Feeding Whole Cottonseed in the 21st Century

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No other feed ingredient provides the combination of effective fiber, energy, and protein like whole cottonseed (WCS). These characteristics make WCS an attractive ingredient for including in rations fed to lactating dairy cows that require high concentrations of energy and adequate effective fiber. But like most ingredients, the composition of WCS has changed. The 2002 cotton crop was negatively affected by tropical storms which has reduced the feeding value of some WCS. These aspects plus the effects of elevated concentrations of free fatty acids in the oil of cottonseed will be addressed in the presentation along with some suggestions for avoiding poor quality WCS.

Changes in Nutrient Composition

The nutrient composition of WCS has changed over the past two decades as illustrated in Table 1. In general, there has been a slight decrease in concentrations of protein and ether extract and an increase in fiber concentrations. Much of the change in nutrient composition can be attributed to the emphasis placed on lint yield by cotton breeders. Although WCS accounts for approximately 55% of the yield per acre, the sale of lint produces 90% of the total revenue per acre. One of the consequences of selecting for higher lint yield is decreased seed size. The size of many of the new varieties of seed cotton is smaller than conventional varieties which have averaged 4,000 to 5,000 seeds/lb. The most popular varieties planted the past few years have averaged 5,500 to 5,600 seeds/lb and one of the newest varieties being introduced has 6,000 to 6,300 seeds/lb. This variety is expected to increase in acreage quickly because of it high lint yield. The trend for higher lint yield varieties will most likely continue into the foreseeable future. Another aspect that has contributed to these changes in nutrient composition is that most WCS have more lint remaining on the seed with increases fiber concentrations and dilutes CP and ether extract concentrations.

Table 1. Change in the chemical composition of whole cottonseed.

Reference	CP	NDF	Ether extract
NRC, 1982	23.9	39.0	20.8
NRC, 1989	23.0	44.0	20.8
Calhoun et al., 1995	22.5	47.2	17.8

Quality Issues

In a normal year, the quality of WCS is not a problem. However, when storms delay harvest and cotton stays wet for extended periods, quality problems do occur.

This was the case for the 2002 cotton crop in much of the Southeast accounting for lower quality WCS, sprouted WCS, and aflatoxin in some loads.

The National Cottonseed Products Association (1997) established a grading system for WCS based on a combination of a quantity (concentration of oil and ammonia) and quality factors (moisture, foreign matter, and free fatty acids in the oil). A description of the quality values used for prime and off quality WCS is provided in Table 2. These standards are used primarily by the oil industry to identify prime WCS for crushing to meet high quality standards for cotton oil. Cotton oil is used primarily by fine restaurants and bakeries because it has a long shelf live and is less prone to rancidity. The majority of WCS fed to dairy cows is not graded but would be probably grade below prime quality in a normal year with quality values and nutrient concentrations between prime and off quality.

Table 2. Quality factors used for grading whole cottonseed.

Item	Prime	Off Quality[1]
Moisture	< 12.0%	≥ 12.5%
Foreign matter	< 1.0%	≥ 10.0%
Free fatty acids in the oil	< 1.8%	≥ 20.0%
Foreign matter + moisture		≥ 25.0%

[1]Cottonseed that is hot or fermented or have been treated by chemical or mechanical processes other than that normally used for cleaning, drying or ginning.

Off quality WCS pose several potential problems besides lower nutrient content. The high moisture content provides conditions favorable for the seed to germinate heat or mold. Heating would presumably reduce protein digestibility in a similar manner observed with heat damaged forages. Moldy WCS may contain aflatoxin and should be tested before feeding to prevent contamination of milk. Germination metabolizes nutrients and increases the concentrations of free fatty acids in the oil (FFA) of WCS.

Elevated Free Fatty Acids in the Oil

Increased concentrations of FFA could presumably interfere with ruminal fermentation and decrease intake and milk yield. Increased concentrations of FFA can occur in WCS before harvest when both temperature and humidity are high resulting in off quality WCS. These WCS have similar nutrient concentrations as higher quality WCS, but the effect of feeding WCS with elevated FFA has not been studied. We conducted two trials to examine the effects of feeding WCS with elevated concentrations of FFA to determine the potential effects on milk yield and composition and ruminal fermentation.

In the first trial, two lots of WCS were obtained from gins in South Georgia which contained either 3 or 12% FFA. Cottonseed from each lot was mixed to provide 3, 6, 9, or 12% FFA. Twenty-four lactating Holstein cows were used in a randomized block design trial to determine the effects of FFA in WCS on nutrient intake, milk yield and milk composition. All cows were fed the control diet for two weeks after which they were assigned randomly to one of four experimental treatments for eight weeks. A description of the diets is provided in Table 3.

Table 3. Ingredient and chemical composition of experimental diets containing whole cottonseed (WCS) with increasing concentrations of free fatty acids in the oil (FFA). Adapted from Sullivan, 2002.

	% FFA in oil of WCS			
	3	6	9	12
Ingredient composition	------------------------ % of DM ------------------------			
Wheat silage	44.9	44.9	44.9	44.9
Ground corn	24.5	24.5	24.5	24.5
3% FFA WCS	12.5	8.3	4.2	
12% FFA WCS		4.2	8.3	12.5
Soybean meal, 48% CP	9.2	9.2	9.2	9.2
Protein supplement[1]	3.8	3.8	3.8	3.8
Mineral-vitamin premix[2]	2.1	2.1	2.1	2.1
Chemical composition	-------------------------- % --------------------------			
DM	57.5	57.4	57.8	57.8
	--------------------- % of DM -----------------------			
CP	19.8	18.8	19.6	19.0
NDF	46.5	47.2	46.8	47.8
ADF	29.8	29.1	28.4	29.6
EE[3]	6.3	6.3	6.4	6.4
NE_l, Mcal/lb[4]	0.79	0.79	0.79	0.79

[1]Protein supplement was composed of 60% menhaden fish meal and 40% distillers grain with solubles.
[2]Premix contained 34% CP from urea; 24.50% CA; 3.68% P, 1.27% Mg, 0.08% K; 3.03% Na; 4.60% Cl, 0.31% S; 11.67 ppm Co; 665 ppm Cu; 4,622 ppm Fe; 58 ppm I; 2,039 ppm Mn; 14.69 ppm Se; 1,943 ppm Zn; 60,360 IU/kg of Vitamin A; 24,145 IU/kg Vitamin D; and 300IU/kg of Vitamin E.
[3]Ether extract.
[4]Determined using NRC (1989) values.

Concentrations of NDF, ADF, and ether extract were similar for the two lots of WCS, but the WCS with 12% FFA has slightly lower concentrations of CP (Table 4). There were only minor differences in the fatty acid composition of the two lots of WCS. Except for the concentration of FFA, these lots of WCS were very similar in nutrient content which is typical during normal years. The nutrient content of the experimental diets was similar and in agreement with formulated values (Table 3).

Table 4. Chemical composition of whole cottonseed (WCS) containing different concentrations of free fatty acids in the oil (FFA). Adapted from Sullivan, 2002.

	% FFA in WCS	
	3	12
	--------------- % of DM ---------------	
DM	88.8	88.0
CP	26.7	24.8
NDF	43.2	43.3
ADF	30.3	30.8
EE[1]	17.0	16.2
	--------------- % of Fatty Acids ---------------	
C10:0	0.1	0.05
C14:0	0.7	0.7
C16:0	22.0	24.3
C16:1	0.5	0.6
C18:0	1.0	2.5
C18:1	16.0	15.6
C18:2	54.3	51.8
C20:0	0.2	0.3
C18:3	0.2	0.2
C9t11	0.06	0.06

[1]Ether extract.

Table 5. Dry matter intake and milk yield and composition of lactating Holstein cows fed diets containing whole cottonseed (WCS) with increasing concentrations of free fatty acids in the oil (FFA). Adapted from Sullivan, 2002.

	% FFA in oil of WCS				
	3	6	9	12	SE
DMI, lb/d	48.9	50.0	48.3	48.5	1.5
Milk, lb/d	72.5	78.7	70.5	74.5	4.2
Fat, %[a]	3.48	3.32	3.67	3.41	0.08
Protein, %	2.63	2.74	2.85	2.81	0.09
Total solids, %	12.22	12.01	12.61	12.18	0.25
ECM[1], lb/d	72.1	73.2	73.9	73.0	3.5

[1]Energy corrected milk.
[a]Cubic response to increasing concentrations of FFA in WCS ($P < 0.05$).

There was no difference in dry matter intake (DMI), milk yield, or concentrations of protein or total solids (Table 5). Concentration of milk fat was highest ($P < 0.05$) for the diet containing WCS with 9% FFA, but there was no difference in yield of milk fat so this difference is most likely due to nonsignificant differences in milk yield. Milk composition is not typically altered by the type of WCS (Santos et al., 2002) or amount fed (Coppock et al., 1987).

The FFA content of the WCS tended to magnify the depression of milk short chain fatty acid synthesis, but did not alter medium or long chain fatty acid content (data not shown). Generally off-flavors due to spontaneous auto-oxidation are associated with increases in milk C18:2 and C18:3 fatty acids, and these fatty acids are often increased with addition of oilseed to the diet (Hermansen, 1995). Concentrations of C18:2 and C18:3 were similar for all diets in the current study suggesting that increased FFA in WCS should not cause any off-flavors in the milk.

In a second trial, four Holstein steers fitted with ruminal and abomasal cannula were used in a 4 x 4 Latin square design trial to determine the effects of elevated FFA in WCS on ruminal fermentation. The concentration of FFA in the 12% FFA WCS from the lactation study was elevated by increasing the moisture content to 20% for 72 hours before drying to approximately 10% moisture. Final concentrations of FFA in the oil of WCS were 8 and 18%. The WCS from each lot were blended to provide concentrations of 8, 11.3, 14.7, or 18% FFA in the oil. Diets were the same as those used in the lactation trial and were formulated to contain 12.5% WCS (DM basis).

Experimental diets averaged 58.9% dry matter (DM) and 19.6% crude protein, 48.6% NDF, 29.2% ADF, and 6.0% ether extract (DM basis) which was consistent with ration formulation. There were no differences in DM intake or apparent ruminal digestibility among treatments (Table 6) which is consistent with the results of the lactation trial. Intake of NDF decreased linearly ($P < 0.005$) as the concentration of FFA in the oil of WCS increased. A trend (P = 0.07) was observed for increased ruminal NDF digestibility because equal amount of NDF were digested in the reticulorumen. This is in contrast to the results of Reddy et al. (1994) in which in vitro NDF digestibility decreased as the extruded soybeans were added to in vitro fermentations. Rupturing the soybean by extrusion allows rapid exposure of the fatty acids to the ruminal microorganism whereas the oil from WCS is gradually released into the ruminal contents after mastification. Intake and apparent ruminal digestibility of ADF were similar among treatments.

A cubic response (P < 0.01) was observed for nitrogen (N) intake because of higher intakes for diets containing WCS with 8 and 14.7% FFA in the oil compared to those containing WCS with 11.3 and 18.0% FFA in the oil (Table 7). This response was due to minor differences in DM intake among treatments. No differences were observed in the apparent ruminal digestibility of nitrogen. Flow of total nitrogen was similar among treatments, but there was a cubic response (P < 0.03) in the flow of microbial nitrogen because of higher flows for diets containing WCS with 14.7% FFA in the oil and lower flows for diets containing WCS with 18% FFA in the oil. There was no difference of nonmicrobial nitrogen to the abomasum. No differences were observed in the efficiency of microbial nitrogen synthesis. Flow of microbial nitrogen to the small intestine was reduced when oilseed was fed to nonlactating dairy cows (Keele et al., 1989), but an increase in microbial nitrogen flow was observed when yellow grease (2.9% FFA) was substituted for tallow (5.5% FFA) (Avila et al., 2000).

Table 6. Effect of increasing concentrations of free fatty acids (FFA) in oil of whole cottonseed (WCS) on nutrient intake and apparent ruminal digestibility. Adapted from Sullivan, 2002.

	% FFA in oil of WCS				
Item	8.0	11.3	14.7	18.0	SE
Intake, kg/d					
DM	9.67	9.21	9.32	9.23	0.27
NDF[a]	4.84	4.42	4.48	4.45	0.14
ADF	2.65	2.50	2.60	2.57	0.14
Apparent ruminal digestibility, %					
DM	50.47	44.88	50.90	51.06	1.37
NDF[b]	64.45	63.88	66.78	69.44	1.52
ADF	61.98	60.37	61.89	63.89	1.40

[a]Linear response to increasing FFA in oil of WCS (P < 0.005).
[b]Linear response to increasing FFA in oil of WCS (P < 0.10).

Table 7. Effect of increasing concentrations of free fatty acids (FFA) in oil of whole cottonseed (WCS) on nitrogen intake and digestibility, and microbial nitrogen synthesis. Adapted from Sullivan, 2002.

	% FFA in oil of WCS				
Item	8.0	11.3	14.7	18.0	SE
Intake, g/d [a]	316.9	303.5	318.7	301.7	8.0
Apparent ruminal digestibility, %	62.9	67.0	62.2	67.0	2.3
Flow to abomasum, g/d					
Total N	192.2	198.4	190.2	200.6	10.7
Microbial N[bc]	66.1	63.2	76.0	56.8	2.8
Non Microbial N	126.0	135.1	114.2	143.7	12.5
Microbial N synthesis, g N/kg OM digested					
Apparent[a]	15.03	16.60	17.70	12.88	0.56
True[a]	17.70	20.03	21.45	14.77	0.84

[a]Cubic response to increasing FFA in oil of WCS ($P < 0.01$).
[b]Quadratic response to increasing FFA in oil of WCS ($P < 0.05$).
[c]Cubic response to increasing FFA in oil of WCS ($P < 0.05$).

Average ruminal pH across all sampling times decreased linearly ($P < 0.05$) as the concentration of FFA in the oil of WCS increased (Table 8). Minimal pH remained above 6.0 and was not different among treatments. The decline in pH was not great enough to greatly alter microorganism populations in the rumen. Total VFA concentrations were highest for diets containing 11.3% FFA in the oil of WCS and lowest for diets containing 14.7% FFA in the oil of WCS causing a cubic effect ($P < 0.05$). No differences were observed in molar proportions of acetate, propionate, butyrate, isovalerate, and valerate, but a linear decrease ($P < 0.02$) in isobutyrate as the concentration of FFA in the oil of WCS increased was observed. The acetate to propionate ratio increased ($P < 0.02$) as the concentration of FFA in the oil of WCS increased due to small nonsignificant changes in molar proportions of acetate and propionate.

Table 8. Effect of increasing concentrations of free fatty acids (FFA) in oil of whole cottonseed (WCS) on ruminal pH and volatile fatty acid (VFA) concentrations. Adapted from Sullivan, 2002.

	% FFA in oil of WCS				
Item	8.0	11.3	14.7	18.0	SE
pH[a]	6.34	6.27	6.20	6.23	0.02
Total VFA, mMol/ml[b]	97.24	107.33	93.52	99.47	2.38
			------------------------ %	------------------------	
Acetate	66.30	64.32	68.12	67.28	1.34
Propionate	18.57	17.98	18.63	17.44	0.39
Butyrate	11.14	11.04	10.89	10.71	0.26
Isobutyrate[a]	2.16	2.20	1.98	1.47	0.12
Isovalerate	2.09	1.97	2.34	1.92	0.22
Valerate	1.75	1.20	1.96	1.55	0.30
Acetate:Propionate[c]	3.60	3.59	3.69	3.90	0.09

[a]Linear response to increasing FFA in oil of WCS ($P < 0.05$).
[b]Cubic response to increasing FFA in oil of WCS ($P < 0.05$).
[c]Linear response to increasing FFA in oil of WCS ($P < 0.02$).

Collectively these results indicate that WCS with up to 18% FFA should not negatively impact nutrient intake. The negative changes in ruminal fermentation observed when WCS contained 18% FFA suggest that milk production could be limited by lower amino acid quality from the reduced flow of microbial nitrogen. The effects of feed WCS with even higher concentration of FFA have not been investigated and merit additional research.

Develop Minimum Specification

To minimize the possibility of receiving poor quality WCS, a set of specifications should be developed listing nutrient concentrations, quality factors, and any other specifics desired. The specifications should be adequate to maintain quality, but not so tight that brokers would have difficulty in filling the order. This will increase the cost of WCS slightly, but the cost of feeding poor quality WCS would be greater. Some general specifications for WCS are:

- ✓ Moisture content less than 12%
- ✓ Oil (ether extract) concentration equal to or greater than 15%

✓ Less than 20 ppb aflatoxin
✓ Less than 18% free fatty acids in oil

Establishing minimum standards for quality and nutrient concentrations also provides a means of negotiation a settlement if the feed is not what was expected. If a load of cottonseed is ordered without any specifications, the purchaser is at the mercy of the broker after the load has been delivered.

Summary

Whole cottonseed is an excellent source of energy, fiber and protein for lactating dairy cows. Changes in the seed size of varieties grown have altered the nutrient content of WCS slightly and this could change more as seed size continues to decrease. Concentrations of free fatty acids in the oil of WCS up to 18% do not appear to alter nutrient intake, but ruminal fermentation may be negatively impacted when the concentration of free fatty acid in the oil of WCS reaches 18%. To avoid poor quality WCS and the potential problems that can be associated with then, producers are encouraged to develop minimum standards for quality and nutrient concentrations to use when buying WCS. As with any feed ingredient, WCS should be stored to maintain moisture concentrations below 12%. Storing WCS with higher moisture concentrations will not decrease quality, but can also result in mycotoxin contamination which will negatively impact performance and health.

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