Tropical Animal Health and Production (2021) 53: 226
https://doi.org/10.1007/s11250-021-02643-0

REGULAR ARTICLES

Productive, nutritional, and metabolic performance of Chino Santandereano cattle receiving different degrees of protein-energy supplementation

David Esteban Contreras Marquez[1] · Emiro Rafael Canchila Asensio[2] · Edwin Davier Correa Rojas[1] · Candido José Ramírez Villareal[2] · Yeisson Yesid Robles Yaruro[2] · Bibiana Andrea Benavides Poveda[1] · Jhonny Steveen Peralta Castiblanco[1] · Dainer Alfonso Lagares Gomez[2] · Andrés Gilberto Calderón Cadena[2]

Received: 27 April 2020 / Accepted: 1 March 2021 / Published online: 25 March 2021

Abstract

Cattle of Colombian creole breed Chino Santandereano in the raising phase were subjected to stabling for 100 days in order to determine the productive, nutritional, and metabolic capacity when exposed to different degrees of protein-energy supplementation. Sixteen whole males with an initial mean weight of 377.69 ± 16.55 kg were used in completely randomized delineation with four treatments and four repetitions per treatment, as follows: UNS, not supplemented; low, supplemented with amounts relative to 0.5% of body weight; medium, supplemented with amounts relative to 1.0% of the live weight; and high, supplemented with amounts relative to 1.5% of body weight. At the end of each experimental period, the animals were weighed, and samples of feed, feces, blood, and urine were collected to determine the performance, consumption, and digestibility of the nutritional components, and nitrogen balance. In the greater performance, consumption, and digestibility of DM, OM, C-NFCP, EE, and NFC, the concentration of ureic nitrogen in blood and urine (P <0.05) was observed in supplemented animals when contrasted with UNS. Bovine Chinese Santandereano presents high productive, nutritional, and metabolic potential as a response to high levels of protein-energy supplementation.

Keywords Protein · Colombian creole breeds · Nitrogen · Weight gain · Consumption · Digestibility

Introduction

The performance of cattle raised in pasture production systems is commonly limited by the nutritional composition of the available pastures, the consumption capacity (Benvenutti et al. 2008), and adaptation to environmental conditions. Where production environments cannot be controlled, there is increased interest in native breeds or ones that are adapted to such environments. In Colombia, there are seven creole and two Colombian breeds, among which is the Chinese Santandereano, resistant to adverse climatic factors, parasite load, and with the ability to maintain itself when exposed to forages of low nutritional quality (Vásquez 2005).

Based on this information, inadequate nutritional strategies were taken by livestock producers, exposing the Chinese from Santander and other creole breeds to extensive production systems with a predominance of pastures with a high regrowth age, a high degree of lignification, and a low protein concentration that directly affects productive and reproductive performance (Poppi et al. 2018). These results have motivated disinterest in the use of many of the creole races, being replaced by foreign races or their crosses. Despite the joint efforts of public entities and associations dedicated to the preservation and multiplication of Colombian creole breeds, the number of livestock owners has drastically reduced (Ruiz Castro 2014). The lack of scientific information that determines the productive potential of each of the creole breeds (Vásquez 2005) is presented as the main generator of the lack of interest. It is necessary to expose these breeds to systems

✉ David Esteban Contreras Marquez
davidestebas@hotmail.com

[1] Department of Animal Science, University of Cundinamarca, Fusagasugá, Cundinamarca 252211, Colombia

[2] Department of Veterinary Medicine and Animal Science, University Institute of La Paz, Barrancabermeja 687031, Colombia

that seek to determine the productive potential when submitted to feed concentrated in highly digestible nutritional components.

For this, our research aims to determine the true productive, nutritional, and metabolic potential stipulated by the genetics of the Chinese Santandereano breed, being the first work in the area of nutrition carried out with this bovine breed.

Materials and methods

Location and animals

The experiment was carried out in the Bovine Culture Sector of the Faculty of Veterinary Medicine and Animal Husbandry of the University Institute of La Paz (Hacienda Santa Lucia), located in the city of Barrancabermeja, Santander, Colombia at 75.94 m above sea level, with 28.1 °C, 165.7 mm, and 84.4% respectively for average temperature, accumulated precipitation, and average relative humidity. Sixteen male uncastrated Chinese Santanderean cattle were used, with an average age and initial weight of 2 years and 377.69±16.55 kg, respectively. The animals were housed in covered cubicles of 3 m^2/animal, with provision for drinking fountains, feeders, and individual salt pans.

Experimental outline and diet

Completely randomized delineation was used with four treatments and four repetitions per treatment, where all the animals received the same supplemental diet, varying the quantity offered, with the treatments being UNS: not supplemented, low: supplemented with relative amounts of 0.5% body weight, medium: supplemented with amounts relative to 1.0% of body weight, and high: supplemented with amounts relative to 1.5% of body weight. The supplementary diet offered was composed of soybeans (35.34%), palm kernel cake (10.00%), ground corn (27.33%), and rice bran (27.33%), being formulated to provide 200 g CP/kg DM. All treatments received hay from Brachiaria humidicola (Rendle) Schweick (Poaceae), water, and mineralized salt ad libitum. The nutritional composition of the hay and supplement offered to the animals can be seen in Table 1.

Experimental procedures and sampling

The experiment lasted 100 days divided into four 25-day experimental periods. The first 22 days of each experimental period were destined to adapt the animals to the diet, plus 3 days to collect feces, urine, blood, and feed. Before the start of the experiment, the animals underwent 15 days of adaptation to the experimental area. At the beginning and end of each experimental period, the animals were weighed after a 14-h feeding fast, to determine the weight gain and subsequently calculate the average daily gain (Marquez et al. 2014; Martins et al. 2017). At the beginning of the experiment and when necessary, all the animals were subjected to ectoparasite and endoparasite control.

The diet was always offered at 07:00 and 15:00. The consumption of hay and the supplement was determined daily by the difference between the quantity supplied of each feed minus the leftovers found 24 h after the supply. The consumption of each nutritional component was determined by the following equation.

$$\mathrm{NAI} = ((\mathrm{IDMH}) \times [N]) + (\mathrm{IDMS} \times [N])$$

where NAI is the amount of nutrient ingested; IDMH is the dry matter consumption of hay; IDMS is the supplement dry matter consumption; and [*N*] is the concentration of each nutrient within the feed based on dry matter.

Once the total dry matter consumption was determined, the feed conversion and efficiency were determined, using the following equations:

Table 1 Nutritional composition of hay and supplement offered to animals in the different experimental periods

Item	*Brachiaria humidicola* hay				Supplement			
	P1	P2	P3	P4	P1	P2	P3	P4
DM (%NM)	82.704	78.292	84.174	82.733	87.979	81.227	82.412	90.501
OM (%DM)	94.280	91.256	93.042	95.618	95.200	94.796	95.891	95.100
CP (%DM)	4.889	5.749	5.176	3.950	21.029	23.972	23.889	20.911
EE (%DM)	2.816	1.278	1.730	1.097	8.380	7.661	7.748	7.202
NDF (%DM)	75.740	78.376	83.537	79.694	30.586	31.475	27.383	32.444
NFC (%DM)	10.834	5.574	2.597	10.875	35.204	31.687	36.869	34.541
DE (Mcal/kg DM)	3.853	3646	3.748	3.806	4.407	4.393	4.443	4.340
ME (Mcal/kg DM)	3.340	3.144	3.241	3.296	3.863	3.851	3.898	3.800

DM dry matter; *NM* natural matter; *OM* organic matter; *PC* crude protein; *EE* ethereum extract; *NDF* fiber in neutral detergent; *NFC* non-fibrous carbohydrates; *DE* digestible energy; *ME* metabolizable energy

$$FC = (DMI/ADG)$$

where FC is the feed conversion in kg/kg; DMI is the dry matter consumption in kg; and ADG is the average daily gain in kg.

$$FE = (ADG/DMI)$$

where FE is the feed efficiency.

In the last 3 days of each experimental period, a digestive test was performed. Stool excretion was determined by total collection immediately after defecation during the 3 days, excretion being the average of the 3 days of collection. Feces, like feed, were analyzed to determine the bromatological composition and to determine the digestibility of each nutrient, using the following equation.

$$\%Digestibility = ((NAI{-}NAE/NAI) \times 100)$$

where NAI is the amount of nutrient ingested and NAE is the excreted amount of nutrients.

Hay and supplement were collected directly from the place where the feed was stored. At every 24 h of the collection period, hay, supplement, and feces samples were weighed, immediately taken to a stove with forced air circulation (Ar SL-102; SOLAB®) at 55-60 °C/72 h, subsequently ground to 1 mm in a Willye-type knife mill (TE-680, SOLAB®), stored in glass pots, and sent to the Animal Nutrition Laboratory of the University of Cundinamarca for the respective analyses.

On the last day of each experimental period, for the evaluation of the nitrogen metabolic characteristics, 4 h after the supply of the supplement, collections of "spot" samples of 10 mL of urine were made by spontaneous urination, and blood collections by puncture of the jugular vein. The urine samples were diluted in 40 mL of H2SO4 (0.036 N) and frozen at −20 °C for subsequent evaluation of urea levels (urease/GLDH method), using commercial kits. For the blood samples, commercial vacuum tubes were used with accelerator coagulation gel, the samples being centrifuged and the plasma frozen, for subsequent analysis for urea (Martins et al. 2017). Urine and blood samples were analyzed in the veterinary clinic of the University Institute of La Paz.

Chemical analysis

Hay, supplement, and feces were analyzed to determine the concentration of dry matter (DM) (INCT-CA G-003/1), ashes (ASH) (INCT-CA M-001/1), organic matter (OM), crude protein (CP) (INCT-CA N-001/1), ether extract (EE) (INCT-CA G-004/1), fiber in neutral detergent (NDF) (INCT-CA F-002/1), and non-fibrous carbohydrates (NFC) according to Detmann et al. (2012) and total digestible nutrients (TDN), digestible energy, and metabolizable energy according to Valadares Filho et al. (2016).

Non-fibrous carbohydrates (NFC) were estimated according to the recommendations of Hall and Akinyode (2000) using the following equation.

$$NFC = 100{-}((\%CP{-}\%CPU + \%of\ urea) + \%NDF + \%EE + \%ASH)$$

where CPU is the crude urea protein.

Blood and urine analyses were performed in automatic equipment for biochemistry, Mindray® brand, model: BS200E, using Bioclin® brand determination kits. The method used was fixed time kinetics, with the samples processed being read spectrophotometrically between 334 and 365 nm wavelength (Marquez et al. 2014; Martins et al. 2017).

The amount of total digestible nutrients (TDN), the contribution of digestible (DE), and the metabolizable energy (ME) per kilogram of dry matter were determined using the equations proposed by Valadares Filho et al. (2016).

$$TDN\ (kg) = ((CCP \times \%DCP) + (CEE \times \%DEE) \times 2.25) + (CNDF \times \%DNDF) + (C{-}NFC \times \%DNFC)$$

where *TDN* is the total digestible nutrients; CCP and DCP are the consumption and digestibility of crude protein; CEE and DEE are the consumption and digestibility of ethereal extract; CNDF and DNDF are the consumption and digestibility of neutral detergent fiber; C-NFC and DNFC are the consumption and digestibility of non-fibrous carbohydrates; and 2.25 is the constant that refers to the energy contribution to more than fats possessed in relation to carbohydrates.

$$DE\ (Mcal/kg\ DM) = ((\%CP \times 0.056) + (\%EE \times 0.094) + (\%NDF \times 0.042) + (\%NFC \times 0.042)){-}0.322$$

where DE is the digestible energy; 0.056, 0.094, and 0.042 are the degrees of combustion of each of the nutritional components; and 0.322 is the fecal metabolic fraction for calculating DE in Mcal/kg DM.

$$ME\ (Mcal/kg\ DM) = (DE \times 0.9422){-}0.303$$

where EM is the metabolizable energy and ED is the digestible energy.

Statistical analyses

Statistical analyses were performed using the R Studio V 3.6.1 statistical software. Each variable was analyzed by applying parametric statistics for orthogonal contrasts, comparison of means by Tukey's test, one-way analysis of variance (ANOVA), collinearity of the data, and PLS partial least squares regression in order to identify the correlation between the variables and their degree of significance on the dependent variable, using the R Studio V 3.6.1 plsreg1 methodology, which predicts the behavior of an independent variable, a technique that generalizes and combines characteristics of the analysis of principal components and models multiple regression when the number of predictors is close to or larger than the observations. The PLS model (see the following equation) describes the relationship between a matrix Y (dependent variables) and a matrix X (predictor variables) expressed as:

$$Y = F\,(X) + E$$

Matrix X refers to the predictor variables and their squares or cross-terms if they have been added. When squares and cross-terms are added to matrix X, this corresponds to the fit of quadratic models.

Results

Supplemented animals presented higher FBW, WG, ADG, FC, and FE when contrasted with NS (P <0.05), with no difference (P > 0.05) between supplemented low, medium, and high (Table 2).

Greater consumption of DM, DMS, OM, CP, EE, NFC, TDN, DE, and ME was observed in supplemented animals when contrasted with NS (P <0.05), presenting greater consumption of DMS, CP, EE, and NFC as degree of supplementation increased (P <0.05). Low and medium treatment animals showed higher DMH consumption when contrasted with high. For the NDF variable, no difference (P > 0.05) in consumption was observed between supplemented animals and NS as between supplemented animals (Table 3).

Greater digestibility of DM, OM, CP, EE, and NFC was observed in supplemented animals in contrast to NS animals (P <0.05) with no difference between supplemented treatments (P > 0.05). For the digestibility of the NDF, no difference was observed between supplemented and NS as between the supplemented treatments (Table 4).

Supplemented animals presented a higher concentration of BUN and UUN, being higher concentrations of these variables in animals of the high treatment when contrasted with low and medium (Table 4).

Table 5 shows the correlation matrix of the nutritional and metabolic variables analyzed in this study, in relation to ADG, outlined in Figs. 1 and 2. A negative correlation can be seen between DMH consumption (−0.878), NDF (−0.505), and digestibility of NDF (−0.505) with ADG, being significant (P <0.05).

The variable consumption of DMS, OM, CP, EE, NFC, TDN, DE, and ME and digestibility of CP, EE, and NFC were highly correlated (> 0.80) and significantly (P <0.05), BUN (0.656) and UUN (0.754) presented a medium and significant correlation (P <0.05), while digestibility of DM and OM had a low correlation (<0.40) not significant (P > 0.05) with ADG. It should be noted that the variables that have the greatest influence on ADG due to its high correlation are DMS, CP, EE, NFC, and NFC digestibility.

Table 2 Productive performance of Chino Santandereano cattle in stables receiving different degrees of supplementation

Item[1]	Treatments				SEM[2]	P-value[3]		
	NS	Low	Medium	High		S vs. NS	L, M vs. H	L vs. M
IBW (kg)	390.50	377.80	371.80	370.80	16.55	0.389	0.847	0.802
FBW (kg)	373.41	465.13	481.46	497.90	20.07	<0.001	0.336	0.575
WG (kg)	−17.09	87.33	109.66	127.10	11.42	<0.001	0.063	0.191
ADG (g)	−169.20	864.60	1085.80	1258.50	113.16	<0.001	0.063	0.191
FC (kg)	73.29	11.34	9.35	8.38	14.92	0.004	0.915	0.926
FE	0.02	0.09	0.11	0.12	0.01	<0.001	0.353	0.437

Treatments, NS: not supplemented; low: supplemented with amounts relative to 0.5% of body weight; medium: supplemented with amounts relative to 1.0% of the live weight; high: supplemented with amounts relative to 1.5% of body weight

[1] I*BW* initial weight; *FBW* final weight; *WG* weight gain; *ADG* daily average gain; *FC* feed conversion; *FE* feed efficiency

[2] Standard error of the mean

[3] S vs. NS: contrast between supplemented animals vs. not supplemented; L, M vs. H: contrast between treatments low + medium vs. high; L vs. M: contrast between treatment low vs. medium. Values differ significantly at $P < 0.05$

Table 3 Consumption of nutritional components of the diet of the bovine Chino Santandereano in stables receiving different degrees of supplementation

Item[1]	Treatments				SEM[2]	*P*-value[3]		
	NS	Low	Medium	High		S vs. NS	L, M vs. H	L vs. M
DM (kg)	6.93	9.03	9.73	10.30	0.525	<0.001	0.179	0.367
DMH (kg)	6.93	7.42	6.59	5.76	0.410	0.487	0.029	0.177
DMS (kg)	0.00	1.61	3.14	4.53	0.205	<0.001	<0.001	<0.001
OM (kg)	6.48	8.48	9.16	9.71	0.534	0.001	0.197	0.392
CP (kg)	0.34	0.72	1.02	1.29	0.047	<0.001	<0.001	<0.001
EE (kg)	0.12	0.25	0.35	0.44	0.030	<0.001	0.001	0.034
NDF (kg)	5.52	6.39	6.19	5.96	0.429	0.204	0.544	0.753
NFC (kg)	0.49	0.89	1.57	2.00	0.184	<0.001	0.005	0.022
TND (kg)	4.36	6.08	7.12	7.69	0.495	<0.001	0.097	0.164
DE (Mcal/day)	22.58	30.42	33.57	36.25	1.890	<0.001	0.090	0.262
ME (Mcal/day)	26.10	35.07	38.62	41.65	2.166	<0.001	0.095	0.269

Treatments, NS: not supplemented; low: supplemented with amounts relative to 0.5% of body weight; medium: supplemented with amounts relative to 1.0% of the live weight; high: supplemented with amounts relative to 1.5% of body weight

[1] *DM* dry matter; *DMH* dry matter of hay; *DMS* dry matter of supplement; *OM* organic matter; *CP* crude protein; *EE* ethereum extract; *NDF* fiber in neutral detergent; *NFC* non-fibrous carbohydrates; *TDN* total digestible nutrients; *DE* digestible energy; *ME* metabolizable energy

[2] Standard error of the mean

[3] S vs. NS: contrast between supplemented animals vs. not supplemented; L, M vs. H: contrast between treatments low + medium vs. high; L vs. M: contrast between treatment low vs. medium. Values differ significantly at $P < 0.05$

Discussion

Supplementation as a route of additional protein-energy supply can generate several effects on forage consumption and total dry matter, such as the substitute (DM consumption is maintained with a reduction in forage consumption), additive (it is stimulated DM consumption while maintaining forage consumption), substitute additive (DM consumption is

Table 4 Digestibility of the nutritional components of the diet and nitrogen status of the bovine Chino Santandereano in stables receiving different degrees of supplementation

Item[1]	Treatments				SEM[2]	*P*-value[3]		
	NS	Low	Medium	High		S vs. NS	L, M vs. H	L vs. M
DM (%)	64.20	69.83	73.18	72.76	2.771	0.032	0.717	0.408
OM (%)	65.41	71.25	73.89	73.78	2.529	0.023	0.703	0.474
CP (%)	55.15	69.85	76.10	75.43	3.291	<0.001	0.553	0.203
EE (%)	49.82	69.78	80.11	79.79	5.531	0.001	0.488	0.213
NDF (%)	65.72	69.78	67.92	67.46	2.869	0.437	0.699	0.655
NFC (%)	67.25	76.34	94.90	92.40	5.553	0.007	0.338	0.035
Nitrogen balance								
BUN (mg/dL)	25.68	30.98	31.65	38.23	2.484	0.017	0.042	0.850
UUN (mg/dL)	21.47	24.34	27.28	30.88	1.611	0.007	0.024	0.221

Treatments, NS: not supplemented; low: supplemented with amounts relative to 0.5% of body weight; medium: supplemented with amounts relative to 1.0% of the live weight; high: supplemented with amounts relative to 1.5% of body weight

[1] *DM* dry matter; *OM* organic matter; *CP* crude protein; *EE* ethereum extract; *NDF* fiber in neutral detergent; *NFC* non-fibrous carbohydrates; *BUN* ureic nitrogen in blood; *UUN* ureic nitrogen in urine

[2] Standard error of the mean

[3] S vs. NS: contrast between supplemented animals vs. not supplemented; L, M vs. H: contrast between treatments low + medium vs. high; L vs. M: contrast between treatment low vs. medium. Values differ significantly at $P < 0.05$

Table 5 Correlation matrix and significance values for the nutritional and metabolic variables evaluated

Item	ADG	Intake										Digestibility						BUN	UUN
		DMH	DMS	OM	CP	EE	NDF	NFC	TDN	DE	ME	DM	OM	CP	EE	NDF	NFC		
ADG	1	<0.001	<0.001	0.001	<0.001	<0.001	0.039	<0.001	<0.001	<0.001	<0.001	0.147	0.086	<0.001	<0.001	0.030	<0.001	0.002	<0,001
DMH	-0.878	1	<0.001	0.113	<0.001	<0.001	<0.001	<0.001	0.020	0.030	0.028	0.461	0.311	<0.001	<0.001	0.003	<0.001	0.049	0.008
DMS	0.980	-0.857	1	<0.001	<0.001	<0.001	0.073	<0.001	<0.001	<0.001	<0.001	0.221	0.146	<0.001	<0.001	0.019	<0.001	<0,001	<0,001
OM	0.750	-0.399	0.814	1	<0.001	0.001	0.556	<0.001	<0.001	<0.001	<0.001	0.214	0.186	0.033	0.057	0.338	0.068	<0,001	<0,001
CP	0.983	-0.848	0.996	0.814	1	<0.001	0.082	<0.001	<0.001	<0.001	<0.001	0.136	0.085	<0.001	<0.001	0.038	<0.001	<0,001	<0,001
EE	0.972	-0.877	0.975	0.743	0.980	1	0.035	<0.001	<0.001	<0.001	<0.001	0.056	0.030	<0.001	<0.001	0.073	<0.001	0.005	<0,001
NDF	-0.505	0.843	-0.446	0.154	-0.433	-0.513	1	0.073	0.857	0.968	0.994	0.950	0.757	0.034	0.002	0.012	<0.001	0.711	0.876
NFC	0.951	-0.847	0.988	0.810	0.971	0.951	-0.445	1	<0.001	<0.001	<0.001	0.398	0.287	0.001	<0.001	0.007	<0.001	0.001	<0,001
TDN	0.850	-0.556	0.886	0.946	0.900	0.880	-0.047	0.859	1	<0.001	<0.001	0.020	0.014	0.001	0.002	0.510	0.007	<0,001	<0,001
DE	0.835	-0.526	0.889	0.989	0.890	0.833	0.011	0.880	0.972	1	<0.001	0.160	0.127	0.008	0.013	0.223	0.016	<0,001	<0,001
ME	0.839	-0.533	0.893	0.988	0.893	0.838	0.002	0.884	0.973	1.000	1	0.159	0.126	0.007	0.012	0.216	0.014	<0,001	<0,001
									Digestibility										
DM	0.367	-0.192	0.313	0.318	0.377	0.472	-0.016	0.219	0.558	0.357	0.358	1	<0.001	0.001	0.019	0.020	0.182	0.410	0.647
OM	0.428	-0.261	0.368	0.337	0.430	0.527	-0.081	0.274	0.584	0.385	0.386	0.997	1	<0.001	0.008	0.042	0.106	0.398	0.594
CP	0.849	-0.761	0.785	0.519	0.824	0.885	-0.515	0.710	0.745	0.621	0.625	0.728	0.775	1	<0.001	0.579	<0.001	0.070	0.035
EE	0.886	-0.883	0.829	0.469	0.849	0.917	-0.684	0.785	0.687	0.588	0.594	0.563	0.623	0.964	1	0.164	<0.001	0.197	0.067
NDF	-0.526	0.680	-0.560	-0.247	-0.507	-0.446	0.595	-0.624	-0.172	-0.312	-0.316	0.556	0.497	-0.145	-0.354	1	0.015	0.252	0.036
NFC	0.901	-0.965	0.868	0.452	0.871	0.913	-0.780	0.847	0.630	0.576	0.582	0.340	0.406	0.869	0.958	-0.579	1	0.100	0.018
BUN	0.656	0.445	0.762	0.815	0.795	0.605	0.088	0.671	0.771	0.821	0.819	0.195	0.200	0.413	0.301	0.269	0.379	1	<0,001
UUN	0.754	0.573	0.866	0.862	0.884	0.716	0.037	0.808	0.813	0.883	0.883	0.109	0.127	0.474	0.418	0.472	0.523	0.958	1

Values differ significantly at $P < 0.05$

ADG daily average gain; *DM* dry matter; *DMH* dry matter of hay; *DMS* dry matter of supplement; *OM* organic matter; *CP* crude protein; *EE* ethereum extract; *NDF* fiber in neutral detergent; *NFC* non-fibrous carbohydrates; *TDN* total digestible nutrients; *DE* digestible energy; *ME* metabolizable energy; *BUN* ureic nitrogen in blood; *UUN* ureic nitrogen in urine

increased with a reduction in forage consumption), stimulant additive (DM consumption is stimulated with increased forage consumption), and substitute with depression (DM and forage consumption is reduced) (Souza et al. 2010).

According to AdaMO (1985), supplementation affects the intake of forage of beef steers; meanwhile, in our study, the low level of supplementation generated an additive effect with stimulation on the intake of DM and DMH, thus being able to state that the consumption of DMH from supplemented animals is dependent on the degree of supplementation provided. These results are interesting when you want to maximize the use of the normally lower-cost basal diet. It should be noted that an increase in performance in the low treatment was not generated by stimulation of DMH consumption given a negative correlation with ADG. The trend of reduction in the consumption of DMH in supplemented animals also appears as an interesting result and maybe a strategy used when it is desired to increase the carrying capacity once the maximum availability of forage mass for a given cultivar has been explored. This behavior can be explained not only by the dilution effect, but also by the concentration of carbohydrates in the supplement that reduces the consumption of DMH (Valente et al. 2013).

The increase in DM intake in supplemented animals when contrasted with UNS can be explained thanks to the supplementation that generates an additive effect, which in turn increases the intake of the nutritional components OM, CP, EE, NFC, TDN, DE, and ME, given the high concentration of these within the DMS, while the intake of DMS is responsible for the increase in the performance of the animals, as the supplement, as well as the nutritional components present, is highly correlated with ADG. Similar results were found by Valente et al. (2013) where restricted animals presented lower DM consumption.

Despite the animals of the supplemented treatments having a higher consumption of DM, the contribution of large

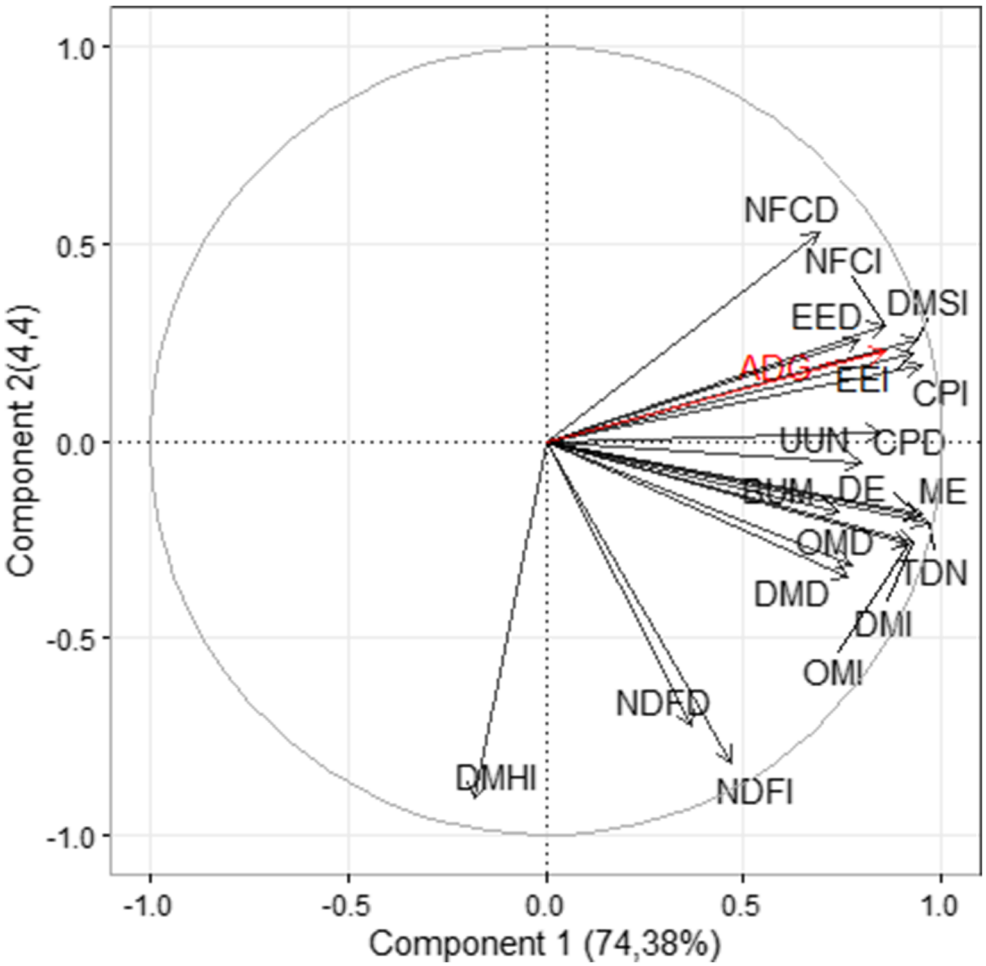

Fig. 1 Correlations between nutritional and metabolic variables, with ADG as the dependent variable. ADG: daily average gain; intake (I) or/and digestibility (D) of DM: dry matter; intake of DMH: the dry matter of hay; intake of DMS: the dry matter of supplement; intake (I) and digestibility (D) of OM: organic matter; CP: crude protein; EE: ethereum extract; NDF: fiber in a neutral detergent; NFC: non-fibrous carbohydrates; TDN: total digestible nutrients; DE: digestible energy; ME: metabolizable energy; BUN: ureic nitrogen in the blood; UUN: ureic nitrogen in urine

amounts of highly soluble nutritional components via supplementation, highly correlated with ADG, increases feeding efficiency and feed conversion, requiring supplemented animals to consume less amount of DM/kg of live weight. The negative performance observed in animals of the UNS treatment can be explained by the low contribution of nitrogen and energy by the hay and the high concentration of NDF perhaps with a high degree of lignification that makes it difficult to take advantage of the nutritional components immersed in the content cell, in addition to the high probability of presenting high levels of nitrogen attached to the fiber (nitrogen insoluble in neutral detergent and acid), all these processes altering the efficiency and feed conversion.

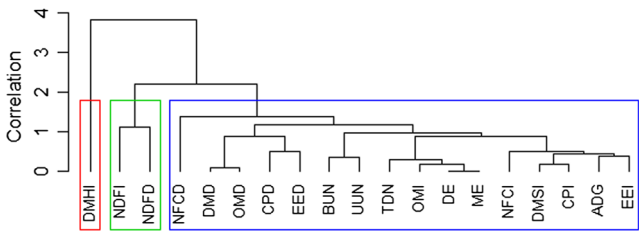

Fig. 2 Correlations of the cluster diagram between nutritional and metabolic variables, with ADG as the dependent variable. ADG: daily average gain; intake (I) or/and digestibility (D) of DM: dry matter; intake of DMH: the dry matter of hay; intake of DMS: the dry matter of supplement; intake (I) and digestibility (D) of OM: organic matter; CP: crude protein; EE: ethereum extract; NDF: fiber in a neutral detergent; NFC: non-fibrous carbohydrates; TDN: total digestible nutrients; DE: digestible energy; ME: metabolizable energy; BUN; ureic nitrogen in the blood; UUN: ureic nitrogen in urine

By presenting the supplement with high concentrations of nutrients normally of greater solubility when compared with fibrous feeds such as forage (Paulino et al. 2008), we can explain the observed increase in the digestibility of DM, OM, CP, EE, and NFC in supplemented animals, results similar to those observed by Acedo et al. (2011). According to Figueiras et al. (2016), the minimum contribution of 8 g of CP/kg DM ingested is necessary to motivate the population growth of ruminal microorganisms and indirectly the digestibility of nutrients. de Oliveira Franco et al. (2017) state that increased intake of CP generates a positive effect on the digestibility of NDF, and nitrogenous compounds trigger events that promote the synthesis of bacterial enzymes that would improve fiber digestibility (Rufino et al. 2016). Given the high protein concentration in the diet of supplemented

animals, sufficient to generate an increase in the degradative activity of the ruminal microflora, we can attribute the absence of difference in the digestibility of NDF between supplemented animals and UNS to the same composition of the fiber present in the hay as previously mentioned, perhaps with high participation of indigestible compounds that hinder the maximized use of the NDF, motivated by the advanced age of regrowth that the cultivar presented at the time of harvest.

Increase in BUN concentrations as the degree of supplementation increases can be explained by higher consumption and digestibility of CP in supplemented animals. Similar results were observed by O'Connor et al. (2019), where the animals with the highest consumption of PC presented a higher concentration of BUN and UUN.

Regardless of the breed of cattle, unsupplemented animals have the metabolic capacity to become more efficient in seeking to control the nitrogen balance (Huntington et al. 2007), trying to counteract low BUN levels, eliminating less UNN, which would improve the amount of metabolizable protein for maintenance and production. Our results show that despite the UNS animals becoming more efficient with as a survival mechanism, they do not manage to increase weight gain (high apparent efficiency of N use is not necessarily indicative of good nutritional balance) when compared to supplemented animals, which presented a lower degree of efficiency in the nitrogen status (Angelidis et al. 2019), different from the results obtained by Marquez et al. (2014) and Ortega et al. (2016) where no difference was observed between supplemented and unsupplemented animals in relation to ADG, probably due to working with pastures with higher nutritional quality.

In the face of a protein deficiency such as that observed in UNS animals, the elimination of nitrogen decreases and the catabolic protein processes in the tissues increase to supply nitrogen to the ruminal environment (Huntington et al. 2007). Although the animals in the UNS treatment reduced the elimination of UUN, these amounts were not enough to satisfy the demands of the microorganisms inside the rumen, perhaps causing mobilization of body reserves that would explain the weight loss observed in this treatment.

When considering the productive response presented by the animals receiving high amounts of nutrients, we can affirm that the Chinese Santandereano breed has high productive potential; the little existing information does not represent the true potential of productive, nutritional, and metabolic performance, since it has been evaluated with animals consuming only forages of the low nutritional contribution that do not exceed, as in the case of the present study, CP higher than 6% with DM base.

Thus, we can conclude that concentrate supplementation improves the consumption, the digestibility of the nutritional components of the diet, and the productive performance of cattle from the Chinese Santandereano breed. These results show that Chinese Santandereano cattle in this environment are capable of good rates of growth when offered moderate amounts of nutrient-dense supplements

Author contribution All authors contributed to the study conception and design. Material preparation, data collection, and analysis were performed by David Esteban Contreras Marquez, Emiro Rafael Canchila Asensio, Edwin Davier Correa Rojas, Candido José Ramírez Villareal, Yeisson Yesid Robles Yaruro, Bibiana Andrea Benavides Poveda, Jhonny Steveen Peralta Castiblanco, Dainer Alfonso Lagares Gomez, and Andrés Gilberto Calderón Cadena. The first draft of the manuscript was written by David Esteban Contreras Marquez and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Funding We received financial support from Instituto Universitario de la Paz (UNIPAZ) and Universidad de Cundinamarca (UdeC).

Declarations All animal care and handling procedures were approved by the Animal Care and Use Committee of the Instituto Universitario de la Paz, Colombia (protocol Unipaz no. 15/2018).

Conflict of interest The authors declare no competing interests.

References

Acedo, T.S., Paulino, M.F., Detmann, E., Valadares Filho, S.C., Sales, M.F.L. and Porto, M.O., 2011. Fontes proteicas em suplementos para novilhos no período de transição seca-águas: características nutricionais Arquivo Brasileiro de Medicina Veterinária e Zootecnia, 63, 895–904

AdaMO, D.C., 1985. Effect of Time of Supplementation on Performance, Forage Intake and Grazing Behavior of Yearling Beef Steers Grazing Russian Wild Ryegrass in the Fall Journal of Animal Science, 61, 1037–1042

Angelidis, A., Crompton, L., Misselbrook, T., Yan, T., Reynolds, C.K. and Stergiadis, S., 2019. Evaluation and prediction of nitrogen use efficiency and outputs in faeces and urine in beef cattle Agriculture, Ecosystems & Environment, 280, 1–15

Benvenutti, M.A., Gordon, I.J., Poppi, D.P., Crowther, R. and Spinks, W., 2008. Foraging mechanics and their outcomes for cattle grazing reproductive tropical swards Applied Animal Behaviour Science, 113, 15–31 (Elsevier)

de Oliveira Franco, M., Detmann, E., de Campos Valadares Filho, S., Batista, E.D., de Almeida Rufino, L.M., Barbosa, M.M. and Lopes, A.R., 2017. Intake, digestibility, and rumen and metabolic characteristics of cattle fed low-quality tropical forage and supplemented with nitrogen and different levels of starch Asian-Australasian Journal of Animal Sciences, https://doi.org/10.5713/ajas.16.0629

Detmann, E., Souza, M.A. de, Valadares Filho, S. de C., Queiroz, A.C. de, Berchielli, T.T., Saliba, E. de O.S., Cabral, L. da S., Pina, D. dos S., Ladeira, M.M. and Azevedo, J.A. G., 2012. Métodos para análise de alimentos Visconde do Rio Branco: Suprema, 1, 1–214

Figueiras, J.F., Detmann, E., Franco, M.O., Batista, E.D., Reis, W.L.S., Paulino, M.F. and Filho, S.C.V., 2016. Effects of Supplements with different protein contents on nutritional performance of grazing cattle during the rainy season Asian-Australasian Journal of Animal Sciences, https://doi.org/10.5713/ajas.16.0125

Hall, M.B. and Akinyode, A., 2000. Cottonseed hulls: working with a novel fiber source In:, Annual Florida Ruminant Nutrition Symposium,

Huntington, G.B., Burns, J.C. and Archibeque, S.L., 2007. Urea metabolism in beef steers grazing Bermudagrass, Caucasian bluestem, or gamagrass pastures varying in plant morphology, protein content, and protein composition1,2,3,4 Journal of Animal Science, 85, 1997–2004

Marquez, D.E.C., Fonseca Paulino, M., Marcondes, M.I., Navajas Rennó, L., Vieira de Barros, L., Soares Martins, L., Maza Ortega, R., Gomes da Silva, A., Mageste de Almeida, D., Paff Sotelo, D. and Moura, F.H., 2014. Nutritional parameters and production of calves on pasture supplemented with different sources of protein foods Semina:Ciencias Agrarias, 35, 2709–2722

Martins, L.S., Paulino, M.F., Marcondes, M.I., Rennó, L.N., de Almeida, D.M., Lopes, S.A., Marquez, D.E.C., Manso, M.R., da Silva, A.G. and Valente, E.E.L., 2017. Cottonseed meal is a suitable replacement for soybean meal in supplements fed to Nellore heifers grazing Brachiaria decumbens Animal Production Science, 57, 1893–1898

O'Connor, A., Moloney, A.P., O'Kiely, P., Boland, T.M. and McGee, M., 2019. Effects of fertiliser nitrogen rate to spring grass on apparent digestibility, nitrogen balance, ruminal fermentation and microbial nitrogen production in beef cattle and in vitro rumen fermentation and methane output Animal Feed Science and Technology, 254, 1–12

Ortega, R.M., Paulino, M.F., Detmann, E., Rennó, L.N., da Silva, A.G., Marquez, D.C., Moreno, D.S., Moura, F.H. and Bitencourt, J.A., 2016. Quantities of supplements for grazing beef heifers in the dry-rainy transition season Semina:Ciencias Agrarias, 37, 461–472

Paulino, P.V.R., Valadares Filho, S. de C., Detmann, E., Valadares, R.F.D., Fonseca, M.A., Véras, R.M.L. and Oliveira, D.M., 2008. Desempenho produtivo de bovinos Nelore de diferentes classes sexuais alimentados com dietas contendo dois níveis de oferta de concentrado Revista Brasileira de Zootecnia, 37, 1079–1087

Poppi, D.P., Quigley, S.P., Silva, T.A.C.C. da and McLennan, S.R., 2018. Challenges of beef cattle production from tropical pastures Revista Brasileira de Zootecnia, 47, 1–9

Rufino, L.M. de A., Detmann, E., Gomes, D.Í., Reis, W.L.S. dos, Batista, E.D., Valadares Filho, S. de C.. and Paulino, M.F., 2016. Intake, digestibility and nitrogen utilization in cattle fed tropical forage and supplemented with protein in the rumen, abomasum, or both Journal of Animal Science and Biotechnology, 7

Ruiz Castro, D.M., 2014. Estimación de la heredabilidad para el peso al nacimiento y el peso al destete en la raza chino santandereano y sus cruces en el departamento de Santander (Universidad Nacional Abierta ya Distancia UNAD)

Souza, M.A., Detmann, E., Paulino, M.F., Sampaio, C.B., Lazzarini, Í. and Valadares Filho, S.C., 2010. Intake, digestibility and rumen dynamics of neutral detergent fibre in cattle fed low-quality tropical forage and supplemented with nitrogen and/or starch Tropical Animal Health and Production, 42, 1299–1310

Valadares Filho, S.C., Costa e Silva, L.F., Lopes, S.A., Prados, L.F., Chizzotti, M.L., Machado, P.A.S., Bissaro, L.Z. and Furtado, T., 2016. BR-CORTE 3.0 Cálculo de exigências nutricionais, formulação de dietas e predição de desempenho de zebuínos puros e cruzados

Valente, E.E.L., Paulino, M.F., Detmann, E., Valadares Filho, S.C., Chizzotti, M.L., Silva, A.G. and Maciel, I.F.S., 2013. Grazing Behavior and Locomotion of Young Bulls Receiving Different Nutritional Plans in a Tropical Pasture Asian-Australasian Journal of Animal Sciences, 26, 1717–1725

Vásquez, H.J.A., 2005. Conservación y utilización de las razas bovinas criollas y colombianas para el desarrollo rural sostenible Archivos de zootecnia, 54, 141–144 (Servicio de Publicaciones)