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Growth performance and economic impact of Simmental fattening bulls fed dry or corn silage-based total mixed rations

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ABSTRACT

Bull-fattening diets in Europe and most developed countries around the world have traditionally been based on corn silage, starch-rich, and high-energy/ high-protein supplemental feeds. The impact of climate change on crop yields feed availability, and price volatility, requires new and adapted feeding strategies, including for fattening bulls. Therefore, the objective of this study was to compare the growth performance and economic impact of a representative, conventional corn silage-based (**CONVL**) total mixed ration, and a dry (**DRY**) total mixed ration (**TMR**) fed to Simmental bulls. For nine months (272 days), 24 bulls (215 ± 10 kg BW) were randomly assigned to one of two TMR feeding groups (n = 12 per group). The DRY–TMR was primarily characterised by the nutrient fibre source, exclusively based on straw and other by-products. The diets were formulated and balanced based on the Cornell Net Carbohydrate and Protein System. After 272 days of fattening, bulls were slaughtered. Feed intake, average daily gain (**ADG**)/DM intake (**DMI**) ratio, and nutrient intake were affected by treatment, time, and their interaction ($P < 0.05$). The treatment affected neither acid detergent lignin intake nor starch intake. Compared with CONVL bulls, animals fed DRY–TMR consumed more non-fibre carbohydrates and rumen undegradable neutral detergent fibre, showing lesser dry and fresh matter intake and less metabolisable energy and physically effective neutral detergent fibre intake. Despite differences in nutrient intake ($P < 0.05$), particle size distribution between the two diets and growth performance were not different ($P = 0.45$). Simmental bulls in both treatment groups reached target weight in a shorter time due to high ADG of 1.87 kg (DRY–TMR) and 1.84 kg (CONVL). Both treatments achieved a positive profit margin (598 ± 28 €/bull). While total income per bull and dressing percentage did not differ between treatments, the substantially higher feed costs ($P < 0.01$) of the DRY–TMR resulted in a higher ($P = 0.04$) income over feed cost in favour of the CONVL treatment group. Despite the higher feed cost of DRY compared with CONVL diets, the better ADG/DMI ratio ($P < 0.01$) of DRY–TMR contributed to lower absolute feed quantity requirements during the fattening period. Due to the positive profit margin and high ADG results, DRY–TMR solutions for fattening bulls based on straw and by-products can be considered a promising alternative feeding strategy.

Implications

International and regional crop and corn silage yields are likely to be severely impacted by global climate change, such as changing precipitation patterns and insufficient water availability. Compared to conventional corn silage, alternative feeds are based on by-products such as straw, which can be efficiently utilised by ruminants to produce food for human consumption. The study found no difference in weight gain between the two diets, despite differences in nutrient intakes and particle size distribution. As a result of the higher average daily gain in both groups (average 1.86 kg/day), Simmental bulls in the current study reached target weight in a shorter fattening period.

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Introduction

In contrast to the United States, where 80% of beef production comes from beef cows, in Europe, about 80% of beef production originates from dairy cattle (Cunningham, 1983). Even within Europe, the relative proportion of beef and dairy breeds and crossbreds used for beef production varies considerably. In addition, rearing and fattening methods differ from country to country. In Germany, Simmental and Holstein are the most common breeds for beef production. German Simmental (Fleckvieh) is a dual-purpose breed widely used in southern Germany that can be intensively fattened to high live weights of up to 850 kg (Augustini et al., 1992; Honig et al., 2020). Almost 50% of the total beef production in Germany originates from bulls (Schütte et al., 2021).

Most of these bulls are fattened in intensive rearing systems with rations based on corn silage and high-energy and/or high-protein supplementary feed (Schütte et al., 2021). Silage used is mostly on-farm-produced corn silage, so bull fattening is primarily tied to cropland locations. Consequently, the competitiveness of corn production relative to grain production determines the regional distribution of intensive fattening of young bulls. In recent decades, the demand for bioenergy in regional markets has led to increased competition in forage and land markets with biogas production, which affects the profitability of cattle fattening (Henke and Theuvsen, 2013). In addition, climate change with less rain and rising temperatures may favour grain corn over silage corn. These factors, which limit the availability of corn silage for feeding in general and for fattening bulls in particular, necessitate alternative rations that provide similar or higher energy levels to meet the genetic growth potential but also provide sufficient fibre for adequate rumen function and rumination.

Therefore, in the face of advancing climate change, changing feed prices, and feed availability, new and adapted feeding strategies in bull fattening must be constantly evaluated. The objective of this study was to compare feed intake, growth performance, and the economic impact of Simmental bulls fed either a conventional corn silage-based ration (**CONVL**) or a dry (**DRY**) total mixed ration (**TMR**) until they reached a final body weight of approximately 750 kg. For this comparison, the DRY–TMR was designed to contain similar proportions of rumen fermentable carbohydrates as the CONVL while providing the option of feeding specific concentrations of structural components (physically effective neutral detergent fibre (**peNDF**) or amylase-corrected neutral detergent fibre (**aNDF**)). The hypothesis was that feeding DRY–TMR would result in comparable growth rates and economic outcomes to feeding corn silage and would have no negative impact on animal performance.

Material and methods

Animals, treatments, and management

The animal experiment was conducted from December 10, 2020 to September 07, 2021 at the Educational and Research Centre for Animal Husbandry, Hofgut Neumühle, Germany. All experimental procedures were approved by the Animal Ethics Committee of the Department for Animal Welfare Affairs (Landesuntersuchungsamt Rheinland-Pfalz, Koblenz, Germany) in agreement with the German Animal Welfare Act (permit number: G-20-20-149). Simmental bulls [n = 24, initial age = 167 d ± 11.7 d, initial live BW = 211 kg ± 9.3 kg (mean ± SD)] were housed in eight group pens and fed one of two diets consisting of conventional (**CONVL**) or dry (**DRY**) TMR. Both TMR diets were offered to the bulls once per day. Bulls were randomly assigned to one of two experimental groups (diets) stratified by BW. The CONVL and DRY groups each consisted of 12 bulls with non-significant differences in the initial BW/experimental group ($P > 0.54$) as determined by a two-tailed t-test with heteroscedastic variance assumption. Within treatments, bulls were randomly assigned to one of four pens located in the bull fattening barn, i.e., groups (three animals/pen). Each pen was equipped with slatted floors and rubber mats and had an area of 11.8 m^2, corresponding to 3.93 m^2 per bull. To allow free access to drinking water, all pens were equipped with two pressure bowls. Diets were formulated according to the NRC (2016) model to provide sufficient energy and protein for a 500 kg fattening bull to support body weight growth of ~2 kg per head per day. As central components, both experimental diets contained typically available feeds such as beet pulp silage, wheat straw, corn, barley grain, canola meal, and mineral and vitamin premix (Table 1). The main distinguishing feature between the DRY and CONVL rations was the absence or presence of corn silage. To prevent sort-

Table 1
Ingredients and chemical composition in Simmental bull diets, including commodity market prices following 2021 board of trade information and average silage production costs.

Feeds (Amount in kg as fed)	Treatments[1]		Investment
	DRY	CONVL	
Corn silage (season 2020)[a]	–	14.00	50 €/t
Beet pulp silage (season 2020)[a]	2.00	3.00	40 €/t
Wheat straw[b]	1.20	0.30	80 €/t
Corn grain ground[b]	3.50	1.20	200 €/t
Barley grain ground[b]	2.00	1.20	200 €/t
Solvent-extracted canola meal[b]	1.10	1.00	300 €/t
Beet pulp pellet (dry)[b]	1.50	–	170 €/t
Beet molasses (liquid)[b]	0.80	–	110 €/t
MiproBull 200 Forte[c]	0.20	0.20	800 €/t
Acid protects TMR[2c]	0.05	0.05	1 700 €/t
∑ kg as fed (DM)	12.35 (8.95)	20.95 (9.22)	
Investment per head * day	2.05 €	1.87 €	
Dietary composition (DM basis)			
DM (%)	72.46	44.00	
ME, MJ/kg	10.50	11.00	
NEm, MJ/kg	6.70	7.10	
NEg, MJ/kg	4.20	4.50	
Crude fibre (%)	8.35	11.08	
aNDFom (%)	27.44	34.30	
ADF (%)	16.31	18.77	
ADL (%)	3.00	2.73	
peNDF (%)	14.77	23.11	
NFC (%)	51.53	45.22	
Sugar (WSC) (%)	8.50	3.44	
Starch (%)	34.52	32.17	
Soluble Fibre (%)	6.92	3.96	
uNDF (%)	7.96	6.57	
CP (%)	13.12	13.75	
Rumen degradable protein (% CP)	60.50	70.70	
Soluble protein (%)	4.54	5.68	
Ether extract (%)	2.85	2.99	
Ash (%)	5.90	4.60	
Ca (%)	0.77	0.75	
P (%)	0.36	0.37	
Mg (%)	0.28	0.26	
Na (%)	0.14	0.19	

Abbreviations: TMR = total mixed ration; ME = metabolisable energy; NEm = net energy for maintenance; NEg = net energy for gain; aNDFom = amylase and ash corrected NDF; peNDF = physically effective NDF; WSCs = water-soluble carbohydrates; uNDF = rumen undegradable neutral detergent fibre; DMI = DM intake; CONVL = conventional corn silage-based ration; DRY = dry total mixed ration.

[1] The main distinguishing feature between the DRY and CONVL rations was the absence or presence of corn silage.

[2] Feed preservative (Propionic-acid, Sorbic-acid, Na- and Ca-Propionate).

[a] Economic evaluation following average silage gross production costs, free feed bunk (KTBL, 2009).

[b] Board of trade Kassa market price information 2021.

[c] Gross market selling prices 2021.

ing within the diets, wheat straw was prechopped at a theoretical chop length of 20 mm, and 6.5% sugar beet molasses were added to the DRY diet.

Bulls were weighed monthly. Daily total DM, metabolisable energy (**ME**), and nutrient intakes such as CP, ether extract (**EE**), crude fibre, non-fibre carbohydrate (**NFC**), sugar, and starch were calculated from daily measurements of fed and rejected diet proportions per group of three animals. Nutrient intake and peNDF per pen were measured by laboratory analysis and diet particle length. The bulls were examined weekly by a veterinarian, and a complete clinical examination was performed immediately in case of suspicious findings. Sorting behaviour was derived from the inconspicuous feeding behaviour during daily visual inspection (absence of pitting or shifting of feed back and forth), accompanied by irregular sieving of the leftovers. During the entire experimental period, no clinical abnormalities were diagnosed and no animal losses occurred.

Sampling and laboratory analysis

For the determination of nutrient content, representative samples of silage, CONVL, and DRY–TMR (800 g per sample) were collected at the start of the trial and the end of every second month, vacuum sealed, and sent to the Sano-CVAS laboratory in Popovaca, Croatia, amounting to a total of five maize silage, five beet pulp silage, and 2 × 5 TMR samples. Samples were air dried at 60 °C for 24 h, ground, and then analysed in vitro according to standard Cornell Net Carbohydrate and Protein System (**CNCPS**) procedures using near-infrared reflectance spectroscopy (**NIR**) and proprietary Cumberland Valley Analytical Services (**CVAS**) European NIR-calibrations (Raffrenato et al., 2018). All subsequently calculated nutrient degradability characteristics were based on the above NIR analysis.

Particle separation

Duplicate samples of both TMR treatments collected from each group feed bunks were taken for particle size separation eight weeks after the start of each diet. Particle size samples were separated using a 3-sieve (19, 8, and 4 mm diameter) particle separator (Wasserbauer Shaky 4.0 model; WPS). The TMR Shaker Box separated the particles into four fractions: long (>19 mm), medium (<19, >8 mm), short (<8, >4 mm), and fine (<4 mm) particles. After separation, the fractions were collected, vacuum sealed, and sent to the Sano-CVAS laboratory in Popovaca, Croatia, for further analysis of the nutrient profile using near-infrared reflectance spectroscopy (**NIR**) and proprietary Cumberland Valley Analytical Services (**CVAS**) European NIR-calibrations. The physical effectiveness factor (pef) was determined as the proportion of DM of particles retained on the top three screens of the TMR Shaker Box (Yang and Beauchemin, 2006). The peNDF was calculated by multiplying the NDF content of the TMR by the pef. The particle size distribution of experimental diets is shown in Table 2.

Table 2
Distribution of particle sizes in Simmental bull diets.

Sieve/Pen (%)	Treatments[1]		SEM	*P*-value
	DRY	CONVL		
>19 mm	0.11	0.32	0.001	0.02
8–19 mm	8.00	42.41	1.000	<0.01
4–8 mm	10.61	22.49	1.050	<0.01
<4 mm	81.28	34.78	0.550	<0.01

Abbreviations: CONVL = conventional corn silage-based ration; DRY = dry total mixed ration.
[1] The main distinguishing feature between the DRY and CONVL rations was the absence or presence of corn silage.

Economic evaluations

To obtain diet/performance-specific income over feed cost (IOFC) results, the required animal biology and management data for the CNCPS diet evaluation (Fox et al., 2004) were obtained from the State Teaching and Testing Facility Hofgut Neumühle in Münchweiler/Germany. After 272 days of fattening, bulls were slaughtered. The diet/performance-specific IOFC for the 272-day fattening period was calculated as follows:

$$\mathrm{IOFC} = \gamma \times d_{(\%)} \times \mu - \delta$$

where

γ: average life weight in kg;
$d(\%)$: dressing percentage;
μ: meat price in €, adjusted for the classification/conformation premium;
δ: dietary costs in €.

To account for a flexible and individual carcass pricing scheme, the meat price was commonly adjusted by the European Union classification of the carcass quality within a bonus/malus context: Meat/Carcass price (€) = base price (classification of the animal type, e.g., veal, young bull, etc.) ± conformation premium (EUROP classification) ± fat-class premium (1–5 classification) (EC, 2008). The bulls were slaughtered at a commercial abattoir under veterinarian supervision. The dressed (free of inner organs) carcasses were cooled for 24 h at 4 °C. Subsequently, the determination of the cold-dressed carcass weight and carcass quality was performed by trained staff. Required agricultural commodity prices were obtained following the 2021 board of trade information. Carcass base price and premiums were calculated/obtained using standard market information from November 2021. Calculation of excretions and nutrient availabilities was conducted following the CNCPS (Fox et al., 2004).

Statistical analyses

A repeated-measures model was fitted to the data using PROC MIXED from SAS (version 9.4; SAS Institute Inc, Cary, NC). The model consisted of treatment, time, and treatment × time interaction as fixed effects. The random effect of pens as the experimental unit (for DMI, ME) intake, nutrient intake, and ADG/DMI ratio) and individual animals as the observational unit (for ADG) were included in the model, based on the experimental design and statistical models for pen studies described by St-Pierre (2007), Tempelman (2009), and Bello et al. (2016). Three variance–covariance structures (autoregressive type 1, compound symmetry, and Toeplitz) were tested, and an autoregressive type 1 covariance structure was selected as the best fit based on the Bayesian information criterion. All residuals were tested for normality using the Shapiro-Wilk statistic and the UNIVARIATE procedure of SAS as well as for homogeneity of variance using Levene's test and visually assessed using quantile–quantile plots. Among all variables, live BW was normally distributed, but DMI, ADG, ADG/DMI, ME intake, net energy of maintenance (**NEm**), net energy of weight gain (**NEg**), and nutrients (crude fibre, amylase and ash corrected NDF (**aNDFom**), ADF, ADL, peNDF, NFC, sugar, starch, soluble fibre, rumen undegradable neutral detergent fibre (**uNDF**), CP, rumen degradable protein (**RDP**), soluble protein, and EE intake were not normally distributed. Data that did not meet the assumptions of normality of residuals had to be log-transformed (base 10). After the log transformation, the distribution of the data was tested again, and the data were normally distributed. The significance threshold was set at $P \leq 0.05$; trends were declared at $0.05 < P \leq 0.10$.

Results

The diets were designed to maintain a similar growth rate. DRY–TMR contained 10.5 MJ ME, 6.7 MJ NEm, 4.2 MJ NEg, 13.1% CP, with 60.5% of the CP considered RDP, 2.9% EE, 51.5% NFC, and 14.8% peNDF per kg DM. The DM content of CONVL–TMR was 44.0% and was lower than the DM content of DRY–TMR, which was 72.5%. Per kg DM, CONVL feed contained 11.0 MJ ME, 7.1 MJ NEm, 4.5 MJ NEg, 13.8% CP, with 70.7% of CP as RDP, 3.0% EE, 45.2% NFC, 23.1% peNDF, meeting the requirements of Simmental cattle.

Intake and growth performance

The results of nutrient intake and growth performance are shown in Table 3 and Fig. 1A–E. Feed intake, ADG/DMI ratio, and nutrient intake were affected by treatment, time, and their interaction ($P < 0.01$). Compared with CONVL bulls, animals fed the DRY–TMR showed a higher intake of NFC, sugar (water-soluble carbohydrates), soluble fibre, and uNDF and a lower fresh and DM intake, lower ME and crude fibre intake, as well as lower aNDFom and ADF, and a lower intake of peNDF. Neither ADL intake nor starch intake was affected by treatment.

Average daily gain was not affected by treatment, but the time and time × treatment interaction was significant ($P < 0.01$). At the beginning of the experiment, ADG remained above 2 kg ADG/d in both groups until day 13 of the experiment. On day 34, ADG was lower in the DRY group compared to the CONVL group. The ADG increased from day 34 to day 90 in both groups up to 2 kg ADG/day and remained at this level until day 119. On day 134, ADG was lower in the CONVL group compared to the DRY group ($P < 0.05$). In both groups, growth rates remained constant and high (d 161–272) until the end of the experiment. On average, bulls fed the DRY–TMR gained 1.87 kg daily for 272 days compared to 1.84 kg daily for the CONVL–TMR bulls. On days 62 and 90, live weight was higher in the CONVL group compared to the DRY group ($P < 0.05$). The treatment did not affect total live weight gain (kg/head over 272 days).

Comparison of economic profits in experimental treatments

The average economic results per treatment, based on 2021 market revenue and profit margin, are given in Table 4. The acquisition cost per young bull was €750 (215 kg average live weight). Together with feed costs, direct bull investments amounted to €1 313 per animal for the DRY and €1 253 per animal for the CONVL treatment group. Compared to the CONVL treatment, the DRY treatment group showed a numerically improved feed efficiency of 4.81 vs 5.36 kg DMI/kg live weight gain ($P = 0.28$), a numerically higher total live weight gain of 505 vs 498 kg/head, and numerically higher ADG of 1.87 vs 1.84 kg/head. Despite the advantages of these performance indicators, the CONVL treatment group achieved a higher profit margin. A comparison of profit margin per bull showed positive economic results for both treatments, with an advantage for the CONVL treatment group. While the total feed cost per bull was highest in the DRY treatment group, the total feed intake was only 58.2% of the amount consumed in the CONVL treatment. The total feed cost in this study represented 29.9% of the monetary income in the DRY and 26.8% in the CONVL treatment group. Accordingly, the investment in the young animal accounted for 39.7% of the monetary income in the DRY and 39.9% in the CONVL treatment group. The realised return on investment was highest at 1.50 in the CONVL treatment group versus 1.44 in the DRY treatment group. When carcass data for the DRY and CONVL–TMR groups were examined, no significant effects were found on the revenue obtained per kg carcass weight and the dressing percentage. Carcass revenue for the DRY treatment group ranged from €4.64 to €4.70/kg and for the CONVL treatment group from €4.64 to €4.68/kg. The dressing percentage ranged from 54.6 to 58.5% for the DRY treatment group and from 54.8 to 61.0% for the CONVL treatment group.

Discussion

This study showed that feeding DRY–TMR or CONVL–TMR yielded high biological performance results of ≥1.84 kg ADG in modern Simmental genetics throughout the fattening period. A comparison of these results suggests an untapped potential for improving animal performance. On the other hand, Honig et al. (2020) reported ADG of up to 1.91 kg/head, confirming the high growth potential of Simmental bulls. Appropriate feed qualities, good hygiene, rumen degradability measurement, adequate feed structure, and feed formulation via CNCPS seem to offer advantages over conventional feed formulation solutions (Sampaio

Table 3
Feed intake and growth performance of fattening bulls fed different experimental diets.

Item	Treatments[1]		SEM	*P*-value		
	DRY	CONVL		Treatment	Time	Treatment × Time
Feed DMI, kg/d	8.95	9.22	0.242	0.01	<0.01	<0.01
ME intake, MJ/d	93.93	101.40	2.580	0.01	<0.01	<0.01
Fresh feed intake, kg/d	12.43	21.43	0.551	<0.01	<0.01	<0.01
Crude fibre intake, kg/d	0.75	1.02	0.025	<0.01	<0.01	<0.01
aNDFom intake, kg/d	2.46	3.16	0.077	<0.01	<0.01	<0.01
ADF intake, kg/d	1.46	1.73	0.042	<0.01	<0.01	<0.01
ADL intake, kg/d	0.27	0.25	0.007	0.5	<0.01	<0.01
peNDF intake, kg/d	1.32	2.13	0.054	<0.01	<0.01	<0.01
NFC intake, kg/d	4.61	4.17	0.121	0.04	<0.01	<0.01
Sugar (WSC) intake, kg/d	0.76	0.32	0.025	<0.01	<0.01	<0.01
Starch intake, kg/d	3.88	2.97	0.081	0.73	<0.01	<0.01
Soluble fibre intake, kg/d	0.62	0.37	0.018	<0.01	<0.01	<0.01
uNDF intake, kg/d	0.71	0.61	0.019	<0.01	<0.01	<0.01
CP intake, kg/d	1.17	1.27	0.032	<0.01	<0.01	<0.01
Soluble protein intake, kg/d	0.41	0.52	0.013	<0.01	<0.01	<0.01
Ether extract intake, kg/d	0.26	0.28	0.007	<0.01	<0.01	<0.01
ADG, kg/d	1.87	1.84	0.042	0.45	<0.01	<0.01
ADG/DMI ratio	0.26	0.24	0.022	<0.01	<0.01	<0.01

Abbreviations: DMI = DM intake; ME = metabolisable energy; aNDFom = amylase and ash corrected NDF; peNDF = physically effective NDF; NFC = non-fibre carbohydrate; WSCs = water-soluble carbohydrates; uNDF = rumen undegradable NDF; ADG = average daily gain; CONVL = conventional corn silage-based ration; DRY = dry total mixed ration.

[1] The main distinguishing feature between the DRY and CONVL rations was the absence or presence of corn silage.

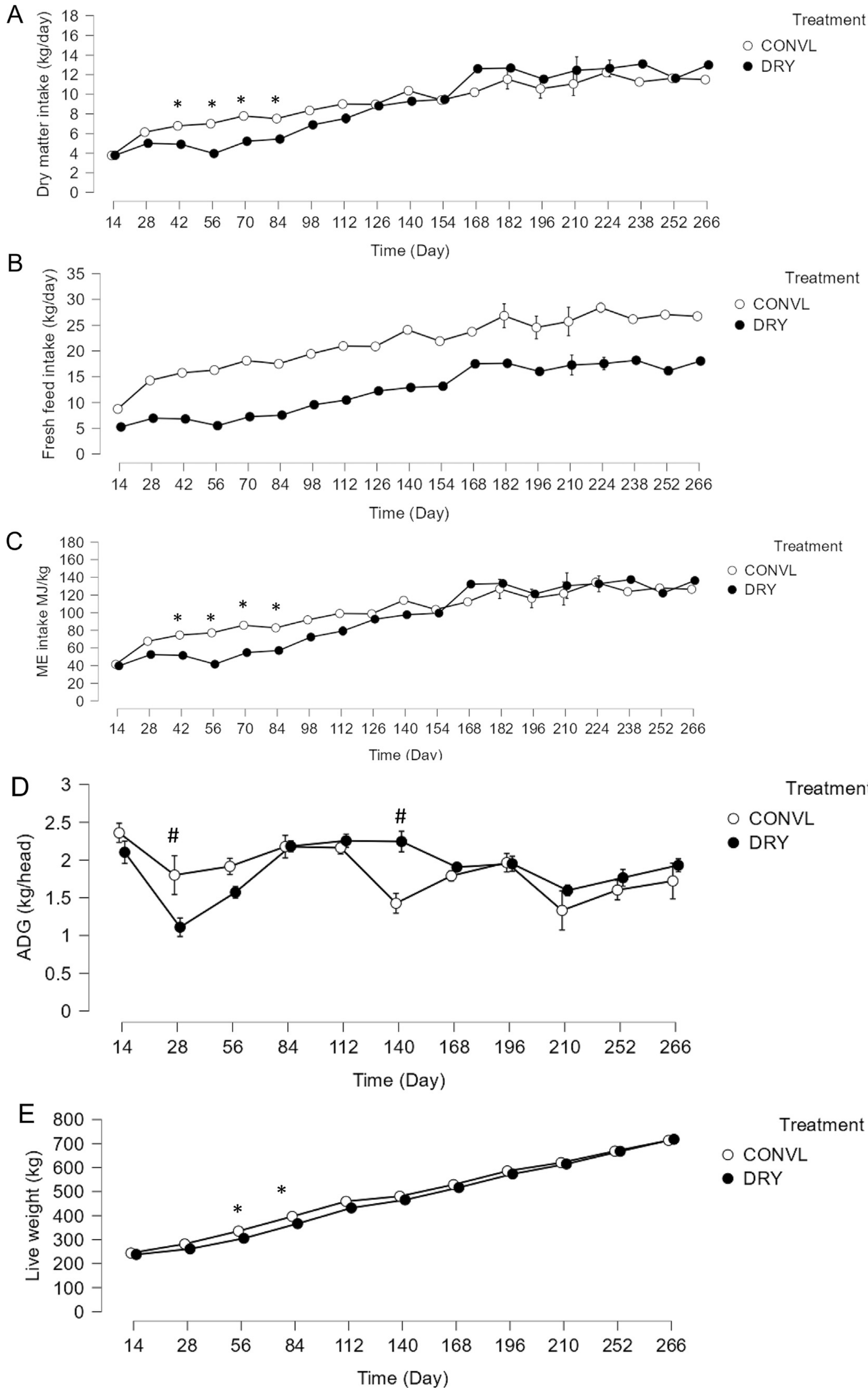

Fig. 1. DM intake (A), fresh feed intake (B), metabolisable energy (ME) intake (C), average daily gain (ADG, D), and live weight (E) of fattening bulls fed dry (DRY) or corn silage (CONVL) total mixed rations (TMRs). Symbols indicate a difference (*P < 0.05, #0.05 < $P \leq$ 0.10) between groups at a given time point (day). Data are presented as means ± SEM.

Table 4
Economic performance of fattening bulls fed different experimental diets.

Item	Treatments[1]		SEM	P-value
	DRY	CONVL		
Final live weight (kg/head at day 272)	718	713	11.0	0.57
Total live weight gain (kg/head during 272 days)	505	498	8.7	0.56
Total DM feed intake (kg/head)	2 451	2 515	46.1	0.36
Total as-fed feed intake (kg/head)	3 404	5 850	87.8	<0.01
Dressing (%)	56.4	56.6	0.50	0.93
Carcass income (€/kg)	4.7	4.7	0.01	0.16
Income (€/head)	1 887	1 877	28.8	0.65
Feed cost (€/head)	564	503	9.8	<0.01
Income over feed costs (€/head)	1 323	1 374	27.7	0.04
Profit margin (€/head)	573	624	27.7	0.04

Abbreviations: CONVL = conventional corn silage-based ration; DRY = dry total mixed ration.
[1] The main distinguishing feature between the DRY and CONVL rations was the absence or presence of corn silage.

et al., 2002; Fox et al., 2004; Schönleben et al., 2020b). Despite the crucial difference in peNDF between the two treatment diets, a constant and homogeneous DM feed intake could be achieved without sorting behaviour at the feed bunk. Preparation of DRY–TMR solutions with typical DM contents of >70% can be challenging in this regard (Miller-Cushon and DeVries, 2009). Especially for dry forage fibre sources such as straw or hay, prechopping to a theoretical chop length of ~20 mm can therefore also be recommended for bull fattening. Confirming the results of Miller-Cushon and DeVries (2009), the straw prechopping achieved and maintained in both treatment groups well-adapted rations with a desired particle length distribution to reduce the sorting behaviour of the animals.

Fattening operations and dairy farms generally try to limit the number of TMR diets produced on-site. Using a limited number of diets simplifies logistics, furthermore reduces potential errors in loading, mixing, and feeding (Hutjens, 2009). Typically, fattening operations use at least two different diets. For example, backgrounding/reception diets differ from grower/finisher diets, primarily in the ratio of forage to concentrate and the content of carbohydrates that are rapidly degraded in the rumen. To stimulate feed intake and minimise digestive disorders (e.g., rumen acidosis, leaky rumen, and leaky gut), backgrounding feeds in Europe often contain relatively high levels of sugar beet molasses and/or beet pulp, combined with minimal amounts of starch from highly processed grains (e.g., cereals and high-moisture corn) as opposed to subsequent grower/finisher feeds.

When considering DRY–TMR solutions, these should add additional efficiency and safety dimensions to the practitioner, as they only need to be prepared once or twice a week compared to traditional TMR. This advantage is already being used, particularly in rearing calves and young stock (Groen et al., 2015), but to our knowledge has not yet made its way into bull fattening feeding strategies. In this study, the DRY–TMR was prepared once per week, stored near the pen, and fed *ad libitum* daily. The CONVL feed was mixed every second day and similarly fed daily *ad libitum* to the bulls. Comparable DM feed intake and ADG performance of both treatment groups demonstrate DRY–TMR rations can be stored for several days while assuring aerobic stability for maintaining consistently high feed intake. Hence, DRY–TMR rations also offer the advantage of time efficiency and scalability. This is of importance, when on-farm labour is a limiting factor, or when animal numbers are smaller, due to farm size or seasonal animal availability. The advantage of storability can be especially important in higher temperatures during the summer as well as in tropical areas. Finally, with each kg DM fed to the animals, the DRY–TMR solution simply offers the economy of scale. Achieving similar DM intake and ADG results, due to the lower water content of the DRY–TMR, only 59% of the total weight fed via the CONVL–TMR had to be handled and processed on-farm.

Consistent with a previous study by Honig et al. (2020), numerical differences were found in meat quality traits between treatment groups. The percentage of dressing and the market price obtained per kg of carcass gave homogeneous and competitive market results in both groups. Compared to the study mentioned above, where a dressing percentage of 59.7% was reported for Simmental bulls with a live weight of 780 kg, the dressing percentage obtained in the present study was lower, 56.4% for the DRY and 56.6% for the CONVL treatment, but agrees with the results of Lukic et al. (2017). This suggests that the variability of carcass weight measurements may be strongly influenced by the cutting method used at the abattoirs.

Profound structural changes and innovations in agriculture are increasingly leading to a rethinking among practitioners, nutritionists, and veterinarians alike. Therefore, economically and environmentally beneficial beef production requires adequate feed availability, animal performance, and profitability. The economic impact of bull fattening is determined by the direct monetary income (profit margin) and the investment in feeds (KTBL, 2008). Accordingly, four different factors influence the economic impact of bull fattening strategies: (1) the price of young bulls, (2) the cost of feed and thus nutrition, (3) the classification achieved and the price of the finished bull, and (4) the biological performance parameters of the animals. These are influenced by farm management (KTBL, 2009) and can extend or shorten the fattening period due to animal health, feed intake, and growth rates. While seasonal influences and market economics mainly determine the cost of the young animal, investment in nutrition, nutritional intensity, and feed bunk management is a day-to-day consideration for the practitioner. According to previous studies, ADG is the most important factor determining the economic efficiency of fattening bulls (Wolfová et al., 2004; KTBL, 2008). Increasing ADG improves feed efficiency, reduces total feed consumption, and reduces days of excretion, and greenhouse gas (**GHG**) emissions (Yan et al., 2009; Garip et al., 2010; FAO, 2010; Schönleben et al., 2020a; Liu et al., 2021). Therefore, focusing on maximum weight gains in bull fattening can not only affect the overall economic outcome but also shorten the production period and reduce emissions per animal and per kg of animal product (animal protein for human consumption).

Conclusions

Our hypothesis that feeding DRY–TMR would lead to comparable growth rates and economic results as feeding corn silage and would not have negative effects on animal growth performance was confirmed by the results obtained. Due to the high average daily gains (average 1.86 kg/day) observed in both groups, the Simmental bulls in the current study reached their target weight in a shorter fattening period compared to typical growth curves for Simmental bulls (ADG = 1.5 kg/day and 500 kg total live weight gain, i.e., 333 days fattening period), which had a positive effect on farm profitability. Despite dietary differences in fibre intake and TMR-specific particle size distributions at comparable intakes of starch and rapidly rumen fermentable carbohydrates, there were no differences in growth performance between the two treatment groups. As shown in the DRY treatment group, ration management at the feed bunk and adequate particle size distribution of feed are essential aspects in optimising rations for finishing bulls. In Europe, exceptionally high demands are placed on the welfare and health of food-producing animals. Combined with the high growth performance of the animals, and the absence of clinically apparent disorders, the bulls could be considered as healthy. The DRY–TMR solutions might thus be an alternative feeding strategy when silage availability is limited in general, or due to reduced workforce requirements and benefits in overall farm management. To improve sustainability in the intensive fattening of bulls, new feeding strategies need to be developed based on advancing climate change. Future research should explore this issue in more depth, such as balancing regionally relevant economic complete-cost approaches and environmental goals of sustainable bull fattening.

Ethics approval

The animal experiment was conducted from December 10, 2020 to September 07, 2021 at the Educational and Research Centre for Animal Husbandry, Hofgut Neumühle, Germany. All experimental procedures were approved by the Animal Ethics Committee of the Department for Animal Welfare Affairs (Landesuntersuchungsamt Rheinland-Pfalz, Koblenz, Germany) in agreement with the German Animal Welfare Act (permit number: G-20-20-149). Animal care and husbandry were performed following the European Commission Directive 2010/63/EU of the European Parliament and of the European Council of 22 September 2010 on the protection of animals used for scientific purposes. Additionally, the bulls were slaughtered following German animal protection law and Council Regulation (EC) No. 1099/2009 on the protection of animals during slaughter.

Data and model availability statement

The data/models were not deposited in an official repository. The data are available upon request from the corresponding author.

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C. Koch participated in the methodology, formal analysis, investigation, validation, and writing the original draft. **M. Schönleben** participated in data curation, formal analysis, software, methodology, writing the original draft, review, and editing. **Joachim Mentschel** participated in conceptualisation, supervision, fundraising, formal analysis, and validation. **N. Göres** participated in the study design, methodology, investigation, and project management. **P. Fissore** participated in conceptualisation, methodology, investigation, and resources. **I. Cohrs** participated in the investigation and project management. **H. Sauerwein** participated in conceptualisation, methodology, investigation, validation, fundraising, writing the original draft, review, and editing. **M. H. Ghaffari** participated in conceptualisation, and methodology, performed the data analysis, visualisation, validation, writing the original draft, and review and revision of the manuscript.

Declaration of interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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