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REGULAR ARTICLES

Proportions of concentrate and rehydrated ground grain corn silage at different storage times for better use of starch by lambs

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Abstract

This study aimed to evaluate the nutritional and bioeconomic potential of rehydrated ground grain corn silage (RGGCS), at different storage times associated with proportions of concentrates for better starch utilization by lambs. Forty Dorper-Santa Inês crossbred lambs were used, with an average body weight of 24 ± 3.9 kg, and an average age of 90 days. The lambs were feedlot for 63 days in experiment design completely randomized, with eight repetitions and five experimental diets: Diet 1: 850 g/kg concentrate including dry ground corn; diet 2: 850 g/kg concentrate including RGGCS ensiled for 45 days; diet 3: 650 g/kg concentrate including RGGCS ensiled for 90 days; diet 4: 650 g/kg concentrate including RGGCS ensiled for 45 days; diet 5: 850 g/kg concentrate including RGGCS ensiled for 45 days. As roughage, silage corn whole plant. Starch intake was higher ($P < 0.05$) with the dry ground corn diet; however, digestibility was lower ($P < 0.05$) for most nutrients compared to the RGGCS diet. A smaller amount of starch in the feces of animals that received the RGGCS diet was found. A diet with 850 g/kg of concentrate, including RGGCS ensiled for 45 days, generates higher net income, increases nutrient intake, and could be an alternative during the fluctuation of corn prices.

Keywords Starch · Performance · Sheep · Production

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Introduction

Corn grain is used globally in animal feed and consists mostly of starch, which serves as the main energy source for feedlot ruminants. However, proteins surrounding starch granules can hinder the attack of rumen microorganisms, and then the processing of corn through rehydration and ensiling can contribute to better use of starch.

Ensiling rehydrated corn grain involves adding water to ground maize kernels until reaching 35% moisture level to be ensiled (Ferraretto et al., 2018). Starch digestibility depends on the organizational structure of starch granules and how it reacts with prolamin, the protein encapsulating starch granules. During the ensiling process, protein subunits attached to starch granules undergo proteolysis, explaining the better digestibility of starch when animals are fed corn with high moisture content as opposed to dried corn grain (Ferraretto et al., 2013).

The storage time of rehydrated corn silage can favor the breakdown of the protein barrier and facilitate the access of ruminal microorganisms to starch (Hoffman et al., 2011).

It is also important to highlight that providing high starch diets increase the risk of metabolic disorders such as acidosis (Krause and Oetzel, 2006). Therefore, the use of different proportions of concentrates in association with dry (hay) or wet (silage) forages is important for ruminal health and better use of corn starch.

The efficiency in starch degradability is due to corn processing and access of microorganisms to starch granules. Caetano et al. (2019) found an increase in feed efficiency in finishing beef cattle due to the input of metabolizable energy and increased use of this energy by the animal.

However, most of these studies focused on in vitro and in situ research, and when in vivo, bovines are used; consequently, starch digestibility results in sheep are not observed, as well as the effects on performance.

This study aimed to evaluate the nutritional and bioeconomic potential of ground and rehydrated corn grain silages at different storage times associated with proportions of concentrates on the productive parameters of finishing lambs.

Material and methods

Ethical standards for animal experimentation

The study was conducted at the Research Laboratory for Ruminant Nutrition and Feeding and the Laboratory of Animal Nutrition in the Department of Agricultural and Environmental Sciences at the Universidade Estadual de Santa Cruz (UESC) in the municipality of Ilhéus, Bahia, Brazil.

Animals, facilities, and experimental diets

Forty castrated male lambs of Dorper-Santa Inês crossbreed, with an average body weight (BW) of 24 kg ± 3.9 kg (mean ± SD) and the average age of 90 days, were used. The lambs were identified, dewormed (albendazol—2.5 mg/kg BW), and feedlot in a barn laid out with covered, slatted floor stalls, equipped with individual feeding and watering troughs. The lambs were feedlot for 63 days, of which 15 days were assigned for adaptation to the diets and 48 days were for the experimental period.

The experimental design was completely randomized, with five experimental diets (Table 1) and eight repetitions. The experimental diets were diet 1: 850 g/kg concentrate, including dry ground corn; diet 2: 850 g/kg concentrate, including RGGCS (rehydrated ground grain corn silage) ensiled for 45 day; diet 3: 650 g/kg concentrate, including RGGCS ensiled for 90 days; diet 4: 650 g/kg concentrate, including RGGCS ensiled for 45 days; diet 5: 850 g/kg concentrate, including RGGCS ensiled for 45 days. The experimental diets consisted of whole plant corn silage as roughage and the concentrate based on soybean meal, urea, mineral premix, limestone, in addition to RGGCS or dry ground corn (Table 1).

Corn kernels were ground in a mill with a 2.0-mm-diameter sieve to make RGGCS. Water was subsequently added to guarantee moisture levels close to 40%. A ratio of 100 kg of corn grain per 40 L of water was used, mixed homogeneously, then transferred and compacted into 200-l-capacity drums where it was sealed and ensiled. The silages were produced before the experimental period so they could be opened after 45 and 90 days of storage.

Intake, apparent digestibility of nutrients, and DM degradability *in situ*

Diets were provided twice a day (8:00 a.m. and 3:00 p.m.), allowing approximately 200 g/kg of DM leftover for voluntary ingestion. The dry matter intakes (DMIs) were calculated as the difference between quantity offered and feed leftover by each animal.

Feces were collected directly from the rectal ampoules of animals during the experimental period. These samples were identified, frozen, and later submitted for laboratory analysis. Dietary component digestibility was estimated using the internal indigestible neutral detergent fiber (iNDF) indicator. Diet, leftovers, and feces samples were incubated in situ for 288 h (Reis et al., 2017). The coefficient of digestibility (CD) of each nutrient was calculated in the following manner: CD = [(nutrient intake – excreted)/intake] × 100.

To estimate degradability in situ, three Dorper-Santa Inês crossbred lambs were used, which were fistulated and given permanent rumen cannula. The following feeds were analyzed: dried corn grain and RGGCS with two storage times (45 and 90 days). The incubation times were 0, 3, 6, 12, 24, 48, and 72 h (Fortaleza et al., 2009). To estimate the

Table 1 Proportions of ingredients and chemical composition of experimental diets

Item	Dry ground corn	Storage time of RGGCS				Corn silage	RGGCS 45 days	RGGCS 90 days
		45 days	90 days	45 days	90 days			
	850 g/kg concentrate			650 g/kg concentrate				
Proportions of ingredients (g/kg DM)								
Corn silage	150.0	150.0	150.0	350.0	350.0			
RGGCS	–	658.1	658.1	399.2	399.2			
Ground corn	658.1	–	–	–	–			
Soybean meal	136.3	136.3	136.3	200.8	200.8			
Urea	10.0	10.0	10.0	2.0	2.0			
Mineral premix[a]	12.0	12.0	12.0	12.0	12.0			
Limestone	18.6	18.6	18.6	20.0	20.0			
Sodium bicarbonate	15.0	15.0	15.0	16.0	16.0			
Chemical composition (g/kg DM)								
Dry matter	773.8	614.4	624.9	580.2	586.6	344.5	603.0	619.0
iDM[b]	99.1	97.5	88.6	142.7	139.1	371.2	36.6	31.3
Organic matter	943.2	944.4	939.8	936.9	934.1	978.5	987.0	980.0
Ether extract	33.7	53.3	45.5	45.4	40.7	44.9	65.2	53.3
Crude protein	171.8	172.7	172.0	172.2	171.8	84.8	96.0	95.0
NDFap[c]	163.8	137.6	134.4	217.4	215.5	443.2	64.9	60.1
iNDF[d]	51.4	53.5	49.2	87.9	86.4	234.9	16.8	14.4
NFC[e]	573.9	580.8	587.9	501.9	506.1	405.6	761.0	771.7
Starch	530.6	453.9	488.5	324.7	343.7	187.4	641.4	694.0
Total carbohydrates	737.7	718.4	722.3	719.2	721.6	848.8	825.9	831.8
TDN[f]	786.4	825.7	818.8	834.0	855.3	758.9	888.2	875.1

RGGCS rehydrated ground grain corn silage,

[a]Mineral premix composition per kg: calcium, 160 g; phosphorus, 16 g; sulfur, 36 g; magnesium 20 g; potassium 34 g; sodium 56 g; cobalt 8 mg; copper 540 mg; chromium 6.7 mg; iodine 27.5 mg; manganese 1.070 mg; selenium, 6.7 mg; zinc, 2000 mg; vitamin A, 168.000 IU; vitamin D 317.000 IU; vitamin E; biotin, 90 mg; amylase, 11.400 KNU; D-Limonese, 3000 mg; *Saccharomyces cerevisiae*, 2.7×10E9 UFC; fluorine 160 mg

[b]Indigestible dry matter

[c]Neutral detergent fiber corrected for ash and protein

[d]Insoluble neutral detergent fiber

[e]Non-fiber carbohydrates

[f]Total digestible nutrients

kinetic parameters of MS, the model proposed by Ørskov and McDonald (1979): $PD = a + b\,(1 - \exp^{-ct})$;

where PD is the potential ruminal degradability of feeds, "*a*" is the soluble fraction; "*b*", potentially degradable insoluble fraction; "*c*", degradation rate of the potentially degradable insoluble fraction; and "*t*" the incubation time in hours. To estimate the effective degradability (ED), the mathematical model was used: $ED = a + [(b * c)/c + k)]$, where k is the estimated solid passage rate in rumen, assuming values between 2, 5, and 8%/h (ARC, 1980).

Performance

Lambs were weighed at the beginning of the study period and every 24 days for a total of two weight measurements to determine their total weight gain. All weighing sessions were conducted after a feed deprivation period of 16 h. Average daily gain (ADG) was determined by dividing the total weight gain by the number of days in the experimental period. Feed efficiency was calculated by dividing the ADG by the DMI of the lambs.

Laboratory analysis

Feed, leftovers, and feces were pre-dried and ground through 1-mm sieve and analyzed for determination of dry matter, mineral matter, crude protein, and ether extract according to methodologies proven by AOAC (2000), by methods 920.15, 932.05, 976.05, and 920.39, respectively.

The analysis of neutral detergent fiber (NDF) was according to Mertens (2002). NDF correction for nitrogenous compounds and neutral detergent insoluble nitrogen (NDIN) compound estimates were carried out according to Licitra et al. (1996). Lignin was determined using the method proposed by Van Soest and Wine (1967). Non-fiber carbohydrate (NFC) content, expressed as % in DM, was calculated according to Hall (2003), in which NFC = 100 − [(CP − CPurea + urea) + NDFap + EE + MM].

where CPurea is crude protein in urea, and NDFap is neutral detergent fiber corrected for ash and protein. TDN content in the diet composition table was estimated using the following formulas:

adCP = 0.7845 × %CP − 0.97 (Detmann et al., 2006a).

adEE = 0.8596 × %EE − 0.21 (Detmann et al., 2006b).

adNDFap = 0.67 × [(NDFap − L) × (1 − (L/NDFap)$^{0.85}$)] (Detmann et al., 2007).

adNFC = 0.9507 × %NFC − 5.72 (Detmann et al., 2006c).

Afterward, TDN was estimated using the equation below:

TDN = adCP% + (adEE% × 2.25) + adNDFap% + adNFC%

where adCP is apparently digestible crude protein; adEE, apparently digestible ether extract; adNDFap, apparently digestible neutral detergent fiber corrected for ash and protein; adNFC, apparently digestible non-fiber carbohydrates; and TDN, total digestible nutrients.

To calculate digestible and metabolized energy (DE and ME, respectively) of the diets, the following equations were used, according to NRC (2001):

DE (Mcal/kg) = (dNFC/100) × 4.2 + (dNDF/100) × 4.2 + (dCP/100) × 5.6 + (dEE/100) × 9.4 − 0.3;

ME (Mcal/kg) = [1.01 × (DE) − 0.45] + 0.0046 × (EE − 3).

where dNFC: digestible non-fiber carbohydrates; dNDFap: digestible neutral detergent fiber corrected for ash and protein; dCP: digestible crude protein; and dEE: digestible ether extract.

Starch quantification was performed using the Anthrone method (Dische, 1962).

Economic analyses of the diets

The economic evaluation took into account the feed offered to the animals without counting other costs in the system. The calculation was based on prices of the feed offered in the experiments in relation to the body weight of the lambs. The values for the economic analysis were US$29.25/kg body weight and the following prices, per kg of dry matter: US$2.92 for corn silage, US$5.18 for RGGCS, US$3.12 for corn grain, US$8.70 for soybean meal, US$33.89 for mineral supplement, US$11.93 for urea, US$1.48 for limestone, and US$23.43 for sodium bicarbonate.

The economic value of each diet offered could be calculated with the cost data of each feed and its DMI during the experimental period using the following equations: Daily diet cost (USD/animal/day) = diet cost × DM intake; weight gain cost (USD/kg) = feed conversion × diet cost; total feed cost (USD) = ADG cost × total weight gain; total revenue (USD) = total weight gain × animal cost price; total cost (%total revenue) = total feed cost × 100/ total revenue; net margin (USD) = Total revenue − total feed cost.

Statistical analysis

The experiment design was completely randomized, with five experimental diets and eight repetitions, considering each lamb as an experimental unit. Was used initial body weight as covariate, and the statistical model adopted was

$$Yij = \mu + \alpha i + \beta\ (Xij - X) + \varepsilon ij$$

where Yij = observed values of variable responses in relation to i experimental diet in repetition (lamb) j.

μ = the mean common to all observations.

αi = effect of experimental diet i.

β = coefficient of linear regression of covariate (X).

Xij = observed covariate value (initial body weight).

$\bar{X}$ = covariate mean (initial body weight).

ε = random error.

Initially, the obtained data was tested regarding error normality and variance homoscedasticity through the Shapiro–Wilk and Bartlett tests, respectively, to confirm basic suppositions for the analysis of variance. The results were then subjected to analysis of variance, and when significant F values were found at 5% probability, the degrees of freedom of experimental goals were broken down using orthogonal contrast technique (C), as presented by Banzatto and Kronka (2006). The contrasts were as follows: contrast 1: comparison between RGGCS and dried corn grain (control); contrast 2: comparing RGGCS storage time (45 *vs* 90 days), independently of concentrate proportion; and contrast 3: comparing diet concentrate proportion (850 *vs* 650 g concentrate/kg DM), independently of storage time (Table 2).

Corn grain, RGGCS stored for 45 days, and RGGCS stored for 90 days were used to obtain dry matter in situ degradability results. The experimental diet means were compared using orthogonal contrasts. Contrast 1: comparison between RGGCS and dried corn grain and contrast 2: comparing RGGCS storage time (45 *vs* 90 days).

Table 2 Distribution of coefficients in the orthogonal contrasts employed in the decomposition of the sum of squares for treatments

Contrasts	Dry ground corn	Storage time of RGGCS			
		45 days	90 days	45 days	90 days
	850 g/kg concentrate			650 g/kg concentrate	
1	2	−1	−1	0	0
2	0	1	−1	1	−1
3	0	1	1	−1	−1

Results

Intake, apparent digestibility, and degradability *in situ*

Lower intake ($P < 0.05$) of most nutrients (DM, OM, CP, NDFap, NFC, starch, and TC) was observed in the RGGCS diet when compared to the dried corn grain (control) diet. Starch intake increased ($P < 0.05$) 14.03% in the RGGCS diet stored for 90 days comparison to RGGCS diet stored for 45 days (Table 3).

The RGGCS diet increased ($P < 0.05$) the digestibility of (OM, EE, CP and TC), and lower amount of starch in the feces, with a reduction of 23.63%, compared to the diet with dry ground corn.

Regarding concentrate proportion, intake of most nutrients (DM, OM, CP, NDFap, and TC) was higher in the 650-g/kg concentrate diet, with increases ranging from 9.1% for dry matter and 8.7 for TC. However, starch and EE intake (354.12 and 47.95 g/day, respectively) were reduced ($P < 0.05$) when compared to the 850-g/kg concentrate diet (Table 3).

The digestibility of most nutrients (DM, OM, CP, NFC, starch, and TC) was lower ($P < 0.05$) in the 650 g/kg concentrate diet in comparison to the 850-g/kg concentrate diet (Table 3).

Table 3 Intake, apparent digestibility coefficients of nutrients from experimental diets

Item	Dry ground corn	Concentrate g/kg		Storage time of RGGCS		SEM	P value		
	850		650	45 days	90 days		C1	C2	C3
Intake (g/day)									
Dry matter	1057.7	949.1	1043.9	982.5	1010.5	20.2	0.005	0.256	0.037
DM (g/kg BW)	32.0	30.4	33.0	31.1	32.2	0.5	0.114	0.130	0.004
Organic matter	1003.2	900.6	979.5	928.2	951.9	18.5	0.004	0.292	0.010
Ether extract	35.6	51.2	48.0	51.9	47.2	1.1	< .001	0.003	0.015
Crude protein	188.4	158.6	179.1	168.0	169.7	3.7	< .001	0.612	0.006
NDFap[a]	185.2	140.9	217.7	174.1	184.6	5.2	< .001	0.070	< .001
NFC[b]	594.1	545.7	534.8	532.1	548.4	10.9	0.020	0.230	0.446
Starch	539.2	463.6	354.1	386.3	431.4	13.1	< .001	0.003	< .001
TC[c]	779.3	686.6	752.5	706.2	732.9	14.4	0.001	0.156	0.005
Digestibility (g/kg DM)									
Dry matter	719.3	764.7	660.9	720.8	704.8	11.8	0.124	0.409	< .001
Organic matter	745.4	781.2	692.8	746.5	727.5	10.7	0.018	0.912	< .001
Ether extract	763.3	877.0	862.8	877.9	861.9	10.4	< .001	0.375	0.430
Crude protein	674.2	723.4	668.9	689.2	703.1	9.5	0.030	0.532	0.008
NDFap[a]	503.7	497.1	503.7	487.6	513.3	11.5	0.834	0.415	0.619
NFC[b]	759.6	810.4	710.8	760.7	760.7	15.5	0.194	0.982	0.006
Starch	940.7	957.2	913.9	932.3	938.9	4.7	0.138	0.409	< .001
TC[c]	760.9	796.0	720.3	757.1	759.3	7.4	0.049	0.982	< .001
TDN[d]	735.3	737.0	698.4	704.3	731.1	20.6	0.978	0.571	0.417
DE (MJ//kg)[e]	13,57	13,63	13,00	13,04	13,54	0.4	0.952	0.551	0.415
Starch in feces	11.6	8.9	9.4	9.4	8.9	0.5	0.046	0.609	0.773

Contrast 1: control × RGGCS; contrast 2: storage time 45 × 90 days; contrast 3: 850 g/kg × 650 g/kg concentrate

RGGCS rehydrated ground grain corn silage, *SEM* standard error of the mean

[a]Neutral detergent fiber corrected for ash and protein

[b]Non-fiber carbohydrates

[c]Total carbohydrates

[d]Total digestible nutrients

[e]Digestible energy in megaJoule

Table 4 Estimation of the parameters of in situ degradation of dry ground corn and RGGCS

Parameter	Dry ground corn	Storage time of RGGCS		SEM	P value	
		45 days	90 days		C1	C2
a [%]	30.9	70.6	57.3	7.6	0.008	0.111
b [%]	31.5	27.4	29.6	2.9	0.716	0.822
c [%h − 1]	0.04	0.02	0.31	0.06	0.350	0.100
Effective degradability kp2 [%]	52.1	84.0	84.8	6.9	0.001	0.778
Effective degradability kp5 [%]	45.3	78.4	82.3	7.4	< .001	0.012
Effective degradability kp8 [%]	41.9	76.1	80.2	7.7	< .001	0.002
Degradability potential 48 h [%]	59.4	83.2	75.6	4.9	0.014	0.324

Contrast 1: control × RGGCS; contrast 2: storage time 45 × 90 days; contrast 3: 850 g/kg × 650 g/kg concentrate. a soluble fraction; b insoluble fraction potentially degradable; c rate of degradation of the potentially degradable insoluble fraction; kp. changeover rates in 2, 5, and 8% h^{-1}

RGGCS rehydrated ground grain corn silage, *SEM* standard error of the mean

Table 5 Performance of feedlot lambs according to experimental diets

Item	Dry ground corn	Concentrate g/kg		Storage time of RGGCS		SEM	P value		
	850		650	45 days	90 days		C1	C2	C3
iBW (kg)a	24.0	24.0	24.0	24.0	24.0	–	–	–	–
fBW (kg)b	40.1	37.1	38.1	37.6	37.5	0.9	0.003	0.890	0.254
ADG (g/day)c	336.1	273.5	292.5	284.1	281.9	7.8	0.890	0.254	0.890
TG (kg)d	16.1	13.1	14.0	13.6	13.5	0.4	0.003	0.890	0.254
FC (g/day)e	2.8	3.3	3.3	3.2	3.4	0.1	0.025	0.332	0.930
FE (g/day)f	372.9	317.6	306.9	318.5	306.0	11.1	0.012	0.474	0.540

Contrast 1: control × RGGCS; contrast 2: storage time 45 × 90 days; contrast 3: 850 g/kg × 650 g/kg concentrate

RGGCS rehydrated ground grain corn silage, *SEM* standard error of the mean

[a]Initial body weight

[b]Final body weight

[c]Average daily gain

[d]Total gain

[e]Feed conversion

[f]Feed efficiency

It was observed that the RGGCS diet favored greater ($P < 0.05$) of the soluble fraction (a) with a mean of 61.91% and higher effective DM degradability at rates of passage of 2, 5, and 8% h^{-1} as well as the potential degradability 48 h, in the RGGCS diet in comparison to dry ground corn diet (Table 4). The effective degradability of the rates of passage in ED5% h^{-1} (82.26) and ED8% h^{-1} (80.24) is greater ($P < 0.05$) in RGGCS stored for 90 days than in RGGCS stored for 45 days (Table 4).

Performance

Lower ($P < 0.05$) performance (fBW, ADG, TG, FC, and FE) was found in the RGGCS, with a decrease of 18.6% for ADG and 14.8% for FE, when compared to diet with ground corn (Table 5). Neither the diets with RGGCS stored for 45 and 90 days nor the concentrate levels (850 vs 650 g/kg) influenced animal performance (Table 5).

Economic analyses of the diets

The cost for RGGCS diets was around US$5.81 higher, an increase of 26.3%, compared to the diet with dry ground corn, while the cost per weight gain was around US$19.28, with an increase of 44.6%. The diets with RGGCS were 19.5% higher in total feed cost. Soon, there was a gross margin in the diets with RGGCS of 15.8% lower than dry ground corn diet (Table 6).

Comparing the proportion of concentrate in diets with RGGCS, the diets with 850 g/kg of concentrate, regardless of the storage time of the RGGCS, had the highest net margin financial (US$2.84/lambs/day). On the other hand, the cost per weight gain was 4.1% higher for the diet with 650 g/kg of concentrate and increased by 11.3% in the total feed cost compared to the diet with 850 g/kg of concentrate (Table 6).

Feed cost and weight gain cost for RGGCS stored for 45 was better than in diets with 90 days, with 11.6 and 12.4% reductions, respectively (Table 6).

Discussion

Intake, apparent digestibility, and degradability *in situ*

The RGGCS diet showed less nutrient intake. Since dry matter intake is influenced by diet energy concentration, animals tend to reduce ingestion when energy satiety is reached because animal energy demand could be met at lower intake levels in feed with high energy content (Mertens, 1994).

According to Silva et al. (2007), diets with intensely processed grains or more degradable starch sources in rumen can reduce DMI due to increased short-chain fatty acid concentration.

Another factor which may have influenced lower DMI and other nutrients is the lower dry matter content in the RGGCS diet when compared with dry ground corn (Table 1). However, increased digestibility of most nutrients (OM, EE, CP, and TC) was found when animals were offered the RGGCS diet. Digestibility outcome is attributed to the amount of available starch, which provides the greatest amount of digestible energy and maximizes utilization.

This fact can be confirmed when lower quantities of starch in feces are observed (8.89 g/kg; Table 3) in lambs given an RGGCS diet. According to Zinn et al. (2007), the higher the starch digestibility, the lower the starch quantities in feces will be.

Starch available in rumen, due to rehydration and ensiling, contributed to a higher degradation rate in fraction "a" and effective degradability of dry matter (Table 4). Higher DM degradation in the RGGCS diet compared to corn grain is related to the ensiling process of rehydrated corn grain, in which the proteins (zeins) surrounding starch granules undergo proteolysis, making starch available and increasing ruminal degradability (Ferraretto et al., 2014).

According to Arcari et al. (2016), an increase in ruminal degradability of rapidly degradable corn starch (a fraction) occurs when corn undergoes the ensiling process. A similar result was found by Castro et al. (2019), who observed a 39% increase in fraction a (rapidly degradable) RGGCS storage for 247 days when compared to dried corn grain.

Corn grain silage storage time aims to break the protein barrier covering starch granules and increase starch digestibility (Kung Jr. et al., 2014), explaining greater starch intake (431.43 g/day; Table 3) in the RGGCS stored for 90 days diet.

Regarding the diet with 650 g/kg of concentrate, the higher DMI and other nutrients may be due to the intake being controlled by the physiological regulation of the animals, according to the supply of their energy requirements.

On the other hand, higher starch intake by animals receiving an 850-g/kg concentrate diet may be associated with the higher proportion of RGGCS in the diet, which is the main source of starch.

According to Forbes (1995), factors such as feeding levels and rumen capacity cause variations in the time the feed remains in this compartment, and therefore, the characteristic of the feed can reduce digestibility, which may have happened in this study, with less digestibility in the diet with 650 g/kg of concentrate, as it has in its composition (Table 1) higher NDF content.

Performance

According to Berchielli et al. (2006), intake is one of the factors with the greatest impact on animal production and affects performance. According to Mertens (1994), approximately 60 to 90% of animal performance variations can be attributed to variations that affect the nutrient intake.

The lower ADG (273.49 g/day) and total gain (13.12 kg) (Table 5) in the RGGCS diets are directly related to lower DMI and consequently justify the lower feed efficiency (317.57 g/day) (Table 5) of the lambs that received the RGGCS diet when compared with the dry corn diet (control diet).

The lack of influence of RGGCS experimental diets stored at 45 and 90 days and in the form of diets with 850 and 650 g/kg of concentrate can be explained due to the animals having similar weight and age, in addition to being consuming digestibility diets higher.

Economic analyses of the diets

Due to higher diet costs and lower net revenue, the RGGCS diets had less bioeconomic return, compared to the control diet. The greatest driving factor behind this result was the cost per kg of dry matter in the RGGCS diets.

However, it is important to evaluate oscillations in the price of corn, as in the case of a reduction in corn price, rehydration, and ensiling may bring better financial returns.

The RGGCS stored for 45 days showed positive results in the total revenue (Table 6). These larger values were due to cost calculations including ADG of lambs, which was superior for RGGCS diets stored for 45 days in comparison to that stored for 90 days.

Table 6 Economic evaluation based on experimental diets

Indicators	Dry ground corn		Concentrate g/kg				Storage time of RGGCS			
			850		650		45 days		90 days	
	US$	%	US$	%	US$	%	US$	%	US$	%
Cost of the diet (US$/kg)a	4.60	100.0	5.81	126.3	5.81	126.3	5.81	126.3	5.81	126.3
Daily cost of the diet (US$/animal)	4.87	100.0	5.70	116.9	5.88	121.1	5.61	115.3	5.96	122.7
Feedlot time (days)	48	–	48	–	48	–	48	–	48	–
Cost of weight gain (US$/kg)b	13.59	100.0	18.87	138.9	19.64	144.5	18.18	133.8	20.44	150.5
Total cost with feed (US$)c	219.16	100.0	247.54	112.9	275.54	125.7	247.74	113.0	276.39	126.1
Total cost (%)	–	46.5	–	64.5	–	67.1	–	62.1	–	69.9
Total revenue (US$)d	471.80	100.0	383.76	81.3	410.38	87.0	398.68	84.5	395.46	83.8
Net margin (US$)e	252.64	100.0	136.22	53.9	134.84	53.4	150.93	59.7	119.07	47.1
Net margin (US$/day)	5.26	100.0	2.84	53.9	2.81	53.4	3.14	59.7	2.48	47.1
Dry matter intake (g/day)	1057.71		949.08		1043.92		982.51 3.24		1010.49	
Feed conversion	2.79		3.31		3.34				3.43	
Total weight gain (kg)	16.13		13.12		14.03		13.63		13.52	
Animal prices US$/kg of body weight			US$29.25							

RGGCS rehydrated ground grain corn silage

[a]Average values (US$) per kg of dry matter of the feed: US$2.92 (corn silage); US$5.18 (RGGCS); US$3.12 (grain corn); US$8.70 (soybean meal); US$11.93 (urea); US$33.89 (mineral supplement); US$1.48 (limestone) and (Bicarbonate) US$ 23.43

[b]Feed conversion multiplied by the cost of the diet

[c]Cost of weight gain multiplied by total weight gain

[d]Total weight multiplied by the price received

[e]Revenue minus the total cost of feed

Net margin is obtained through total weight gain by the animal cost price. The best feed conversion of lambs receiving an 850 g/kg concentrate diet enabled a better bioeconomic return than the 650 g/kg concentrate diet while reducing diet costs.

The present study revealed that performance results for lambs receiving an RGGCS diet fell short of expectations. However, ADG met the requirements recommended by NRC (2007). Additionally, RGGCS is an alternative that can take advantage of fluctuating corn prices in the market (low price), favoring better bioeconomic returns.

Conclusion

Rehydrated ground grain corn silage can be an alternative to the fluctuation in corn price. Otherwise, it becomes unnecessary since just the grinding dry corn is satisfactory for performance lambs high.

The reduction of starch in the feces of lambs fed with RGGCS in diet shows the better use of starch in the gastrointestinal tract.

The process of storing the silage for 45 days is indicated to rehydrated ground grain corn, since starch digestibility was not changed by longer storage times.

Using 850 g/kg of concentrate in the diet better feed conversion and brings the best economic returns.

Author contribution Conceived the experiment: Azevedo, J.A.G. Performed the fieldwork: Guimarães, G.S, Cairo, F.C., Silva C.S, and Nunes, F.S. Performed statistical analysis and interpretation of results, Azevedo, J.A.G., Guimarães, G.S., Souza, L.L., Carvalho, G.G.P., Pina, D.S., Araújo, G.G.L, and Silva, R.R. Wrote the manuscript, Guimarães, G.S and Azevedo, J.A.G. All the authors read and approved the manuscript.

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Availability of data and materials The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate The study strictly conformed to Brazilian legislation regarding animal research and was approved under protocol number 024/18 by the Commission for Ethical Use of Animals at the Universidade Estadual de Santa Cruz (UESC).

Competing interests The authors declare no competing interests.

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