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Residual intake and gain for the evaluation of performance, non-carcass components, and carcass characteristics of confined crossbred Texel lambs

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ABSTRACT - We evaluated performance, non-carcass components, and carcass characteristics of crossbred Texel lambs in different categories of residual intake and gain (RIG). We assessed 77 crossbred (¼ Pantaneira and ¾ Texel) non-castrated animals in two study phases. The first phase included 47 lambs with an initial average weight of 29.9±5.5 kg, and the second phase included 30 lambs with initial average weight of 22.4±3.3 kg. Dry matter intake (DMI) and average daily gain (ADG) were evaluated for 70 days. Animals were divided into three groups in terms of efficiency: efficient (high RIG), intermediate (medium RIG), or inefficient (low RIG), based on the standard deviation of the mean for the RIG variable. We measured the yield of non-carcass components, carcass characteristics, and yield of meat cuts. Efficiency group had no association with DMI, nor with initial and final body weights of the animals. The ADG of efficient (0.310 kg day^{-1}) and intermediate (0.290 kg day^{-1}) animals was greater than observed in inefficient (0.260 kg day^{-1}) animals. Lambs in the efficient and intermediate groups had significantly higher levels of all efficiency indicators evaluated. Efficient and intermediate animals yielded significantly more wool/skin in comparison with lambs in the inefficient group. Animals with high RIG also had lower relative weight of testicles/scrotal sac in comparison with inefficient animals. Fat deposition in the omentum and mesentery as well as total fat were decreased in efficient animals. No significant differences occurred among groups regarding carcass characteristics and yield of meat cuts. The RIG index allows for the identification of lambs with higher growth rates and greater wool/skin yield and lower proportion of visceral fat.

Keywords: feedlot, residual feed intake, sheep, tissue composition, visceral fat

Introduction

Intensive production systems and use of feed concentrates constitute some of the strategies used to avoid the exposure of lambs to verminoses and sanitary problems associated with pastures (Fernandes et al., 2011). These strategies also boost animal performance, reducing production cycles and improving the financial viability of farms. However, intensive systems have more elevated feed costs (Pacheco et al., 2014). The identification of lamb breeds that convert feed into body mass more efficiently can thus further reduce costs and shorten production cycles (Lima et al., 2013).

Several efficiency indicators exist, including feed conversion ratio (FCR), gross feed efficiency (GFE), residual feed intake, and residual body weight gain (Archer et al., 1999). However, animal selection based on such indices may result in excessive body weight (BW) gain, increases in adult body size, alterations to carcass composition, or increases in feed intake. Thus, Berry and Crowley (2012) proposed a new indicator named residual intake and gain (RIG) specifically designed to identify animals that display a better BW gain:feed intake ratio. The use of RIG, which has no phenotypical dependence on BW, may improve feed efficiency, reduce confinement time, and allow for slaughter at an early stage with no elevation in the adult size of lambs.

The study of variations in feed efficiency unveils differences in responses of efficient and inefficient animals. Previous work has shown that efficient animals display different BW gain patterns, including reduced fat thickness during finishing, smaller visceral fat depots, and reduced non-carcass weight (Gomes et al., 2012; Redden et al., 2013; Nascimento et al., 2016; Moraes et al., 2017).

In addition to higher performance, efficient lambs should also have satisfactory quality and carcass yield. A few previous studies have attempted to correlate performance and carcass characteristics with RIG levels in bovine animals. However, data regarding sheep breeds remain scant. Thus, we assessed performance, non-carcass components, and carcass characteristics of crossbred Texel lambs segregated into three groups according to RIG.

Material and Methods

Experiments were conducted in two phases in Campo Grande, Mato Grosso do Sul, Brazil (20°26'34"S, 54°38'47" W, 532 m). The first phase took place between September and December of 2015, and the second phase between July and October of 2016. The Commission for the Ethical Use of Animals approved all procedures (case number 632/2014 – CEUA).

Animals used in this study were purchased from a farm located in the city of Ribas do Rio Pardo, Mato Grosso do Sul, Brazil. The farm is specialized in the production of lambs in the weaning phase in extensive system and aims at the marketing of lambs for rearing and finishing. During the first phase, 47 crossbred Texel lambs (¼ Pantaneira and ¾ Texel) were used. All animals were non-castrated males at an age of 132±14 days and average initial weight of 29.9±5.5 kg. The second phase included 30 non-castrated male lambs of the same crossbreed, at an age of 106±16 days and initial average weight of 22.4±3.3 kg. During the two phases, animals received identification tags and were randomly distributed into 2.5-m^2 individual stalls, with slatted suspended floors and individual feeding and watering equipment.

Lambs were allowed to adapt to diet, handling, and stalls for 25 days. Feces samples were collected from all animals on the day after landing for evaluation of parasite load. All animals were weighed and treated against ectoparasites and endoparasites (active principle: Closantel, Levamisole hydrochloride, Toltrazuril, and Moxidectin). After 10 days of deworming, feces were collected again to verify if there was reduction of the parasitic load. For animals that still had infestation, the second dose was applied. During the 25 days of adaptation, each animal was provided with corn silage and gradually increasing dosage of concentrate up to the level set for diet. After adaptation, lambs were confined for 70 days.

The experimental diet was formulated according to NRC (2007) recommendations, for weight gain of 200 g day^{-1}. Silage made with the aerial part of corn was used as roughage, and the concentrate included cracked corn, soybean meal, mineral mixture, urea, and supplements. The roughage:concentrate ratio was 40:60 (Table 1). Lambs were fed twice daily, at 07:30 and 14:30 h. The amount of feed provided was adjusted daily to allow for 100 g kg^{-1} leftovers. Water was provided *ad libitum*.

Samples of silage, concentrate, and leftovers were collected from each stall every 14 days and kept frozen at –20 °C until analysis. Levels of dry matter (method number 967.03), gross protein (GP) (method number 981.10), mineral matter (MM) (method number 942.05), and ether extract (EE) (method number 920.29) were determined according to the AOAC (1995).

The analyses of neutral detergent fiber (NDF), acid detergent fiber (ADF), and lignin were conducted as per Van Soest (1991). Levels of NDF and ADF were corrected for protein content (NDFp and ADFp).

Table 1 - Proportions of ingredients and chemical composition of the experimental diet

Item	Phase 1 - 2015	Phase 2 - 2016
Ingredient (g kg^{-1})		
Corn silage	400.0	400.0
Cracked corn	389.4	389.4
Soybean meal	168.0	168.0
Mineral mixture[1]	9.0	9.0
Urea	3.0	3.0
Supplements[2]	30.6	30.6
Chemical composition		
Dry matter (g kg^{-1} of NM)	553.0	523.2
Gross protein (g kg^{-1} of DM)	154.0	149.7
Mineral matter (g kg^{-1} of DM)	52.7	54.5
Ethereal extract (g kg^{-1} of DM)	30.8	28.1
NDFp (g kg^{-1} of DM)	246.5	304.3
ADFp (g kg^{-1} of DM)	120.4	154.0
Non-fibrous carbohydrates (g kg^{-1} of DM)[3]	527.4	471.9
Total digestible nutrients (g kg^{-1} of DM)[4]	763.4	727.2

NM - natural matter; DM - dry matter; NDFp - neutral detergent fiber corrected for protein; ADFp - acid detergent fiber corrected for protein.
[1] Composition by kilogram: calcium, 4.07 g; phosphorus, 1.35 g; copper, 3.75 mg; cobalt, 0.30 mg; manganese, 8.66 mg; zinc, 27.35 mg; iodine, 0.44 mg; selenium, 0.16 mg; sulfur, 1.27 g; sodium, 2.42 g; vitamin A, 20,000.00 UI; vitamin D, 2,000.00 UI; vitamin E, 60.40 UI; sugarcane yeast, 20.45 g; crude protein, 199.71 g; non-protein nitrogen, 14.10 g; total digestible nutrients, 798.48 g.
[2] Aroma of milk, molasses, yeast, vitamin, sulfur, sodium bicarbonate, and calcium carbonate.
[3] NFC roughage = 100 – (GP + MM + NDFp + EE) (Sniffen et al., 1992) and NFC concentrate = 100 – ((GP – GP derived from urea + inclusion of urea) + MM + NDFp + EE) (Hall, 2000).
[4] TDN = 91.0246 – (0.571588 × NDF) (Cappelle et al., 2001).

The concentration of non-fiber carbohydrates (NFC) in roughage was estimated as described by Sniffen et al. (1992): NFC = 100 – (GP + MM + NDFp + EE). Levels of NFC in concentrate were determined according to Hall (2000): NFC = 100 – [(GP – GP derived from urea + inclusion of urea) + MM + NDFp + EE]. Total digestible nutrients (TDN) were calculated from the equation proposed by Cappelle et al. (2001): 91.0246 – (0.571588 × NDF).

Initial empty body weight (EBWi, kg) and final empty body weight (EBWf, kg) of the feed efficiency evaluation period were measured following 16 h of food and water fasting. The mid-test metabolic BW (MMBW) was calculated as the mean between EBWi and EBWf.

Initial body weight (BWi, kg) and final body weight (BWf, kg) were obtained before feeding to minimize differences in animal gut fill but with no food and water restriction. Lambs were weighed every 14 days without fasting for the calculation of the observed average daily gain (ADG, kg day^{-1}), which was calculated by regression between individual BW and days on feedlot using PROC REG (Statistical Analysis System, version 9.2.), in which the slope represents growth rate.

The observed dry matter intake (DMI, kg day^{-1}) was calculated as the difference between the amount of dry matter provided to each lamb and the amount of dry matter in leftover. Feed conversion ratio was calculated as the ratio between DMI and ADG, and GFE, its inverse (ADG:DMI).

Residual feed intake (RFI, kg day^{-1}) was determined from the equation proposed by Koch et al. (1963): RFI = DMI – DMIp, in which DMIp is the predicted DMI. This one was calculated from the regression of DMI as a function of MMBW and ADG, using the MIXED procedure of the SAS, resulting in these equations for phase 1 (1) and phase 2 (2):

$$\text{DMIp} = -0.83003 + 0.10541\ \text{MMBW} + 2.06102\ \text{ADG} + \varepsilon \quad (1)$$

and

$$\text{DMIp} = -0.45803 + 0.09082\ \text{MMBW} + 1.29052\ \text{ADG} + \varepsilon, \quad (2)$$

in which ε is the model error.

Residual gain (RG, kg day^{-1}) was also obtained from Koch's equation: RG = ADG – ADGp, in which ADGp is the predicted ADG. This one was determined from the regression of ADG as a function of MMBW and DMI, using the MIXED procedure of SAS, resulting in these equations for phase 1 (3) and phase 2 (4):

$$ADGp = 0.28925 - 0.02235\ MMBW + 0.25057\ DMI + \varepsilon \quad (3)$$

and

$$ADGp = 0.13235 - 0.00488\ MMBW + 0.19244\ DMI + \varepsilon \quad (4)$$

The RIG (kg day^{-1}) was determined from the equation proposed by Berry and Crowley (2012): RIG = –1 × RFI + RG. Both RFI and RG were previously standardized to a variance of 1, and other effects considered in the estimates of RFI and RG were ignored, because they had already been considered in the calculation of these indicators.

After 70 days in evaluation, lambs were taken to a slaughterhouse in Campo Grande, Mato Grosso do Sul. After fasting from food and water for 16 h to obtain slaughter BW (SBW), lambs were desensitized by cerebral concussion and slaughtered. Blood was collected in a recipient and weighed. Animals were skinned and eviscerated. Non-carcass components were separated and weighed, including external components (skin/wool, hooves, head, tail, and testicles/scrotal sac), organs (tongue/trachea/esophagus, heart, lungs, spleen, liver/gall bladder/diaphragm, kidneys, reproductive/urinary organs, stomachs, and small and large intestines), and visceral fat depots (cardiac, omental, mesenteric, perirenal, and inguinal). Total fat was calculated as the sum of all fat depots. Components of the gastrointestinal tract (GIT) were weighed before and after emptying of contents, for the determination of empty GIT weight.

Hot carcass weight (HCW) was measured, and hot carcass yield (HCY) calculated as HCY = HCW/SBW × 100. After a 24-h cooling period at 2 ºC, cold carcass weight (CCW) was also obtained, and yield was calculated as CCY = CCW/SBW × 100. These variables were used in the calculation of weight loss by cooling: WLC = (HCW – CCW/HCW) × 100.

Cooled carcasses were cut longitudinally along the mid line with an electric saw. The left half-carcass was used in the evaluation of the following biometric indicators: external carcass length, internal carcass length (ICL), leg length, leg thickness, and maximum thoracic depth. Carcass compactness index (CCI) was calculated as CCI = CCW/ICL.

Loin eye area (LEA) was obtained with the exposure of the *longissimus lumborum* through a cut across the carcass, between the 12th and 13th thoracic vertebrae. The area exposed was drawn on tracing paper, scanned, cropped, and measured with a leaf area measuring device Li-Cor (model 3100). Subcutaneous fat thickness (SFT) was measured in the terminal third of the *longissimus lumborum* with a caliper (Osório and Osório, 2005).

The left half-carcass was divided into eight anatomical regions [shoulder, leg, rib, loin, breast, rack, neck, and HH section (between the 9th and 11th ribs)], which were separately weighed for the determination of absolute weights and weights as a percentage of cooled half-carcass weight. Rib, loin, breast, rack, and HH section were grouped and considered a sole rib cut.

Tissue composition was determined from a sample taken from the HH section of each animal. Samples were marked, conditioned in plastic bags, and stored at –20 °C until analysis. Frozen HH section samples were thawed at 4 °C, weighed, and dissected with a scalp and surgical tweezers for the separation of muscle, fat, and bones. Tissue components were individually weighed, and percentage contribution to the total thawed HH section weight was estimated as (g of tissue/g of HH section) × 100 (Hankins and Howe, 1946). We also obtained the of muscle:bone and muscle:fat ratios. The proportions of muscle, fat, and bone in the carcasses were estimated with the equations proposed by Morais et al. (2016).

We calculated RIG for each lamb, and three groups of animals were established during each of the two study phases as follows: animals with RIG equal to or greater than 0.5 standard deviations above the average were grouped as efficient (high RIG); those with RIG equal to or greater than 0.5 standard deviations below the average were grouped as inefficient (low RIG); and animals between these two groups were classified as intermediate (medium RIG).

Data from the two study phases were grouped and analyzed according to a completely randomized design, considering the fixed effect of RIG groups and random effect of assays, in which each animal represented an experimental unit, according to the statistical model described below (5):

$$Yij = \mu + \beta i + \gamma j + eij, \quad (5)$$

in which μ is the fixed overall mean effect; βi is fixed RIG effect; γj is the random effect of assays, in which each animal represented an experimental unit; and *e*ij is the random residual error associated with Yij.

Data were also analyzed for the presence of outliers and considered statistically significant when P<0.05, using the PROC MIXED of SAS.

Results

Among the animals evaluated, 22 (29%) were classified as inefficient (low RIG), 20 (26%) as efficient (high RIG), and 35 (45%) were placed in the intermediate group (medium RIG). The mean, maximum value, minimum value, and standard deviation for RIG in the study population were 0.00, 5.11, −4.06, and 1.78 kg day^{-1}, respectively. No significant differences for BWi, BWf, DMI, and TDN intake in absolute terms (kg day^{-1}) and as relative of BW (g kg^{-1} day^{-1} of BW) were observed among RIG groups (P>0.05; Table 2).

We observed a significant difference (P<0.0001) in ADG among RIG groups. Efficient and intermediate animals had ADG of 0.310 and 0.290 kg day^{-1}, respectively, which differed from inefficient animals (0.260 kg day^{-1}). Animals with high RIG were also more efficient than those with medium and low RIG (P<0.0001) in terms of FCR, GFE, RFI, and RG (Table 2). In comparison with inefficient animals, the efficient group had 27.6% lower FCR, 23.1% higher GFE, 0.150 kg day^{-1} lower RFI, and 0.060 kg day^{-1} greater RG (P<0.05; Table 2).

No differences were found among RIG groups in the relative weights of total non-carcass components, blood, head, hooves, tail, organs, and filled and emptied GIT (P>0.05; Table 3). Efficient and intermediate animals yielded more wool/skin (mean of 12.3 kg/100 kg of SBW) than inefficient lambs (mean

Table 2 - Performance and efficiency indicators of confined crossbred Texel lambs grouped by residual intake and gain (RIG)

Variable	Minimum mean squares of RIG groups[1] (n = 77)			P-value[2]
	Low (inefficient)	Medium (intermediate)	High (efficient)	
Number of animals	22	35	20	-
Average age (days)	118±13.5	119±13.3	120±13.5	0.909
Initial BW (kg)	27.8±3.76	25.6±3.71	25.6±3.77	0.200
Final BW (kg)	45.6±4.66	45.8±4.59	47.1±4.67	0.667
ADG (kg)	0.26±0.01b	0.29±0.01a	0.31±0.01a	<0.0001
DMI (kg day^{-1})	1.28±0.17	1.27±0.16	1.22±0.17	0.636
DMI (g kg^{-1} day^{-1} of BW)	34.7±0.80	35.3±0.72	33.6±0.82	0.086
TDNI (kg day^{-1})	0.98±0.15	0.97±0.15	0.94±0.15	0.666
TDNI (g kg^{-1} day^{-1} of BW)	26.3±1.13	26.8±1.10	25.6±1.14	0.095
FCR (kg of DMI kg^{-1} of ADG)	4.99±0.40a	4.28±0.40b	3.91±0.40c	<0.0001
GFE (kg of ADG kg^{-1} of DMI)	0.20±0.02c	0.24±0.02b	0.26±0.02a	<0.0001
RFI (kg day^{-1})	0.06±0.01a	0.01±0.01b	−0.09±0.01c	<0.0001
RG (kg day^{-1})	−0.03±0.003c	0.00±0.003b	0.03±0.003a	<0.0001
RIG (kg day^{-1})	−4.06	0.00	5.11	<0.0001

BW - body weight; ADG - average daily gain; DMI - dry matter intake; TDNI - total digestible nutrients intake; FCR - feed conversion ratio; GFE - gross feed efficiency; RFI - residual feed intake; RG - residual gain.
[1] Different letters in the same row indicate significant differences according to t test (P<0.05).
[2] P-value regarding the effect of RIG group.

of 11.0 kg/100 kg of SBW). However, the relative weight of testicles/scrotum was lower in efficient animals in comparison with inefficient animals (1.13 *versus* 1.33 kg/100 kg of SBW, respectively; P<0.05; Table 3). Similarly, the relative weights of omental, mesenteric, and total fat depots were greater in inefficient animals in comparison with efficient and intermediate animals (P<0.05).

No differences among groups were observed regarding SBW (46.6 kg), HCW (23.1 kg), CCW (22.5 kg), HCY (49.4 kg/100 kg of SBW), CCY (48.1 kg/100 kg of SBW), WLC (2.57 g/100 g), and carcass biometric indicators (P>0.05; Table 4).

Average shoulder, neck, rib, and leg yields were, respectively, 18.2, 7.49, 44.0, and 30.3 kg/100 kg of CCW; we found no differences among groups (P>0.05; Table 5).

Animals in different RIG groups had similar proportions of tissue components (muscle, fat, bone, muscle:fat ratio, and muscle:bone ratio) estimated from HH section samples (9th to 11th ribs; P>0.05; Table 6).

Table 3 - Non-carcass components in the relative weights of slaughter body weight (SBW) of confined crossbred Texel lambs grouped by residual intake and gain (RIG)

Non-carcass component (kg/100 kg of SBW)	Minimum mean squares of RIG groups[1] (n = 77)			P-value[2]
	Low (inefficient)	Medium (intermediate)	High (efficient)	
External component				
Blood	4.04±0.11	3.95±0.09	3.85±0.13	0.531
Head	4.91±0.09	4.99±0.07	4.84±0.09	0.398
Wool/Skin	11.0±0.36b	12.3±0.28a	12.3±0.37a	0.019
Hooves	2.16±0.04	2.28±0.03	2.27±0.04	0.058
Tail	0.60±0.07	0.67±0.07	0.65±0.08	0.294
Testicles/scrotal sac	1.33±0.15a	1.18±0.15b	1.13±0.15b	0.028
Organ				
Tongue/trachea/esophagus	0.92±0.33	0.88±0.32	0.90±0.33	0.546
Heart	0.39±0.01	0.39±0.01	0.39±0.01	0.874
Lungs	0.93±0.03	0.90±0.02	0.90±0.03	0.715
Spleen	0.18±0.01	0.18±0.01	0.17±0.01	0.555
Liver/gall bladder/diaphragm	1.94±0.06	1.90±0.05	1.93±0.06	0.712
Kidneys	0.23±0.01	0.25±0.01	0.24±0.01	0.369
Reproductive/urinary organs	0.25±0.03	0.31±0.03	0.31±0.04	0.190
Full stomachs	9.59±0.56	9.68±0.52	9.79±0.56	0.890
Small intestine, full	1.91±0.14	2.13±0.13	2.07±0.14	0.117
Large intestine, full	2.03±0.08	2.16±0.06	2.07±0.08	0.371
Empty stomachs	2.63±0.11	2.72±0.09	2.74±0.13	0.753
Small intestine, empty	1.20±0.06	1.19±0.05	1.29±0.07	0.540
Large intestine, empty	0.66±0.03	0.69±0.02	0.71±0.03	0.517
Gastrointestinal tract content	4.48±0.15	4.60±0.13	4.73±0.17	0.567
Fat depot				
Cardiac	0.21±0.04	0.23±0.04	0.23±0.04	0.615
Omental	2.30±0.17a	1.85±0.15b	1.89±0.17b	0.011
Mesenteric	1.48±0.08a	1.29±0.07b	1.20±0.09b	0.017
Perirenal	1.49±0.24	1.19±0.23	1.26±0.24	0.101
Inguinal	0.88±0.07	0.88±0.06	0.76±0.08	0.424
Total fat	5.91±0.91a	4.99±0.89b	4.95±0.91b	0.012

[1] Different letters in the same row indicate significant differences according to t-test (P<0.05).
[2] P-value regarding the effect of RIG group.

Table 4 - Carcass characteristics of confined crossbred Texel lambs grouped by residual intake and gain (RIG)

Variable	Minimum mean squares of RIG groups (n = 77)			P-value[1]
	Low (inefficient)	Medium (intermediate)	High (efficient)	
SBW (kg)	45.7±2.91	46.1±2.81	48.0±2.93	0.392
HCW (kg)	22.5±1.24	23.0±1.17	23.7±1.26	0.524
CCW (kg)	22.0±1.41	22.3±1.34	23.1±1.42	0.511
HCY (kg/100 kg of SBW)	49.2±0.68	49.8±0.60	49.3±0.69	0.600
CCY (kg/100 kg of SBW)	48.0±0.49	48.4±0.39	48.0±0.52	0.719
WLC (g/100 g)	2.45±0.94	2.73±0.93	2.53±0.95	0.558
ECL (cm)	82.3±2.67	83.3±2.62	83.1±2.68	0.614
ICL (cm)	63.2±1.40	65.0±1.33	65.5±1.42	0.058
LL (cm)	34.5±2.25	34.9±2.23	34.7±2.25	0.838
LT (cm)	11.2±0.34	10.7±0.28	10.7±0.35	0.408
MTD (cm)	22.5±3.66	22.2±3.66	22.6±3.66	0.491
CCI (kg/cm)	0.35±0.02	0.34±0.01	0.35±0.02	0.675
LEA (cm^2)	17.7±1.06	17.4±0.99	18.2±1.07	0.586
SFT (mm)	5.56±0.94	5.69±0.92	5.50±0.95	0.902

SBW - slaughter body weight; HCW - hot carcass weight; CCW - cold carcass weight; HCY - hot carcass yield; CCY - cold carcass yield; WLC - weight loss by cooling; ECL - external carcass length; ICL - internal carcass length; LL - leg length; LT - leg thickness; MTD - maximum thoracic depth; CCI - carcass compactness index; LEA - loin eye area; SFT - subcutaneous fat thickness.
[1] P-value regarding the effect of RIG group.

Table 5 - Yields of meat cuts of cooled half-carcasses of confined crossbred Texel lambs grouped by residual intake and gain (RIG)

Variable (kg/100 kg of CCW)	Minimum mean squares of RIG groups (n = 77)			P-value[1]
	Low (inefficient)	Medium (intermediate)	High (efficient)	
Shoulder	17.6±0.41	18.3±0.33	18.8±0.43	0.119
Neck	7.95±0.42	7.14±0.36	7.38±0.44	0.219
Rib	44.3±0.53	44.0±0.46	43.8±0.54	0.745
Leg	30.2±0.43	30.6±0.34	30.0±0.46	0.569

CCW - cold carcass weight.
[1] P-value regarding the effect of RIG group.

Table 6 - Tissue components estimated from HH section samples of confined crossbred Texel lambs grouped by residual intake and gain (RIG)

Tissue component of carcass	Minimum mean squares of RIG groups (n = 77)			P-value[1]
	Low (inefficient)	Medium (intermediate)	High (efficient)	
Muscle (kg/100 kg of CCW)	52.7±0.52	53.2±0.42	52.5±0.55	0.565
Fat (kg/100 kg of CCW)	30.0±1.38	29.4±1.30	29.1±1.39	0.676
Bone (kg/100 kg of CCW)	14.2±0.47	14.8±0.38	15.3±0.50	0.281
Muscle to fat ratio	1.80±0.08	1.84±0.07	1.84±0.08	0.889
Muscle to bone ratio	3.77±0.10	3.64±0.08	3.54±0.11	0.325

CCW - cold carcass weight.
[1] P-value regarding the effect of RIG group.

Discussion

The lack of difference for BWi and BWf among animals (P>0.05; Table 2) may result from the inclusion of RFI and RG in the model, which, in turn, were derived from MMBW. The method makes RIG phenotypically independent from BW (Koch et al., 1963; Berry and Crowley, 2012). These results agree with previous reports by Berry and Crowley (2012) and Nascimento et al. (2016), who evaluated calves and found similar BW across groups with different RIG levels. Thus, RIG provides a good indicator of efficiency for lambs – selection with this indicator does not elevate BWf; thus, it probably does not produce increases in the adult size of the animal, which may lead to increased nutritional requirements.

The 16.1% higher ADG observed in efficient lambs may have resulted from lower maintenance energy requirements – not evaluated in the present study. Changes to energy partition in the animals may have occurred, because TDN intake through the diet was similar in all groups (Table 2). Available energy may have been directed in greater proportion to net requirements related to gain, translating into the improved performance observed in efficient animals. These results resemble those reported by Berry and Crowley (2012) and Nascimento et al. (2016), who observed that high-RIG bovine animals had, respectively, 17.7 and 20.4% greater BW gain than low-RIG animals.

The comparison of efficient and inefficient lambs shows that RIG provides a good indicator that will allow for reduced time in confinement, because accelerated growth is associated with early finishing (Leme and Gomes, 2007). Reduction of production cycle has a direct impact on feed costs, which represent approximately 70% of finishing stage costs (Pacheco et al., 2014).

The similar DMI and TDN intake observed among RIG groups in the present study differ from those published by Berry and Crowley (2012), who observed that high-RIG calves had 5.45% lower DMI than inefficient animals. Nascimento et al. (2016) also reported lower DMI (9.6%) and TDN intake (10.5%) in efficient Nellore calves than in inefficient animals.

Differences observed for FCR and GFE (Table 2) were expected, because animals had similar DMI and different ADG levels. Average FCR and GFE were better among efficient animals. However, these indicators must be used with caution because of their close correlation to ADG (Archer et al., 1999), which could result in increases in the adult size of animals.

Total non-carcass components represented, on average, 40.6 kg/100 kg of SBW, value close to that obtained by Pompeu et al. (2013). Wool and skin represent the most valuable non-carcass components, making up 10 to 20% of total animal value (Camilo et al., 2012; Pompeu et al., 2013). This important source of revenue leads producers to improve herd sanitary conditions, thus increasing product quality (Santos et al., 2015).

Inefficient animals had higher mean testicle/scrotal sac weight than efficient and intermediate lambs. We did not measure the separate weights of testicles and scrotal sac. However, our results likely reflect greater fat deposition in the scrotal sac of inefficient animals, which had larger visceral fat depots (P<0.05; Table 3). Furthermore, these results may be associated with the precocious sexual development of inefficient animals, because scrotal circumference is an indicator of early puberty (Kealey et al., 2006). We did not measure scrotal circumference in the present study. However, a strong correlation exists between the weight of testicles/scrotal sac and scrotal circumference (0.60; Santos et al., 2016a). Thus, animals with heavier testicles would likely have larger scrotal circumference. However, more studies are needed to relate RIG to reproductive traits.

As observed with testicles/scrotal sac, relative weights of omental, mesenteric, and total fat depots were greater in inefficient animals, in comparison with efficient and intermediate animals (Table 3). These results resemble those reported by Gomes et al. (2012), who evaluated Nellore calves divided into groups according to RIG levels and found 21.5% lower fat deposition in the GIT of efficient animals.

The discrepancies between weight gain and visceral fat deposition observed in efficient versus inefficient animals may result from different energy partition into muscle and adipose tissues. Lambs synthetize muscle more efficiently than they do adipose tissue. For each kilogram of BW gain, the animal requires 1.2 Mcal of metabolic energy for the deposition of water and protein and 8.0 Mcal for the deposition of fat (NRC, 2007). Thus, internal fat displays a wider range of variation, and its deposition requires a larger amount of maintenance energy (Redden et al., 2013). Indeed, visceral fat deposition is among the causes for inefficient energy use by farm animals (Redden et al., 2013; Moreno et al., 2014). Energy ingestion and the relative weight of organs were similar across the different RIG groups (Table 2). Therefore, the higher ADG of efficient animals may have resulted from lower maintenance energy expenditure in fat tissue synthesis. Lamb internal fat has no use for human consumption; thus, fat deposition directs energy away from the production of components with commercial value (Carvalho and Medeiros, 2010; Moreno et al., 2014).

The lack of effect on carcass characteristics among efficiency groups was expected, because animals were slaughtered with similar BW (P>0.05). Weight, yield, and size of animals at slaughter have a positive correlation with carcass characteristics (Cyrillo et al., 2012; Santos et al., 2016b). Our results corroborate previous findings by Nascimento et al. (2016), who evaluated HCW and HCY of Nellore calves and found no significant differences among RIG groups. Reis et al. (2015) also found no significant differences in SBW and HCW in heifers with different RIG levels.

The average HCY (49.4 kg/100 kg SBW) found for non-castrated male lambs (¾ Texel + ¼ Pantaneiro) in our study was higher than that reported by Carvalho and Medeiros (2010) for non-castrated male lambs (½ Texel + ½ undefined; 47.4 kg/100 kg SBW). Lima et al. (2013) also published HCY (48.7 kg/100 kg SBW) and CCY (47.2 kg/100 kg SBW) for male Texel lambs that were lower than those found in the present work. Thus, we found good HCY (49.4 kg/100 kg SBW) and CCY (48.1 kg/100 kg SBW) that fell within the ideal range of 40 to 50 kg/100 kg SBW established for meat-producing sheep breeds, such as Texel (Silva Sobrinho, 2006).

Weight loss by cooling did not vary significantly across RIG groups. The level of WLC observed was adequate (2.57 g/100 g), falling within the previously reported range of 1 to 7 g/100 g for sheep (Martins et al., 2000). This indicator varies with the uniformity of fat layer on the carcass, sex, SBW, temperature, and relative humidity of the cold chamber.

Carcass biometric indicators may have reflected the observed lack of variation in SBW, because biometric indicators are associated with SBW (Pinheiro and Jorge, 2010; Cyrillo et al., 2012). Similarly, Nascimento et al. (2016) could not find differences in carcass depth and internal length when assessing Nellore calves segregated according to RIG level. Basarab et al. (2003) evaluated the carcasses of bovine animals within different RIG groups and did not observe differences in internal and external carcass length, thoracic depth, and leg length and thickness. These measurements provide a good indicator of carcass and meat cut yields (Cyrillo et al., 2012). They also constitute an important data set for the evaluation of carcasses according to sheep carcass classification systems (União Europeia, 2008).

A few indicators assess the quality of the final commercial product (Souza et al., 2014), such as carcass compactness index, which had an average of 0.35 kg/cm in the present study. Variations in RIG level did not correspond to changes in LEA and SFT assessed through cuts to the *longissimus lumborum* muscle (P>0.05). According to Silva Sobrinho and Osório (2008), the SFT reported here (5.58 mm) falls within the adequate range for animals in the finishing stage (5 to 10 mm). This fat layer may have contributed to a relatively low WLC (2.57 g/100 g), because fat protects carcasses against water loss during the cooling process (Silva et al., 2014).

Gomes et al. (2012) as well as Reis et al. (2015) reported similar results and found no differences in LEA and SFT in the carcass of calves that had been grouped according to RFI level. Nascimento et al. (2016) also did not observe differences in SFT when evaluating the *longissimus lumborum* of calves with varying levels of RFI and RIG. However, these authors detected larger LEA in animals with higher RFI and RIG, suggesting that the animals had greater muscle deposition. In contrast, Leme and Gomes (2007) reported lower SFT in bovine animals classified as efficient according to RFI.

Despite divergent results regarding RFI, a few studies suggest that the use of this indicator may produce carcasses with decreased fat finishing. The fat layer has a direct association with qualitative aspects of carcasses (Yamamoto et al., 2013). Thus, losses during finishing can negatively affect carcass value. Moreover, animals with less subcutaneous fat deposition are late developers that need more time in confinement, which, increase production costs. The association of RIG and SFT may eliminate the problem of insufficient fat at slaughter, because RIG identifies animals with elevated growth rates and adequate finishing.

The similar yield of meat cuts observed in all RIG groups reflects the similar SBW and carcass sizes of animals in different groups. Previous works provided evidence of moderate to high correlation among BW, carcass yield, and yield of meat cuts in sheep (Pinheiro and Jorge, 2010; Souza et al., 2014). According to Fernandes et al. (2011), when animals of the same breed have equivalent body conformation, their carcass weight, carcass yield, and relative weight of meat cuts are also similar.

Lima et al. (2013) assessed Texel lambs with SBW of 40.6 kg and found shoulder, neck, rib, and leg yields of 19.3, 5.72, 41.4, and 32.6 kg/100 kg of CCW, respectively, values that closely match those reported here. Cutting the carcass into specific parts that suit different consumers optimizes yield, avoids waste, and allows for adequate pricing (Silva Sobrinho and Silva, 2000). Such process represents an important step in the production of lamb meat.

The mean proportions of carcass muscle (52.8 kg/100 kg of CCW) and bone (14.8 kg/100 kg of CCW) were lower than those reported by Rosa et al. (2002), who studied non-castrated male Texel lambs and found proportions of 61.9 and 19.4 kg/100 kg of CCW for muscle and bone tissue, respectively. We found 29.5 kg/100 kg of CCW fat in comparison with 18.1 kg/100 kg of CCW reported by these authors. In the present work, mean values of muscle:fat and muscle:bone were 1.82 and 3.62, respectively.

Diverging results such as these, regarding muscle and fat percentages, may reflect differences in SBW and age at slaughter in other studies. Increasing SBW and age reduce the muscle:fat ratio, because each tissue reaches physiological maturity in different life phases of lambs (Lemes et al., 2014). Fat deposition is greater in more mature animals with higher SBW (Owens et al., 1995). The weight of mature Texel lambs is 37.0 kg (Malhado et al., 2008). However, lambs in the present study had a mean SBW of 46.6 kg, whereas in the previous study (Rosa et al., 2002), lambs were slaughtered with weights ranging between 25 and 33 kg, providing a possible explanation for the different proportions of muscle.

Efficient and inefficient animals often have different body compositions. These differences often represent a limitation of the use of efficiency indicators: efficient animals likely display lower fat deposition and have smaller body reserves (Leme and Gomes, 2007). This premise is aligned with previous findings (Basarab et al., 2003) indicating decreased fat deposition in efficient animals grouped by RFI level. Nevertheless, Reis et al. (2015) evaluated HH section carcass composition of calves grouped according to RFI and found no significant differences among groups.

In general, carcasses produced during the current study had good muscle composition and fat finishing within the adequate range for commercial cuts. The Texel breed and its crossbreeds are known for producing lean meat with a better muscle:bone ratio (Mendonça et al., 2008). The diet used in our study allowed animals to perform at their fullest potential, with ADG values above the expected in every RIG group. The higher growth rate of efficient animals and adequate finishing indicate that the appropriate use of RIG as indicator might reduce the production cycle.

Conclusions

As an indicator, residual intake and gain index allows for the identification of crossbred Texel lambs with higher growth rates, greater wool and skin yield, and lower proportion of undesirable non-carcass components such as visceral fat, without impairing carcass characteristics and yield of meat cuts.

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