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Importance of Water Quality in Small Ruminants' Productivity

Review Article

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ABSTRACT

Successful breeding and raising of sheep and goats depend on appropriate sanitary and nutritional management, where water plays a crucial role. Alterations in water quality and availability might lead to alterations in animal productivity. Small ruminants are capable of ingesting water in a wide range of qualities with little or no effect on health and performance, however; some elements and microorganisms present in high concentrations can produce a negative effect on health status and weight gain performance, being the quality of water, an essential factor affecting the profitability of small ruminant production. The effects on cattle's productive performance of compounds like total dissolved solids, sulfates, and sulfur in drinking water have been documented. However, there needs to be more information available on the effect on sheep and goats, being necessary to increase the efforts to carry out studies to evaluate the effect of the physicochemical and microbiological quality of drinking water on the health and productive performance of small ruminants. Water quality affects the efficiency of diet energy utilization in lambs. However, there is scares information about this topic to reevaluate the qualification of water as "well water". This review presents the effects of drinking water's different physicochemical and microbiological characteristics on the productivity of small ruminants. Also, it addresses water quality and its effect on productivity from an energy perspective.

KEY WORDS energetics, goats, health, production, sheep, water quality.

INTRODUCTION

The total water requirement of small ruminants is a complex process. It seeks to achieve a balance to ensure that the total water intake into the body (free drinking water, water in consumed feed, metabolic water resulting from nutrient degradation) is equivalent to the total water loss (water excreted in urine and feces, water secreted in milk, sweat, and respiratory vapor) (Ensminger *et al*. 1990; Beede, 2012). Water balance efficiency is a function of multiple factors such as body metabolism, environmental temperature, body surface area and mass, water quality, species, physiological state, production stages, breed, wool cover, and physicochemical composition of feed (NRC, 2007).

The parameters for evaluating water quality should include microbiological, physical, and chemical elements, as any other element that may directly or indirectly affect the health of animals. Water quality is defined by its elements; however, the effects can be modified when interacting with animals and food. Research has shown a positive relationship between access to potable water and growth performance factors such as feed intake and daily weight gain (Landefeld and Bettinger, 2005). However, the effects of water quality on the efficiency of dietary energy utilization are absent. It can be assumed that the water source's quality ultimately affects its acceptability by livestock and, in turn, affects feed intake and nutrient utilization (Fernández-Cirelli *et al*. 2010). Access to abundant and good-quality water supplies can improve livestock productivity (Quintuña and Faicán, 2019).

Water intake

Daily water intake in small ruminants varies from approximately 5 to 20% of their body weight (Schoeman and Visser, 1995). This variation is influenced by factors such as environmental temperature, feed, breed, age, and physiological stage (Olkowski, 2009; Whaley *et al.* 2022). Ehrlenbruch *et al.* (2010) reported that the type of forage affects the daily water intake of dairy goats since they have a significantly higher daily water intake when fed hay with 82.4% dry matter (DM) than silage with 25.3% DM (6.2 *vs.* 4.4 L/goat/day, respectively). On the other hand, Schoeman and Visse (1995) report that, within the same species, water consumption varies among breeds, mentioning that, of the Black-headed Persian, Dorper, and South African Merino sheep breeds, the Persian is the most efficient in terms of metabolic water utilization, since the Dorper and Merino can consume, respectively, up to 53% and 77% more water per kg of body weight gain compared to the Persian.

Although water intake may vary by different factors, Forbes (1968), used dry matter intake (DMI) to predict water consumption through the following equation: Water intake (L/day)= 3.86 × DMI - 0.99. This equation has been widely tested and corroborated as a practical and accurate method for predicting the water intake of small ruminants (NRC, 2007).

Effect of water intake on feed intake

Under environmental comfort conditions, the amount of water voluntarily consumed by ruminants is considered twice the proportion of DMI. This ratio increases when animals are fed diets with high-protein or high-salt (Akinmoladun *et al.* 2019) or very dry or dusty feeds (NRC, 2007). This case is related to their water reserve system, which can store and use water for the ruminants when environmental conditions demand it. When water availability is gradually reduced from 100% to 40% of ad libitum intake, DMI has decreased by 31 and 44% in Katahdin lambs, 22 and 34% in Boer goats, and 19 and 35% in Spanish goats (Mengistu *et al.* 2016).

Physicochemical and biological quality of drinking water

Water quality is a term used to describe water's chemical, physical and biological properties. Water quality depends mainly on its intended use. In the case of drinking water for animals, the properties that water must have to qualify as safe drinking water are stipulated. It is based on those consumed by animals that do not hurt their productivity and health (Olkowski, 2009).

The water-leading properties for animal productivity and animal health

Temperature

Under favorable climatic conditions, water temperature has little or no effect on water intake, although being more preferably water with temperatures between 17 and 28 ˚C (Herrera, 2012). A study performed by Petersen *et al.* (2016) suggests that at a critical low-ambient temperature (i.e., -10 ˚C), cows increased 30% water consumption when water temperature was warm instead of cold. Nevertheless, water temperature did not affect nutrient digestion in any case.

pH

Water's pH measures the concentration of hydrogen ions and controls the solubility and concentrations of elements in water (Morgan, 2011). The pH value of drinking water can vary from 6 to 8 (Olkowski, 2009). The effects of these pH values on livestock health and production are poorly understood. The main problem of pH alteration in drinking water is related to the acceptability of drinking water, as animals may refuse to drink water with extreme pH (<5 and 9<). Acidic water which has a pH of less than 5 tends to have a sour taste. In contrast, a water with pH greater than 9 has a metallic taste (Raisbeck *et al.* 2008). Slightly alkaline water (pH 7-7.3) is considered optimal for consumption. Water that has a pH out of the normal limits has corrosive effects on pipes and installations and possible adverse effects on health and animal production (Tuells and Erviti, 2016). For example, consuming of water with a pH below five can reduce feed intake, contributing to metabolic acidosis (Olkowski, 2009; Curran, 2014). Because such water slightly acidifies the diet, it is not recommended for especially feedlot animals. In contrast, alkaline water with a pH above 9 can increase the risk of metabolic alkalosis, lead to digestive disorders, poor feed conversion, and reduce feed and water intake (Mahdy *et al.* 2016).

Total dissolved solids (salinity)

Among the most critical factors determining water suitability for livestock is the concentration of salts in the drinking water (Marín, 2022). Salinity can be measured as Total Dissolved solids (TDS) and is expressed in parts per million (ppm) (which is equivalent to mg/L or mg /mL); the constituents associated with salinity are bicarbonate ($NaHCO_3$), sulfate ($SO4_2$), and silica (SiO_2), and a group of lower concentrations of constituents including iron (Fe), nitrate (NO3-), strontium (Sr), potassium (K), carbonate (CO32-), phosphorus (P), boron (B), and fluoride (NaF) (Bagley *et al.* 1997). The main disadvantage of supplying salt water to livestock is related to acceptance problems due to lower acceptability of water, or the behavioral response of animals to protect themselves from salt stress which, as a consequence, causes a reduction in water intake per unit body weight (Lopez *et al.* 2016; Sharma *et al.* 2017) which causes a decrease in dry matter (and energy) intake. However, it has been reported that the salinity of drinking water does not influence feed intake in ruminants with TDS levels below 1% (1000 ppm) (Masters *et al.* 2007; Tsukahara *et al.* 2016; Cervantes-Noriega *et al.* 2022) (Table 1).

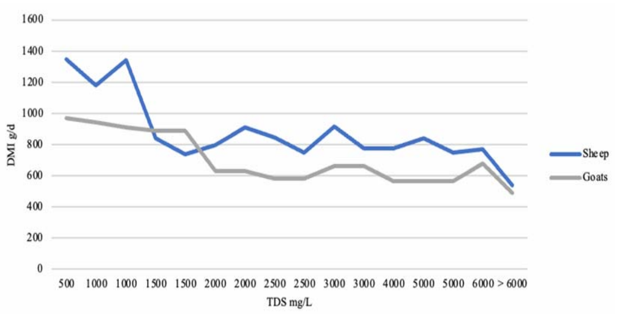

Figure 1 Behavior of dry matter intake (DMI), according to the concentration of TDS in drinking water

Safety limits for TDS are unclear and vary among species. Different publications have recommended maximum levels (Bagley *et al.* 1997; Lardy *et al.* 2008; Olkowski, 2009). Different studies have established that goats are more tolerant to high drinking water TDS concentrations than lambs. According to the above, McGregor (2004) mentions that young sheep can consume water with 5000 mg/L TDS without adversely affecting their productivity, while young goats can consume up to 7000 mg/L, a notably higher level. As for adult animals, he mentions that both species can tolerate twice as much TDS as young animals; adult goats can take up to 14000 mg/L TDS, while adult sheep have 10000 mg/L. Accordingly, Castro *et al.* (2017) found no effect of supplementing up to 8300 mg/L TDS in drinking water on slaughter weight, hot and cold carcass weight, and carcass traits in adult Santa Inés lambs. However, there are contradictions about the maximum limit of TDS consistently affecting productivity in small ruminants. Hussein *et al.* (2020) reported reductions in carcass yield in adult Ossimi lambs consuming 15000 mg/L TDS (Table 2). However, Mdletshe *et al.* (2017) report a decrease in daily weight gain of 16.2% of adult Nguni goats when they drank only 5500 mg/L TDS. On the other hand, Assad and El-Sherif (2002) observed more significant daily weight gain in lambs that drank water with 13535 mg/L TDS than those that drank fresh water. Nevertheless, this may be attributed not precisely drinking water with a high salt content had more water retention throughout the body rather than to more significant muscle mass gain (Table 3).

Sulphates

Sulfate is the most common form of sulfur (S) in drinking water for livestock, but in some water sources, due to the highly reducing environment, sulfate can be reduced to sulfide (Olkowski, 2009); sulfur makes up one-third of the molecular weight of sulfate (Umar *et al.* 2014). Hydrogen sulfide is the most common form of sulfur present in water, giving it the characteristic odor associated with "rotten eggs," which, for non-adapted animals, can be a significant restriction (APHIS and USDA, 2000). Water's sulfate also contributes to total sulfate in the ration and should be considered when investigating outbreaks of polioencephalomalacia in the feedlot. Polioencephalomalacia is a diagnostic term describing necrosis of the brain's gray matter (Niles, 2017), characterized by neuromuscular disturbances in animals (Umar *et al.* 2014). This disease can occur when total sulfate in the ration exceeds 1% on a dry matter basis (Carson, 2000). In ruminants, almost all ingested sulfate is reduced to sulfide by rumen microbes, absorbed, and sequentially oxidized to sulfite and sulfate in tissues. Sulfate is recycled into the rumen via saliva (Olkowski, 2009). High sulfate concentrations have been reported to negatively affect ruminal microorganisms, decreasing their number and, consequently, the total microbial metabolic activity (Loneragan *et al.* 2001; Patterson and Johnson, 2003). They also interfere with the intestinal absorption of other minerals, such as copper (Irisk, 2012). A study by Loneragan *et al.* (2001) reported a linear decrease in average daily weight gain in ruminants as the sulfate concentration in the drinking water increased from 136 to 2360 mg/L.

Nitrates and nitrites

Nitrate ion (NO_3) is both a product and a reactant in the chain of animal and plant nitrogen metabolism (Pereira and Ramirez, 2021). Their presence in water is associated with contamination from decomposing organic matter, aquatic plants, algae, fish, or other dead animals in water reservoirs, and soil fertilizers (Bolaños-Alfaro *et al.* 2017). Reducing nitrate to nitrite in the rumen is required against intoxication problems because nitrite is approximately ten times more toxic than nitrate. Once nitrite passes into the bloodstream, it reacts with hemoglobin and thus drastically reduces the oxygen-carrying capacity of erythrocytes, resulting in a condition called methemoglobinemia (Wang *et al.* 2021). Symptoms of this case are characterized by muscle weakness, ataxia, tremors, hypersensitivity and difficulty breathing, as well as abortions and deaths (Trheebilcock-and Montoya, 2018). Nitrate toxicity or safety is determined by many factors, including the amount of nitrate consumed daily, the animal's previous exposure to high nitrate levels, feeding practices, nutrition quality and general health.

Table 1 Hot carcass weight (kg) and hot carcass yield (%) of sheep with different concentrations of total dissolved solids (TDS)

TDS, mg/L	Final weight, kg	Hot carcass weight, kg	Hot carcass yield, %	Author
< 1000	44.8	19.7	44	Hussein *et al.* (2020)
< 1000	23.4	9.3	40	Yousfi *et al*. (2016)
< 1000	37.0	20.3	55	De Almeida *et al*. (2021)
< 1000	27.2	12.4	46	Castro *et al*. (2017)
< 1000	56.2	33.6	60	Cervantes-Noriega *et al.* (2022)
1000	54.1	31.8	59	Cervantes-Noriega *et al.* (2022)
1500	34.7	14.9	43	Hussein *et al.* (2020)
2500	23.6	9.2	39	Yousfi *et al*. (2016)
3200	25.2	11.8	47	Castro *et al*. (2017)
5800	27.8	12.7	46	Castro *et al*. (2017)
8000	23.1	9.4	40	Yousfi *et al*. (2016)
8300	26.5	12.2	46	Castro *et al*. (2017)

Table 2 Average daily gain (ADG, g/d) of sheep with different concentrations of total dissolved solids (TDS)

TDS, mg/L	ADG g/d	Author
< 1000	260.0	Cervantes-Noriega *et al.* (2022)
< 1000	110.0	De Albuquerque *et al*. (2020)
< 1000	156.0	De Araújo *et al*. (2019)
1000	239.0	Cervantes-Noriega *et al.* (2022)
1000	128.6	Wilson *et al*. (1966)
1500	171.4	Wilson *et al*. (1966)
2000	177.0	De Matos *et al*. (2021)
2000	162.0	De Matos *et al*. (2021)
3000	153.0	De Araújo *et al*. (2019)
6000	120.0	De Albuquerque *et al*. (2020)
8500	100.0	De Albuquerque *et al*. (2020)
8500	75.0	Castro *et al*. (2017)
> 10000	25.0	Assad and El-Sherif (2002)
> 10000	24.0	Hussein *et al.* (2020)

Therefore, not only the nitrate concentration of water should be considered, but food and other sources as well. Anyway, total nitrates concentrations up to 1g/L of water did not cause adverse effect in healthy lambs fed balanced diet (Undersander *et al*. 2016).

Chlorides

Chlorides are the most common form of chlorine in water; they can be present in various chemical forms naturally or when added during water treatment (Olkowski, 2009). Chlorides are generally sodium, magnesium, calcium, and potassium, which give water a bitter taste and can cause diarrhea (Cajape, 2021). The estimates of the adverse effects of chloride in the water itself are assumptions because chloride in water under normal circumstances is generally associated with sodium. Sodium chloride (NaCl) or common salt confers a salty taste to water. It is the most beneficial combination of chlorides as a nutrient since it stimulates consumption and favors food digestion. However, in excess, it limits water consumption (Walker, 2021).

Microorganisms

Water can be an important reservoir and route of transmission for microorganisms. Although most of these microorganisms are harmless, some can cause health problems in livestock and be transmitted to humans (Carrasco-Letelier *et al.* 2016; Meehan *et al.* 2021). Among these microorganisms, we can find bacteria (e.g., *Salmonella* spp., *Vibrio cholera*, *Leptospira* spp., *Clostridium* spp., and *Escherichia coli*), viruses (rotavirus, some coronaviruses, etc.) and protozoan parasites (*Cryptosporidium* spp. and *Giardia* spp.) (McAllister and Topp, 2012). Microorganisms, unlike physical and chemical parameters that only show the punctual situations at the time the sample was taken, reflect the changes that have occurred in a water resource over time and constitute an indicator of the degradation of water bodies (Pullés, 2014; Ríos-Tobón *et al.* 2017). Exposure of grazing animals to pathogens in their drinking water sources has been reported to pose a health risk and may compromise livestock productivity. Lewerin *et al.* (2019) reported using hydrological and hydrodynamic modeling that exposure of grazing cattle to pathogens such as *E. coli*, *Salmonella*, and *Cryptosporidium* in their water source poses a risk to both livestock and human health, as cattle can be reservoirs and disseminators of these types of enteric pathogens. In the regard to the presence of enteric bacteria in drinking water sources for cattle, LeJeune *et al.* (2001) sampled 473 cattle water troughs, from which they isolated *Salmonella* spp. in 0.8% and *E. coli* 0157 in 1.3% of the troughs, mentioning that the level of contamination by *E. coli* increased as the distance between the troughs and the feeders decreased, and as the exposure of the drinking water to sunlight decreased. Likewise, other studies have reported the detection of *E. coli* O157 in livestock water sources, including ponds, free-flowing water such as streams, and water tanks (Van Donkersgoed *et al.* 2001; Shere *et al.* 2002; Renter *et al.* 2003). However, these studies do not evaluate the effects of the presence and consumption of these bacteria in drinking water on health status and productivity of livestock, so there is a necessity for increased efforts to assess the health risk of exposing livestock to pathogenic microorganisms in their drinking water sources. In this way, Cervantes-Noriega *et al.* (2022) conducted a study where they evaluated the effects on health and productivity of sheep that drank water without the detectable presence of bacteria and sheep that drank water with 93 MPN/ml of total coliforms, 47 MPN/mL of fecal coliforms and 43 MPN/ml of *E. coli*. These authors report an 8% increase in daily weight gain, a 3% improvement in dietary energy utilization, and a 33% decrease in diarrhea in sheep that drank water with no bacteria present.

Calcium and magnesium (hardness)

Hardness measures the concentration of divalent (positively charged) metal cations dissolved in water. It is generally expressed as the sum of calcium and magnesium concentrations expressed as calcium carbonate equivalents; it is considered a global indicator of mineralization (Higgins and Agouridis, 2008). Other cations such as zinc, strontium, iron, aluminum, and manganese also contribute to hardness but are generally present in lower concentrations (German *et al.* 2008).

Some authors do not recommend the consumption of 'hard' water since it can increase the risk of urinary tract disorders, such as urolithiasis. They mention that animals should not drink this type of water since it increases the content of mineral salts in the urine, causing saturation of these salts, causing them to precipitate and allowing the creation of crystals that adhere to each other when they are not dissolved, increasing the growth of uroliths (Carrillo-Díaz *et al.* 2015; Matto *et al.* 2015; Ramírez *et al.* 2020).

Water quality and dietary energy utilization

Most of the reports that study the effect of water quality on animal productivity is focused on the relationship gain-to-feed ratio. However, this ratio does not explain in a precise manner the efficiency with which of the diet energy is utilized, due to confounding effects of ADG and DMI (Andreini *et al.* 2020). Another approach to measure the efficiency of diet energy utilization by animals is the observed-to expected dietary net energy which is important and practical applications of current standards for energetics in nutrition research (Zinn *et al.* 2008; Estrada-Angulo *et al.* 2013). The estimation of dietary net energy (NE) based on measures of growth-performance and the ratio of apparent energy retention per unit DMI reveal differences in the efficiency of energy utilization of the diet itself, independently of confounding effects of average daily gain (ADG) and DMI associated with gain efficiency measures (gain-to-feed ratios). Thus, it provides important insight into potential treatment (or environmental) effects on the efficiency of energy utilization (Urías-Estrada *et al.* 2021). An observed-to-expected dietary NE ratio of 1.00 indicates that performance is consistent with dietary NE values based on tables of feedstuff standards and observed DMI. A ratio that is greater than 1.00 is indicative of greater efficiency of dietary energy utilization. Whereas, a ratio that is lower than 1.00 indicates lower than expected efficiency of energy utilization (Castro-Pérez *et al.* 2022). It is important to highlight that the prediction equations are accurate as long as the energy content of the diets is greater than 1.80 Mcal of net energy for maintenance (range ≥1.80<2.30 Mcal NEm/kg diet; Urías *et al.* 2021). Therefore, with diets with lower energy content, this approach is not valid. There is very little information about the effect of water quality on efficiency of energy utilization of diet. Taken growth performance data of Loneragan *et al.* (2001) from feedlot cattle (consumed a diet with 2.18 Mcal NEm/kg) drinking water contained high sulfur concentration (2,360 mg/L) showed a lower 5.3% lower efficiency of energy utilization when compared with cattle that receive water with low sulfur concentration (136 mg/L). Similarly, Zinn *et al.* (1997) reported a diminished efficiency on energy utilization of diet (2.26 Mcal NEm/kg diet) by 7% when cattle consumed sulfur at a rate of 0.25% of DM intake. The impact on energy utilization when comparing “well water” (1933 SO_4 mg/L) with filtered water (reverse osmosis, 608 SO_4 mg/L) was less in feedlot cattle. In this sense, cattle that were offered filtered water showed only 1.2% greater efficiency on dietary energy utilization (1.003 *vs*. 0.991). Regarding feedlot lambs, no information about efficiency of energy utilization is available.

Furthermore, the literature available does not permit this type of estimation because the diets offered in these experiments are below of 1.80 Mcal NEm/kg diet. A recent study (Cervantes-Noriega *et al*. 2022) evaluated well water (WW, 776 mg/L TDS and CFU=93/mL) vs the same well water filtered and sanitized (FILT, 256 TDS, non-detectable UCF) in feedlot lambs fattening during 89 days with a high-energy diet (1.98 Mcal NEm/kg diet). Lamb drinks FILT showed an increase of 3% of dietary energy utilization (1.02 *vs*. 0.99) and reduced 33% diarrhea frequency. In the same way, FILT increased 5.3% carcass weight and 9.2% longissimus muscle area. Those authors concluded that reduction of total solids at minimum and the elimination of bacterial load promote a better energy utilization which is reflected in improvements in growth and in some traits of the carcass. It is necessary for further research to quantify the effects of water quality on the efficiency utilization of diet energy. For that, the recommendation of net energy concentration in diets should be greater than 1.80 Mcal/kg in those experiments.

CONCLUSION

Water is an essential nutrient, often disregarded since it is consumed in large quantities. Poor quality water increases the risk that its contaminants reach a level that can harm health. Therefore, the quality and availability of drinking water should be evaluated as a possible cause of inefficient productive performance and non-specific diseases in livestock. Efforts to assess water quality must include obtaining a complete history, considering existing standards, and recommending allowable limits for livestock drinking water quality. The general recommendation is that each livestock farm must carry out a physicochemical and microbiological characterization of its drinking water and thus take the appropriate actions to offer drinking water with the quality characteristics that allow the animals, according to their zootechnical purpose, to express their full potential. It is necessary for further research to quantify the effects of water quality on the efficiency utilization of diet energy. For that, the recommendation of net energy concentration in diets should be greater than 1.80 Mcal/kg in those experiments.

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