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Liquid feeding does not suppress drinking motivation in heavy pigs

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ABSTRACT

The experiment aimed to obtain information on the water requirements, drinking behavior and drinking motivation of liquid-fed pigs and was conducted during the hot season. Eighty castrated male pigs (initial body weight: 36 kg) fed a liquid diet (water:feed ratio of 3:1), capable of guaranteeing the fulfilment of the theoretical water requirements, were assigned to two experimental groups either receiving drinking water via nipple drinkers (CON, Control) or having non-functioning drinkers available (RW, Restricted Water). The availability of extra water did not affect the pigs' growth parameters (ADG - average daily gain, DMI -dry matter intake and FCR -feed conversion ratio) nor the quality of the carcasses and meat, including the sensory properties of hams cured over 18 months. Similarly, no significant differences were found in the lesions detected in the body and stomach surfaces and the neutrophils to lymphocytes ratio. Also, general behavior was not modified by the treatment except for the percentage of observed time spent drinking, which was significantly higher in the CON pigs (0.42 vs 0.21%; $P<0.01$) and resulted in a greater water consumption (13.54 vs. 7.39 l/day; $P<0.01$) that increased sharply as animal age and environmental temperature increased. Additionally, even though their drinkers did not dispense water, the animals in the RW group maintained some motivation to use the drinkers throughout the trial. The apparent lack of effect of prolonged water rationing on most of the parameters observed and, on the other hand, the evident impact of fresh water supply on drinking behaviour warrant more specific measurements applicable to farm conditions that may help identify animals suffering from prolonged thirst.

1. Introduction

Water has often been referred to as "the forgotten nutrient" since it has received much less attention than any other nutrient, and its requirements for pigs are not as well understood as those for other nutrients (Brooks and Carpenter, 1990). To date, information regarding water requirements for all productive categories, strategies to optimize water delivery (drinker type, water flux etc.) and pen design (e.g., drinker location, ratios of pigs to drinkers) are still limited (Azarpajouh et al., 2018). Improving knowledge on the water requirements of swine would make it possible to optimize water use by reducing water wastage and raising the level of animal welfare

Abbreviations: ADG, average daily gain; BW, body weight; CON, control; DM, dry matter; DMI, dry matter intake; FCR, feed conversion ratio; LD, Longissimus dorsi; N:L, neutrophils to lymphocytes ratio; PDO, Protected Designation of Origin; RW, restricted water; SM, Semimembranosus; WI, water intake.

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by properly fulfilling a fundamental need. Furthermore, precise information on pigs' water needs and drinking behavior could allow a more accurate administration of those drugs and additives that must be delivered through drinkable water, avoiding over- and under-dosages leading to animal health issues, economic waste and, in some cases, environmental spillage and contamination.

As a result of prolonged thirst, pigs experience craving or urgent need for water, accompanied by a negative affective state, eventually leading to dehydration as metabolic requirements are unmet. Insufficient water intake will also cause reduced feed intake. The preventive measures to ensure adequate and continuous access to water of appropriate quality guarantee that drinkers work correctly and are clean and easily reachable (EFSA AHAW Panel, 2022).

The EU legislation on the protection of pigs (EC, 2008) states that "all pigs over two weeks of age must have permanent access to a sufficient quantity of freshwater". In 2021, the Italian Ministry of Health further clarified that no derogation is possible to this disposition, regardless of the feeding system (MinSal, 2021), strengthening the prohibition of the malpractice to provide water only with feed (especially when animals are fed on a liquid diet), or to leave it accessible only for a limited period of time in order to reduce water waste.

There are two main reasons why it is difficult to establish a daily water allotment with the certainty that it will satisfy the water requirements of all individuals: first, water needs can vary considerably depending on the animal's physiological state, rearing environment, season and diet. Secondly, a consumption-based estimate may not be accurate due to inevitable waste (Nannoni et al., 2013). Waste can be due to drinker type (Tavares et al., 2014), leaking drinkers, pigs' explorative behavior, stereotypies, incidental activation, etc. (Little et al., 2022). Therefore, accurate water needs can be estimated only with a multidisciplinary approach including physiological, pathological, productive and behavioral indicators, along with water consumption data.

As in other countries, liquid feeding is a common technique in Italian heavy pig production, and feed is mixed with water or whey, with a water-to-feed ratio of about 3:1 or 3.5:1 (Vitali et al., 2021). Theoretically, liquid-fed pigs should not require an additional source of water given that their water requirements are satisfied through the daily allotment of liquid feed, and this is assumed to be the case with the traditional 3:1 water-to-feed ratio (Mavromichalis, 2006). However, both Vermeer et al. (2009) and Nannoni et al. (2013) showed that wet-fed pigs are still motivated to obtain additional fresh water from drinkers, even during the cold season (October to February) (Nannoni et al., 2013). It should also be considered that individual differences between pigs in a pen may result in uneven distribution of the water provided by the liquid feed, leading to some pigs being unable to meet their water requirements

Table 1
Ingredient and chemical composition of the diets used during the trial (all values are expressed as g/kg).

Phase Days of trial	35–60 kg 1–35	60–110 kg 36–91	110–170 kg 92–187
Ingredients			
Corn	414.5	468.7	472.0
Barley	180.0	200.0	200.0
Soybean meal 440 g CP/kg	180.0	130.0	75.0
Wheat bran	140.0	125.0	125.0
Cane molasses	15.0	10.0	10.0
Sunflower meal	33.4	33.0	60.0
Sugar beet pulp	-	-	30.0
Calcium carbonate	20.0	15.0	15.0
Dicalcium phosphate	3.0	4.0	3.0
Sodium chloride	3.0	3.0	3.0
Sodium bicarbonate	1.0	1.0	1.0
Lysine	2.4	4.0	2.0
Methionine	0.9	0.6	-
Threonine	0.8	0.4	-
Phytase	1.0	1.0	1.0
Mineral-Vitamin Premix[a]	5.0	4.3	3.0
Chemical composition			
Dry matter	899.1	897.2	898.3
Crude protein (CP)	168.2	146.4	137.2
Lysine[b]	10.6	9.41	8.41
Ether extract	40.9	50.2	56.3
Neutral detergent fiber (NDF)	135.4	138.7	136.2
Acid detergent fiber (ADF)	46.3	47.2	48.0
Ash	46.2	49.5	42.3
Calcium[b]	11.3	9.5	9.5
Phosphorus[b]	6.9	6.0	6.0
Digestible energy (DE)[b], kcal/kg	3215	3200	3250

[a] Contents per kg of diet: 30–60 kg: 14750 I.U. vit A; 1500 I.U. vit D3; 16.5 mg vit E; 1.79 mg vit K; 3.13 mg vit B1; 10.84 mg vit B2; 62.5 mg niacin; 8.97 mg vit B6; 75 μg vit B12; 675 mg choline chloride; 29.44 mg calcium D-pantothenic acid; 4.5 mg folic acid; 50 mg Zn; 250 mg Fe; 15 mg Cu. 60–110 kg: 12685 I.U. vit A; 1290 I.U. vit D3; 14.19 mg vit E; 1.54 mg vit K; 2.70 mg vit B1; 9.32 mg vit B2; 53.75 mg niacin; 7.71 mg vit B6; 64.5 μg vit B12; 580.5 mg choline chloride; 25.32 mg calcium D-pantothenic acid; 3.87 mg folic acid; 43 mg Zn; 215 mg Fe; 12.9 mg Cu. 110–170 kg: 8850 I.U. vit A; 900 I.U. vit D3; 9.9 mg vit E; 1.07 mg vit K; 1.88 mg vit B1; 6.50 mg vit B2; 37.5 mg niacin; 5.38 mg vit B6; 45 μg vit B12; 405 mg choline chloride; 17.66 mg calcium D-pantothenic acid; 2.7 mg folic acid; 30 mg Zn; 150 mg Fe; 9 mg Cu.

[b] = the superscript indicates calculated parameters, all other parameters were analyzed

(Meunier-Salaün et al., 2017).

The present study, conducted under controlled experimental conditions during the hot season (March to September), aimed to gain insights into the water requirements of liquid-fed pigs provided or not with an additional supply of fresh water made available through drinking nipples. We hypothesized that animals experiencing water restriction would show a worsening in their health and welfare parameters (assessed through animal-based measures) and that this could negatively affect also growth parameters, meat and ham quality. The main production parameters of these animals (including the quality of the meat and hams) and some welfare indicators were collected and analyzed. Furthermore, the motivation of liquid-fed pigs to obtain additional water was studied through the provision of non-functioning nipple drinkers.

2. Material and methods

The experiment was carried out in the facilities of the Department of Veterinary Medicine (DIMEVET) of the University of Bologna (Ozzano Emilia, Italy). The experimental protocol was approved by the Ethical Committee of the University of Bologna, Italy (Authorization 725_3587_1).

2.1. Animals, housing and feeding

Eighty hybrid (PIC Camborough × Goland C21) castrated male pigs with an initial average body weight (BW) of 36±4.03 kg (75 days old) were used. Pigs were kept in collective pens (16 replications of 5 animals per pen, 8 replications per treatment) on a totally slatted floor with a size of 2.20 × 3.20 m that, excluding the space occupied by the trough feeder (2.20 × 0.35 m), guaranteed a floor space per head of 1.20 m^2 per pig. Each pen was equipped with a nipple drinker (that was initially installed at the height of the animal' withers -about 45 cm- and then monthly adapted to follow the growth of the animals, up to a final level of 75 cm above the floor) and a collective stainless feeder (allowing access to all animals at the same time). Hanging chains and softwood (poplar) were assembled on farm and provided as environmental enrichment materials. Pens were located in rooms equipped with a forced-air ventilation system. Pigs received 12 hours of artificial light (60 lux) every day (from 8 am to 8 pm), supplied by neon tubes. According to the guidelines for Parma Ham production (Consortium for Parma Ham, 1992), they were slaughtered at an average BW of approximately 170 kg after a 15-hour fast. In order to meet the pigs' requirements, three commercial feed formulations based on corn and soybean meal were used (Table 1).

Pigs were liquid-fed at 9% of their metabolic BW ($BW^{0.75}$) up to a maximum of 3.1 kg of dry feed (i.e., 12.4 kg liquid feed) per pig, divided into two meals (8:30 am and 3:30 pm). The liquid feed was prepared by mixing weighed amounts of feed (the same for both groups) and drinking water (from the aqueduct) in a manual liquid feeding preparation and distribution system (CIMA srl, Correggio, Italy). The water-to-feed ratio was 3:1 (3 kg of water were added per each kg of dry feed), corresponding to a water supply (approximately 9 kg/day/pig at the end of the trial) able to fulfil the theoretical water requirement (Mavromichalis, 2006) and to a 0.225 dry matter (DM) content of the liquid feed (900 g of DM for each 4 kg of liquid feed). The fattening phase took place between March 1st and September 5th 2021 (i.e., in the hot season) and lasted 187 days. Animals were homogeneously allotted (on the basis of their BW) to two experimental groups: 1) **CON (Control)**: 8 collective pens (replications), each having a nipple drinker which allowed the animals to drink water *ad libitum,* in which the flow rate was 1 l/min; 2) **RW (Restricted water)**: 8 collective pens (replications), each having a nipple drinker, but which was not working: water supply to these pens had previously been discontinued. Consequently, these pigs had no additional fresh water available, and the only water source for them was liquid feed.

2.2. Growth and blood parameters

Pigs were individually weighed at the beginning of the trial (day 1), on days 72, 128 and at the end of the trial (day 187) to calculate average daily weight gain (ADG). Feed intake of every pen was recorded, in order to calculate feed conversion rate (FCR). Data collection of growth parameters stopped on day 187, when the pigs reached the required slaughtering BW of approximately 170 kg.

Blood samples were collected at the beginning, middle (90 days) and end of the trial (187 days) from 32 animals (16 randomly selected pigs per group, the same 2 pigs from each pen were sampled at all time points). To this aim, pigs were restrained with a snare and 15 mL of blood was drawn collected into two tubes containing EDTA from the jugular vein. Blood was refrigerated immediately upon collection and sent to the DIMEVET laboratory (Ozzano Emilia, Italy), where the complete blood count (CBC) was performed using the hematology analyzer ADVIA 2120 (Siemens Healthcare, Milan, Italy) and obtaining the analysis of the following parameters: hematocrit, hemoglobin, erythrocytes, leukocytes, neutrophils, lymphocytes. Neutrophils to lymphocytes ratio (N:L) was subsequently calculated.

2.3. Water consumption, visits to the drinkers and behavior

In the CON group, water-meters (Superdry, Eur-8, Idrotech, Udine, Italy) were installed along the water distribution system. Every water-meter recorded water consumption (i.e., water intake + water wastage) from the drinker of a single pen. Water consumption was recorded every 2 weeks and average daily water consumption per pig was calculated.

Starting from the fifth day of the trial, the daily behavior of all pigs was videotaped monthly by means of a digital closed-circuit system (DSE, Turin, Italy) for a total of 7 daily (from 7.30 am to 6.00 pm) videotaping sessions. No recording of vocalization was made. Videos were examined by a single trained operator and animal behavior (time budget) was assessed by scan sampling at 10 minutes intervals according to a predetermined ethogram for heavy pigs (Nannoni et al., 2019) that included the following behaviors: standing inactive, sitting inactive, lateral recumbency, sternal recumbency, eating, drinking, walking, exploring the floor, neutral social interaction, agonistic social interaction (including tail biting), interactions with enrichment tools and pen structures. To allow for individual behavioral observations, four animal marking sticks of different colors were chosen (blue, green, red and purple—RAIDEX GmBH, Dettingenan der Erms, Germany) and randomly assigned to four pigs. A spot of the assigned color was painted on the back of each pig on the day before each videotaping session. The fifth pig was left uncolored.

To assess drinking behavior, three of the seven video recording sessions (corresponding to the first, fourth and last) were watched in continuous mode, and drinking behavior (number and duration of visits to the drinkers) was assessed. A visit was defined as a contact with the drinker lasting more than 1 second and, when visible, followed by deglutition. If two consecutive contacts were less than 3 s apart, they were considered as a single visit (Nannoni et al., 2013).

2.4. On-farm lesion assessment

The presence of skin and tail biting lesions was assessed according to the Welfare Quality® protocol for growing and finishing pigs (Welfare Quality ®, 2009), with some adaptations (skin lesions were assessed on both sides of the body), and the result was evaluated following the scale described in the Welfare Quality® protocol. In the protocol, the body was divided into 5 regions (ears, front, middle, hindquarters, and legs) and scored as "a" (up to 4 lesions), "b" (5–10 lesions) or "c" (11–15 lesions). Each pig was then scored using a 0-to-2 scale, where 0 corresponded to a pig having the full body classified as "a" and 2 to a pig having at least two body regions or more classified as "c", or at least one body region with more than 15 lesions.

Tail biting was assessed according to the following scale: 0 (intact tail, no evidence of tail biting), 1 (superficial biting but no evidence of fresh blood or swelling) and 2 (fresh blood, evidence of swelling or infection, or tissue missing with the formation of a crust) (Welfare Quality ®, 2009).

Lesions were scored approximately every 7 weeks, for a total of four assessments. A preliminary assessment was made when animals arrived at the farm to verify the absence of differences at the start of the experiment.

2.5. Parameters at slaughter and ham quality

All pigs were slaughtered in the same slaughtering session, at an average body weight of 171 kg, according to the required body weight for Parma Ham production (Consortium for Parma Ham, 1992). Pigs were transported and slaughtered according to the EU legislation (EC, 2005, 2009). Animals were delivered to a commercial abattoir and slaughtered after a 15-h fast. During transport and lairage, treatment groups were kept separated (no mixing). Animals were slaughtered immediately after transport (no lairage time). They were stunned (head-only electrical stunning), bled, and carcasses were processed using conventional practices.

At the slaughter plant, carcass weight and the weight of the main carcass cuts (thigh, loin and shoulder) were recorded; lean meat percentage and back-fat thickness were measured by Fat-o-Meater (FOM-SFK, Copenhagen, Denmark). The dressing out percentage and the main cuts' yield were later calculated based on carcass weight. PH measurements were taken in the Longissimus dorsi (LD) and Semimembranosus (SM) muscles at 45 minutes post-mortem (pH45') and in the SM at 24 h post-mortem (pH24h) by a portable pH meter (model 250 A, Orion Research, Boston, MA, USA). At 24 h post-mortem, instrumental color (Minolta CR-400 Chromameter Minolta Camera, Osaka, Japan, D65 illuminant, color space La*b*) was measured in the LD muscle, and samples of the muscle were taken in order to determine drip loss and cooking loss according to Honikel (1998). Shear Force was measured on 6 cores from the cooked samples using an Instron Universal Testing Machine, model 1011 (Instron Ltd., Wycombe, England) fitted with a Warner-Bratzler (WB) device at a cross-head speed of 200 mm/min.

Stomachs (20 randomly-selected animals per group) were collected at slaughter and transferred to the Department of Veterinary Medicine (DIMEVET) at the University of Bologna (Ozzano Emilia, Italy). There, stomachs were opened along the greater curvature, emptied, and gently washed removing stomach content to evaluate the lesion on the *pars oesophagea*. A picture of each stomach was taken, and lesions on the *pars oesophagea* were scored according to Hessing et al. (1992), cited by Amory et al., (2006). using the following scale: 0 (intact epithelium); 1 (small degree of hyperkeratosis occupying $<$50% of total surface); 2 (distinct hyperkeratosis at stage 1: $>$ 50% of total surface but thickness $<$1 mm); 3 (distinct hyperkeratosis at stage 2: $>$ 50% of total surface but $>$ 1 mm thickness); 4 (hyperkeratosis plus less than five erosions $<$ 2.5 cm in diameter); 5 (hyperkeratosis plus more than five erosions and/or erosions $>$ 2.5 cm in diameter); 6 (hyperkeratosis plus more than 10 erosions and/or erosions $>$ 5 cm in diameter, and/or ulcers, with or without bleeding, or stenosis of the esophagus towards the stomach). Scores were then regrouped in 3 classes of damage: absent or slight (0−1−2), medium (3−4), and severe (5−6).

Hams (20 randomly-selected thighs per group) were followed during the whole dry-curing process. They were weighted after dissecting from the carcass, after trimming and at the end of the dry-curing period (18 months). Weight losses were calculated for each productive step. After trimming, color of the SM muscle was assessed using the same colorimeter described above.

The dry-curing process according to the Parma Ham specifications (Consortium for Parma Ham, 1992) requires that thighs be first salted for about 25 days, then they rest for a maximum period of 90 days in refrigerated, humidity-controlled rooms. Hams are then hung in well-ventilated rooms for three months; after this period, the exposed muscular surface is greased, and hams are transferred to the cellars (cooler darker and less ventilated rooms) and hung on racks until the dry curing is completed (minimum 12 months from salting).

The end product was dissected and a slice (including both the Biceps Femoris (BF) and the Semimembranosus (SM) muscles) was evaluated visually by a panel of trained experts. The evaluation was expressed according to Sardi et al. (2012) on a scale ranging from 1 to 10 (1=absence of the trait; 10=maximum presence) for the following parameters: wet surface, texture, color inhomogeneity and marbling for the lean portion; texture, thickness, and oily surface for the fat. An overall score was attributed as a global evaluation of the ham, expressed on a scale ranging from 1 to 10 (1=very bad quality; 10=optimal characteristics).

2.6. Statistical analysis

Data were analyzed using the software Statistica (2014). Normality of data was assessed by the Kolmogorov–Smirnov. The statistical unit was the pen for the growing and water consumption data; the individual (pig or ham) for overall behavior, drinking behavior (visits to the drinker), blood parameters, carcass, meat, and ham quality data. Growth parameters, water consumption, carcass and meat quality data were submitted to one-way analysis of variance (ANOVA) using the presence/absence of additional fresh water as the main effect. For nonparametric data (visits to the drinker, behavioral traits, body and gastric lesions, and sensory evaluation of hams), the Mann-Whitney test was used. Class distributions (for body, tail and gastric lesions) were analyzed using the chi-squared test. For blood parameters, the absence of significant effects between groups at day 1 was tested using ANOVA, and data from day 1 were then used as a covariate. Blood parameters on day 90 and 187 were analyzed using ANCOVA (analysis of covariance), with the experimental group and time as the main effects. The significance level for all statistical tests was set at $P < 0.05$.

3. Results

No occurrence of disease was recorded during the trial, and no pig had to be removed from the experimental protocol. Due to the rationed feeding regime, no feed residues were observed. Table 2 shows the productive traits observed during the trial. No significant differences were observed in BW, ADG, FCR or dry matter intake (DMI) between treatments.

The daily water intake (WI: sum of water from liquid feed and from nipple drinkers), and water intake: dry matter intake ratio (WI: DMI) are also shown in Table 2. Consumption from the nipples increased significantly ($P< 0.001$) and proportionally as the trial progressed (*i.e.*, as both age of the animals and external temperatures increased). Figures 1 and 2, shown in the Supplementary Materials, display more detailed data on feed consumption by month and temperature records across the entire trial, respectively.

For animals in the RW group, WI corresponded with the daily water allotment provided with the liquid feed. Water consumption from the drinkers (difference between CON group, that could obtain water from the drinkers, and RW group, receiving only the liquid feed) was approximately 3–3.6 l/pig/day (days 1–71 and 72–128 of the trial) and increased up to 11 l/pig/day (days 127–187 of the trial). Figures S1 and S2 demonstrate the dramatic increase in water consumption as of July, when external temperatures exceeded

Table 2
Live weight, average daily gain and feed conversion ratio observed in the two experimental groups.

Group	CON	RW	SEM	P-value
Body weight (kg)				
Initial (day 1)	35.7	36.7	1.06	0.623
Day 72	90.4	91.3	1.29	0.778
Day 128	135.7	135.9	1.39	0.945
Final weight (day 187)	171.1	172.0	1.53	0.745
Average daily gain (kg/day)				
1–72 days,	0.771	0.769	0.011	0.897
73–128 days	0.823	0.812	0.007	0.471
129–187 days	0.610	0.622	0.009	0.501
Overall (1–187 days)	0.728	0.727	0.007	0.996
Feed conversion ratio (kg/kg)				
1–72 days	2.42	2.44	0.031	0.708
73–128 days	3.29	3.34	0.034	0.452
129–187 days	4.40	4.27	0.059	0.283
Overall (days 1–187)	3.32	3.32	0.031	0.974
Dry matter intake (DMI) (kg/day)				
1–72 days	1.64	1.64	0.013	1.000
73–128 days	2.34	2.34	0.000	1.000
129–187 days	2.65	2.65	0.011	1.000
Overall (days 1–187)	2.17	2.17	0.008	1.000
Water intake (WI) l/day				
1–72 days	8.78	5.60	0.427	<0.001
73–128 days	11.58	7.99	0.474	<0.001
129–187 days	19.20	9.02	1.436	<0.001
Overall (days 1–187)	13.54	7.39	0.796	<0.001
WI:DMI (l water/kg DM)				
1–72 days	5.34	3.41	0.247	<0.001
73–128 days	4.94	3.41	0.198	<0.001
129–187 days	7.51	3.41	0.590	<0.001
Overall (days 1–187)	6.24	3.41	0.366	<0.001

The experimental unit was the pen. Values are means of 8 replicate pens (5 pigs per pen) per group. CON, control; RW, restricted water; SEM, Standard Error of the Mean

30°C.

Table 3 shows drinking behavior data. No differences were observed either in the number and the duration of the visits or in the total time spent daily with the drinkers on the first observation time (day 5 of the trial). Significant differences were observed in average drinking bout (i.e., visit to the drinker) number and duration in the middle and at the end of the trial, with values considerably higher in the CON compared to the RW group, especially at the end of the trial, as temperatures were higher, and animals were older. Total daily time spent with the drinkers followed a similar pattern with significantly higher duration in the CON group both in the middle and at the end of the trial.

Table 4 shows the time budget of the two experimental groups. No statistically significant differences were observed, with the only exceptions of sternal recumbency and drinking time (both higher in the CON than in the RW group). Concerning sternal recumbency, the significant differences are not considered of practical importance as overall recumbency (sternal ± lateral recumbency) time was very similar between the two groups, indicating the absence of notable effects on the overall activity level.

Blood parameters at the three blood samplings are shown in Table 5. No statistically significant differences were observed between the experimental groups at the beginning of the trial. An effect of time emerged as the trial progressed, with a time-dependent increase in hematocrit and hemoglobin, and a decrease in leukocytes. Treatment had a significant effect on erythrocytes and a tendential effect on hemoglobin, with higher concentrations in the RW group for both variables. Time × treatment group interaction was not significant for all blood parameters ($P>0.05$).

Table 6 shows the lesions assessed on farm (skin and tail scores) and post-mortem (ulceration of the *pars oesophagea* of the stomach). No statistically significant difference was observed between the groups in the average score (points). Also, the analysis of class distribution with the chi-squared statistics highlighted no significant differences between the groups (data not shown).

Tables 7 and 8 show carcass, meat and ham quality. No differences between the experimental groups were observed in any of the quality parameters.

4. Discussion

Overall, water restriction applied during the hot season to liquid-fed heavy pigs receiving a rationed diet caused no alteration in growth parameters, time budgets (with the only exception of drinking time), lesions assessed on-farm (skin and tail) and post-mortem (gastric ulcers), and the main carcass, meat and ham quality parameters. Data recorded for these parameters are in line with the common productive and meat quality requirements for Italian heavy pigs (Consortium for Parma Ham, 1992) and with the previously observed time budgets (Nannoni et al., 2019), lesion scores (Vitali et al., 2019), physiological parameters (Thorn, 2010) and meat quality traits (Sardi et al., 2012; Vitali et al., 2019) assessed in the same category of pigs. An effect of water restriction on blood parameters was observed, with a significant increase in erythrocyte and a tendential increase in haemoglobin concentration. This slightly higher haemoconcentration in the RW group seems to indicate the presence of physiological adaptations in response to water restriction, while remaining within the physiological range (Thorn, 2010). Unfortunately, due to the lack of studies available on the effects of water restriction on meat quality, the only direct comparison we can make is with a previous study from our research group (Nannoni et al., 2013) in which meat and hams traits were unaltered by water restriction. The observed meat and hams parameters were very similar to those reported in the present study. It is important to highlight that the absence of differences in meat and ham quality is regarded favourably in certified food chains (Parma ham production, in this case), since they rely on a very standardized quality of the thigh.

On the contrary, considerable differences between groups were observed in water intake, average duration of visits to the drinker, total daily time spent at the drinker (assessed in continuous -all occurrences sampling technique-), and overall drinking time (assessed by scan sampling).

The absence of difference in most productive, welfare and quality traits agree with what is reported in the literature. Barber et al. (1963) and Holme and Robinson (1965) had previously observed that water:feed ratios ranging from 1.5:1–3.0:1 seemed to have little

Table 3
Visits to the drinkers, average and total daily time spent at the drinker by the two experimental groups, assessed at three timepoints: beginning, middle and end of the trial.

Group	CON	RW	SEM	P-value
Beginning (day 5)				
Visits to the drinkers, Nr.	4.41	3.44	0.509	0.626
Average time spent at the drinker, s/visit	4.45	4.59	0.364	0.554
Total daily time spent at the drinker, s/day	24.72	18.31	3.129	0.541
Middle (day 87)				
Visits to the drinkers, Nr.	6.50	2.13	0.876	0.003
Average time spent at the drinker, s/visit	4.73	2.57	0.547	0.039
Total daily time spent at the drinker, s/day	42.84	13.44	5.742	0.005
End (day 176)				
Visits to the drinkers, Nr.	14.84	3.34	1.478	<0.001
Average time spent at the drinker, s/visit	10.49	3.10	0.907	<0.001
Total daily time spent at the drinker, s/day	182.72	27.38	21.878	<0.001

The experimental unit was the individual. Values are means of 8 replicate pens (5 pigs per pen) per group. CON, control; RW, restricted water; SEM, Standard Error of the Mean

Table 4
Behavior (time budget) of animals in the two experimental groups during the entire trial (7 videotaping session from 8 am to 8 pm). Data are expressed as percentage of the observed time.

Group	CON	RW	SEM	P-value
Standing inactive	3.14	3.27	0.097	0.442
Sitting inactive	1.29	1.22	0.085	0.397
Lateral recumbency	41.50	43.38	0.636	0.204
Sternal recumbency	31.95	30.11	0.473	0.038
Sum of lateral + sternal recumbency (Total recumbency)	73.45	73.49	0.544	0.924
Eating	3.07	3.21	0.080	0.315
Drinking	0.42	0.21	0.034	0.001
Walking	1.81	1.93	0.107	0.746
Exploring the floor	11.25	11.32	0.366	0.964
Neutral interaction	3.41	3.28	0.155	0.618
Agonistic interaction (including tail biting)	0.39	0.50	0.056	0.204
Interactions with enrichment tools and structures	1.76	1.52	0.112	0.787

The experimental unit was the individual. Values are means of 8 replicate pens (5 pigs per pen) per group. CON, control; RW, restricted water; SEM, Standard Error of the Mean

Table 5
Blood parameters of the two experimental groups at different sampling points.

	Day 90		Day 187			P-value		
Group	CON	RW	CON	RW	SEM	treatment	time	treatment×time
Hematocrit, %	40.83	42.34	44.06	45.01	0.501	0.204	0.035	0.768
Hemoglobin, g/dL	12.76	13.47	14.03	14.43	0.175	0.091	<0.001	0.621
Erythrocytes, Cell/μL	7558333	8044167	7763333	7982500	73220.41	0.031	0.652	0.408
Leukocytes, Cell/μL	21873	20318	16160	14942	461.87	0.129	0.001	0.852
Neutrophils (N), %	27.93	28.29	27.62	28.58	0.83	0.763	0.996	0.880
Lymphocytes (L), %	62.85	62.45	60.89	58.42	0.89	0.536	0.199	0.654
N:L ratio	0.46	0.47	0.47	0.53	0.02	0.548	0.512	0.646

The experimental unit was the individual pig. Values are means of 8 replicate pens (2 pigs per pen) per group.
Data from day 1 were used as covariates.
CON, control; RW, restricted water; SEM, Standard Error of the Mean

Table 6
On-farm lesions (tail and skin scores) and lesions assessed post-mortem (gastric lesions, i.e., ulcerations of the *pars oesophagea*) in the two experimental groups.

Group	CON	RW	SEM	P-value (Mann-Whitney)
On-farm lesions				
Skin score, Pts	0.94	0.92	0.029	0.818
Tail score, Pts	0.32	0.35	0.034	0.453
Gastric lesions				
Pars oesophagea, Pts	4.11	3.90	0.292	0.564
Class distributions (%)				**P-value (chi-squared)**
Skin lesions class distribution				
0	15.6	14.0		
1	75.0	79.7		0.581
2	9.4	6.3		
Tail lesions class distribution				
0	72.7	67.2		
1	22.7	30.5		0.283
2	4.7	2.3		
Gastric ulcers class distribution				
0–1–2	21.1	25.0		
3–4	26.3	30.0		0.892
5–6	52.6	45.0		

The experimental unit was the individual pig. Values are means of 8 replicate pens (5 pigs per pen for on-farm lesions and 20 randomly-selected pigs per treatment for gastric ulcers).
CON, control; RW, restricted water; SEM, Standard Error of the Mean; Pts, Points

effect on the performance or carcass quality of growing-finishing swine. Lack of differences was also observed during a trial carried out in the same experimental setting during the cold season (Nannoni et al., 2013). The persistence of this lack of noticeable effects also during the hot season warrants a high degree of caution since, in the present study, most of the signs of prolonged thirst could be

Table 7
Carcass and meat quality of the two experimental groups.

Group	CON	RW	SEM	P-value
Carcass quality				
Slaughter weight (SW), kg	171.1	172.0	1.53	0.745
Carcass weight (CW), kg	146.44	147.58	1.571	0.720
Dressing, kg/100 kg BW	83.45	83.80	0.163	0.289
Fat-o-Meater, lean kg/100 kg BW	51.58	50.72	0.520	0.416
Fat thickness, mm	30.60	32.44	1.132	0.422
Loin, kg/100 kg CW	11.51	11.54	0.109	0.600
Shoulder, kg/100 kg CW	13.38	13.19	0.148	0.659
Thigh, kg/100 kg CW	24.79	24.56	0.136	0.264
pH 45' loin (LD muscle)	6.48	6.45	0.034	0.879
pH 45' thigh (SM muscle)	6.49	6.56	0.031	0.340
pH 24 h thigh (SM muscle)	5.76	5.82	0.017	0.187
Meat quality				
Thigh color (SM muscle)				
L	48.87	48.30	0.406	0.505
Hue	0.56	0.55	0.012	0.600
Chroma	11.34	11.04	0.281	0.640
Loin color (LD muscle)				
L	40.03	39.45	0.328	0.385
Hue	0.37	0.37	0.007	0.999
Chroma	22.04	21.76	0.427	0.749
Drip loss, %	0.92	0.95	0.034	0.424
Cooking loss, %	28.89	27.56	0.354	0.082
Shear Force (WBS), kg/cm^2	3.30	3.34	0.086	0.829

The experimental unit was the individual pig. Values are means of 8 replicate pens (5 pigs per pen) per group. CON, control; RW, restricted water; CON, control; RW, restricted water; SEM, Standard Error of the Mean; WBSF, Warner Bratzler shear force; LD, Longissimus dorsi, SM, Semimembranosus

Table 8
Hams seasoning losses and sensory analysis of the two experimental groups.

Group	CON	RW	SEM	P-value
Hams weight, kg				
Before trimming	16.86	17.05	0.168	0.374
After trimming	14.54	14.73	0.143	0.230
Dry-cured hams (18 months)	9.42	9.67	0.111	0.405
Trimming loss, %	13.72	13.63	0.167	0.254
Dry-curing loss, %	35.25	34.36	0.381	0.225
Sensory analysis (overall score), Pts	6.50	6.46	0.143	0.887

The experimental unit was the individual pig. Values are means of 8 replicate pens (20 randomly-selected pigs per treatment). CON, control; RW, restricted water; SEM, Standard Error of the Mean

detected only by specific and experimentally designed measurements of the drinking behavior, that at present are unlikely to be viable under commercial farming conditions. This means that the risk of overlooking situations of potential prolonged thirst might be elevated under commercial conditions, especially if water requirements are insufficient or only partially met. To address this issue, also the NRC recommends that pigs fed with wet feeding systems should always have access to an additional source of fresh water to ensure adequate water intake in case of sudden changes in barn temperature or in feed composition (e.g., high salt or protein concentrations) (National Research Council, 2012).

The first differences observed concerned water intake. Animals having water available via the drinkers (CON) assumed additional water on top of the liquid feed, with a variable amount that increased from an additional 60% of the daily allotment with the liquid feed in the first period of the trial to an additional 137% in the last period. This increase was particularly evident starting from the month of July, when external temperatures increased above 30°C and the ventilation system was unable to bring the internal temperature below 28°C in the hours of maximum solar irradiance. However, it should be noted that, besides the hot season, a role in this increase in water consumption can also be played by the fact that the feeding of heavy pigs is rationed and in particular, after 120 kg of BW, the daily feed allotment is kept constant to limit the weight increase in order to comply with the requirements of the PDO (Protected Designation of Origin) production specifications (average BW: 160 kg; BW range 144–184 kg and minimum age at slaughter of 9 months) (Consortium for Parma Ham, 1992). It is therefore possible that animals, at least in the last part of the trial, may have assumed additional water to reach a sense of satiety or as part of a redirected behaviour in response to feed restriction (Meunier-Salaün et al., 2017). Unfortunately, it is not possible to evaluate the effects of these two components (temperature increase and feed restriction as animals grow older) separately. The voluntary water intake of growing pigs fed ad libitum is approximately 2.5 kg of water for each kg of feed, while in restricted fed pigs the value increases to 3.7 kg (Cumby, 1986), and the difference may be due to the tendency of pigs to fill themselves with water if their appetite is not satisfied by the feed allowance (Yang et al., 1984; National Research Council, 2012). Nonetheless, the fact that water consumption was also increased during the first period of the trial indicates how the consideration that a 3:1 water:feed ratio is theoretically sufficient to cover the water needs of liquid-fed pigs (Mavromichalis, 2006) should be revised since animals seem to have a need to obtain fresh water via the drinkers regardless of their age. In the present trial, even in the first phase, the WI:DMI ratio in the CON group reached 5.3 litres of water per kg of DM. This observation on the motivation to obtain fresh water agrees with previous considerations from Vermeer et al., (2009) and Nannoni et al. (2013). This motivation and its persistence are also confirmed by behavioural observations. The analysis of visits to the drinkers showed that animals continued to access the drinkers throughout the trial, regardless of the drinkers' functioning state, indicating a persistent motivation to obtain fresh water even in animals that were well aware their drinker was not working. Noteworthy, the number of visits to the drinkers (corresponding to drinking bouts in the CON group and failed drinking attempts in the RW group) did not statistically differ between groups at the beginning of the experimental trial. This could be explained by the fact that before the trial (during all the postweaning phase) all pigs had nipple drinkers available. This common previous experience could explain the similar behaviour also at the beginning of the trial since they were all expecting the drinkers to be working. In addition, the number of visits/pig/day and water consumption from the drinkers observed in this trial were considerably higher than data obtained in the same experimental setting during the winter season (1–2 visits/day, with a water consumption from the drinkers of 0.5–1.4 l/pig/day) (Nannoni et al., 2013) indicating a clear seasonal effect, and not only the effect of feed restriction.

As expected, the duration of the single visit was higher in the CON group (due to the time required to drink), except at the beginning of the trial, when it is likely that animals in the RW group were attempting for a more prolonged time to obtain water from the drinkers.

However, the overall daily time spent at the drinker was higher in the CON group and dramatically increased in the last period of the trial. Our data differ considerably from those observed on dry-fed growing pigs (21 kg BW), who accessed drinkers for on average 44 times/day and spent 594 s drinking, with an average water use of 4.99 l/pig per day (of which more than 30% was wasted) (Andersen et al., 2014).

Another interesting observation with respect to water deprivation is that, as shown in Table 3, in RW group visits to the drinker decreased in middle of the trial and increased again in end phase. This seems to demonstrate that, although as the trial progressed the pigs were 'trained' in the absence of water from the nipples, in the end phase, the need to drink overshadowed this 'training'. This could be due to the increase in environmental temperatures. The marked feed restriction, especially during the last month of the trial, is another factor that probably increased water consumption since animals drank more water as a means to achieve a sense of satiety. Although in this trial it was not possible to measure water wastage and all water consumed from the drinkers was considered in the WI:FI ratio, it cannot be ruled out that a part of the water dispensed by the drinkers may have been wasted or used by the animals to cool down the environment, especially at the end of the trial. Close et al. (1971) observed this behavioural response at temperatures of 30°C and above, with pigs voiding urines and faeces over the whole pen area and spilling water from the water bowl, presumably in an attempt to cool the pigs' body surface (as also reviewed by Nannoni et al., 2020). Despite the observed differences in drinking behaviour, time budgets did not show alterations in the overall behaviour. This, together with the results obtained for physiological parameters and lesion scores, seems to indicate how the overall welfare state of the animals did not seem to be deeply affected by the prolonged water restriction. More specific measurements are indeed needed to identify a relevant welfare hazard such as prolonged thirst.

5. Conclusions

A better knowledge of the pig's water needs and drinking behaviour is essential to obtain high production standards, guarantee animal welfare and reduce waste of water and those substances (drugs, additives) which can be administered to animals via drinkable water. Based on our results, liquid-fed heavy pigs receiving a rationed diet are motivated to obtain additional fresh water from the drinkers, even if their theoretical water requirement is met by the daily allotment of liquid feed. Although no alterations were observed in growth parameters, time budgets, blood parameters, lesions, meat and ham quality traits, animals having fresh water available showed a considerable use of water from the drinkers, increasing sharply as animal age and environmental temperature increased. Animals who did not have working drinkers available were still motivated to access fresh water and continued to access the drinkers throughout the trial although they were not functioning. The apparent lack of effect of prolonged water rationing on most of the parameters observed and, on the other hand, the evident impact of fresh water supply on drinking behaviour warrant the need for more specific measurements applicable to farm conditions, that may help identify animals suffering from prolonged thirst. To improve the ability to detect water deprivation, we suggest that the next stage of this research could use Precision Livestock Farming techniques to monitor individual drinking behaviour and water consumption. This would allow to estimate and understand also the individual behavioural variability.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.anifeedsci.2024.116004.

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