The *Journal of Cotton Science* 5:92-102 (2001)
http://journal.cotton.org, © The Cotton Foundation 2001

ENGINEERING & GINNING

Extruding Cotton Gin Byproducts to Reduce Chemical Residues

Michael Buser *

INTERPRETIVE SUMMARY

An estimated 1.2 million metric tons of cotton gin byproducts other than cottonseed are produced annually by U.S. cotton gins, creating a significant disposal problem in the ginning industry. Cotton gin byproducts include soil, plant parts, immature seed, and fiber normally removed by seed cotton cleaners such as cylinder cleaners and stick machines. Currently, the most common methods of disposal or reutilization include composting, direct land application, and livestock feed. Whereas ~37% of U.S. cotton gins use gin byproducts at a profit or at no cost, 63% pay for disposal. The nutritional value of cotton gin byproducts is similar to roughage-type feeds; that fact has created an interest in adding this material to livestock feed rations. The use of cotton gin byproducts in livestock rations could increase gin profits, reduce landfill disposal, and add an alternative roughage-type feed for the livestock industry. At present, the primary concerns associated with feeding cotton gin byproducts to livestock are the feeding restrictions on the labels of several cotton crop chemicals.

An extrusion process was evaluated to determine the chemical residue reductions associated with this method for processing cotton gin byproducts. The extrusion process applies pressure and shear to the material being extruded and internally mixes the cotton gin byproducts to create a more uniform final material. The mixing process, along with pressure and shear, produces frictional forces between the material particles and between the particles and the internal barrel components, thereby heating the product being extruded. Cotton gin byproducts (composed mainly of soil, leaf material, and fiber with a relatively low percentage of burs) from picker-harvested cotton were used in this study and compared with stripper-harvested cotton. Because these types of cotton gin byproducts tend to ball up and hang in the extruder barrel, a lubricating substance, such as cottonseed, had to be added to the cotton gin byproducts so the material would flow through the extruder. Based on preliminary extrusion tests, the minimum concentration of cottonseed needed in the mixtures to maintain a uniform material flow was 25%.

To evaluate the chemical residue reductions associated with the extrusion process, additional chemicals had to be applied to the cotton gin byproducts so specific residue analysis could be performed. Chemical application concentrations were 0.8% of recommended field application concentrations. Various mixing ratios of cotton gin byproducts and cottonseed were evaluated for chemical residue reduction and nutritional value. Further, the extrusion process was evaluated in terms of material processing time for mixtures containing 75% cotton gin byproducts. Results from the extrusion tests indicated that some, but not all, residue levels of the chemicals tested were decreased by the extrusion process and further diluted by addition of cottonseed to cotton gin byproducts. After one stage of processing, typical reductions, which do not incorporate dilution effects, were 27 and 40% for methyl parathion and tribufos (DEF), respectively. Reductions of 52 and 95% were found after four stages of processing for methyl parathion and thidiazuron (Dropp), respectively. The extrusion process did not appear to substantially affect most of the nutritional values that were analyzed; however, crude protein and soluble protein were decreased after four stages of processing by 10 and 29%, respectively. Increasing the amount of cottonseed in the mixture further enhanced the nutritional value of the product. Although these tests indicated that the

M. Buser, USDA-ARS Cotton Ginning Res. Unit, Stoneville, MS 38776. Received 16 Oct. 2000. *Corresponding author (mbuser@ars.usda.gov).

extrusion process reduced some chemical residue levels, feeding cotton gin byproducts to livestock is not recommended until tolerance levels have been established by the Environmental Protection Agency under the Food Quality Protection Act. Further research should be conducted to evaluate the effects of extrusion temperature, and should focus on a broader range of chemical residues.

ABSTRACT

An extrusion process was evaluated to determine the chemical residue reductions associated with that process. The cotton gin byproducts used in this study were from picker-harvested cotton and consisted primarily of leaf and plant material, fiber, and soil. Sufficient cottonseed was added to the cotton gin byproducts to maintain a uniform material flow through the extruder. To evaluate the chemical residue reductions associated with the process, additional chemicals were applied to the cotton gin byproducts so specific residue analysis could be performed. Chemical application concentrations were 0.8% of recommended field application concentrations. Various mixing ratios of cotton gin byproducts and cottonseed were evaluated in terms of chemical residue reduction and nutritional value. In addition, the extrusion process was evaluated for material processing time for mixtures that contained 75% cotton gin byproducts. Results from the extrusion tests indicated that some, but not all, residue levels of the chemicals tested were decreased by the extrusion process and further diluted by the addition of cottonseed. After one stage of processing, typical reductions, which did not incorporate dilution effects, were 27 and 40% for methyl parathion (O,O-dimethyl O-p-nitrophenyl phosphorothioate) and tribufos (S,S,S-tributyl phosphorotrithioate), respectively. After four stages of processing, reductions were 52 and 95% for methyl parathion and thidiazuron [N-Phenyl-N'-(1,2,3-thiadiazol-5-yl)urea], respectively. The extrusion process did not substantially impact most of the nutritional components that were analyzed; however, crude protein and soluble protein were decreased after four stages of processing by 10 and 29%, respectively.

An estimated 1.2 million metric tons of cotton gin byproducts are produced by U.S. cotton gins annually, creating a significant disposal problem in the ginning industry (Thomasson, 1990). The quantity of cotton gin byproducts bale^{-1} of ginned lint varies by harvesting method. Spindle-picked seed cotton contains from 37 (Pendleton and Moore, 1967) to 148 (Reeves, 1977) kg bale^{-1}, with typical estimates of 34 to 68 kg bale^{-1} (Parnell et al., 1994). Stripper harvesting produces from 238 (Pendleton and Moore, 1967) to 671 (Kolarik et al., 1978) kg bale^{-1} cotton gin byproducts, with representative estimates of 318 to 455 kg bale^{-1} (Parnell et al., 1994).

Extractors on stripper harvesters can reduce the byproducts per bale by ~60 to 70% (Williford et al., 1994). Currently, the preferred method of disposal and utilization is direct land application, with well over half of all cotton gin byproducts being returned to the land (F. Johnson, personal communication, 2001). Other uses include as a feed supplement and bedding material for cattle. A lot of cotton gin byproducts also are transported to landfills.

Kolarik et al. (1978) reported that 37% of surveyed gins used cotton gin byproducts either at a profit or at no cost to the gins, whereas the other 63% of gins paid for disposal. Even two decades after the Kolarik survey, disposal costs to gins and cotton producers constitute a major economic problem. Parnell et al. (1994) estimated that the cotton ginning industry would spend $15 to $25 million annually for cotton gin byproduct disposal.

Typical cotton gin byproducts consist mainly of fruit and vegetative parts of the cotton plant that were collected during harvest and removed by seed-cotton cleaning during processing at the gin. These plant parts include fragments of leaves, stems, petioles, bracts, bolls, and lint. The natural constituents of cotton gin byproducts are like those of any biomass: organic matter that includes lignin and cellulose with an ash content of ~10%. Because of these constituents, a keen interest in processing a livestock feed composed of cotton gin byproducts has emerged, and during the last 50 years, a vast amount of supportive information has been generated.

Lalor et al. (1975) reported that cotton gin byproducts could be used as ruminant roughage because of moderate protein and energy value, which is comparable to Bermuda and prairie hay. Numerous feeding trials have been conducted. No significant differences were found in rates of weight gain, slaughter weights, or carcass characteristics between steers on a cotton gin byproducts ration and those on a regular ration (Williams et al., 1982). Stent (personal

communication, 1974) suggested a ration of 25% cotton gin byproducts was acceptable, if it were economically feasible. Monetary estimates for cotton gin byproducts as a feed product range from $21 (Williams et al., 1982) to $39 (Lalor et al., 1975) Mg ha^{-1}, based on nutritional values.

Use of cotton gin byproducts as a livestock feed throughout the Cotton Belt is not widespread due to its limited protein availability, relatively poor digestibility in ruminants, and chemical residues. Sagebiel and Cisse (1984) suggested that the analyses that showed limited protein availability of cotton gin byproducts because of lignin and silica contents, low digestibility, and low energy derived by ruminants, were not representative of the actual available protein.

Digestibility can be improved through chemical treatment of cotton gin byproducts. Gaseous oxidants such as ozone, hydrogen peroxide, and other superoxide species can be dissolved in a caustic solution and blended with cotton gin byproducts to increase in vitro digestibility (Cornett, 1991). Although research has shown the benefits of the inclusion of cotton gin byproducts in livestock rations, the widespread practice is discouraged because chemical residue tolerances for most crop protection chemicals used in cotton have not been established. In addition, certain crop production chemicals are labeled “Do not feed to livestock any crop material that has had this chemical applied,” making the feeding of cotton gin byproducts to any livestock illegal.

The potential for chemical residues in cotton gin byproducts results from the application of crop protection chemicals (insecticides, herbicides, growth regulators, and defoliants) during production. Some chemical compounds have been updated with shorter half-lives. Arsenic has been phased out. Even with new chemistries, some chemical labels prohibit feeding cotton gin byproducts to livestock when that chemical has been used on the crop. Chemical labeling is a major concern in the ginning industry, particularly because of the registration and re-registration of several crop chemicals under the Food Quality Protection Act. Representatives of the industry have met with regulators from EPA in efforts to incorporate more realistic data in assessing crop protection chemicals used on cotton (Swanson, 1998).

Because some chemicals breakdown with heat and some have relatively short half-lives, blending cottonseed and cotton gin byproducts in an extruder at high temperatures and pressures may reduce levels of some residues in cotton gin byproducts (Mayfield, personal communication, 1994). Using an 11.4-cm expander cooker (Anderson International, Cleveland, OH), Thomasson et al. (1998) conducted an expansion study to determine the chemical residue reductions associated with cottonseed and cotton gin byproduct mixtures. Mixing ratios, in terms of percentage of cottonseed to percentage of cotton gin byproducts, included 50:50, 75:25, and 90:10. The mixtures were shown to have relatively good nutritional values and no palatability problems. The expansion process reduced methomyl (S-methyl-N-[(methylcarbamoyl)oxy] thioacetimidate) residues by 45% and thidiazuron [N-phenyl-NN-1,2,3-thiadiazol-5 ylurea] (Dropp 50WP, AgrEvo, Wilmington, DE) residues by ~90%.

A twin-screw extruder was used to process cotton gin byproducts treated with a solution of SP2000, an oxidant that appears to improve the digestibility of low quality roughage (J.K. Bernard, personal communication, 1998). When operated at ~316 g cm^{-2} pressure and an exit temperature of 88ºC, the extruder improved the texture of cotton gin byproducts, increased bulk density by 61.5%, and did not negatively affect nutrient digestibility. SP2000 further increased the digestibility of cotton gin byproducts. A feeding trial showed no significant differences in nutrient intake of the extruded materials when compared to pelleted cottonseed hulls (J.K. Bernard, personal communication, 2001).

Extrusion is a process that applies pressure and shear to the material being extruded; in addition, the material is mixed internally in the extruder to create a more uniform final product. The mixing process, along with the pressure and shear, produce frictional forces between the material particles and between the particles and the internal barrel components of the extruder, which results in heating of the product being extruded. These four characteristics of extrusion are extremely dependent on one another; therefore, these characteristics will be consolidated and defined as the extrusion process. The extrusion process will be quantified in terms of extruder temperature (this parameter is based on the characteristics previously discussed).

This study focuses on cotton gin byproducts and cottonseed mixing ratios with relatively high cotton gin byproduct concentrations, higher extrusion temperatures, and multiple-pass extrusion as a means of testing the effects of increased dwell time. Work is based on a study by Thomasson et al. (1998). The purpose is to determine the feasibility of extruding cottonseed and cotton gin byproducts together to produce an acceptable livestock feed.

Specific objectives include: 1) evaluate changes in chemical residue levels and nutritional values associated with the extrusion process; 2) analyze the effects of mixing ratio on chemical residue dilution and nutritional value; 3) determine the effect of material dwell time on chemical residue levels and nutritional values.

MATERIALS AND METHODS

This project was divided into two efforts to fulfill the objectives of the study. The two endeavors are: (i) an evaluation of chemical residue reductions and nutritional values associated with extruding various mixing ratios of cotton gin byproducts and cottonseed at relatively high extruder temperatures; (ii) an evaluation of chemical residue reductions and nutritional values associated with multiple-pass extrusion of a mixture of 75% cotton gin byproducts and 25% cottonseed.

This study used cotton gin byproducts from picker-harvested cotton, which is composed mainly of soil, leaf material, and fiber with a relatively low percentage of burs, as compared with stripper-harvested cotton. Because this type of cotton gin byproduct tends to ball up and hang in the extruder barrel, a lubricating substance, such as cottonseed, had to be added to the cotton gin byproducts for the material to flow through the extruder. Because preliminary extrusion tests showed ~25% cottonseed was required to maintain a uniform material flow, all tests in this study used a mixture of cotton gin byproducts and at least 25% cottonseed.

The chemical residue study for various mixing ratios used 455 kg cotton gin byproducts and 455 kg cottonseed. The cotton gin byproducts (which did not include motes from the upper moting system of a gin stand or lint cleaner waste) and cottonseed were collected during the ginning of spindle-picked, Mid-South seed cotton. Burdette Gin Company in Burdette, Mississippi, supplied the cotton gin byproducts and the cottonseed was collected at the U.S. Cotton Ginning Laboratory, USDA-ARS, in Stoneville, Mississippi. Similar cotton gin byproducts and cottonseed were provided by the U.S. Cotton Ginning Laboratory for the multiple-pass extrusion tests.

To determine whether the extrusion process would reduce chemical residue levels in cotton gin byproducts, known concentrations of chemicals were added to the cotton gin byproducts. Application of additional chemicals, in known quantities, ensured chemical presence in all the cotton gin byproducts used in the study. In this way, a relatively uniform minimum level of chemical concentrations was established in the initial samples before extrusion. Application of these chemicals to cotton gin byproducts after ginning allowed the chemical residue analyses to focus on specific residues, thereby increasing the efficiency and precision of the residue analyses.

Five chemicals commonly used in cotton (based on J.R. Williford's recommendation, personal communication, 1998) were applied to cotton gin byproducts: 1) tribufos [S,S,S-Tributyl phosphorotrithioate] (DEF 6, Bayer, Kansas City, MO); 2) thidiazuron; 3) methyl parathion; 4) ethephon [(2-Chloroethyl) phosphonic acid] (Prep, Aventis, Research Triangle Park, NC); and 5) lambda cyhalothrin [alpha-cyano-3-phenoxybenzyl 3-(2-chloro-3,3,3-trifluoropropenyl)-2,2-dimethylcyclopropanecarboxylate; a 1:1 reaction mixture of the (Z)-(1R,3R), (S) ester and (Z)-(1S,3S), (R) ester] (Karate, Syngenta, Greensboro, NC).

Because tribufos is commonly applied before harvesting, it probably is the most highly concentrated residue found in gin byproducts (W.D. Mayfield, personal communication, 1994). Tribufos applied at 0.8% of the normal application rate represented the high end of the expected chemical residue range for it in cotton gin byproducts, excluding major statistical outliers (unpublished data, USDA-ARS, Cotton Ginning Res. Unit, Mesilla Park, NM). The five selected chemicals were applied to the cotton gin byproducts at 0.8% of the normal application

---

Mention of a trade name, propriety product or specific equipment does not constitute a guarantee or warranty by the U.S. Department of Agriculture and does not imply approval of a product to the exclusion of others that may be suitable.

rates, or 1.12, 0.18, 0.90, 0.45, and 0.11 kg km^{-2} for tribufos, thidiazuron, ethephon, methyl parathion, and lambda cyhalothrin, respectively.

Application of the chemicals to cotton gin byproducts was performed at the U.S. Cotton Ginning Laboratory. The cotton gin byproduct material was spread in a thin layer on a plastic sheet. The Application and Production Technology Research Unit of the USDA-ARS in Stoneville used a side-boom spray rig mounted on a tractor to apply the chemicals one at a time to the cotton gin byproducts in pre-discussed concentrations. After the recommended re-entry period, the cotton gin byproduct was baled. The cotton gin byproduct bales and cottonseed were then shipped to Des Moines, Iowa, for extrusion.

The commercial-scale extruding machinery at the Insta-Pro International Research and Development Facility in Des Moines was used in this study. Both sections of this study used the Insta-Pro Model 2500 extruder followed by an Insta-Pro air-type belt drier to cool the material. This extruder was a single-screw, adiabatic extruder that generated heat through friction. Commonly referred to as a high-temperature, short-time extruder, it can achieve temperatures up to 180°C in >20 s. The inside diameter of the barrel was 16.5 cm, the overall length was 107 cm. It was configured with two compression chambers and a constant diameter screw, as shown in Fig. 1. Change in pitch of the worm flights caused compression in the extruder. Shear was controlled through the selection of the size of the steamlocks and screw flight, and by adjustment of the nose bullet and cone in the last chamber of the barrel. The barrel wall and steamlocks were grooved to allow more mixing and shearing (Said, 2000).

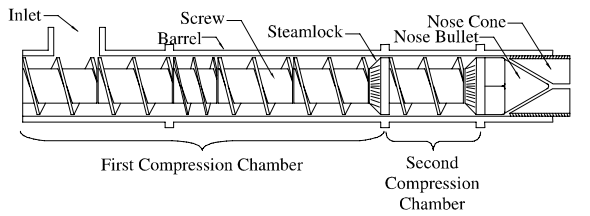

Figure 1. A cross-sectional view of the barrel of the Insta-Pro Model 2500 extruder that was built at the Pro International Research and Development Facility in Des Moines, Iowa, and used in this study.

Material was fed into the top of the extruder through an electronically controlled volumetric feeder equipped with an agitator, which provided a uniform and free flow of material. After material had entered the inlet chamber, it was forced into the first steamlock by the screw. Grooves in the steamlock walls allowed for a gradual buildup in pressure as the material passed through the compression chambers. When the material reached the last chamber, which contained the nose bullet and cone, a maximum pressure of 2750 kPa was achieved.

Mixing Ratio Study

Mixing ratios of cotton gin byproducts and cottonseed were based on recommendations from Thomasson et al. (1998), which suggested that mixing ratios composed of <25% cottonseed produced a loose and fluffy product. Mixing ratios used in this study were 25:75, 30:70, 40:60, 50:50, and 60:40 (% cottonseed:% cotton gin byproducts). Three replicates of each mixing ratio, a total of 15 test lots, were performed,. Each test lot consisted of 46 kg material.

At various stages in the preparation process, samples of cotton gin byproduct, cottonseed, and the five mixtures of these two products were collected for chemical residue and nutritional analysis. Each sample consisted of 10 subsamples taken from random locations within the lot. Before the chemicals were applied to the cotton gin byproducts, five random samples were taken for chemical residue analysis. These samples generated the base residue levels, which were compared to samples collected before mixing to determine the amounts of additional chemicals that settled on the cotton gin byproducts during chemical application.

Prior to mixing the cotton gin byproducts and cottonseed, a total of 13 cotton gin byproduct and three cottonseed samples were taken randomly for residue and nutritional analyses. Ten cotton gin byproduct samples were used for residue analyses; three cotton gin byproduct and three cottonseed samples were used for initial nutritional analyses.

Before each cotton gin byproduct and cottonseed mixture was extruded, six random samples were taken. Five of the individual samples were blended together for chemical residue analysis, and one sample was used to determine the nutritional value of the mixture.

After the extrusion process, six random samples were collected. Residue analyses were performed on a sample that was blended from five of the collected samples, and one sample was used

to determine the nutritional value of the mixture. The Alabama State Pesticide Laboratory at Auburn University analyzed chemical residue samples and Dairy One in Ithaca, New York, analyzed nutritional samples for ration balance and ash analyses.

The experimental design was completely randomized with treatments replicated three times. Data were subjected to analysis of variance, and means were separated by Waller-Duncan's multiple-range test with the threshold for significance set at $P = 0.05$.

Multiple-pass Study

During the multiple-pass study, an extruder temperature range of 129 to 140°C was maintained; 95 to 100 A were used to operate the extruder. The water injection rate was held constant at 19 L h^{-1}. The mixing ratio was 75% cotton gin byproducts to 25% cottonseed. The samples collected during the study were analyzed for methyl parathion, tribufos, thidiazuron, and lambda cyhalothrin chemical residues.

The multiple-pass extrusion process required a total of 125 kg material for each of the three replications performed. The lot size was based on an estimate of the amount of material required to reach steady-state conditions minus the amount of material collected for samples after each pass. After the material was mixed, it was fed through the extruder, then through a cooler. Samples for chemical residue and nutritional analyses were collected in the same manner as the mixing ratio test.

After initial samples were collected, the entire sample was processed through the extruder and cooler, followed by sample collection; then the sample was reprocessed through the extruder and cooler. After the material exited the system for the second time, samples were collected for the same analyses and in the same manner as in the first pass. This process was repeated two additional times with samples collected after each pass. Nutritional samples were shipped to the same laboratory as the samples collected in the mixing ratio test. The Mississippi State Chemical Laboratory at Mississippi State University analyzed the chemical residue samples.

The experimental design was a randomized complete block with treatments replicated three times. Data were subjected to analysis of variance, and means were separated by Waller-Duncan's multiple-range test at $P = 0.05$. No interactions were observed between treatments and blocks; further, the blocks did not significantly impact the analyses.

RESULTS

Originally, the mixing ratio and multiple-pass extrusion studies were to focus on five chemical residues: tribufos, thidiazuron, ethephon, methyl parathion, and lambda cyhalothrin. After both laboratories began analyzing the samples, ethephon analysis was not completed due to potential accuracy problems associated with the chemical properties and analysis procedures. Due to time and resource constraints at Alabama State Pesticide Laboratory, thidiazuron analyses were not conducted on the mixing ratio study.

Mixing Ratio Study

During the mixing ratio study, an internal extruder temperature of 130 to 135°C was maintained; ~95 to 100 A were used to operate the extruder. The water injection rates were 38, 38, 30, 11, and 8 L h^{-1} for the 75, 70, 60, 50, and 40% cotton gin byproduct mixtures, respectively. The production rates were 500, 568, 646, 750, and 791 kg h^{-1} (wet basis) for the 75, 70, 60, 50, and 40% cotton gin byproduct mixtures, respectively. As expected, the water injection rates decreased and the production rates increased as the percentage of cottonseed in the mixture increased.

Before additional chemicals were applied, cotton gin byproduct samples contained 0.48 mg kg^{-1} tribufos and no detectable concentrations of methyl parathion or lambda cyhalothrin. Chemical residue levels were expected to deviate slightly from the amount applied to the material due to: 1) the natural breakdown of the chemicals between times of application and extrusion and 2) losses associated with the application process. The chemical residue results of the mixing ratio study are presented in Table 1 by mixing ratio and processing method, extruded or non-extruded. Based on the chemical residue analyses before chemical application and before extrusion, there were large deviations in the target and actual chemical residue levels in the cotton gin byproducts. For example, the target level of tribufos (for this test) was 38 mg kg^{-1}, but the level obtained was ~20 mg kg^{-1}. Therefore, the range of

Table 1. Chemical residues for various mixing ratios of cotton gin byproducts (CGBP) and cottonseed.†‡

CGBP	Methyl parathion		Tribufos		Lambda cyhalothrin	
Non-extruded	Extruded	Non-extruded	Extruded	Non-extruded	Extruded	
%	mg kg^{-1}					
100	3.44	-§	19.90	-	0.66	-
75	2.96a	2.28b	19.90a	11.56b	0.47a	0.35a
70	3.16a	2.56b	16.27a	9.95b	0.49a	0.43a
60	2.57a	1.62b	9.01a	5.40a	0.43a	0.34a
50	2.37a	1.80b	11.79a	6.67a	0.68a	0.38a
40	1.74a	1.21b	6.81a	4.58a	0.46a	1.17a
0¶	0	-	0	-	0	-

† All chemical residue values are based on dry matter.
‡ Means in a row for a given chemical not having a letter in common are significantly different at *P*= 0.05 according to the Waller-Duncan's multiple-range test.
§ Not reported.
¶ No additional chemicals were applied to the cottonseed.

differences for non-extruded vs. extruded that are presented in Table 1 are based on extremely low levels of methyl parathion and lambda cyhalothrin, especially.

As expected, significant reductions of chemical residues were detected with the addition of cottonseed that was not sprayed with additional chemicals. These reductions represent a dilution effect. Based on the information in Table 1, methyl parathion levels were decreased by ~50% in the 40% cotton gin byproducts plus 60% cottonseed mixtures when compared with its residue level in 100% cotton gin byproducts. Similar results were observed for tribufos and lambda cyhalothrin. Generally, the residue levels decreased as the percentage of cottonseed in the mixture increased.

Table 1 also shows the differences in chemical residue levels for the extruded vs. non-extruded material for given mixing ratios. The 100% cotton gin byproduct samples were collected after chemical application and before mixing. They show that the chemical application process increased the chemical residue levels to 3.44, 19.9, and 0.66 mg kg^{-1} for methyl parathion, tribufos, and lambda cyhalothrin, respectively. Table 1 shows that the extrusion process significantly (α= 0.05) reduced levels of methyl parathion in all mixing ratios used in this study.

The extrusion process also significantly reduced tribufos chemical residue levels at the 70 and 75% cotton gin byproduct ratio but did not significantly affect (α = 0.05) the other ratios, although the apparent decrease was ~40% for all mixing ratios. Lambda cyhalothrin was not significantly affected by extrusion in the mixing ratio study; however, it should be noted that lambda cyhalothrin residue levels were <1 mg kg^{-1} prior to extrusion. A statistical outlier in the lambda cyhalothrin data set with a value of 3 mg kg^{-1} was observed for the extruded 40% cotton gin byproduct material, which greatly affected the reported mean.

The chemical residue analyses from the mixing ratio study were adjusted by the percentage of cotton gin byproduct weight in the mixture to compare the effect of extrusion on methyl parathion, tribufos, and lambda cyhalothrin residues. Table 2 shows the adjusted chemical residue levels. Methyl parathion and tribufos were shown as lowered significantly by extrusion, whereas lambda cyhalothrin levels were unaffected. An outlier in the lambda cyhalothrin data set skewed its extruded residue level (Table 2). If the outlier were omitted from the lambda cyhalothrin data set, a significant decrease of 34% would have been observed for the composite extruded material. The estimated reduction rates that are owing to the extrusion process for methyl parathion and tribufos were 27 and 40%, respectively.

Table 2. Chemical residues based on mixing ratio information and adjusted by cotton gin byproduct weight.†‡

Processing method	Methyl parathion	Tribufos	Lambda cyhalothrin
	mg kg^{-1}		
Non-extruded	4.37a	21.08a	0.91a
Extruded	3.20b	12.68b	1.06a

† All chemical residue values are based on dry matter.
‡ Means in a column not having a letter in common are significantly different at *P* = 0.05 according to the Waller-Duncan's multiple-range test.

Nutritional values for the extruded mixtures of cotton gin byproducts and cottonseed are shown in

Table 3. The significant differences in several of the nutritional components were expected due to the varying amount of cotton gin byproducts. Crude protein, net energy of maintenance, net energy of gain, and total digestible nutrients increased significantly; whereas, acid detergent fiber and ash content decreased as the percentage of cottonseed increased. As expected, the nutritional value of the product increased as the percentage of cottonseed increased in the mixture. The effects of extrusion on nutritional value will be discussed in the multiple-pass extrusion section below.

Multiple-pass Study

Chemical residue results of this study, based on the number of times the material was processed, are shown in Table 4, and those based on a composite summary in Table 5.

In the multiple-pass extrusion study, methyl parathion was not significantly affected by the first two stages of extrusion ($\alpha = 0.05$); however, the residues were reduced significantly by the third stage of extrusion. The residue means continually decreased with increased processing. In a comparison of non-extruded vs. extruded

Table 3. Nutritional values of non-extruded cottonseed (CS) and cotton gin byproducts (CGBP) and various mixing ratios of extruded cotton gin byproducts and cottonseed.†‡

	Non-extruded		Extruded				
Nutrient value	100% CS	100% CGBP	25% CS	30% CS	40% CS	50% CS	60% CS
Crude protein, %	30.0a	15.5d	16.6cd	17.4cd	17.7cbd	19.1bc	20.1b
Adjustable crude protein, %	30.0a	15.5d	16.6cd	17.4cd	17.7cbd	19.1bc	20.1b
Soluble protein, %	21.7a	19.0a	14.8a	16.5a	9.8a	23.0a	14.8a
Acid detergent fiber, %	30.3b	46.5a	47.3a	47.1a	44.5a	46.7a	43.8a
Neutral detergent fiber, %	41.5c	51.8b	56.0ab	58.1a	54.5ab	55.1ab	53.0ab
Total digestible nutrients, %	80.0a	37.3f	41.5de	40.3e	42.8cd	44.5bc	45.7b
Net energy of maintenance, MJ kg^{-1}	8.76a	3.39f	3.85de	3.69e	3.98cd	4.15bc	4.23b
Net energy of gain, MJ kg^{-1}	6.45a	0.17e	0.75d	0.54 de	0.92cd	1.09bc	1.30b
Calcium, %	0.19e	2.11a	1.92ab	1.90ab	1.69bc	1.39cd	1.10d
Phosphorus, %	0.84a	0.26e	0.41d	0.42d	0.49c	0.56b	0.61b
Magnesium, %	0.40a	0.34b	0.35b	0.36ab	0.38ab	0.38ab	0.37ab
Potassium, %	1.22c	1.61a	1.64a	1.63a	1.53ab	1.57ab	1.48b
Sodium, %	0.004e	0.049ab	0.051a	0.047ab	0.042bc	0.035c	0.026d
Iron, mg kg^{-1}	86e	1043a	554bc	631b	581b	400d	428dc
Zinc, mg kg^{-1}	41a	30cd	29d	33bc	35b	33bc	35b
Copper, mg kg^{-1}	5.67a	4.00b	4.33b	4.50b	5.00ab	4.50b	4.83ab
Manganese, mg kg^{-1}	14e	83a	59bc	63b	59bc	48cd	44d
Molybdenum, mg kg^{-1}	1.20b	1.73a	1.25b	1.47ab	1.50ab	1.42b	1.35b
Sulfur, %	0.29c	0.39a	0.37ab	0.37ab	0.35ab	0.32bc	0.32bc
Ash, %	-§	-	12.1ab	12.5a	11.3b	9.1c	8.6c

† All nutritional values are based on dry matter.

‡ Means in a row not having a letter in common are significantly different at *P* = 0.05 according to the Waller-Duncan's multiple-range test.

§ Not reported.

Table 4. Chemical residues for 75% cotton gin byproducts plus 25% cottonseed mixture that was extruded multiple times.†‡

	Methyl parathion		Tribufos		Lambda cyhalothrin		Thidiazuron	
Times processed	Mean	SD	Mean	SD	Mean	SD	Mean	SD
	mg kg^{-1}		mg kg^{-1}		mg kg^{-1}		mg kg^{-1}	
0	12.8a	5.3	46.4b	7.1	3.9a	2.2	8.33a	1.20
1	9.4ab	1.3	71.1a	9.3	3.0a	0.5	0.41b	0.17
2	7.9ab	3.0	63.8ab	17.6	2.6a	0.3	0.39b	0.12
3	4.4b	2.1	63.6ab	14.0	2.5a	0.5	0.38b	0.22
4	3.1b	0.9	67.0ab	16.9	3.3a	1.7	0.34b	0.10

† All chemical residue values are based on dry matter.

‡ Means in a column not having a letter in common are significantly different at *P* = 0.05 according to the Waller-Duncan's multiple-range test.

Table 5. Chemical residues for 75% cotton gin byproduct and 25% cottonseed mixtures.†‡

Processing	Methyl parathion		Tribufos		Lambda cyhalothrin		Thidiazuron	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
	mg kg^{-1}		mg kg^{-1}		mg kg^{-1}		mg kg^{-1}	
Non-extruded	12.8a	5.3	46.4b	7.1	3.9a	2.2	8.33a	1.12
Extruded	6.2b	3.2	66.4a	13.0	2.8a	0.9	0.38b	0.14

† All chemical residue values are based on dry matter.

‡ Means in a column not having a letter in common are significantly different at *P* = 0.05 according to the Waller-Duncan's multiple-range test.

Table 6. Nutritional values for 75% cotton gin byproducts and 25% cottonseed extruded multiple times. †‡

Nutrient value	Pass 0	Pass 1	Pass 2	Pass 3	Pass 4
Crude protein, %	18.7ab	19.7a	18.1bc	17.0c	16.9c
Adjusted crude protein, %	18.7ab	19.7a	18.1bc	17.0c	16.9c
Soluble protein, %	20.0a	14.0b	14.7b	14.7b	14.3b
Acid detergent fiber, %	52.2ab	49.0b	52.1ab	53.9ab	54.7a
Neutral detergent fiber, %	60.1bc	59.2c	63.4abc	66.2a	64.7ab
Total digestible nutrients, %	43.8ab	44.3a	42.7abc	41.7c	42.3bc
Net energy of maintenance, MJ kg^{-1}	2.85ab	2.93a	2.68abc	2.47c	2.60bc
Net energy of gain, MJ kg^{-1}	0.63ab	0.71a	0.42abc	0.29c	0.38bc
Calcium, %	1.45ab	1.67a	1.48ab	1.41b	1.39b
Phosphorus, %	0.43b	0.48a	0.44b	0.41b	0.42b
Magnesium, %	0.33bc	0.37a	0.34b	0.32c	0.33bc
Potassium, %	1.44	1.45	1.44	1.41	1.43
Sodium, %	0.018	0.019	0.018	0.017	0.018
Iron, mg kg^{-1}	1127	1290	1270	1157	1377
Zinc, mg kg^{-1}	147	158	159	144	14
Copper, mg kg^{-1}	6.83	7.33	7.33	6.67	6.67
Manganese, mg kg^{-1}	57	63	59	56	57
Molybdenum, mg kg^{-1}	0.90	1.03	1.17	0.90	1.27
Sulfur, %	0.30ab	0.32a	0.30ab	0.29ab	0.28b

† All nutritional values are based on dry matter.

‡ Means in a row not having a letter in common are significantly different at P = 0.05 according to the Waller-Duncan's multiple-range test. Where letters are not shown, the differences were not significant.

material, the methyl parathion residue levels were significantly decreased (α = 0.05 level) by the extrusion process. Sample standard deviations were also lower for the extruded material as compared with the non-extruded material. The residue levels appeared to be reduced by ~52%, based on composite means.

Tribufos residue results were highly variable, and the residue levels of the non-extruded material were significantly lower than the levels of the material processed through the extruder one time. tribufos residues were significantly increased by extrusion (Table 5). Because there is no logical explanation for such an increase, the results likely represent an anomaly caused by an unknown problem with the residue analysis. No meaningful information about the effects of extrusion on tribufos residue levels was obtained in this study.

Lambda cyhalothrin residue results for the multiple-pass study are similar to the results obtained in the mixing ratio study. Residue levels were not significantly impacted by increased processing, although levels appeared to decrease with increased processing. The composite means (Table 5) show an apparent decrease in lambda cyhalothrin levels of ~28%; however, this decrease is not significant at the 0.05 level. Residue sample standard deviations also were lower in the extruded material, as compared with the non-extruded material.

Thidiazuron residues were reduced significantly by the first pass of extrusion and appeared to decrease continually with additional processing. The composite means were decreased significantly, by ~95%. In addition, the thidiazuron sample variance was lower in the extruded material than in the non-extruded material.

Several significant differences in nutritional values were detected in the multiple-pass extrusion study (Table 6). Crude protein, adjusted

crude protein, total digestible nutrients, net energy of maintenance, and net energy of gain were significantly lowered at the 0.05 level. Most of these decreases appeared to be minor in comparison to the significant decrease in soluble protein. Soluble protein was reduced by ~30%, based on means taken before extrusion and after the first pass of extrusion. Significant differences in acid detergent fiber and neutral detergent fiber were detected between treatments. These differences could not be attributed to the extrusion process, because the differences typically did change with increased processing. Generally, fiber values decreased after the first pass of extrusion and they slightly increased and/or decreased with additional processing. No significant differences at the 0.05 level were detected in mineral values, except for P and Mg. The differences in P and Mg were similar to the differences detected in the fiber values and were not attributed to the extrusion process.

CONCLUSIONS

The ability to use cotton gin byproducts in livestock rations could increase gin profits, reduce landfill disposal, and generate an alternative roughage-type feed for the livestock industry. The primary concern associated with feeding cotton gin byproducts to livestock is the potential for harmful chemical residues in the material. An extrusion process was evaluated to determine the chemical residue reductions associated with this processing method.

Cotton gin byproducts used in this study (mainly soil, leaf material, and fiber) from picker-harvested cotton had a relatively low percentage of burs as compared with stripper-harvested cotton. Because cotton gin byproducts have a tendency to ball up and hang in the extruder barrel, a lubricating substance, such as cottonseed, had to be added for the material to flow through the extruder. Based on preliminary extrusion tests, the minimum concentration of cottonseed in the mixtures to maintain a uniform material flow was 25%.

To evaluate the chemical residue reductions associated with the process, additional chemicals were applied to the cotton gin byproducts so specific residue analysis could be performed. Chemical application concentrations were 0.8% of generally recommended field application concentrations. Various mixing ratios of cotton gin byproducts and cottonseed were evaluated in terms of chemical residue reduction and nutritional value. Further, the extrusion process was evaluated in terms of material processing time.

During the study in which various mixing ratios of cotton gin byproducts and cottonseed were tested, the water injection rates decreased and production rates increased as the percentage of cottonseed in the mixture increased. Increases in the concentration of cottonseed in the mixtures enhanced nutritional values.

Chemical residues were significantly lowered by the addition of cottonseed to the mixture. Methyl parathion and tribufos were significantly reduced by the extrusion process – 27 and 40%, respectively. There was some evidence that lambda cyhalothrin levels were also reduced by the extrusion process, but these results likely were skewed by an outlier in the data set.

Based on the multiple-pass extrusion study, methyl parathion and thidiazuron residues can be reduced by extruding the material multiple times or by increasing the material dwell time. Methyl parathion and thidiazuron residue levels were significantly reduced by approximately 52 and 95% as a result of the extrusion process. Lambda cyhalothrin levels were not significantly reduced by the extrusion process; however, an apparent decrease of 28% was observed between composite means in non-extruded and extruded material.

Extruding the material multiple times produced significant differences in several of the analyzed nutritional values. Crude protein and total digestible nutrients were approximately 10 and 4% higher for the non-extruded material as compared with the material that was extruded four times. The most notable change in the nutritional values was soluble protein that decreased by ~30% after the first pass of extrusion.

Although this study indicates that methyl parathion, tribufos, and thidiazuron residues are reduced by the extrusion process, further work is needed to determine the expected chemical residues and residue levels in cotton gin byproducts across the Cotton Belt. Lowering residue levels in cotton gin byproducts by extrusion may be a step in the right direction. However, until residue tolerances for cotton gin byproducts are established by EPA, it will be difficult to determine whether extrusion alone

will permit the safe feeding of cotton gin byproducts in all areas of the Cotton Belt.

ACKNOWLEDGMENTS

The author thanks Burdette Gin Co.; Application and Production Technology Unit, USDA-ARS, Stoneville, MS; Insta-Pro International; Danny LeCompte, Auburn University; the Cotton Foundation; Southern Cotton Ginners Association.

REFERENCES

Cornett, S. 1991. It's no fairy tail. Beef. Sept. p. 6-8.

Kolarik, W.J., W.F. Lalor, and M.L. Smith. 1978. Cotton gin waste in Texas. The Cotton Gin and Oil Mill Press. 79(22): 14-16.

Lalor, W.F., J.K. Jones, and G.A. Slater. 1975. Cotton gin trash as a ruminant feed. The Cotton Gin and Oil Mill Press. 76(6): 28-29.

Parnell, C.B. Jr., E.P. Columbus, and W.D. Mayfield. 1994. Abatement of air pollution and disposal of gin waste. p. 172-194. *In* Cotton Ginners Handbook. USDA-ARS Agric. Handb. 503. U.S.Gov. Print Office, Washington, DC.

Pendleton, A.M. and V.P. Moore. 1967. Ginning cotton to preserve fiber quality. USDA-Fed. Ext. Serv. Publ. ESC-560. U.S.Gov. Print Office, Washington, DC.

Reeves, B.G. 1977. Using trash fuel saves $, but more research needed. Cotton International Edition. p. 78-82.

Sagebiel, J.A., and N. Cisse. 1984. Feeding cotton gin trash to wintering pregnant beef cows. Proc. Am. Soc. Anim. Sci., West. Sect. 33:130-133.

Said, N.W. 2000. Dry extruders. p. 51-62. *In* M.N. Riaz (ed.) Extruders in food applications. Technomic Publ., Lancaster, PA.

Swanson, D. 1998. Ginners' groups meet with EPA to discuss feeding of gin byproducts. The Cotton Gin and Oil Mill Press. Editor. 99(25):7-8.

Thomasson, J.A. 1990. A review of cotton gin trash disposal and utilization. p. 689-705. *In* Proc. Beltwide Cotton Prod. Res. Conf., Las Vegas, NV. 9-14 Jan. 1990. Natl. Cotton Counc. Am., Memphis, TN.

Thomasson, J.A., W.S. Anthony, J.R. Williford, W.H. Johnson, S.R. Gregory, M.C. Calhoun, R.L. Stewart. 1998. Processing cottonseed and gin waste together to produce a livestock feed. p. 1695-1698. *In* Proc. Beltwide Cotton Conf., San Diego, CA. 5-9 Jan. 1998. Natl. Cotton Counc. Am., Memphis, TN.

Williams, G.F., P. Piumsomboon, P.D. Hickman, and C.B. Parnell Jr. 1982. A simulation model for using cotton gin trash as a cattle feed supplement. ASAE 82-5025. ASAE Publ., St. Joseph, MI.

Williford, J.R., A.D. Brashears, and G.L. Barker. 1994. Harvesting. p. 15. *In* Cotton Ginners Handbook. USDA-ARS Agric. Handb. 503. U.S. Gov. Print Office, Washington, DC.