Effect of the administration of a molasses-based sugar liquid feed in partial replacement of starch on production performance, ruminal functionality, animal health and meat quality in fattening beef cattle

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SUMMARY

The aim of the present study was to evaluate the effect of a partial substitution of starch with sugar from molasses-based sugar liquid feed on growth performance, health status, ruminal parameters in fattening beef cattle under field conditions.
A total of 196 newly arrived male Charolaise cattle were assigned to two study groups: i) Control (n= 98; 424.26 ± 28.98 kg live weight), basal diet; ii) Treatment (n= 98; 412.85 ± 26.30 kg live weight), partial substitution of starch with sugar, through a reduction of 5.64 %, on dry matter basis, of with 7.7%, on dry matter basis, of a molasses-based sugar liquid feed. Growth performances, dry matter intake (DMI), feed conversion rate (FCR), carcass characteristics, meat quality and health status were evaluated. Ruminal parameters, such as daily average pH and time below the threshold of 5.8, indicator of risk of acidosis, were evaluated on 10 animals per group using the alarms released by the ruminal boluses Smaxtec Premium.
The treatment significantly improved the average daily gain (ADG) (1.486 *vs* 1.419 kg/head/d in the Control group) (P<0.001) and intermediate ones (1.493 *vs* 1.44 and 1.471 *vs* 1.360 kg/head day in the Control group respectively for ADG_{0-126} and $ADG_{126-186}$) (P<0.001). Also, the intermediate (606.69 *vs* 600.98 kg in the Control group) and final weights (695.01 *vs* 682.56) were significantly higher (P<0.001) in the Treatment group. The average daily ruminal pH vas significantly lower in the Treatment group (6.68±0.30 *vs* 6.74±0.32 in the Control group) (P<0.05). The time spend under the threshold of 5.8 was significantly lower in treated animals (0.14 *vs* 0.67 h/d) (P<0.05). A tendency toward a significant effect of the treatment was found in the incidence of bovine respiratory disease (BRD) (19.58 *vs* 24.48 % in the Control group) (P<0.1). No significant differences were found in the incidence of lameness and mortality. The carcass weight was significantly higher in treated animals (413.26 *vs* 404.08 kg of carcass weight in the Control group) (P<0.001), while carcass characteristics weren't affected. Meat colour was improved by the treatment in terms of red index (15.34 *vs* 14.29 in the Control group) (P<0.05) and chroma (19.83 *vs* 18.58 in the Control group) (<0.05).
In conclusion, using a molasses-based sugar liquid feed to substitute part of the starch sources can effectively improve the growth performance of beef cattle, due to the positive effects on health and rumen activity. It can be, thus, a valuable strategy to improve sustainability, due to its effect on animal welfare, production efficiency, and circularity of the entire system.

KEY WORDS

Sugar liquid feeds, beef cattle, efficiency, welfare.

INTRODUCTION

Currently, the zootechnical sector is facing many challenges, related to the topics of "sustainability" and "sustainable development", that cover both environmental, social, and even economical points [1-2].
From an environmental point of view, emissions of greenhouse gases (GHGs), excessive consumption and pollution of the water sources and pressure on agricultural lands and forests are the main issues in which the zootechnical sector is involved. Manure storage and enteric fermentation of ruminants are the main sources of GHGs emissions [3]. Water pollution is also correlated to the management of manure and fertilizers used on the fields to produce feed raw material [4]. Also, the cultivation and production of feeds are the main responsible of the increased pressure on water sources and deforestation from the zootechnical sector worldwide [5,6]. This latter aspect leads also to another criticism often made upon livestock farming: the use of arable land and of human-edible raw materials to produce animal feeds instead of being directly used for humans [7]. Other concerns related to the social pillar of sustainability are the need to feed a growing world population while protecting animal welfare and reducing antibiotic use in farming animals [8]. Indeed, excessive, and incorrect use of antibiotics

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at the farm level, frequently driven by poor welfare conditions, is one of the possible triggers for the development of antimicrobial resistance [9]. The problem of antimicrobial resistance is one of the most important issues for public health worldwide [10]. Reducing wastes production and increasing cooperation between the different parts of the food chain are other critical issues for the social pillar of sustainability [3,8,11]. From an economical point of view, both profit for the farmers and equity in the prices of the final products are the main topics that needed to be addressed [8].

Among all the zootechnical productions, cattle farming, especially beef production, is often the most criticized for sustainability issues. Beef cattle farming is responsible for about 35% of the total livestock farming methane emissions, with ruminal emissions accounting for the highest share, followed by feed production due to the negative effect of deforestation and land use change [12]. Also, beef cattle farming has a high water-footprint (33% of the total water footprint of the livestock sector) [13]. Moreover, around 70% of the global agricultural land and 30-40% of human-edible feed crops, mainly cereals such as corn, are currently used in cattle diets to maintain high production efficiency [14,15].

Considering the use of antimicrobials, cattle farming is behind swine and poultry industries in terms of quantities used [9]. Indeed, during the arrival period, beef cattle are exposed to several risk factors, such as weaning, long-distance transport, mixing, feed and water restrictions, adaptation to new environmental and feed conditions, that can impair their immune systems and increase the risk of contaminations with pathogens, leading to a higher need of antimicrobials [16]. The most frequent threat is represented by bovine respiratory disease (BRD) [17]. Moreover, the incidence of BRD at the arrival can negatively affect production efficiency during the entire fattening period [16,17]. Besides an increase of the sanitary costs, the final productivity and even the efficiency of feed conversion is reduced. It can lead to both economic losses for the farmers and to sustainability issues, such as increased intensity of GHGs' emissions and pressure on scarce resources, such as water, land and crops, when expressed as a function of the units of final products (e.g. kg of meat or kg of proteins) [1].

Nutrition can have a proactive role in the direction of optimizing the sustainability of beef cattle farming. Besides effectively satisfying all the specific nutritional requirements for each of the fattening stages, diet can directly affect the health, welfare and thus efficiency of beef cattle. Indeed, through nutrition is possible to enhance rumen functionality [18]. The rumen is the metabolic center of cattle physiology. Thus, it is of fundamental importance to safeguard its stability and efficiency to improve overall health and productivity [19]. Nutritional imbalances, such as excess of starch, can cause sudden changes in the ruminal environment, especially of its pH, that can impair its stability and functionality. It can lead thus to the onset of digestive disorders, such as acidosis [18]. Those diseases, besides reducing the overall production efficiency and welfare of the animals, are often the door opener for other health problems, such as bloat, enterotoxaemia, and laminitis [16,17]. Moreover, animals that are weaker and stressed by the gastroenteric issues are at higher risk of immunosuppression and thus of contracting BRD [17].

The selection of safer raw materials and the correct balance of them can be an effective strategy to safeguard the ruminal environment [18].

Moreover, the use of some specific by- and co-products of other food and human activities, instead of more traditional feeds such as corn meal and soybean meal, can be an effective strategy to reduce the overall impact of the diet production, the competition between human and animals and, also to increase the circularity in the food system [7,20].

The use of molasses as energy sources in partial replacement of the traditional ones, can be an effective strategy to address those points. Molasses can be described as co-products of sugar production, and thus as circular feeds. Using them as animal feeds allows the recovery and efficient reuse of their energy and protein content, instead of being lost [21]. Moreover, partially replacing starch-containing feed sources with molasses can be an effective strategy to reduce the risk of acidosis in cattle, due to the different effect of starch and sugar on ruminal fermentation and pH, while maintaining a good production of volatile fatty acids (VFAs)[22-24]. Moreover, integrating molasses in the diets of cattle can help avoiding the sorting the TMR, that usually leads to a higher intake of starch components, increasing the risk of acidosis [24].

However, the results in both dairy and beef cattle about the effect of the partial substitution of starch-containing sources with molasses and molasses-based sugar liquid feeds, on both production performances, health status, carcass characteristics and ruminal parameters are interesting but still variable [23-25]. The variation is mainly attributable to the level of inclusion of them in the diet, their nutritional values, as well as to the genetic type of the animal used, the feeding management and diet characteristics [25]. Also, beside simple molasses, that can be widely different in terms of nutritional values, molasses-based sugar liquid feeds are now used. Molasses-based sugar liquid feeds consist in liquid products that are composed of molasses of different origins, and also different simple sugars, with the main aims to standardize and improve the nutritional values of the product. They can also be enriched with integrations such as pre- and probiotics.

The aim of the present trial was thus to evaluate the potential replacement in beef cattle diets of part of the corn meal, with a molasses-based sugar liquid feed, on growth performance, health, ruminal safety and meat quality.

MATERIALS AND METHODS

The procedures relating to animals were carried out in compliance with the directive of the Council of the European Communities (2010/63 / EU), implemented by the Italian Ministry of Health (Legislative Decree 26, March 4, 2014).

Animals, housing, and trial groups

The study took place in a beef fattening unit, located in northern Italy (via Viola 6, 37050 Roverchiaretta, (VR), Italy), that well-represent the typical intensive beef cattle fattening farms. A total of 196 Charolaise bulls, imported from France, were enrolled at the arrival (d0). They were individually weighed and evaluated for body conformation using a 5-point scale (1: profiles straight and poor muscle development; 2: profiles between whole straight to low convex and medium muscle development; 3: profiles low convex and good muscle development; 4: profiles on the whole convex and very good muscles development; 5: all profiles convex and exceptional muscles development) [26]. The animals were then grouped by weight and conformation,

Table 1 - Composition and nutritional values of the diets used in the trial calculated by the rationing software (Plurimix).

	Control				Treatment			
	Adaptation d0-30	Intermediate d31-75	Fattening D76-100	Finishing d101-186	Adaptation d0-30	Intermediate d31-75	Fattening D76-100	Finishing d101-186
Composition, kg/head								
Corn Silage 350832	5.00	8.00	8.00	6.00	5.00	8.00	7.50	6.00
Corn meal 69% starch	0.50	3.50	6.00	7.50	-	3.00	5.40	6.80
Feedstuff[1]	6.00	2.00	2.00	2.00	6.00	2.00	2.00	2.00
Beet pulp dry	-	0.70	0.70	0.70	-	0.70	0.70	0.70
Wheat straw	1.20	0.90	0.90	0.90	1.00	0.90	0.90	0.70
Sugar liquid feed	-	-	-	-	1.00	0.80	1.00	1.00
Nutritional values, % on d.m.								
Total as fed, kg	12.70	15.10	17.60	17.10	13.00	15.40	17.50	17.20
Total dry matter, kg	8.46	9.20	11.34	11.97	8.49	9.21	11.30	11.92
Dry matter, %	66.7	60.92	64.43	70.00	65.31	59.80	64.57	69.30
UFC, kg d.m.[2]	0.90	0.93	1.00	1.04	0.90	0.93	1.00	1.04
Crude Protein	10.11	13.54	12.55	12.37	10.26	13.53	12.58	12.42
Sugar	3.51	3.54	3.92	3.37	7.55	7.48	6.90	6.50
Starch	29.49	36.29	42.68	46.26	25.60	32.67	39.16	43.22
NDF[3]	40.58	34.60	29.96	26.92	38.14	33.78	28.89	26.92
Fat	2.38	2.80	3.06	3.19	2.36	2.78	2.99	3.15
Ca tot	0.76	0.67	0.51	0.47	0.74	0.68	0.53	0.50
P tot	0.41	0.33	0.32	0.32	0.40	0.32	0.31	0.32

[1]On dry matter basis: 0.90 UFC, 36.62% CP, 5.59% Sugar, 12.70% Starch, 25.67 NDF, 1.79 Fat, 3.07 Ca, 0.68 P;[2]d.m.= dry matter;[3]NDF= neutral detergent fiber.

and randomly assigned to two balanced groups: i) Control: 98 heads (424.26 ± 28.98 kg live weight); ii) Treatment: 98 heads (412.85 ± 26.30 kg live weight).
The bulls were housed on slatted floor in a close barn, in 28 pens with 7 animals each (3.5 m^2 each).
The trial lasted for the entire fattening period of 186 days.

Nutritional management

The two groups were fed following the same nutritional plan, characterized by four different formulations for each specific fattening stage (arrival, intermediate, fattening and finishing), studied to meet the specific growth needs in those different phases (Table 1) [27]. Inside each phase, the diets were isoenergetic and isonitrogenous but differed in the two groups to allow the partial substitution of corn meal and silage, and thus of the starch percentage, with the molasses-based sugar liquid feed (Table 2).
The two different TMRs were administered *ad libitum* for the entire fattening period and delivered once a day in the morning by a feed mixer wagon, provided with electronic scale to weigh the inclusion of each ingredient and the amount of the TMR unloaded.
Water was available *ad libitum*.

Table 2 - Nutritional values of the molasses-based sugar liquid feed used in the trial.

Chemical composition	
Dry matter, %	65.00
Humidity, %	35.00
Ash, % on d.m.	4.70
Crude Protein, % on d.m.	6.00
Fat, % on d.m.	0.20
Sugars, % on d.m.	54.10

Parameters recorded

Growth performance

Individual body weight was recorded before morning feeding at three timepoints, enrolment day (d0), day 126 (d126) and before slaughter (d186). The individual average daily gain (ADG) was then calculated for each period, from d0 to d126 (ADG_{0-126}), from d126 to d186 ($ADG_{126-186}$) and from d0 to d186 (ADG_{0-186})
The daily feed intake of each pen in the two groups was evaluated once a week by weighing the TMR administered and the residue in the manger 24 h later. Then the feed intake was corrected for the dry matter level of the diet, to obtain the dry matter intake (DMI), The FCR was then calculated, comparing the average DMI of each pen from d0 to d186, with the ADG_{0-186} of the same pen.

Health status

The individual health status was checked twice a day by the farm veterinary and qualified animal health care staff of the farm, during the entire fattening period. Any cases of morbidity and mortality were recorded, with specific attention on the incidence of bovine respiratory disease (BRD) and lameness. Sick animals were treated according to the procedures, medications, and sanitary protocols adopted by the farm veterinary staff.

Ruminal functionality

The reticulorumen pH of 10 animals per group was monitored through an indwelling and wireless data transmitting system, constituted by ruminal boluses (SmaXtec animal care GmbH, Graz, Austria). Ten boluses (5 for each group) were implanted at the arrival day and then other 10 were implanted on day 100 of the rearing phase on the same animals, to cover all the experimental period considering that the maximum efficiency and accuracy lasted on average for 100-130 days. The system consists in wireless, indwelling rumen pH monitoring boluses (SmaXtec Premium Bolus SX-1042A), a base station that

Table 3 - Technical specifications of the Smaxtec boluses used in the trial.

Technical Aspects	
Dimension	132×35 mm (length×diameter)
Measurement interval	10 min
Measurement range (pH)	pH 3-9
Measurement range (temperature)	0°C-80°C
Measurement accuracy (pH)	Up to day 90 pH ± 0.2; up to day 150 pH± 0.4
Measurement accuracy (temperature at 39°C)	±0.05°C
Measurement resolution (pH)	pH 0.01
Measurement resolution (temperature)	0.01°C
Activity index	0 to 100
Measurement duration pH measurement	150 days (5 month)
Battery life (temperature and activity measurement)	Up to 4 years

allows the boluses to be read and the data to be transferred to the software, and a specific software that collect and analyses all data. According to the manufacturers' instructions, firstly all devices were calibrated and successively the boluses were administered through a balling gun by mouth to each animal. The boluses captured data about reticulorumen pH every 10 min. The main technical data about SmaXtec Premium Bolus SX-1042A are reported in the Table 3.
The raw data were firstly averaged as hourly means. Then the daily average was evaluated. Also, following Penner et al. (2009), the total time spent below ruminal pH 5.8 was evaluated [23] for each bolus and each day. Also, an opposite threshold of 6.8 was included in the evaluation. The time spent over this threshold was evaluated in the same way as the lower threshold. Then the daily averages of pH and daily hours spent under the thresholds of 5.8 and over 6.8 of each bolus were averaged per group. Moreover, the software was set up to deliver different types of alarms when the ruminal environment exceeded or reached some specific thresholds, that are representative of negative and threatening conditions that can lead to health and welfare impairment. Those alarms were monitored daily, collected and their frequency was evaluated, to underline a possible effect of the treatment on the ruminal safety. An explanation of the alarms can be found in Table 4. Data for rumen pH and alarms were collected for all the study period from arrival to slaughtering.

Table 4 - Explanation of the different alarms released by the Smaxtec software.

Alarm	Explanation
Reduction in feed efficiency	On <date> there were large fluctuations in pH (pH daily amplitude of <value>), which reduce nutrient utilization.
Abrupt increase in the average daily pH	On <date> the average daily pH increased in comparison with the previous day by <value>.
Abrupt decrease in the average daily pH	On <date> the average daily pH dropped in comparison to the previous day by <value>.
Increased risk of acidosis	On <date> the pH was below 5.8 for <value> minutes.

Slaughtering performance and meat quality

Data about carcass weight, carcass conformation and fattening (SEUROP) scores were collected for all animals at the slaughterhouse. The dressing percentage was obtained comparing the final live weight with the cold carcass weight, obtained after 24h of chilling at a temperature of 0°C to 4°C. Carcass conformation and fattening scores were assessed by an expert judge following the EU legislation (Council Regulation EEC n. 1026/91, 22 April 1991) [28], using the SEUROP classification method, with a conformation scale ranging from S to P (S-superior: all profiles extremely convex, exceptional muscle development, double-muscled conformation; E-excellent: all profiles convex to super-convex, exceptional muscle development; U-very good: profiles on the whole convex, very good muscle development; R-good: profiles on the whole straight, good muscle development; O-pretty good: profiles straight to concave, medium muscle development; P-poor: all profiles concave to very concave, poor muscle development), and a fattening scale ranging from 1 to 5 (1-low: none up to low fat cover; 2- slight: slight fat cover, flesh visible almost everywhere; 3-medium important: flesh, with the exception of the round and shoulder, almost everywhere covered by fat, slight fat deposits in the thoracic cavity; 4-high: flesh covered by fat, round and shoulder still partly visible, medium fat deposits in the thoracic cavity; 5-very high: carcass well covered by fat, heavy fat deposits in the thoracic cavity).
After 24 hours form slaughter, 20 carcasses per group were selected for pH evaluations, performed with a portable pH-meter (HI 98150, HANNA Instruments Inc., Woonsocket, RI, The USA) equipped with a glass electrode (3 mm Ø conic tip) suitable for meat penetration, and values were obtained for each sample from the average of three measurements.
Samples of *Longissimus dorsi* were taken from the same 20 carcasses and analysed for colorimetric characteristics.
The color analysis was performed, using a CR310 Chromameter, on an 8-mm measuring. The chromameter was set on D65 illuminant and calibrated with the CIE LAB color space system, using a white calibration plate, according to the CIE LAB system. Lightness (L*), redness (a*) yellowness (b*), hue angle (h), and chroma (C) values were calculated for each sample as the average of 10 repetitions.

Statistical analysis

The statistical analyses of all the data were performed using the SAS software.
Pen was considered the experimental unit for growth performance (body weight and average daily gain), carcass weight and feed intake. ANOVA was carried out on those data through a mixed model (PROC MIXED, SAS 9.4, SAS Cary NC). Initial weights were used as covariate.
Data related to ruminal pH variations were analysed though a mixed model for repeated measures. The single animal was the statistical unit for those measures.
For non-continuous variables, such as incidence of pathologies and mortality cases, carcass classification a chi square test (PROC FREQ) was applied.
Differences were considered significant at $P \leq 0.05$, while a tendency was set up at $P<0.1$.

RESULTS

Growth and production performance

Data related to growth and production performance are reported in Table 5. The treatment has led to an improvement ADG, both considering the ADG_{0-186} (1.486 *vs* 1.419 kg/head/d in the Control group) (P ≤0.001), the ADG_{0-126} (1.493 *vs* 1.448 kg/head/d in the Control group) and the $ADG_{126-186}$ (1.471 *vs* 1.360 kg/head/d in the Control group) (P ≤0.001).
Specifically, this difference was equal to 67 g/head/d considering the entire rearing period, resulting in a 4.7% of increase in terms of ADG_{0-186} in the Treatment group.
Those improvements in the daily gains have led to higher weights in treated animals, both at d126 (606.69 vs 600.98 kg in the Control group) (P ≤0.001) and at the end of the fattening period (695.01 vs 682.56 kg/head/d in the Control group) (P ≤0.001).
The DMI resulted to be significantly higher in the Treatment group (10.81 *vs* 10.36 kg/head/d of dry matter in the Control group) (P<0.05). However, the FCR wasn't affected by the treatment.

Health status

Data related to the health status recorded during the entire fattening period are reported in Table 6.
A tendency toward a statistically significant effect of the treatment was found in terms of incidence of BRD (19.58 *vs* 24.48 % in the Control group) (P<0.1), resulting in a 20% reduction. No significant effects were found in terms of mortality rate and lameness incidence.

Rumen functionality

Data related to the ruminal parameters, detected with the Smaxtec Premium boluses during the entire fattening period, are reported in Table 7. The ruminal pH was significantly modified by the treatment. The average daily pH was significantly lower in treated animals (6.68 *vs* 6.74 in the Control group) (P<0.05). However, the average daily time (h/day) spend under the threshold of 5.8 was significantly lower in the Treatment group (0.14 *vs* 0.67 h/d in the Control group) (P<0.05). This overall differences in the time spend daily at pH lower than 5.8 is also visible in Figure 1.
No differences between the two groups were highlighted for the higher threshold of 6.8.

Table 5 - Growth performance and production parameters.

	Control	Treatment	P Value
Weight, kg			
0	418.53	418.53	-
126	600.98	606.69	<0.001
186	682.56	695.01	<0.001
ADG[1], kg/head/d			
0-126	1.448	1.493	<0.001
126-186	1.360	1.471	<0.001
0-186	1.419	1.486	<0.001
DMI[2], kg d.m.[3]	10.36	10.81	<0.05
FCR[4]	7.30	7.27	ns

[1]ADG= average daily gain, kg/head/d; [2]DMI= dry matter intake, kg; [3]d.m. = dry matter; [4]FCR= feed conversion rate

Table 6 - Health status in the two study groups.

Parameter, % (n[1])	Control	Treatment	P Value
BRD[2] morbidity, % (n)	24.48 (24)	19.58 (19)	P<0.1
Lameness[3], % (n)	3.06 (3)	2.06 (2)	ns
Mortality, % (n)	1.02 (1)	1.02 (1)	ns

[1]n=number of animals; [2]BRD= bovine respiratory disease; [3]Lameness = all the cases recorded as "lameness" were derived from nutritional issues

Table 7 - Ruminal parameters recorded by the Smaxtec Premium Boluses in the two experimental groups.

	Control	Treatment	P
Average daily pH, avg[1]±ds[2]	6.74 ± 0.32	6.68 ± 0.30	<0.05
Hours per day pH<5.8, h/d[3]	0.67	0.14	<0.05
Hours per day pH>6.8, h/d	7.23	7.83	ns

[1]avg= average daily pH values; [2]ds= standard deviation of the daily pH; [3]h/d= hours per day

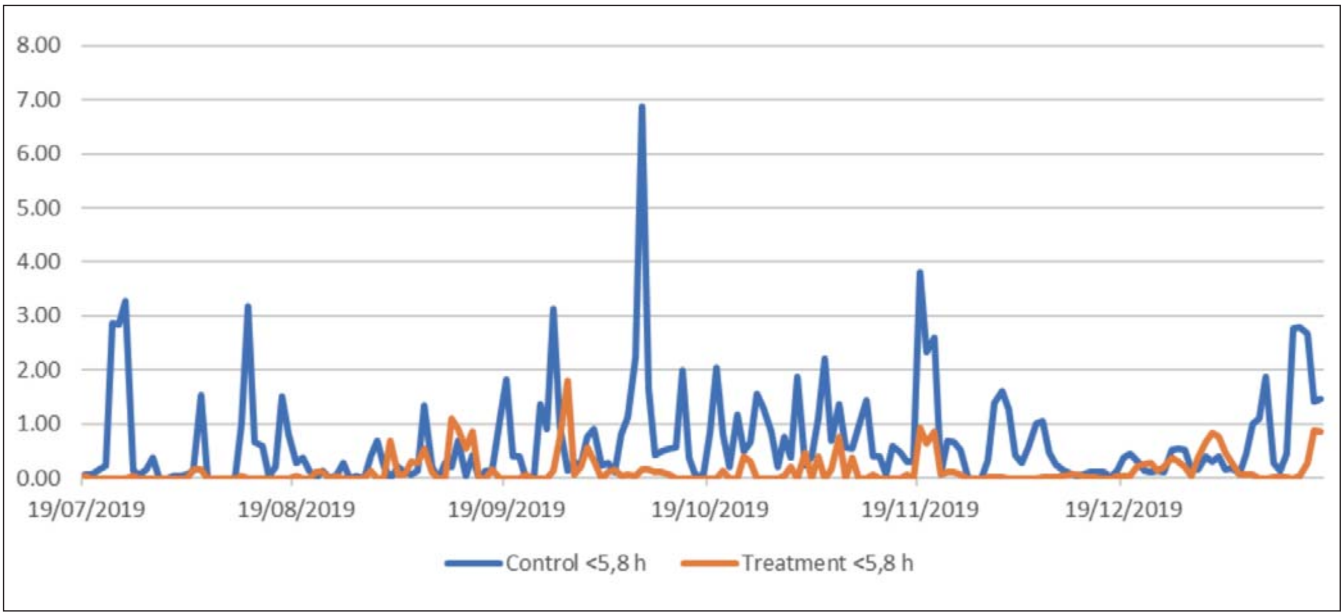

Figure 1 - Hours per day spent with pH below the threshold of 5.8 during the entire fattening period.

Slaughtering performance and meat quality

Data related to slaughtering performance are reported in Table 8. The carcass weight resulted to be significantly influenced by the treatment (413.26 *vs* 404.08 in the Control group) (P<0.001). No difference was conversely found in terms of dressing percentage and carcass classifications.
Data related to the analyses performed about meat quality are reported in Table 9. The treatment had a significant effect on the pH values at 24, with treated carcasses showing a lower average pH (5.66 *vs* 5.73 in the Control group) (P<0.001).
In terms of colour-related parameters, the treatment has led to a significantly higher red index (15.34 *vs* 14.29 in the Control group) and chroma (19.83 *vs* 18.58 in the Control group) (P<0.05).

Table 8 - Parameters evaluated at slaughter.

	Control	Treatment	P
Carcass hot weight, kg	404.08	413.26	<0.001
Dressing percentage, %	59.20	59.47	ns
SEUROP			
Cat. E, % (n)	89.69 (87)	94.90 (93)	ns
Cat. U, % (n)	10.31 (10)	5.10 (5)	ns
Fatness			
Cat. 2, % (n)	61.86 (60)	63.27 (62)	ns
Cat. 3, % (n)	38.14 (37)	36.73 (36)	ns

Table 9 - Meat characteristics: pH at 24h and color.

	Control	Treatment	P
pH 24 hours post mortem	5.73	5.66	<0.001
Meat colour			
L[1]	40.07	41.79	ns
a[2]	14.29	15.34	<0.05
b[3]	11.86	19.83	ns
h[4]	0.69	0.69	ns
Chroma	18.58	19.83	<0.05

[1] L=Lightness; [2]a= redness; [3]b= yellowness; [4]h= hue angle.

DISCUSSION

In the present study, the inclusion of a molasses-based sugar liquid feed has led to a significant increase in the overall growth performances. However, the results can be widely variable mainly due to the difference in the nutritional values of the molasses and liquid feeds used and depending on the levels of inclusion in the diets [25]. Percentage of inclusion that exceeded 10% on dry matter are indeed reported to have potential negative effects on growth performance and diet digestibility, with even possible drawbacks on gastrointestinal health [25]. The increased growth performance detected in the present trial should be attributed to both a higher feed intake and to an improved ruminal stability that led to a more ruminal efficiency and to a reduction in the incidence of digestion disorders, such as subclinical acidosis.
The inclusion of molasses has been reported to increase the palatability of feeds, mainly due to their sweet taste [21, 25]. Moreover, Allen et al. (2009) found that propionate, the main product of the ruminal fermentation of starch, have negative feedback on the nervous systems, leading to a higher and faster sense of satiety [29]. Thus, the partial substitution of starch with

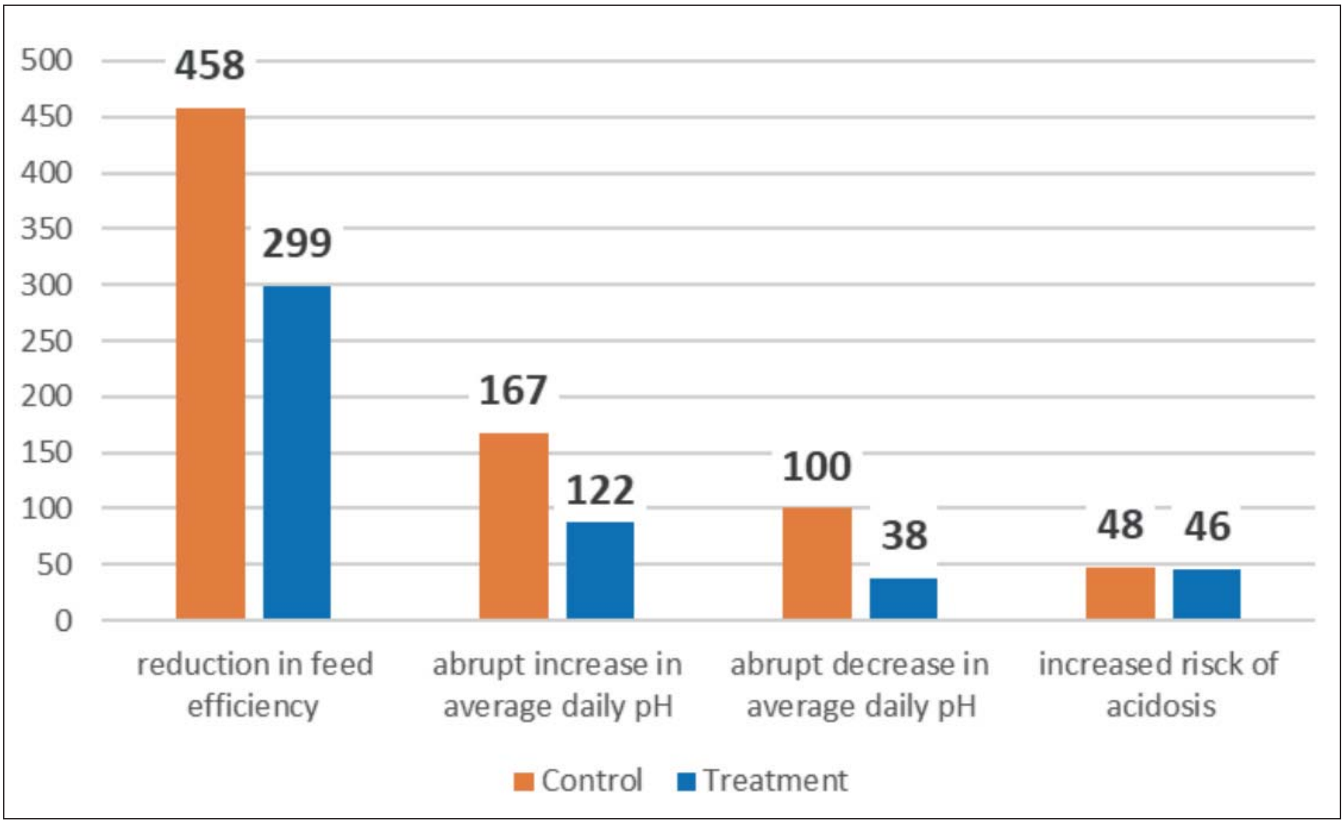

Figure 2 - Frequency of different alarms, released by the Smaxtec Premium boluses, correlated with changing in the ruminal safety and balance, in the two groups.

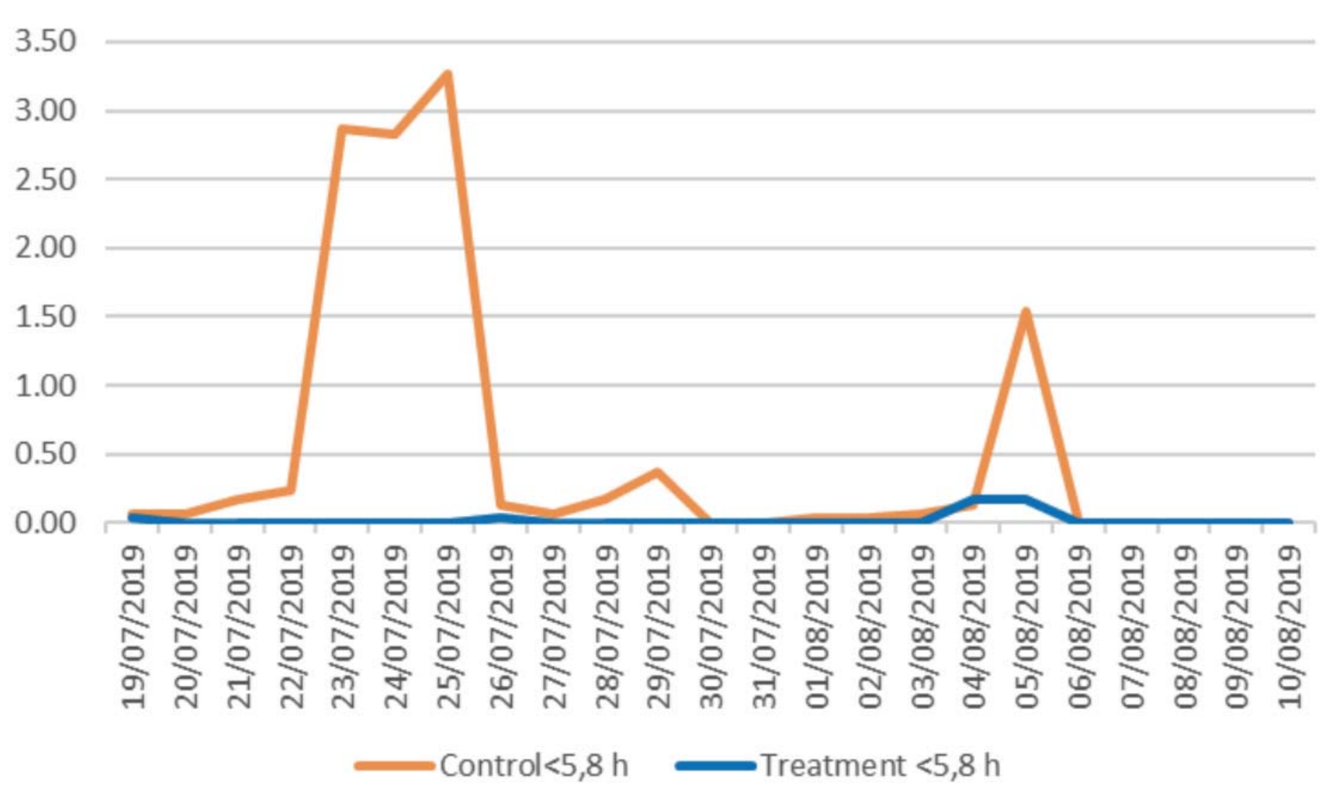

Figure 3 - Hours per day spent with pH below the threshold of 5.8 during the adaptation period.

sugars could have altered this mechanism. Indeed, the fermentation of sugars in the rumen leads mainly to the production of butyrate instead of propionic acid, that doesn't have this negative effect on satiety [24,30].
Moreover, butyrate is a stimulus for the growth and functionality of ruminal papillae, leading to a better and faster uptake of the VFAs, optimizing rumen stability and activity and thus the ingesta rumen retention time. [24].
The faster uptake of the VFAs, combined with the fact that butyrate is less acidogenic then propionic acid, can explain also the data obtained in the present study on ruminal parameters with significantly lower pH in treated animals but also higher pH stability in those animals. Indeed, the time spent at pH under the threshold of 5.8 was lower in treated animals. Those data underline a more stable pH during the day, as highlighted also in Figure 1, and agree with previous studies done in dairy cows, where the time spent at critical pH was lower in animals fed with sugar sources [23,24].
The better stability of the ruminal environment highlighted in the present study, is also confirmed by the information related to the incidence of the different alarms released by the boluses, reported in Figure 2. Indeed, the abrupt changes in the ruminal pH and risk of reduction in the feed efficiency, were more frequent in control animals, as an image of a less stable pH during the day. It could highlight a possible higher frequency of critical conditions in the rumen of control animals, that could have led to a higher incidence of cases of health problems, both subclinical acidosis and BRD.
During the arrival phase, that is usually the most critical in intensive beef cattle farming, the pH was more stable in treated animals, with less time spent at critical pH levels, as visible in Figure 3.
Indeed, as visible from Figure 1 and 3, there were a substantially higher daily variability in the ph of control animals in the adaptation and during the changing between adaptation to intermediate and between intermediate and fattening, compared to treated animals. The shift between diets is usually a perturbation for the ruminal environment, that can lead to important imbalances. Thus, the treatment turned out to be effective in reducing that risk. The shift from fattening to finishing diets affected to a lower extent the pH variability in both groups, as visible in Figure 1, probably because the rumen environment was already adapted to a high-starch diet.
Avoiding nutritional imbalance and other sources of stress, such as an instable ruminal pH, is a key to reduce the overall incidence of health problems in adaptation phase, as well as to maximize the general resilience and resistance of the animals during the entire fattening period [16,17]. This aspect is of utmost importance with the aim of reducing the overall incidence of diseases, to maximize animal welfare and reduce the use of antimicrobials. Zeineldin et al., (2018) found that the ruminal microflora can affect the host immune system. Thus, every nutritional imbalance can further reduce immune function, which, during the arrival phase, is often already partially compromised by the stress condition related to transport, environment changes and social interactions [17,31].
A higher instability of the ruminal pH is negative for the functionality of some of the main ruminal bacterial populations, especially the cellulolytic ones [32]. The use of sugars sources have led to an increase of NDF digestibility both in *in vitro* and *in vivo* studies done in dairy cows [23,30]. Also, in the review of Santos-Torres et al. (2023) a potential positive effect of molasses administration on the overall dry matter digestibility was highlighted [25]. Those aspects can further explain the im-

provements in the growth performances detected in the Treatment group.
A better ruminal stability, with a lower risk of critical conditions, can also affect meat quality, due to its effect on animal behaviour and temperament [33]. Indeed, ruminal instability often led to a higher level of nervousness in the animals, that, especially at the end of the fattening period, can reduce muscle glycogen, thus limiting the decrease in meat pH after slaughter [34]. In agreement with this thesis, in the present trial the meat pH of carcasses of the Treatment group was significantly lower, highlighting a possible better level of glycogen in the muscle. It is well known that meat pH affects meat colour modifying the interaction between myofibrillar protein and then light refraction. Thus, a lower meat pH improves colour parameters as red index and chroma [35].

CONCLUSIONS

In relation to the important aim of reaching a "sustainable" beef cattle farming, many strong and substantial changes and improvement have to be made, working on topics such as vaccine prophylaxis, structural improvements, and precision agriculture. However, even the attention to small details can lead to strong and important results, as highlighted by the findings of the present trial.
The reduction of feed sorting, as well as the modulatory effect of sugars on ruminal pH, have led to a more stable ruminal environment and to a more functional ruminal microflora, reducing thus the risk of subclinical acidosis, one of the main health risks and causes of welfare impairment in beef cattle farming. Consequently, the animals were healthier and more resilient, an aspect that might also explain the lower incidence of BRD.
A simple nutritional strategy has thus a significant effect on health and welfare, reducing the needs of antimicrobial treatments and the worries correlated to animal welfare.
Furthermore, production performance was also positively affected by these changes in rumen and general health, leading to both better farm profitability and improved sustainability in its environmental sense. Indeed, a more efficient animal corresponds to a lower emissivity of GHG, in terms of intensity per unit of final product and to a lower pressure on other scarce resources, such as water and crops. Moreover, the circularity of the entire system is improved, due to better recycling and reuse of the nutrients along the food chain.
The use of a molasses-based sugar liquid feed in partial replacement of starch sources can be thus a valuable strategy to achieve higher sustainability levels, due to their effect on both animal welfare, production efficiency, and circularity of the entire system.

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