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BeefSpecs fat calculator to assist decision making to increase compliance rates with beef carcass specifications: evaluation of inputs and outputs

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Abstract. This study evaluated the BeefSpecs fat calculator, a decision-support system developed to assist the beef industry to increase compliance rates with carcass specifications (weight and fat specifications). A challenge to the BeefSpecs calculator and a sensitivity analysis were used to evaluate the inputs and outputs of BeefSpecs. Five industry datasets (n = 80, 97, 68, 25, and 13 for Datasets 1–5, respectively) of *Bos taurus*, *Bos indicus*, and *Bos taurus* × *Bos indicus* breeds for steers and heifers were collated to challenge BeefSpecs, and a nine-way factorial matrix (n = 57 600) of input variables was created for the sensitivity analysis. There were no significant ($P > 0.05$) differences in the mean bias between observed and predicted values in any of the datasets but there were significant ($P < 0.01$) differences in the unity of slope for Datasets 2, 3, and 5. The root-mean-square error was 1.72, 2.61, 2.87, 2.68, and 2.00 mm for Datasets 1–5. The decomposition of the mean-square error of prediction indicated that most of the error contained in the predictions of all models was of a random nature (94%, 85%, 85%, 95% for Datasets 1–4), except in Dataset 5, which had a 47% proportion of error in the slope component. All datasets indicated little bias (0.13%, 12.19%, 12.69%, 0.60%, and 0.12% for Datasets 1–5) in the model predictions. An analysis of variance with the nine-way factorial matrix on the predicted output of final P8 fat was conducted for the sensitivity analysis. A significant ($P < 0.01$) four-way interaction of days on feed × frame score × initial liveweight × sex was detected. Final P8 fat was sensitive to measurement error in the inputs of frame score when animals had longer feeding periods (e.g. 180 days) and to initial P8 fat when animals had lower initial liveweights (e.g. 200 kg) and higher frame scores (e.g. 7). For each unit of error in estimating frame score, BeefSpecs predicts final P8 with an error of up to 2.3 mm in heifers and up to 1.7 mm in steers. Error in the estimation of initial P8 fat of 2 mm will result in an error of up to 3 mm in the prediction of final P8 fat. The sensitivity analysis of BeefSpecs input variables (frame score and initial P8 fat) on the prediction of final P8 fat indicates that increasing the accuracy of estimating frame score and P8 fat is an issue that needs addressing.

Additional keywords: cattle, DSS, frame score, P8 fat depth.

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Introduction

The BeefSpecs fat calculator (http://beefspecs.agriculture.nsw.gov.au/, accessed 26 August 2014) is a decision-support system (DSS) developed to assist the beef industry increase compliance rates with the carcass specifications hot standard carcass weight (HSCW, kg) and P8 fat (mm). The early stages of BeefSpecs development (Walmsley *et al*. 2011) and a sensitivity analysis of the impact of on-farm measured inputs on the predictive accuracy of BeefSpecs (Walmsley *et al*. 2013) have been outlined previously.

A model that predicts the effects of nutrition on composition of empty body gain in beef cattle (Keele *et al*. 1992) was modified to underpin BeefSpecs, and a description of that modification is provided by Walmsley *et al*. (2014). Keele *et al*. (1992) conducted a sensitivity analysis of the changes in simulated empty-body fat-free weight (EBFFW) in response to a change of ±10% in six parameters. The study found that K_{max} (the maximum value for the fractional growth rate of EBFFW relative to the fractional growth rate of empty body weight, EBW) and $EBFFW_{MAT}$ (EBFFW for mature cattle of a specific sex and genotype) were the most sensitive parameters for growing cattle of 180–450 kg EBFFW. The sensitivity of changes in θ (the fattening parameter that modulates the effect of rate of EBW gain on empty body composition) in response to changes of ±5% in the parameter K_{max} across different breeds was reported by Williams *et al*. (1995). In that study, changes in θ did occur across breeds in relation to changes in K_{max}, $EBFFW_{MAT}$, and observed empty-body ether-extractable lipid percentage. Evaluation of the original model (Keele *et al*. 1992) using eight datasets across breeds, frame score, and dietary treatments was reported by Williams *et al*. (1992). The BeefSpecs inputs described in Walmsley *et al*. (2014) include: sex, breed type, initial liveweight (LW), frame score, initial P8 fat, hormonal growth promotant, feed type (grass or grain), days on feed (DOF), growth rate (kg/day), and dressing percentage. BeefSpecs outputs include predicted final P8 fat, and calculations of final LW and HSCW.

Challenging the model with independent data is an important step in evaluating a model. It is equally important to undertake a sensitivity analysis of any model-based system (Saltelli and Annoni 2010). A preliminary sensitivity analysis (Walmsley *et al*. 2013) indicated that the accuracy of final P8 fat predictions was most sensitive to frame score and initial P8 fat inputs.

This study evaluated the sensitivity of inputs against final P8 fat to determine whether an automated system (e.g. laser or 3D camera technology) is required by the beef industry to estimate frame score and initial P8 fat. Such a system would be needed only if it were ascertained that on-farm measurements were sensitive to the accuracy of prediction. The objectives of this study were: (1) to challenge BeefSpecs with five independent datasets; and (2) to evaluate the BeefSpecs fat calculator on the sensitivity of two key inputs (frame score and initial P8 fat) to determine whether measurement error affects the prediction of final P8 fat.

Materials and methods

Model description

In brief, BeefSpecs combines the predictive powers of animal growth and body compositional models with experimental information relating to animal growth and fatness in response to on-farm management decisions. The dynamic computer model reported by Keele *et al*. (1992) was the source for the development of the BeefSpecs fat calculator. The Keele *et al*. (1992) model was originally developed to predict the composition of EBW gain from LW change in growing cattle. This model was then integrated with a feed energy intake model that predicted composition of EBW changes in mature cattle (Williams and Jenkins 1997). Subsequently, a model that predicts the composition of EBW changes at all stages from birth to maturity was developed (Williams and Jenkins 1998).

Table 1. Description and summary of datasets used to evaluate the BeefSpecs predictions of final P8 fat
iBW, initial body weight (kg); FS, frame score (1–9); iP8, fP8: initial, final P8 fat (mm); DOF, days on feed; ADG, average daily gain (kg/day)

	iBW	FS	iP8	fP8	DOF	ADG
			Dataset 1. *Bos Taurus* steers			
n	80	80	80	80	80	80
Minimum	206	3	3	6	203	0.64
Maximum	332	7	10	16	203	1.19
Mean	270	5.4	5.53	9.68	203	0.94
s.d.	27.85	0.77	1.78	2.21	0	0.10
			Dataset 2. *Bos Taurus* heifers			
n	97	97	97	97	97	97
Minimum	230	3	1	3	102	0.49
Maximum	452	7	11	17	112	1.32
Mean	352	4.58	4.72	9.59	108.60	0.81
s.d.	34.84	0.81	2.15	2.89	4.76	0.17
			Dataset 3. *Bos indicus* ($n = 35$) and *Bos taurus* × *Bos indicus* ($n = 33$) steers			
n	68	68	68	68	68	68
Minimum	400	5	2	2	30	0.26
Maximum	635	9	15	17	128	2.17
Mean	519	6.60	7.60	10.49	96.66	0.77
s.d.	48.86	0.74	2.69	3.07	28.56	0.28
			Dataset 4. *Bos taurus* × *Bos indicus* steers			
n	25	25	25	25	25	25
Minimum	408	3	2	5	176	0.35
Maximum	502	6	8	21	176	0.85
Mean	454	4.56	4.44	8.84	176	0.61
s.d.	25.57	0.82	1.69	3.45	0	0.12
			Dataset 5. *Bos taurus* × *Bos indicus* heifers			
n	13	13	13	13	13	13
Minimum	244	4	2	3	45	0.44
Maximum	334	6	9	9	45	1.33
Mean	296	4.77	4.00	6.23	45	1.01
s.d.	25.36	0.73	2.12	2.05	0	0.29

Data

Evaluation data

Industry datasets were sourced from several locations to evaluate the predictive accuracy of BeefSpecs. In this study, five datasets (Table 1) from various locations in New South Wales were selected. The datasets contain different breed types (*Bos taurus*, *Bos indicus*, and crosses *Bos taurus* × *Bos indicus*) and sexes (steers and heifers). Sourcing pure *Bos indicus* cattle was difficult; hence, only a few *Bos indicus* steers are contained in Dataset 3 (Table 1), which also contains crossbred steers. No data from purebred *Bos indicus* heifers were obtained. All animals in these datasets were recorded at an initial point and then at the end of the feeding period; thus, no animal has multiple records.

Sensitivity data

A data matrix of BeefSpecs inputs and outputs was created using the BeefSpecs model (Walmsley *et al*. 2014) to conduct the sensitivity analysis. The inputs are described above and reported in Table 2 along with the levels chosen for each input. These input levels (Table 2) produced an array of 57 600 model runs. The matrix was created by incrementally changing each input. The matrix also includes the BeefSpecs predictions of final P8 fat and the calculated final LW and HSCW. This study evaluates only the sensitivity of BeefSpecs prediction of final P8 fat to the inputs frame score and initial P8 fat.

Statistical analyses

Predicted final P8 fat analysis

Five datasets (Table 1) were used to evaluate the predictive accuracy of P8 fat. Model evaluation of predicted P8 fat was conducted using a customised procedure in the R statistical package (R Development Core Team 2009). Model predictions of P8 fat were evaluated by use of mean bias (MB) (Eqn 1):

$$\frac{\sum (O_i - P_i)}{n}, \tag{1}$$

where n is number of animals, O_i is observed P8 fat, and P_i is predicted P8 fat, for $i = 1$ to n. The error of prediction was assessed by use of the mean-square error of prediction (MSEP) (Eqn 2):

$$\frac{\sum_{i=1}^{n} (O_i - P_i)^2}{n}, \tag{2}$$

where terms are as defined above. The root MSEP (RMSEP) was used as a measure of the accuracy of prediction. The MSEP was decomposed into bias, slope, and random components as a proportion of MSEP to assess the error structure following the techniques outlined by Bibby and Toutenburg (1977). The statistical significance of each MB was evaluated via a paired *t*-test of the mean of the differences between the observed and model-predicted values. A Student's *t*-test for slope (H_o: slope = 1) was evaluated at $P = 0.01$.

Sensitivity analysis

The sensitivity analysis was conducted according to the technique described by Saltelli *et al*. (2000), which uses the actual units of measurement for each variable and estimates the direct impact on model outputs attributable to input variability (caused by uncertainty or errors in recording). The sensitivity of output relative to input is defined as follows:

$$S_{i,j} = \partial Y_i / \partial X_j, \tag{3}$$

where $S_{i,j}$ is the sensitivity of the output variable Y_i (e.g. P8 fat estimated from the ANOVA results) relative to the input variable X_j (e.g. frame score, initial P8 fat, and initial LW).

An analysis of variance (ANOVA) was conducted on the predicted output of final P8 fat from BeefSpecs, using a nine-way factorial matrix ($n = 57\,600$) containing the input variables (Table 2) described above. The ANOVA was conducted using GENSTAT Release 14.1 (VSN International 2011) to investigate the dominant main effects and higher order interactions. Sensitivities (Eqn 3) were then calculated for the key dimensions of interest (i.e. the sensitivity of final P8 estimated from the ANOVA to the inputs frame score and initial P8 fat).

Table 2. BeefSpecs inputs and their levels used during the factorial sensitivity analysis

Variable	Units	Levels
Sex	–	Steer, heifer
Feed type	–	Grass, grain
Hormone promotant	–	None, oestrogen, androgen
Breed type	–	*Bos taurus*, European, *Bos indicus*, or 3-way cross
Days on feed	days	60, 120, 180
Frame score	–	2, 4, 6, 8
Initial P8 fat	mm	2, 4, 6, 8, 10
Initial liveweight	kg	200, 250, 300, 350, 400
Growth rate	kg/day	0.5, 1.0, 1.5, 2.0

Table 3. Statistical evaluation across five datasets of differences between observed and BeefSpecs-predicted final P8 fat

MSEP, Mean-square error of prediction; Bias, MSEP decomposed into error due to overall bias of prediction; Slope, MSEP decomposed into error due to deviation of the regression slope from unity; Random, MSEP decomposed into error due to the random variation

Item	Dataset				
	1	2	3	4	5
n	80	97	68	25	13
Mean observed (mm)	9.68	9.59	10.49	8.84	6.23
Mean predicted (mm)	9.61	9.99	10.90	9.39	6.19
Mean bias (mm)	0.06	–0.41	–0.41	–0.55	0.04
b-coefficient	0.78	0.63	0.60	1.11	0.49
R	0.65	0.54	0.49	0.63	0.67
P-value[A]	0.75	0.12	0.24	0.32	0.94
P-value[B]	0.03	<0.01	<0.01	0.71	<0.01
MSEP	2.96	6.81	8.22	7.19	4.00
Root-MSEP (mm)	1.72	2.61	2.87	2.68	2.00
Bias (%)	0.13	2.44	2.05	4.18	0.04
Slope (%)	5.77	12.19	12.69	0.60	47.27
Random (%)	94.10	85.37	85.27	95.22	52.69

[A]Paired *t*-test for the mean bias ($P < 0.05$).
[B]Student's *t*-test for the slope (H_o: slope = 1) at ($P < 0.01$).

Results

Model prediction of final P8 fat

The MB across all datasets indicates that final P8 fat was over-predicted for Datasets 2–4 and under-predicted for Datasets 1 and 5 (Table 3). There were no significant differences ($P > 0.05$) in MB between observed and predicted values in any of the datasets (Table 3). There were no significant differences ($P > 0.05$) when testing for the slope (H_o: slope = 1) for Datasets 1 and 4; however, significant differences ($P < 0.01$) were found for Datasets 2, 3, and 5 (Table 3). Dataset 1 has the lowest RMSEP, followed by Dataset 5, with Datasets 2–4 similar to each other (Table 3). The decomposition of the MSEP revealed that most of the error contained in the predictions for Datasets 1–4 was of a random nature. Dataset 5 had a larger proportion of error in the slope component, although the majority of error was still of a random nature. All datasets indicated that there was little bias in BeefSpecs predictions (Table 3). The highest absolute MB was 0.55 mm, which is lower than the 1.5-mm error of ultrasound scanners (Upton *et al.* 1999).

A plot of observed versus predicted final P8 fat with a 1 : 1 ($y = x$) line and a plot of the residuals (observed – predicted) with a horizontal line ($y = 0$) across all datasets provided additional detail on the accuracy of predicting final P8 fat (mm) (Fig. 1). In Dataset 1, the data followed the 1 : 1 line and the residuals demonstrated an error of ±5 mm. The data tended to fan out, indicating that the error in prediction increased as the level of fat increased, but the residuals did not show any tendency for a bias in the slope. In Dataset 2, the data again followed a 1 : 1 relationship, with a greater error (±8 mm) than in Dataset 1. The residuals in this case did not fan out but there was an indication of bias in the slope. Dataset 3 was similar to Dataset 2 and again indicated a bias in the slope. Dataset 4 followed the 1 : 1 line and the residuals demonstrated an error of ±5 mm, with the exception of one steer with a predicted final P8 fat of 13.5 mm with an error of 7.5 mm. The residuals did not show any

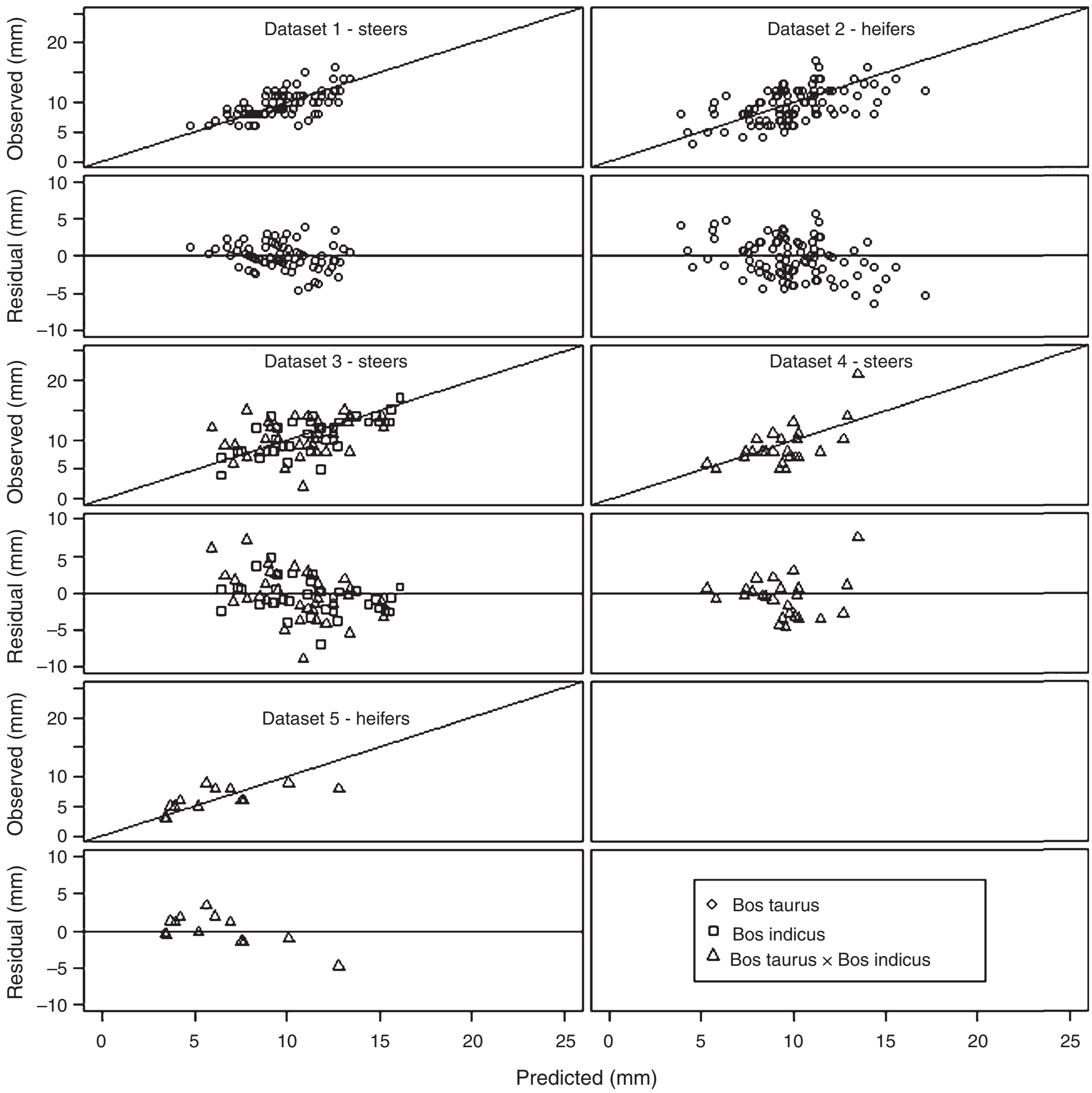

Fig. 1. Observed versus predicted and residuals of final P8 fat (mm) of steers and heifers across breeds for challenge Datasets 1–5.

bias in the slope. Dataset 5 generally followed the 1 : 1 line. The residuals had a dispersion of ±5 mm and the residuals demonstrated a bias in the slope.

Sensitivity analysis

The dominant four-way interaction was DOF × frame score × initial LW × sex, with $F_{(24,\ 9504)} = 11\,231$ ($P < 0.01$). The key contrasts in this complex interaction are summarised as follows.

Sensitivity of predicted P8 fat and the frame score input

Figure 2 shows that final P8 was most sensitive to frame score when animals undertook longer feeding periods (e.g. 180 days). This sensitivity was particularly evident in low frame-score heifers that began at higher initial LW (Fig. 2*a*). For each unit of error in estimating frame score, BeefSpecs is anticipated to predict final P8 with an error of up to 2.3 mm in heifers and up to 1.7 mm in steers (Fig. 2*a*, *b*). It was also evident that during shorter feeding periods (e.g. 60 days) any inaccuracies in the estimation of frame score resulted in smaller predictive errors for final P8 fat only, particularly when animals had higher frame scores (Fig. 2*c*, *d*).

Sensitivity of predicted final P8 fat and the initial P8 fat input

Figure 3 shows that final P8 was most sensitive to measurement error in initial P8 fat when animals had lower initial LW (e.g. 200 kg) and higher frame scores (e.g. 7). Although not presented in Fig. 3, these sensitivities were also more evident for shorter feeding periods (60 or 120 days). The average sensitivity of animals across sexes and frame scores with an initial LW of 200 kg and initial P8 fat of 2 mm was 1.51 mm (Fig. 3.). This result means that an error in the estimation of initial P8 fat of 2 mm will result in an error of up to 3 mm in the prediction of final P8 fat.

Discussion

The fundamental research behind BeefSpecs has come from several large, growth-path studies (Dicker *et al.* 2001;

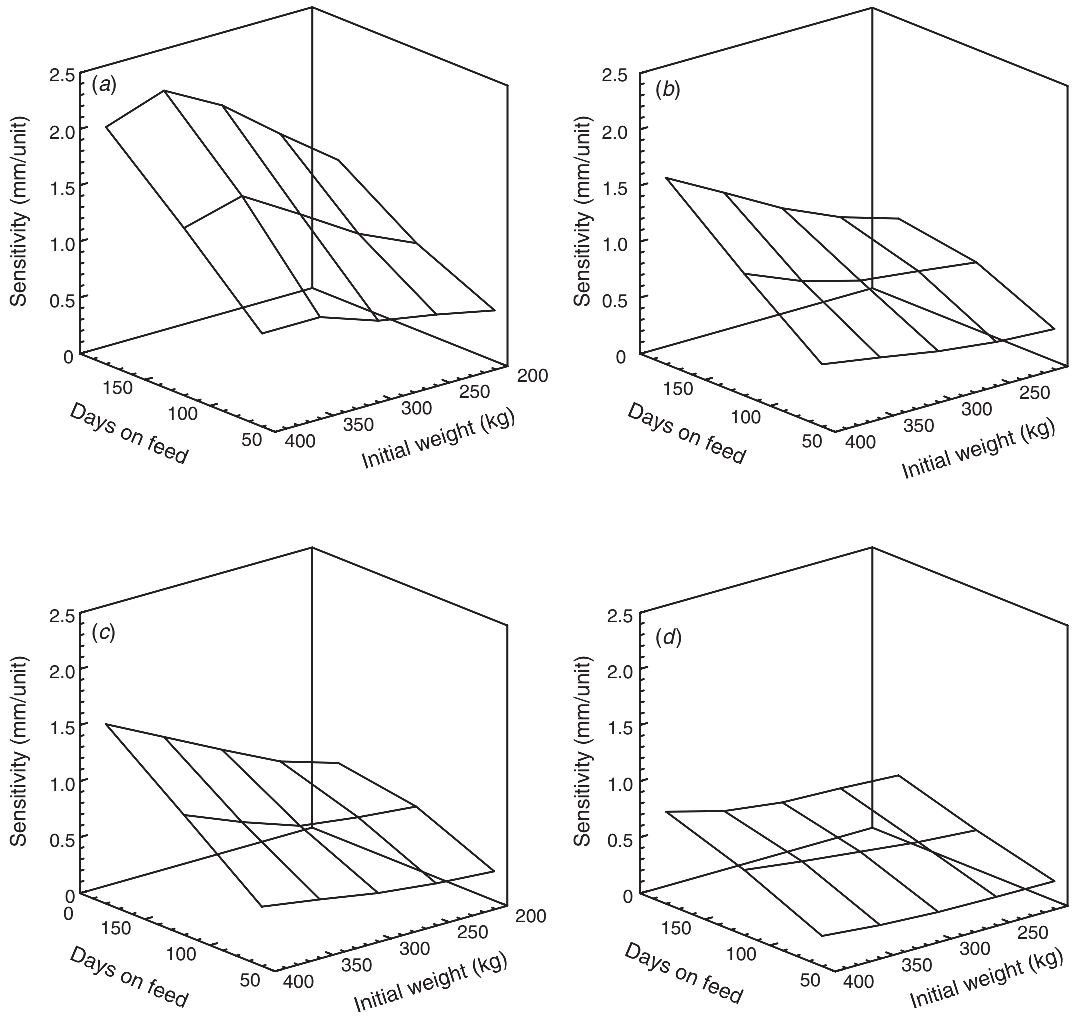

Fig. 2. Sensitivity (mm/unit; absolute value |mm/unit|, i.e. positive) of BeefSpecs prediction of final P8 fat (mm) to the input of frame score in the relationship to days on feed and initial liveweight (kg) for: (*a*) heifers and (*b*) steers with low frame score (3), and (*c*) heifers and (*d*) steers with high frame score (7).

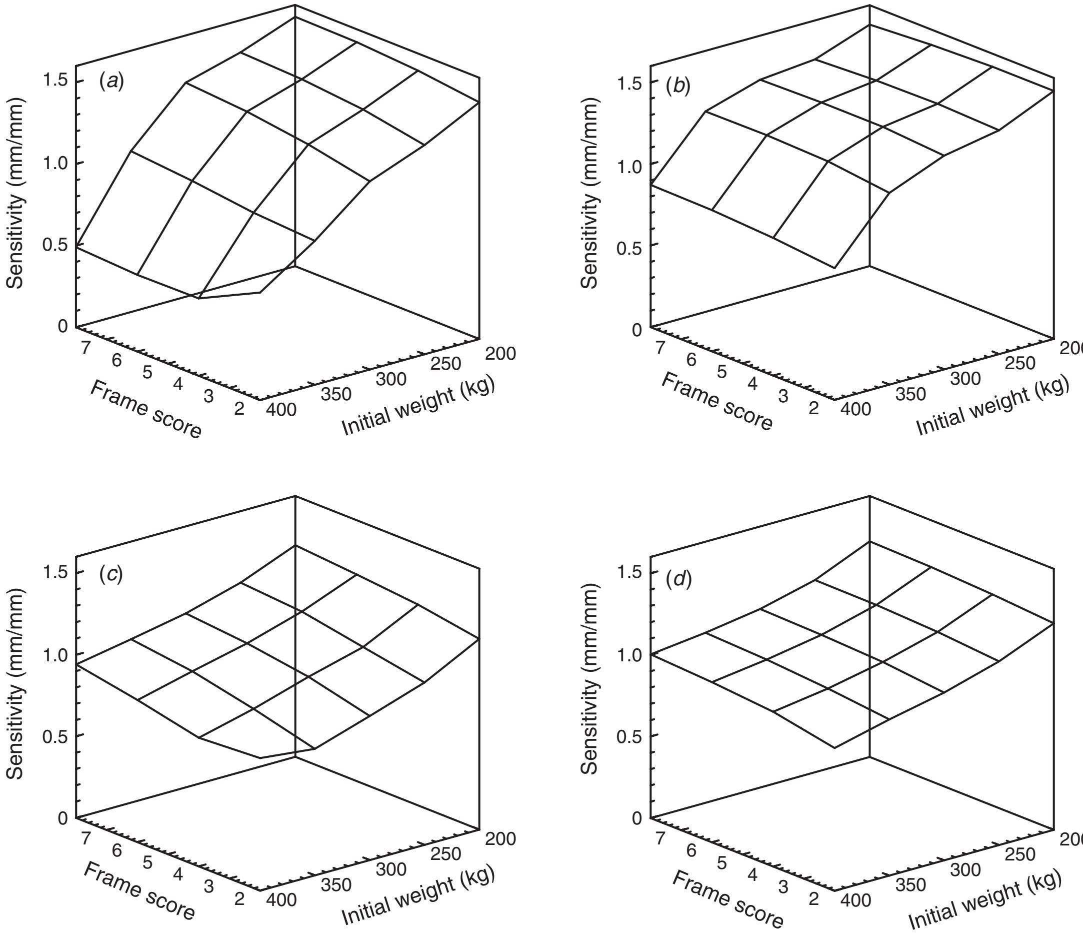

Fig. 3. Sensitivity (mm/mm; absolute value |mm/mm|, i.e. positive) of BeefSpecs prediction of final P8 fat (mm) to the input of initial P8 fat (mm) in the relationship to frame score and initial weight (kg) for: (*a*) heifers and (*b*) steers with low initial P8 fat (3 mm), and (*c*) heifers and (*d*) steers with high initial P8 fat (9 mm).

Robinson *et al.* 2001; McKiernan *et al.* 2009). The outcomes from these and subsequent studies (McPhee *et al.* 2012) demonstrate that backgrounding and finishing growth rates affect fat deposition. Growth rate (kg/day) encompasses both the availability and digestibility of the pasture and is a major driver of the BeefSpecs calculator. This study has evaluated the model prediction of P8 fat and the sensitivity of the inputs frame score and initial P8.

Model prediction of P8 fat

The five datasets used to evaluate BeefSpecs were independent datasets collected from beef producers across New South Wales. The data provided a fair representation of input variables (e.g. different breed types for steers or heifers) that were used to evaluate BeefSpecs. Accuracy of the prediction of final P8 fat was high compared with the mean values of the observed and predicted P8 fat. All datasets showed no significant ($P > 0.05$) differences in the MB between observed and predicted values (Table 3). However, there were significant ($P < 0.01$) differences in the unity of slope in Datasets 2, 3, and 5. The bias in the slope of Datasets 2, 3, and 5 is illustrated in Fig. 1. The non-significant ($P > 0.01$) differences in slope for Datasets 1 and 4 indicate that the prediction of final P8 fat was good for *Bos taurus* steers and *Bos taurus* × *Bos indicus* steers, respectively. As additional datasets become available, improvements to the BeefSpecs model could reduce the bias in the slope.

The random component of the MSEP decomposition was high for all datasets except Dataset 5, indicating that the accuracy of BeefSpecs when predicting final P8 fat values for Datasets 1–4 was high. However, as mentioned above, there were significant ($P < 0.01$) differences in the slope, confirming difference in the slope from unity for Datasets 2, 3, and 5, with deviations of the regression slope from unity of 12%, 13%, and 47%, respectively.

The proficiency levels accepted for accreditation to register ultrasound scanners to enter data into the national estimated breeding value (EBV) evaluation system BREEDPLAN (http://breedplan.une.edu.au/, accessed 26 August 2014) are ≤1.5 mm (Upton *et al.* 1999). The absolute mean bias between observed and predicted final P8 fat across all datasets (Table 3) was lower than the accuracy of the ultrasound scanner data that is entered into BREEDPLAN. The results reported in Table 3 indicate that the accuracy of predicting BeefSpecs final P8 fat is as good as that of the ultrasound data entered into BREEDPLAN.

The datasets used to evaluate BeefSpecs have also been used to determine the variation that exists between the observed and predicted final P8 fat. This variation in the data between observed and predicted has been used to generate an estimate of the likely error of estimating P8 fat when drafting cattle at a specific LW and initial P8 fat specification. An illustration of this concept was reported by Walmsley *et al*. (2011).

Sensitivity analysis

The results of the sensitivity analysis indicate that the predictions of final P8 fat are sensitive to the frame score and initial P8 fat inputs. These results highlight how important it is that both frame score and initial P8 fat are accurately measured. The error of estimating P8 fat manually on live animals by different industry assessors was found to be 4.55 mm in one dataset ($n = 174$; B. Littler, unpubl. data). This error highlights the importance of training assessors to a very high level of competency to assess live animals or the need to develop a technique that can accurately estimate P8 fat in live animals. A recent study using 3D camera technology on steers found an MB of 0.14 mm ($n = 20$; RMSE = 1.1 mm) between ultrasound observed and 3D camera predicted values when using a challenge dataset on the estimation of rib fat (MJ McPhee, BJ Walmsley, B Skinner, A Alempijevic, unpubl. data). These promising results suggest that the technology could be used on-farm for routine estimation of frame score and initial P8 fat.

Conclusions

This study has evaluated BeefSpecs with five independent datasets and reported on the sensitivity of final P8 fat predictions to frame score and initial P8 fat inputs. A reasonably good representation of purebred and crossbred animals and sexes was used to evaluate the BeefSpecs predictions of final P8 fat. Datasets 1 and 4 indicated that the BeefSpecs fat calculator accurately predicted final P8 fat for *Bos taurus* and *Bos taurus* × *Bos indicus* steers, respectively. Improving the accuracy of estimating frame score and initial P8 fat was identified by the sensitivity analysis as an area for further research. A fully integrated system using 3D cameras to estimate frame score and initial P8 fat as inputs to BeefSpecs has the potential to improve the profitability of the beef industry significantly. This new technology also has potential applications in both the sheep and dairy industries.

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