist sand and were allowed to harden for 7 days before testing. The sheep teeth were mounted in similar sections of 2-inch pipe, but because of the shortness of the teeth, Woods metal was used instead of cement. Both the sheep and cow teeth were mounted so that the plane of their crushing surface was perpendicular to the direction of the applied testing load. About 10 or 12 folds of Kraft paper were placed between the surface of the tooth and the load in order to distribute the load over the entire surface of the tooth. The teeth were tested in a Tinus-Olsen machine. The load required to break off any part of the tooth was taken to be the crushing strength. The crushing surfaces of the teeth were roughly corrugated and some of them were so worn that they had one or more sharp edges or points.

The manner of mounting the teeth and the manner of applying the load to the teeth are slightly different in these tests from conditions in the mouths of the animals. In the latter case, especially with very hard foods, the loads are applied at an angle of approximately 20° and are usually concentrated on the hard upstanding ridges of the teeth.

Table 1 shows the results of the tests on teeth of cows and sheep. It will be noticed that the load required to break the 35 cow teeth tested ranged from 1080 to 4550 pounds with an average of 2165 pounds. The

Table 1. Crushing tests of sheep and cow teeth (total load in lbs.)

Sheep teeth.....	420, 540, 800, 920, 960, 1000, 1010, 1020, 1050, 1090, 1100, 1160, 1160, 1220, 1220, 1230, 1240, 1300, 1320, 1320, 1360, 1360, 1360, 1430. Average—1108.
Cow teeth.....	1080, 1420, 1420, 1460, 1480, 1580, 1600, 1620, 1620, 1680, 1730, 1770, 1800, 1800, 1800, 1800, 1860, 1880, 2080, 2100, 2120, 2170, 2240, 2250, 2320, 2440, 2460, 2560, 2640, 2670, 2780, 3580, 3580, 3850, 4550. Average—2165.

load required to break the 24 sheep teeth tested varied from 420 to 1430 pounds with an average of 1108 pounds. By similar tests (discussed on a subsequent page), the crushing strength of samples of commercial cracked cake was found to vary from 65 to 8240 pounds with an average of 1328 pounds. It is evident that some of this cracked cake was harder than the teeth of both cow and sheep, and that teeth could be broken if the animals applied sufficient force in chewing. These tests will be considered further in connection with the classification of cracked cottonseed cake with respect to hardness.

RELATION OF SIZE AND SHAPE OF SPECIMEN TO HARDNESS

Each of the four sizes of cottonseed cake contains pieces of different size and shape. Since the crushing or cracking strength may depend upon the size and shape of the pieces selected, it is desirable to know something regarding the relation of size to the two tests selected.

The effect of the size and shape of various specimens of cottonseed cake is given in Table 2. On account of the difficulty of securing comparable specimens of cracked cake, these comparisons were made

Table 2. Relation of the shape, size, and thickness of squares to crushing strength of cottonseed cake

Laboratory number	Approximate shape	Approximate dimensions (inches)	Average crushing strength (lbs.)	Average Unit crushing strength (lbs. per sq. in.)	Average area of specimens (sq. in.)	Average thickness of specimens (in.)	Number of specimens averaged
38492-A	Rectangular	1 x2 x½	8566	4690	1.829	.62	24
	Rectangular	½x2 x½	5864	5120	1.146	.60	36
	Square	1 x1 x½	3591	3695	.972	.66	16
	Square	½x ½x½	880	2300	.382	.58	9

upon pieces cut from slab cake. The crushing strength depends upon the size of the piece of cake and decreases decidedly as the size of the specimen decreases.

The size of the test specimen greatly affects both the total crushing strength and the load per square inch required to crush the specimen. The smaller specimens of the same slab of cake are much more easily crushed than the larger ones. The results indicate that the shorter dimension of the crushed surface is the controlling factor. For instance, while the average area of the ½"x 2" test specimens is slightly larger than that of the 1"x 1" specimens, the load per square inch is larger for the latter than for the former.

The average thickness of the test specimens is also given in Table 2. It will be seen from these results that there is no direct relation between the crushing strength and the thickness of the specimens used. Because of the nature of the samples, the thickness of the specimen varies to so slight an extent that a complete investigation of this problem with specimens of widely varying thickness could not be made.

Table 3. Crushing tests on squares and cores of cottonseed cake of various sizes and shapes

Laboratory number	Approximate shape of specimen	Approximate size of specimen (inches)	Average crushing strength		Standard deviation		Number of specimens averaged
			Total (lbs.)	Unit (lbs. sq. in.)	Deviation	Per cent of average	
38492	Square	2 x2 x½	15500	3880	—	—	2
	Rectangular	2/2 x2 1/16x½	8570	4700	479	5.58	24
	Rectangular	9/16 x2 1/16x½	4300	3660	315	7.35	20
	Rectangular	9/16 x2 5/8x½	4150	3640	336	8.10	16
	Rectangular	1 1/16 x2 1/16x½	3950	3460	593	15.00	36
	Square	1 x1 x½	3470	3560	346	9.99	46
	Cylindrical	61/64 (dia) x½	2060	2888	254	12.33	24
	Square	33/64 x 5/8x½	930	2470	135	14.50	31

If slab cottonseed cake is to be tested, a specimen of standard size should be adopted. The difficulty involved in sawing any type of rectangular specimen to the exact size and shape desired, suggested the idea of using a core drill for cutting these specimens. A drill bit was constructed so that it would fit a Riehle core drill which is used for coring rock for test specimens. This drill cut a core 1 inch in diameter from any part of the cake desired and produced cores of uniform diameter.

A comparison of the results of the tests on cores of cottonseed cake with those of rectangular specimens of the same cake is shown in Table 3. It will be noticed that the standard deviation for the cores is higher than that for other types of specimens shown, but on account of the ease of preparation of the core it was decided to use the cores in testing the crushing strength of slab cottonseed cake.

RELATION OF CRUSHING STRENGTH TO CRUSHING BY THE HEEL OF THE BOOT

It has been the practice of some stockmen for years to test the hardness of cottonseed cake by placing a piece of cracked cake on a

Table 4. Comparison of "bootheel" test with ball and crushing tests

Type of specimens	"Bootheel" test	Crushing test	Ball test
	Results of test	(lbs.)	(lbs.)
1 inch cores	Not crushed	976	457
¾ inch cubes	Not crushed	1616	339
⅝ inch cubes	Not crushed	1145	259
½ inch cubes	Crushed	615	172

Table 5. Comparison of bootheel and crushing tests on cottonseed cake (12 pieces tested in each case)

Laboratory number	Type of specimen	Bootheel test		Crushing test
		Number of specimens crushed	Mean crushing strength of specimens not crushed by bootheel (lbs.)	Mean crushing strength (lbs.)
40718	1″ cores	0	1713	1596
40634–B	1″ cores	0	1211	1178
40640–B	1″ cores	0	808	793
40718	1″ squares	0	2197	2283
40640–B	1″ squares	0	1979	2051
40634–B	1″ squares	0	1733	1692
40718	¾″ squares	0	1125	1185
40640–B	¾″ squares	0	846	850
40634–B	¾″ squares	0	718	673
40718	½″ squares	8	543	485
40640–B	½″ squares	6	447	333
40634–B	½″ squares	12	....	229

concrete floor or slab, standing on it with the heel of one foot, and then spinning around with the full weight of the body on the test specimen or otherwise crushing it with the heel of the boot. If the specimen is crushed by this procedure, the stockman considers it soft enough for feeding, and if the specimen is not crushed by this test, he considers it too hard for feeding. For convenience, we term this the "bootheel test." This test, however, is indefinite because of the various degrees of roughness of the bootheel and the floor, and the various weights of the persons making the test. The size and the shape of the test specimens also affect the results.

Attempts were made to ascertain the relations between the bootheel test, the splitting test, and the crushing test. Cubes of different sizes and cores were cut from different samples of cake. These specimens were tested as follows: The first cube or core in the series was tested by the crushing test, the second was tested by means of the bootheel test, the third was crushed, the fourth was tested by the splitting test, the fifth was tested by means of the bootheel test, and the sixth was tested by the splitting test. Splitting or crushing tests thus were made on samples from both sides of a bootheel test, so that a comparison could be made of the relation of the crushing or the splitting test to the bootheel test.

The results of this work are shown in Tables 4 and 5. They indicate that a sample which meets the bootheel test must have a crushing test of less than 450 pounds. Most of the samples of commercial cracked cottonseed cake tested had average crushing strengths that exceeded 449 lbs. and thus could not meet the bootheel test.

CRUSHING WITH A TOOTH AS RELATED TO OTHER TESTS

Because of the similarity of the action of the ball test to the action of the cow's tooth upon cottonseed cake, it was decided to determine the relation between the ball test and the force necessary to crush a section of cottonseed cake with the grinding surface of a tooth as one of the

Table 6. Comparison of ball and tooth tests

	Number of cores tested	Average ball test (lbs.)	Average tooth test (lbs.)	Average ratio of ball to tooth test
Set 1	20	256	384	.666
Set 2	24	355	630	.564
Set 3	20	360	478	.753
Set 4	24	395	694	.570
Set 5	24	397	731	.543
Set 6	20	479	630	.760
Average		374	591	.643

crushing surfaces. A molar of a cow was mounted, as already described, for a crushing test of the tooth. Specimens of 24 one-inch cores were cut from the same cake and sanded smooth. The odd numbered cores

were used in making the ball test, and the even numbered cores were crushed by means of the tooth. The results are shown in Table 6.

In each case it requires more force to crush the cake by the tooth than to split it by means of the ball. The splitting action of the ball required only about 64% of the force required by the tooth to crush the cake.

It is to be expected that the "tooth" test would give higher figures than the ball test because of the distribution of the crushing forces over the greater area of the crushing surface of a tooth. The sharp ridges of enamel which corrugate the surface of a cow tooth, however, tend toward a very non-uniform distribution of the crushing forces over the surface of the tooth and this tendency will affect the relation of the ball and tooth tests.

Table 7 shows the results of a comparison of crushing and tooth tests. These tests were conducted in the same manner as the ball and tooth tests except that the crushing test was substituted for the ball test. The sample which has the highest crushing test gives the highest tooth test, and the sample with the lowest crushing test gives the lowest tooth test.

Table 7. Comparison of crushing and tooth tests on 24 one-inch cores

	40718		40633–C		40654	
	Crushing test (lbs.)	Tooth test (lbs.)	Crushing test (lbs.)	Tooth test (lbs.)	Crushing test (lbs.)	Tooth test (lbs.)
Average.....	1659	787	1244	610	2674	971

The tooth crushed the cake with about half as much force as was required by the compression test with two samples, and with about one-third as much force with the other sample, which was the highest. This will be taken into consideration in a subsequent discussion.

EFFECT OF MOISTURE UPON HARDNESS

Animals moisten their food with saliva while chewing it, and the cow swallows her food and then brings it back for further chewing. The moistening may result in a decrease in the effort required to crush the material. In order to test this point, samples soaked in water for various lengths of time were compared with the original samples.

Ten one-inch cores were cut from a sample of cottonseed cake and were numbered in order of their position in the series. The odd-numbered cores were tested by crushing in the usual manner, and the even-numbered cores were soaked in water for five minutes before testing. All loose disintegrated parts of the specimens were removed by rubbing with a cloth before the specimens were tested.

Other tests were made with the time of soaking 10 minutes, 20 minutes, and 30 minutes respectively. The average of the crushing tests

of six untreated specimens in each test was taken as a basis for comparison in determining the effect of soaking on the treated specimens.

The results of the tests are shown in Table 8. The force required to crush the cake decreases with the time of soaking for the entire time of

Table 8. Effect of soaking in water on crushing strength (in pounds) of cottonseed cake

Laboratory number	Type of specimen	Original (average)	Wet 5 minutes	Wet 10 minutes	Wet 20 minutes	Number of tests averaged
40650	1″ cores	965	692	603	433	10
40633–C	1″ cores	1399	1111	912	670	10
40633–G	1″ cores	1950	1647	1468	1121	10
40634–B	1″ cores	2138	1483	1166	1063	10
40633–A	1″ cores	2183	1649	1451	1258	10
40956–A	1″ cores	2507	1759	1434	1171	10
40654	1″ cores	2762	1728	1228	1003	10
38492–D	1″ squares	3733	2360	2300	1970	6
	Average.....	2205	1554	1320	1086	

the experiment, up to 20 minutes. The first five minutes has the greatest proportional effect upon the crushing strength. The decrease in crushing strength is about one-third in the first five minutes, and is more than one-half in 20 minutes.

VARIATIONS IN HARDNESS OF COMMERCIAL CRACKED CAKE

About 75 samples of cracked cottonseed cake received from various sources were tested by the ball test and the crushing test. The results given in Table 9 are the averages of six specimens of each sample.

The data in Table 9 show that the mean values for the crushing test vary from 127 lbs. to 3693 lbs., and that the variations from the smallest load to the greatest load were from 65 lbs. to 8240 lbs. Averages are given by groups of samples. These averages ranged from 208 to 3058 pounds.

The variation of the mean for the ball test on each sample was from 81 lbs. to 635 lbs. The variation from the smallest ball test to the greatest ball test was from 30 lbs. to 1130 lbs. Averages are also given by groups of samples. These averages varied from 121 to 390. The range of variation was much greater for the compression test than for the ball test.

VARIATIONS IN HARDNESS OF SLAB CAKE

Samples of slab cake secured from various sources were subjected to the two tests. The tests were made on cores of uniform size. Table 10 shows the values obtained for the compression tests and ball tests on cores from 56 samples of slab cake. The averages for the compression test vary from 710 lbs. to 3427 lbs., and the variation from smallest load

to greatest load is from 440 lbs. to 4300 lbs. There was thus a wide variation in the hardness of slab cake. The variation was not as great as it was with cracked cake, but this was partly due to the variation in the sizes and shapes of the pieces of cracked cake.

Table 9. Ball and crushing tests on nut-size cracked cake

Laboratory number	Origin of sample	Ball test on 6 specimens (lbs.)			Crushing test on 6 specimens (lbs.)		
		High	Low	Mean	High	Low	Mean
38500	Munger Cotton Oil Co., Mexia	170	50	92	180	90	127
38562	Luling Oil & Mfg. Co., Luling	170	70	90	310	70	148
40902	San Antonio Oil Works, San Antonio	115	45	81	325	65	197
41091	Gainesville Oil Mill, Gainesville	180	40	118	365	85	205
38493	La Grange	270	120	195	380	120	205
38491	H. G. Wicker, Converse, Texas	230	90	153	330	110	215
39765-C	Southland Cotton Oil Co., Waxahachie	135	65	96	465	110	223
38490	Brazos Valley Oil Mills, Waco	180	70	118	520	120	230
38575	Schulenburg Oil Mill, Schulenburg	240	70	127	450	130	262
40635	Dallas Oil and Ref. Co., Dallas	180	100	144	380	160	264
	Averages for preceding ten samples	187	72	121	371	106	208
60335					530	140	269
38765-A	Southland Cotton Oil Co., Waxahachie	250	90	151	420	145	271
38568	El Paso Industries, El Paso	210	110	158	330	190	280
39118*	Brownwood Cotton Oil Mill, Brownwood	160	40	106	410	105	296
38619	Richmond Cotton Oil Co., Richmond	410	130	253	390	230	310
38502	Farmers & Ginners Cotton Oil Co., Austin	200	80	127	520	180	325
38503	Waco Cotton Oil Co., Waco	190	30	118	510	220	350
38580	Ballinger Cotton Oil Co., Ballinger	270	120	190	440	270	351
39147	Nat'l Cottonseed Products Ass'n, Dallas	300	150	215	440	230	351
40641	Richmond Cotton Oil Co., Richmond	220	60	163	780	260	426
40644	Planters Cotton Oil Co., Inc., Ennis	220	70	151	805	250	427
39148	Industrial Cotton Oil Mill, Waco	320	180	261	905	285	570
	Averages for preceding eleven samples	250	96	172	541	215	360
38508	Memphis Cotton Oil Co., Memphis, Texas	320	150	217	1080	250	580
38489	Traders Cotton Oil Co., Ft. Worth	260	120	181	980	290	593
60336					1650	250	652
38561	Lockhart Oil & Gin Co., Lockhart	520	70	278	1370	200	670
40658	Clarksville Cotton Oil Co., Clarksville	225	90	131	1440	370	758
40914	Bonham Cotton Oil Co., Bonham	155	40	95	1230	450	944
38569	El Paso Cotton Industries, El Paso	360	190	277	1530	390	953
39070	Cottonseed Crushers Ass'n, Dallas	330	160	261	1600	580	958
40913	Austin Oil Mfg. Co., Austin	240	60	164	1220	465	963
40660	West Texas Cotton Oil Co., Seymour	410	140	294	1460	520	1049
40651	Quanah Cotton Oil Co., Quanah	400	240	348	1240	720	1008
40648	Fidelity Products Co., Houston	420	95	250	2640	380	1079
40657	East Texas Cotton Oil Co., Terrell	440	130	298	2600	570	1096
	Averages for preceding eleven samples	335	113	222	1559	406	877
39765-B	Southland Cotton Oil Co., Waxahachie	390	130	251	2120	580	1167
41092	Jayton Cotton Oil Mill, Jayton	260	90	158	1430	425	1190
40904	El Paso Cotton Industries, El Paso	180	60	99	2110	550	1256
38621	International Vegetable Oil Co., Houston	390	190	265	2060	560	1303
39071	Cottonseed Crushers Ass'n, Dallas	390	270	307	2780	750	1316
40649	South Texas Cotton Oil Co., Houston	440	170	323	2860	500	1339
38617	Vernon Cotton Oil Co., Vernon	390	130	286	1870	760	1343
40865	West Texas Cotton Oil Co., Abilene	355	90	222	1910	880	1356
38603	Lockney Cotton Oil Co., Lockney	650	290	415	2070	860	1365
40646	Southland Cotton Oil Co., Waxahachie	360	150	243	4020	420	1367
40625	Lubbock Cotton Oil Co., Lubbock	400	140	329	2500	740	1386
	Averages for preceding eleven samples	382	155	263	2339	639	1308

* Sheep size

Table 9. Ball and Crushing tests on nut-size cracked cake—(Continued)

Laboratory number	Origin of sample	Ball test on 6 specimens (lbs.)			Crushing test on 6 specimens (lbs.)		
		High	Low	Mean	High	Low	Mean
40645	Merchants & Planters Oil Co., Houston....	360	100	200	2340	620	1392
39067	South Texas Cotton Oil Co., Houston.....	570	370	457	1660	1125	1422
40659	Lamar Cotton Oil Co., Paris.....	660	60	381	2300	580	1428
39065	South Texas Cotton Oil Co., Houston.....	660	340	455	1950	580	1484
41090	Nacogdoches Oil Mill, Nacogdoches.....	435	130	272	2640	760	1523
40862	Mt. Pleasant Oil Mill, Mt. Pleasant.....	395	180	367	4660	780	1581
38565	San Marcos Oil Mill, San Marcos.....	500	280	401	2680	910	1598
40866	Brady Cotton Oil Co., Brady.....	430	180	276	2310	970	1696
38618	Quanah Cotton Oil Co., Quanah.....	450	250	371	2780	930	1721
40647	Travis Oil Mills, Corpus Christi.....	260	90	186	2540	965	1735
40919	Richmond Cotton Oil Co., Richmond.....	195	60	131	2840	865	1760
	Averages for next preceding eleven samples	446	185	318	2609	826	1576
40903	Gonzales Cotton Oil & Mfg. Co., Gonzales.	460	110	246	2760	980	1851
38620	Van Alstyne Cotton Oil Co., Van Alstyne..	370	190	296	2600	1250	1910
38574	San Angelo Cotton Oil Co., San Angelo....	630	360	453	2870	1470	1997
40719	Childress Cotton Oil Mill, Childress.....	620	210	395	3080	810	2030
41135	Quanah Cotton Oil Co., Quanah.....	420	220	329	2740	1220	2049
40863	Amarillo Cotton Oil Co., Amarillo.....	270	90	194	2950	1215	2175
38576	Sweetwater Cotton Oil Co., Sweetwater....	330	190	257	5610	460	2287
40931	West Texas Cotton Oil Co., Ballinger.....	305	130	247	3200	1410	2308
40900	Childress Cotton Oil Mill, Childress.....	430	80	221	5400	960	2368
40901	Bonham Cotton Oil & Mfg. Co., Bonham..	460	175	248	3345	1210	2378
38622	Quanah Coal & Grain Co., Quanah.....	350	200	273	8240	620	2383
	Averages for preceding samples.....	422	178	287	3890	1055	2158
40861	Alamo Cotton Oil Mill, San Antonio.....	460	150	309	6120	1140	2386
38577	Kimbell Oil Mill, Sherman.....	390	250	330	4350	660	2603
40702	San Marcos (Mr. Johnson).....	440	205	290	4320	1480	2608
40971	Chillicothe Cotton Oil Co., Chillicothe.....	450	260	397	3320	1790	2673
41492	Kelley & Batsell, Claude.....	680	240	437	4980	1120	2818
40642	Vernon Cotton Oil Co., Vernon.....	370	185	280	4250	1250	2889
40920	Rio Grande Valley Cotton Oil Co., Clint...	510	195	336	5650	1460	3053
38602	Planters Cotton Oil Co., Bonham.....	480	320	390	4480	2610	3181
40864	West Texas Cotton Oil Co., Plainview.....	460	180	345	4620	1880	3416
41089	Lubbock Cotton Oil Co., Lubbock.....	460	270	373	4760	1020	3518
38507	Oil Mill and Fertilizer Works, Henderson,..	1130	350	635	7410	1800	3618
38501	Marshall Cotton Oil Co., Marshall.....	880	470	607	5260	1880	3693
	Averages for preceding eleven samples....	548	258	390	4958	1543	3058

The variation of the averages for the ball test was from 186 lbs. to 538 lbs. The variation from the smallest ball test to the greatest ball test was from 145 lbs. to 670 lbs. The results of the ball tests did not vary as much as those of the crushing test.

Table 11 shows ball and crushing tests on 1 inch square specimens cut from 22 slabs of cottonseed cake. The mean values for the compression tests vary from 1606 lbs. to 3560 lbs., while the variation from the lowest crushing test to the highest crushing test on individual specimens are from 800 lbs. to 4280 lbs. These tests were run in conjunction with feeding and other tests and are tabulated here for comparisons of the ball and crushing tests on this type of specimen.

Table 10. Ball and crushing tests on one inch cores of cottonseed cake

Laboratory Number	Origin of sample	Ball test				Crushing test			
		Number of cores tested	High (lbs.)	Low (lbs.)	Average (lbs.)	Number of cores tested	High (lbs.)	Low (lbs.)	Average (lbs.)
39678-C	Traders Cotton Oil Mill, Ft. Worth...	12	210	155	186	12	815	560	710
39679-B	Palestine Oil Mill & Fertilizer Co., Palestine.....	12	540	385	460	12	1130	580	835
39678-B	Traders Cotton Oil Mill, Ft. Worth ...	12	320	160	221	12	1215	705	937
39680-A	Ballinger Cotton Oil Co., Ballinger....	12	485	345	425	12	1280	620	948
39680-B	Ballinger Cotton Oil Co., Ballinger.....	12	315	145	245	12	1540	440	963
40653	Lavaca Oil Mill, Hallettsville.....	25	340	170	262	25	1340	740	1027
40703	San Marcos Oil Mill, San Marcos.....	25	300	150	245	25	1560	870	1071
40650	Quanah Cotton Oil Co., Quanah.....	25	460	240	383	25	1500	600	1093
	Average of next preceding eight determinations.....		371	219	303		1298	639	948
40633-B	Bryan Cotton Oil Mill, Bryan.....	25	360	210	288	25	1560	670	1143
40634-A	Dallas Oil & Refg. Co., Dallas.....	25	425	290	371	25	1640	870	1169
40640-B	Richmond Cotton Oil Co., Richmond..	25	400	245	325	25	1400	775	1181
40643-C	Vernon Cotton Oil Co., Vernon.....	25	460	150	292	25	1620	720	1199
39678-A	Traders Cotton Oil Co., Ft. Worth....	12	395	235	323	12	1695	935	1216
40956-B	West Texas Cotton Oil Co., Ballinger..	25	490	320	396	25	1680	900	1226
40704	San Marcos Oil Mill, San Marcos.....	25	370	190	267	25	1510	920	1234
39680-C	Ballinger Cotton Oil Co., Ballinger....	12	450	295	370	12	1840	950	1234
	Average of next preceding eight determinations.....		419	272	329		1618	843	1200
40634-B	Dallas Oil & Rfg. Co., Dallas.....	25	480	250	393	25	1690	870	1245
40956-A	West Texas Cotton Oil Co., Ballinger..	25	520	300	398	25	1890	850	1266
40643-B	Vernon Cotton Oil Co., Vernon.....	25	480	250	369	25	1920	670	1322
39073-D	Bryan Cotton Oil Co., Bryan.....	12	420	310	369	12	1580	910	1331
39073-E	Bryan Cotton Oil Co., Bryan.....	12	500	240	404	12	1600	970	1338
40633-C	Bryan Cotton Oil Co., Bryan.....	25	370	200	291	25	1820	840	1405
39116	Rotan Cotton Oil Co., Rotan.....	12	620	330	436	12	1780	800	1412
40633-A	Bryan Cotton Oil Co., Bryan.....	25	450	295	364	25	2180	900	1415
	Average of next preceding eight determinations.....		480	272	378		1808	851	1342
40640-A	Richmond Cotton Oil Co., Richmond..	25	490	265	384	25	1830	1000	1416
40629	Taft Cotton Oil Co., Taft.....	25	520	250	420	25	1780	1000	1435
39117	Sweetwater Cotton Oil Co., Sweetwater	12	350	240	282	12	1880	910	1456
40633-E	Bryan Cotton Oil Co., Bryan.....	25	540	310	385	25	1930	1000	1533
40633-F	Bryan Cotton Oil Co., Bryan.....	25	390	195	291	25	1900	1300	1557
38944	Bryan Cotton Oil Co., Bryan.....	12	350	250	306	12	1950	1340	1561
40718	Childress Cotton Oil Mill, Childress...	25	540	350	445	25	1920	1040	1604
39057	Bryan Cotton Oil Co., Bryan.....	12	490	330	393	12	1850	1310	1613
	Average of next preceding eight determinations.....		459	274	363		1880	1113	1522
40624-B	Lubbock Cotton Oil Co., Lubbock....	25	570	235	431	25	2060	1190	1634
40633-H	Bryan Cotton Oil Co., Bryan.....	25	395	230	326	25	1910	1320	1655
40643-A	Vernon Cotton Oil Co., Vernon.....	25	540	320	411	25	2600	1250	1670
40624-A	Lubbock Cotton Oil Co., Lubbock....	25	590	250	447	25	2700	800	1679
40633-D	Bryan Cotton Oil Co., Bryan.....	25	460	315	391	25	2295	1120	1722
38592	Southland Cotton Oil Co., Waxahachie	12	380	340	360	12	2020	1470	1733
40633-G	Bryan Cotton Oil Co., Bryan.....	25	460	290	393	25	2160	1160	1796
39073-C	Bryan Cotton Oil Co., Bryan.....	12	420	270	346	12	2460	920	1809
	Average of next preceding eight determinations.....		477	281	394		2276	1154	1712

Table 10. Ball and crushing tests on one inch cores of cottonseed cake—(Continued)

Laboratory Number	Origin of sample	Ball test				Crushing test			
		Number of cores tested	High (lbs.)	Low (lbs.)	Average (lbs.)	Number of cores tested	High (lbs.)	Low (lbs.)	Average (lbs.)
39081-B	Traders Cotton Oil Co., Ft. Worth....	12	465	245	385	12	2550	1000	1854
39766-A	Peoples Oil Mill, Wharton.....	12	455	280	390	12	2400	1680	1876
38492-F	Bryan Cotton Oil Mill, Bryan.....	12	490	330	393	12	2170	1230	1890
38878-B	Richmond Cotton Oil Mill, Richmond	12	620	410	538	12	2210	1670	1900
38492-E	Bryan Cotton Oil Co., Bryan.....	12	590	360	462	12	2760	1410	1947
38492-D	Bryan Cotton Oil Co., Bryan.....	12	440	290	370	12	2530	1620	2061
39766	Peoples Oil Mill, Wharton.....	12	660	440	531	12	2665	1305	2068
38564-C	Mutual Cotton Oil Co., Ft. Worth....	12	420	310	343	12	2580	1875	2131
	Average of next preceding eight determinations.....		518	333	427		2483	1474	1966
38941	Bryan Cotton Oil Co., Bryan.....	12	520	350	440	12	2820	1320	2154
40654	Southland Cotton Oil Co., Waxahachie	25	670	400	524	25	3220	1540	2326
39111-B	Richmond Cotton Oil Co., Richmond..	0	.....	.....	.....	12	3280	2040	2492
38943	Bryan Cotton Oil Co., Bryan.....	12	630	370	511	12	3290	2440	2720
39679-A	Palestine Oil Mill and Fertilizer Co., Palestine.....	12	540	280	488	12	3820	1920	2768
38878-A	Richmond Cotton Oil Co., Richmond..	12	540	450	483	12	3510	2550	2835
38942	Bryan Cotton Oil Co., Bryan.....	12	550	290	480	12	4110	2330	2886
38570	Marshall Cotton Oil Co., Marshall....	12	540	415	493	12	4300	2920	3427
	Average of next preceding eight determinations.....		570	365	488		3581	2146	2731

Table 11. Ball and crushing tests on one inch squares of cottonseed cake

Laboratory number	Origin of sample	Ball test				Crushing test			
		Number of squares tested	High (lbs.)	Low (lbs.)	Average (lbs.)	Number of squares tested	High (lbs.)	Low (lbs.)	Average (lbs.)
38592	Southland Cotton Oil Co., Waxahachie	6	440	280	368	6	2390	800	1606
38581	Ballinger Cotton Oil Co., Ballinger...	6	570	330	453	6	2800	1020	1610
39081-A	Traders Oil Mill, Ft. Worth.....	36	600	330	472	17	2720	1680	1941
38564	Mutual Cottonseed Oil Mill, Ft. Worth	6	450	330	366	6	2210	1850	2045
38579	Taft Cotton Oil Mill, Taft.....	6	510	380	420	6	2320	1770	2090
39111-A	Richmond Cotton Oil Co., Richmond.	45	600	250	431	24	2610	1310	2114
38563	Palestine Oil Mill & Fertilizer Co., Palestine.....	6	770	440	638	6	2570	1510	2208
38575	Schulenburg Oil Mill, Schulenburg ...	6	450	280	387	6	2580	2010	2338
38570	Marshall Cotton Oil Co., Marshall...	6	730	570	648	6	3470	1890	2828
38492-D	Bryan Cotton Oil Co., Bryan.....	24	500	350	440	24	2680	3170	2890
38492-B	Bryan Cotton Oil Co., Bryan.....	0	–	–	–	66	3560	1610	2920
38492-C	Bryan Cotton Oil Co., Bryan.....	0	–	–	–	144	3610	2480	3027
38571	Marshall Cotton Oil Co., Marshall...	6	570	440	515	6	3870	2940	3373
38492-E	Bryan Cotton Oil Co., Bryan.....	35	710	430	539	46	4280	2230	3466
38492-A	Bryan Cotton Oil Co., Bryan.....	0	–	–	–	46	4020	3190	3560
39066	Houston Cotton Oil Mill, Houston...	19	350	200	289	0	–	–	–
39073	Bryan Cotton Oil Co., Bryan.....	36	280	390	334	0	–	–	–
39080-A	Lubbock Cotton Oil Co., Lubbock...	45	530	290	437	0	–	–	–
39080-B	Lubbock Cotton Oil Co., Lubbock...	36	620	280	449	0	–	–	–
38492-F	Bryan Cotton Oil Mill, Bryan.....	55	510	380	451	0	–	–	–
39878-A	Richmond Cotton Oil Co., Richmond.	58	760	245	633	0	–	–	–
39878-B	Richmond Cotton Oil Co., Richmond.	39	820	380	641	0	–	–	–

HARDNESS AS RELATED TO OPINION OF CRUSHERS AS TO QUALITY OF CAKE

Some of the mill operators expressed their opinions of the hardness of the samples sent. Samples are classified in Tables 12 and 13 according to the opinion of the operators and are compared with the results obtained by ball and crushing tests.

The results on the slab cake are given in Table 12. One slab classed as soft had an average crushing strength of 1027 pounds. Twelve slabs

Table 12. Slab cottonseed cake classified according to opinion of oil mill operators

Classification according to mill-operators			Ball test (lbs.)			Crushing test (lbs.)		
Soft	Not too hard	Hard	High	Low	Mean	High	Low	Mean
40653			340	170	262	1340	740	1027
	39680-A		485	345	425	1280	620	948
	39680-B		315	145	245	1540	440	963
	40650		460	240	383	1500	600	1093
	40643-C		460	150	292	1620	720	1199
	39680-C		450	295	370	1840	950	1234
	40643-B		480	250	369	1920	670	1322
	39116		620	330	436	1780	800	1412
	39117		350	240	282	1880	910	1456
	40718		540	350	445	1920	1340	1561
	40643-A		540	320	411	2600	1250	1670
	38618		450	250	371	2780	930	1721
	38564		420	310	343	2580	1875	2131
		38581	570	330	453	2800	1020	1610
		40654	670	400	524	3220	1540	2326

classed as not too hard had crushing strengths varying from 948 to 2131 pounds. Two slabs classed as hard had crushing strengths of from 1610 to 2326 pounds.

Table 13 shows the classification of the opinions regarding the cracked cake. Cracked cake classed as soft varied from 223 to 2287

Table 13. Cracked cottonseed cake classified according to the opinion of oil mill operators

Classification according to mill-operators			Ball test (lbs.)			Crushing test (lbs.)		
Soft	Not too hard	Hard	High	Low	Mean	High	Low	Mean
39765-C			135	65	96	465	110	223
39070			330	160	261	1600	580	958
38576			330	190	257	5610	460	2287
	39765-A		250	90	151	420	145	271
	38568		210	110	158	330	190	280
	38580		270	120	190	440	270	351
	38569		360	190	277	1530	390	953
	39765-B		390	130	251	2120	580	1167
	39071		390	270	307	2780	750	1316
	38565		500	280	401	2680	910	1598
	40642		370	185	280	4250	1250	2889
	38570		540	415	493	4300	2920	3427
		41292	680	240	437	4980	1120	2818

pounds crushing strength. That classed as not too hard varied from 271 to 3427 pounds in crushing strength. The sample classed as hard was crushed at 2818 pounds.

RELATION OF HARDNESS TO CONSUMPTION OF CRACKED COTTONSEED CAKE BY COWS

A series of experiments was conducted in order to determine the edibility of cottonseed cake of varying degrees of hardness. Four cows of the Division of Dairy Husbandry which had been on pasture for some time were placed in a dry lot. In a preliminary period, these cows were fed one pound of cracked cottonseed cake each day, and nothing else. A very small amount of mixed dairy feed was sprinkled over the cracked cake at each feeding during the first few days of the experiment in order to induce the cows to eat the cake. These cows were first fed on samples of soft cracked cake.

Two of the cows refused to eat the soft cracked cake, even though almost starved for several days, while the other two cows ate practically all of the soft cake fed to them. The two cows refusing the cake were returned to the pasture, and the remaining two cows were fed harder samples of cake. Table 14 shows the result of this first series of feedings. No hardness tests were run on the mixture of cake used in the first three feedings, as these feedings were for the purpose of separating the cows that refused the cake from those that would eat the cake and of getting them accustomed to the cake. The other tests are given in Table 14.

The feeding experiments were repeated at a later date with the results shown in Table 15. In these experiments, four cows were fed hard cake, and the cows that refused the cake were replaced by others until four cows were obtained that ate any of the samples fed to them. The

Table 14. Results of feeding one pound of cracked cottonseed cake to cows

Laboratory number	Cow No. 321 Age 7 years		Cow No. 196 Age 9 years		Ball test (lbs.)	Crushing test (lbs.)
	Amount consumed (lbs.)	Per cent consumed	Amount consumed (lbs.)	Per cent consumed		
Mixture	1.0	100	1.0	100	....	....
"	0.8	80	0.9	90	....	....
"	1.0	100	1.0	100	....	....
38620	....	....	1.0	100	296	1910
38576	1.0	100	....	....	257	2286
38501	0.4	40	....	....	607	3693
38507	....	....	0.6	60	635	3618
38501	0.5	50	....	....	607	3693
38507	....	....	0.5	50	635	3618
38574	0.5	50	0.7	70	453	1997
38580	1.0	100	1.0	100	190	351
38580	1.0	100	1.0	100	190	351
38565	1.0	100	1.0	100	401	1598

Table 15. Results of feeding cracked cottonseed cake to cows

Laboratory number	Size of pieces fed	Crushing test (lbs.)	Ball test (lbs.)	Cow No. 311 (Age 8 years)			Cow No. 196 (Age 9 years)			Cow No. 321 (Age 7 years)			Cow No. 184 (Age 11 years)		
				Amount fed (lbs.)	Amount consumed (lbs.)	Per cent consumed	Amount fed (lbs.)	Amount consumed (lbs.)	Per cent consumed	Amount fed (lbs.)	Amount consumed (lbs.)	Per cent consumed	Amount fed (lbs.)	Amount consumed (lbs.)	Per cent consumed
40642	1″ to 1½″	2888.7	280.4	2	0	0	2	2	100	2	2	100	2	0	00
40642	.....	.....	.....	2	0	0	2	2	100	2	2	100	2	.3	15
40642	.....	.....	.....	2	0	0	2	1.5	75	2	1	50	2	0	00
				Cow No. 335 (Age 6 years)											
40642	.....	.....	.....	2	.4	20	2	2	100	2	2	100	2	2	100
40642	.....	.....	.....	2	.6	30	2	2	100	2	2	100	2	1.8	90
40642	.....	.....	.....	2	0	00	2	2	100	2	2	100	2	1.1	55
40642	.....	.....	.....	2	0	00	2	2	100	2	2	100	2	0	00
40642	.....	.....	.....	2	1	50	.....	.....	.....	.....	.....	.....	2	1.6	80
				Cow No. 318 (Age 8 years)											
40642	.....	.....	.....	1	.8	40	.....	.....	.....	.....	.....	.....	.....	.....	.....
													Cow No. 193 (Age 12 years)		
40642	.....	.....	.....	2	1.7	85	.....	.....	.....	.....	.....	.....	1	1	100
40642	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	2	2	100
40702	¼″ to 2½″	2607.5	290.0	1	1	100	1	1	100	1	1	100	1	1	100
40861	½″ to 2″	2385.0	308.9	1	1	100	1	1	100	1	1	100	1	1	100
40861	¼″ to 2½″	2385.0	308.9	1	1	100	1	1	100	1	1	100	1	1	100
40863	¼″ to 2¼″	2175.4	193.8	1	1	100	1	1	100	1	1	100	1	1	100
40863	¼″ to 2″	3415.8	345.4	1	1	100	1	1	100	1	1	100	1	1	100
40900	¼″ to 1½″	2367.5	221.3	1	1	100	1	1	100	1	1	100	1	1	100
40901	½″ to 2″	2377.9	247.9	1	.8	80	1	1	100	1	1	100	1	1	100
40901	½″ to 2″	2377.9	247.9	1	.8	80	1	1	100	1	1	100	1	1	100
40901	½″ to 2¼″	2377.9	247.9	1	.8	80	1	1	100	1	1	100	1	1	100
40920	½″ to 2½″	3052.5	336.3	1	1	100	1	1	100	1	1	100	1	1	100

feeding of these cows continued for ten days on samples of varying degrees of hardness.

The results of these two experiments show that the consumption of cake is affected not so much by the hardness of the cake as by the idiosyncrasies of the animals. Some cows seem to be able and willing to eat some cottonseed cake of the hardest type, while others refused to eat the cake of the softest type.

RELATION OF HARDNESS TO CONSUMPTION BY COWS OF SQUARES CUT FROM SLAB CAKE

In this experiment, samples of slab cake were cut into 1″ and 1½″ squares, and these specimens were fed to the cows at the same time in the recorded proportions. It was noticed that some of the cows refused to eat any of the cake no matter how soft. Such cows were eliminated from the test, until at the end of the test only three cows were being fed on the cake. A few of the cows were eliminated only after they had refused to eat the cake until they became very weak from starvation. The cut specimens of slab cake were fed during and after the experiments in feeding cracked cake to the cows previously referred to.

Table 16 shows the result of feeding specimens of slab cake to cows. This table tends to show that the consumption of the specimens is influenced considerably by the size to which the specimens are cut.

The experiments in feeding cut specimens of slab cake were repeated later with the results shown in Table 17. When the feedings were again started, Cow 312 refused to eat the cut specimens of cake. She was returned to the herd and the feeding was continued with only three cows. No reason can be given for her refusal of the cake, for an inspection of Table 16 shows that in the previous tests she ate the hardest cake offered.

In these experiments, two cows that were accustomed to cracked cottonseed cake consumed specimens 1″ square of two of the hardest samples of cottonseed cake which were on hand.

A comparison of Tables 14, 15, 16, and 17 seems to indicate that the shape and size of the cake which is fed to the cows have much to do with the consumption of the cake by the cows.

RELATION OF HARDNESS TO CONSUMPTION OF COTTONSEED CAKE BY SHEEP

Four grown sheep kept in a pen were first fed 3¾ pounds of pebble-size cake at feeding in the evening. The cake was placed in a large trough in the pen and remained available to the sheep until the next feeding time. All of this cake was consumed. The second feeding consisted of 4 pounds of soft sheep size cake, and was conducted in the same manner as the first feeding. All of this cake was consumed before the next feeding. The feedings were continued with tested samples of

Table 16. Results of feeding squares of slab cottonseed cake to cows

Laboratory number	Feeding No.	Type of specimen	Ball test (lbs.)	Crushing test (lbs.)	Cow No. 179 (Age 11 years)			Cow No. 321 (Age 7 years)			Cow No. 312 (Age 8 years)			Cow No. 38 (Age 10 years)		
					Number of specimens fed	Number of specimens consumed	Per cent specimens consumed	Number of specimens fed	Number of specimens consumed	Per cent specimens consumed	Number of specimens fed	Number of specimens consumed	Per cent specimens consumed	Number of specimens fed	Number of specimens consumed	Per cent specimens consumed
39066	1	1″ square	320	.....	4	2	50	4	4	100	4	1	25	4	0	00
39066	2	1″ square	320	.....	4	4	100	4	4	100	4	4	100	4	4	100
39111-A	10	1″ square	431	2114	66	66	100	66	66	100	.....	.....	.....	66	66	100
39080-A	7	1″ square	437	.....	66	0	00	66	66	100	.....	.....	.....	66	66	100
39080-B	8	1″ square	449	.....	66	60	91	66	60	91	.....	.....	.....	66	66	100
38492-F	5	1″ square	451	.....	14	14	100	14	14	100	14	14	100	14	14	100
39081-A	9	1″ square	472	1941	60	52	87	60	32	53	.....	.....	.....	60	53	88
38492-E	3	1″ square	539	3466	3	2	67	3	3	100	3	0	00	3	0	00
39081-A	9	1½″ square	621	.....	8	0	00	8	6	75	.....	.....	.....	8	8	100
38878-A	6	1″ square	633	.....	15	0	00	15	15	100	15	15	100	15	15	100
39080-B	8	1½″ square	633	.....	10	0	00	10	0	00	.....	.....	.....	10	10	100
38878-B	4	1″ square	641	.....	10	2	20	10	4	40	10	10	100	10	1	10
39111-A	10	1½″ square	740	5292	6	0	00	6	0	00	.....	.....	.....	6	0	00
38878-B	4	1½″ square	1051	.....	6	0	00	6	0	00	6	6	100	6	0	00

Table 17. Feeding one inch square specimens of slab cottonseed cake to cows

Laboratory number	Cow No. 196 Age 9 years			Cow No. 321 Age 7 years			Ball test on 1"cores from same sample	Crushing test on 1" cores from same cake
	Amount fed (lbs.)	Amount consumed (lbs.)	Per cent consumed	Amount fed (lbs.)	Amount consumed (lbs.)	Per cent consumed		
38570	1.0	0.1	10	10	0.1	10	648	2828
38570	0.9	0.3	33	0.9	0.5	56	648	2828
38571	1.0	0.2	20	1.0	0.4	40	515	3373
38571	1.0	0.4	40	1.0	0.5	50	515	3373

cracked cake and cut specimens of slab cake, but the amount of cake fed at each feeding was reduced. One feeding, Sample No. 57421, was of a sample received with a complaint that the cake was too hard for sheep to eat, but the sheep used in this experiment readily consumed all

Table 18. Results of feeding cottonseed cake to sheep

Laboratory number	Type of cake	Feeding	Ball test (lbs.)	Crushing test (lbs.)	Amount fed (lbs.)	Amount consumed (lbs.)	Per cent consumed
.....	Pebble size.....	1	....	....	3.75	3.75	100
.....	Sheep size.....	2	....	....	4.0	4.0	100
38502	Sheep size.....	3	127	325	4.0	4.0	100
38568	Sheep size.....	5	158	280	4.0	4.0	100
38579	½" cut squares	7	163	1091	4.0	4.0	100
38621	Nut size.....	8	265	1303	0.75	0.75	100
38571	¾" cut cubes...	6	364	1354	4.0	2.3	58
38565	Nut size.....	9	401	1598	0.75	0.75	100

the cake. Table 18 shows the results of the tests. These results seem to indicate that the size and shape of the cake have a great influence on its consumption by the sheep. It will be noticed that, although the ¾" cut cubes are softer and have a lower compression test than some samples of cracked cake, these cubes were refused while the cracked cake was consumed.

CLASSIFICATION OF COTTONSEED CAKE WITH RESPECT TO HARDNESS

The preceding work has been used in making a tentative classification of cottonseed cake with respect to hardness.

As stated previously, two major factors govern the desired hardness of cottonseed cake. One of these factors is the excessive loss involved in handling very soft cake, and the other factor is the refusal of the animal to eat the cake which is too hard.

There is considerable difficulty in setting arbitrary limits to the hardness of the cake because of the difference in the demands of the feeders in various localities. According to letters which have been received on this subject, feeders in some localities demand a very soft cake, while

in other localities some feeders demand a hard cake because of the unjustified belief that the increased difficulty of mastication increases the digestion of the cake. Feeders in still other localities demand a cake that will not crumble but will cause no difficulty in mastication.

Cottonseed cake may be arbitrarily classed with respect to hardness as soft, medium, hard, and very hard cake. Some soft cake may have excessive losses in feeding; medium cake may be considered as cake which is firm, but which will cause no difficulty in mastication; hard cake may be considered as cake which may cause difficulty in mastication, but which will be entirely consumed by some animals; and very hard cake may be considered as cake which may be too hard for many animals to consume.

The data presented in the preceding pages were used to classify cottonseed cake with respect to its hardness on the basis of the crushing test. The crushing test seems better suited to this purpose than the ball test for several reasons. One reason is that it shows a wider range in the hardness of the various samples of cake. This greater spread enables a better classification to be made. It also seems to be more closely related to the hardness of the cake than does the ball or splitting test.

Taking all the data into consideration, we have made the following tentative classification of cottonseed cake with respect to its crushing strength:

Soft	0 - 400 lbs.
Medium Hard	401 - 1500 lbs.
Hard	1501 - 2500 lbs.
Very hard	Above 2501 lbs.

This classification is tentative, but should serve as a basis for further study, as well as for practical use. The reasons for adopting this classification are given below. Soft cake is considered to be that which will fully meet the bootheel test (Table 5) of 450 pounds, and is softer than any of the teeth of the sheep, one of which was crushed at 420 pounds. Medium hard cake is considered to have a crushing strength less than practically all of the cow teeth (Table 1). The mean crushing strength of cracked cake (Table 2) and slab cake (Table 13) which, in the opinion of the mill operators, was not too hard, is in the majority of the samples less than the 1500 pounds maximum taken for medium hard cake, though some specimens are harder than others. The very hard cake has a crushing strength greater than some of the cow teeth examined.

Only 11 of the 76 samples of cracked cake have a mean higher crushing strength than the 2500 pounds, although about 30 of the samples contain specimens having a crushing strength of over 2500 pounds.

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SUMMARY

The force required to crush the cottonseed cake between flat surfaces was adopted as the best method of ascertaining the hardness of cottonseed cake as related to its consumption by animals.

The average crushing tests of samples of cracked cottonseed cake ranged from 127 lbs. to 3698 lbs., and of samples of slab cake from 710 lbs. to 3427 lbs. The average ball tests for the cracked cake varied from 92 lbs. to 607 lbs., and for the slab cake from 186 lbs. to 493 lbs.

Crushing tests for the molar teeth of cows ranged from 1080 lbs. to 4550 lbs. with an average of 2165 pounds. For sheep, they ranged from 420 lbs. to 1430 lbs. with an average of 1108 pounds.

The size and shape of the specimen materially affected the crushing strength. The smaller pieces had lower crushing strengths.

The so-called "bootheel test" used by stockmen to determine the hardness of cottonseed cake crushed specimens which had a crushing strength of less than 450 lbs.

Soaking specimens of cottonseed cake in water materially decreased their crushing strength. The decrease was about one-third for the first five minutes of soaking and about one-half for 20 minutes of soaking. Moistening with saliva therefore decreases the force required to crush the cake in the mouth of the animal.

Feeding tests with cows and sheep showed that while the size, shape, and hardness of the cottonseed cake seemed to have some effect, the idiosyncrasies of the animals themselves seem to be the controlling factor in the consumption of cottonseed cake by the animals. Some cows would eat hard cake readily, while other cows could hardly be induced to eat soft cake.

Cake with a crushing strength of less than 400 pounds is tentatively classed as soft for cows; cake with a crushing strength of from 400 to 1500 pounds is tentatively classed as medium hard for cows; cake with a crushing strength of 1501 to 2500 pounds is classed as hard; and that with a crushing strength of over 2500 pounds is classed as very hard.