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Meat quality of Santa Inês sheep raised in confinement with diet containing cactus pear replacing corn

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ABSTRACT - The objective of this study was to assess the tissue component yields and the physical, chemical and sensory characteristics of meat from Santa Inês sheep fed diets in which cactus pear partially or completely replaced corn. The study used 45 Santa Inês rams with initial live weight of 25±2.5 kg and final weight of 35±1.5 kg in a completely randomized design with five treatments (0, 25, 50, 75 and 100%) and nine replicates per treatment. The leg of the animal was used to analyze the tissue component yields, and the *longissimus dorsi* muscle was used for assessment of the sensory characteristics and the physical and chemical compositions. The inclusion of cactus pear in the diet increased the adipose tissue percentage quadratically, up to 50%, reducing the muscle/fat ratio. The lipid content of the meat decreased with the inclusion of cactus pear in the diet. The results indicate that cactus pear can replace 100% of the corn in the diets of Santa Inês sheep kept in confinement, resulting in a decreased lipid percentage and without compromising the physical and sensory characteristics of the meat.

Key Words: meat tenderness, *Opuntia ficus indica*, proximate composition, sensory characteristics

Introduction

The growing global demand for sheep meat, coupled with consumer demands for higher quality meat with lower lipid and cholesterol contents (Schönfeldt & Gibson, 2008), has attracted interest from academic researchers and industry with the aim of producing a standardized product that meets these demands.

In the semi-arid region of Brazil, the staple food of ruminants derives from the Caatinga vegetation, which is influenced by the season characteristic of the region. During the dry season, the quality of forage is significantly reduced and characterized by cell wall lignification and low crude protein content. Cactus pear (*Opuntia ficus indica* MILL) is well adapted to the soil and climate of this region and thus, has the potential to substitute corn, which has a high cost due to competition for the feeding of poultry, pigs and humans. As forage, cactus pear has low dry matter (DM), a low crude protein percentage and a high concentration of non-fibrous carbohydrates and neutral detergent-soluble fibers (Wanderley et al., 2002). The percentage of starch is high in relation to other forages, varying from 12 to 18% (Retamal et al., 1987), providing water, energy, minerals and vitamin A to herds, especially during the dry season.

According to Huidobro & Cañeque (1994), the economic value of livestock animals is essentially determined by the tissue composition, the yield of the parts and the chemical composition of the meat. Meat quality can be assessed based on the nutritional and hygienic profile, ease of use and handling and product presentation. To determine the factors that influence these qualities, research has utilized chemical, physical and sensory tests that assess the characteristics perceived by the consumer at the time of purchase or consumption (Sañudo, 1992).

The most important physical properties of meat are temperature, pH, color, tenderness and weight loss by cooking (Dabés, 2001). From these, pH is the most relevant factor, as it influences water retention capacity and weight loss by cooking and shear force (Bressan et al., 2001). According to Devine et al. (1993), pH also influences the tenderness, succulence, flavor, aroma and color of meat. Decreases in pH and temperature during the process of *rigor mortis* directly influence the meat quality. Color is the most important characteristic for the consumer at the time of purchase, and it reflects the chemical state and myoglobin content in the muscle. Color is also influenced by pH and the *post mortem* glycolysis rate.

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The purpose of this study was to assess the tissue component yields and the physical, chemical and sensory characteristics of meat from Santa Inês sheep fed diets in which cactus pear partially or completely substituted corn.

Material and Methods

The experiment was conducted at the Small Ruminant Research Unit of the Agricultural Sciences Center at Universidade Federal da Paraíba, located in the municipality of São João do Cariri, Paraíba, in the Cariri Oriental microregion of Brazil. The experimental area is located at coordinates 7º 23' 27" S and 36º 31' 58" W. The local climate is classified as Bsh (hot semi-arid) according to the Köppen climate classification system.

Forty-five Santa Inês rams with an average weight of 25±2.5 kg were used in the study. The animals were kept in individual stalls with packed dirt flooring, provided with food and water troughs and were given the experimental diets. The animals were weighed, identified, treated for ecto- and endoparasites and vaccinated against clostridiosis. Animals were weighed every seven days, from the start of the experiment until slaughter.

The feed consisted of the following: Tifton hay (*Cynodum* sp), soybean meal, corn meal, wheat meal, calcium carbonate, sodium bicarbonate and cactus pear. The diets (Table 1) were formulated to meet the requirements of sheep with a live weight of 25 kg and a daily gain of 250 g/day (NRC, 1985). The treatments consisted of increasing levels of cactus pear substitution of corn: 0, 25, 50, 75% and 100%. The experimental feeds were completely mixed in order to induce higher consumption by the animals and were given twice a day. The total DM intake was determined by the daily amounts of feed supplied and rejected, and feed was supplied to ensure approximately 10% leftovers.

When the animals reached a live weight of 35±2.3 kg, they were given a liquid diet (solid fasting) for a period of 12 hours before slaughter. The slaughter method used was stunning at the atlanto-occipital region, followed by bleeding, skinning and evisceration. The carcasses were identified by animal and treatment, and the values for pH, temperature and color of the *semimembranosus* muscle (on the left leg) were determined before refrigeration (time 0). The carcasses were subsequently transported to cold storage, where they remained for 24 hours at 4 ºC, hanging from the Achilles tendon by hooks 14 cm apart from each other.

The pH, color and temperature measurements of the *semimenbranosus* muscle were taken 45 minutes and 24 hours after slaughter. A Testo 205 portable pH meter was used to measure pH and temperature, using the methodology described in AOAC (2000). Meat color was measured using a Minolta CR-200 calorimeter, which measures luminosity, red and yellow contents, respectively.

Legs were stored in plastic bags, according to the methodology described by Silva Sobrinho (1999), for quantitative and qualitative analyses of meat. Legs were then dissected for assessment of tissue composition, and the following groups of tissue were separated: fat, muscle,

Table 1 - Ingredients in diets and feed composition for different levels of replacement of corn by cactus pear

Ingredients (g/kg of natural matter)	Replacement level (%)				
	0	25	50	75	100
Cactus pear	0.0	70.0	140.0	210.0	280.0
Corn meal	280.0	210.0	140.0	70.0	0.0
Soybean meal	176.0	176.0	176.0	176.0	176.0
Wheat meal	114.0	114.0	114.0	114.0	114.0
Tifton hay	400.0	400.0	400.0	400.0	400.0
Mineral	15.0	15.0	15.0	15.0	15.0
Calcium carbonate	15.0	15.0	15.0	15.0	15.0
Feed composition (g/kg)					
Dry matter	894.6	593.4	444	354.6	295.2
Organic matter	907.2	899.3	891.4	883.5	875.6
Mineral matter	51.1	58.4	65.6	72.8	80.00
Crude protein	162.4	159.1	155.7	152.3	148.9
Ether extract	23.8	22.5	21.1	19.8	18.5
Neutral detergent fiber	426.00	439.8	453.6	467.4	481.2
NDFap	383.3	398.5	413.7	428.9	444.2
Acid detergent fiber	203.2	215.4	227.7	239.9	252.1
Total carbohydrates	762.7	760.0	757.6	755.1	752.6
Non-Fibrous carbohydrates	379.4	361.5	343.9	326.2	308.4
Total digestible nutrients[1]	638.8	621.5	604.2	586.9	569.5
Metabolizable energy (Mcal/kg DM)	2.30	2.24	2.18	2.12	2.05

NDFap - Neutral detergent fiber adjusted for ash and protein; DM - dry matter.
[1]TDN (%) = (%CPd + %NDFd %+ %NFCd + (%EEd * 2.25))-7, as described by Weiss (1999).

bone and remaining tissue. After separating the tissue, five muscles that cover the leg (*adductor*, *semitendinosus*, *semimembranosus*, *biceps femoris* and *quadriceps*) were weighed. The length of the femur was measured to obtain the muscularity index of the leg, using the formula described by Purchas et al. (1991):

[MIP = √(5M WT/FC)/FC],

where: MIP = muscularity index of the leg; 5M WT = 5-muscle weight (*biceps*, *quadriceps*, *semitendinosus*, *semimembranosus* and *adductor*); FC = femur circumference.

Samples of *longissimus* muscle were packed and stored in a freezer at -20 °C for 30 days for the following analyses: proximate chemical composition (ash, moisture, protein, lipids), physical composition (weight loss by cooking, shear force) and sensory analysis. All physical and chemical analyses were done in duplicate, using methodology adapted from Madruga et al. (2001).

The moisture, ash and protein contents were determined according to the AOAC (2000), using methods 985.41, 920.153 and 928.08, respectively.

The total lipids were measured according to the methodology described by Folch et al. (1957). Thirty milliliters of a chloroform-methanol (2:1 v/v) mixture were added to 2 g of weighed sample. The mixture was stirred for 2 minutes using a Biomatic vortex, and then filtered using qualitative filter paper. After filtration, the wall of the vial containing the sample was washed with 10 mL of the solvent mixture, which was subsequently filtered and added to the first filtrate. The final volume was recorded.

Sodium sulfate at 1.5% level was added to a 20% volume of the final filtrate. After the mixture was stirred and the phases were allowed to separate, 5 mL from the bottom phase were removed and transferred to a previously weighed beaker. The beaker was placed in a 105 °C oven until the solvent mixture evaporated. It was then left to cool in a desiccator and weighed along with the fat residue.

The weight loss due to cooking was determined following the procedure described by Duckett et al. (1998a). The samples, composed of three slices of approximately 2.5 cm in length, were weighed, placed in a container covered with aluminum foil and baked in a pre-heated oven to 170 °C until the core temperature reached 70 °C. Core temperature was measured using a copper-constantan thermocouple equipped with a digital reader (Delta OHM, model HD9218, Italy). Samples were subsequently cooled to room temperature and re-weighed. The losses due to cooking were calculated using the differences in weight before and after heat treatment and are expressed as percentages (g/100 g).

For texture evaluation, shear force was measured using the methodology described by Duckett et al. (1998b). The samples used were the same as those used for analysis of weight loss due to cooking. After cooking and weighing, two cylinders were removed from each meat slice in the direction of the fiber, using a cylindrical hollow punch of 1.6 cm in diameter. Cylinders were cut transversely using a TA-XT2 texturometer (Surrey, England) equipped with a Warner Bratzler blade, which was operated at 20 cm/min. The peak shear force was recorded and expressed as Kgf/cm^2.

Samples from the *longissimus dorsi* muscle were used for the sensory analysis of the meat. The samples were defrosted in a refrigerator for 12 hours, separated by treatment and cut into 2.5-cm cubes. Meat cubes underwent a dry cooking process in an electric grill for approximately 8 minutes (4 minutes for the upper portion and 4 minutes for the lower portion), without the addition of salt or condiments. Samples were cooked as the tasters arrived for the test. The panel consisted of eleven trained tasters, using non-structured 9-cm scales used to indicate the intensity of sensory characteristics (varying from the least favorable condition to the most favorable; Figure 1). There were three replicate rounds per sample group, and each replicate included five samples representing the five different experimental treatments, in accordance with the methodologies described by Amarine et al. (1965), Larmond (1979) and Madruga et al. (2000).

The experimental design was completely randomized, with five treatments and nine replicates per treatment. In addition to analysis of variance, regression analyses were also performed for each of the experimental replacement levels of corn by cactus pear. Statistical analyses were conducted using the computer program SAEG (version 9.1).

Results and Discussion

The replacement of corn by cactus pear influenced the percentage of fat in the legs of sheep quadratically ($P<0.05$), reaching a maximum level of 7.61%, which corresponds to a 44.53% replacement level. According to Fernandes et al. (2010), however, there is still no minimum value for fat thickness in sheep that can be used to determine an excess or reduction of fat deposition. In contrast to the effect on fat, the replacement of corn by cactus pear did not affect the percentage of muscle and bone ($P>0.05$). The changes in the yield of adipose tissue related to diet are directly associated with energy supply, but they may also be influenced by breed or age.

The muscle/fat ratio was affected quadratically ($P<0.05$), reflecting the quadratic effect on the percentage of fat. The muscularity index of the leg was not influenced (P>0.05) by the inclusion of cactus pear in the diet. The mean muscularity index value observed was 0.36 kg/cm (Table 2), which is similar to previously reported values for the Santa Inês breed and indicates good muscle conditions of the animals in the study. Silva Sobrinho et al. (2005) reported mean values of 0.42 g/cm in a study of crossbred Ile de France × Ideal lambs, showing the potential of the Santa Inês breed relative to other breeds developed for meat production.

Substituting corn with cactus pear had no effect (P>0.05) on the initial and final pHs of the carcasses, and the rates of pH decrease after slaughter and the final pH values varied. While final pH values are typically below 5.8 (Hoffman et al., 2003; Silva Sobrinho et al., 2005), the final pH values for all of the treatments in this study were below 5.8 (average of 5.68), indicating a desirable increase in the activity of calpains and cathepsins, which contribute to the softening of meats (Teixeira et al., 2005).

The values of luminosity, and colors red and yellow were not affected (P>0.05) by the incorporation of cactus pear into the diet. Higher values indicate increased color intensity or tonality. These tonalities reflect the amount of myoglobin and the relative proportions of this pigment, which can be found in several forms: reduced myoglobin (Mb, purple color), oxymyoglobin (MbO_2, red color) and metamyoglobin (MetMb, brown color). Meat color is a critical component of purchasing decisions, and variability in color results in numerous factors, including species, age of the animal, breed, gender, feeding system and pre- and post-slaughter conditions.

The weight loss due to cooking was not influenced (P>0.05) by the inclusion of cactus pear in the diet (Table 3), and its mean value was 28.40%. weight loss due to cooking is an important quality characteristic, as a measure of meat yield at the time of consumption (Pardi et al., 1993). The values observed in this study are similar to those reported by Bressan et al. (2001) for Santa Inês lambs (29.1%) and below those reported by Costa et al. (2009), who observed a value of 27.68% for lambs of the same genotype. Johnson et al. (2005) observed values of weight loss due to cooking of 30.4 and 30.6% in the *longissimus dorsi* muscles of ram and ewe lambs with approximate live weights of 38 and 35 kg, respectively.

The texture of the meat, as measured by shear force, did not vary (P>0.05) with the inclusion of cactus pear in the diet. This may be due to the fat score and solubility characteristics of the proteins present in this meat. According to the literature, sheep meat is tender when shear

Table 2 - Tissue component and leg muscularity index yields for different levels of replacement of corn by cactus pear

Variables	Replacement level (%)					CV (%)	Regression equation	R²
	0	25	50	75	100			
Leg (kg)	2.445	2.419	2.393	2.367	2.340	5.69	Y= 2.392ns	-
Muscle (%)	69.45	66.38	68.64	66.15	68.49	6.02	Y= 67.82ns	-
Fat (%)	6.34	7.37	7.60	7.03	5.66	25.08	$Y= 6.34+0.057\times P-0.00064\times P^2$	0.89
Bone (%)	19.94	20.68	19.02	18.23	21.08	13.62	Y= 19.79ns	-
Others (%)	4.68	3.91	4.54	5.30	4.73	36.33	Y=4.63ns	-
M:B	3.56	3.28	3.64	3.66	3.31	14.92	Y=3.49ns	-
M:F	11.35	9.67	9.31	10.25	12.51	23.23	$Y= 11.35-0.09\times P+0.001\times P^2$	0.82
MIP(g/cm)	0.366	0.361	0.360	0.360	0.353	5.64	Y= 0.360ns	-

ns - not significant; *(P<0.05); **(P<0.01); CV - coefficient of variation; M:B - musclue:bone ratio; M:F - muscle:fat ratio; MIP - muscularity index of the leg.

Table 3 - The effect of different levels of replacement of corn by cactus pear in the diet of Santa Inês sheep on the physical characteristics of the meat

Components	Replacement level (%)					Regression equation	CV (%)
	0	25	50	75	100		
Initial pH	6.71	6.69	6.53	6.90	6.82	Y = 6.73ns	4.6
L	19.53	19.91	16.74	20.76	19.97	Y = 19.38ns	20.92
a	4.49	5.03	4.17	5.42	5.16	Y = 4.85ns	33.65
b	19.71	20.80	21.11	19.91	20.04	Y = 20.31ns	9.01
Final pH	5.63	5.67	5.74	5.71	5.67	Y = 5.68ns	6.22
WLC	27.70	27.66	29.22	29.45	29.19	Y = 28.40ns	10.22
SF	2.54	2.40	2.40	2.15	2.85	Y = 2.50ns	18.93

ns (P>0.05).
L, a and b - intensity of luminosity, red color and yellow color, respectively; WLC - weight loss due to cooking; SF - shear force; CV - coefficient of variation.

force is below 8 Kgf/cm^2, acceptable when it falls between 8 and 11 Kgf/cm^2 and hard if the value exceeds 11 Kgf/cm^2 (Bickerstaffe et al., 1997). The mean shear force value of 2.5 Kgf/cm^2 in this study indicates that the sheep meat assessed can be classified as very tender.

The inclusion of cactus pear in the diet of sheep did not influence (P>0.05) moisture, ash or protein percentages of the *longissimus dorsi* muscle (Table 4). In sheep meat, the proximate composition varies with animal age, slaughter weight, fat content and nature of the diet, with mean values of 75% moisture, 2.5% fat and 1.2% ash (Ortiz et al., 2005). The values observed in this study are similar to those reported by Costa et al. (2009), who observed mean values of 22.93, 0.89, 74.41 and 2.22% for protein, ash, moisture and lipids, respectively, and indicate the meat had good nutritional quality. The protein values observed were also similar to those reported by Madruga et al. (2005) and Santos et al. (2008), who obtained values ranging from 19.08 and 21.06% for sheep of the same genotype.

The lipid content showed a decreasing linear effect (P<0.05) and may have reflected in decreased metabolizable energy as the corn replacement level by cactus pear increased. Replacing up to 100% of corn by cactus pear has desirable effects, as it produces legs with a reduced fat yield and similar muscle yield to those found in animals fed corn (Brito Neto et al., 2007; Sousa et al., 2007). Madruga et al., (2005) also reported reductions in fat content, with mean values of 2.74%, when cactus pear was included in the diet of Santa Inês lambs.

The sensory analysis of the meat indicates that no characteristics were influenced (P>0.05) by the inclusion of cactus pear in the diet (Table 5; Figure 1). The characteristics of succulence, taste and overall acceptability were 5.38, 4.17 and 6.29, respectively. These organoleptic characteristics are associated with meat tenderness and determine the pleasant or unpleasant feeling that leads to acceptance or refusal by the consumer.

A mean value of 3.17 was observed for meat hardness, reflecting good pre-slaughter management conditions. Meat hardness is directly related to pre-slaughter factors, including pre-slaughter stress, and *post-mortem* factors that alter myofibrillar structures. The *post-mortem* glycolysis rate, for example, is determined by several factors, including the final pH and the process of maturation. The sensory analysis results show that the meat in this study could be classified as tender and succulent and had a characteristic taste of sheep meat and good overall acceptability.

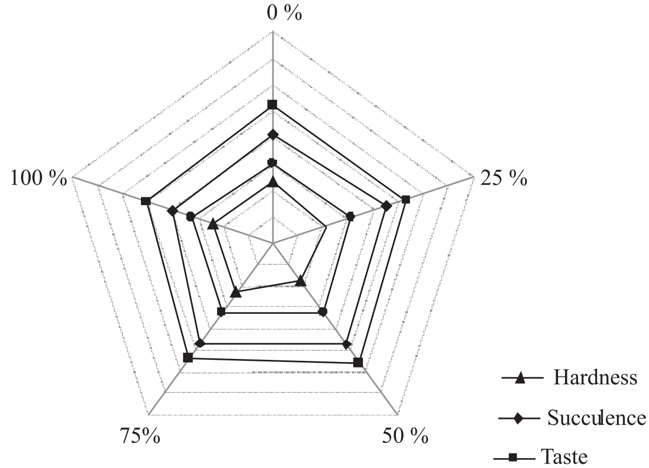

Figure 1 - Sensory characteristics of the meat of Santa Ines sheep fed diets with different levels of replacement of corn by cactus pear.

Table 4 - Chemical composition of Santa Inês sheep meat for different levels of replacement of corn by cactus pear

Composition (%)	Replacement level (%)					CV (%)	Regression equation	R^2
	0	25	50	75	100			
Moisture	75.49	75.59	75.68	75.32	75.83	1.14	Y = 75.59ns	-
Lipids	2.85	2.71	2.57	2.42	2.28	25.27	Y = 2.852 - 0.005724* P	0.61
Protein	20.74	20.55	20.68	20.83	21.03	3.72	Y = 20.77ns	-
Ash	1.01	1.00	1.01	1.05	1.01	6.16	Y = 1.02ns	-

ns (P>0.05); *(P<0.05).
CV - coefficient of variation; R^2 - coefficient of determination.

Table 5 - Sensory characteristics of the meat from sheep fed diets with different levels of replacement of corn by cactus pear

Composition (%)	Replacement level (%)					Regression equation	CV (%)
	0	25	50	75	100		
Hardness	3.31	3.12	2.74	3.30	3.38	Y = 3.17ns	34.82
Succulence	5.14	5.55	5.68	5.61	4.93	Y = 5.38ns	32.13
Taste	4.03	4.12	4.22	4.25	4.22	Y = 4.17ns	47.1
Overall acceptability	6.21	6.31	6.59	6.37	5.98	Y = 6.29ns	23.01

CV - coefficient of variation.

Conclusions

Cactus pear can replace up to 100% of corn in the diets of Santa Inês sheep raised in confinement and produces a decrease in the percentage of lipids. These changes occur without compromising the tissue component yield of the leg or altering the physical or sensory characteristics of the meat.

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