Livestock Science 159 (2014) 133–140

Contents lists available at ScienceDirect

Livestock Science

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

Water and concentrate intake, weight gain and duration of diarrhea in young suckling calves on different diets

J. Wenge [a], I. Steinhöfel [b], C. Heinrich [b], M. Coenen [a], L. Bachmann [a,*]

[a] Institute for Animal Nutrition, Nutrition Diseases and Dietetics, Faculty of Veterinary Medicine, Universität Leipzig, Leipzig, Germany
[b] Köllitsch, Farm for Teaching and Research of the Department of Animal Production of the Saxon State Office for Environment, Agriculture and Geology, Köllitsch, Germany

ARTICLE INFO

Article history:
Received 25 April 2013
Received in revised form
3 November 2013
Accepted 8 November 2013

Keywords:
Calf
Water intake
Drinking
Oral rehydration
Diarrhea

ABSTRACT

Diarrheic calves are fed with milk or milk replacer and oral rehydration solutions (ORS) to ensure energy and electrolyte supply. An easy and time-saving method is the preparation of ORS in milk. As milk-based ORS are hypertonic solutions administration of them may trigger thirst. Therefore, we hypothesized that restrictively fed calves receiving ORS prepared in milk had a higher water intake than restrictively and *ad libitum* fed calves receiving ORS prepared in water during diarrheic episodes.

The daily water intake was measured in 100 individually-housed Holstein Friesian calves from day 2 to 21 of life. One group of the calves was fed with restrictive amounts of milk, the other group got milk *ad libitum* by an automated milk feeder. Nearly all calves spontaneously developed diarrhea within the observation period from day 2 to 21 of life. In cases of diarrhea the restrictively-fed calves received ORS prepared in milk or ORS prepared in water two hours after their milk meal, whereas the *ad libitum*-fed calves only got ORS prepared in water. All calves had *ad libitum* access to water. The daily intake of water, milk, and ORS and weight gain during diarrheic episode were determined. Data were expressed as arithmetic means ($\pm$ standard deviation) and analyzed by using a one-way ANOVA or repeated-measures ANOVA.

From day 2 to 21 of life calves fed with restrictive amounts of milk had higher water intakes related to the total dry matter intake (DMI) with 1.6 L/kg of total DMI than *ad libitum*-fed calves (0.9 L/kg of total DMI) per day. In cases of diarrhea water intake increased in all feeding groups. The calves receiving milk-based ORS had the highest water intake with 1.7 L/d during the period of diarrhea compared to the calves received ORS prepared in water. Moreover, the calves fed ORS in milk showed with 4.6 L/d the highest daily ORS intake. There were no differences in the duration of diarrhea or the daily weight gain during period of diarrhea between the feeding regimens. Therefore, it can be concluded that all feeding regimens were suitable in the treatment of calf diarrhea. The simplest method to treat calves suffering from diarrhea is the preparation of ORS in milk, but then *ad libitum* availability of water is absolutely necessary. Moreover, calves drink considerable amounts of water within the first 3 weeks of life and therefore should be provided with water for animal welfare reasons.

1. Introduction

Few studies deal with the water intake of calves (Jenny et al., 1978; Kertz et al., 1984; Hepola et al., 2008). According to the German enactment of animal welfare

* Corresponding author. Tel.: +49 341 9738373; fax: +49 341 9738399.
E-mail addresses: wenge.julia@web.de (J. Wenge), ilka.steinhoefel@smul.sachsen.de (I. Steinhöfel), christian.heinrich@smul.sachsen.de (C. Heinrich), coenen@vetmed.uni-leipzig.de (M. Coenen), bachmann@vetmed.uni-leipzig.de, fridamin@gmx.de (L. Bachmann).

1871-1413/$ - see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.livsci.2013.11.004

and farming of animals that is called “Tierschutz-Nutztierhaltungsverordnung” (TierschNutztV, 2006) calves over 2 weeks of age have to be allowed *ad libitum* access to water. Prior to this age they must supply their daily need for fluid through the intake of milk or milk replacer (**MR**). Considering the feeding practice of calves there are differences in the water intake between *ad libitum*-fed and restrictively-fed calves. Calves fed MR *ad libitum* drank only 0.45 kg water per day until weaning at the age of 5 weeks (Richard et al., 1988). Whereas animals fed restrictive volumes of MR had a daily water intake of more than 1.0 kg within the first 3 weeks of life (Kertz et al., 1984).

Calf diarrhea especially occurs in the first weeks of life (Azizzadeh et al., 2012) and is associated with fecal losses of water and electrolytes that leads to an isotonic or hypotonic dehydration in diarrheic calves. Hyponatremia is the most common abnormality in blood chemistry in these calves (Dalton et al., 1965). The treatment of calf diarrhea is based on the administration of oral rehydration solutions **(ORS)** for diarrheic calves with a sufficient suckle reflex. In addition to ORS treatment, they should receive their milk meal which is necessary to maintain energy supply (Heath et al., 1989). Preparing ORS in milk or MR is an easy way for farmers to provide diarrheic calves with electrolytes without adverse effects (Bachmann et al., 2009; Goodell et al., 2012). Such milk–ORS-mixtures are hypertonic, and administering them should cause thirst. Therefore, calves receiving milk–ORS have to have *ad libitum* access to water to adjust their hydration status (Bachmann et al., 2012). In a previous study the daily water intake increased 25 to 50% when calves developed diarrhea (Jenny et al., 1978). A similar result was noted by Kertz et al. (1984). In this study calves with *ad libitum* access to water gained more body weight and ingested more calf starter. Currently no study exists which considers the influence of feeding hypertonic ORS on the water intake of diarrheic calves.

The objectives of the present study were to examine the influences of different milk feeding regimens (*ad libitum* and restrictive) on the water, concentrate and milk intake of calves up to 3 weeks of age. Moreover, the influence of 3 different treatment/feeding regimens while diarrheic disease of the calves up to 3 weeks of age on the water, concentrate, milk and ORS intake as well as daily weight gain and duration of diarrhea were determined. The 3 treatment/ feeding regimens during calf diarrhea were *ad libitum* milk feeding plus ORS prepared in water (**milk a.l.+water–ORS**), restrictive milk feeding plus ORS prepared in water (**water–ORS**) and restrictive milk feeding with ORS prepared in the milk (**milk–ORS**).

2. Materials and methods

Experiments were approved by federal authorities for animal research (Landesdirektion Leipzig, Germany) and conducted in accordance with the principles of the German Animal Welfare Act.

2.1. Animals

Water, milk and concentrate intake was measured in 100 calves (54 male and 46 female) from day 2 to 21 of life, born at Köllitsch, Germany, (the farm for teaching and research of the Department of Animal Production of the Saxon State Office for Environment, Agriculture and Geology) from April through September 2012. 92 calves were of Holstein-Friesian breed and 8 were crossbreeding of Holstein-Friesian × Belgian Blue-White. Diarrhea occurred in 98 of these calves. Calves were removed from the study when diseases other than diarrhea occurred such as omphalitis, pneumonia and arthritis with disturbed general condition. This accounted for only 2 calves. The diarrheic period of each calf was determined by its fecal consistency whereas a soupy or watery fecal consistency was classified as having diarrhea. The period of diarrhea was finished when the feces had a pulpy or pasty consistency again. Within the period of diarrhea, data for ORS intake, weight gain and duration of diarrhea were gathered for 81 of the 98 diarrheic calves. These 81 datasets were used for the analysis of diarrheic calves during the period of diarrhea. The calves had *ad libitum* access to water and were provided with hay and concentrate feed.

2.2. Experimental design

Within 30 min after birth each calf was separated from its dam, weighted, moved to an individual calf box with straw bedding where it was randomly assigned to the restrictive milk feeding regimen or the *ad libitum* milk feeding regimen.

The restrictive milk feeding group received 2 L of milk 3 times a day (0700, 1600, 2200 h) via nipple bucket and the other group received milk *ad libitum* at a nipple-feeding station by an automated milk-feeder. Independent of the feeding group, all calves were fed at least 2 L of colostrum from a bottle within 2 h of birth and 2 L at the next usual feeding time.

Experiments started the day after birth. Each morning each calf received a bucket with 5 L of fresh water in its box which was weighted before and again after 24 h. To calculate the evaporation of water from the bucket an additional one was placed in the middle of the area where the newborn calves were housed and also weighted every 24 h. The daily water intake of a calf was calculated by the difference in weight of the bucket of each calf minus evaporation. Each calf also received a bowl with concentrate that was composed in equal parts of a pelleted concentrate (88% dry matter content, 20% crude protein; Kälbersegen 50 16-F, Basu Mineralfutter GmbH, Germany) and crushed barley (proportion of 1:1). The amount of concentrate intake was also determined daily.

Every morning the rectal temperature and the fecal consistency (scored from 1 to 4 where 1 = pasty; 2 = pulpy; 3 = soupy; 4 = watery; Groutides and Michell, 1990) of each calf was recorded. Calves with fecal consistency 3 or 4 were classified as having diarrhea. The animals were weighted and a fecal sample was collected and analyzed microscopically for *Cryptosporidium* oocysts according to Heine (1982). Additionally a quick test (Fassisi®BioDa,

Table 1
Feeding regimes of the calves during diarrheic episode.

Feeding regimes	Feeding time					
	Morning (0700)	Midmorning (0900)	Afternoon (1600)	Evening (1800)	Night (2200)	Midnight (2400)
Milk–ORS[a]	2 L Milk+ORS	–	2 L Milk+ORS	–	2 L Milk+ORS	–
Water–ORS	2 L Milk	ORS in 2 L water	2 L Milk	ORS in 2 L water	2 L Milk	ORS in 2 L water
Milk a.l.[b]+water–ORS	Milk *ad libitum* ORS in 2 L water		ORS in 2 L water		ORS in 2 L water	

[a] Oral rehydration solution.
[b] Milk *ad libitum*.

sandwich-immunoassay) was used to detect *rota* and *corona virus, E. coli* (K99) and *Cryptosporidium parvum*. In the case of diarrhea, the restrictively-fed calves were randomly assigned to one of the following oral rehydration treatments: one group received ORS (Lytafit®, Albrecht GmbH, Aulendorf, Germany) prepared in 2 L milk **(milk–ORS)** 3 times a day (30 calves) and the other group got ORS prepared in 2 L water **(water–ORS)** 2 h after feeding of the milk meal 3 times a day (26 calves). The *ad libitum*-fed calves received ORS prepared in 2 L water **(milk a.l.+ water–ORS)** 3 times a day in addition to *ad libitum* milk administration (25 calves) (Table 1). The daily intake of water, milk, ORS and general condition were recorded. When the feces had a consistency of 1 or 2 the calves were weighted again and the ORS-feeding was discontinued. During the study there was a high level of care by the examiner. When the calves had not ingested their milk meals they were encouraged to drink by leading them to the nipple. When diarrhea occurred the examiner accustomed the calves to the bucket containing water–ORS. They had to learn that there was water–ORS available.

2.3. Measurements and analyses

The term " total fluid" that will appear in the following text is defined as the sum of water and milk intake (milk dry matter content was subtracted) and for the calves which received ORS prepared in water in case of diarrhea additionally the volume of water used for preparing ORS (ORS–water). The period of diarrhea is an individual period of each calf from the beginning of diarrheic disease (the first diarrheic day) to the end. Diarrhea is associated with watery or soupy feces. ORS intake refers to the intake of the commercial product Lytafit® (Albrecht) that contained according to the manufacturer's data glucose, sodium bicarbonate, sodium chloride, lactose, potassium chloride, calcium chloride, magnesium chloride and glycine. The application of Lytafit® (Albrecht) was in portions of 75 g dissolved in 2 L water or 2 L milk dependent on the feeding group. The total electrolyte intake was determined by the sum of sodium $[Na^+]$, potassium $[K^+]$ and chloride $[Cl^-]$ ions contained in milk and ORS. The milk used was a mixture of raw milk from in-house cows considered to be in mid-lactation. Osmolality, $[Na^+]$, $[K^+]$, $[Cl^-]$ and energy content were estimated or calculated according to the specifications of the manufacturer of the ORS, according to Gaucheron (2005) for milk electrolytes and to Kamphues et al. (2009) for the energy content of milk, respectively (Table 2). The energy intake arises from the sum of energy contained in the ingested milk, ORS and concentrates. The term "total dry matter intake" (total DMI) is defined as the sum of the dry matter intake (DMI) of milk and concentrate ingested by the calves and in case of diarrheic treatment additionally the DMI of the ORS.

Table 2
$[Na^+]$, $[K^+]$, $[Cl^-]$, osmolality and energy content of milk, water-based oral rehydration solution (ORS) and milk-based ORS.

Feeding regimes	$[Na^+]$ (mmol/L)	$[K^+]$ (mmol/L)	$[Cl^-]$ (mmol/L)	Osmolality (mOsm/L)	Energy content (MJ/L)
Milk	25[a]	40[a]	30[a]	290	2.57[b]
Water–ORS	81[c]	13[c]	45[c]	365	0.52[c]
Milk–ORS	106[a,c]	53[a,c]	75[a,c]	655	3.09[b,c]

[a] Gaucheron (2005).
[b] Kamphues et al. (2009).
[c] Manufacturer's information (Albrecht GmbH, Aulendorf, Germany).

2.4. Statistical analyses

Data were expressed as arithmetic means (+/− standard deviation) and analyzed by using a one-way ANOVA or repeated-measures ANOVA. LSD-test was used for posthoc analysis and *P*-values were adjusted to Benjamini and Hochberg (1995) procedure. One-way ANOVA was used for analysis of mean values per day *i.e.* water, concentrate, milk and dry matter intake within the observation period, as well as intakes of water, milk, ORS, total fluid, dry matter, total electrolytes, $[Na^+]$, $[K^+]$, $[Cl^-]$ and energy and weight gain during diarrheic disease. Duration of diarrhea of the different treatment groups was also analyzed using one-way ANOVA. Repeated-measures ANOVA were used for analyzing the effects of time, feeding regimen and time × feeding regimen on daily measured parameters, *i.e.* water, concentrate and milk intake. For the parameters that offered statistically significant effects of time or feeding regimen an LSD-test was used to detect differences within or between the feeding regimens. For statistical analysis, the software STATISTICA (version 7, StatSoft GmbH, Hamburg, Germany) was used.

3. Results

3.1. Water, concentrates, milk and dry matter intake within the observation period

The water intake of calves increased with age ($P<0.01$). Calves also showed great individual differences in the water intakes from the beginning of the trial on day 2 of life (Fig. 1). Overall, restrictively-fed calves had higher mean water intakes over the course of the study (1.1 L/d) than *ad libitum*-fed calves (0.8 L/d; $P<0.05$). However, repeated-measures ANOVA did not reveal any significant differences between the groups at any day throughout the observation period ($P>0.05$). According to the ambient temperature water intake increased with rising temperature (data not shown).

In the first 21 days of life *ad libitum*-fed calves ingested 10 g and the restrictively-fed calves 13 g of concentrate per day ($P=0.40$). In the first 7 days of life the calves had only daily intakes of 5 g in the restrictively-fed and 3 g in the *ad libitum*-fed group, respectively. At the end of the trial, when the calves were 3 weeks old, they had concentrate intakes of 55 g for the restrictive and 20 g for the *ad libitum* group, respectively (Fig. 2). There were no statistically significant differences between the restrictive and *ad libitum* group during the observation period.

The milk intake during the first week of life (before diarrhea) was significantly different between the restrictively-fed and *ad libitum*-fed calves with 5.6 L *versus* 9.5 L/d ($P<0.01$).

The ratio of daily water intake to total DMI was 1.6 L/kg of total DMI for the restrictively-fed and 0.9 L/kg for the *ad libitum*-fed calves from day 2 to 21 of life ($P<0.01$). Considering the total fluid there was a ratio of daily total fluid intake of 8.4 L/kg of total DMI for the restrictive group and 7.7 L/kg of total DMI for the *ad libitum* group, respectively ($P<0.01$).

3.2. Milk, water, fluid and dry matter intake during diarrhea

The milk intake decreased in all feeding regimens after the appearance of diarrhea that was measured on an individual basis of each calf distinguished by soupy or watery feces. Compared with the mean daily milk intakes during the 4 days before diarrhea the calves that received milk–ORS showed a significant reduction of milk intake only on the second diarrheic day ($P<0.05$). The water–ORS group had a significantly lower milk intake from the second to the fourth diarrheic day ($P<0.01$) and the milk a.l.+water–ORS group had lower intake from day 1 to 6 of diarrhea ($P<0.01$). On the first day of diarrhea there was a drop in milk intake of 10.2 L before diarrhea to 6.6 L in the milk a.l.+water–ORS group. From day 4 to 7 of diarrhea their intake increased. However, at day 5 and 6 of diarrhea the milk intake was still statistically significant different from the pre-diarrheia period ($P<0.01$, Fig. 3). The *ad libitum*-fed calves had significantly higher daily milk intakes (10.2 L/d) during the 4 days before diarrhea than the restrictively-fed groups (5.8 L/d) and also significantly higher milk intakes on the seventh day of diarrhea than the water–ORS calves ($P<0.05$; Fig. 3). The mean daily milk intake over the diarrheic period was higher for the milk a.l.+water–ORS calves compared to the milk–ORS calves and the water–ORS group ($P<0.01$; Table 3).

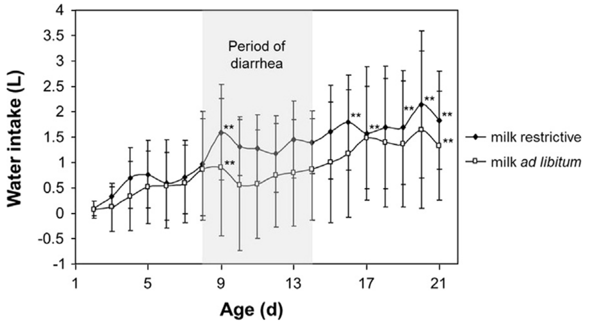

Fig. 1. Water intake (arithmetic mean ± standard deviation) of calves during the observation period from the second to the 21st day of life divided into the restrictive and *ad libitum* milk feeding regimens. The area shaded in gray shows the period of diarrhea which usually began on the eighth day of life and lasted 5+/−2 d. Asterisks (**) indicate statistically significant differences from the mean value of water intake of day 2 and 3 of life (P time < 0.01, P treatment > 0.01; P time × treatment > 0.01).

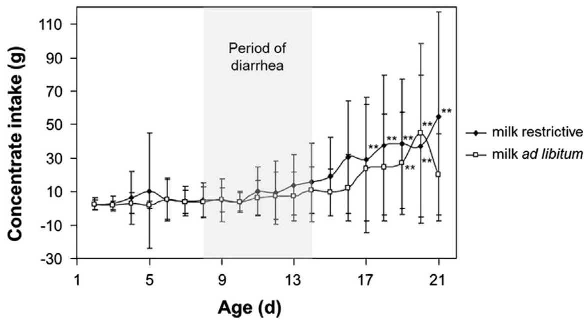

Fig. 2. Concentrate intake (arithmetic mean ± standard deviation) of calves during the observation period from the second to the 21st day of life divided into the restrictive and *ad libitum* milk feeding regimens. The area shaded in gray shows the period of diarrhea which usually began on the eighth day of life and lasted 5+/−2 d. Asterisks (**) indicate statistically significant differences from the mean value of the concentrate intake of day 2 and 3 of life (P time < 0.01, P treatment > 0.01; P time × treatment > 0.01).

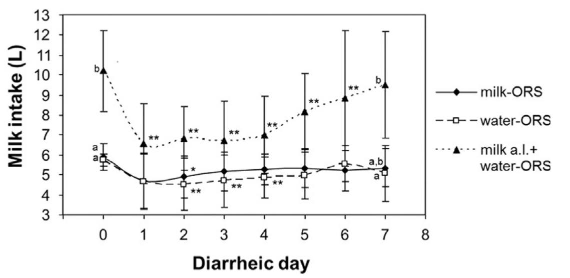

Fig. 3. Milk intake (arithmetic mean +/− standard deviation) before (0 = arithmetic mean of the daily milk intake during the four days before the occurrence of diarrhea) and during the diarrheic period of the milk–ORS, water–ORS and milk a.l.+water–ORS feeding regimens. ORS = oral rehydration solution. milk a.l. = milk *ad libitum*. Asterisks (*, **) indicate statistically significant differences from baseline (*$P<0.05$; **$P<0.01$). Lowercase letters indicate statistically significant differences between the feeding regimens.

Table 3
Duration of diarrhea, daily milk, oral rehydration solution (ORS), total electrolyte[a], water, total fluid[b], energy intake[c] and weight gain (means ± standard deviation) during diarrheic period of the milk–ORS, water–ORS and milk a.l. + water–ORS (milk *ad libitum* + water–ORS) feeding regimes.

	Feeding regimes			*P* Feeding regime
	Milk–ORS 30	**Water–ORS** 26	**Milk a.l. + water–ORS** 25	
Duration of diarrhea (d)	5.00 ± 1.39	5.650 ± 2.23	4.680 ± 1.63	0.14
Milk intake (L)	$5.06^{a}0 \pm 1.07$	$4.80^{a}0 \pm 1.26$	$7.15^{b}0 \pm 2.13$	< 0.01
ORS intake (L)	$4.57^{a}0 \pm 1.40$	$3.15^{b}0 \pm 1.98$	$1.99^{c}0 \pm 2.06$	< 0.01
Total electrolyte intake (mmol/L)	$1116^{a}0 \pm 272$	$887^{b}0 \pm 319$	$958^{b}0 \pm 321$	< 0.01
Water intake (L)	$1.72^{a}0 \pm 1.19$	$0.95^{b}0 \pm 0.96$	$0.63^{b}0 \pm 0.73$	< 0.01
Total fluid intake (L)	$6.63^{a}0 \pm 1.74$	$8.84^{b}0 \pm 2.48$	$9.69^{b}0 \pm 2.89$	< 0.01
Energy intake (MJ)	$15.4^{a}0 \pm 3.3$	$13.9^{a}0 \pm 3.5$	$19.4^{b}0 \pm 5.4$	< 0.01
Weight gain (g)	6580 ± 324	4740 ± 265	5870 ± 390	0.15

Lowercase letters indicate statistically significant differences between the feeding regimes.
Faults discovered adjusted *P*-values.
[a] Total electrolyte intake = $[Na^+]+[K^+]+[Cl^-]$ of ingested milk and ORS.
[b] Total fluid intake = water + milk + ORS–water.
[c] Energy intake = energy of ingested milk + ORS.

After the beginning of diarrhea the water intake in all feeding regimens increased. The largest increase was seen in the milk–ORS regimen. The ratio of daily water intake to total DMI in the milk–ORS group increased from 0.8 L/kg to 2.3 L/kg from before diarrhea to day 1 of diarrhea with a decrease of the daily total DMI from 0.8 kg to 0.7 kg. The modest increase of water intake was noticed in the milk a.l. + water–ORS group (0.3 L) but the ratio of daily water intake to total DMI increased statistically significant from 0.4 L/kg to 0.9 L/kg on the first diarrheic day ($P = 0.01$). The daily total fluid intake (water + ORS–water + milk) in the diarrheic period was the greatest for the milk a.l. + water–ORS calves followed by the water–ORS calves. The ratio of daily total fluid intake to total DMI was 7.6 L/kg for the milk a.l. + water–ORS group and 11.2 L/kg for the water–ORS group ($P < 0.01$). The milk–ORS group had a total daily fluid intake of 6.0 L ($P < 0.01$; Table 3) with a ratio of daily total fluid intake to total DMI of 7.2 L/kg in the period of diarrhea. In all feeding groups there was an increase of the total fluid intake over the period of diarrhea.

3.3. Electrolyte and energy supply during diarrhea

The daily ORS intake offered during the period of diarrhea was significantly higher for calves fed milk–ORS followed by the water–ORS group ($P < 0.01$; Table 3). Moreover, the milk–ORS group ingested the highest total electrolyte amount ($[Na^+]+[K^+]+[Cl^-]$) per day. The second highest daily total electrolyte intake was observed in the milk a.l. + water–ORS calves despite the lowest ORS intake but the highest milk intake of all groups (Table 3). Due to ORS administration during the period of diarrhea the total electrolyte intake increased in all groups from 677 mmol/d before diarrhea to 992 mmol/d ($P < 0.01$). On closer examination of the electrolytes it was apparent that there were differences between the groups in the ingested amounts of $[Na^+]$, $[K^+]$ and $[Cl^-]$. The milk–ORS calves had the highest $[Na^+]$ (494 mmol/d) and $[Cl^-]$ (355 mmol/d) intakes while the milk a.l. + water–ORS group had the highest $[K^+]$ intake with 312 mmol/d ($P < 0.01$). The energy intake decreased in all feeding regimens after the appearance of diarrhea. On the first diarrheic day the milk a.l. + water–ORS group had a drop in daily energy intake of 26.2 MJ before diarrhea to 17.3 MJ. Thereafter, the milk intake of the milk a.l. + water–ORS calves rose continuously and if diarrhea still occurred on the seventh day the calves reached energy intakes as before the disease. The milk–ORS calves took in 15.9 MJ energy per day from the third diarrheic day compared to 15.2 MJ/d before the beginning of diarrhea ($P > 0.05$). The energy intake of the water–ORS group was decreased over the diarrheic period to the intake before without statistical significance. The milk a.l. + water–ORS calves had a higher daily energy intake over the diarrheic period compared with the other groups ($P < 0.01$; Table 3).

3.4. Diarrhea and weight gain

Ninety-eight of the calves developed diarrhea within the observation period. Nearly all animals were tested positive for *Cryptosporidium parvum*. However, 3 calves were additionally positive for *rota virus*. Only 1 calf had no evidence of a pathogen. Diarrhea usually started on the eighth day of life without any significant differences between the feeding regimens. No calf died due to diarrhea. The mean duration of diarrhea was between 4.7 d (milk a.l. + water–ORS; with a range of 3 to 8 d), 5.0 d (milk–ORS; with a range of 3 to 12 d) and 5.7 d (water–ORS; with a range of 2 to 8 d) with no statistically significant effects of the feeding regimens. The daily weight gains during the period of diarrhea were also not statistically significantly different between the feeding regimens (Table 3).

4. Discussion

There are studies concluding that water intake for restrictively-fed calves is low until weaning (0.17 kg/d, de Passillé et al., 2011), whereas others measured considerable intakes of water (1 kg/d) (Jenny et al., 1978; Kertz et al., 1984). In the present study restrictively-fed calves drank 1.1 L water per day within the first 3 weeks of life. We do not think that the water intake of young calves can be ignored, as even heavier ruminating adult goats have only a daily water intake of 2.4 L (Bøe et al., 2011). In studies in which calves were fed acidified MR *ad libitum* they drank smaller amounts of water (0.4 kg/d) (Richard et al., 1988; Hepola et al., 2008). The *ad libitum*-fed calves in the present study had twice higher mean daily water intakes within the observation period. Restrictively-fed calves have to fulfill their fluid requirements that exceed the available daily amount of milk with an increased water intake. Furthermore, restrictively-fed animals maybe have higher water intakes due to hunger. The missing satiety of calves fed low volumes of milk was expressed in other trials by considerably more visits to the milk feeder without receiving milk compared to calves fed large volumes of milk (Borderas et al., 2009; de Passillé et al., 2011). It was suggested 30 years ago that calves benefit from the provision of water early in life through improved performance (Thickett et al., 1981). However, *ad libitum* water access for young calves in Europe is often still not realized at dairy farms because legislation dictates *ad libitum* water access only for calves older than 2 weeks of life.

In the study of Jenny et al. (1978) water intake increased 25 to 50% when calves had diarrhea, whereas Kertz et al. (1984) noticed only minor effects. The increased water intake in the present study from day 8 (0.9 L) to day 9 (1.4 L) of life is related to the occurrence of diarrhea, usually beginning on the eighth day of life. Due to increased losses of fluid via feces the calves had a greater need of water to prevent dehydration. More than a threefold increase of the mean daily water intake (0.5 to 1.7 L/d) was recorded in the milk–ORS calves during the period of diarrhea. They ingested a hypertonic solution that might increase plasma osmolality, an effect which causes thirst by dehydration of brain osmoreceptors (Thornton, 2010).

Usually great individual differences between the water intakes of young calves were noticed (Jenny et al., 1978; Thickett et al., 1981; Kertz et al., 1984). This underlines that it is not acceptable to specify an age limit from which calves have to have *ad libitum* water access. Calves should be familiarized with water intake before the beginning of diarrhea (Bachmann et al., 2012) that occurs usually in the first weeks of life (Jasper and Weary, 2002). The Swiss animal welfare act states that calves have to have water access anytime (TSchV, 2008).

Concentrate intake remained low during the observation period (12 g/d) especially within the first 10 days of life (4 g/d; Fig. 2). Similar results were ascertained before (Kertz et al., 1984; Borderas et al., 2009). In the study of Kertz et al. (1984) the water intake of calves in their first days of life is high relative to their concentrate intake due to the low concentrate intake of young calves. The results of the present trial confirm the data of Kertz et al. (1984). Therefore, water intake is not only induced by concentrate intake. That intake of concentrate follows water intake and not *vice versa* was also determined in recent studies (Richard et al., 1988). From day 11 to 21 of life low-fed calves daily consume 22 g concentrates *versus* 16 g/d of calves fed higher amounts of milk, an effect which was statistically not significant. Calves may try to compensate for the low energy sustenance through lower milk intake and higher concentrate intakes. However, this mechanism may not succeed in the first weeks of age because of incomplete rumen development (Borderas et al., 2009; de Passillé et al., 2011). Concentrate intakes are reduced according to high milk intakes. Calves prefer milk to concentrates and, if possible, satisfy their energy requirement with milk intake (de Passillé et al., 2011).

The ratio of daily total fluid intake to total DMI within the observation period was 8.4 L/kg of total DMI for the restrictive group and 7.7 L/kg of total DMI for the *ad libitum* group, respectively. Calves in our trial ingested the principal amount of the total fluid (80%) as well as of the total DMI (96%) with their daily milk intake. The ratio of daily water intake to total DMI was 1.6 L/kg of total DMI for the restrictively-fed and 0.9 L/kg of total DMI for the *ad libitum*-fed calves from day 2 to 21 of life. Quigley et al. (2006) determined a higher ratio of water intake to total DMI with approximately 2 L/kg of total DMI before weaning. In studies with heifers and lactating dairy cows the ratio of daily water intake to DMI was about 4 L/kg DMI. After weaning cattle ingest food with higher dry matter contents than in milk or MR and have to fulfill their fluid requirements by water intake (Kramer et al., 2009; Lascano and Heinrichs, 2011).

The milk intake of calves decreased in the period of diarrhea in all feeding regimens which may be due to a reduced appetite (Garthwaite et al., 1994). However, the milk a.l.+water–ORS calves had with 7.2 L/d higher milk intakes than the milk–ORS (5.1 L/d) and water–ORS calves (4.8 L/d) in the period of diarrhea. Appleby et al. (2001) ascertained that in calves fed higher amounts of milk the days with diarrhea were reduced and this might be caused due to higher resistance towards pathogens induced by better nutrition. The duration of diarrhea was not different between the feeding regimens in our trial. Despite the lowest ORS intake of 2.0 L/d, the milk a.l.+water–ORS calves had daily total electrolyte intakes of 958 mmol and total fluid intakes of 8.8 L/d during the period of diarrhea that could compensate the fluid and electrolyte losses caused by diarrhea. The milk–ORS group had the highest daily ORS intake (4.6 L). The calves of the milk–ORS group were already used to drink the milk meal, while the other groups had to learn water–ORS intake. Therefore, the calves fed milk–ORS had the highest [Cl^-], [Na^+] and total daily electrolyte intakes (1116 mmol). Diarrhea is distinguished by a decrease in extracellular fluid volume and a negative sodium and potassium balance (Dalton et al., 1965). Clinically diarrheic calves are often dehydrated due to the reduction of total body water (Thornton and English, 1978). Jones et al. (1984) determined a trend towards increasing plasma osmolality after the administration of a hyperosmotic ORS to diarrheic calves. This results in the stimulation of thirst, increased water intake and increased fluid absorption from the gastrointestinal tract, followed by rehydration.

The daily weight gain during the period of diarrhea was not statistically different between feeding regimens although the milk a.l.+water–ORS calves had significantly higher energy intake (19.5 MJ/d). Therefore, contrary to our expectations the milk a.l. + water–ORS calves gained only 587 g/d. The water–ORS group descriptively had the lowest daily milk, energy and total electrolyte intake. This resulted in mean daily weight gains of 474 g during the diarrheic period. Comparatively, the milk–ORS group had a daily weight gain of 658 g with a daily energy intake of 15.5 MJ. The milk–ORS calves ingested 15% of their energy via ORS intake. Compared to this, the milk a.l. + water–ORS group received energy mainly by milk and only 5% came from ORS intake. The ORS contained glucose as a fast available energy source and amino acids that are directly absorbed from the small intestine, whereas milk contains lactose and proteins which have to be hydrolyzed before the adsorption by the enzyme lactase into glucose and galactose or by peptidases into tri- and di-peptides, respectively (Hartmann, 2002). An infection with *Cryptosporidium* species leads to villous atrophy and crypt hyperplasia mainly in the jejunum and ileum (Heine et al., 1984). There are depressed levels of enzyme activities caused by mucosal damage that affect digestion and absorption (Tzipori et al., 1982). Diarrheic calves have a reduced activity of the leucyl aminopeptidases, an enzyme that splits the peptides of alimentary proteins in the intestinal lumen (Krautzig et al., 1986). Dargel and Hartmann (1984) determined that the activity of lactase in the small intestine in diarrheic calves is decreased by half compared to healthy contemporary calves. A reduced enzymatic activity resulted in a lower digestibility of milk ingredients and a greater fecal excretion of undigested nutrients. The milk–ORS group had [Na^+] intakes of 106 mmol/L that corresponds to the recommendation that an oral rehydration therapy solution should have [Na^+] of 90–130 mmol/L (Constable et al., 2009). High [Na^+] contents are necessary to reduce the negative sodium balance in the diarrheic calves. The used ORS contains higher amounts of [Na^+] than milk (Table 2). Additionally the transport of glucose and amino acids from the gut lumen into the enterocytes of the small intestine is mainly mediated via a Na^+-dependent co-transport system (Souba and Pacitti, 1992; Hartmann, 2002). The intake of electrolytes and organic solutes into enterocytes increases the osmotic pressure. Consecutively water follows and may lead to a higher body weight (Krautzig et al., 1986). Probably the water–ORS group had a worse absorption of nutrients due to low ORS intakes and the time lag between the milk and ORS feeding that results in high [Na^+] availability when nutrients are low and *vice versa*. The force for the absorption of [Na^+] is driven by a concentration gradient between extra- and intracellular space. This gradient is sustained by the Na^+/K^+-ATPase that is not impaired in young diarrheic animals (Krautzig et al., 1986). The ingredients of ORS may be absorbed to a higher extent compared to milk because they do not have to be hydrolyzed and provide high amounts of Na^+ available for the absorption via Na^+-dependent co-transport systems.

However, it also might be that the results concerning the weight gains of the feeding regimens are random appearances. There were no statistical significances and great individual differences in weight gains. Moreover, we did neither determine absorption of nutrients, dry matter content of feces nor urine excretion. Therefore, our assertions are speculative and further examinations have to be conducted.

5. Conclusions

All feeding regimens used in this study were suitable in the treatment of calf diarrhea. The simplest method to treat calves suffering from diarrhea is the preparation of ORS in milk, but then *ad libitum* availability of water is strictly required. Moreover, restrictively-fed calves and even *ad libitum*-fed calves drink considerable amounts of water within the first 3 weeks of life and therefore, should be provided with water for animal welfare reasons.

Conflict of interest

None.

Acknowledgements

This project was financially supported by DFG (Bonn, Germany). The authors thank the Department of Animal Production of the Saxon State Office for Environment, Agriculture and Geology in Köllitsch (Germany) under the direction of Mr. Bergfeld and the farm for teaching and research in Köllitsch (Germany) under the direction of Mr. Kunze and its employees who were involved in the realization of the experiments. Moreover, the authors thank Mr. Dangschat, English instructor and Dr. Elizabeth L. Williams, medical doctor for the linguistic revision of the manuscript.

References

Appleby, M.C., Weary, D.M., Chua, B., 2001. Performance and feeding behaviour of calves on *ad libitum* milk from artificial teats. Appl. Anim. Behav. Sci. 74, 191–201.

Azizzadeh, M., Shooroki, H.F., Kamalabadi, A.S., Stevenson, M.A., 2012. Factors affecting calf mortality in Iranian Holstein dairy herds. Prev. Vet. Med. 104, 335–340.

Bachmann, L., Homeier, T., Arlt, S., Brueckner, M., Rawel, H., Deiner, C., Hartmann, H., 2009. Influence of different oral rehydration solutions on abomasal conditions and the acid-base status of suckling calves. J. Dairy Sci. 92 (4), 1649–1659.

Bachmann, L., Schmidt, B., Rauwolf, U., Wenge, J., Coenen, M., 2012. Change of plasma volume, osmolality, and acid-base status in healthy calves after feeding of milk and water- and milk-based oral rehydration solutions. J. Dairy Sci 95 (10), 1–9.

Benjamini, Y., Hochberg, Y., 1995. Controlling the false discovery rate: a practical and powerful approach to multiple testing. J. R. Stat. Soc. Ser. B Stat. Methodol 57 (1), 289–300.

Borderas, T.F., de Passillé, A.M.B., Rushen, J., 2009. Feeding behaviour of calves fed small or large amounts of milk. J. Dairy Sci. 92 (6), 2843–2852.

Bøe, K.E., Ehrlenbruch, R., Andersen, I.L., 2011. The preference for water nipples vs. water bowls in dairy goats. Acta Vet. Scand. 53, 50.

Constable, P.D., Grünberg, W., Carstensen, L., 2009. Comparative effects of two oral rehydration solutions on milk clotting, abomasal luminal pH, and abomasal emptying rate in suckling calves. J. Dairy Sci 92 (1), 296–312.

Dalton, R.G., Fisher, E.W., McIntyre, W.I., 1965. Changes in blood chemistry body weight and haematocrit of calves affected with neonatal diarrhoea. Br. Vet. J. 121 (1), 34–41.

Dargel, D., Hartmann, H., 1984. Die Aktivität der β-Galaktosidase im Darmkanal von klinisch gesunden und durchfallkranken Kälbern sowie Ferkeln. Monatsh. Veterinarmed 39, 742–745.

de Passillé, A.M., Borderas, T.F., Rushen, J., 2011. Weaning age of calves fed a high milk allowance by automated feeders: effects on feed, water, and energy intake, behavioural signs of hunger, and weight gains. J. Dairy Sci 94 (3), 1401–1408.
Garthwaite, B.D., Drackley, J.K., McCoy, G.C., Jaster, E.H., 1994. Whole milk and oral rehydration solution for calves with diarrhea of spontaneous origin. J. Dairy Sci. 77 (3), 835–843.
Gaucheron, F., 2005. The minerals of milk. Reprod. Nutr. Dev. 45, 473–483.
Goodell, G.M., Campbell, J., Hoejvang-Nielsen, L., Stansen, W., Constable, P.D., 2012. An alkalinizing oral rehydration solution containing lecithin-coated citrus fiber is superior to a nonalkalinizing solution in treating 360 calves with naturally acquired diarrhea. J. Dairy Sci 95 (11), 6677–6686.
Groutides, C.P., Michell, A.R., 1990. Intravenous solutions for fluid therapy in calf diarrhoea. Res. Vet. Sci. 49, 292–297.
Hartmann, H., 2002. Gastrointestinale Funktionen beim durchfallkranken Kalb und wirksamer Einsatz von Diättränken. Tierarztl. Prax. Ausg G Grosstiere Nutztiere 30, 201–206.
Heath, S.E., Naylor, J.M., Guedo, B.L., Petrie, L., Rousseaux, C.G., Radostits, O.M., 1989. The effects of feeding milk to diarrheic calves supplemented with oral electrolytes. Can. J. Vet. Res. 53 (4), 477–485.
Heine, J., 1982. Eine einfache Nachweismethode für Kryptosporidien im Kot. Zentralbl. Veterinaermed. B 29, 324–327.
Heine, J., Pohlenz, J.F.L., Moon, H.W., Woode, G.N., 1984. Enteric lesions and diarrhea in gnotobiotic calves monoinfected with *Cryptosporidium* species. J. Infect. Dis. 150 (5), 768–775.
Hepola, H.P., Hänninen, L.T., Raussi, S.M., Pursiainen, P.A., Aarnikoivu, A.-M., Saloniemi, H.S., 2008. Effects of providing water from a bucket or a nipple on the performance and behavior of calves fed *ad libitum* volumes of acidified milk replacer. J. Dairy Sci. 91 (4), 1486–1496.
Jasper, J., Weary, D.M., 2002. Effects of *ad libitum* milk intake on dairy calves. J. Dairy Sci. 85 (11), 3054–3058.
Jenny, B.F., Mills, S.E., Johnston, W.E., O´Dell, G.D., 1978. Effect of fluid intake and dry matter concentration on scours and water intake in calves fed once daily. J. Dairy Sci. 61, 765–770.
Jones, R., Phillips, R.W., Cleek, J.L., 1984. Hyperosmotic oral replacement fluid for diarrheic calves. J. Am. Vet. Med. Assoc. 184 (12), 1501–1505.
Kamphues, J., Coenen, M., Iben, C., Kienzle, E., Pallauf, J., Simon, O., Wanner, M., Zentek, J., 2009. Supplemente zu Vorlesungen und Übungen. In: der Tierernährung. (Ed.), , M.&H. Schaper, Hannover. Germany, pp. 99.
Kertz, A.F., Reutzel, L.F., Mahoney, J.H., 1984. *Ad libitum* water intake by neonatal calves and its relationship to calf starter intake, weight gain, feces score, and season. J. Dairy Sci. 67 (12), 2964–2969.
Kramer, E., Stamer, E., Spilke, J., Thaller, G., Krieter, J., 2009. Analysis of water intake and dry matter intake using different lactation curve models. J. Dairy Sci. 92 (8), 4072–4081.
Krautzig, I., Dargel, D., Hartmann, H., Milnik, H., 1986. Zum Verhalten einiger Enzymaktivitäten im Darmkanal von klinisch gesunden und durchfallkranken Kälbern sowie Ferkeln. Monatsh. Veterinarmed 41, 520–523.
Lascano, G.J., Heinrichs, A.J., 2011. Effects of feeding different levels of dietary fiber through the addition of corn stover on nutrient utilization of diary heifers precision-fed high and low concentrate diets. J. Dairy Sci 94 (6), 3025–3036.
Quigley, J.D., Wolfe, T.A., Elsasser, T.H., 2006. Effects of additional milk replacer feeding on calf health, growth, and selected blood metabolites in calves. J. Dairy Sci. 89 (1), 207–216.
Richard, A.L., Heinrichs, A.J., Muller, L.D., 1988. Feeding acidified milk replacer *ad libitum* to calves housed in group *versus* individual pens. J. Dairy Sci. 71 (8), 2203–2209.
Souba, W.W., Pacitti, A.J., 1992. How amino acids get into cells: mechanisma, models, menus, and mediators. J. Parenter. Enteral Nutr 16 (6), 569–578.
TSchV (Tierschutzverordnung). 2008. Art. 37 Feeding. Schweizerischer Bundesrat. Switzerland.
Thickett, W.S., Cuthbert, N.H., Brigstocke, T.D.A., Lindeman, M.A., Wilson, P.N., 1981. The management of calves on an early-weaning system: the relationship of voluntary water intake to dry feed intake and live-weight gain to 5 weeks. Anim. Prod. 33, 25–30.
Thornton, J.R., English, P.B., 1978. Body water of calves: change in distribution with diarrhoea. Br. Vet. J. 134 (5), 445–453.
Thornton, S.N., 2010. Thirst and hydration: physiology and consequences of dysfunction. Physiol. Behav. 100 (1), 15–21.
TierschNutztV (Tierschutznutztierhaltungsverordnung). 2006. §11 Monitoring, Caring and Feeding of Calves. Bundesjustizministerium Germany.
Tzipori, S., Angus, K.W., Campbell, I., Gray, E.W., 1982. Experimental infection of lambs with *Cryptosporidium* isolated from a human patient with diarrhoea. Gut 23, 71–74.