ROASTED COTTONSEED FOR DAIRY COWS — RESEARCH REVIEW

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Introduction

Heat causes a chemical reaction to occur between the protein and sugars present in feedstuffs. This results in the formation of protein-sugar complexes known as Maillard products (Eichner and Wolf, 1983). The extent of these reactions is influenced by the temperature, duration of heating, amount of sugar present, and moisture content. Fortunately the latter two variables do not fluctuate so much with cottonseed, so the two variables having the most impact on formation of Mallard products are temperature and duration of heating.

Heat treatment of protein can increase the amount of protein escaping degradation in the rumen. Too little heat, however, results in poorly protected protein. Too much heat can cause the formation of Maillard products that cannot be utilized in the intestine. This "heat damaged" protein passes all the way through the gut. Thus, it is essential to apply an appropriate amount of heat to obtain a high quality "by-pass" protein.

Heat treatment of soybeans for lactating dairy cows has grown rapidly in the United States, with one estimate suggesting that approximately 500,000 metric tons of full fat soybeans were heated in 1993 (unpublished survey, Satter and Dhiman). Although cottonseed contains about 60% as much protein as soybeans, and protein quality is not as good because of lower lysine content, cottonseed enjoys a prominent role in many dairy diets as a source of energy, protein, and fiber.

Several studies have shown that heat treatment of cottonseed can reduce protein degradation in vitro and in situ (Tagari, Pena, Satter, 1986; Stutts et al, 1988) as well as in vivo (Pena et al, 1986). The studies of Tagari et al (1986) and Stutts et al (1988) demonstrated that protein degradation decreased as temperature increased, but there was no effort made in these studies to identify the optimum heat treatment.

This paper will review several research projects that were funded by Cotton Incorporated in an effort to establish whether properly heat-treated cottonseed could support increased milk production when fed to lactation dairy cows.

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Trial I

The objective of Trial I was to identify the optimum heating conditions for cottonseed to improve its value as a supplement for lactating dairy cows. Optimum conditions for heat processing had to be established before proceeding with large scale lactation studies. All preliminary research to establish the proper roasting conditions was conducted by L.D. Satter at the USDA-ARS, U.S. Dairy Forage Research Center at the University of Wisconsin, Madison.

Linted cottonseed was roasted in a Jet Pro roaster to give a variety of heat exposures. In addition to raw or unheated cottonseed, which served as a control, cottonseed was heated and in some cases steeped or conditioned for an additional 30 minutes. The temperature of linted cottonseed leaving the roaster, and the time of steeping for each of the treatments was as follows:

Unheated control, 134º C - 0 min steep, 134º C - 30 min, 141º C - 0 min, 141º C - 30 min, 150º C - 0 min, 150º C - 30 min, 155º C - 0 min, 155º C - 30 min, 159º C - 0 min, 159º C - 30 min, 176º C - 0 min, 176º C - 30 min, 210º C - 0 min, and 210º C - 30 min.
The seeds were cooled immediately after roasting if they were not steeped, or immediately after steeping if they went through the steeping process.

The amount of undegraded intake protein (UIP) is the same as by-pass protein, and is a measure of the amount of protein escaping degradation by rumen microbes. This was measured by the procedure of Broderick (1987), and involves incubation of the cottonseed with a preparation of rumen bacteria. The amount of protein degraded by the bacteria during the incubation is measured. This laboratory procedure simulates what happens in the rumen, and provides an estimate of the amount of by-pass protein that might be measured in a cow. The amount of by-pass protein (UIP) increases with heating, but the increase is quite modest until a temperature of 159º C - 30 min steep is achieved. As heat exposure increased beyond this point, UIP increases sharply.

As heat exposure increases, and as by-pass protein is increased, lysine availability in the intestine can be reduced. Lysine availability was measured by the dinitroflorobenzene technique (AOAC, 1984). The available lysine expressed as mg of lysine per g of nitrogen, decreased a modest amount until a temperature of 159 C - 30 min was reached, and then lysine availability plummeted. Therefore, temperatures in excess of 159 C - 30 min resulted in considerable heat damage to the protein.

The amount of lysine escaping degradation <u>and</u> available in the small intestine is termed postruminal available lysine (PRAL). It is obtained by multiplying the amount of available lysine by the fraction (percentage) of UIP (by-pass protein). The amount of PRAL increased a modest amount and seemed to plateau between 141º C - 0 min and 159º C - 30 min. The objective of heat treatment is to maximize the amount of postruminal available lysine, because that is the amount of lysine that is available for absorption from the small intestine.

Roasting and steeping was repeated as follows:

Unheated control, 136º C - 0 min, 136º C - 30 min, 146º C - 0 min, 146º C - 30 min, 148º C - 0 min, 148º C - 30 min, 154º C - 0 min, 154º C - 30 min, 160º C - 0 min, 160º C - 30 min, 171º C - 0 min, and 171º C - 30 min.

The estimated increase in PRAL, based on the laboratory procedures used, were relatively modest and somewhat smaller than was achieved with similar heat treatment of soybeans. The laboratory methods available for estimating protein degradation in the rumen are crude, and at best give relative approximations. Based on the measures used in Part A of Trial I, it appeared that the optimal heat treatment was somewhere between 140º C and 160º C, and that the supply of lysine presented to the small intestine increased by about 33%.

Trial II

The purpose of Trial II was to measure the extent of protein degradation when heated cottonseed was incubated with rumen micro-organisms and to chemically measure the amount of available lysine in heated cottonseed samples. Both linted and delinted cottonseed were roasted in a Jet-Pro Roaster (Jet-Pro Co., 1117 Santa Fe, Atchison, KS 66002) to achieve a variety of heat exposures. Some of the samples were cooled immediately after roasting, others were moved directly from the roaster to 55 gallon drums for 30 minutes of steeping or conditioning before cooling. The temperature of cottonseed in the steeping barrels was typically 10-20º F cooler than the exit temperature from the roaster. This cooling was due primarily to heat of evaporation of water which was lost during steeping. Consequently, the temperature of cottonseed during steeping or conditioning was lower than the roasting temperature but changed very little during steeping after the initial drop in temperature.

Results for linted cottonseed and delinted cottonseed will be discussed together, as treatments for the two types of cottonseed paralleled one another. Rumen degraded protein ("by-pass" protein), as measured by the procedure of Broderick (1987), increased from about 23% in the unheated cottonseed to about 40% at a temperature of about 320º F and steeping time of 30 min. Holding the hot cottonseed for 30 min always increased the amount of by-pass protein, but the increase was small. Steeping soybeans for 30 min seemed to have a greater effect on by-pass protein when measured by the same technique (Hsu and Satter, 1995).

Available lysine started to decrease as temperature approached 286º F, and decreased very rapidly as temperatures exceeded 320º F. Cottonseed heated to 410º F and steeped for 30 min had virtually no available lysine.

The amount of lysine escaping microbial degradation and yet available in the intestine, termed postruminal available lysine, increased from about 46 mg/g N in the unheated cottonseed to approximately 60-63 mg/g N in some of the moderately heated cottonseed samples. Steeping was without effect on postruminal available lysine as determined by the procedures used in this experiment. The amount of postruminal available lysine seemed to plateau between 277º F and 318º F.

The increase in postruminal available lysine, based on the procedures used, was relatively modest and somewhat smaller than was achieved with similar heat treatment of soybeans (Hsu and Satter, 1995). The laboratory methods available for estimating protein degradation in the rumen are crude, and at best give relative approximations. Based on the measures used in this experiment, it appears that the optimal temperature for heat treatment of cottonseed is somewhere between 277º F and 318º F, and that the supply of lysine presented to the small intestine is increased by about 33% with this heat treatment.

Trial III

Selected linted (unheated control, 286º F - 30 min, 311º F - 30 min, 318º F - 30 min, 349º F - 0 min) and delinted (unheated control, 295º F - 30 min, 309º F - 30 min, 320º F - 0 min, 340º F - 0 min) cottonseed samples were ground through a 2mm Wiley mill screen. Five gram samples of ground cottonseed were placed in Dacron® bags, and the bags were suspended in the rumen of two ruminal cannulated Holstein cows fed free choice twice daily a total mixed ration composed of (dry matter [DM] basis) 50% alfalfa silage, 37% ground corn, 11.5% soybean meal, and 1.5% mineral and vitamin mix. Bags were inserted into the rumen and allowed to incubate for 0,1,2,4,8,16,32, or 48 h. A description of the Dacron® bag procedure used is given by Weakley et al (1983). A non-linear kinetic digestion model (Mertens and Loften, 1980) was used with the Marquart method of SAS (SAS, 1985) to estimate crude protein degradation rate. A fractional passage rate of 0.7 h was used to estimate rumen undegraded protein using the relationship described by Orskov and McDonald (1979). Treatments were compared by least significant difference (SAS, 1985) after a significant F test.

Protein degradation rate and calculated rumen undegraded protein values were evaluated. As expected, rumen undegraded protein increased as the amount of heat exposure increased. The amount of rumen undegraded protein in the heated cottonseed samples was about 2 to 4 times greater than in the unheated control samples. Heating to at least 286º F - 30 min significantly increased rumen undegraded protein, although heating to higher temperatures further increased rumen undegraded protein.

The estimates of rumen undegraded protein obtained with the Dacron® bag technique are consistently lower than those obtained with the in vitro technique. This is not surprising, as rumen undegraded protein estimates are highly dependent upon the technique used. Although laboratory procedures are useful in ranking treatment samples according to resistance to protein undegradation, absolute values can differ considerably from those obtained with live animals. The Dacron® bag method provides information about protein degradability, but does not give any information about the amount of protein that is irreversibly lost or damaged by excessive heat. It can be concluded, however, that temperatures in excess of 286º F - 0 min do substantially increase the amount of rumen undegraded protein.

Trial IV

In Trial IV, delinted cottonseed was roasted in a Jet-Pro roaster, and the following treatments were prepared: Unheated control, 277º F - 30 min, 295º F - 30 min, 313º F - 30 min, and 331º F - 30 min. Ten Holstein heifers weighing approximately 1000 lbs. were assigned to five treatments in a double 5 x 5 Latin square experiment. The heifers were fed once daily total mixed rations containing (DM basis) 50% alfalfa silage, 25% high moisture ear corn, 23.5% cottonseed (one of the five treatments listed above) and 1.5% of a mineral and vitamin ADE mix. The alfalfa silage (48.9% DM) contained (DM basis) 24.9% CP, 35.1% NDF and 28.4% ADF. The high moisture ear corn contained 67.9% DM and 9.2% CP, and the cottonseed averaged 22.8% CP (DM basis). Crude protein content of the diets averaged 20.1%. Each period lasted seven days, with the first five days of each period used for adjustment, and the last two days for sampling blood from the tail vein/artery 5 h after feeding. One blood sample was obtained on each of the last two days, and composited prior to amino acid (AA) analysis. Treatment differences were determined for a Latin square design by least significant difference (SAS).

The concentrations in blood plasma, branched-chain amino acids (BCAA; sum of leucine, isoleucine, and valine), essential AA (EAA; sum of threonine, valine, methionine, isoleucine, phenylalanine, tryptophane, lysine, histidine, and arginine), total amino acids, and lysine were evaluated. The BCAA are reported because concentrations of these amino acids in plasma are more highly correlated to protein uptake from the small intestine than other AA (Harper et al, 1984). Liver metabolism of BCAA is limited; therefore, these amino acids appear in extrahepatic circulation. Other EAA, which are absorbed from the intestine in amounts exceeding the animals' requirement, tend to increase in blood plasma, but to a lesser extent than the BCAA (Harper et al, 1984). Thus, concentrations of BCAA in blood plasma can be a useful indicator of protein uptake from the intestine.

Heating of cottonseed increased the concentration of BCAA in blood plasma, with the highest concentrations being achieved with the two highest temperatures. Since the BCAA are not very susceptible to heat damage, one would not expect to see reduced absorption of these amino acids with the temperatures used in this study.

The EAA, including lysine, tend to increase as absorption of protein increases, assuming that protein is fed in excess of the animal's requirement. The increase, however, is not as large as with the BCAA because the liver catabolizes these amino acids when they are in excess of requirements. There was a tendency ($P < .18$) for the EAA to increase with increased treatment temperatures, but as expected, the increase was small. The same trend would be expected for total amino acids. The concentration of lysine remained constant, except for the highest temperature treatment. With this treatment, lysine concentration in blood plasma tended to decrease, an indication that perhaps lysine availability was reduced with the highest treatment temperature.

This type of study reveals little about the amount of rumen undegraded protein or postruminal available protein, but it can indicate the relative ability of a diet (treatment) to improve protein nutrition of the animal. Based on this experiment, it appears that the optimum treatment was between 295º F - 30 min and 313º F - 30 min.

Trial V

In Trial V ten Holstein cows between 4-7 weeks into lactation were assigned to two 5 x 5 Latin squares. The same diet formulations used in the heifer experiment were used in this study. The alfalfa silage (46.8% DM) contained (DM basis) 24.9% CP, 34.3% NDF and 27.7% ADF. The high moisture ear corn contained 68.7% DM and 9.1% CP (DM basis), and the cottonseed averaged 22.8% CP (DM basis). Crude protein content of the diets averaged 20.1% (DM basis). Periods were three weeks in length, with feed intake and milk production being measured daily in the third week of each period. A composite of the a.m.-p.m. milk samples from each of the last 2 d in each period were analyzed for fat and protein contents by infrared analysis (filters A and B) by Wisconsin DHIA (Majeski, 1988). Treatment differences were identified for a Latin square design by least significant difference (SAS) after a significant F test.

Results of this lactation study are in Table 1. No treatment differences were observed in dry matter intake. Milk production was greatest ($P < .01$) with the 295º F - 30 min heat treatment, indicating that this was the optimum temperature for heat treating cottonseed, Milk production was least with the highest temperature treatment (331º F - 30 min), suggesting that heat damage may have occurred with that treatment. As indicated in the earlier experiments, lysine availability was reduced when temperatures in this range were used. Milk composition was largely unaffected, except protein content of milk from the control temperature which tended to be lower than other treatments. Milk yield was greatest with the 295º F - 30 min treatment.

This type of experimental design is suitable for identifying the best treatment, but is not a good design for determining the milk production response that is likely to be achieved with feeding of heated cottonseed. The experience with roasted soybeans (Faldet and Satter, 1991) is that it takes several weeks for the full response in milk production to become evident. The short three week periods used in this experiment probably did not allow full expression of protein potential benefit from feeding heat treated cottonseed.

The five experiments reviewed thus far were supportive of one another in identifying the optimum temperature for heat treating cottonseed. The in vitro study suggested the optimum was somewhere between 277º F and 318º F. The in situ study, while not enabling identification of an optimum treatment as such, did indicate that significant protection of protein from microbial degradation did occur with temperatures in excess of 286º F - 30 min. The heifer experiment, where the concentration of BCAA in blood plasma was the indicator of protein uptake from the intestine, suggested that the optimum treatment was between 295º F - 30 min and 313º F - 30 min. Lastly, the lactation study suggested 295º F was the optimum treatment. It is concluded that cottonseed should be heated to 295º F in a roaster, then immediately steeped or conditioned for 30 min to obtain optimum protection of protein for dairy cows. Interestingly, these are the exact conditions identified as being optimum for heat treating soybeans for lactating cows (Hsu and Satter, 1995; Faldet et al, 1992).

Trial VI

Having established the optimum temperature for heat treating cottonseed, the next step involved two large scale lactation studies. In the first study linted cottonseed was heated to 295º F in a Jet-Pro roaster and steeped for 30 min prior to cooling.

Thirty-eight cows in their second or subsequent lactation were assigned sequentially, as they calved, to one of three treatments. After calving all the cows were fed a pre-treatment diet for two weeks and were then switched to a treatment diet during week three of lactation. The three treatments were soybean meal (SBM), linted cottonseed (LCS), and heat treated linted cottonseed (HLCS). Treatment diets were fed through week 17 of lactation. Diets were fed as total mixed rations once daily 5 to 10% in excess of the previous day's consumption on an as fed basis. The diet containing soybean meal (SBM) served also as a pre-treatment diet.

Feed offered and feed refused were weighed daily. Milk weights were recorded twice daily. Milk samples were collected at two consecutive milkings each week and were analyzed for fat, protein, solid not fat, and lactose using infrared analysis by Wisconsin DHIA.

Dry matter intake, milk yield and milk composition results were summarized in Table 2. Cows fed heat treated cottonseed had slightly higher dry matter intake compared with the other two treatments. Cows fed cottonseed did not peak as high in milk yield as cows fed soybean meal, however, persistency of milk yield was better in cows fed cottonseed. Further, cows fed heat treated cottonseed had slightly higher milk yield compared with unheated cottonseed. Milk composition was similar among treatments.

The researchers in Trial VI (Satter, L.D., et. al.) attempted to maximize cottonseed intake in order to increase sensitivity of the experiment. Cottonseed made up 21.5% of the diets, and having so much cottonseed in a diet that was suddenly introduced during week three of lactation was too much of a change at a critical time for the cows. Consequently, the cottonseed cows simply did not do as well in early lactation as the soybean meal supplemented group. The cows fed heated cottonseed eventually surpassed the soybean mean group, but the experiment ended after week 17 of lactation, and total milk for the heated cottonseed and soybean meal groups was about equal.

Trial VII

In this trial cows were introduced to their diets during the latter part of the dry period, and diets were formulated to contain 15% cottonseed. Linted cottonseeds were brought to 295º F in a Jet-Pro roaster and steeped for 30 min prior to cooling.

Fifty-one multiparous cows were used to determine the effect of feeding optimally heat treated linted cottonseed on performance of dairy cows. Cows were randomly assigned before calving to one of three treatments according to calving date. Diets contained 50% forage and 50% grain (DM basis). The forage portion of the diet was 2/3 alfalfa silage and 1/3 corn silage. The grain portion of the diet contained high moisture ear corn along with either 12% soybean meal (SBM), or 6.8% soybean meal + 15.0% untreated linted cottonseed (LCS), or 6.8% soybean meal + 15% heat treated linted cottonseed (HLCS) as protein supplements. HLCS was heated to 146º C and steeped for 30 min prior to cooling. The experiment started at calving and lasted until cows completed wk 28 of lactation. Diets were balanced for protein (16.5% CP) and fed as a TMR once daily. Starting at wk 9 of lactation, cows in all treatments received a biweekly injection of rBST.

Results are summarized in Table 3. Cows in the soybean meal, linted cottonseed, or heated linted cottonseed treatments had similar feed intake. Cows fed heated linted cottonseed produced 4.4 lb. more milk compared with cows in the soybean meal or linted cottonseed treatments (P = .2). Similar feed intake and a slight increase in milk yield increased the feed efficiency of cows fed heated linted cottonseeds (P = .1). Milk fat percent was the same across treatments. Milk protein content was decreased in cows fed cottonseed compared with soybean meal. Cows in the heated linted cottonseed treatment started the experiment with lower milk protein content. During the previous lactation, milk protein content of cows in the soybean meal, linted cottonseed, and heated linted cottonseed treatments were 3.31, 3.31, and 3.22 respectively, suggesting the two cottonseed treatments probably did not differ in milk protein content. Cows fed cottonseed (heated or unheated) had slightly higher body weight gain and body condition score.

Trial VIII

In Trial VIII twenty-four lactating Holstein cows (142 DIM) were used in a replicated 4 x 4 Latin square trail to determine the effect of feeding processed whole cottonseed on milk production and nutrient digestibility. Experimental diets contained 15% of the DM as whole cottonseed, roasted whole cottonseed, a roasted and pelleted blend of whole cottonseed and soybean meal, or an extruded blend of whole cottonseed and soybeans. Apparent digestibilities of DM and NDF were greater and total fatty acids was lower for extruded cottonseed compared with roasted cottonseed. No differences were observed among treatments in DMI, yield of milk, protein, lactose, SNF, and energy-corrected-milk, or percentages of milk lactose and SNF (Table 4). Milk fat percentage was greatest for whole cottonseed and roasted whole cottonseed, intermediate for roasted-pelleted cottonseed, and lowest for extruded cottonseed. Yield of milk fat was lowest for extruded cottonseed. Milk protein percentage was lower for roasted-pelleted cottonseed compared to roasted whole cottonseed. Cows fed extruded and roasted-pelleted cottonseed gained BW whereas cows fed whole or roasted cottonseed lost BW. Total gossypol concentrations differed among treatments with greatest concentrations observed with roasted cottonseed and lowest with extruded cottonseed. (Table 4)

Trial IX

Heat treatment of any feed will reduce the amount of crude protein that is available to rumen microflora for degradation. If conditions in the rumen are not optimal for microbial protein synthesis (e.g. energy spilling or evolution of excessive ammonia) then the inclusion of a high quality protein source that is unavailable to rumen microflora may increase milk production.

Trial IX was conducted on a 250 cow New Mexico dairy to determine the effects of replacing whole cottonseed with roasted whole cottonseed on milk production and milk components. Prior to this, a trial conducted in Wisconsin (Trial VII) had shown an increase in milk production when roasted whole cottonseed was fed in place of whole cottonseed.

A ration typical of those fed in the western United States was fed for the entire trial. The trail consisted of four periods; periods one and three were those when whole cottonseed was fed, periods two and four were those when roasted whole cottonseed was fed. The periods were to have been 21 days in length, actual times were 20, 21, 21, and 21 days for periods one, two, three, and four, respectively. Data were collected on average milk production per cow per day, butterfat and protein. The first ten days of each period were assumed to be the adaptation period. Statistical analysis was by student t-test.

Two truckloads (approximately 45 tons) of cottonseed, for this trial, were heat treated at a commercial chili roasting facility in Artesia, New Mexico, that was capable of heating the cottonseed to 146º C and maintaining that temperature for 30 minutes.

Data are shown in Table 5. No differences were seen in any of the variables measured (P>.05). Milk production averaged 59.2 pounds when whole cottonseed was fed and 59.8 pounds when roasted whole cottonseed was fed. Fat corrected milk (lb. 3.5 FMC/day) averaged 72.6 and 63.1 for control and treatment. Production of energy corrected milk (fat and protein) was 62.5 pounds per day for the periods when whole cottonseed was fed and 62.7 pounds per day for the periods when roasted whole cottonseed was fed. Plasma gossypol increased 27% when roasted cottonseed was substituted for unroasted cottonseed in the diet.

Conclusion

Heat treatment can be used to increase the proportion of undegradable intake protein in cottonseed. Optimum roasting conditions appear to be 146º C (295º F) for 30 minutes. The feeding of properly heat treated cottonseed to dairy cows has been shown to support increased milk production when compared to unroasted cottonseed. However, these results have been inconsistent and lack the statistical significance necessary to make a strong recommendation in favor of feeding roasted cottonseed.

It appears that extensive heating of cottonseed, containing intact pigment glands (where gossypol is located) either physically or chemically increases the availability of gossypol in cows resulting in elevated plasma gossypol levels.

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Table 1. Milk production and milk composition of cows fed diets supplemented with cottonseed exposed to different heat treatments (L.D. Satter, et. al., U.S. Dairy Forage Research Center, Madison, Wisconsin)

Parameter	Treatment						
	Unheated Control	277º-30 min	295º-30 min	313º-30 min	331º-30 min	SEM	P=
Dry matter intake, lb/d	55.40	55.90	57.00	56.80	54.10	.92	.19
Milk, lb/d	81.20^{b}	80.70^{b}	84.00^{a}	81.40^{ab}	78.80^{bc}	.95	.01
Fat, %	3.31	3.32	3.32	3.32	3.53	.09	.32
Protein, %	2.87^{b}	3.01^{a}	2.94^{ab}	2.96^{a}	2.94^{ab}	.03	.02
Fat Yield, lb/d	2.68	2.68	2.79	2.71	2.77	.09	.79
Protein Yield, lb/d	2.33^{b}	2.40^{ab}	2.46^{a}	2.40^{ab}	2.31^{b}	.04	.04
Solid not fat, %	8.38^{b}	8.52^{a}	8.46^{ab}	8.43^{b}	8.41^{b}	.03	.04

[1] Covariate adjusted means.

Table 2. Dry matter intake, milk yield, and milk composition[1]. Trial VI.

Parameter	Treatment				
	Soybean Meal	Linted Cottonseed	Heated Linted Cottonseed	SEM	P =
Dry Matter intake, lb/d	56.70	56.90	58.20	.40	.07
Milk Yield, lb/d	83.10	81.10	83.80	.70	.20
Milk Fat, %	3.37	3.47	3.31	.04	.80
Milk Protein,%	2.78	2.70	2.71	.01	.70
Milk Lactose, %	4.85	4.80	4.79	.01	.20
Milk Solid not fat, %	8.38	3.22	8.29	.02	.08

Table 3. Daily dry matter intake, milk yield, and milk composition. Trial VII.

Parameter	Treatment				
	Soybean Meal	Linted Cottonseed	Heated Linted Cottonseed	SEM	P=
Dry matter intake, lb/d	52.80	51.90	52.10	1.10	.700
Milk, lb/d	83.80	84.30	88.70	2.20	.200
Milk fat, %	3.45	3.41	3.42	.19	.900
Milk protein, %	3.24^{a}	3.10^{b}	3.00^{b}	.04	.001
Fat yield, lb/d	2.86	2.86	2.99	.09	.500
Protein yield, lb/d	2.71	2.60	2.64	.07	.400
Feed efficiency, bFCM/lbDMI	1.61	1.63	1.71	.04	.100
Weight gain[1], lb	79.00	112.00	108.00		
Gain in body condition score[2]	.20	.30	.40		

[1] Average weight at wk 27 and 28 minus average weight at wk 1 and 2 of the experiment.
[2] Body condition score at the end of the experiment minus beginning score. Range from 1 to 5, where 5 is the highest condition.

Table 4. Dry matter intake, milk yield and composition and change in body weight of lactating cows fed diets containing processed whole cottonseed. Trial VIII. (J.K. Bernard, University of Tennessee, Jackson)

	Treatment					
Parameter	WCS[1]	RCS	PCS	ECS	SEM	P=
DMI, kg/d	20.50	20.20	20.70	19.80	.50	.610
DMI, %BW	3.42	3.34	3.40	3.29	.08	.680
Milk, kg/d	27.30	27.00	27.60	28.30	.60	.430
Fat, %	3.72[a]	3.67[a]	3.41[b]	3.13[c]	.07	.000
Fat, kg/d	1.00[a]	.97[a]	.93[a]	.86[b]	.03	.001
Protein, %	3.09[de]	3.10[d]	3.02[e]	3.04[de]	.03	.041
Protein, kg/d	.83	.83	.83	.86	.02	.600
Lactose, %	4.88	4.85	4.87	4.86	.03	.860
Lactose, kg/d	1.33	1.31	1.35	1.37	.03	.520
SNF, %	8.58	8.60	8.51	8.53	.04	.280
SNF, kg/d	2.32	2.30	2.34	2.40	.05	.510
ECM, kg/d	26.60	26.20	25.70	25.30	.60	.390
Change in BW, kg	-5.40[d]	-4.60[d]	3.10[e]	2.90[e]	2.90	.060
Total Gossypol[1] (µg/mL)	1.40	1.80	1.10	.60	.06	.0001

WCS = Whole cottonseed, RCS = roasted whole cottonseed, PCS = pelleted whole cottonseed plus soybean meal, and ECS = extruded whole cottonseed plus soybeans.

[1]Total Gossypol in the plasma

[abc] Means with unlike superscripts differ ($p < 0.01$)

[def] Means with unlike superscripts differ ($p < 0.05$)

Table 5. Milk Production & Milk Composition. Trial IX. (C.A. Old, MacGowan-Smith Ltd., Nutrition Consulting Exeter, California)

	Treatment		
Parameter	Whole Cottonseed	Roasted Whole Cottonseed	P
Milk (lb/cow/day)	59.20	59.80	.200
3.5 FCM (lb/cow/day)	62.60	63.10	.240
3.5 ECM (lb/cow/day)	62.50	62.70	.390
Milk butterfat, (%)	3.85	3.83	.470
Milk protein, (%)	3.18	3.12	.420
Plasma Gossypol (µg/ml)	4.83	6.11	.001