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Comparison between the effects of zilpaterol hydrochloride and R-salbutamol fed during the finishing period on the growth and carcass characteristics of feedlot cattle

E.C. Webb[1,3,#], C. Stock[1] & S.D. Morris[2]

[1]Department of Animal Science, Faculty of Natural and Agricultural Sciences, University of Pretoria, Private Bag X20, Hatfield, 0028, South Africa
[2]Private Feedlot Consultant, P.O. Box 53, Strathaven, 2031, South Africa
[3]Department of Animal Science, Tarleton State University, Texas A&M University System, 76401 Texas, USA

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Abstract

This study aimed to compare the effects of feeding 60 mg of the β-adrenergic agonist, zilpaterol HCl (Zilmax®), per steer per day versus feeding 120 mg of the β-adrenergic agonist, R-salbutamol (Salbutamate®10%), per steer per day for the last 30 days of the finishing period on the growth, efficiency, and carcass characteristics of 228 typical South African feedlot steers in a completely randomised control study. The steers were slaughtered at the same abattoir after a 3-day withdrawal period. The growth and feedlot parameters included starting mass, slaughter mass, average daily gain, live mass gain, and lean carcass gain. The carcass characteristics included warm (WCW) and cold carcass mass (CCW), carcass length (CL), subcutaneous fat thickness measured over the 13th rib (SCF), dressing percentage, carcass compactness, carcass classification score, age code, and fat code using the South African carcass classification system. The inclusion of zilpaterol HCl as a feed additive resulted in higher growth and efficiency, with an ADG of 1.3 kg/day (P <0.05) in steers fed zilpaterol HCl compared to 1.1 kg/day for steers fed R-salbutamol. Steers in the zilpaterol HCl experimental group had a 12.5 kg higher average slaughter mass, yielding ~3 kg higher calculated lean gain than steers fed R-salbutamol. Steers fed zilpaterol HCl yielded better carcass characteristics of 11.4 kg higher CCW and marginally longer carcasses compared to steers fed R-salbutamol. Therefore, the overall growth, feedlot performance, and carcass characteristics were higher in the zilpaterol HCl-fed steers than in R-salbutamol-fed steers.

Keywords: β-adrenergic agonist, feed additive, growth, average daily gain, lean gain, carcass characteristics
[#]Corresponding author: edward.webb@up.ac.za

Introduction

The current world population is expected to reach nearly 9.5 billion people by the year 2050 (UN, 2019). To keep up with the increasing food demand, it is vital to produce meat for human consumption sustainably and ethically, which can be achieved by vertical integration of production systems, using unconventional species, and employing technologies to enhance production responsibly (Webb and Webb, 2022). One way to increase beef production is by using approved growth-enhancing molecules, such as steroidal implants and β-adrenergic agonists, commonly referred to as β-agonists (Anderson *et al*., 2005; Webb, 2021). Zilpaterol hydrochloride (zilpaterol HCl) is a β-agonist that has been approved for use in beef feedlots in South Africa since 1995, Mexico since 1996, and the USA since 2006 (Webb & Casey, 1995; Avendaño-Reyes *et al*., 2006; Brooks *et al*., 2009; Shook *et al*., 2009; Webb *et al*., 2018). Zilpaterol HCl is widely used throughout the beef feedlot industry in South Africa and is considered the industry norm. R-salbutamol (Salbutamate® 10%) is a new addition to the list of β-agonists available in South Africa, which was

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originally used as a bronchodilator in the treatment of asthma in humans, and more recently it has been tested as a growth enhancer in livestock, with pigs being the first animals to be tested in 1996 (Oksbjerg *et al.,* 1996).

There have been numerous studies testing the efficacy of zilpaterol HCl on finishing feedlot cattle (Webb & Casey, 1995; Maritz, 1996; Morris, 1997; Avendaño-Reyes *et al*., 2006; Vasconcelos *et al*., 2008; Brooks *et al*., 2009; Elam *et al*., 2009; Hilton *et al*., 2009; Leheska *et al*., 2009; Montgomery *et al*., 2009a & 2009b; Rathmann *et al*., 2009; Shook *et al*., 2009; Hope-Jones *et al*., 2012; Strydom *et al*., 2011; Steenekamp, 2014; Webb & Agbeniga, 2018). However local studies comparing R-salbutamol with zilpaterol HCl have not been conclusive in determining the comparative effects of the molecules in finishing feedlot cattle for various reasons (Steenekamp, 2014). Two of these reasons were complications with the use of electromagnetic gate feeders (Calan feeding gate system) and an unusually cold and rainy season, which resulted in low feed intakes and therefore inconclusive results (Steenkamp, 2014). Therefore, an objective study simulating commercial feedlot conditions was required to compare the effects of zilpaterol HCl and R-salbutamol in typical South African feedlot cattle.

This research aimed to compare the effects of R-salbutamol (Salbutamate® 10%; fed at 120 mg per steer per day) versus zilpaterol hydrochloride (Zilmax®; fed at 60 mg per steer per day) over the last 30 days of the feedlot finishing period on the growth, efficiency, and carcass characteristics of typical feedlot steers.

Methods and materials

Ethical approval was obtained for this research from the Animal Ethics Committee of the University of Pretoria, with ethics approval number, EC040/10. The experimental animals were typical, South African feedlot steers fed from an average starting mass of 240 kg at a large commercial feedlot in the North-West province of South Africa. The trial was conducted from June to August, 2016 and the backgrounding phase of the cattle was for ~50 days before feedlot entry. The weather conditions ranged from minimum temperatures of 5–11°C, to maximum temperatures of 18–22°C. The feedlot recorded two rainy days, receiving 5.12 mm of rainfall; relative humidity was 35–47% (WWO, 2021). The trial was conducted during this period due to the climatic conditions being moderate, which is regarded as ideal for feedlotting.

The steers were selected as weaners from a larger group of uniform steers, after the standard backgrounding phase and before entering the feedlot. These steers were adapted and grown for 80 d in the feedlot, weighed before the finisher period and stratified from light to heavy, and then randomly allocated into two treatment groups, namely R-salbutamol (120 mg Salbutamate® 10%/steer/day as per label recommendation; e.g. inclusion of 210g Salbutamate® 10%/ton of feed at a 90% dry matter content) and zilpaterol HCl (60 mg Zilmax®/steer/day as per label recommendation; e.g. inclusion of 105g Zilmax®/ton of feed at a 90% dry matter content). After randomisation into experimental groups, the starting mass of experimental groups was compared statistically to ensure that the average starting mass of the treatment groups was similar, and to ensure a completely impartial comparison between the two β-agonist molecules. The animals were then further subdivided by random allocation into replicate groups of 20 steers per replicate group. All steers were fed the same finishing phase diet for 30 days but supplemented with either of the β-agonists for the duration of the finishing period.

The β-agonists were withdrawn after the 30-day finishing period, to comply with the recommended 3-d withdrawal period, during which the finisher ration was fed without any exogenous growth molecule supplementation before slaughter. The steers were weighed on the day the 3-d β-agonist withdrawal period commenced, as well as the day before slaughter. The procedures during the trial and general animal husbandry were strictly managed per the research protocol and by applying standard feedlot operating procedures. The feedlot manager monitored animal husbandry and health daily by observing the animals and identifying any potentially sick animals. A qualified feedlot veterinarian treated any morbid or diseased animals. Post-mortem lung and liver lesion scoring were conducted, which included lung lesions and adhesions and liver abscesses. Two animals were diagnosed with lung lesions or adhesions and liver abscesses and were omitted from the final data. Figure 1 provides a schematic illustration of the experimental design and random allocation of feedlot steers to treatment groups and replicates.

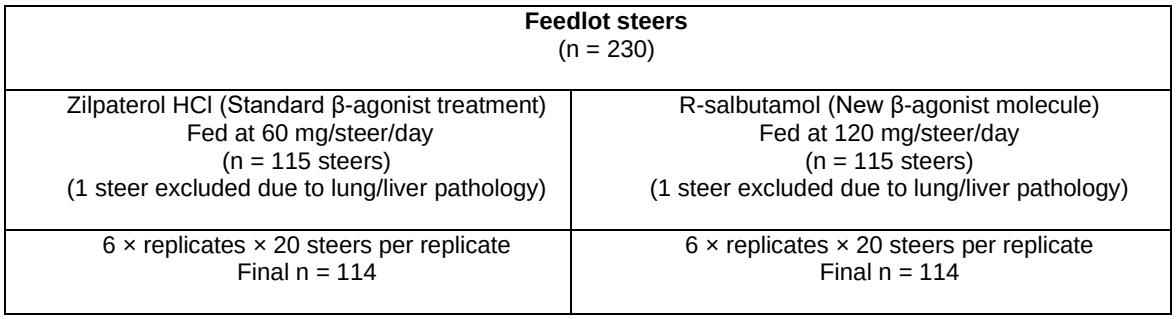

Figure 1 Illustration of the β-adrenergic agonist treatments, replicates, and the number of steers per replicate

The steers were fed a typical feedlot finisher diet with *ad libitum* access to feed and a constant supply of clean and fresh water. The dietary ingredients and nutrient content of the feedlot ration are presented in Table 1.

Table 1 Trial feed ration for R-salbutamol versus zilpaterol HCl

	kg/feed wagon
Feed ingredient	
Sunflower/Oilcake 36% protein	40
Soya Oilcake	50
Eragrostis curvula/Smuts finger grass	80
Feed lime	30
Maize bran	60
Molasses	90
Hominy Chop	1380
Silage	486
Peanut Shells	60
Sunflower Hulls	40
Water	53.35
Salt (dry)	10.51
Urea (dry)[1]	18.22
PREMIX T2 9029[2]	0.9
Rumensin 20%	0.384
Tylan® Premix (Tylosin)	0.2256
β-Adrenergic agonist	β-Ag[3]
Total mass (kg)	2400.02
Nutrient Content	**Amount**
DM (%)	78.44
Daily feed intake (kg/day)	10.77
Dry matter intake (kg/day)	8.44
peNDF	13.54
EE (%DM)	6.44
CP (%)	14.84
Monensin (mg/day)	32.74
ME (MJ/kg)	11.30
Ca (g/kg)	5.98
P (g/kg)	3.80
Vit-A (KIU)	0.3
Vit-D (KIU)	0.04
Vit-E (IU)	0.11

[1] Added as 82.08 kg 22.2% urea and 12.8% salt;[2] Premix T2 9029 (FE6792);[3] β-Ag: Either Salbutamate®10% at 0.288 kg per feed wagon, or Zilmax® at 0,2592 kg per feed wagon

Growth and feedlot performance parameters were recorded to compare the effects of the β-agonists on feedlot performance and carcass characteristics. The starting mass (kg) was measured

at the end of the grower period and thus the start of the finishing period in the feedlot. The end treatment mass (kg) of each steer was recorded after the 30 d of the finishing period, during which time the steers were fed either of the β-adrenergic agonists supplemented in the feed. Live mass gain (kg) was calculated by subtracting the starting mass from the end treatment mass of each animal, reflecting the total mass that the steers had gained during the 30-d treatment period over the finishing phase. Average daily gain (ADG; kg/day) was calculated by dividing the total mass gain (end treatment mass – starting mass) by the number of treatment days (30 d).

Carcass characteristics that were recorded included warm carcass mass (WCW) and cold carcass mass (CCW) at ~24 h post-mortem. Carcass length (cm) was measured from the caudal edge of the last sacral vertebra to the dorso-cranial edge of the atlas (Webb & Agbeniga, 2020). Carcasses were retrospectively categorised into two carcass mass categories, according to Webb & Agbeniga (2020), namely medium (240–320 kg) and large (321–410 kg), to investigate the effects of the β-agonist treatments on medium and heavy carcasses (representative of medium and late physiological maturity types of cattle). Fat thickness (mm) was measured ~5 cm from the medial line at the 13th rib. The dressing percentage was calculated by dividing the cold carcass mass by the live mass at slaughter. The percentage of muscle in the carcasses was calculated using a regression equation obtained from the dissection data from the study by Steenekamp (2014) on similar cattle and using the same β-agonist feed supplements during the finisher phase. The equation was:

$$\text{Muscle \%} = [55{,}515 - (0{,}897 \times \text{SCF}) - (0{,}022 \times \text{SW}) + (0{,}332 \times \text{DP\%})] \quad (1)$$

where SCF, subcutaneous fat thickness over the 13th rib (mm); and SW, slaughter mass (kg). The dressing percentage (DP%) was calculated as:

$$\text{DP\%} = (\text{CCW (kg)} / \text{slaughter mass (kg)}); R^2 = 0.33 (P < 0.014) \quad (2)$$

Lean gain during the finisher period (kg) is an estimated value of the approximate amount of muscle mass gain (kg) during the finisher period and was calculated using the following equation:

$$\text{Lean gain (kg)} = [\text{percentage muscle (\%)} \times \text{live mass gain (kg)}] / 100 \quad (3)$$

Carcasses were classified according to the South African Beef Carcass Classification system (Meat Classification Regulation No. 863 in Government Gazette, September 2006). This included the age code, (Class A = no permanent incisors; Class AB = 1 – 2 permanent incisors; Class B = 3–6 permanent incisors; Class C > 6 permanent incisors), and fat code (0 = no visible fat; 1 = very lean, 0–1 mm fat; 2 = lean, 1–3 mm; 3 = medium, 3, 1–5 mm; 4 = fat, 5, 1–7 mm; 5 = moderately overfat, 7, 1– 10 mm, and 6 = excessively overfat, >10 mm). Carcass conformation score was described as: codes 1 (very flat), 2 (flat), 3 (medium), 4 (round), or 5 (very round). Carcass conformation gives an indication of muscle thickness or compactness within carcasses that have a similar fatness score. Higher carcass conformation and fat scores reflect a higher proportion of saleable meat yield (percentage of expensive cuts).

All the data were recorded in Microsoft Excel and then imported into IBM SPSS Statistics 27 for statistical analyses. The data were tested for normal distribution and then analysed using General Linear Model (GLM) procedures. The effects of β-agonist treatment and carcass size category on the growth, feedlot, and carcass characteristics were tested using GLM multifactorial analysis of variance (MANOVA) procedures.

Differences between treatment means (LSMeans and standard errors) were tested at significance levels of $P < 0.05$ and $P < 0.01$. Live mass at the start of the treatment period was included as a covariate in MANOVA analyses to correct for any possible differences that existed before the trial commenced. The comparisons between treatment means and carcass mass groups were done using Bonferroni multiple range tests to correct for the small differences in the number of observations (n) per experimental and replicate group. Categorical data, such as carcass classification, fat code, and carcass conformation were evaluated using Chi-square analysis at a level of significance of $P < 0.05$.

Results and Discussion

Growth parameters and feedlot performance of steers fed zilpaterol HCl or R-salbutamol during the finisher period are summarised in Table 2. The pooled average mass of steers at the start of the finisher phase was ~464 kg ($P > 0.05$). Feedlot data obtained specifically for ADG's during the finishing phase have not been published in previous South African feedlot studies, but studies in the

USA reported ADGs of 1,27 kg/day when fed zilpaterol HCl for 30 d during the finishing phase (Elam *et al*., 2009). ADGs obtained from studies over the entire feedlot period ranged from 1,89 kg/steer/day in the starter and grower phase to 1,27 kg/steer/day in the finishing phase, and with an overall recorded ADG of 1,66 kg/steer/day (Elam *et al*., 2009). The data obtained in the present study is in line with the range described in other studies for ADG, starting at 1.7–2 kg/day during the grower phase and decreasing approximately 1,3 kg/day during the finishing phase (Elam *et al*., 2009; Strydom *et al*., 2009; O'Neill *et al*., 2010; Webb & Agbeniga, 2020).

Table 2 Growth parameters and feedlot performance (least square means ± standard error) of feedlot steers fed 60 mg zilpaterol HCl per steer per day versus steers fed 120 mg R-salbutamol per steer per day

	R-salbutamol (n = 114)	**Zilpaterol HCl** (n = 114)	**Pooled average** (n = 228)
Starting mass (kg)	460.2 ± 44.15	467.6 ± 47.37	463.9 ± 45.84
End treatment mass (kg)	494.1 ± 47.67[a]	506.6 ± 48.94[b]	500.4 ± 48.61
Live mass gain (kg)[#]	33.9 ± 15.11[a]	39.0 ± 14.16[b]	36.5 ± 14.83
ADG (kg/day)	1.1 ± 0.50[a]	1.3 ± 0.47[b]	1.2 ± 0.49
Lean gain (kg)[*]	19.7 ± 8.84[a]	22.7 ± 8.43[b]	21.2 ± 8.75

[a, b] Means with different superscript letters differ (P <0.05); SE, standard error; ADG, average daily gain during the finisher period (kg/day); [#]%live mass gain during the finisher period; *lean gain during the finisher period

Differences were found for slaughter mass, live mass gain, ADG, and lean gain in the steers in the different experimental groups (P <0.05). The mean slaughter mass of R-salbutamol-fed steers was lower (494,1 kg; P <0,01) compared to steers fed zilpaterol HCl (506,6 kg; P <0.05). The mean slaughter mass of steers in the present study was lower than that reported in the USA by Montgomery *et al*. (2009b) of 565 kg, and that reported by Baxa *et al*., (2004) of 614 kg. It is well known that cattle are grown much larger in the USA and therefore slaughtered at a much heavier mass. South African feedlot studies have reported values for live mass at slaughter ranging from 520 kg (Moholisa *et al*., 2018; Webb & Agbeniga, 2020) to 575,5 kg (Strydom *et al*., 2009).

The live mass gain of R-salbutamol-fed steers was lower (33,9 kg; P <0,01) compared to those fed zilpaterol HCl (39,0 kg) during the finishing phase. Steers fed zilpaterol HCl gained on average 5,1 kg more than those fed R-salbutamol during the final 30 d of the finishing period. Therefore, zilpaterol HCl reflected a more typical β-agonist effect in terms of increasing live mass gain and lean gain (repartitioning of energy to protein accretion) during the finishing phase. Most feedlot studies measure live mass gain from the beginning of the feedlot period after adaptation from backgrounding, and therefore there is no comparable South African literature on growth during the finishing period. In a study in the USA by Elam *et al*. (2009), during the final 50 d on the feed before slaughter, including 30 d of zilpaterol HCl feeding, the average live mass gain was 57,7 kg (566,4–624,1kg).

Zilpaterol HCl-fed steers had a higher mean ADG (1,3 kg/day; P <0,05) during the finishing phase compared to R-salbutamol-fed steers (1,1 kg/day). In the feedlot studies in the USA, the ADG of cattle fed zilpaterol HCl for 30 d or 50 d, with a 5-d withdrawal period, were 1,59 kg/day (Montgomery *et al*., 2009b) and 1,29 kg/day (Elam *et al*., 2009), respectively.

The estimated lean gain (kg) of steers fed zilpaterol HCl was higher (22,7 kg; P <0.01) compared to that of steers fed R-salbutamol (19,7 kg). The difference in estimated lean gain is important because it affects the income of the feedlot due to lean or muscle gain in the finishing phase, which contributes to carcass mass at slaughter and profit per carcass. The mean lean gain of zilpaterol HCl-fed steers was 3 kg higher than in R-salbutamol-fed steers, which equates to approximately R162,00 higher income per average carcass.

The graph in Figure 2 presents the regression of mass gain over time during the finisher period and illustrates the higher growth response in cattle supplemented with zilpaterol HCl compared to R-salbutamol (R^2 = 0,128; P <0.001). The data obtained after the classification of carcasses into medium (240–320 kg CCW) and large (321–410 kg CCW) mass categories is presented in Table 3. This was done to determine the influence of R-salbutamol and zilpaterol HCl on steers of different physiological maturity types (medium and large carcass mass categories).

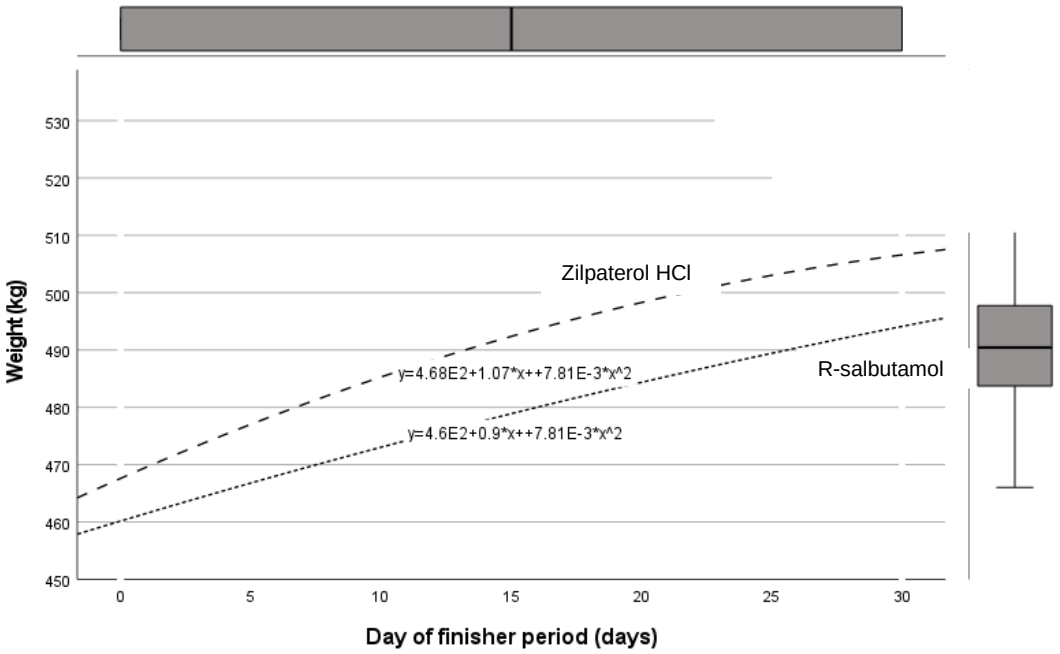

Figure 2 The regression of mass gain (growth) over days fed in steers fed either R-salbutamol or zilpaterol HCL during the finisher period

Table 3 Growth and feedlot performance (least square means ± standard error) of feedlot steers of medium and large size fed 60 mg zilpaterol HCl per steer per day versus 120 mg R-salbutamol per steer per day

	R-salbutamol		Zilpaterol HCl	
	Medium size (n = 75)	**Large size** (n = 39)	**Medium size** (n = 58)	**Large size** (n = 56)
Slaughter mass (kg)	468.0 ± 31.05[a]	544.5 ± 30.46[b]	470.0 ± 27.80[a]	544.5 ± 35.30[b]
Live mass gain (kg)	32.0 ± 14.35[a]	37.6 ± 16.0[a]	36.3 ± 19.6[a]	41.8 ± 14.35[b]
% Live mass gain[#]	6,83%[a]	6,90%[a]	7,72%[b]	7,68%[b]
ADG (kg/day)	1.1 ± 0.48[a]	1.3 ± 0.53[ab]	1.2 ± 0.54[ab]	1.4 ± 0.49[b]
Lean gain (kg)[*]	18.7 ± 8.38[a]	21.7 ± 9.44[ab]	21.5 ± 8.22[ab]	24.0 ± 8.54[b]

[a, b] Means with different superscript letters differ (P <0.05); ADG, average daily gain during the finishing period; [#]% live mass gain during the finishing phase; *lean gain during the finisher period

The mean slaughter mass (kg) of medium-framed steers fed zilpaterol HCl (470,0 kg) was similar to the medium-framed steers fed R-salbutamol (468,0 kg). Similarly, the mean slaughter mass of the large-framed steers fed zilpaterol HCl (544,5 kg) was similar to that of the large-framed steers fed R-salbutamol (544,5 kg). Both the medium-framed groups fed R-salbutamol (468,0 kg) and zilpaterol HCl (470,0 kg; P <0,05) were smaller than the large-framed steers fed either R-salbutamol (544,5 kg) or zilpaterol HCl (544,5 kg). Large-framed steers fed zilpaterol HCl gained more mass (live mass gain) (P <0,05) during the finishing period compared to the large-framed steers fed R-salbutamol, or medium-framed steers fed either zilpaterol HCl or R-salbutamol. This reflects the beneficial effects of zilpaterol HCL in larger-framed steers, as well as the greater capacity of later physiological maturity types of cattle in terms of their greater capacity to grow more efficiently to a heavier mass, as previously reported (Webb & Casey, 2010). The live mass gained by medium-framed cattle fed R-salbutamol was similar to that of medium-framed cattle fed zilpaterol HCl.

Large-framed steers in the zilpaterol HCl experimental group had a higher ADG (1,4 kg/day; P <0,05), than the medium-sized steers fed R-salbutamol (1,1 kg/day). Although the interaction between the mass category and β-agonist treatment was not statistically significant in terms of ADG, Table 2 indicates that zilpaterol HCl supplementation resulted in higher mean ADGs (P <0,05) when compared to R-salbutamol-fed steers. The mean lean gain (kg) of medium-framed steers fed zilpaterol HCl (21,5 kg) was numerically higher but not statistically different to medium-framed steers fed R-salbutamol (18,7 kg); similarly, mean gain in large-framed steers fed zilpaterol HCl (21,7 kg) was numerically higher but not statistically different from steers fed R-salbutamol (18,7 kg). Mean

lean gain was higher for large-framed steers supplemented with zilpaterol HCl (24,0 kg; *P* <0,05), compared to medium-framed steers supplemented with R-salbutamol.

The effects of the different β-agonist treatments on carcass characteristics are presented in Table 4. The differences in carcass mass between β-agonist treatments were significant (*P* <0,05), with the R-salbutamol-fed steers producing a lower CCW (307,4 kg; *P* <0.05) than the zilpaterol HCl-fed steers (318,8 kg). The mean CCW for zilpaterol HCl fed steers in the present study (318,8 kg) compares favourably with previous feedlot studies in South Africa, with values varying from 311 kg (Moholisa *et al*., 2018) to 350 kg (Strydom *et al*., 2009; Webb & Agbeniga, 2020), whereas that recorded for R-salbutamol-fed steers was slightly below this range at 307,4 kg.

Table 4 Carcass characteristics (least square means ± standard error) of feedlot steers fed 60 mg zilpaterol HCl per steer per day versus 120 mg R-salbutamol per steer per day

Carcass characteristics	**R-salbutamol** (n = 114)	**Zilpaterol HCl** (n = 114)	**Pooled average** (n = 228)
WCW (kg)	313.7 ± 31.47^{A}	325.3 ± 34.23^{B}	319.5 ± 33.32
CCW (kg)	307.4 ± 30.84^{A}	318.8 ± 33.55^{B}	313.1 ± 32.66
Carcass length (cm)	122.4 ± 13.71^{A}	123.0 ± 4.61^{B}	122.7 ± 10.21
Fat thickness (mm)	8.0 ± 4.84	7.6 ± 4.56	7.8 ± 4.70
Hot Dressing %	63.5 ± 2.09^{A}	64.2 ± 1.70^{B}	63.8 ± 1.93
Cold Dressing %	62.2 ± 2.05^{A}	62.9 ± 1.67^{B}	62.6 ± 1.90
Percentage Muscle	58.2 ± 4.60^{A}	58.4 ± 4.20^{B}	58.3 ± 4.40
Carcass compactness (kg/cm)	2.7 ± 2.14	2.6 ± 0.20	2.6 ± 1.52

[a, b] Each superscript is significantly different at a 95% level of significance (*P* <0.05); WCW, warm carcass mass (kg); CCW, cold carcass mass (kg)

Carcass length differed (*P* <0,01) between steers fed zilpaterol HCl (123,0 cm) and those fed R-salbutamol (122,4 cm; Table 4), but the numerical difference is probably too small to be of practical significance. Subcutaneous fat thickness did not differ between treatments, but the pooled average fat thickness in this study (7,8 mm), was lower compared to the 9,1 mm reported in a previous zilpaterol HCl study (Strydom *et al*., 2009).

Hot dressing % of R-salbutamol fed steers (63,5%) was lower (*P* <0,01) than in zilpaterol HCl-fed steers (64,2%). Similarly, cold dressing % of R-salbutamol-fed steers (62,2%) was lower (*P* <0,01) than that of the zilpaterol HCl-fed steers (62,9%). In a study by Montgomery *et al*., (2008), the hot dressing % for steers fed zilpaterol HCl for 35 d during the finisher period was 66%, whereas Elam *et al*. (2009) reported a yield of 65,03%. The higher carcass yields in the studies by Montgomery *et al*. (2008) and Elam *et al*. (2009) are likely due to the longer feeding of zilpaterol HCl and the considerably larger size of USA feedlot cattle. In a previous study in South Africa on steers fed zilpaterol HCl, the hot dressing % was reported as 61,4% (Strydom *et al*., 2009). The observed higher efficiency of zilpaterol HCl compared to R-salbutamol may be associated with the findings by Timmerman (1987) concerning differences in half-life and receptor sensitivity of different β-adrenergic agonists.

R-salbutamol appears to be faster acting, with a shorter half-life, than zilpaterol HCl, which may result in receptor downregulation earlier on in the finishing phase, resulting in a slightly lower growth response. The difference in the percentage of muscle was numerically small (0,2%), but statistically significant (*P* <0,01) between R-salbutamol-fed steers (58,2%) and zilpaterol HCl-fed steers (58,4%). This is in line with the higher dressing percentages, carcass mass, live mass gain, and lean gain recorded for steers fed Zilpaterol HCl.

The effects of β-agonist treatment and steer frame size (based on medium and large-size carcass categories) on carcass characteristics are presented in Table 5. Medium-sized steers supplemented with either R-salbutamol or zilpaterol HCl yielded smaller carcasses (*P* <0,05) compared to large-sized steers. Within carcass size categories, β-agonist treatment did not influence warm or cold carcass mass.

Similarly, carcass length differed between carcass size categories (*P* <0,05), but not between β-agonist treatment groups. There was no significant difference in subcutaneous fat thickness (cm)

between any of the frame-size groups, which confirms the lipolysis effect of β-agonists, as previously reported (Timmerman, 1987). The dressing percentage was interesting, because zilpaterol HCl demonstrated a more pronounced (*P* <0,05) effect in large-sized carcasses compared to medium-sized carcasses, whereas the difference between medium and large-sized carcasses was not significant in steers supplemented with R-salbutamol (Table 5). The overall effects of β-agonist treatment on dressing percentage and carcass compactness were not statistically significant.

Table 5 Carcass characteristics (least square mean ± standard error) of feedlot steers for different carcass size categories fed 60 mg zilpaterol HCl per steer per day versus 120 mg R-salbutamol per steer per day

Carcass characteristics	R-salbutamol		Zilpaterol HCl	
	Medium	**Large**	**Medium**	**Large**
	(n = 75)	(n = 39)	(n = 58)	(n = 56)
WCW (kg)	295.6 ± 19.0[a]	348.5 ± 18.92[b]	298.6 ± 18.95[a]	352.9 ± 22.57[b]
CCW (kg)	289.7 ± 18.65[a]	341.5 ± 18.55[b]	292.6 ± 18.58[a]	345.9 ± 22.12[b]
Carcass length (cm)	120.0 ± 16.21[a]	126.9 ± 3.81[b]	120.1 ± 3.36[a]	126.1 ± 3.68[b]
Fat thickness (mm)	8.4 ± 5.04	7.3 ± 4.41	7.3 ± 3.98	8.0 ± 5.1
Hot dressing %	63.2 ± 2.03[a]	64.0 ± 2.12[ab]	63.5 ± 1.46[a]	64.8 ± 1.70[b]
Cold dressing %	62.0 ± 1.99[a]	62.8 ± 2.09[ab]	62.3 ± 1.43[a]	63.5 ± 1.67[b]
Percentage muscle	58.3 ± 4.80	57.9 ± 4.36	59.3 ± 3.55	57.5 ± 4.69
Carcass compactness	2.7 ± 2.64	2.7 ± 0.13	2.4 ± 0.14	2.7 ± 0.14

[a, b] superscripts are significantly different at a 95% level of significance (*P* <0.05); WCW, warm carcass mass (kg); CCW, cold carcass mass (kg)

The results of the conformation and fat classification of carcasses from steers treated with the different β-agonist molecules are presented in Table 6. There were proportionately more conformation score 4 carcasses from steers supplemented with the zilpaterol HCl (*P* <0,05) compared to those supplemented with R-salbutamol during the finishing phase. Carcasses in the zilpaterol HCl treatment group were classified more consistently in the carcass conformation category 4 (56,7%; *P* <0,05), compared to those from the R-salbutamol treatment group, which reflects a more marked increase in muscularity and carcass conformation in steers supplemented with zilpaterol HCl.

Overall, the carcass data presented in Table 6 reflects a higher proportion of A2 carcasses (77,6%) than A3 carcasses (18,0%), with a small proportion of A4 carcasses (4,4%). This confirms the repartitioning effects of β-agonists and the tendency towards a leaner carcass, regardless of the β-agonist treatment used, which is in line with consumer preferences for lean and less fatty meat (Higgans, 2004; Webb & O'Neill, 2008). In feedlot cattle, particularly during the finishing phase, there is generally a risk for cattle to deposit excess fat and hence, exceed fat code 3. However, the use of β-agonists aids in reducing or maintaining a moderate carcass fat content, and therefore increases the proportions of carcasses with a desirable fat code of 3.

In a recent study that compared the fat codes of steers with or without the supplementation of a β-agonist in the feed for 30 d during the finishing phase, the fat codes of carcasses from zilpaterol HCl-fed steers were leaner (fat codes 2, 13%; 3, 87%) compared to those that were not fed a β-agonist (fat codes 3, 67%; 4, 33%) (Moholisa *et al*., 2018). The results presented in Table 6 indicate no statistical difference between the fat code of animals treated with the different types of β-agonists. Thus, in the current study, carcass fat classification was not affected by the type of β-agonist treatment, since both β-agonists resulted in higher proportions of A2 and A3 carcasses, i.e., leaner carcasses, which generally obtain a higher price than A4 carcasses.

Table 6 Effects of R-salbutamol and zilpaterol HCl supplementation in the feed on carcass fat classification

			R-salbutamol (n = 114)	Zilpaterol HCl (n = 114)	Total (n = 228)
Carcass Classification	3	Count	44[a]	22[b]	66
		% within carcass class	66.7%	33.3%	100.0%
		% within treatments	38.6%	19.3%	28.9%
		% of total	19.3%	9.6%	28.9%
	4	Count	65[a]	85[b]	150
		% within carcass class	43.4%	56.7%	100.0%
		% within treatments	57.0%	74.6%	65.8%
		% of total	28.5%	37.3%	65.8%
	5	Count	5	7	12
		% within carcass classification	41.7%	58.3%	100.0%
		% within treatments	4.4%	6.1%	5.3%
		% of total	2.2%	3.1%	5.3%
Fat code	2	Count	83	94	177
		% within fat code	46.9%	53.1%	100.0%
		% within treatments	72.8%	82.5%	77.6%
		% of total	36.4%	41.2%	77.6%
	3	Count	24	17	41
		% within fat code	58.5%	41.5%	100.0%
		% within treatments	21.1%	14.9%	18.0%
		% of total	10.5%	7.5%	18.0%
	4	Count	7	3	10
		% within fat code	70.0%	30%	100.0%
		% within treatments	6.1%	2.6%	4.4%
		% of total	3.1%	1.3%	4.4%

[a, b] Values with different superscript letters are different (P <0.05)

Figure 3 presents the regression of lean gain over CCW in steers treated with R-salbutamol and Zilpaterol HCl and shows a higher lean gain of steers in the Zilpaterol HCl experimental group. Regression equations for the lean gains of each of the treatment groups are provided, with an R^2-value of 0,44 and P <0,001.

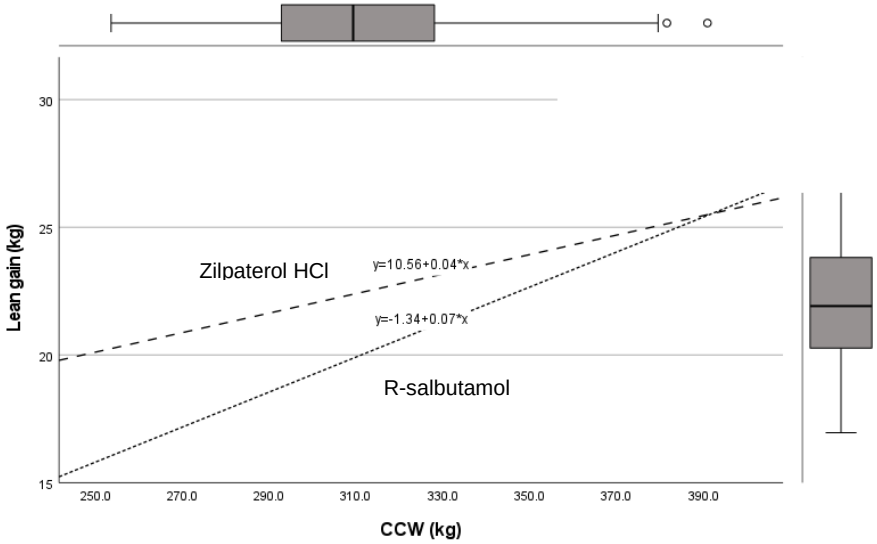

Figure 3 The regression of lean gain (kg) with cold carcass weight (kg) for steers supplemented with R-salbutamol or zilpaterol HCl in the feed during the finishing period

Conclusion

This study aimed to compare the effects of R-salbutamol versus zilpaterol HCl on the growth, efficiency, and carcass characteristics of typical South African feedlot steers during the final 30 d of feeding during the finisher phase. Zilpaterol HCl-fed steers had an overall higher live mass and growth performance during this phase compared to those fed R-salbutamol. Steers fed zilpaterol HCl also produced a heavier average slaughter mass and yielded an additional 5,1 kg of carcass mass due to a higher ADG. The mean lean gain of zilpaterol HCl-fed steers was 3 kg higher than in R-salbutamol-fed steers. The interactions between β-agonist treatment and frame-size category showed more substantial live mass gains in larger-framed zilpaterol HCl-fed steers compared to the other categories, including the larger-framed R-salbutamol fed steers, but other growth and feedlot performance characteristics within the same mass category were similar. Zilpaterol HCl supplementation of steers outperformed R-salbutamol in terms of carcass characteristics, with a higher CCW. The effect of β-agonist treatment on carcass length was marginal, but both β-agonist molecules decreased the carcass fat classification scores towards a more desirable A2 and A3 carcass, thus producing leaner carcasses and meat, which complies with the current consumer demand for beef in South Africa. Zilpaterol HCl improved carcass dressing percentage, especially in large-framed steers, compared to those supplemented with R-salbutamol.

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Authors' Contributions

EW and SM planned the experiments and supervised the study. SM was responsible for the veterinary supervision of experimental animals. EW analysed the data and CS and EW wrote the draft manuscript. EW, SM, and CS edited the manuscript and EW did the final editing and submission of the manuscript.

Conflict of Interest Declaration

The authors declare no conflict of interest.

References

Anderson, D.B., Moody, D.E. & Hancock, D.L., 2005. Beta-adrenergic Agonists. In G. Pond & A. W. Bell (Eds.) Encyclopedia of Animal Science. New York: Marcel Dekker, Inc.

Avendaño-Reyes, L., Torrez-Rodríguez, V., Meraz-Murillo, F.J., Pérez-Linares, C., Figueroa-Saavedra, F. & Robinson, P.H., 2006. Effects of two β–adrenergic agonists on finishing performance, carcass characteristics, and meat quality of feedlot steers. J. Anim. Sci. 84, 3259–3265.

Baxa, T. J., Hutcheson, J. P., Miller, M. F., Brooks, J. C., Nichols, W. T., Streeter, M. N., Yates, D. A. & Johnson, B.J., 2008. Zilpaterol-HCl alters myosin heavy chain mRNA abundance in finishing steers. MSc Dissertation, Kansas State University.

Berry, B. W., Smith, G. C. & Carpenter, Z. L., 1973. Beef carcass length and yields of boneless retail cuts. J. Anim. Sci., 37, 5, 1132–1136.

Brooks, J. C., Claus, H.C., Dikeman, M.E., Shook, J., Hilton, G.G., Lawrence, T.E., Mehaffy, J.M., Johnson, B.J., Allen, D.M., Streeter, M.N., Nicholis, W.T., Hutcheson, J.P., Yates, D.A. & Miller, M.F., 2009. Effects of zilpaterol hydrochloride feeding duration and post-mortem aging on Warner–Bratzler shear force of three muscles from beef steers and heifers. J. Anim. Sci., 87, 3764–3769.

Elam, N.A., Vasconcelos, J.T., Hilton, G., VanOverbeke, D.L., Lawrence, T.E., Montgomery, T.H., Nichols, W.T., Streeter, M.N., Hutcheson, J.P., Yates, D.A. & Galyean, M.L., 2009. Effect of zilpaterol hydrochloride duration of feeding on performance and carcass characteristics of feedlot cattle. J. Anim. Sci., 87, 2133–2141.

Higgans, A. J., 2004. Fat versus lean: The quest for beautiful buttocks. Vet. J., 217–218. Retrieved from https://pubmed.ncbi.nlm.nih.gov/15080867/.

Hilton, G. G., Montgomery, J. L., Krehbiel, C. R., Yates, D. A., Hutcheson, J.P., Nichols, W.T., Streeter, M.N., Blanton, J.R. & Miller, M.F., 2009. Effects of feeding zilpaterol hydrochloride with and without monensin and tylosin on carcass cutability and meat palatability of beef steers. J. Anim. Sci., 87, 1394–1406.

Hope–Jones, M., Strydom, P. E., Frylinck, L., & Webb, E. C., 2012. The effect of dietary beta–agonist treatment, vitamin D3 supplementation and electrical stimulation of carcasses on colour and drip loss of steaks from feedlot steers. Meat Sci., 90, 607–612. Retrieved from https://pubmed.ncbi.nlm.nih.gov/22035636/.

Leheska, J. M., Montgomery, J. L., Krehbiel, C. R., Yates, D. A., Hutcheson, J. P., Nichols, W. T., Streeter, M., Blanton, J. R. Miller, M. F., 2009. Dietary zilpaterol hydrochloride. II. Carcass composition and meat palatability of beef cattle. J. Anim. Sci., 87, 1384–1393.

Maritz, J. L., 1996. The physiological response of feedlot steers to the β–adrenergic agonist Zilpaterol. MSc Agric. Dissertation, University of Pretoria, South Africa.

Moholisa, E., Strydom, P. E. & Hugo, A., 2018. The effect of beef production system on proximate composition and fatty acid profile of three beef muscles. S. Afr. J. Anim. Sci., 48(2). Retrieved from https://journals.co.za.uplib.idm.oclc.org/doi/pdf/10.4314/sajas.v48i2.10.

Montgomery, J. L., Krehbiel, C. R., Cranston, J. J., Yates, D. A., Hutcheson, J. P., Nichols, W. T., Streeter, M. N., Swingle, R. S. & Montgomery, T. H., 2009a. Effects of dietary zilpaterol hydrochloride on feedlot performance and carcass characteristics of beef steers fed with and without monensin and tylosin. J. Anim. Sci., 87, 1013–1023.

Montgomery, J. L., Krehbiel, C. R., Cranston, J. J., Yates, D. A., Hutcheson, J. P., Nichols, W. T., Streeter, M. N., Bechtol, D. T., Johnson, E., TerHune, T. & Montgomery, T. H., 2009b. Dietary zilpaterol hydrochloride. I. Feedlot performance and carcass characteristics of steers and heifers. J. Anim. Sci., 87, 1374–1383.

Morris, S. D., 1997. A withdrawal study of the growth promoting agent, Zilpaterol in feedlot steers. MSc Agric. Dissertation, University of Pretoria, South Africa.

Oksbjerg, N., Fernandez, J. A., Jorgensen, H., Olsen, O. H., Rolph, T. & Agergaard, N., 1996. Effects of salbutamol on protein and fat deposition in pigs fed two levels of protein. J. Anim. Physiol. Anim. Nutr., 75, 1–5, 1–12. https://doi.org/10.1111/j.1439–0396.1996.tb00462.x.

O'Neill, H.A., Casey, N.H. & Webb, E.C., 2010. Interactive effect of feed protein level and zilpaterol hydrochloride on feedlot performance and meat quality of steers, S. Afr. J. Anim. Sci., 40(3), 1–5.

Rathmann, R. J., Mehaffey, J. M., Baxa, T. J., Nicholis, W. T., Yates, D. A., Hutcheson, J. P., Brooks, J. C., Johnson, B.J., & Miller, M., 2009. Effects of duration of zilpaterol hydrochloride and days on the finishing diet on carcass cutability, composition, tenderness, and skeletal muscle gene expression in feedlot steers. J. Anim. Sci., 87, 3686–3701.

Shook, J. N., Van Overbeke, D. L., Kinman, L. A., Krehbiel, C. R., Holland, B. P., Streeter, M. N., Yates, D. A., & Hilton, G. G., 2009. Effects of zilpaterol hydrochloride and zilpaterol hydrochloride withdrawal time on beef carcass cutability, composition, and tenderness. J. Anim. Sci., 87, 3677–3685. Retrieved from https://pubmed.ncbi.nlm.nih.gov/19684279/.

Steenekamp, S., 2014. Growth performance and meat characteristics of feedlot cattle fed R–salbutamol or zilpaterol hydrochloride during the finishing period. MSc Dissertation University of Pretoria. Retrieved from https://doi.org/http://repository.up.ac.za/dspace/handle/2263/43564.

Strydom, P. E., Hope-Jones, M., Frylinck, L., & Webb, E. C., 2011. The effects of a beta-agonist treatment, Vitamin D3 supplementation, and electrical stimulation on meat quality of feedlot steers. Meat Sci., 89, 462–468. https://doi.org/10.1016/j.meatsci.2011.05.012.

Timmerman, H., 1987. β–adrenergics: Physiology, pharmacology, applications, structures, and structure–activity relationships. In: Beta–agonists and Their Effects on Animal Growth and Carcass Quality. A publication of the Commission of the European Communities. Elsevier Applied Science. pp. 13–28.

UN, 2015. Sustainable Development Goals. Retrieved from https://sdgs.un.org/goals.

Vasconcelos, J. T., Rathmann, R. J., Reuter, R. R., Leibovich, J., McMeniman, J., Hales, K. E., Covey, T. L., Miller, M. F., Nichols, W. T. & Galyean, M. L., 2008. Effects of duration of zilpaterol hydrochloride feeding and days on the finishing diet on feedlot cattle performance and carcass traits. J. Anim. Sci., 86, 2005–2015.

Webb, E.C. & Casey, N.H., 1995. Fatty acids in carcass fat of steers treated with a ß–adrenergic agonist feed additive and a trenbolone acetate + oestradiol-17ß implant. Meat Sci. 41(1), 69–76.

Webb, E.C. & O'Neill, H. A., 2008. The animal fat paradox and meat quality, Meat Sci. 80, 28–36.

Webb, E.C. & Casey, N. H., 2010. Physiological limits to growth and the related effects on meat quality. Livest. Sci. 130, 33–40.

Webb, E. C. & Erasmus, L. J., 2013. The effect of production system and management practices on the quality of meat products from ruminant livestock. S. Afr. J. Anim. Sci. 43(3), 413–423.

Webb, E. C., 2015. Description of carcass classification goals and the current situation in SA. S. Afr. J. Anim. Sci., 45 (3), 229–233.

Webb, E.C., Allen, J. & Morris, S., 2018. Effects of a non–steroidal growth implant and dietary zilpaterol hydrochloride on growth and carcass characteristics of feedlot lambs. S. Afr. J. Anim. Sci. 48(4), 601–608.

Webb, E. C. & Agbeniga, B., 2020. Timing and duration of low voltage electrical stimulation on selected meat quality characteristics of light and heavy cattle carcasses. Anim. Prod. Sci. 60, 967–977.

Webb, E. C., 2021. Cis/Trans-fatty acid content of red meats and the related effects on meat quality and human health. In: Meat and Nutrition. Ranabhat, C. L. (Ed). Intech Open. London, UK.

Webb, E.C. & Webb, E.M., 2022. Ethics of meat production and its relation to perceived meat quality. Chapter 25 In: New Aspects of Meat Quality, 2nd Edition, From Genes to Ethics. P. Purslow, (Ed), Elsevier, ISBN: 9780323858793.

WWO, 2021. Potchefstroom climate weather averages, North-West ZA. World Weather Online. https://www.worldweatheronline.com/potchefstroom–weather–averages/north–west/za.aspx.