



Effect of Sodium Bicarbonate Supplementation on Carcass Characteristics of Lambs Fed Concentrate Diets at Different Ambient Temperature Levels

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ABSTRACT: The objective of this study was to investigate the influence of ambient temperatures on carcass characteristics of lambs fed concentrate diets with or without NaHCO₃ supplementation. A slaughter study was carried on 12 male Black Belly Barbados lambs randomly drawn from a growth trial (35 weeks). The lambs were divided into four equal groups and allotted in a 2×2 factorial design. The lambs were allotted at random to two dietary treatments of a basal diet (35:65 roughage:concentrate) or basal diet supplemented with 4% NaHCO₃ at different ambient temperatures (20°C and 30°C) in an environment controlled chamber for 10 days. Lambs were slaughtered for carcass evaluation at about 262 days of age (245 days of growth trial, 7 days adaptation and 10 days of experimental period). Ambient temperature had significant ($p < 0.05$, $p < 0.05$, $p < 0.01$, and $p < 0.001$) effects on meat color from the ribeye area (REA), fat, leg and *longissimus dorsi* muscles with higher values recorded for lambs in the lower temperature group than those from the higher ambient temperature group. Significant differences ($p < 0.05$) in shear force value (kg/cm²) recorded on the leg muscles showed higher values (5.32 vs 4.16) in lambs under the lower ambient temperature group compared to the other group. Dietary treatments had significant ($p < 0.01$, $p < 0.01$, and $p < 0.05$) effects on meat color from the REA, fat, and REA fat depth (cm²) with higher values recorded for lambs in the NaHCO₃ supplementation group than the non supplemented group. Similarly, dietary treatments had significant differences ($p < 0.05$) in shear force value (kg/cm²) of the leg muscles with the NaHCO₃ groups recording higher (5.30 vs 4.60) values than those from the other group. Neither ambient temperature nor dietary treatments had any significant ($p > 0.05$) effects on pH, and water holding capacity on both muscles. These results indicated that NaHCO₃ supplementation at low ambient temperatures had caused an increase in carcass characteristics leading to significant effect on meat quality. (**Key Words:** Ambient Temperature, Sodium Bicarbonate, Carcass, Lambs)

INTRODUCTION

The value of meat animals lies in the acceptability in the market, and many factors such as nutrition or dietary manipulation have been reported (Mahgoub et al., 2000; Joy et al., 2008) to exert several influences on the carcass conformation, fatness degree, organs and certain muscles in sheep, thereby influencing the customer's public decisions when selecting fresh meat product. Likewise, it is widely reported that meat and fat colour are among the most

important attributes taken into account by consumers in their purchase decision and thus the effect of feeding systems on carcass traits should be studied in order to avoid consumer meat rejection (Carrasco et al., 2009). The decrease in good quality pastures coupled with confinement animal agriculture has made it necessary to feed livestock additional supplement for good productivity. Furthermore, feed availability from natural grazing is limited and of low quality.

Fattening schemes usually wean lambs early and place them on high-concentrate diets in order to obtain high energy intakes, rapid attainment of adequate slaughter weight, reduced days in feed and shortened slaughter cycle (Bodas et al., 2007; Perlo et al., 2008). However, the use of

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such diets leads to digestive disturbances. In addition, high ambient temperatures combined with relative humidity, air movement and solar radiation causes animal body temperature to rise above the upper critical temperature. This may cause several physiological side effects and economic impact on animal output (Kadim et al., 2008). Furthermore, high ambient temperatures may affect muscle glycogen level and subsequent ultimate pH, which could present one of the significant factors which cause deterioration of meat quality characteristics. To avoid such incidence, several nutritional therapies have been suggested including the use of dietary buffers.

Although there is evidence supporting the use of sodium bicarbonate (NaHCO_3) in small ruminant production, few studies on carcass characteristics of sheep with *ad libitum* access to concentrate diet have appeared in literature (Bodas et al., 2010) particularly, in tropical conditions. Bodas et al. (2007) associated the inclusion of this salt in diets to changes in blood biochemical profile, increases in bicarbonate, base excess and $p\text{CO}_2$ (with steers) which influenced pH fall post-mortem and meat characteristics by modifying the activity of enzymes associated with carbohydrate metabolism. NaHCO_3 could alter the proportions of the volatile fatty acids in the rumen by modifying either bacteria and ciliate protozoal populations or rate and extent of degradation of feed (Santra et al., 2003). These changes in the volatile fatty acid pattern could affect fatty acid composition of the meat. The aim of the present study was to investigate the influence of ambient temperatures on carcass characteristics of lambs fed concentrate diets with or without NaHCO_3 supplementation.

MATERIALS AND METHODS

Animals, housing, and feeding

A slaughter study was carried on 12 male lambs (17.0 kg average live weight, 3 to 4 months old) randomly drawn from a growth trial and allotted by a 2×2 factorial design for a period of 10 days. The lambs (Black Belly Barbados), were divided into four equal groups and fed basal diet (35:65 roughage:concentrate) or basal diet supplemented with 4% NaHCO_3 at different ambient temperatures (20°C and 30°C) all through the 10 days experimental period. Diet comprised of dry matter: 55%, net energy for milk: 1.092, crude protein: 8.15, Ca: 0.8, P: 0.59 and acid detergent fiber: 39.91. The animals were balanced for body weight and housed in an environment controlled chamber in individual pens of size (1 m \times 1.5 m) with steel slatted floors. Feed was offered *ad libitum*. All animals had free access to water through automatic drinkers. Prior to the experiment, the animals were dipped in a solution of Gematox to eliminate ectoparasites. All animals were injected with Ivomec for control of endo and ectoparasites. Lambs were

slaughtered for carcass evaluation.

Slaughter and carcass evaluation

At the end of the growth trial, the animals were slaughtered at about 262 days of age (245 days of growth trial, 7 days adaptation and 10 days of experimental period) for carcass evaluation. The animals were fasted for 6 hours before slaughter. All animals, however, had free access to water until slaughtered in the abattoir following routine commercial slaughterhouse standard procedures. The animals were transported in a truck and were subsequently held in the slaughter house lairage for about 1 hour before slaughter. Each animal was carefully handled to minimize excitement. After 1 hour the animals were weighed again, stunned, bled, skinned and eviscerated. Each carcass was split along the vertebral column into left and right halves using a knife. *Longissimus dorsi* and leg muscles from the right side of the half carcass were collected within 20 min of slaughter trimmed and analyzed for meat quality traits. The pH was recorded 45 min after carcass dressing (pH_{45}) using a digital pH meter (inoLab pH 720 WTW pH/mV/Temperature Meter, Wissenschaftlich-Technische Werksatten GmbH, Weilheim, Germany) by direct insertion of a combined electrode in the muscle. Subsequently, ultimate pH (pH_u) of minced meat samples was recorded at 24 h post mortem. The water holding capacity (WHC) was determined from two sample sites i.e. from the leg and *longissimus dorsi* muscles area on the left half of the carcass and was estimated by filter paper pressing technique in screw plates as described by (Manso et al., 2009). The shear force value of meat samples from the leg and *longissimus dorsi* muscles were determined as described by (Bodas et al., 2007) by Warner-Bratzler shear press device mounted on a texture Analyser QTS 25 (CNS Farnell, Borehamwood, England). The dressed carcass was then split into fore and hind quarters and ribeye area (REA cm^2) was recorded on the cut surface of *longissimus dorsi* muscle at the interface of 12th and 13th rib. Fat colour was evaluated in subcutaneous dorsal fat.

Statistical analysis

Data on carcass characteristics were analysed using the GLM (General Linear Model procedures SAS [Statistical Analysis System]) version 6.21. The data on all the carcass traits were subjected to an analysis of variance (ANOVA) by the GLM procedure. Means were compared using the least square means procedure SAS (Statistical Analysis System) and the level of significance declared at $p < 0.05$.

RESULTS

Data presented in Table 1 shows the quality attributes of the experimental lamb's meat. Ambient temperature had

Table 1. Effect of ambient temperature on meat characteristics: REA, fat, and Back-fat thickness (cm) of the experimental lambs

Traits	Ambient temperature (°C)		SEM	Sig.	Interaction AT×D
	20	30			
Colour					
REA	6.38 ^a	6.12 ^b	0.08	*	*
Fat	3.50 ^a	2.87 ^b	0.22	*	NS
Leg	6.38 ^a	5.80 ^b	0.07	***	NS
Long.	6.65 ^a	6.18 ^b	0.09	**	NS
REA (cm ²)	27.78	26.11	20.50	NS	NS
Fat depth (cm ²)	0.54	0.45	0.05	NS	NS
BFT (cm)					
Shoulder	0.12	0.09	0.01	NS	NS
12th to 13th rip	0.23	0.13	0.04	NS	NS
Rump	0.06	0.05	0.01	NS	NS

REA, ribeye area; SEM, standard error of the mean; Sig., significant; AT, ambient temperature; D, diet; AT×D, ambient temperature×diet; Long., *Longissimus dorsi* muscle; BFT, back-fat thickness.

^{a,b} Means within row without common superscript differ (p<0.05).

* p<0.05; ** p<0.01; *** p<0.001. NS, not significant (p>0.05).

significant (p<0.05, p<0.05, p<0.01 and p<0.001) effects on meat color from the REA, fat, leg and *longissimus dorsi* muscles respectively. Higher mean values were recorded for lambs exposed to the lower temperature regime compared to those in the higher ambient temperature group. Effect of diets on meat characteristics: REA, fat, and Back-fat thickness (cm) of the experimental lambs are shown in Table 2. Lambs fed concentrates and supplemented with NaHCO₃ had higher meat color values for REA (p<0.01), fat (p<0.01), and fat depth (cm²) (p<0.05) post-mortem compared with the non supplemented group. Though with

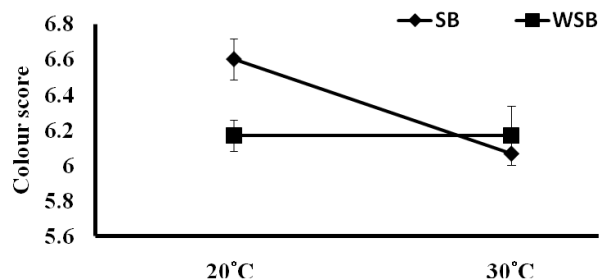
Table 2. Effect of diet on meat characteristics: REA, fat, and Back-fat thickness (cm) of the experimental lambs

Traits	Diets		SEM	Sig.	Interaction AT×D
	SB	WSB			
Colour					
REA	6.33 ^a	6.17 ^b	0.08	**	*
Fat	4.25 ^a	3.75 ^b	0.22	**	NS
Leg	6.15	6.03	0.07	NS	NS
Long.	6.43	6.40	0.09	NS	NS
REA (cm ²)	26.13	27.76	20.50	NS	NS
Fat depth (cm ²)	0.41 ^a	0.58 ^b	0.05	*	NS
BFT (cm)					
Shoulder	0.11	0.10	0.01	NS	NS
12th to 13th rip	0.22	0.15	0.04	NS	NS
Rump	0.06	0.05	0.01	NS	NS

REA, ribeye area; SB, sodium bicarbonate; WSB, without sodium bicarbonate; SEM, standard error of the mean; Sig., significant; AT, ambient temperature; D, diet; AT×D, ambient temperature×diet; Long., *Longissimus dorsi* muscle; BFT, back-fat thickness.

^{a,b} Means within row without common superscript differ (p<0.05).

* p<0.05; ** p<0.01. NS, not significant (p>0.05).

**Figure 1.** Interactions between ambient temperature and dietary treatments on rib eye area colour characteristics. SB, sodium bicarbonate; WSB, without sodium bicarbonate.

no effect, the muscular development as indicated by REA was higher in the non supplemented group as compared to the supplemented group. Significant interactions were observed between ambient temperature×dietary treatment for REA and fat colour (p<0.5 and p<0.05 respectively) Figure 1. Table 3 shows the effects of ambient temperature on meat characteristics for pH, WHC, and shear force values of leg and *Longissimus dorsi* muscles of the experimental lambs. However, ambient temperature had no significant (p>0.05) effects on pH and WHC on both muscles. At pH₄₅, the lower ambient temperature group showed lower pH values (6.08 vs 6.39 and 6.20 vs 6.31) on both muscles (leg and *longissimus dorsi* respectively) compared to the lambs in the other group. On the other hand, ambient temperature had significant differences (p<0.05) in shear force value (kg/cm²) of meat from the leg muscles. Higher values (5.32 vs 4.16) were recorded in

Table 3. Effect of ambient temperature on meat characteristics: pH, WHC, and shear force values of leg and *Longissimus dorsi* muscles of the experimental lambs

Traits	Ambient temperature (°C)		SEM	Sig.	Interaction AT×D
	20	30			
pH ₄₅					
Leg	6.08	6.39	0.10	NS	NS
Long.	6.20	6.31	0.06	NS	NS
pH _u					
Leg	5.51	5.48	0.08	NS	NS
Long.	5.44	5.51	0.05	NS	NS
WHC (%)					
Leg	91.36	66.37	27.13	NS	NS
Long.	71.03	75.72	24.96	NS	NS
SF (kg/cm ²)					
Leg	5.32 ^a	4.16 ^b	0.09	*	NS
Long.	4.82	4.80	0.09	NS	NS

WHC, water holding capacity; SEM, standard error of the mean; Sig., significant; AT, ambient temperature; D, diet; AT×D, ambient temperature×diet; pH₄₅, pH 45 minutes post slaughter; pH_u, ultimate pH; Long., *Longissimus dorsi* muscle; SF, shear force.

^{a,b} Means within row without common superscript differ (p<0.05).

* p<0.05; NS, not significant (p>0.05).

lambs under the lower ambient temperature regime compared to the lambs in the other group. A similar pattern was observed for dietary treatments in which the NaHCO₃ supplemented group recorded lower pH values in the first 45 min compared to those in the other group post-mortem (Table 4). Leg muscle showed a marked decrease in pH values at 24 h (pHu) post slaughter in both temperature treatments. Similarly, dietary treatments had significant differences ($p < 0.05$) in shear force value (kg/cm²) of meat from the leg muscles with the NaHCO₃ groups recording higher (5.30 vs 4.60) values than those from the other group. After 24 h, meat characteristics (Warner-Bratzler shear force) measured on *Longissimus dorsi* muscle, showed higher shear force values in the NaHCO₃ supplemented group than the non supplemented group. However, neither ambient temperature nor dietary treatment had any effect on shear force value for meat from the *Longissimus dorsi* muscle.

DISCUSSION

Limited published literature is available on the effect of NaHCO₃ supplementation on carcass characteristics and meat quality of lambs fed concentrate diet under different ambient temperature levels. Meat colour is related to the concentration of pigments, mainly myoglobin, and its chemical state, the structure and physical state of muscle proteins and the proportion of intramuscular fat (Bodas et al., 2007). It is one of the main parameters influencing consumer purchasing decisions more than any other quality

factor because consumers use discoloration as an indicator of freshness and wholesomeness. Thus, an increase in intramuscular fat could lead to a lower myoglobin and sarcoplasmic proteins concentration in the meat, inducing changes in meat color (Bodas et al., 2007). In this study, the effect of ambient temperature on meat color characteristics for REA and fat on the leg and *longissimus dorsi* muscles were below the range of those reported by other authors (Bodas et al., 2007). The depth to which oxygen diffuses in meat depends on the oxygen consumption rate by meat and temperature. At low temperatures and low pH values, more oxymyoglobin is formed, leading to increased oxygen solubility and inhibition of oxygen consumption enzyme activity (Kadim et al., 2008). On the other hand, high temperatures and high pH values increases mitochondrial activity as well as oxygen consumption in post-mortem muscles and therefore, decreased availability of oxygen in meat, which in turns increases the concentration of deoxygenated myoglobin thus resulting in a dark colour (Kadim et al., 2008). The fat content was lesser in NaHCO₃ treated lambs than those fed without NaHCO₃ diet. This effect of NaHCO₃ could be advantageous since excess fat is less desirable as it needs to be trimmed and reduces carcass value (Sen et al., 2006). In our study, the greater amounts of fat seen on the meat of the NaHCO₃ supplemented group further agrees with Badas et al. (2007) who suggested that greater amounts of fat are associated with lower shear force values in ruminant meat. Neither ambient temperatures nor dietary treatments influenced back-fat thickness (cm) measured on the shoulder between the 12th to 13th rib and on the rump for lamb meat. This could be attributed mainly to the similar growth and body weight gains obtained during the growing period. However, Mitlohner et al. (2001) reported lower fat thickness in steers kept under heat stress conditions.

Meat quality is considerably affected by a number of different factors such as breed, postmortem processes taking place in muscle tissue, including changes in meat pH, water content, intramuscular fat and connective tissue (Barton et al., 2010; Pogorzelska et al., 2013). The ultimate pH of muscle is a major determinant of meat quality (Kadim et al., 2007) and is related to the depletion of glycogen and liberation of lactic acid pre- and post-slaughter. The lambs under the higher ambient temperature seemed to be the most stressed, which is reflected by the higher pHu. The relationship between meat tenderness and its ultimate pH has been studied. When ultimate pH increases from 5.5 to 6.0, tenderness decreases, but when ultimate pH increases above 6.0, tenderness increases. A possible reason for this biphasic relationship could be lower proteolytic activity at intermediate pH (5.8 to 6.3) because it lies outside the pH optima for two separate enzyme systems. Increasing tenderness from 6 to 7 is attributed to an increase in calpain

Table 4. Effect of diet on meat characteristics: pH, WHC, and shear force values of leg and *Longissimus dorsi* muscles of the experimental lambs

Traits	Diets		SEM	Sig.	Interaction AT×D
	SB	WSB			
pH ₄₅					
Leg	6.17	6.3	0.10	NS	NS
Long.	6.19	6.32	0.06	NS	NS
pH _u					
Leg	5.39	5.6	0.08	NS	NS
Long.	5.48	5.47	0.05	NS	NS
WHC (%)					
Leg	75.34	82.39	27.13	NS	NS
Long.	79.53	67.22	24.96	NS	NS
SF(kg/cm ²)					
Leg	5.30 ^a	4.60 ^b	0.09	*	NS
Long.	5.20	4.42	0.09	NS	NS

WHC, water holding capacity; SB, sodium bicarbonate; WSB, without sodium bicarbonate; SEM, standard error of the mean; Sig., significant; AT, ambient temperature; D, diet; AT×D, ambient temperature×diet; pH₄₅, pH 45 minutes post slaughter; pH_u, ultimate pH; Long., *Longissimus dorsi* muscle; SF, shear force.

^{a,b} Means within row without common superscript differ ($p < 0.05$).

* $p < 0.05$; NS, not significant ($p > 0.05$).

activity. However, another possible reason is that sarcomere length increases as ultimate pH decreases below 6.2 (Miranda-de la Lama et al., 2009). Miranda-de la Lama et al. (2012) reported that glycogen reserves can be significantly depleted in animals exposed to pre-slaughter stress, limiting post-mortem glycogenolysis and glycolysis, resulting in meat with an above normal ultimate pH. Our results agree with Kadim et al. (2008) who reported significantly higher meat pH for lambs transported in summer. The mean pH45 of muscles from the high ambient temperature group was higher than those from the low ambient temperature group, which implied that pre-rigor pH declined with slower rate in the former group. These findings are in accordance with those of Bray et al. (1989) who found that stressful conditions lead to depletion of muscle glycogen reserves before slaughter which subsequently increases the ultimate pH of meat. Kadim et al. (2007) found that muscle from stressed sheep had significantly higher ultimate pH values than unstressed animals and concluded that a higher pH above 6.0 was associated with dark meat. Low pH values contribute to myoglobin oxygenation which leads to the formation of a thick layer of bright-red oxymyoglobin on the meat surface (Pogorzelska et al., 2013). The pH of muscles has an influence on the processing suitability of beef, including water-binding capacity, tenderness, color and shelf-life (Pogorzelska et al., 2013). The present study showed lambs fed concentrates with NaHCO_3 had lower rate of pH reduction in the first 45 min after slaughter. This effect could be related to an increase in the buffer capacity of biological fluids in response to NaHCO_3 intake since bicarbonate supplementation increased blood bicarbonate concentration before slaughter. Changes in pH during the post mortem period could have an influence in the WHC of the meat. Bodas et al. (2007) reported a slight raise in WHC when pH values were above 5.8. As pH values observed in this study are below this, no differences could be expected in response to pH variation. Though there were no differences in pH and WHC in this study, however, irrespective of treatment, the lambs treated without NaHCO_3 had higher pH resulting in a lower WHC in their meat. This is again favorable since meat with lower WHC will lose water resulting in higher cooking loss (Sen et al., 2006). Elevated pH affects several meat characteristics including modifications of membranes and extracellular fluids, which affect the meat's electrical properties (Safari et al., 2010). The lack of dietary effect on pH values in the present study agrees with the observation made on Assaf lambs fed *ad libitum* commercial concentrates and barley straw or whole grain and protein supplement Safari et al. (2010). The lowest value of WHC was observed in the lambs under the lower temperature condition agrees with reports by Miranda-de la Lama et al. (2009) who observed

lower values for WHC during winter, indicating that meat during this season retains more water than in summer. Water is normally held in the myofibrils in the space between the filaments and a small proportion of this water is bound to proteins by electrostatic attraction. Water may also be held in the space between myofibrils, in the intracellular space and in the interfascicular space.

Generally, Warner Bratzler shear values of meat that exceed 5.5 kg would be considered as objectionably tough. Kadim et al. (2007) found strong negative effects of the hot season on the quality of beef meat. In line with our results, these authors reported lower Warner-Bratzler shear force values and darker meat of *M. longissimus thoracis* in heat-stressed beef cattle when compared with muscle samples collected during the cool season. Pouillot et al. (2009), found higher incidence of dark cutting beef (higher pH and darker meat) in beef from September to January suggesting temperature-related stress as possible causes. In our study, there were significant differences in shear force values of meat on the leg muscles in both treatments and were within normal range which agrees with the results obtained by Kadim et al. (2007) and Bodas et al. (2007). The meat from the lambs under the lower temperature had higher SF than the meat from other group. This could mean coldness was stressful, which is reflected by the significantly higher values of pHu. REA is an indicator of the amount of lean muscle associated with a carcass. As the REA increases, the amount of muscle in a carcass increases. The reduction in REA seen in this experiment with the NaHCO_3 group agrees with the findings of Kadim et al. (2007). These authors revealed that increasing levels of sodium in the diet, when NaHCO_3 is included as a buffer, may reduce gain as it reduces *longissimus dorsi* muscle area.

CONCLUSIONS

Ambient temperature had significant effect on meat colour characteristics. Animals reared under the higher ambient temperature had higher mean meat colour values and lower ultimate pH, WHC and meat shear force. NaHCO_3 supplemented lambs had higher values for meat color from the REA, fat, and REA fat depth (cm^2) and in shear force value of the leg muscles than the non-supplemented group. In conclusion, the results suggest that NaHCO_3 supplementation in concentrate diet under higher ambient temperature improved meat and carcass characteristics of lambs.

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