Abstract

Byproduct as whole cottonseed (WCS) and soybean hulls are quite used in finishing diets to feedlot lambs and WCS is a potential source to be included in lambs diet when prices are advantageous. The most part of the studies with WCS is used as a replacement of cereals as corn. Thus, this study was conducted to evaluate the effect of replacing a fibrous by-product (soybean hulls) with increasing levels of WCS (0, 10 and 20%) on the performance, carcass traits and meat quality of feedlot lambs. Thirty crossbred lambs (15 males and 15 females, 20±1.6 kg) were fed 1 of 3 high concentration diets: CTL (without WCS), WCS10 (with 10% WCS), and WCS20 (with 20% WCS) in a block design (sex) for 56 days. Feeding 10 or 20% WCS significantly (P=0.013) improved the feed conversion without affecting the final weight gain, average daily gain or dry matter intake in kg/d. However, the DMI (in %) of live weight was affected by treatments (P<0.0001): lambs fed the CTL and the WCS10 diet consumed more DMI than the lambs from WCS20 diet (4.19, 4.03 and 3.6%, respectively). The hot carcass weight, dressing percentage, longissimus muscle area and fat thickness were not affected by the WCS levels. The shear force and meat colour were similar among treatments. These results suggested that fattening lambs may benefit from an increase in feed efficiency from 10% WCS up to 20% without negatively impacting carcass and meat quality.

Introduction

Whole cottonseed (WCS) is a byproduct of the textile industry that contains high levels of oil, protein and fibre and can be used to reduce ruminal problems in high concentration diets due to its slow nutrient release (Martin, 1990). Moreover, WCS has high levels of fatty acids, which may lead to increased weight gain and greater fat deposition in the carcass (Calkins and Hodgen, 2007).

A major limitation for using cotton by-products in animal nutrition is the presence of high levels of gossypol, which is a toxic compound. However, ruminants have the ability to detoxify large amounts of gossypol within the rumen (Reiser and Fu, 1962). Whole cottonseed is a low-cost byproduct, which can help to reduce feedlot costs. Soybean hulls are also a byproduct and an alternative fibre source that may be used to maintain neutral detergent fibre while increasing the energy concentration of ruminant diets (Araujo et al., 2008). However, when prices are at an advantage compared to soybean hulls, WCS could be potentially used as a feed source for lambs diet.

In some studies concerning the effects of WCS as a replacement of cereals (Cunha et al., 2008; Dayani et al., 2011; Kandalys et al., 1998; Lugnibuhl et al., 2000; Moore et al., 1994) on the performance and carcass traits of sheep and goats contradictory results have been reported. Moreover, there is a lack of results about the effects of the replacement of fibrous by-products (as soybean hulls) by WCS on performance and meat quality of lambs. Thus, we hypothesised that through replacing a fibrous by-product like soybean hulls with different WCS levels we can increase the feed efficiency of lambs and meat quality. Therefore, the objective of the current study was to evaluate the effect of the replacement of a fibrous by-product (soybean hulls) with increasing levels of WCS (0, 10 and 20%) on performance, carcass traits and meat quality of male and female crossbred lambs during feedlot fattening.

Materials and methods

Animals and diets

All animals were managed under approved animal care and use guidelines. The experiment was carried out in Pirassununga, state of São Paulo, Brazil (21°59’45” S; 47°25’32” W; altitude 610 m).

This study was conducted with 15 female and 15 male crossbred lambs (fifty days of age) with an initial mean body weight (BW) of 20±1.6 kg. The crossbreeds were from two genetic groups: i) crosses between a Dorper ewe and Texel ram, and ii) crosses between a Dorper ewe and Santa Inês ram. The animals were allocated in three treatments of ten lambs per treatment in a randomised block design. After completion of the sanitary management against endo- and ecto-parasites, 28 lambs were housed in collective pens (two animals per pen) and 2 lambs were housed in individual pens, with dimensions of 1.20 x 2.00 m with a concrete floor, feed bunk and water trough.

The experimental period was 56 days, preceded by seven days for the management of and adaptation to the diets. The lambs were fed diets ad libitum once a day (07:00), and the amount of feed offered per animal was recorded and adjusted according to daily feed orts and calculated not to exceed 10% of the total weight of the diet. Fresh and clean water was available at all times.

Treatment diets had increasing levels of WCS as follows: i) control (CTL) without WCS, ii) 10% WCS (10WCS), and iii) 20% WCS (20WCS). The most part of the studies with WCS is used as a replacement of cereals as corn.
(20WCS), on a dry matter (DM) basis. The ingredient proportions and the nutrient composition of the experimental diets are presented in Table 1. The experimental diets were formulated and calculated according to the National Research Council (1985).

The feed and ors samples were weighed and sampled three times per week to determine the dry matter, estimated consumption, and feed efficiency. Samples of the concentrate mixtures and forage were collected and stored at -20°C for subsequent analyses as follows: DM, organic matter (OM), mineral matter (MM), ether extract (EE), crude protein (CP), neutral detergent insoluble nitrogen (NIDN), acid detergent insoluble nitrogen (ADIN) and lignin according to the methods described by AOAC (2005). The contents of the neutral detergent fibre (NDF), ash- and protein-free neutral detergent fibre (apNDF) and acid detergent fibre (ADF) were obtained according to a method described by Van Soest et al. (1991). The dietary metabolisable energy (ME) was determined using the small ruminant nutrition system, version 1.8.0 (Cannas et al., 2004).

Animal weights were determined every 14 days after complete fasting for 16 hours, for a total of four weightings and four periods. The individual lamb average daily gain (ADG) was calculated as the difference between weights over the period.

The performance evaluation was computed from the measurements taken throughout the trial period. The feed efficiency (GF) and dry matter intake (DMI) were calculated in kg/day.

Carcass and meat quality analysis

At the end of the experiment (56 days) all of the animals (hundred and thirteen days of age) were slaughtered on the same day. The dressing percentage was calculated by the ratio of hot carcass weight and carcass weight at slaughter × 100. Carcass (left side) then was divided between the 12th and 13th ribs to determine the longissimus muscle area and the fat thickness (FT) through a boxed grid in square centimeters (cm²). The FT was obtained ¼ distance from the medial side of longissimus dorsi to its lateral midline side.

During the deboning, three steaks of longissimus muscle with 2.5 cm of the left half of the carcass of each animal were removed, which were then identified and vacuum-packed. A steak from each animal was frozen at -20°C for a posterior objective analysis of tenderness and colour. After thawing for 24 h at 0°C, the steaks were unpacked and rested with the surface exposed to the environment for 20 min for myoglobin oxygenation (Abularrach et al., 1998).

The colour of the steaks was determined with a portable colourimeter (MiniScan XE model; Hunter Lab, Reston, VA, USA), using the scale L*, a*, b* of the CIELab system, where L* is the luminosity associated with the chroma (L* 0 black, 100 white), a* is the chroma ranging from green (-) to red (+), and b* is the chroma ranging from blue (-) to yellow (+) (Houben et al., 2000). The measurements were taken on the surface of interest in three

| Item                          | Treatments |
|-------------------------------|------------|
| **Ingredient and chemical composition of the treatment diets.** |            |
| Item                          | CTL        | WCS10      | WCS20      |
| Ingredient proportions, % DM  |            |            |            |
| Corn silage                   | 10.00      | 10.00      | 10.00      |
| Corn grain (ground)           | 20.00      | 20.00      | 20.00      |
| Soybean meal                  | 2.00       | 0.00       | 0.00       |
| Urea                          | 1.00       | 0.88       | 0.58       |
| Trace mineralised salt        | 0.70       | 0.70       | 0.70       |
| Whole cottonseed              | 0.00       | 10.00      | 20.00      |
| Soybean hulls (pelleted)      | 66.00      | 58.00      | 49.00      |
| Rumensin                      | 0.03       | 0.03       | 0.03       |
| **Chemical composition**      |            |            |            |
| DM, %                         | 89.90      | 89.40      | 89.80      |
| CP, % DM                      | 12.60      | 12.80      | 13.80      |
| NDF, % DM                     | 45.30      | 42.20      | 42.50      |
| ADF, % DM                     | 39.50      | 37.10      | 36.80      |
| EE, % DM                      | 2.50       | 3.90       | 5.40       |
| Ash, % DM                     | 3.90       | 4.10       | 4.40       |
| ME, Mcal kg⁻¹                | 1.92       | 1.99       | 2.06       |

Table 1. Effect of whole cottonseed levels on performance of fattening crossbred lambs.

| Item                          | Treatments |
|-------------------------------|------------|
| Item                          | CTL        | WCS10      | WCS20      | SEM | P     |
| IBW, kg                       | 39.4       | 36.9       | 41.8       | 3.13 | 0.360 |
| FBW, kg                       | 61.1       | 62.0       | 67.3       | 4.68 | 0.423 |
| ADG, kg day⁻¹                  | 0.195      | 0.225      | 0.210      | 0.02 | 0.388 |
| DMI, kg day⁻¹                  | 2.08       | 1.95       | 1.89       | 0.15 | 0.339 |
| DMI, % LW                     | 4.19a      | 4.03b      | 3.66      | 0.09 | <0.0001 |
| ME intake, Mcal kg⁻¹           | 3.99       | 3.88       | 3.90       | 0.29 | 0.833 |
| G:F, total weight gain         | 168b       | 210a       | 208b       | 0.01 | 0.028 |

Table 2. Effect of whole cottonseed levels on performance of fattening crossbred lambs.

Carcasses were immediately weighed to obtain the hot carcass weight, and kept at room temperature (12°C) for 24 h. After that period carcasses were re-weighed, to obtain the cold carcass weight. The carcass pH and temperature were measured at one hour and at twenty-four hours post-mortem using a pH meter equipped with a penetrating glass elec-
different areas of each sample, and the averages were calculated. After this procedure, the steaks were wrapped in foil and cooked in an electric oven at 170°C until the meat internal temperature reached 65±5°C (AMSA, 1978), measured by individual analogue thermometers (Good Cook Meat Thermometer; Good Cook, Rancho Cucamonga, CA, USA) with a type sensor and a metal needle that was inserted into the centre of the steaks. Then, the steaks were cooled to 5°C for 12 hours in the refrigerator. Subsequently, six cylinders that were 12 mm in diameter were removed with an electric punch from each steak. The tenderness was determined using a Warner-Bratzler shear (WBS) force equipment (G-R Manufacturing Co., Manhattan, KS, USA) equipped with a WBS blade. The measurement was recorded as the average of a minimum of six replicates of the maximum force needed to shear the samples perpendicularly to the axis of the fibre direction.

Statistical analysis
The experimental unit was the pen for performance data, and the animal for carcass traits and meat quality. The block effect was sex (male and female). The effects of treatments were analysed using the PROC MIXED of SAS (version 9.1) according to the following model:

\[ Y_{ij} = \mu + B_i + T_j + e_{ijk} \]

where \( Y_{ij} \) is the dependent variable, \( \mu \) is the overall mean; \( B_i \) is block effect, \( T_j \) is fixed effect of WCS levels (0,10 and 20%), and \( e_{ijk} \) is the residual error.

The effects of treatments were determined with averages calculated by the LSMEANS submitted to the t-Test. The initial BW and carcass weight were included in the model as covariate respectively to performance and carcass variables. Block and covariate effect were removed from the model if no effect were observed for both.

Results and discussion
There were no significant block and covariate effects for any variables analysed.

The lambs presented similar DMI in kg/day (Table 2) although, the DMI in% of LW was affected by treatments: lambs fed the CTL and the WCS10 diet consumed more DM than the WCS20 treatment (4.19; 4.03 and 3.6%, respectively). Luginbuhl et al. (2000) and Moore et al. (1994) also reported an inhibitory effect of increasing levels of WCS on the DMI of meat goats and ewes, respectively, although in both studies Luginbuhl et al. (2000) and Moore et al. (1994) replaced corn by WCS unlike this study, which replaced soybean hulls by WCS. Regardless of the fact that WCS is replacing corn or soybean hulls in diets, the result is an increase in dietary fat content, which can affect negatively the DMI (Palmiquist, 1994).

There were no differences in the ADG (Table 2) among treatments. Nonetheless, the lambs fed the CTL (P=0.013) diet had a lower G:F (169 g/kg) than those fed the WCS10 (209 g/kg) and WCS20 (208 g/kg) diets. Similar to our findings, Cranston et al. (2014) evaluated cottonseed product diets (WCS and cottonseed hulls) with the same percentage of NDF as the control diet (without WCS) and observed lower DMI, similar ADG and better G:F for steers fed the WCS and cottonseed hulls diet compared to the CTL diet (without cottonseed).

Reasons for the increase in G:F by lambs fed the WCS diets compared with those fed the CTL diet are unknown, but possibly this result reflects a greater metabolisable energy (ME) concentration for the 2 WCS diets than for the CTL diet. Based on formulated values (Table 1), the CTL diet had a lower EM concentration (1.92 Mcal/kg) than the WCS diets (1.99 Mcal/kg, respectively). Hence CTL diet was less energy dense than the WCS diets. The EM intake (Table 2) was similar among treatments, probably due to the decrease in DM intake observed, since the intake of EM is the product of DM and diet EM (DM*EM).

The observed effects by WCS inclusion could also be explained by the increase of lipid content of the diets (Cunha et al., 2008). The high lipid content of WCS may depress cell-wall degradation (Moore et al., 1986), due to some mechanisms as the physical coating of fibre by lipids, the shortage of cations due to formation of insoluble soaps, the inhibition of rumen microbial activity, and modification of the microbial population (Dayani et al., 2011).

In the current study, the G:F was similar for both levels of WCS. On the contrary, Cunha et al. (2008) fed lambs with increasing levels of WCS (0, 20, 30 and 40%) and found that the ADG decreased, and the G:F showed a decreasing linear effect with the inclusion of WCS. Luginbuhl et al. (2000) also found lower ADG when feeding WCS to meat goats, though they – as Cunha et al. (2008) – used WCS to replace corn (unlike this study).

No carcass traits (hot carcass weight, dressing percentage, longissimus muscle area, fat thickness, renal pelvic and inguinal fat and pH) were affected by treatments (Table 3).

Table 3. Individual effects of whole cottonseed levels on carcass traits of fattening cross-bred lambs.

| Item                        | Treatments | CTL  | WCS10 | WCS20 | SEM  | P      |
|-----------------------------|------------|------|-------|-------|------|--------|
| Hot carcass weight , kg     |            | 14.9 | 15.2  | 16.9  | 1.03 | 0.376  |
| Dressing, %                 |            | 48.7 | 49.1  | 50.0  | 1.03 | 0.408  |
| Longissimus muscle area, cm²|            | 13.1 | 14.5  | 15.4  | 0.72 | 0.090  |
| Fat thickness, mm           |            | 2.6  | 3.2   | 3.4   | 0.65 | 0.738  |
| Renal pelvic and inguinal fat, kg |    | 0.33 | 0.40  | 0.42  | 0.10 | 0.284  |
| pH 1h                       |            | 6.2  | 6.3   | 6.2   | 0.08 | 0.670  |
| pH 24h                      |            | 5.5  | 5.5   | 5.6   | 0.05 | 0.407  |

Table 4. Individual effects of whole cottonseed levels on meat quality of fattening cross-bred lambs.

| Item                        | Treatments | CTL  | WCS10 | WCS20 | SEM  | P      |
|-----------------------------|------------|------|-------|-------|------|--------|
| WBS, kg                     |            | 3.74 | 2.77  | 2.23  | 0.32 | 0.090  |
| L*                          |            | 38.16| 38.60 | 37.70 | 1.35 | 0.986  |
| a*                         |            | 11.74| 11.52 | 11.59 | 0.46 | 0.625  |
| b*                         |            | 12.95| 13.49 | 12.59 | 0.51 | 0.524  |

CTL, diet without whole cottonseed; WCS10, diet with 10% whole cottonseed; WCS20, diet with 20% whole cottonseed.
Similarly, Cranston et al. (2006) found no differences on carcass characteristics when they evaluated WCS or pelleted cottonseed with the same percentage of NDF in finishing diets to feedlot steers.

The dressing percentage and renal pelvic and inguinal fat were not affected by WCS levels, indicating that most likely the WCS diets did not increase the fat deposition.

Neither WBS nor colour was affected by WCS levels (Table 4). Warner-Bratzler shear force values obtained in both treatments are low (CTL:3.7; WCS10:2.8; WCS20:2.2 kg) and characteristic of very tender meat (Santos-Silva et al., 2002). Few studies examining the inclusion of WCS in the diet of lambs have evaluated its effects on meat quality. Vieira et al. (2010) found that lambs fed increasing levels of WCS (0, 20, 30 and 40%) presented no differences in the WBS of the longissimus muscle area, similar to our findings.

There was no change of L*, a* and b* intensity when WCS was utilised in the diet. This possible similarity may be related to the similar ages of animals in this study, since the slaughter age could affect the colour of the lamb meat (Lanza et al., 2011).

Conclusions

When replacing fibrous byproduct (as soybean hulls) in finishing diet, the inclusion of WCS (10 and 20%) for fattening lambs is seemingly more efficient. These results suggest that fattening lambs may benefit from an increase in feed efficiency from 10% WCS up to 20% without negatively impacting the carcass and meat quality. Furthermore, WCS could be used as a sheep feed source for reduce feedlot costs according to its availability and price.

References

Abularach, M.L.S., Rocha, C.E., Felício, P.E., 1998. Quality traits of boneless rib cut (L. Dorsi muscle) from Nelore young bulls. Cienc. Tecnol. Aliment. 18:205-210.

Araujo, R.C., Pires, A.V., Susin, I., Urano, F.S., Mendes, C.Q., Rodrigues, G.H., Packer, I.U., 2008. Apparent digestibility of diets with combinations of soybean hulls and coastcross (Cynodon sp.) hay offered to ram lambs. Sci. Agric. 65:581-588.

AMSA, 1978. Guidelines for cookery and sensory evaluation of meat. American Meat Science Association, Chicago, IL, USA.

AOAC, 2005. Official methods of analysis. 18th ed. Association of Official Analytical Chemists, Gaithersburg, MD, USA.

Calkins, C., Hodgren, J., 2007. A fresh look at meat flavor. Meat Sci. 77:63-80.

Cannas, A., Tedeschi, L.O., Fox, D.G., Pell, A.N., Van Soest, P.J., 2004. A mechanistic model for predicting the nutrient requirements and feed biological values for sheep. J. Anim. Sci. 82:149-169.

Cranston, J.J., Rivera J.D., Galayan M.L., Brashears, M.M., Brooks, J.C., Markham, C.E., McBeth, L.J., Krehbiel, C.R., 2006. Effects of feeding whole cottonseed and cottonseed products on performance and carcass characteristics of finishing beef cattle. J. Anim. Sci. 84:2186-2199.

Cunha, M.G., Carvalho, F.E.R., Veras, A.S.C., 2008. Performance and apparent digestibility of feedlot sheep fed with different dietary whole cottonseed levels. Rev. Bras. Zootec. 37:1103-1111.

Dayani, O., Dadvar, P., Afsharmanesh, P., 2011. Effect of dietary whole cottonseed and crude protein level on blood parameters and performance of fattening lambs. Small Ruminant Res. 97:48-54.

Houben, J.H., Van Dijk, A., Elkelenboom, G., Hoving-bolink, A.H., 2000. Effect of dietary vitamin E supplementation, fat level and packaging on colour stability and lipid oxidation in minced beef. Meat Sci. 55:331-336.

Kandylis, K., Nikokryis, P.N., Deligiannis, K., 1998. Performance of growing fattening lambs fed whole cottonseed. J. Sci. Food Agr. 78:281-289.

Lanza, M., Fabro, C., Scerra M., Bella, M., Pagano, R., Brogna, D.M.R., Pennisi, P., 2011. Lamb meat quality and intramuscular fatty acid composition as affected by concentrates including different legume seeds. Ital. J. Anim. Sci. 10:87-94.

Luginbuhl, J.M., Poore, M.H., Corad, A.P., 2000. Effect of level of whole cottonseed on intake, digestibility and performance of growing male goats fed hay-based diet. J. Anim. Sci. 78:1677-1683.

Martin, S.D., 1990. Gossypol effects in animals can be controlled. The Miller Publishing Co., Minnetonka, MN, USA.

Ministério da Agricultura, 1997. Regulamento da Inspeção Industrial e Sanitária de Produtos de Origem Animal (RIISPOA). Aprovado pelo decreto n 30691 de 29 de março de 1952, alterado pelo Decreto 1253 de 25 de junho de 1962. Alterado pelo Decreto 2244 de 04/06/1997. Departamento Nacional de Inspeção de Produtos de Origem Animal, Brasília, DF, Brazil.

Moore, J.A., Poore, M.H., Pond, K.R., 1994. Performance of lambs fed varying levels of whole cottonseed. J. Anim. Sci. 72(Suppl.1):382.

National Research Council, 1985. Nutrient requirements of sheep. 6th ed. National Academy Press, Washington, DC, USA.

Palmquist, D.L., 1994. The role of dietary fats in efficiency of ruminants. J. Nutr. 124:1377-1382.

Reiser, R., Fu, H.C., 1962. The mechanisms of gossypol detoxification by ruminant animals. J. Nutr. 76:215-218.

Santos-Silva, J., Mendes, I.A., Bessa, R.J.B., 2002. The effect of genotype, feeding system and slaughter weight on the quality of light lambs. Growth, carcass composition and meat quality. Livest. Prod. Sci.76:17-25.

Van Soest, P.J., Robertson, J.B., Lewis B.A., 1991. Methods for dietary fibre, neutral-detergent fibre and nonstarch polysaccharides in relation to animal nutrition. J. Dairy Sci. 74:3583-3597.

Vieira, T.R.L., Cunha, M.G., Santos, D.S., Garrutti, T.F.D., Félix, S.S.S., 2010. Physical and sensorial properties of Santa Ines lamb meat terminated in diets with increasing levels of whole cotton seed (Gossypium hirsutum). Cienc. Tecnol. Aliment. 30:372-377.