Livestock Science 185 (2016) 68–73

Contents lists available at ScienceDirect

Livestock Science

journal homepage: www.elsevier.com/locate/livsci

Short communication

Early exposure to and subsequent beef cattle performance with saline water

A. López [a,b,d,*], J.I. Arroquy [a,b,d], R.A. Distel [c,e]

[a] Instituto Nacional de Tecnología Agropecuaria, EEA-Santiago del Estero, Jujuy 850, Santiago del Estero, Argentina
[b] Facultad de Agronomía y Agroindustria, Universidad Nacional de Santiago del Estero, Av. Belgrano (s) 1912, Santiago del Estero, Argentina
[c] Departamento de Agronomía, Universidad Nacional del Sur, San Andrés 800, Bahía Blanca, Argentina
[d] CITSE – Consejo Nacional de Investigaciones Científicas y Técnicas de la República Argentina, Santiago del Estero, Argentina
[e] CERZOS – Consejo Nacional de Investigaciones Científicas y Técnicas de la República Argentina, Bahía Blanca, Argentina

ARTICLE INFO

Article history:
Received 6 November 2014
Received in revised form
14 January 2016
Accepted 16 January 2016

Keywords:
Beef cattle
Early experience
Plasma rennin activity
Saline water tolerance

ABSTRACT

Two experiments were conducted to evaluate the impact of early life exposure to high salt water on later cattle performance with saline water. In Exp. 1, 24 cow/calf pairs were randomly assigned to one of two treatments: exposure to high salt water [HSW; 7478 mg/kg of total dissolved solids (TDS)] or to low salt water (LSW; 512 mg/kg TDS) when calves were 2 to 6 mo. old. Then all calves drank low salt water for 6 mo, and subsequently high salt water for 30 d. During the last period HSW tended to eat 10% less DM (DMI; $P=0.07$) and drank 22% less water than LSW (WI; $P<0.01$). Total tract DM digestibility (TTDMD; $P=0.92$), blood parameters (hemoglobin and hematocrit; $P>0.13$), plasma glucose ($P=0.18$), serum minerals ($P>0.08$) and weight gain (ADG; $P=0.85$) were not affected by treatment. In Exp. 2, 24 pregnant heifers in the last month of gestation were randomly assigned to either HSW (10827 mg/kg TDS) or LSW. The exposure period ended when calves were 3 month old. Then all calves drank low salt water for 95 d, and subsequently high salt water for 30 d. During the last period no significant differences between treatments were observed for DMI ($P=0.43$), WI ($P=0.61$), TTDMD ($P=0.92$), blood parameters ($P>0.42$), plasma rennin activity (PRA; $P=0.35$), and ADG ($P=0.16$). However, HSW drank less ($P<0.01$) high salt water than LSW during the first two hours of drinking water restoration after a water deprivation period of 20 h. Overall, in the conditions of our study we did not find evidence that early exposure to saline water induces tolerance and improves later performance of beef cattle with salty water. However, reduced water intake (Exp. 1) and increased thirst threshold (Exp. 2) of animals early exposed to saline water need further consideration.

1. Introduction

Adequate quality of drinking water for livestock is essential to maintain acceptable levels of productivity (NRC, 2000). However, in many parts of the world ruminants are faced with drinking water containing high concentrations of total dissolved solids (TDS; Basán Nickisch, 2007; FAO, 2007). Saline water causes reductions in water and food intake, jeopardizing cattle performance and health (Weeth and Hunter, 1971; Loneragan et al., 2001; Ward and Patterson, 2004; Grout et al., 2006). It has been suggested that neurological, physiological, and morphological processes are amenable to change early in life and can be altered so that animals can better adapt to the environment in which they are backgrounded (Provenza and Balph, 1990). If so, exposure to saline water early in life may induce tolerance and improve later performance of beef cattle with salt water, mainly through modification in kidney functions. Although nephrogenesis ends shortly after birth, newborn's kidney remains functionally primitive with respect to the capacity to concentrate urine (Little and McMahon, 2012).

Prior studies in rats and sheep have shown that high salt intake during pregnancy and the early postnatal period can reduce feed and water intake and salt balance in the offspring when they ingest the same diet later in life (Alves da Silva et al., 2003; Digby et al., 2010a). These authors suggested that these induced changes are linked to alterations in the renin-angiotensin system (RAS). Offspring from ewes that grazed saltbush (20% salt) excreted salt more rapidly and consumed less water compared with those from ewes that grazed pasture based on subterranean clover, which was attributed to lower rennin activity in the former (Chadwick et al., 2009a). Since the negative impact of poor quality water on animal performance depends largely on their water requirements

* Corresponding author at: Instituto Nacional de Tecnología Agropecuaria, EEA-Santiago del Estero, Jujuy 850, Santiago del Estero, Argentina.
E-mail address: lopez.agustin@inta.gob.ar (A. López).

http://dx.doi.org/10.1016/j.livsci.2016.01.013
1871-1413/

(Patterson and Johnson, 2003), any permanent alteration in water intake may change the ability of animals to tolerate water with high salt content. We hypothesize that experience early in life with saline water improves cattle performance with salt water later in life. Our objective was to determine the effects of early life experience of calves with high salt water or low salt water on water and food intake, digestibility, blood parameters and weight gain when forced to drink high salt water later in life.

2. Materials and methods

For Experiment 1 and 2, we selected mother cows and calves with caving date between late December and early January from a commercial herd (Braford × Criollo Argentino; Instituto Nacional de Tecnología Agropecuaria [*INTA*] Santiago del Estero, Argentina). All cows were raised in the same environment, and none of them had previous experience with saline water. Animals were treated according the protocol approved by INTA for experimental animal care and use (INTA, 2013).

3. Experimental design

3.1. Experiment 1

The experiment was run with 24 cow-calf pairs. When calves averaged 2 mo of age and 78 ± 20 kg of BW (mean ± SD), 12 cow-calf pairs were randomly assigned to one of two treatments: early exposure to high salt water (HSW) or early exposure to low salt water (LSW). Total dissolved solids (TDS) in HSW were 7478 mg/kg, of which 3103 mg/kg were sulfates. The same values for LSW were 512 mg/kg TDS and 146 mg/kg TDS, respectively, and consisted of tap water. High salt water was made by mixing sodium chloride (NaCl) and sodium sulfate Na_2SO_4 salts in tap water until the target concentration was reached. The exposure period lasted 105 d; during the first 60 d calves were with their mothers. Thereafter, calves were weaned and the exposure period continued until d 105. All cow-calf pairs were fed alfalfa hay (*Medicago sativa*; 14% CP and 47% NDF) during lactation (first 60 d of the exposure period), and all weaned calves were fed a mixed ration (39% alfalfa, 40% corn and 21% roasted soybean; 15% CP and 40% NDF) during the last 45 d of the exposure period. Both groups, HSW and LSW, had *ad libitum* access to drinking water and food. Once the exposure period was completed, all calves grazed on rangeland and drank *ad libitum* tap water for 6 months (backgrounding period). During backgrounding, one calf per treatment was removed from the trial due to health problems. Immediately after the backgrounding period, 11 calves (169 ± 24 kg BW) from each treatment were assigned to individual pens (2 × 3.5 m), and fed a total mixed ration (14% CP; 50% NDF) composed of 65% alfalfa hay, 20.5% ground corn,13% roasted soybean plus 1.5% mineral mix (33% Limestone, 1.47% Copper sulfate, 0.04% Calcium Iodate, 0.014% Cobalt carbonate, 6.67% Magnesium Oxide, 7.20% Zinc sulfate, 0.014% Sodium selenite, 3.88% Iron sulfate, 2.67% Calcium carbonate).The diet was offered once daily (0800 h) at 130% of voluntary intake. Calves were allowed to adapt to the pens for 5 days, drinking tap water. Immediately after, we started an evaluation period, during which both groups were forced to drink high salt water (the same water quality that HSW calves had been exposed early in life) for 30 days. Feed and water intake of each calf were evaluated daily throughout the evaluation period, whereas feed digestibility was estimated in six calves from each group. Blood samples were extracted from all calves at the beginning (d 0) and at the end of the evaluation period (d 30), to evaluate concentrations of hemoglobin and hematocrit (hematological indicators), plasma glucose, and blood mineral profiles. Calves were weighed on d 0, 113, 294 and 331 of the experiment.

3.2. Experiment 2

Twenty four pregnant heifers were assigned to one of two treatments: LSW or HSW. Total dissolved solids in HSW were 10827 mg/kg TDS, of which 146 mg/kg were sulfates. The same values for LSW were 512 mg/kg and 146 mg/kg, respectively, and corresponded to tap water. High salt water was made by mixing NaCl salt in tap water until the target concentration was reached. The exposure period lasted 135 days: last 30 days of gestation and first 45 days of lactation, immediately followed by 60 days of exposure of calves alone. Pregnant and lactating cows were fed tropical grass hay (*Panicum maximum* , cv. Gatton; 7% CP and 78% NDF), whereas early weaned calves were fed a commercial feed specially formulated to fulfill young calf requirements plus alfalfa hay until the end of the exposure period. Both groups, HSW and LSW, had *ad libitum* access to drinking water and food. Once the exposure period was completed, all calves were fed a balanced ration (17% CP and 48% NDF) and they drank tap water for 95 d (backgrounding period). The diet was formulated with 60.5% alfalfa hay, 2% roasted soybean, 15% ground sorghum, 22% soybean meal, and 0.5% mineral mix (same composition as in Exp. 1). Immediately after the backgrounding period, calves from both treatments ($n=12$; 94 ± 17 kg BW) were assigned to individual pens (2 × 3.5 m) and fed the same ration as in the backgrounding period. Calves were allowed to adapt to the pens for 5 days, drinking tap water. Immediately after, we started an evaluation period, during which both groups were forced to drink high salt water (similar water quality that HSW calves had been exposed early in life; 12614 mg/kg TSD of which 480 mg/kg were sulfate) for 30 days. The day before the beginning of the evaluation period (d 0), calves were subject to a water deprivation period of 20 h. During d 1 of the evaluation period the rate of saline water intake was recorded at 1, 2, 6, 12 and 24 h post feeding. In this experiment, the level of thirst (motivation to drink) was regarded as the pattern of initial water intake after water deprivation. The diet was offered at the same time as in Exp. 1 (0800 h), once daily. Food and water intake, feed digestibility ($n=8$), and blood parameters were assessed as in Exp. 1. Calves were weighed on d 140, 231 and 265 of the experiment.

4. Measurements and sampling

In both experiments, during the evaluation period we measured forage and water intake, and collected samples for analyzes. Forage intake was calculated by subtracting DM refused from dietary DM offered daily, whereas water consumption was measured by the daily change in water depth in the water trough of each individual pen. In both experiments, forage and orts samples were collected just before feeding and composited on equal weight basis across days. Feed digestibility was determined by an external marker (LIPE®); fecal grab samples were collected from each calf ($n=6$ Exp. 1, $n=8$ Exp. 2) every 6 h from d 26 to d 29 of the evaluation period, advancing the sampling time 4 h each day in order to minimize concerns about diurnal variation in marker excretion. Fecal samples were composited across days within calf. In both trials, blood samples were taken from the jugular vein on d 0 and d 30 of the evaluation period. Immediately after collection, blood samples were placed into EDTA tubes to determinate hematological indicators, glucose and plasma renin activity analysis (PRA, Exp. 2 only), and in tubes without anticoagulant for the quantification of minerals. Measurements of BW on d 113 and d 331 (Exp. 1) and on d 140 and d 265 (Exp. 2) were performed once

animals drank tap water for one week in order to avoid disturbances in the weight due to water retention in the body.

5. Sampling processing and laboratory analysis

Forage, orts and fecal samples were partially dried in a forced-air oven (96 h at 55 °C), weighed, and ground (No. 4 Wiley Mill, Thomas Scientific, Swedesboro, NJ) to pass through a 1-mm screen. Partially dried samples of feed and orts were dried for 24 h at 105 °C to determine DM. Feed samples were analyzed for NDF with the ANKOM-Fiber Analyzer 200 (ANKOM Technology, Fairport, NY, USA) using the procedure described by Komarek (1993), and for total N using the procedure of Kjeldahl described by AOAC (1990). For quantification of the external marker LIPE®, processed fecal sample were directly analyzed by an infrared spectrometer equipped with an ATR device (Dr. Eloisa O.S. Saliba; Universidade Federal de Minas Gerais, Departamento de Zootecnia, Escola de Veterinária, Bello Horizonte, MG, Brazil). Plasma glucose was determined photometrically by the GOD/PAP method (Metrolab 330 spectrophotometer), while an automatic analyzer Mindray BC-5300 was used to evaluate hematological indicators. Serum concentration of sodium, potassium and calcium were measured using a Diestro® 103 semiautomatic electrolyte analyzer (JS Medicina Electrónica, Villa Martelli, Bs.As., Argentina). Phosphorus (UV method) and magnesium (colorimetric method) were analyzed by a Roche Hitachi 912 Chemistry Analyzer (Roche, Basel,Switzerland). PRA was indirectly measured by the generation of Angiotensin I using a commercial kit (Angiotensin 1 RIA Kit; Beckman Coulter, Villa Martelli, BuenosAires, Argentina).

6. Statistical analysis

Data from both trials were statistically analyzed as a completely randomized design. The results on consumption and blood parameters were evaluated as repeated measures over time using MIXED procedure of SAS (SAS Inst. Inc., Cary, NC). The type of covariance structure for repeated measures was compound symmetry (TYPE=CS). To meet the assumptions of normality PRA values had to be transformed to natural log. Feed digestibility and average daily weight gain (ADG) were analyzed using the GLM procedure of SAS. In both models, treatment mean comparisons were tested using the LSMEANS option of SAS, and treatment means were declared statistically different at $P < 0.05$.

7. Results

7.1. Experiment 1

7.1.1. Liveweight gain

There was no treatment effect on the ADG of calves in any period during the experiment (exposure period: 0.33 vs. 0.27 kg/d, SEM=0.03, $P=0.11$; backgrounding period: 0.31 vs. 0.31 kg/d, SEM=0.02, $P=0.94$; and evaluation period: 0.39 vs. 0.38 kg BW/d, SEM=0.05, $P=0.85$).

7.1.2. Intake and total tract digestibility

Calves in HSW treatment tended to eat 10% less feed ($P=0.07$) and drank 22% less water ($P < 0.01$; Table 1) than LSW calves throughout the evaluation period (Table 1); however, despite these differences, WI: DMI ratio did not differ ($P=0.15$) between treatments. Early exposure to high salt water did not affect total tract digestibility of DM (TTDMD; $P=0.92$). Both LSW and HSW calves had a feed digestibility of about 73%.

Table 1
Food (DMI) and water (WI) intake, WI: DMI ratio and total tract DM digestibility (TTDMD) of calves with (HSW) or without (LSW) experience early in life with high salt water (Exp. 1 and Exp. 2).

Item	LSW	HSW	SEM	*P*-value
Exp. 1				
DMI[a], g/kg $BW^{0.75}$	99.48	89.86	3.62	0.07
WI[a], g/kg $BW^{0.75}$	455.32	352.76	24.56	< 0.01
WI:DMI[a]	4.85	4.35	0.23	0.15
TTDMD[b], g/kg DM	732.3	730.3	0.01	0.92
Exp. 2				
DMI[a], g/kg $BW^{0.75}$	74.29	78.14	3.37	0.43
WI[a], g/kg $BW^{0.75}$	622.42	600.18	30.51	0.61
WI:DMI[a]	9.44	8.38	0.55	0.18
TTDMD[b], g/kg DM	730	730	0.01	0.92

[a] Exp. 1: $n=11$, Exp. 2: $n=12$.
[b] Exp. 1: $n=6$, Exp. 2: $n=8$.

Table 2
Blood parameters of calves with (HSW) or without (LSW) experience early in life with high salt water (Exp. 1 and Exp. 2).

Item[b]	Day 0[a]			LSW	Day 30		
	LSW	HSW	*P*-value		HSW	*P*-value	SEM
	Exp. 1						
Hemoglobin, g/dl	13.63	13.89	0.54	13.78	14.46	0.13	0.30
Hematocrit, %	40.63	41.54	0.49	41.97	44.26	0.1	0.93
Glucose, mg /dl	65.45	62.64	0.45	72.27	66.73	0.15	2.61
Na, mg/100 ml	446.18	383.82	0.01	427.09	432.73	0.81	16.57
Ca, mg/100 ml	8.15	8.13	0.94	7.53	8.03	0.16	0.24
P, mg/100 ml	11.13	11.72	0.20	8.08	8.45	0.42	0.32
Mg, mg/100 ml	1.78	1.96	0.25	1.62	1.60	0.90	0.11
K, mg/ 100 ml	24.23	22.93	0.39	20.3	20.78	0.75	1.05
	Exp. 2						
Hemoglobin, g/dl	10.6	10.55	0.93	13.32	13.76	0.38	0.38
Hematocrit, %	33.39	33.02	0.80	41.34	42.38	0.46	1.04
Glucose, mg /dl	73.81	71.42	0.75	64.56	60.00	0.53	5.38
Na, mg/100 ml	311.08	308.58	0.43	320.08	320.47	0.9	2.19
Ca, mg/100 ml	9.85	10.1	0.38	10.62	10.74	0.68	0.20
P, mg/100 ml	7.02	6.88	0.7	6.39	6.47	0.82	0.26
Mg, mg/100 ml	2.49	2.29	0.10	1.63	1.71	0.51	0.08
K, mg/100 ml	19.12	19.39	0.78	24.27	24.8	0.57	0.66

[a] Day 0=start of evaluation period; Day 30=end of evaluation period.
[b] Exp. 1: $n=11$, Exp. 2: $n=12$.

7.1.3. Hematological indicators, plasma glucose and serum minerals.

There was no treatment × day interaction neither for hemoglobin nor for hematocrit as well as plasma glucose and minerals in serum ($P > 0.16$), except for Na concentration where the interaction tended to be significant ($P=0.07$). None of the blood variables analyzed in the study were affected by treatments ($P > 0.13$), except for Na on d 0 (Table 2). Hematocrit and plasma concentration of glucose were higher at the end of the evaluation period, whereas serum concentration of Ca, P, Mg and K were higher at the beginning of the evaluation period.

7.2. Experiment 2.

7.2.1. Liveweight gain

In this trial, early exposure to saline water intake did not affect the subsequent performance of calves. Average daily gain of LWS and HWS calves were similar during the backgrounding (0.31 vs. 0.34 kg/d, SEM=0.04, $P=0.66$) and evaluation period (0.30 vs. 0.20 kg/d, SEM=0.05, $P=0.16$).

7.2.2. Water intake rate after water deprivation

Early exposure treatment × hour interaction was significant for

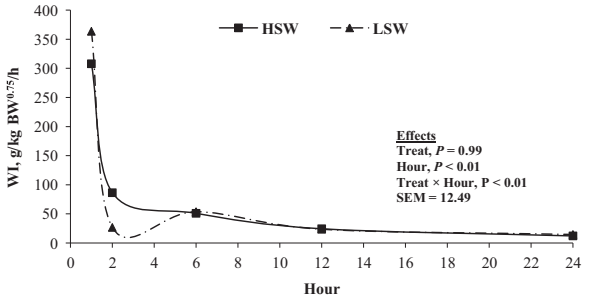

Fig. 1. Water intake (WI) after 20 h of water deprivation of calves with (HSW) or without (LSW) experience early in life with high salt water (Exp. 2). Each value represents the mean of 12 calves.

water intake rate ($P<0.01$) after a water deprivation period of 20 h (Fig. 1). LSW calves drank more than HSW calves ($P<0.01$) during the first hour after the deprivation of water. In the next hour water intake rate declined sharply; however, the reduction was more noticeable in LSW than in HSW calves ($P<0.01$). Thereafter, and until the end of the day, there was no difference in water intake rate between both groups of calves ($P>0.87$).

7.2.3. Intake and total tract digestibility

No significant differences were observed either in feed ($P=0.43$) and water ($P=0.61$) intake or WI: DMI ratio ($P=0.18$) between treatment groups during the evaluation period (Table 1). Similar to results in Exp.1, there were no differences in feed digestibility between LSW and HSW calves ($P=0.92$).

7.2.4. Hematological indicators, plasma glucose, and serum minerals

There was no treatment × day interaction for hematological indicators as well as plasma glucose and minerals in serum ($P>0.35$; Table 2), except for Mg ($P<0.03$). None of the blood parameters analyzed were affected by the treatments ($P>0.42$), but there was a day effect ($P<0.04$). Hemoglobin, hematocrit and serum concentration of Na, Ca and K were higher at the end of the evaluation period, whereas concentration of glucose, P and Mg were higher at the beginning of the evaluation period.

7.2.5. Plasma renin activity

There was no treatment effect on PRA ($P=0.35$), although a significant effect of day ($P<0.01$) was observed (Table 3). Plasma rennin activity was lower at the end of the evaluation period in both treatments.

8. Discussion

Overall, under the experimental conditions of these studies we did not find evidence that early exposure of cattle to saline water improves their performance later in life when drinking this type of water. However, reduced water intake (Exp. 1) and increased thirst threshold (Exp. 2) of animals exposed to saline water early in life deserve further consideration, as discussed below.

Table 3
Plasma renin activity (PRA) of calves with (HSW) or without (LSW) experience early in life with high salt water (Exp. 2).

Item[a]	LSW	HSW	SEM	*P*-value
	Log_e (ng/ml h)			
Day 0[b]	0.34	0.08	0.20	0.21
Day 30	−0.79	−0.86	0.20	0.75

[a] $n=12$.
[b] Day 0= start of evaluation period; Day 30= end of evaluation period.

In Exp. 1, HSW calves drank less salt water and tended to eat less than LSW calves over 30 d evaluation period. This observation may suggest that early exposure to salt water has the potential to produce physiological changes related to water intake regulation. Previous work (Curtis et al., 2004; McBride et al., 2006; Chadwick et al., 2009a; Digby et al. 2010a) has shown that high salt diets during gestation and early post-calving periods affect adult offspring´s water and food intake, which appears to be related to alterations in the renin-angiotensin system (RAS). Reduced renal rennin secretion depresses water intake through lowering circulating level of angiotensin II (Ang II; bioactive peptide with potent vasoconstrictor action synthesized from the release of hormone renin) (Fitzsimons, 1998). Szczepanska-Sadowska et al. (2003) showed that transgenic rats with high level of Ang II in the hypothalamus had higher water and food intake. Therefore, the lower water intake observed in HSW calves may have been associated with depletion in basal renin levels. Moreover, during the exposure period, HSW calves drank 18% less water than LSW (data not shown), generating hypertonic conditions that might have altered the set point of osmoregulatory mechanisms in controlling water intake (Chadwick et al., 2009a; Desai et al., 2003). On the other hand, the lack of significant difference in food intake between HSW and LSW calves during the evaluation period might be due to the close relationship between water and food consumption (Silanikove, 1992; Brew et al., 2011). Probably, the reduction in water intake (about 22%) observed in HSW calves was not enough to affect food intake. Utley et al. (1970) observed a 20% reduction in feed intake in steers when the supply of drinking water was limited to 60% of voluntary intake, but no differences in feed intake were found when consumption of water was limited to 80% of voluntary intake. During the exposure period HSW and LSW calves consumed the same amount of food (data not shown); therefore, we discard that the observed responses may have been due to under nutrition at an early age.

In Exp. 2 we did not observe differences in water and food intake between HSW and LSW during the evaluation period. However, at the beginning of the evaluation period the basal level of PRA was about 30% lower in HSW calves than in LSW calves (1.12 vs 1.57 ng/ml h, respectively), whereas PRA levels became similar between experimental groups after drinking high salt water for 30 d. While lower levels of PRA were an expected response due to increased salt intake during the evaluation period, the lack of differences suggests that both LSW and HSW calves had the same ability to excrete salt via urine. If so, this may explain why there were no differences in food and water intake between both experimental groups. Similarly, Chadwick et al. (2009a) observed a 40% reduction of basal PRA in offspring of ewes fed a high salt diet during pregnancy and lactation, although PRA levels became similar to that of control sheep after consuming a high salt diet. On the other hand, we observed a lower initial high salt water intake in HSW than LSW calves after water deprivation for 20 h, indicating an increased thirst threshold in the former. The powerful of dipsogenic action of AngII through the activation of the renin-angiotenisn system is well known (Fitzsimons, 1998; McKinley and Johnson, 2004; Geerling and Loewy, 2008).The influence of Ang II on water ingestive behavior has been clearly documented, especially when infused directly into the brain (lateral ventricle) of sheep and cattle (Weisinger et al., 1986; Blair-West et al., 1989; Fitzsimons, 1998). Sheep infused Ang II into the brain drank 1.4–2.8 times more water than control animals, demonstrating that Ang II produced sensations of thirst (Sunagawa et al., 2001). Water deprivation in ruminants activates the renin-angiotensin system (Silanikove, 1994) increasing circulating Ang II (Parker et al., 2004), indicative also of its role in stimulating water intake (Fitzsimons, 1998). Moreover, a decrease in blood of Ang II

through an inhibitor of the renin-angiotensin system reduced the urge to drink water (Blair-West et al., 1988). Therefore, the behavior of calves in Exp. 2 after the restoration of drinking water could be explained by the difference in the basal level of PRA between HSW and LSW calves. This suggests that salt water intake during gestation and/or early postnatal period alters thirst threshold of offspring. However, there were no differences in water intake during the 30 d of the evaluation period, which could be explained by decreased sensitivity of RAS to salt water in HSW as commented before. Digby et al. (2010b), who reported similar results in the alteration of thirst threshold, observed a decrease in the concentration of aldosterone in lambs from ewes fed high salt diet than in control animals. This depressed responsiveness of aldosterone could be related to RAS suppression. So, it is possible that other factors besides high salt intake at an early age modulate the type of response that animal express when exposed high salt water or high salt diets during the adulthood (Chadwick et al., 2009a, 2009b). Our experiments differed not only in the exposure period (postnatal in Exp. 1 and pre and postnatal in Exp. 2), but also in the type of dissolved salts in the high salt drinking water. In Exp. 2 calves could probably increase their water intake to maintain body homeostasis during the exposure period, while in Exp. 1 calves did not have that same chance because of the high levels of sulfate in drinking water. Thus, this may have led to different states of plasma tonicity (Ross et al., 2005; Ross and Desai, 2005), and may help explain the differences (Exp. 1) or the lack of differences (Exp. 2) in high salt water intake between HSW and LSW calves.

The changes that we and other researchers (Chadwick et al., 2009a; Digby et al. 2010b) observed regarding water intake and thirst threshold are likely to be important during the adaptation period to saline water or in situations where water consumption is restricted for several hours. Prasetiyono et al. (2000) found a negative correlation between thirst level (defined as water intake for 30 min after 2 h of feeding) and food intake in water-deprived goats, whereas Sunagawa et al. (2001) reported significant reductions in feed intake due to thirst sensations in the brain of sheep infused intracerebroventricular with Ang II. In a more recent experiment, Sunagawa et al. (2007) demonstrated that intracerebroventricular infusions of somatostatin (prevents Ang II secretion; Weisinger et al. (1991) increased feed intake in goats fed on dry forage. These authors suggested that the decrease in feed intake during the first two hours of feeding was caused by thirst-controlling peptides. Therefore, it may be possible that animals with higher thirst thresholds (due to lower basal levels of renin) could consume more food during short periods of water deprivation. However, the lack of differences in blood parameters between HSW and LSW calves suggests that any alteration produced in the mechanisms of salt excretion could be counteracted in the short time. In a recent study, Tay et al. (2012) did not observe changes in the ability to excrete salt in lambs from ewes fed a high salt diet during gestation; despite the fact that fetal nephrogenesis was affected, the kidney was able to compensate for the reduction in the number of glomeruli by increasing their size.

We conclude that, under present experimental conditions, early exposure to high salt water did not induce tolerance and improve later performance of beef cattle with salty water. However, reduced water intake (Exp. 1) and increased thirst threshold (Exp. 2) of animals exposed to saline water early in life warrant future consideration, due to both theoretical and practical implications.

Acknowledgments

This study was conducted with funding from the Instituto Nacional de Tecnología Agropecuaria (INTA)-Programa Nacional de Producción Animal – Proyecto Alimentación de Bovinos para Carne PNPA No. 1126023, Argentina. The authors thank to Dr. Juan J. Villalba (Department of Wildland Resources, Utah State University) for his thorough review of the manuscript.

References

Alves da Silva, A., de Noronha, I.L., de Oliveira, I.B., Malheiros, D.M.C., Heimann, J.C., 2003. Renin-angiotensin system function and blood pressure in adult rats after perinatal salt overload. Nutr. Metab. Cardiovasc. Dis. 13, 133–139.
AOAC (Association of Analytical Chemists), 1990. Official Methods of Analysis, 15th ed. AOAC, Arlington, VA, USA.
Basán Nickisch, M., 2007. Manejo de los recursos hídricos en zonas áridas y semiáridas para áreas de secano. INTA, Buenos Aires, Argentina.
Blair-West, J.R., Denton, D.A., McKinley, M.J., Weisinger, R.S., 1988. Angiotensin-related sodium appetite and thirst in cattle. Am. J. Physiol. 255, 205–211.
Blair-West, J.R., Denton, D.A., McKinley, M.J., Weisinger, R.S., 1989. Sodium appetite and thirst in cattle subjected to dehydration. Am. J. Physiol. 257, 1212–1218.
Brew, M.N., Myer, R.O., Hersom, M.J., Carter, J.N., Elzo, M.A., Hansen, G.R., Riley, D.G., 2011. Water intake and factors affecting water intake of growing beef cattle. Livest. Sci. 140, 297–300.
Chadwick, M.A., Vercoe, P.E., Williams, I.H., Revell, D.K., 2009a. Dietary exposure of pregnant ewes to salt dictates how their offspring respond to salt. Physiol. Behav. 97, 437–445.
Chadwick, M.A., Vercoe, P.E., Williams, I.H., Revell, D.K., 2009b. Programming sheep production on saltbush: adaptations of offspring from ewes that consumed high amounts of salt during pregnancy and early lactation. Anim. Prod. Sci. 49, 311–317.
Curtis, K.S., Krause, E.G., Wong, D.L., Contreras, R.J., 2004. Gestational and early postnatal dietary NaCl levels affect NaCl intake, but not stimulated water intake, by adult rats. Am. J. Physiol. 286, 1043–1050.
Desai, M., Guerra, C., Wang, S., Ross, M.G., 2003. Programming of hypertonicity in neonatal lambs: resetting of the threshold. Endocrinology 144, 4332–4337.
Digby, S.N., Blache, D., Masters, D.G., Revell, D.K., 2010a. Responses to saline drinking water in offspring born to ewes fed high salt during pregnancy. Small Rumin. Res. 91, 87–92.
Digby, S.N., Masters, D.G., Blache, D., Hynd, P.I., Revell, D.K., 2010b. Offspring born to ewes fed high salt during pregnancy have altered responses to oral salt loads. Animal 4, 81–88.
FAO. 2007. Water quality for livestock and poultry. In: Water Quality for Agriculture ⟨http://www.fao.org/docrep/003/t0234e/T0234E07.pdf⟩. (accessed 29.09.11).
Fitzsimons, J.T., 1998. Angiotensin, thirst and sodium appetite. Physiol. Rev. 78, 583–686.
Geerling, J.C., Loewy, A.D., 2008. Central regulation of sodium appetite. Exp. Physiol. 93, 177–209.
Grout, A.S., Veira, D.M., Weary, D.M., von Keyserlingk, M.A.G., Fraser, D., 2006. Differential effects of sodium and magnesium sulfate on water consumption by beef cattle. J. Anim. Sci. 84, 1252–1258.
INTA, 2013. Guía para cuidado y uso de animales de experimentación. http://www.inta.gob.ar/documentos/manuales sobre cuidado y supervisación y uso de animales.pdf.
Komarek, A.R., 1993. A filter bag procedure for improved efficiency of fiber analysis. J. Dairy Sci. 76 (Suppl. 1), S250.
Little, M.H., McMahon, A.P., 2012. Mammalian kidney development: principles, progress, and projections. Cold Spring Harb. Perspect. Biol. 4, a008300.
Loneragan, G.H., Wagner, J.J., Gould, D.H., Garry, F.B., Thoren, M.A., 2001. Effects of water sulfate concentration on performance, water intake, and carcass characteristics of feedlot steers. J. Anim. Sci. 79, 2941–2948.
McBride, S.M., Culver, B., Flynn, F.W., 2006. Prenatal and early postnatal dietary sodium restriction sensitizes the adult rat to amphetamines. Am. J. Physiol. 291, 1192–1199.
McKinley, M.J., Johnson, A.K., 2004. The physiological regulation of thirst and fluid intake. Physiology 19, 1–6.
NRC, 2000. Nutrient Requirements of Beef Cattle, 7th rev. ed. Natl. Acad. Press, Washington, DC.
Parker, A.J., Hamlin, G.P., Coleman, C.J., Fitzpatrick, L.A., 2004. Excess cortisol interferes with a principal mechanism of resistance to dehydration in *Bos indicus* steers. J. Anim. Sci. 82, 1037–1045.
Patterson, T., Johnson, P., 2003. Effects of water quality on beef cattle. In: Proceedings of the Range beef cow symposium XVIII, Mitchell, Nebraska.
Prasetiyono, B.W.H.E., Sunagawa, K., Shinjo, A., Shiroma, S., 2000. Physiological relationship between thirst level and feed intake in goats fed on alfalfa hay cubes. A. Australas. J. Anim. Sci. 13, 1536–1541.
Provenza, F.D., Balph, D.F., 1990. Applicability of five diet-selection models to various foraging challenges ruminants encounters. In: Hughes, R.N. (Ed.), Behavioural Mechanisms of Food Selection. NATO ASI Series G: Ecological Sciences, Vol.20. Springer-Verlag, Berlin. Heildelberg, Germany, pp. 423–459.
Ross, M.G., Desai, M., 2005. Gestational programming: population survival effects of drought and famine during pregnancy. Am. J. Physiol. 288, 25–33.
Ross, M.G., Desai, M., Guerra, C., Wang, S., 2005. Prenatal programming of hypernatremia and hypertension in neonatal lambs. Am. J. Physiol. 288, 97–103.

Silanikove, N., 1992. Effects of water scarcity and hot environment on appetite and digestion in ruminants: a review. Livest. Prod. Sci. 30, 175–194.
Silanikove, N., 1994. The struggle to maintain hydration and osmoregulation in animals experiencing severe dehydration and rapid rehydration: the story of ruminants. Exp. Physiol. 79, 281–300.
Sunagawa, K., Weisinger, R.S., McKinley, M.J., Purcell, B.S., Thomson, C., Burns, P.L., 2001. The role of angiotensin II in the central regulation of feed intake in sheep. Can. J. Anim. Sci. 81, 215–221.
Sunagawa, K., Ooshiro, T., Murase, Y., Hazama, R., Nagamine, I., 2007. Mechanisms controlling feed intake in large-type goats fed on dry forage. Asian Australas. J. Anim. Sci. 20, 1182–1189.
Szczepanska-Sadowska, E., Paczwa, P., Dobruch, J., 2003. Enhanced food and water intake in renin transgenic rats. J. Physiol. Pharmacol. 54, 81–88.
Tay, S.H., Blache, D., Gregg, K., Revell, D.K., 2012. Consumption of a high-salt diet by ewes during pregnancy alters nephrogenesis in 5-month-old offspring. Animal 6, 1803–1810.
Utley, P.R., Bradley, N.W., Boling, J.A., 1970. Effect of restricted water intake on feed intake, nutrient digestibility and nitrogen metabolism in steers. J. Anim. Sci. 31, 130–135.
Ward, E.H., Patterson, H.H., 2004. Effects of thiamin supplementation on performance and health of growing steers consuming high sulfate water. J. Anim. Sci. 55, 375–378.
Weeth, H.J., Hunter, J.E., 1971. Drinking of sulfate-water by cattle. J. Anim. Sci. 32, 277–281.
Weisinger, R.S., Denton, D.A., McKinley, M.J., Muller, A.F., Tarjan, E., 1986. Angiotensin and Na appetite of sheep. Am. J. Physiol. 251, 690–699.
Weisinger, R.S., Blair-West, J.R., Denton, D.A., Tarjan, E., 1991. Central administration of somatostatin suppresses the stimulated sodium intake of sheep. Brain Res. 543, 213–218.