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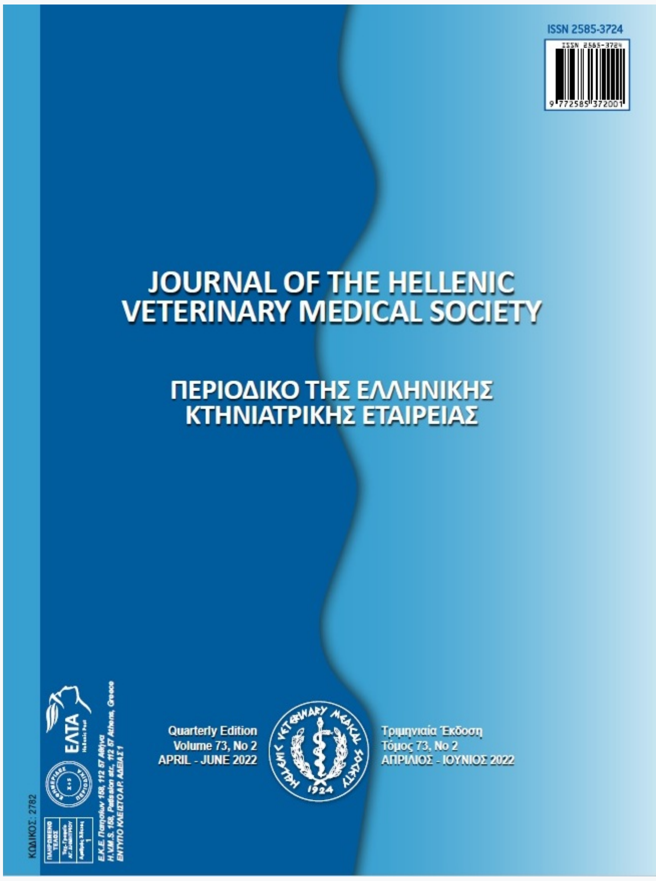

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Partial replacement of broom sorghum panicle residue and tallow with whole cottonseed in growing-finishing diets for lambs

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ABSTRACT: Sixty-four Pelibuey × Katahdin male lambs (14.3± 2.2 kg initial live weight) were used in an 84-d growing-finishing trial toevaluate optimal levels of inclusion of whole cottonseed (WCS) in a broom sorghum panicle residue-based diet. Dietary treatments consisted of partial replacement of broom sorghum panicle residue (SPR) and tallow with 0, 10, 20 or 30% WCS. Control diet contained 66.5% PSR and 3% tallow, and replacing were as follows: 10% of WCS replaced 9% SPR and 1% tallow (WCS10), 20% WCS replaced 18 SPR and 2% tallow (WCS20), and 30% WCS replaced 27% SPR and 3% tallow (WCS30). Inclusion of WCS increased (quadratic component, P=0.03) average daily gain (ADG), dry matter intake (DMI) and gain efficiency. However, with increasing level of WCS substitution the observed/expected dietary net energy ratio decreased (linear effect, P<0.01). The estimated NE_m value for WCS was determined by the replacement technique at the 10, 20 and 30% inclusion levels was 2.48, 2.23, and 2.15 Mcal/kg, respectively. Consistent with the increased final weight, hot carcass weight and *longissimus muscle* area were increased (linear effect, P≤0.03) with an increasing level of WCS inclusion. While, dressing percentage and fat thickness tended to increase (linear effect, P=0.10) with increasing WCS level. The partially replacement of broom sorghum panicle residue and tallow by up to 20% of WCS in finishing diets for lambs enhances ADG, gain efficiency, carcass weight, and LM area. However, the net energy value of WCS decreases with the level of inclusion greater than 10%.

Keywords: whole cottonseed, broom sorghum residue, tallow, lambs, performance, carcass

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INTRODUCTION

When priced competitively with corn, whole cottonseed (WCS) is a popular by-product feed for feedlot cattle and lambs. Whereas its tabular net energy value (2.40 Mcal/kg NE_m) is comparable with that of steam flaked corn, it also contains moderately high levels of crude protein (22-24%) and fiber (42-46% NDF; NRC, 2007). The high energy value of WCS is largely a reflection of its high (23%) fat content. *Sorghum panicle* residue (SPR), a byproduct of *Sorghum vulgare* (obtained in the manufacture of brooms and wisks), is also a popular substitute for grain in growing-finishing diets for feedlot lambs (Estrada *et al*., 2012). However, due to its high indigestible fiber content, its energy value is considerably lower than that of conventional feed grains (1.50 and 0.91 Mcal/kg NE_m and NE_g, respectively; Estrada-Angulo *et al*., 2019).When SPR-based finishing diets are fed to lambs supplemental fat and/or WCS may be added to increase diet energy density. However, the net energy value of WCS and fat can vary depending on ingredient replaced and its inclusion level, this mainly due to associative effects with other components (e.g. source of fiber) of diet (Zinn and Plascencia, 1993), or by the quantity of lipid ingested (Zinn and Jorquera, 2007). The influence of level of substitution on the replacement value of WCS for SPR in finishing diets for feedlot lambs has not been previously reported. The objective of the present study was to evaluate how level of substitution affects the feeding value of WCS in SPR-based finishing diets for feedlot lambs. Treatment effects will be assessed in terms of lamb growth performance, dietary net energy and carcass characteristics.

MATERIALS AND METHODS

This experiment was conducted at the Universidad Autónoma de Sinaloa Feedlot Lamb Research Unit, located in Culiacán, México (24° 46’ 13” N and 107° 21’14” W;55 m above sea level with a tropical climate). All animal management procedures were conducted within the following guidelines of locally approved techniques for animal use and care: NOM-051-ZOO-1995: Humanitarian care of animals during their mobilization; NOM-062-ZOO-1995: Technical specifications for the care and use of laboratory animals, livestock, farms, production, breeding and breeding centres, zoos and exhibition halls must comply with the basic principles of animal welfare; and NOM-024-ZOO-1995: Stipulations and characteristics of animal health during transport.

Diets, animals and experimental design

Six weeks prior to initiation of the study, 64 lambs (Pelibuey × Kathadin, 14.3± 2.2 kg initial live weight) were treated for endoparasites (Albendaphorte 10%, Animal Health and Welfare, México City, México), injected with $1x10^6$ IU vitamin A (Synt-ADE®, Fort Dodge, Animal Health, México City, México), and vaccinated for *Mannheimia haemolytica* (One shot Pfizer, México City, Mexico). Three weeks before starting the study all lambs were fed the basal diet (0% WCS, Table 1). Upon initiation of the 84-d trial, lambs were individually weighed and randomly assigned within four uniform weight groupings to 16 pens (4 lamb/pen).Individual pens were 6 m^2 with overhead shade, automatic waterers and 1 m fence-line feed bunks. Dietary treatments consisted in partial replacement of broom sorghum panicle residue and tallow with 0, 10, 20 or 30% of whole cottonseed as follows: Control diet contained 66.5% PSR and 3% tallow, and replacing were: 10% of WCS replaced 9% SPR and 1% tallow (WCS10), 20% WCS replaced 18 SPR and 2% tallow (WCS20), and 30% WCS replaced 27% SPR and 3% tallow (WCS30). Composition of experimental diets are shown in Table 1. Dietary treatments were randomly assigned to pens within blocks, resulting in 4 pens replicates per treatment (total of 16 lambs per treatment). Lambs were weighed just prior to the morning feeding on days 1, 56 and 84. Live weight (LW) registered on days 1 and 56 was converted to shrunk body weight (SBW) by multiplying the weight by 0.96 to adjust for the gastrointestinal fill (Cannas *et al*., 2004). All lambs were fasted (drinking water was not withdrawn) for 18 h before recording the final LW (Estrada-Angulo et al., 2018). Lambs were allowed *ad libitum* access to water and dietary treatments. The amounts of feed offered were weighed daily. Lambs were provided fresh feed twice daily at 0800 and 1400 h in a 40:60 proportion (regarding the quantity of total feed offered as fed basis), adjusted in the morning feeding to allow for a minimal (~50 g/kg) feed refusal. Refusals were collected and weighed before to the morning feeding.

Sample analysis

Feed, SPR, and WCS samples were subjected to the following analysis: DM (oven drying at 105°C until no further weight loss; method 930.15; AOAC 2000); ash (method 942.05; AOAC 2000), Kjeldahl N (method 984.13; AOAC 2000); neutral detergent fiber [NDF; Van Soest *et al*. 1991, corrected for NDF-ash, incorporating heat stable α-amylase (Ankom Tech-

Table 1. Dietary composition of experimental diets fed to lambs

	Whole cottonseed level, % of diet DM			
Item	0	10	20	30
Ingredient composition, % DMB				
Corn stubble	10.00	10.00	10.00	10.00
Broom sorghum residue, ground[a]	66.50	57.50	48.50	39.50
Whole cottonseed[b]	0.00	10.00	20.00	30.00
Soybean meal	5.00	5.00	5.00	5.00
Tallow	3.00	2.00	1.00	0.00
Cane molasses	10.00	10.00	10.00	10.00
Meat meal (rendered pork)[c]	3.00	3.00	3.00	3.00
Trace mineral salt [d]	2.50	2.50	2.50	2.50
Net energy concentration[e], Mcal/kg of DM basis				
EN_m, Mcal/kg	1.60	1.63	1.65	1.68
EN_g, Mcal/kg	1.00	1.03	1.05	1.08
Nutrient composition, % of DM[f]				
Crude protein	13.10	14.86	16.13	17.35
NDF	35.06	36.87	38.45	40.50
Ether extract	4.70	5.47	5.91	6.49

[a]Composition of broom sorghum panicleresidue (%): 90.30 DM; 95.58 OM, 11.77 CP; 31.26 NDF, and 6.60 ether extract.
[b] Composition of WCS (%): 94.53 DM; 95.19 OM; 27.06 CP; 49.12 NDF, and 18.86 ether extract.
[c] Pure pork meat meal (El Kowi Enterprice, Hermosillo, Sonora, México).
[d] Mineralized salt contained: Ca, 13.58%; Na, 7.80%; Cl, 12.20%; P, 2.20%; Mg, 1.00%; K, 0.70%; $CoSO_4$, 0.068%; $CuSO_4$, 1.04%; $FeSO_4$, 3.57%; ZnO, 1.24%; $MnSO_4$, 1.07%, KI 0.052%.
[e]Based on tabular net energy (NE) values for individual feed ingredientspublished by NRC (2007) with exception of broom sorghum which were assigned 1.50 and 0.91 Mcal/kg of NE_m and NE_g respectively (Estrada-Angulo *et al*., 2019).
[f]Dietary composition was determined by analyzing subsamples collected and composited throughout the experiment. Accuracy was ensured by adequate replication with acceptance of mean values that were within 5% of each other.

nology, Macedon, NY) at 1 mL per 100 mL of NDF solution (Midland Scientific, Omaha, NE)], and ether extract (method 920.39; AOAC, 2000).

Calculations

Average daily gain (ADG) was computed by subtracting the initial SBW from intermediate (56 d) and final (77 d) SBW and dividing the result by the corresponding number of days on feed. Gain efficiency was computed by dividing ADG by the corresponding average daily DMI. One approach for evaluation of the efficiency of dietary energy utilization in growth-performance trials is the ratio of observed-to-expected DMI and observed-to-expected dietary NE. Based on diet NE concentration and measures of growth performance, there is an expected energy intake. This estimation of expected DMI is performed based on observed ADG, average SBW, and NE values of the diet (Table 1): expected DMI, kg/d = (EM/NE_m) + (EG/EN_g), where EM (energy required for maintenance, Mcal/d) = $0.056\times SBW^{0.75}$, EG (energy gain, Mcal/d) = $0.276\times ADG\times SBW^{0.75}$, and NE_m and NE_g are corresponding NE values based on the ingredient composition of the experimental diet (Table 1, NRC, 2007). The coefficient (0.276) was taken from NRC (1985) assuming a mature weight of 113 kg for Pelibuey × Katahdin male lambs (Canton and Quintal, 2007). The observed dietary net energy was calculated using EM and EG values, and DMI observed during experiment by means of the quadratic formula: $x = (-b - \sqrt{b^2-4ac})/2c$, where $x = NE_m$ (Mcal/kg), a =-0.41EM, b = 0.877 EM + 0.41 DMI + EG, and c = -0.877 DMI (Zinn *et al*., 2008).

Given that the NE_m values of broom sorghum and tallow are 1.50 and 6.30 Mcal/kg, respectively (Estrada *et al*., 2019; NRC, 2007), so the comparative NE_m values for the WCSat each level of substitution was estimated by replacement equation technique as follows:

NE_m, Mcal/kg WCS10 = (((0.9568×1.50) + (0.0431×6.3)) - ((1.60 - 1.65)/0.695) - ((0.8227×1.50) + (0.0288×6.3)))/0.1438

NE_m, Mcal/kg WCS20 = (((0.9568×1.50) + (0.0431×6.3)) - ((1.60 - 1.65)/0.695)- ((0.6978×1.50) + (0.01438×6.3)))/0.2877

NE_m, Mcal/kg WCS30 = (((0.9568×1.50) + (0.0431×6.3)) - ((1.60 - 1.65)/0.695)- ((0.5883×1.50) + (0.0×6.3)))/0.4316

The constants 0.9568 and 0.0431 represent the proportion of SPR and tallow in the basal diet, while the constants 1.50 and 6.3 represent the NE_m of SPRand tallow replaced by WCS; the constant 1.60 represents the EN_m observed to basal diet; the constant 0.695 represents the total percentage of SPR and tallow in basal diet; the constants 0.1438, 0.2877, and 0.4316 correspond to the proportion of WCS which replaced SPR and tallow in the basal diet; and finally, the constants 0.8227 and 0.0288; 0.6978 and 0.0143, and 0.5883 and 0.00 represent the proportion of SPR and tallow in the WCS replaced diets. Dietary NE_g of WCS was derived from dietary NE_m as: NE_g Mcal/kg = 0.877 NE_m- 0.41 (Zinn *et al.*, 2008).

Carcass evaluation

Hot carcass weights (HCW) were obtained from all lambs at time of harvest. After carcasses (with kidneys and internal fat included) were chilled at -2°C to 1°C for 48 h, the following measurements were obtained: 1) fat thickness perpendicular to the *m. longissimus thoracis* (LM),measured over the centre of the ribeye between the 12th and 13th ribs; 2) LM surface area, measured using a grid reading of the cross-sec-

Table 2. Effect of treatments on growth performance, dietary energy and estimated energy value of whole cottonseed

	Whole cottonseed level, % diet DM					*P* value[a]	
Item	0	10	20	30	SEM	Linear	Quadratic
Days on test	84	84	84	84			
Pen replicates	4	4	4	4			
Live weight, kg [b]							
Initial	14.42	14.25	14.28	14.28	0.35	0.57	0.32
Final	27.18	28.68	29.12	28.45	0.39	0.09	0.03
Average daily gain, kg	0.152	0.172	0.177	0.169	0.07	0.08	0.03
Dry matter intake,kg/d	0.752	0.796	0.827	0.795	0.017	0.11	0.04
Gain to feed, kg/kg	0.202	0.216	0.214	0.213	0.004	0.14	0.04
Observed dietary Net energy,Mcal/kg							
Maintenance	1.60	1.65	1.64	1.64	0.014	0.21	0.09
Gain	0.99	1.04	1.03	1.03	0.013	0.21	0.09
Observed-to-expected dietary Net energy ratio							
Maintenance	1.00	1.02	0.99	0.97	0.008	0.02	0.09
Gain	0.99	1.01	0.98	0.95	0.012	<0.01	0.14
Observed-to-expected daily dry matter intake	1.00	0.99	1.02	1.04	0.011	<0.01	0.18
Whole cottonseed NE, Mcal/kg[c]							
Maintenance		2.48	2.23	2.15			
Gain		1.76	1.55	1.48			

[a]*P* = observed significance level for linear and quadratic effects of supplemental WCS.
[b]Initial live weight (LW) was reduced by 4% to adjust for the gastrointestinal fill. Final LW was obtained following an 18-h fast without access to feed (access to drinking water was not restricted).
[c] Estimated by replacement equation technique.

Table 3. Effect of treatments on carcass characteristics of lambs

	Whole cottonseed level, % diet DM					*P* value[a]	
Item	0	10	20	30	SEM	Linear	Quadratic
Hot carcass weight, kg	14.61	15.38	15.75	15.49	0.19	<0.01	0.02
Dressing percentage	53.64	53.49	54.00	54.33	0.30	0.10	0.47
Cold carcass weight	14.40	15.16	15.52	15.26	0.18	<0.01	0.02
Longissimus muscle area, cm^2	6.46	6.99	7.08	6.98	0.11	<0.01	0.03
Fat thickness	1.49	1.55	1.67	1.68	0.08	0.09	0.77
Kidney-pelvic-heart fat, %	1.88	1.85	2.00	1.92	0.09	0.46	0.91

[a]*P* = observed significance level for linear and quadratic effects of supplemental WCS.

tional area of the ribeye between the 12th and 13th ribs; and 3) kidney, pelvic and heart fat (KPH). The KPH was removed manually from the carcass, and then weighed and is reported as a percentage of the cold carcass weight (USDA, 1982).

Statistical analysis

The power test for this study was calculated using the POWER procedure of the SAS 9.0 package, entering the information on treatment means, square root of the EMS, type I error value of 5% and the number of repetitions per treatment, being >90% for all variables with significant treatment effect. The study was analyzed as a randomized complete block design using the MIXED procedure of SAS (2004), with pens as experimental units. The quantitative trend relationship between the WCS inclusion level was investigated using polynomial response functions. Treatment differences were considered a trend at $P> 0.05$ and $P\leq 0.10$.

RESULTS

No animal presented health problems that affected the development or results of the experiment, or that warranted its exclusion from the experiment.

The chemical composition of WCS and SPR are described in footnotes of Table 1. Chemical composition of WCS and SPR were consistent with values previously reported (Zinn and Plascencia, 1993, NRC, 2007; Estrada *et al*., 2019).

Effects of replacing SPR with different levels of WCS on growth performance, dietary energy and energy value of WCS are shown in Table 2. Observed NE of control diet was 0.99 of expected, and this confirms the validity of NE_m value of 1.50 Mcal/kg determined previously by Estrada *et al*. (2019) for SPR. Inclusion of WCS increased (quadratic component, P=0.03) ADG, DMI and gain efficiency. However, with increasing level of WCS substitution the observed/expected dietary net energy ratio decreased linearly (P<0.01). Using the replacement technique, the corresponding NE_mvalues for WCS at the 10, 20 and 30% levels of inclusion were 2.48, 2.23, and 2.15 Mcal/kg, respectively.

Treatment effects on carcass characteristics are shown in Table 3. Hot carcass weight and LM area increased (linear effect, $P\leq$0.03) with increasing level of WCS inclusion. Whereas, dressing percentage and fat thickness tended to increase (linear effect, P=0.10) with increasing WCS level.

DISCUSSION

Like our results, Kandylis *et al.* (1998) reported an increase in DMI in finishing lambs received up to 20% of WCS in the diet. However, others report shown that WCS did not affected DMI (Karalazos *et al*., 1992; Dayani *et al*., 2011), or even, that the inclusion of WCS in diet decrease DMI in growing-finishing lambs (Luginbuhl *et al*., 2000). The inconsistencies between the experiments related to dry matter intake of lambs received WCS could be associated mainly with differences in diet characteristics (i.e. the concentration of protein level, fat, and fiber). In such a way that when WCS replace a lower palatability and digestibility ingredient (as is this case), DMI can be affected positively.

The basis for increased ADG with increasing levels of WCS substitution can be explained by differences in CP concentration in diets, since the energy concentration in diets was quite similar. Replacing SPR and tallow with increasing levels of WCS increased ostensibly dietary CP concentration, and although Control diet was putatively adequate in CP to sustain optimal growth (NRC, 2007), several studies (Dabiri and Thonney, 2004; Sultan et al., 2010; Estrada et al., 2018), reported increased ADG when light-weight finishing lambs were fed higher levels of CP.This effect is most noticeable in lambs fed isocaloric finishing diets containing less than 14% CP (Dabiri and Thonney, 2004; Sultan*et al*., 2010, Kaya *et al*., 2009). Whereas, substitution of WCS for SPR may have enhanced diet palatability, it has been postulated that increasing level CP protein supplementation may also indirectly stimulate energy intake by enhancingruminal organic matter fermentation, and modulation of gastric empty (Zinn and Shen, 1998).

The increase in ADG and gain efficiency was maximal with a 10 to 20% WCS inclusion rate. Current standards (NRC, 2007) assign an energy value of 2.40 Mcal NE_m/kg for WCS. Using the equation replacement technique, the comparative NE value for WCS at the level of 10% was in reasonably agreement (1.03) with those reported in nutritional standards published for lambs (NRC, 2007), while at 20 and 30% WCS level the comparative NE_m corresponded to 0.93 and 0.90 of the NRC published value (2007).The basis for a decrease in NE value WCS beyond the 10% level of substitution may reflect changes in the level of dietary lipid.Lipid concentration in WCS (~23%) contributes around 50% of total energy contained in WCS. It is well recognized that with higher lipid intakes the NE_m

value of dietary lipid declines in a linear fashion (Zinn and Jorquera, 2007). Additionally, higher lipid intakes can detrimentally affect ruminal fiber digestibility (Wiseman and Garnsworthy, 1997). When WCS was substituted for low-fiber feedstuffs (viz. corn or tapioca), in otherwise high-energy finishing diets, the derived NE values for WSC were not diminished with greater inclusion rates.

Increases in HCW and LM with an increasing proportion of WCS are consistent with changes in ADG and final live weight (Félix-Bernal *et al*., 2014; Hernández *et al*., 2017). The tendency of a lower dressing percentage of lambs receiving diets with a greater amount of SPR reflects the comparatively low apparent digestibility of SPR fiber, resulting in greater ruminal fill (Vinhas-Voltolini *et al*., 2011). The observed increase in fat thickness is consistent with greater ADG and final carcass weight (Estrada-Angulo *et al*., 2018).

CONCLUSION

Partially replacement of broom sorghum panicle residue and tallow by up to 20% inclusion of WCS in finishing diets for lambs enhances ADG, gain efficiency, carcass weight, and LM area. However, the net energy value of WCS decreases with the level of inclusion in diet greater than 10%. This decrease on energy value becomes important to consider by feed formulators, mostly if the energy value of WC (2.40 Mcal NEm/kg) is taken as a cost opportunity to include in diets.

CONFLICT OF INTEREST

No potential conflict of interest was reported by the authors.

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