A novel production profile classification system for incoming calves that predicts feedlot growth performance

Andreas H. R. Hentzen [A] and Dietmar E. Holm [A] *

[A] Department of Production Animal Studies, Faculty of Veterinary Science, University of Pretoria, Private Bag X04, Onderstepoort 0110, South Africa.

* Correspondence to: dietmar.holm@up.ac.za

Abstract

Context: Mitigating financial risk in the feedlot environment is an ongoing occurrence, and good production is a key risk mitigator. However, production protocols are based on historic averages because of the inability to predict growth potential of incoming calves. Production profiling of individual incoming feeder calves could address these limitations.
Aims: The aim of this study was to establish criteria for optimal sorting of incoming feeder calves into various cattle groups in a feedlot that maximises feedlot profit.
Methods: South African feeder calves (*n* = 436) were classified into four production-profile (PP) categories according to a predetermined set of phenotypic traits: PP 3 (*n* = 72) representing feeder calves with the poorest feedlot growth potential, PP 2− (*n* = 191) with below-average potential, PP 2+ (*n* = 139) with above-average potential and PP 1 (*n* = 34) with above-average feedlot growth potential. After combining the data of PP 2− and PP 2+ into PP 2, mixed modelling of economically important feedlot growth traits (average daily gain (ADG), carcass ADG, and carcass exit weight) was performed to evaluate the effect of PP classification (PP 1 and PP 3), while adjusting for potential confounding effects such as starting weight (entry weight) and gender.
Key results: Carcass weights for calves with a PP classification of 3 and 1 were 15.54 kg less ($P < 0.000$), and 11.34 kg more ($P = 0.007$) respectively, than those with a PP classification of 2 (261.27 kg, 95% CI 257.94–264.57), after adjusting for entry weight, calf gender and the random effect of the feeding pen. Similar to carcass weight, calves with a PP 3 classification were outperformed by other classifications in all the measured traits ($P < 0.05$).
Conclusions: This is the first report demonstrating the ability of subjective production-profile classification to predict growth performance of individual feeder calves.
Implications: The opportunity of the PP classification system lies in value-based procurement of incoming feeder calves based on their growth potential at the start of the feeding period, and then to use technology to improve and finalise the current subjective PP classification system.

Keywords: animal functional traits, animal production, cattle feedlot, phenotype, precision farming, production profiling.

Introduction

Precision farming has emerged as a potential solution to address the challenges faced by the feedlot industry world-wide. Value-based procurement of incoming feeder calves can mitigate some of the financial risk caused by feeder calves with a low inherent growth potential. Previous studies reported the influence of calf gender and breed composition on buying preference and, therefore, the price of incoming feeder calves, as well as options relating to marketing of weaned calves; however, these studies did not investigate the true value of these characteristics on feedlot growth parameters (McCabe *et al*. 2019; Yan *et al*. 2022).

The beef sector is re-evaluating production methods that help decrease the carbon footprint, without adverse effects on food security. By improving efficiency in the intensive feeding industry, a positive contribution is made to reducing the carbon footprint (Crawford *et al*. 2022). This study attempts to predict the more efficient animal before the feeding period commences, by establishing production profiles.

It is common practice to feed cattle in batches. The data collected, such as feed intake, amount fed, days on feed (DoF), and days to marketing, to name a few are based on historic averages of the pen or batch (Schipper *et al*. 1989). This historic data (average) are analysed and remedial action is implemented. Historic data means whatever action is taken, are mainly reactive. The batches fed are being determined by weight and gender at arrival of the feedlot (Leeuw 2002). Cattle are typically fed to a common market endpoint where carcass weight and grading influence income (Smith *et al*. 1989). Research has focused more on how to improve and/or influence the marketing of carcasses for optimal income (Trenkle 2002). Sorting strategies for market optimisation have been introduced into the feedlots, towards the end of the feeding period (Cooper *et al*. 2000). Furthermore, predicting final weight and carcass weight after a feeding period has attracted research interest (Perry *et al*. 1993; Purchas *et al*. 2002). The research focused on final weight and did not consider the phenotypic makeup of the feeder calf on arrival at a commercial feedlot.

Gilbert *et al*. (1993) measured animals and studied the interaction between linear measurements and production outcomes following two different feeding programs. Smith *et al*. (1989) came close to predicting carcass outcome in their research where they used ultrasound to predict fat thickness and rib-eye area. Conroy *et al*. (2010) predicted carcass weight, kill-out proportion, carcass value, and proportion of high-value meat cuts in the carcass with pre-slaughter muscular scores. The muscular and skeletal scores were conducted at 8–12 months of age and again at pre-slaughter. These represent valuable research, but differed from this study in that the muscle and skeletal scores were conducted with the carcass in mind, and not the future growth, as was the case in this study. Furthermore, in Conroy's study, the cattle were not in a feedlot. Other studies that predicted performance used intake of dry matter and net energy of gain (Neg) early in the feeding period, and not phenotypic evaluation (Silvestre *et al*. 2019). Another study predicting growth performance in the feedlot used faecal near-infrared spectroscopy as a predictive measure (Jancewicz *et al*. 2017).

The current study attempts to estimate the growth potential of feeder calves at the start of their feeding period, which, to our knowledge, has not been done before. This could be done by classifying individual feeder calves according to their individual growth potential before they are placed into the feedlot. The concept of successfully estimating the growth potential of feeder calves before their feeding period, on the basis of their phenotypic appearance, can lead to altered and improved feeding and management programs in the future. The successful implementation of this concept could then lead to precision feeding based on the growth potential of each individual animal, which will support food security, mitigate some (financial) risks and minimise the effect of food production on greenhouse-gas emissions.

The hypothesis (H0) is that feeder cattle in South Africa cannot be sorted into respective production-profile groups, on the basis of their phenotypic appearance, before their feeding period in the feedlot commences.

The objectives of the study are as follows:

- To establish categories of production profiles at feedlot entry, on the basis of phenotypic traits that are associated with feedlot growth potential.
- To establish the relevance of the production-profile categories.

Materials and methods

This study is a prospective observational study in a South African beef feedlot and was approved by the Animal Ethics Committee of the University of Pretoria (AEC No. 192-21 and No. 051-23).

The study unit is the individual identified animal at the beginning of the feeding period, and the intervention is the subjective classification of each feeder calf into one of four production-potential (PP) categories, on the basis of their phenotype. The allotment of the PP to the respective study animal was undertaken on arrival at the feedlot, prior to processing. After processing, the animals were randomly allocated to different pens, by gender and PP classification. These PP comingled groups were fed as described below.

Animals

Our data represents feeder calves that were classified at the onset of the feeding period, repeated annually for 3 years (2019, 2020 and 2021), and followed prospectively to determine their growth performance during the feeding period. The study population (n = 436) consisted of feeder calves of different origin and mixed gender, with 18% females representing the norm for the South African feedlot industry (Ford 2002). The entry weight of the feeder calves ranged at the beginning of the feedlot phase, from 251 to 275 kg. The exact age of the animals was unknown and ranged from approximately 7 to 13 months as is the industry standard in South Africa (Ford 2002). The animals were mixed beef breeds, as per the industry standard in South Africa (Ford 2002).

Environment, feeding, housing, and management of the feeder calves

The study was performed on the Onderstepoort campus of the University of Pretoria, Faculty of Veterinary Science, from mid-summer to late autumn. The facility is located at 25°38′58″S, 28°11′7″E, with an elevation of 1276 m above sea level, and with mean minimum and maximum summer and autumn temperatures of 15°C and 34°C, and 12°C and 30°C respectively, in this area.

The study animals went through a 60-day preconditioning period before being placed into the feedlot (Hentzen *et al*. 2020). At the time of entering the preconditioning period and subsequent placement into the feedlot, all animals were vaccinated and treated for internal and external parasites, as per the feedlot prescribed protocol (Table 1). The implant strategy followed the prescribed protocol (Table 1).

Table 1. Summary of processing protocols at the start of preconditioning and the feeding phase.

Item	Preconditioning	Processing at the feedlot
Viral vaccination	MLV [A] 5-way	MLV [A] 5-way
Respiratory bacterial vaccination	*Mannheimia haemolytica* (leucotoxin)	*Mannheimia haemolytica* (leucotoxin)
Other bacterial vaccinations	7-way clostridial (toxoid), botulism (toxoid) and anthrax (avirulant live)	10-way (toxoid)
Endo- and ectoparaciticides	Endectocide (1% ivermectin)	Endectocide (1% doramectin), topical pyrethroid pour-on
Metaphylaxe	–	Depending or perceived risk per pen, either oxytetracycline or tulathromycin, or none
Growth promoter implant	40:8 TBA [B]:oestradiol	200:28 TBA [B]:oestradiol

[A] Modified live virus containing modified live strains of infectious bovine rhinotracheitis (IBR), bovine viral diarrhoea (BVD Types 1 and 2), para-influenza virus (PI3), and bovine syncytial virus (BRSV).
[B] Trenbolone acetate.

Feeder calves enrolled in this study were fed a feedlot ration formulated by a feedlot nutritionist registered with the South African Council for Natural Scientific Professions (SACNASP) and fed according to general feedlot norms. A balanced starter ration was formulated to achieve a protein content of 14–16% crude protein (CP). Metabolisable energy (ME) of 10.5–11.3 MJ ME/kg was fed for the first 14 days; a grower ration was formulated to achieve a protein content of 13–14% CP with 11.3–11.7 MJ ME/kg energy and was fed for the next 55 days, and a finisher ration was formulated to achieve 12–14% CP, 12.1–12.6 MJ ME/kg and was fed for the remainder of the feeding period. The finisher ration included a β-2 agonist (zilpaterol hydrochloride 4.8%, Growfactor®, Virbac South Africa) at the recommended inclusion rate.

The cattle were housed and kept in eight purposefully designed rectangular feedlot pens (45 m × 12.5 m) with a feeding trough on one of the short sides, and with shade netting across the width of all pens. Animals were fed in groups not exceeding 25 animals per pen, with similar numbers of animals in each of the eight pens per year. Animals with different PP classifications were represented in all eight pens each year. Animals were fed twice daily according to the intake of the previous days to a zero-bunk score (Schutz *et al*. 2011), and had continuous access to clean, fresh water.

Each year, all cattle were harvested on the same day and at the same slaughter facility, as is commonly the practice in large commercial feedlots in South Africa. In other words, cattle were not individually selected on the basis of market readiness, but were fed to the common market endpoint, grade A2/A3 (Webb 2015), for a fixed feeding period as a group. The duration was 104 days on feed (DoF) for the 2019 (n = 120) and 2021 (n = 156) cohorts, and either 116 (n = 79) or 117 (n = 80) DoF for the 2020 cohort. The harvesting of the 2020 cohort was delayed due to the impact of the Covid-19 pandemic restrictions.

The pens were cleaned of excess cattle dung once every month or when necessary. Animals in each pen were observed twice daily for any signs of disease and/or discomfort. Animals identified as sick, or in discomfort, were removed and treated according to the overseeing veterinarian's protocol. Animal welfare and management, including health management, was according to prescribed protocol and or best management practices.

Phenotypic PP classification

The study animals were individually evaluated by an experienced observer who is a specialist veterinarian (the author) on their phenotypic appearances. The development of the PP classification system evolved over a period of 8 years. Other studies have demonstrated the repeatability of similar methodologies, which have been in use in research (Perry *et al*. 1993; Reinhardt *et al*. 2009). The animal inclusion criteria for classification were the composite observable characteristics or traits (phenotype) of muscular and skeletal development, ratios thereof, and body capacity. Animals individually evaluated according to muscle and skeletal development with subsequent scoring was the intervention. Considering the phenotype presentation, each animal was categorised into one of the four production profiles (PP). The allocation for each animal followed the same methodology. Animals were evaluated from the front, the side, and from behind. The evaluation is a holistic evaluation of all traits, skeleton, and muscle. The phenotypic appearance was evaluated and an average animal (PP 2) was taken as the reference. This means, for example, the chest width of the average animal (PP2) was the reference and used to categorise into wider or narrower chest width. The evaluated animal was then classified as PP 2+ if deemed to have a better growth potential than the average (PP 2), and animals having less growth potential than the average were classified as PP 2−. In the case where the animal in question had better growth potential than the above-average (PP 2+) animal, the animal was classified as PP 1. In the same way, if the animal in question had a poorer growth potential than the below-average (PP 2−) animal, the animal was classified as a PP 3. The specific traits considered for the subjective classification are summarised in Table 2, and graphically demonstrated in Fig. 1.

Table 2. Composite observable characteristics or traits of muscular, skeletal, ratio and capacity development used to subjectively classify animals per production-potential (PP) category.

Anatomic site	**Trait**	**Production-potential (PP) category**			
		PP 3	**PP 2–**	**PP 2+**	**PP 1**
Muscle traits					
Shoulder (M. deltoides; main and lateral head of Triceps brachi)	Convexity	Concave	Flat, tends to be concave	Flat, tends to be convex	Convex
Forearm	Muscularity (M. extensor radialis; common digital extensor)	Poor hardly visible	Visible muscling	Bulging	Noticeable bulging
	V-shape	Absent			Pronounced
	Ratio diameter proximal(head of radius): distal (Ulna notch)	1:1	>1:1, but <1.5:1	>1.5:1 but <2:1	2:1
	Circumference (proximal extremity of radius)	Small			Large
Lumbodorsal line (horisontal line behind shoulder to Tuber coxae)	Convexity	Concave	Straight	Straight to convex	Convex
Loin	Muscularity (musculature around lumbar spine)	Poor hardly visible	Visible muscling	Bulging	Noticeable bulging
Rump	Convexity (gluteal muscle)	Concave	Flat, tends to be concave	Flat, tends to be convex	Convex
Buttocks	Convexity (M. semitendinosus; M. semimembranosus)	Concave, meagre	Flat, tends to be concave	Flat, tends to be convex	Very convex
Neck	Muscularity (Cervical trapezius; M. omotransversarius; M. brachiocephalicus)	Thin and flat			Thick and full
Skeletal traits					

Cannon bone	Length (carpal–>fetlock)	Short			Long
	Circumference (narrowest point of carpus)	Small			Big
Hock joint	Circumference	Small			Big
Length in body	Length (head to tail)	Short			Long
Hip	Height	Low			High
Spring of rib	Angle from vertical (rib 3–13)	High ('flat')			Low ('barrel shape')
Hip Tuber coxae	Width (medial to outer tuber coxae)	Narrow			Wide
Withers	Hight	Low			High
Stifle	Width (medial of lateral femur condyle)	Narrow			Wide
Chest	Width (medial to lateral Tuberosita of Humerus)	Narrow (standing 'on' feet)			Wide (standing 'between' feet)
Neck	Length (head to middle of shoulders)	Long			Short
Rump Tuber coxae–Tuber ishii	Length	Short			Long
Pins Tuber ishii–Tuber ishii	Width	Narrow			Wide
Head	Length	Long			Short
	Width	Narrow			Broad
	Ratio length:width	High (long and narrow)			Low (short and broad)
Capacity traits					
Rip cage	Volume	Small			Big
	Shape	Flat			Broad, rounded
	Depth	Shallow			Deep

Body	Body	Short, flat and thin			Long, broad and deep
General appearance	Muscularity	Poor			Good
	Shape	Angular/fine			Round/coarse
	Thickness	Loose			Compact
Hindquarter	Volume	Empty and narrow			Full and broad

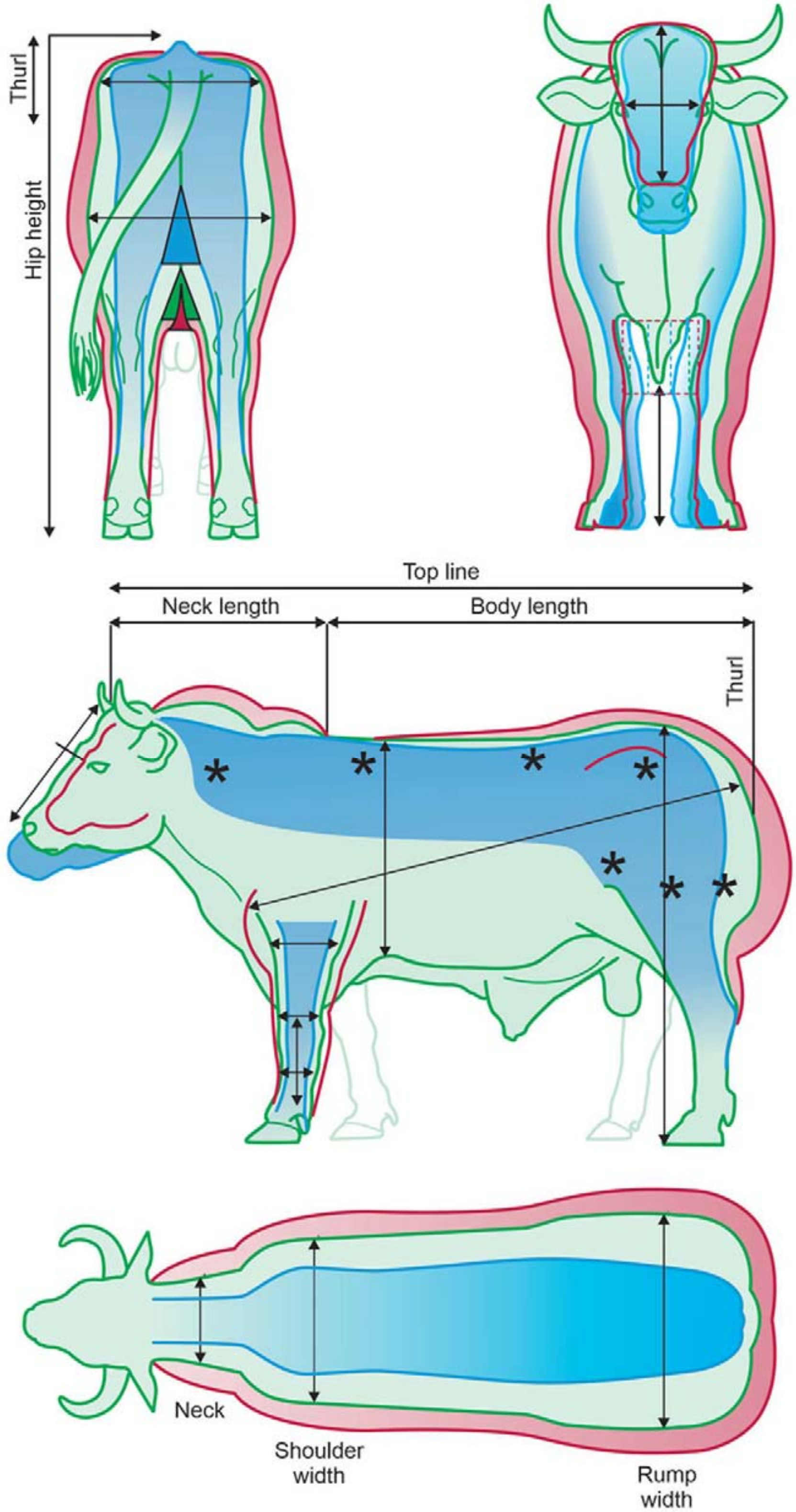

Fig. 1. Schematic illustration of the skeletal and muscular traits evaluated and described in Table 2. PP3 animal (blue), PP2 animal (green) and PP1 animal (red).

Production data collection

On termination of the feeding period, all animals were harvested at a registered slaughter facility approximately 80 km from the feedlot. Outcome data points were collected, so as to analyse the data and establish the actual growth compared with the allocated PP classification at the beginning of the feeding period. Data collected included the following (Hentzen *et al*. 2020):

$$\text{Live gain in feedlot} = \text{Out weight (kg)} - \text{In weight (kg)}$$

$$\text{ADG in feedlot} = \text{Gain (kg) / Days on feed}$$

$$\text{Carcass in weight} = 0.694 \times \text{SBW} - 38.43\ \text{kg}$$

$$\text{Carcass gain (kg)} = \text{Carcass out (kg)(measured)} - \text{calculated carcass in weight (kg)}$$

$$\text{Carcass ADG} = \text{Carcass gain (kg)/Days on feed}$$

Statistical analyses

Data were captured in a spreadsheet and transferred to STATA 14.0 (Statacorp, TX, USA) for analysis. Analysis between means of the series of measurements collected and the digital model was performed by one-way ANOVA, by using the Bonferroni test to estimate significance of differences between means. Results are statistically significant if $P < 0.05$.

Subsequent mixed-effects regression models for carcass and growth outcomes were constructed, adjusting for possible confounding factors, with calf as the experimental unit and pen as a random effect. All potential covariates with univatiate Wald *P*-values of <0.10 were initially included in the models, and covariates with Wald *P*-values of <0.05 were kept in the models. The following potential covariates were considered: gender, entry weight (live and calculated carcass weight), days on feed (DoF), morbidity, year, pen as fixed effect and animal ID as random effect. Validity of the models was confirmed by the chi-squared statistic, to estimate the overall effect of the model on the dependent variable and was considered a good fit if $P < 0.05$. For the purpose of the mixed-effects models, PP 2+ and PP 2− were combined as PP 2, representing the average feeder calf, so as to compare the carcass and growth outcomes of the better (PP 1) and weaker (PP 3) calf with that of the average (PP 2) calf after adjusting for possible confounders.

Results

Population

In total, 436 mixed-gender beef breeds, feeder calves were each classified into one of the four PP categories. PP 3 was made up of 72 animals in total, inlcuding 55 males and 17 females, representing 17% of the total. The largest numerical group was PP 2− with 191 animals, made up of 162 males and 29 females, presenting 44% of the total. PP 2+ was the second-largest group, representing 32% of the total, and consisted of 139 feeder calves, of which 28 were female. PP 1 was assigned to 34 animals, 8% of the total, of which 29 were male and five were female (Table 3).

Table 3. Descriptive statistics per production-profile (PP) classification.

Item	Overall data (mean ± s.d.)	Number per production-profile (PP) classification			
		3	2−	2+	1
n (male;female)	436 (357;79)	72 (55;17)	191 (162;29)	139 (111;28)	34 (29;5)
Mean entry weight (kg)	255.01 (29.45)	251.17a	252.71a	255.14a	275.47b
Mean exit weight (kg)	457.02 (47.24)	427.51a	454.85b	466.66b	492.76c
Mean liveweight gain (kg)	200.86 (45.88)	176.34a	202.04b	211.20b	217.29b
Mean ADG (kg/day)	1.82 (0.46)	1.60a	1.80b	1.88b	1.97b
Mean dressing percentage (%)	56.97 (3.09)	56.03a	56.55a,b	57.12b,c	57.96c
Mean carcass weight (kg)	259.63 (31.57)	239.81a	257.43b	266.60c	285.85d
Mean carcass gain (kg)	125.20 (27.75)	108.06a	124.58b	131.97cd	137.72d

Means within a row followed by the same letter are not significantly different (at $P = 0.05$).

The proportion of male animals in the study group did not differ significantly ($P > 0.05$) among the PP categories. Four (0.9%) animals were treated for bovine respiratory disease over the 3-year period.

Feedlot production data

The animals were fed to the common South African market endpoint of A2/A3 grading (Webb 2015). There were no animals with a fat grade below two, following the feeding period.

The mean entry weight of PP 1 calves was significantly ($P < 0.002$) higher than that with other PP classifications. Calves categorised as PP 3 classification had an average liveweight of 24 kg less than did those categorised as PP 1 classification when placed in the feedlot. The mean entry weight of PP categories 2+, 2−, and 3 were similar ($P > 0.05$). The females came in heavier than their male counterparts (270.24 kg vs 253.63 kg, $P < 0.001$). The carcass entry weights were calculated and showed similar trends as described for live entry weight per PP category and gender.

The mean live exit weight (kg) after the fixed feeding period differed among the PP categories ($P < 0.001$); however, PP 2+ and PP 2− categories did not differ ($P = 0.108$). PP 3 category had the lowest exit weight of 427.50 kg (liveweight basis). It was followed by PP 2−, PP 2+, and PP 1, which had the highest outweight of 492.76 kg. A numerical difference of 11.81 kg was realised between PP 2− and PP 2+. The difference in the live exit weight of the lightest, PP 3, compared with the heaviest, PP 1, was 65.25 kg and was significant ($P < 0.001$).

The captured mean carcass weight (kg) differed significantly ($P < 0.034$) among the PP categories. PP 3 had the lowest mean carcass weight of 239.81 kg, followed by PP 2− (257.43 kg), PP 2+ (266.60 kg), and PP 1 (285.85 kg) (Table 3).

Measuring the mean liveweight gains in the feedlot and dressing percentage, the trend of PP 3 being the poorest performing PP category continued, as was the case for the calculated carcass gain using our formula described previously (Hentzen *et al*. 2020) (Table 3).

The mean rate of gain (ADG) was calculated on a live as well as carcass basis. The trend of PP 3 performing the poorest continued. The results were no different when calculating the carcass rate of gain (CADG). The rate of gain of PP 3 was significantly slower than in the other categories on a live-ADG basis ($P < 0.000$) (Table 3).

The above results were obtained using ANOVA. The ANOVA analyses cannot explain all the effects, such as the effect of gender, entry weight, year, and random effects of group and individual animals. Mixed multiple-regression models were used for that purpose.

After combining the data of the PP 2− and PP 2+ categories into category PP 2, and after adjusting for the significant effects of the group of animals (feeding pen), the year, the entry weight, and the gender, carcass weight for calves with a PP classification of 3 and 1 were 15.54 kg less ($P < 0.000$), and 11.34 kg more ($P = 0.007$) than those with a PP classification of 2 (261.27 kg, 95% CI 257.94–264.57) respectively (Table 4). The effect of entry weight was significant (regression coefficient = 0.71, i.e. for every 1 kg heavier entry weight, calves produced 0.71 kg more carcass at the end of the feeding period). The multiple-regression model demonstrated that the effect of PP classification on carcass weight remained significant even after adjusting for the effect of the entry weight of calves (i.e. both the entry weight and the PP classification had independent significant effects on carcass weight).

Table 4. Mixed-effects regression model of the carcass weight (kg).

Predictor	**Level**	**Coefficient**	**95% CI**		***P*-value**
PP class	1	11.34	3.13	19.55	0.007
	2	0.00			
	3	−15.54	−21.36	−9.73	0.000
Gender	Female	0.00	–	–	–
	Male	19.38	11.77	26.99	0.000

Entry weight (kg)		0.71	0.61	0.82	0.000
Cohort date	2019	0.00	–	–	
	2020	27.39	18.22	36.57	0.000
	2021	24.75	16.63	32.88	0.000
		Variance	**95% CI**		***P*-value**
Random effects	Pen	37.06	13.02	105.49	0.001

When using a similar model looking at the carcass gained (kg) over the feeding period, it is evident that PP 3 and PP 1 gained 15.54 kg less and 11.34 kg more respectively, than did PP 2 ($P < 0.001$).

A similar mixed-effects linear regression model of carcass ADG over the feedlot period, adjusted for the random effect of group, date, and gender, demonstrated that PP 3 and PP 1 had 0.14 kg/day lower and 0.10 kg/day higher rate of carcass gain than did PP 2 (representing the average carcass growth) respectively ($P < 0.000$).

Discussion

The current best management practice in feedlots in South Africa (excluding custom feeder yards) is based on managing the average, as reported by Dave Ford, former CEO of the South African Feedlot Association at the Aldam cattle school in 2009. Sorting before the feeding period commences does occur, but gender and weight are the only categories used for sorting, and with the wide range of entry weight as well as gender representation seen in the different PP classifications in our data, this traditional sorting clearly does not provide an adequate representation of the growth potential of each individual animal. Sorting is also undertaken before harvesting to improve the product sold (Cooper *et al*. 2000). Cooper's reported sorting method is different from the intention of sorting methods based on PP as presented here, where sorting attempts to aid in categorising feeder calves into groups on the basis of growth potential before the feeding period commences. The batches of cattle purchased and/or the groups that enter the feedlot vary considerably in phenotypic appearance. The seed-stock industry is forever measuring to improve the seed stock produced (Bosman 1999; Bonsma 2001; Massman 2015). Part of their method is phenotypic evaluation. The phenotypic evaluation from the seed-stock industry indicating growth potential was considered in this work. Using phenotypic evaluation to evaluate feeder calves for their growth potential in the feedlot on the basis of muscle and skeletal development is discussed.

The developed subjective classification system is based on the phenotypically evaluated growth potential of the individual animal before it commences with the feeding period in the feedlot. Because average-based procurement and average-based management systems are mainly followed, our intention was to determine the potential value of individual categorisation of feeder calves, before the commencement of the feeding period, according to their production profile (Table 2). It is an individual proactive approach, compared with a historic group average, which is a retrospective approach.

The growth potential is based on muscular, skeletal, ratios, and body capacity development. The feeder calves with PP 3 were outperformed by the other PP categories (PP 2−; PP 2+; PP 1) in all aspects. This is after adjusting for the fact that calves with PP 1 classification had a heavier mean entry weight (kg). It has been shown that feeder calves, at placing into the feedlot, with better muscling and better skeletal development, are heavier than are counterparts that are less developed in that regard (Maslov 2013; Kamilov *et al*. 2014). The poorer growth of the PP 3 was shown in important economic production parameters. Calves classified as PP 3 were inferior in all feedlot and carcass growth measurements. This included economically important parameters such as carcass weight (kg), carcass weight gain (kg), and carcass average daily weight gain (CADG). These are but a few economic parameters supporting financial gain in the feedlot environment (Fisher 1989). The economically important growth parameters in this study were measured both on a live and carcass basis. The weight gained in the feeding period, both on a live and carcass basis, represents the amount of added weight to the purchased weight. It is the sum of ADG and time in the feedlot. The rate at which the weight was gained (ADG), on a live, and on a carcass basis, measured over the feeding period in the feedlot contributed substantially to the exit weight (kg). Since PP 3 was outperformed by all the other PP categories in the economically important measurements, it can be assumed that the income from this group is the lowest, because the value (R/kg) for carcass was the same for all animals. They were all fed to the same end-stage for the South African market (Webb 2015). This study has shown that compared with PP3, the PP 1 class can be finished, to the market endpoint of A2/A3, like all the other PP categories, with an increased income when fed for the same period (DoF).

The PP 1 gained the most kilograms (live and carcass), and did so at the quickest rate (live and carcass), resulting in the highest-weight (kg) carcass eligible to be sold. Furthermore, the results of this study suggest a positive influence on the dressing percentage because the additional carcass weight came from carcass growth (Table 3). However, it has previously been well described that dressing percentage is positively correlated with carcass weight (Bruns *et al*. 2004) and, in our data, the correlation between PP classification and carcass gain appears to be higher than that between PP classification and dressing percentage (Table 3). Several confounding factors affecting dressing percentage have been described previously, which may account for this finding (Geay 1978; Kirton *et al*. 1984; Aleksic *et al*. 2002; Litherland *et al*. 2010; Coyne *et al*. 2019). For this reason, and due to their economic importance, we used carcass outcomes rather than dressing percentage to model the effect of PP classification.

In this study, the dry-matter intake (DMI) of individual calves could not be measured. This resulted in not being able to measure feed-to-gain ratio. There is a positive genetic and phenotypic association between ADG and feed conversion ratio (FCR) (Torres-Vázquez *et al*. 2018). On the basis of that research, it can be assumed that PP 3 calves with lower ADG and CADG represent feeder calves with a poorer FCR. The better ADG group in this study, had the heaviest carcasses, further corresponding with the study of Torres-Vázquez *et al*. (2018) and further supporting the assumption concluding that the better ADG group has a better feed-to-gain ratio. This supports why the heavier cattle could finish in the same days on feed, using the current feeding protocol.

Further studies should be conducted by applying the same methodology, in a commercial feedlot where individual FCR and dressing percentage should be studied in more detail. The difference among the important growth parameters in PP categories, with PP 3 being the weakest, followed by PP 2−, then PP 2+ and PP 1, was constant (Table 3). The confidence interval was not always significant. In the economic important growth parameters where significance was not obtained, the reason is likely to be found in the subjective evaluation. It is possible that the experienced observer classified calves as PP 2+, which should have been PP 1 cattle, and *vice versa*. The carcass gain of PP 1 was 6.96 kg more than that of PP 2+ ($P = 0.103$). Together with the carcass rate of weight gain (CADG) of PP 1 being better than that of PP 2+ ($P < 0.001$) resulted in a nominal sellable exit-weight carcass of PP 1 that tended to be 7.9 kg more than for PP 2+ ($P = 0.071$). This is based on mixed-effects linear regression models of carcass weight and carcass gain, adjusted for the effects of date and gender and the random effect of group. This demonstrated that the additional carcass gain, and carcass rate of weight gain achieved by PP 1 feeder calves is almost completely in the form of carcass growth.

Therefore, when using PP 2 (representing the average feeder calf) as a reference point, and considering the fact that current production protocols are designed for the PP 2 category of calf, our data show that current feedlot production systems probably do not realise the additional growth potential of PP 1 calves. Similarly, it could be argued that our current production systems probably over-invest in PP 3 calves that will not realise the growth that the production protocol is designed for.

This predictive PP classification opens the doors for value-based procurement strategies in the feedlot industries. In the feedlot, there is potential to use these data for precision feeding and management in future. Calves with PP 1 are the most efficient and have the potential to be fed for longer; because their ADG, CADG, and the assumed feed-to-gain ratio are the best, their cost of gain is assumed to be the lowest, and with that, they are an ideal feeder calf (Wells 2020). Feeding these calves for longer, more weight is added economically with improved financial returns. In contrast, calves with PP 3 probably need to be fed shorter. Further room for improvement is to feed the PP 1 calves different rations and/or times on rations, from those fed to other PP calves, with the goal of exploiting the growth potential through precision feed and feeding protocols. The adaptation of precision management has benefited the agricultural landscape (Adrian *et al*. 2005). It further has the potential to influence breeding strategies (seed-stock selection) downstream and beef production (carcass quality) upstream.

On the basis of Crawford's *et al*. (2022) research, the classification of feeder calves into efficiency groups has the potential to decrease the carbon footprint, because the efficiency of PP differs. Low-energy ratios for PP3 and alternate ratios for PP1 can be formulated with the aim of a net reduction in the carbon footprint. This net reduction in the carbon footprint is believed to be bigger than the current management practice of feeding to the average (Crawford *et al*. 2022).

In the South African feedlot industry, heifers are part of the group of feeder calves placed in the feedlot. The 18% (79/436) heifers in the study group make this study population representative of the industry (Ford 2002). The heifers had a higher entry weight (kg) than did their representative male counterparts per classification. The heavier female placing weight is assumed to make up for the shorter feeding period (104 days). Heifers are known to have a slower rate of gain than for males (Reyneke 1976). This results in lower gains and thus lower selling weights when fed over the same period as for male counterparts. Higher placing weights were the corrective action. The effect of entry weight was accounted for in the mixed linear regression models. It is interesting to note that PP 1 and PP 2+ heifers have a better carcass weight gain (kg) than do males in PP 3. This sheds new light on procurement decisions when it comes to purchasing heifers for the feedlot. Heifers have been assumed to achieve less growth than their male counterparts, irrespective of their growth potential (Thrift *et al*. 1969). This study has shown that some heifers, on the basis of the PP classification in this study, actually have more growth potential than do some males when fed under the same conditions. Furthermore, this study has supplied numerical differences that can aid in establishing better value propositions for heifers and poor growth-potential feeder calves.

To our knowledge, no previous study has attempted to classify feeder calves on comprehensive phenotypic traits, into production-potential categories before the feeding period commences. Previous studies investigated some traits using linear measurements, such as the circumference of the upper arm and the correlation with growth (Gilbert *et al*. 1993). Body dimensions were considered and study animals received two different rations, not resembling a feedlot environment. Studies were conducted in the 1950s measuring animals and correlated production in subsequent growth environments. The author chose not to consider those data, since the phenotypic feeder calves have changed since (Massman 2015). In this study, it was successfully shown, that the growth of the feeder calf can be predicted, by using described PP categorisation. This is despite the subjective evaluation. The value of subjective evaluation is still used in other research (Reinhardt *et al*. 2009; Tatum *et al*. 2012; Parham *et al*. 2019). The experience of the evaluator contributed to the repeatability but is not essential as described by Parham *et al*. (2019). The hypothesis that feeder calves cannot be categorised into production-potential categories before the feeding period commences, is proven wrong.

With this study as a baseline, measurements, ratio and the accuracy of PP classification could be further improved by substituting the current subjective classification with digital imaging and artificial intelligence (AI) technology.

Studies improving the subjective classification methodology are indicated. This can lead to objective measurements, such as image technology, which can be used in further studies attempting to define the meaning and assist in redefining current (average) best-managed practices to precision-based practices in feedlots.

Conclusions

The results of this study have led to the conclusion that feeder calves can be successfully classified according to their future growth potential, on the basis of a subjective categorisation of phenotype traits before their feedlot phase commences. Calves with a PP 3 classification were outperformed by those with PP 2−, PP 2+, and 1 classification in all the measured traits.

This study is fundamental in contributing to future studies, current commercial applications, and has the potential to change the feedlot, seed stock, and beef landscape by establishing precision management practices based on the growth potential of individual animals at feedlot entry.

Data availability

The data obtained in this study are stored in the University of Pretoria's research data management platform (https://researchdata.up.ac.za/account/items/23929170/edit).

Conflicts of interest

The authors declare no conflicts of interest.

Declaration of funding

The project was funded by the Technology Innovation Agency of South Africa (Department of Trade and Industry), Project number 11406/01.

Acknowledgements

The authors thank the staff and students of the Faculty of Veterinary Science for their support during data collection.

References

- Adrian AM, Norwood SH, Mask PL (2005) Producers' perceptions and attitudes toward precision agriculture technologies. *Computers and Electronics in Agriculture* **48**, 256-271.
- Aleksic S, Miščević B, Petrović MM, Pavlovski Z, Josipovic S, Tomasevic D (2002) Investigation of factors affecting the results regarding the dressing percentage value of male young cattle of Domestic Simmental breed and crossbreds of Domestic Simmental and Limousine breed. *Biotechnology in Animal Husbandry* **18**(3–4), 9-14.
- Bonsma J (2001) 'Livestock production: man must measure.' 2nd edn. pp. 100–107. (Agri Books: South Africa)
- Bosman DJ (1999) Selecting cattle for functional efficiency. In 'Beef breeding in South Africa. Commemorating 40 years of beef cattle performance testing 1959-1999'. (Eds MM Scholtz, L Bergh, DJ Bosman) pp. 13–24. (Agricultural Research Council Animal Improvement Institute: Irene, South Africa)
- Bruns KW, Pritchard RH, Boggs DL (2004) The relationships among body weight, body composition, and intramuscular fat content in steers. *Journal of Animal Science* **82**, 1315-1322.

- Conroy SB, Drennan MJ, Kenny DA, McGee M (2010) The relationship of various muscular and skeletal scores and ultrasound measurements in the live animal, and carcass classification scores with carcass composition and value of bulls. *Livestock Science* **127**, 11-21.
- Cooper R, Klopfenstein T, Milton T (2000) Sorting or topping-off pens of feedlot cattle. Nebraska Beef Cattle Reports, 365. University of Nebraska-Lincoln, Animal Science Department
- Coyne JM, Evans RD, Berry DP (2019) Dressing percentage and the differential between live weight and carcass weight in cattle are influenced by both genetic and non-genetic factors. *Journal of Animal Science* **97**, 1501-1512.
- Crawford DM, Hales KE, Smock TM, Cole NA, Samuelson KL (2022) Effects of changes in finishing diets and growth technologies on animal growth performance and the carbon footprint of cattle feeding: 1990 to 2020. *Applied Animal Science* **38-1**, 47-61.
- Fisher J (1989) Economics of beef feedlot production, Ontario, 1987, Economics and Policy Coordination Branch. Report No. 89–10. Ontario Ministry of Agriculture and Food, Toronto, ON, Canada.
- Ford D (2002) South African Feedlot industry and economics of beef production. The South African Feedlot Association, Chapter 2. In 'Feedlot management'. (Ed. KL Leeuw) pp. 12–26. (Agricultural Research Council Animal Production Institute: Irene, Pretoria, South Africa)
- Geay Y (1978) Dressing percentage in relation to weight, sex and breed. In 'Patterns of Growth and Development in Cattle: A Seminar in the EEC Programme of Coordination of Research on Beef Production held at Ghent', 11–13 October 1977. pp. 35–46 (Springer: Netherlands).
- Gilbert RP, Bailey DRC, Shannon NH (1993) Body dimensions and carcass measurements of cattle selected for postweaning gain fed two different diets. *Journal of Animal Science* **71**, 1688-1698.
- Hentzen AHR, Thompson PN, Holm DE (2020) The effect of preconditioning on production and antibiotic use in a South African beef feedlot. *Animal Production Science* **60**(15), 1822-1829.
- Jancewicz LJ, Penner GB, Swift ML, Waldner CL, Gibb DJ, McAllister TA (2017) Predictability growth performance in feedlot cattle using fecal near-infrared spectroscopy. *Canadian Journal of Soil Science* **97**, 701-720.
- Kamilov FK, Farshatova ER, Enikeev DA (2014) Cellular-molecular mechanisms of bone tissue remodeling and its regulation. *Fundamentalnye Issledovaniya* **7**, 836-842.
- Kirton AH, Carter AH, Clarke JN, Duganzich DM (1984) Dressing percentages of lambs. *Proceedings of the New Zealand Society of Animal Production* **44**, 231-233.
- Leeuw KJ (2002) Introduction to nutrition. Agricultural Research Council Animal Nutrition and Animal Products Institute, Irene. Chapter 4. In 'Feedlot management'. (Ed. K-J Leeuw) pp. 54–62. (Agricultural Research Council Animal Production Institute: Irene, Pretoria, South Africa)
- Litherland A, Dynes R, Moss R (2010) Factors affecting dressing-out percentage of lambs. *Proceedings of the New Zealand Society of Animal Production* **70**, 121-126.
- Massman CP (2015) 'Visual evaluation of Simmental Fleckvieh cattle.' (Bayern-Genetik GmbH: Munich, Germany)

- Maslov LB (2013) Mathematical model of structural adjustment of bone tissue. *Russian Journal of Biomechanics* **17**, 39-63.
- McCabe ED, King ME, Fike KE, Hill KL, Rogers GM, Odde KG (2019) Breed composition affects the sale price of beef steer and heifer calves sold through video auctions from 2010 through 2016. *Applied Animal Science* **35**, 221-226.
- Parham JT, Tanner AE, Wahlberg ML, Grandin T, Lewis RM (2019) Subjective methods to quantify temperament in beef cattle are insensitive to the number and biases of observers. *Applied Animal Behaviour Science* **212**, 30-35.
- Perry D, Yeates AP, McKiernan WA (1993) Meat yield and subjective muscle scores in medium weight steers. *Australian Journal of Experimental Agriculture* **33**, 825-831.
- Purchas RW, Fisher AV, Price MA, Berg RT (2002) Relationships between beef carcass shape and muscle to bone ratio. *Meat Science* **61**, 329-337.
- Reinhardt CD, Busby WD, Corah LR (2009) Relationship of various incoming cattle traits with feedlot performance and carcass traits. *Journal of Animal Science* **87**, 3030-3042.
- Reyneke J (1976) Comparative Beef production from bulls, steers and heifers under intensive feeding conditions. *South African Journal of Animal Science* **6**, 53-58.
- Schipper C, Church T, Harris B (1989) A review of the Alberta certified preconditioned feeder program (1980–1987). *Canadian Veterinary Journal* **30**, 736-741.
- Schutz JS, Wagner JJ, Neuhold KL, Archibeque SL, Engle TE (2011) Effect of feed bunk management on feedlot steer intake. *The Professional Animal Scientist* **27**, 395-401.
- Silvestre AM, Cruz GD, Owens FN, Pereira MCS, Hicks RB, Millen DD (2019) Predicting feedlot cattle performance from intake of dry matter and Neg early in the feeding period. *Livestock Science* **223**, 108-115.
- Smith MT, Oltjen JW, Dolezal HG, Gill DR, Behrens BD (1992) Evaluation of ultrasound for prediction of carcass fat thickness and longissimus muscle area in feedlot steers. *Journal of Animal Science* **70**(1), 29-37.
- Tatum JD, Platter WJ, Bargen JL, Endsley RA (2012) Carcass-based measures of cattle performance and feeding profitability. *The Professional Animal Scientist* **28**, 173-183.
- Thrift FA, Kratzer DD, Kemp JD, Bradley NW, Garrigus WP (1969) Effect of sire, sex and sire x sex interactions on beef cattle performance and carcass traits. *Journal of Animal Science* **30**, 182.
- Torres-Vázquez JA, van der Werf JHJ, Clark SA (2018) Genetic and phenotypic associations of feed efficiency with growth and carcass traits in Australian Angus cattle. *Journal of Animal Science* **96**, 4521-4531.
- Trenkle A (2002) Effects of sorting steer calves on feedlot performance and carcass value. *Iowa State University Animal Industry Report* **1**(1).
- Webb EC (2015) Description of carcass classification goals and the current situation in South Africa. *South African Journal of Animal Science* **45**, 229-233.
- Wells S (2020) Prediction of the growth performance of feedlot cattle using phenotypic and anthropometric measures. MSc thesis, University of Pretoria, South Africa.
- Yan M, Schmit TM, Baker MJ, Le Roux MN, Gómez MI (2022) Sell now or later? A decision model for feeder cattle selling. *Agricultural and Resource Economics Review* **51**(2), 343-360.