Effects of Drinking Water Desalination on Several Traits of Dairy Cows in a Mexican Semiarid Environment

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Abstract: High salt concentration in drinking water on dairy cattle farms in the semiarid region of northern Mexico is a concern because it can negatively affect health and productive performance of dairy cows. The study was conducted to assess the effect of drinking water quality on feed intake, daily milk yield and composition, milk fat depression and somatic cell count of dairy cows in a Mexican semiarid environment. Multiparous Holstein cows (n = 29) were individually fed on a total mixed ration during the first 15 weeks of lactation. Fifteen cows were randomly assigned to the control group, which received a daily supply of non-desalinated drinking water (concentration of total dissolved salts >1,809 mg L^{-1}) from the farm's water well, and cows in the treatment group (n = 14) had access to reverse osmosis desalinated drinking water, with a low concentration of total dissolved salts (<554 mg L^{-1}). Milk yield and composition were not affected by drinking water treatment. However, milk production efficiency was 17% higher ($p<0.05$) for cows on the reverse osmosis desalinated drinking water treatment, due to a 9% reduction in daily dry matter intake. Furthermore, the risk of milk fat depression was 3.3 times higher ($p<0.05$) and somatic cell count was 111% higher ($p<0.05$) for cows in the control group. Lactating cows that had access to reverse osmosis desalinated drinking water produced milk more efficiently and had some health and productive performance advantages; however, an economic evaluation is needed before implementing desalination by reverse osmosis on a large scale.

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1. Introduction

Water is the most important nutrient that the cow obtains through direct ingestion of feed and, in lesser proportion, from water generated by body metabolism. Because water is a dissolvent that reacts easily with the environment, it rapidly incorporates minerals, salts and toxic substances that, if ingested in excess, can affect the health and productive performance of cattle (NRC, 2005).

Water salinity is measured as the content of total dissolved salts (TDS), which expresses the sum of inorganic matter dissolved in the water and is the main criterion used to assess quality of drinking water for livestock (NRC, 2001). High TDS content in the drinking water of dairy cows can cause imbalances of some minerals in the body (mainly sodium, potassium, copper, magnesium, iron, arsenic and sulfur) and can negatively affect the cow's milk production performance (NRC, 2005). How drinking water with TDS levels above 1000 mg L^{-1} affects production of dairy cows is not clear. Results from experimental studies vary, mainly due to variations in the specific TDS composition of the drinking water, the production level of the experimental animals used, the productive traits studied, and whether the cows were grazed or housed; therefore, it is important to determine the advantages of using desalinated drinking water under practical scenarios of dairy cattle farming.

In Mexico, cows' milk production was 10.9 million tons in 2013. The area known as "Comarca Lagunera", located in a hot semiarid environment, is the most important milk-producing region of the country contributing 20% of its total milk production (SIAP, 2013). The drinking water given to dairy cattle in this region is groundwater pumped from deep wells and its salinity is high, over 2000 mg L^{-1} (CONAGUA, 2000). Water treatment methods are an option for dealing with increasing salt content in places at risk, such as the Comarca Lagunera. Farmers have concerns about the high salinity of water available for dairy cows, and some have begun to implement techniques to desalinate the drinking water on their farms. This alternative is attractive because the cost of desalination has been falling and farmers can easily implement this technology at the individual farm level. The objective of this study was to assess some effects of drinking water desalinated by a reverse osmosis technique on feed intake, daily milk yield and composition, milk fat depression and somatic cell count of lactating Holstein cows in a total confinement system in a semiarid environment.

2. Materials and Methods

The study was conducted at the dairy experimental station "18 de Julio" of the Universidad Autónoma Chapingo, located in the municipality of Tlahualilo, in the state of Durango, Mexico (the Comarca Lagunera region). The place is located at 25º54'07" N and 103º35'09" W. According to García (2004), the altitude is 1,137 m and average annual temperature is 21.1ºC; the climate is dry with summer rain and annual rainfall of 239 mm, distributed from July to September.

2.1 Animals, treatments, management and feeding

The experiment was carried out from October 2011 to January 2012 (fall and winter), using twenty-nine Holstein-Friesian cows (body weight 750.00±76 kg, with two or more lactations, 10 days in milk, and body condition score around 3, on a scale of 1 to 5). The study followed the institutional guidelines approved by the Animal Care and Use Committee of the Universidad Autónoma Chapingo, based on the norms of the Canadian Council on Animal Care in Science (CCAC, 2009).

Cows were stratified by body weight and randomly assigned to one of two treatments (15 cows to treatment 1 and 14 to treatment 2): 1) non-desalinated water (NDW) with high TDS concentration (>1,809 mg L^{-1}) and 2) water desalinated by reverse osmosis equipment (DWO), which had a low TDS concentration (<554 mg L^{-1}). Both NDW and DWO were obtained from the same deep well at the dairy farm.

The cows were fed individually during the first 15 weeks of lactation with a total mixed ration containing 46% forage and 54% concentrate feed (Table 1). The diet was formulated following NRC recommendations (NRC, 2001) for lactating dairy cows. Cows were fed at four different times during the day: 7:00 to 9:30, 12:30 to 14:30, 17:30 to 18:30 and 22:30 to 24:00 h. Cows were trained to feed in individual feeding spaces accommodated along the corral's feeding trough. In these individual spaces, cows were locked up until they finished feeding. The amount of feed offered and feed rejected was recorded after each feeding time. To facilitate handling, the cows were identified with earrings of different colors and progressive numbers from 1 to 29. The experimental diets were offered during 105 d of lactation.

At the beginning of every day, each cow selected an individual feeding space in the feeding trough and the quantity of feed corresponding to the cow's number and treatment was given. The offered feed was previously weighed and recorded. At the end of each feeding, the orts were collected and recorded. Body weight changes were recorded every week and milking was done three times a day at intervals of eight hours between milking. The milking routine was performed in a double-8 herringbone milking parlor (Alpha Laval™, St. Louis, MO, USA) and it included washing and drying udders with disinfectant, teat pre-sealing, blunting, milking and teat sealing. Health of the animals was controlled during the experimental phase and illness was not observed. Milk yield efficiency was determined considering feed intake and daily milk yield. For each cow, feed and orts were sampled every week to determine nutrient intake and quality of feed consumed during the experimental period. After collection, samples were stored at -20ºC. Later, the samples were dried at 55 to 65ºC in a forced-air oven for 48 h in order to determine dry matter (DM); samples were then ground in a Wiley mill (A. H. Thomas, Philadelphia, PA, USA). Percent DM was determined after drying in an oven at 100ºC for 24 h. Finally, samples were burned in a muffle furnace at 500ºC to determine organic matter (OM) and ash (AOAC, 2000). Neutral detergent fiber (NDF) and acid detergent fiber (ADF) were also determined (Van Soest *et al*., 1991).

2.2 Sample collection, handling and laboratory analyses

The salt concentration in the drinking water was determined by chemical analyses of the samples collected directly from the water troughs in the morning, at midday and in the afternoon. The water samples were homogenized and stored in previously sterilized Nalgene receptacles. The chemical composition of the water was determined under the Official Mexican Norm NOM 127SSA1-1994, using the maximum permitted limits of water components for human consumption (SSA, 2000) as criteria.

2.3 Estimation of response variables

Daily, samples of offered and unconsumed feed were collected in 500 g plastic bags and frozen at -4ºC for 14 days. Each sample was later thawed and dried in a forced air oven (Kafo series 1600, Taiwan) at 55 to 60ºC for 72 h to determine the percentage of dry matter (AOAC, 2000). Daily feed intake (kg cow^{-1}) was obtained by the difference between offered and unconsumed feed. Dry matter intake (DMI) was estimated by multiplying daily feed intake by the percentage of dry matter in the corresponding daily ration. Dairy cows were milked three times a day at 2:00, 10:00 and 18:00 h. Individual daily milk yield was estimated once a week using Waikato MK V lactometers (Waikato NZ) and, at the same time, milk samples were collected in 120 mL plastic vials. To each sample, a bromopol tablet (BROMOPOL, BSM2, D&F Control, San Ramon, CA, USA) was added as a preservative; the milk samples were immediately placed in refrigeration for later analyses of milk composition. The milk samples were analyzed using a MilkoScan FT 120 equipment (Foss, Denmark), which determines percentages of fat, protein and lactose. Somatic cell count in the milk (cells mL^{-1}×1,000) was determined with Fossomatic 90 equipment (Multispec, Foss Food Technology Corp., Eden Prairie, MN, USA). Yields (kg cow^{-1} day^{-1}) of fat, protein and lactose were obtained by multiplying daily milk yield by the percentage of the respective component.

Efficiency was calculated as the quotient of daily milk yield divided by daily DMI. The body weight and body condition score of each cow were measured at calving and every 14 days afterwards. The health of each cow was monitored daily during the first 10 days after calving, before their inclusion in the experimental treatments.

2.4 Statistical analyses

The experiment had a completely randomized design and each cow constituted one experimental unit. The variables estimated weekly were analyzed as repeated measurements over time, following the procedure proposed by Littell *et al*. (2006); fixed effects of treatment, experimental week, and interaction between treatment and experimental week were included in the statistical model, as well as the random effect of cow nested within treatment and the linear and quadratic effects of the covariables days in milk and the initial value of the respective analyzed variable (SAS, 2009).

A variable that indicated normal or low content of milk fat was obtained by dividing the percentage of fat by the percentage of protein in milk. When the quotient was less than 1, it indicated milk fat depression; when the quotient was more than 1, the value indicated adequate fat content in the milk. To determine the risk of milk fat depression, a multiple logistic regression model was used with the LOGISTIC procedure of SAS (SAS, 2009), considering a binomial distribution where the probability ($\boldsymbol{P_i}$) that a cow presents milk fat depression, given its consumption of high or low saline water, was estimated with the following model:

$$\boldsymbol{P_i = Prob(y_i = y_1 | x_1, \ldots, x_k) = \frac{1}{1 + exp\left[-\left(\beta_0 + \sum_{i=1}^{k} \beta_i x_i\right)\right]}}$$

where *yi* is the first order value of the response variable, β_0 is the intercept, and *βi* are regression coefficients associated with the independent variables and sampling period (*xi…xk*). In addition, relative risks that cows had milk fat depression were estimated by referring to the statistical probability that the cows exposed to the main risk factor (consumption of water with high TDS content) would have the condition of daily milk yield with milk fat depression, adjusted by the model (Hosmer and Lemeshow, 1989).

3. Results

In general, the effects of the treatments continued throughout the experimental period, with small specific interactions for some traits in some weeks; therefore, the results of effects during an experimental week and treatment by experimental week are not shown in this study. Also, the body condition of the cows was similar in the two treatments but cows in the NDW treatment had higher ($p<0.05$) body weight (5.0%) and metabolic body weight (3.8%) than cows in the DWO treatment at the beginning of the trial; these differences were constant throughout the experimental period (Figure 1).

Information on the analyses of the water offered to dairy cows in both treatments is presented in Table 2. Due to the filtration process by the reverse osmosis treatment, the desalinated water had less TDS (69%), carbonates (74%), sulfates (82%), nitrates (58%), arsenic (75%) and a lower pH (11%) than the non-desalinated water. On the other hand, the desalinated water had a higher (78%) chloride content than non-desalinated water.

Table 3 shows the means of several variables of the desalinated and non-desalinated drinking water during the trial. Daily yields of milk, fat, protein and lactose were similar for the two treatments ($p>0.05$). However, cows in the DWO group consumed 9% less dry matter ($p<0.05$) than those in the NDW group and, as a consequence, milk yield efficiency of cows in the DWO treatment was 17% higher ($p<0.05$) than in the NDW treatment. Also, somatic cell count in milk from cows consuming NDW were 111% higher than in milk from cows consuming DWO ($p<0.05$).

The means of fat (3.1 to 3.2%), protein (2.9 to 3.0%) and lactose (4.8 to 4.9%) percent, as well as the milk urea nitrogen content (10.9 to 11.6 mg dL-1) were similar in milk of cows given either treatment ($p>0.05$). The logistic regression coefficient value for NDW relative to DWO was 1.2±0.3 and the confidence interval of relative risk at 95% was [1.8, 6.1]. Thus, the cows that drank water with a high TDS content (NDW) had a risk of producing milk fat depression 3.3 times higher ($p<0.01$) than cows that drank water with a low TDS concentration (DWO).

4. Discussions

In desalinated water of the present study, the levels of TDS, sulfates, nitrates and arsenic were above the maximum permissible levels suggested by Mexican Official Standard (SSA, 2000). The process of desalination reduced TDS, sulfates and arsenic from high to permissible levels. However, although the desalination treatment decreased the amount of sulfates, it was not enough to achieve the maximum permissible value specified by the Mexican Official Standard. The decrease in sulfates in water is important because it can contribute to more efficient utilization of other minerals, such as Cu^+, Mo^+ and Fe^+, in a total mixed ration for dairy cows (Loneragan *et al*., 2001; Van der Welle *et al*., 2008). The high content of nitrates in the desalinated water can be explained by the large amounts of chemical fertilizers and manure used in modern agriculture practiced in the studied region (Lucassen *et al*., 2006). Lowering the nitrate content is important since high levels can increase the risk of nitrate poisoning (Van der Welle *et al*., 2006; Erisman *et al*., 2013). Also, the reduction of arsenic is important not only for the health of animals but also for humans, since this element is highly toxic (Nickson *et al*., 2005). On the other hand, the desalination process increased the content of chlorides, which is explained by the addition of sodium hypochlorite to the water as a bactericide. High levels of chloride in the drinking water often change the electrolyte balance and intracellular pressure of the body. These high chloride levels might increase the risk of dehydration and other health problems in the animals, since the kidneys are exposed to greater than normal physiological pressure than normal, as they need to remove the excess of these compounds (Curran and Robson, 2007). Despite the foregoing, in the present study, the chloride content in the desalinated water did not exceed the levels suggested by the Mexican standard.

Results on milk yield using drinking water with high or low TDS concentration have varied depending on the conditions of specific studies. Reports of no differences in daily milk yield, similar to the present study, were published by Revelli *et al*. (2005), Valtorta *et al*. (2008) and Arjomandfar *et al*. (2010). In contrast, some authors have published results indicating that cows consuming water with a low TDS concentration had higher milk yield (5.8 to 9.8%) than cows consuming water with a high TDS concentration (Jaster *et al*., 1978; Bahman *et al*., 1993; Solomon *et al*., 1995). The results on milk quality reported by Valtorta *et al*. (2008) and Arjomandfar *et al*. (2010) coincide with the estimates of the present study, but differ from those of Solomon *et al*. (1995). These authors estimated higher yields of fat (1.02 *vs.* 0.96 kg cow^{-1} d^{-1}), protein (1.01 *vs.* 0.93 kg cow^{-1} d^{-1}) and percentage of lactose (4.50 *vs.* 4.44%) in milk from cows that drank water with a low TDS concentration. Moreover, Revelli *et al*. (2005) observed that the percentage of fat in milk was higher when cows drank water low in salts, but the percentages of protein, lactose and casein in milk were similar in groups of cows that drank water with either a high or low TDS concentration. In the study, the lack of differences in milk composition is explained because the animals that were used in this experiment have been drinking salty water for a long time; and perhaps, most of them had adapted to the consumption of this quality of water before entering the experiment. Moreover, the salt concentration in the non-desalinated water is on the allowable limits for animal consumption proposed by Lardy *et al*. (2008); this means that the drinking water offered to the animals in the area of study could be classified as moderate in quality because of its contents of anions and cations.

Under the conditions of this study, the cows in the DWO group had less dry matter intake and higher milk yield efficiency than in the NDW group; this differs from those results published by others. Solomon *et al*. (1995) reported similar feed intake (22.6 *vs.* 23.0 kg MS cow^{-1} d^{-1}) for dairy cows that drank water with either high or low salt concentrations, whereas Valtorta *et al*. (2008) found similar feed intake values of 18.0, 17.4 and 17.3 kg MS cow^{-1} d^{-1} ($p>0.05$) for grazing dairy cows that drank water with 1,000, 5,000 or 10,000 ppm TDS values, respectively. In the present study, the higher DMI in the NDW group could be explained by the high levels of sulfates that adversely affect rumen microorganisms, reducing their number and activity (Umar *et al*., 2014). The reduction of sulfate to sulfide (S^{-2}) in the rumen and its absorption depends on a prior period of adaptation to the presence of sulfate in the ruminal environment. Sulfides that form of Ca, Cu and Mg precipitates in the rumen often lead to low digestion of feed DM. The high level of sulfate in non-desalinated water could have been the cause of diarrhea lasting about two weeks observed during the adjustment period. Once the cows on the high sulfate drinking water were adapted, their daily DMI increased. As a consequence of the lower DMI for cows using low-salt water, their milk yield efficiency was higher than the group that received high-salt content water but milk yield was the same.

Revelli *et al*. (2005) found that somatic cell count in milk was similar (336,000 *vs.* 312,000 cells mL^{-1}) for dairy cows consuming water with either a high or low TDS concentration; however, in this study cows in the NDW group had higher somatic cell count than in the DWO group (111%), suggesting an effect of drinking water quality on the dairy cows' immune response. Therefore, cows consuming desalinated water are expected to be healthier. This result is important not only because of a possible economic advantage of using desalinated drinking water but also because of improved welfare status of animals on desalinated drinking water.

There have been few studies on the risk of milk fat depression due to the quality of drinking water in dairy cows. Our study, however, indicates possible economic advantages to using desalinated water. Beede (2005) and Coria *et al*. (2007) mentioned that content of minerals in the diet and availability and quality of drinking water could affect the dilution ratio of feed in the rumen, decreasing fiber fermentation and some metabolite precursors of fat synthesis in milk. Milk fat depression syndrome is an increasing problem in Mexican dairy cattle herds and has caused economic losses, since this type of milk does not receive economic compensation from the national dairy processing industry.

In general, under the conditions of this study, no advantages of drinking water desalinated by a reverse osmosis technique were found for certain variables in lactating Holstein cows. Some of the results suggest that cattle can stabilize the electrolytic balance in body fluids; thus permitting cows can ingest moderate quantities of TDS in drinking water without substantially affecting their productive performance. However, some health and productive performance advantages were detected. Economic evaluation of the whole system is needed before implementing this desalination technique on a large scale.

High salinity in water is a frequent problem in arid and coastal areas of the world (Meybeck *et al*., 1996); therefore, the economic and biological impacts of drinking water desalination techniques need to be determined under specific scenarios of genotypes and environments, especially for animal systems under tropical or arid conditions.

Table 1. Ingredients used and chemical composition of the diet offered during the trial.

Item	Contents
Ingredient (% on a DM basis)	
Alfalfa fresh	16.7
Alfalfa hay	6.4
Corn silage	22.8
Concentrate mixture*	54.1
Chemical Composition (%)	
Crude protein	16.6
Rumen undegradable protein	32.4
Neutral detergent fiber	30.2
Acid detergent fiber	18.9
Calcium	0.8
Phosphorus	0.4
Net energy for lactation [&]	1.7

**Ingredients:* 28.7% rolled corn, 1.7% sugar cane molasses, 6.4% soybean meal, 9.4% cottonseed, 6.3% wheat bran, 0.9% Megalac® Rumen Bypass Fat (Church and Dwight Co., Inc. USA), 0.1% mineral premix, 0.1% vitamin premix, 0.5% calcium carbonate

[&]Expressed as Mcal kg^{-1} DM and estimated according to NRC (2001)

Table 2. Chemical composition of desalinated (DWO) and non-desalinated drinking water (NDW) used during the trial

	Treatment		
Component	DWO	NDW	NOM*
Total dissolved salts (ppm)	553.0	1,810.0	1,000
Carbonates (ppm, calcium + magnesium)	115.2	448.5	500
Chlorides (ppm)	242.6	136.5	250
Sulphates (ppm)	132.0	717.4	400
Nitrates (ppm)	11.1	26.5	10
Arsenic (ppm)	0.01	0.04	0.025
pH	7.4	8.3	6.5 to 8.5

**NOM* Mexican Official Norm-127SSA1-1996 (SSA, 2000)

Table 3. Means of several variables in dairy cows drinking desalinated (DWO) and non-desalinated (NDW) water during the first 15 weeks of lactation

Variable	Treatment		p>F
	DWO	NDW	
Body weight (kg)	731.7±7.9	696.9±8.1	0.0401
Body weight$^{0.75}$ (kg)	140.6±1.15	135.5±1.17	0.0415
Dry matter intake (DMI, kg cow^{-1} d^{-1})	24.3±0.57	26.7±0.60	0.0400
Milk yield (MY, kg cow^{-1} d^{-1})	40.8±1.7	38.6±1.8	0.1426
Milk fat (kg cow^{-1} d^{-1})	1.27±0.008	1.29±0.01	0.1235
Milk protein (kg cow^{-1} d^{-1})	1.16±0.03	1.11±0.04	0.1272
Lactose (kg cow^{-1} d^{-1})	1.87±0.09	1.89±0.08	0.2394
Milk urea nitrogen (mg dL^{-1})	11.2±0.31	10.7±0.33	0.2921
Milk yield efficiency*	1.70±0.063	1.45±0.061	0.0071
Somatic cell count[§]	136.3±61.3	288.1±63.3	0.0432

*Expressed as kg MY cow^{-1} d^{-1}/kg DMI cow^{-1} d^{-1}

[§]Number of cells $mL^{-1}\times 1000$

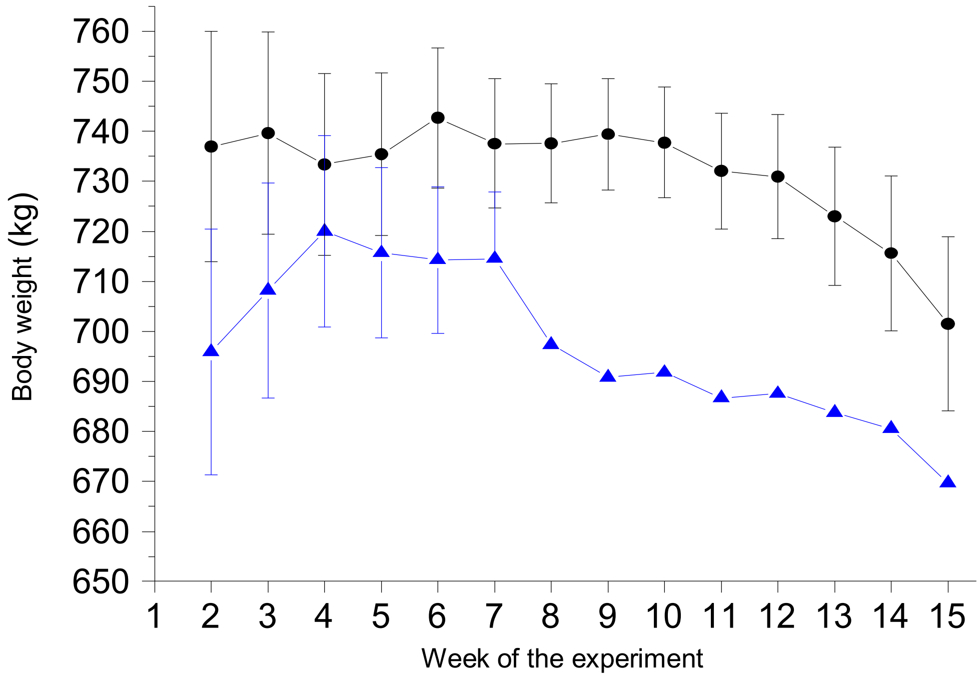

Figure 1. Least square means and standard errors of cow body weight by week of the experiment of Holstein cows drinking reverse osmosis-treated water (▲ DWO) or untreated plain water (● NDW) from the farm's deep well.

5. Conclusions

Desalination by reverse osmosis of water from a farm well reduced the contents of total dissolved salts, carbonates, sulfates, nitrates and arsenic. The continuous daily supply of desalinated drinking water improved the udder health and productive response of lactating Holstein cows in the studied semiarid region of Mexico. Holstein dairy cows that drank water with a low concentration of total dissolved salts had better milk yield efficiency, lower feed intake, lower somatic cell count, and lower risk of milk fat depression than those cows drinking untreated water from the farm's deep well.

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