Effects of water desalination on milk production and several blood constituents of Holstein cows in a hot arid climate

Arjomandfar, M.[1]; Zamiri, M. J.[2*]; Rowghani, E.[2]; Khorvash, M.[3] and Ghorbani, Gh.[3]

[1]Graduated from College of Agriculture, Shiraz University, Shiraz, Iran; [2]Department of Animal Sciences, College of Agriculture, Shiraz University, Shiraz, Iran; [3]Department of Animal Sciences, College of Agriculture, Esfahan University of Technology, Esfahan, Iran

[*]**Correspondence:** M. J. Zamiri, Department of Animal Sciences, College of Agriculture, Shiraz University, Shiraz, Iran. E-mail: Zamiri@shirazu.ac.ir

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Summary

Fourteen primiparous Holstein cows (180.0 ± 4.3 days in milk) with a mean (±SD) daily milk yield of 35.0 ± 1.3 kg and a body condition score of 3.2 ± 0.2 were allotted into two groups (n = 7), and were fed a ration consisting of (dry matter basis) 35% corn silage, 25% alfalfa hay and 40% concentrates. Salt was provided free choice. The experiment was performed during the period of heat stress, i.e., when the temperature-humidity index was greater than 72. One group was offered desalinated water containing 570 mg total dissolved solids (TDS) and another group was offered water containing 1400 mg TDS per L. Milk yield was measured weekly, and milk samples were taken on days 21 and 42 for determination of milk composition. Blood samples were taken on days 21 and 42 from the median caudal vein of the tail and the serum concentrations of Na^+, K^+, Ca^{2+}, Mg^{2+}, tri-iodothyronine (T_3) and thyroxine (T_4) were measured. Ruminal fluid was taken by rumenocentesis on day 42 for determination of volatile fatty acids (VFA) and pH. Milk yield, milk composition, serum concentrations of T_3 and T_4, Na^+, Ca^{2+} and Mg^{2+}, ruminal fluid VFA concentration and pH were not significantly affected by water TDS (P>0.05); however, cows receiving desalinated water produced 2 kg more milk per cow per day. Serum K^+ concentration was significantly higher in cows consuming saline water (P<0.05). The present data indicated that water with a TDS of 1400 mg per L had no adverse effect on lactating cows; therefore, it is not necessary to desalinate water in the region under study. However, in light of the possible effects of saline water on thyroid hormones, further studies concerning the influence of saline water on the metabolism of high producing cows in hot climates are warranted.

Key words: Cow, Milk, Water desalination, Thyroid hormone, Total dissolved solids

Introduction

Water is a major constituent of the body and is important for proper functioning of various physiological processes including the ionic balance, digestion, absorption, metabolism, heat balance, and elimination of waste products from the body (Reece, 2005). Lactating cows also require a large amount of water for milk production which is met mainly through drinking water, although some water is also available from food and metabolic processes in the body (Houpt, 1996).

The importance of water quality for dairy cattle has long been emphasized (Waldner and Looper, 2007). Water containing ≤5000 mg of total dissolved solids (TDS) per L has been considered satisfactory for lactating cows, but TDS levels greater than 7000 should be avoided (NRC, 2001). However, the available findings on the effect of water salinity on milk production of lactating cows, especially high producing cows under heat stress, are limited and to some extent contradictory (Jaster *et al.*, 1978; Challis *et al.*, 1987; Wegner and Schuh, 1988; Bahman *et al.*, 1993; Solomon *et al.*, 1995).

Ray (1986) reported that beef cattle under heat stress, consuming a low energy diet and water containing 6000 mg TDS per L had a lower daily gain as compared with 1300 mg TDS per L, and increasing the energy density of the diet alleviated the detrimental effect of the high TDS level on the daily gain. Milk production of the cows kept under cold conditions and offered water containing 4400 mg TDS per L was not different from those offered natural drinking water (Wegner and Schuh, 1988); however, the saline water resulted in decreased milk production of the cows under heat stress. Jaster *et al.* (1978) noted a depression in the milk yield of about 2 kg per head per day and a decline in the production persistency of the cows, with an initial mean milk production of about 37 kg, consuming tap water plus 2500 mg NaCl per L. According to Bahman *et al.* (1993), a water TDS of 3574 as compared with 449 did not affect the milk yield and composition of cows in a hot environment producing 20 to 25 kg milk, but the decline in the milk yield as the experiment progressed was less at the higher TDS level. They also noted that cows on the higher TDS level tended to have higher plasma concentrations of minerals and thyroid hormones. Solomon *et al.* (1995) found that the improvement of water quality by desalination increased the milk yield and composition of dairy cows in a hot arid environment. Valtorta *et al.* (2008) recently showed that the water TDS level did not affect the milk production, milk composition, condition score, or body weight of grazing Holstein cattle, although 10000 mg/L TDS did increase the water intake.

Water intake might also increase during stress, which will result in an increased load of some minerals and subsequently can affect homeostasis. In fact, Raisbeck *et al.* (2009) believe that TDS in drinking water is not a good predictor of animal health, and that TDS values less than 500 mg per L may adversely affect the animals. Because high-producing cows are already under stress, they may be more adversely affected by increased water TDS during heat stress. Therefore, the purpose of the present experiment was to study the effect of desalination of natural drinking water containing 1400 mg TDS per L on high-producing Holstein cows during summer in a hot, arid environment near the city of Esfahan. We investigated the effect of water desalination on the milk yield and composition, several blood constituents, and ruminal fluid pH and volatile fatty acid (VFA) production of high producing cows during heat stress. The effect of TDS on the ruminal VFA production of high-producing cows has received little attention, although Valtorta *et al.* (2008) reported that the water TDS level did not affect the VFA production of grazing Holstein cattle during the summer in Argentina.

Materials and Methods

The experiment was carried out on a commercial dairy farm 45 km north-west of Esfahan city. Fourteen first parity lactating Holstein cows (35.0 ± 1.3 (SD) kg milk per day; 180 ± 4 days in milk; and a body condition score of 3.2 ± 0.2) were randomly allotted to two groups to receive water containing either 1400 or 570 mg TDS per L. The water routinely offered to cows in this farm contains 1400 mg TDS per L, and had a TDS of 570 after desalination (Reverse Osmosis System, SR-108), Avayeh Sabz Co., Kashan, Iran). The mineral content of the water is shown in Table 1. The experiment was performed during the period of heat stress, i.e., when the temperature-humidity index was greater than 72. The cows were fed with a balanced ration (NRC, 2001) consisting of (dry matter basis) 35% corn silage, 25% alfalfa hay and 40% concentrates. Salt was provided free choice. The overall feed consumption of each experimental group was determined once per week.

Table 1: Mineral concentration (mg per L) of saline (TDS = 1400 mg per L) and desalinated (TDS = 570 mg per L) water

Ion	Saline water	Desalinated water
Sodium	259	80
Potassium	15	5
Calcium	144	50
Magnesium	52	25
Chloride	357	130
Sulfate	312	100

After an adaptation period of 10 days, milk and blood sampling were performed over a 6-week period. Daily milk production was measured one day per week. Milk composition was determined in the samples taken on days 21 and 42. Blood samples were obtained from the median caudal vein of the tail one day before the start of the experiment and on days 21 and 42. Serum was separated, after centrifugation of blood samples at 3000 rpm for 15 min, to determine the serum levels of Na^+, K^+, Ca^{2+}, Mg^{2+}, tri-iodothyronine (T_3) and tetra-iodothyronine (T_4). The sensitivity, intra-assay CV, and inter-assay CV were 0.5 nmmol per L, 2.0 and 3.0% for T_3 (n = 20), and 0.3 nmol per L, 4.54 and 7.65% for T_4, respectively. Milk fat, protein and lactose were measured by using the Milkoscan (Foss 605 B, Foss Electeric, Denmark), milk urea by commercial kits (Zistshimi, Tehran), thyroid hormones by radioimmunoassay kit (Immunotech Lab., USA), Na^+ and K^+ by flame photometry (Wagtech 401, USA), and Ca^{2+} and Mg^{2+} by spectrophotometry according to Lamkin and Williams (1965) using commercial kits (Shim-Enzyme and Darman-Kav, respectively). Ruminal fluid (5 mL) was taken by rumenocentesis (Garrett *et al*., 1999) one day before the start of the experiment and on the last day of the experiment to determine the pH (Jenway 3510 pH-meter, UK) and VFA (Bal *et al*., 2000). Ruminal fluid was strained through a layer of cheesecloth, acidified with 10 mL 10% H_2SO_4 and kept frozen at -10°C until used for VFA analysis by using a gas chromatograph (0.25 × 0.32, 0.3 µm i.d. fused silica capillary, model No. CP-9002 Vulcanusweg 259 a.m., Chrompack, Delft, The Netherlands). Crotonic acid was used as a standard for VFA determination.

Milk yield data were analyzed by Proc Mixed of the SAS, using repeated measure ANOVA. Milk composition was analyzed by Proc GLM where the milk yield was included as the covariate. Other data were analyzed by the GLM procedure, with values measured the day before the start of the experiment as the covariates (SAS, 2003). The data are reported as mean ± SE.

Results

Decreasing the TDS level of the drinking water from 1400 to 570 mg per L did not significantly affect the daily milk production and composition in the present experiment, although the average daily milk production was about 2 kg higher per cow receiving desalinated water (Table 2). Serum concentrations of sodium, calcium and magnesium ions and T_3 were not influenced by the water salinity or the duration of treatment, but there was a significant (P=0.037) effect of water salinity on the serum potassium level on day 42 of the experiment (Table 3). On day 21, serum T_4 levels tended (P=0.10) to be higher in cows on saline water. Neither pH nor the concentrations of VFA in the ruminal fluid

Table 2: Effect of saline (TDS = 1400 mg L^{-1}) and desalinated water (TDS = 570 mg L^{-1}) on daily milk production (kg) and composition (%) of heat-stressed lactating Holstein cows (mean ± SE)

	Saline water	Desalinated water
Daily milk production	30.84±1.44	32.82±1.44
Milk dry matter	8.83±0.08	8.76±0.08
Milk protein	2.92±0.03	2.90±0.10
Milk fat	3.51±0.20	3.42±0.19
Milk lactose	2.41±0.19	2.44±0.20
Milk urea	0.08±0.00	0.07±0.00

Table 3: Effect of saline (TDS = 1400 mg L^{-1}) and desalinated water (TDS = 570 mg L^{-1}) on blood serum levels of cations (meq per L) and thyroid hormone (nmol per L) in heat-stressed lactating Holstein cows on days 21 and 42 of the experiment (mean ± SE)

Blood constituent	Day 21		Day 42	
	Saline	Desalinated	Saline	Desalinated
Sodium	145.4±1.7	143.4±1.3	153.2±1.7	147.6±2.2
Potassium	4.62±0.09	4.50±0.11	4.86±0.28	4.56±0.11*
Calcium	4.64±0.13	4.67±0.12	4.57±0.20	4.57±0.23
Magnesium	2.16±0.28	2.16±0.17	2.21±0.10	1.93±0.10
Tri-iodothyronine	3.41±0.37	3.57±0.20	4.12±0.29	4.49±0.30
Tetra-iodothyronine	65.45±13.08	35.20±8.45†	39.50±10.83	34.60±8.63

*Probability of difference from saline water (P=0.037). †Probability of difference from saline water (P=0.10)

Table 4: Effect of saline (TDS = 1400 mg L^{-1}) and desalinated water (TDS = 570 mg L^{-1}) on ruminal fluid pH and volatile fatty acid composition (%) in heat-stressed lactating Holstein cows on day 42 of the experiment (mean ± SE)

	Saline water	Desalinated water
pH	6.05±0.08	6.20±0.08
Acetate	66.66±1.11	65.12±0.56
Propionate	17.18±0.58	17.82±0.37
Isobutyrate	1.78±0.05	1.73±0.03
Butyrate	12.90±0.44	13.53±0.23
Isovalerate	1.04±0.03	1.04±0.02
Valerate	0.75±0.04	0.72±0.04

were significantly affected by the water salinity used in the present experiment (Table 4). Although individual feed consumption was not measured, the feed conversion ratio was almost the same for the cows receiving saline and desalinated water (0.77 vs. 0.70, respectively). Treatment by week interactions were not significant for any of the measurements (P>0.05).

Discussion

Water desalination to 570 mg per L had no significant effect on most of the parameters studied, although the K^+ ion concentration in the blood serum was significantly decreased. Increased serum K^+ ion concentration in the cows offered water containing a higher TDS level may become detrimental to homeostasis in the long term.

The inconsistencies observed on the effect of TDS level on lactating cows could partly be due to experimental protocols, such as the number of cows, source of water (natural saline or salinated with NaCl), the level of TDS used, the duration of the treatment, and the presence of minerals that may affect the performance but are not measured in such studies; usually, those minerals that are important in contributing to TDS levels are measured (Jaster *et al*., 1978; Challis *et al*., 1987; Wegner and Schuh, 1988; Bahman *et al*., 1993; Solomon *et al*., 1995).

Jaster *et al*. (1978) reported a depression in the daily milk yield of about 2 kg for cows on salt water, and stated that although the difference was small, it reflected a trend which, if extended over the entire lactation, could be dramatic. In a study comparing the effect of desalinated water with water containing >4000 mg TDS per L on high producing lactating cows in a hot environment, Solomon *et al*. (1995) found increases in water intake, milk production, and milk composition (lactose, protein, fat), although dry matter intake was not influenced by the water type. According to Bahman *et al*. (1993), brackish water (3574 mg TDS per L) did not significantly affect the milk production and composition of cows in a hot environment as compared with fresh water (449 mg TDS per L), but the decline in milk production was significantly less for brackish water. Brackish water tended to increase the plasma levels of minerals and thyroid hormones. Their cows were not high producers and had a daily milk production of 23.5 and 21.4 kg, respectively for brackish and fresh water. The cows in the study of Bahman *et al*. (1993) received NaCl only in the form of mineralized salt blocks, and were probably salt-deficient; therefore, due to the lower milk yield of these cows the water quality was probably not a limiting factor (Solomon *et al*., 1995). Unlike the study of Bahman *et al*. (1993), in our experiment the cows (high producers) offered desalinated water produced about 2 kg more milk than those offered saline water (TDS = 1400 mg per L) and the cows were not salt-deficient, as their rations were prepared to supply sufficient minerals.

Similar to the findings of Wegner and Schuh (1986), the serum concentrations of Na, Ca, and Mg ions were not significantly affected by desalinating water to the TDS level of 570 mg per L in our study. However, the serum concentration of the K ions was higher on day 42 of the experiment in the cows receiving more saline water. Bahman *et al*. (1993) indicated a tendency for higher levels of all these ions in the plasma of the cows on saline water, which could be due to a higher level of TDS than in our experiment. Homeostatic mechanisms control the level of minerals in body fluids; therefore, the concentrations of minerals tend to stabilize after a period of saline water intake (NRC, 2001). The blood levels of minerals may remain slightly higher than normal physiological values when TDS levels are higher, as in the study of Bahman *et al*. (1993). Aldosterone is the principal hormone controlling the concentrations of sodium and potassium ions by acting on the kidneys, colon, salivary glands and sweat glands (Goodman, 2003). An increased concentration of potassium ion or a decreased level of sodium ion in blood triggers aldosterone secretion, which results in the active reabsorption of sodium ions, and the excretion of potassium ions in kidney nephrons. Sweating during hot weather is accompanied by increased sodium ion excretion; therefore, provided the water does not contain harmful levels of toxic elements, the ingestion of slightly more saline water under these conditions may be beneficial. It is noteworthy that concentrations of minerals in milk were not influenced by water salinity (Jaster *et al*., 1978). Water consumption was not measured in our study, however, some researchers (Jaster *et al*., 1978; Solomon *et al*., 1995) found increased consumption of saline water by lactating cows, while others reported no significant effect of salinity on water intake (Bahman *et al*., 1993). These inconsistencies may reflect the differences in the milk yield of the cows in these experiments. In all of these studies, the saline water containing <5000 mg TDS per L was considered to be satisfactory for ruminants (NRC, 2001).

On day 21, serum T_4 levels tended (P=0.10) to be higher in the cows on saline water, although the T_3 levels remained unchanged throughout the experiment. In the study of Bahman *et al*. (1993), the cows receiving saline water for 26 weeks tended to have higher plasma concentrations of both T_3 and T_4. In the latter study, the iodine intake of the cows on saline water was higher than their requirements, but this increased iodine uptake was ruled out as the cause of increased thyroid hormone concentration. Further research is needed to substantiate these findings and clarify any possible mechanisms.

Our work showed no significant effects of water TDS on the pH and VFA levels in the ruminal fluid. Valtorta *et al*. (2008) recently reported that water TDS up to 10000 mg per L did not influence the VFA production of grazing Holstein cows. Ingestion of a large volume of saline water has the potential to alter the pH and thus the microbial function and activity; however, the secretion of a large volume of saliva of high buffering capacity seems to have compensated for any effect of ingested minerals on ruminal pH (Valtorta *et al*., 2008).

The present data indicated that water with a TDS of 1400 mg per L had no adverse effect on lactating cows; therefore, it is not necessary to desalinate water in the region under study. However, in light of the possible effects of saline water on thyroid hormones, more comprehensive research concerning the influence of saline water on the metabolism of high producing cows in hot climates is warranted.

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