Does a single adjustment in the meat standards Australia beef grading model cater for different hormonal growth promotant formulations?

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ABSTRACT

This paper investigated whether a single Hormonal Growth Promotant (**HGP**) adjustment in the Meat Standards Australia (**MSA**) beef grading model adequately predicted consumer eating quality of beef from cattle treated with different HGP formulations. This paper used consumer sensory data from two experiments. In experiment one, a total of 300 steers were allocated to three treatments; control (**CON-100-F**), 100 day oestradiol only HGP (**OES-100-F**), or a combination of trenbolone acetate and oestradiol HGP (**TBA+OES-100-F**) and finished in a feedlot for 73 days. In experiment two, a total of 200 steers were allocated either control or 400 day oestradiol only HGP treatments and finished on pasture for 389 days. Steers were slaughtered by finishing regime and carcass traits recorded. The anterior and posterior portions of the *m. longissimus lumborum* (LL-A and LL-P, respectively) and *m. gluteus medius* (**GM**) were collected and aged for five or 35 days. Grilled meat samples were scored for tenderness, juiciness, liking of flavour and overall acceptability using untrained consumers. Sensory scores were weighted by 0.3. 0.1, 0.3 and 0.3, respectively and summed to calculate a meat quality (**MQ4**) score. Residual MQ4 scores were calculated (observed MQ4 minus the predicted MQ4 score). The MSA model accounts for varied impacts of different HGPs on eating quality through a single HGP adjustment, and indirect impacts on carcass traits. For the majority of the HGP treatment samples, the residual MQ4 scores were not different to zero (5/18), or were positive i.e. the MSA model under-predicted these samples (11/18). Under-prediction was predominately for 35 day aged (7/9) and GM HGP treatment samples (6/6) and was considered low, with the majority less than ±5 MQ4 units. Under-prediction could be considered as advantageous through providing an additional safeguard to protect the interests of the consumers, rather than if the model had over-predicted and resulted in a more negative eating quality experience than expected. Some over-prediction was observed in the CON-100-F and TBA+OES-100-F treatment samples, which may be due to factors such as genetic variation and/or production environment. Minimal bias was observed when residual MQ4 was regressed against predicted MQ4 for the range of feeding regimes, muscles, ageing periods and treatment groups. This study showed that a single HGP adjustment in the MSA beef grading model, combined with the indirect effects of the different HGP formulations on carcass traits, provided a reasonable prediction of meat eating quality for different HGP formulations.

Implications

The Meat Standards Australia beef grading model predicts the eating quality of 39 cuts from the carcass for various cooking methods. The MSA model accounts for the meat quality impact of different formulations of Hormonal Growth Promotants both through a direct HGP treatment effect combined with indirect changes on carcass traits. This is possible as the MSA model makes use of a multiple regression approach, where the total impact of a treatment can be described by both direct and indirect effects on MQ4 score.

Introduction

The Meat Standards Australia (**MSA**) beef grading model predicts the palatability of 39 muscle portions prepared using up to eight different cooking methods (version 1.7, 2009), based on the relationship between critical control point (**CCP**) variables includ-

ing on-farm inputs, carcass traits and processing interventions on untrained consumer sensory scores (Polkinghorne et al., 2008). A unique feature of the MSA model is the ability to incorporate the CCPs across the supply chain that impact eating quality, such as *Bos Indicus* content or ageing period, rather than carcass traits alone. Likewise, the MSA model predicts eating quality of individual muscle portions by cooking method, rather than an overall grade for the whole carcass, which has been shown to be inadequate for providing accurate predictions for every portion in the carcass (Polkinghorne, 2005). Since commercial implementation in 2000, the MSA model has been continually enhanced through the generation of controlled research data, with the aim of capturing the widespread diversity of Australian beef production systems (Watson et al., 2008a). Ongoing data generation and validation of the MSA model prediction of eating quality is essential to ensure that it provides an adequate prediction of changing cattle populations, production systems and consumer preferences.

Previous work has reported on the MSA beef grading model observed meat quality (**MQ4**) score minus the predicted MQ4 score, or residual MQ4 score. Watson et al. (2008a) conducted an analysis whereby residual MQ4 scores were calculated for the whole MSA model dataset. Using a previous version of the MSA Model (SP2004), Watson et al. (2008a) reported that only 7% of muscle by cooking combinations were significantly different to a mean residual of zero, and the mean MQ4 score had a SD of +/− 8–10 MQ4 points. Using carcasses sampled from Australian Angus and Korean Hanwoo breeds, Thompson et al. (2008b) demonstrated that the MSA model predicted within ±2 meat eating quality (MQ4) for the *mm. longissimus lumborum* and *triceps brachii* muscles when prepared as grills and Korean BBQ, from Achilles hung or tenderstretch carcasses, although the residuals were larger for the *m. semimembranosus*. The MSA beef grading model has also been shown to be reasonably accurate for international cattle/production systems and consumers (Thompson et al., 2008b, Farmer et al., 2010, Legrand et al., 2013).

A body of research conducted in the mid-2000s demonstrated that the use of hormonal growth promotants (**HGPs**) during the growth and finishing of cattle had a negative impact on beef eating quality (Thompson et al., 2008a; 2008c, Watson, 2008, Watson et al., 2008d). Subsequently, a single HGP adjustment was introduced to the MSA beef grading model of up to six MQ4 points depending on the muscle portion (Watson et al., 2008a). The impacts of HGP use on eating quality in the MSA model included both a single adjustment for all HGP implants and indirect effects due to impacts that HGP implants have on carcass traits. Therefore, the total HGP impact was a summation of both the direct impacts and the associated changes that occurred due to HGP implantation such as heavier carcasses, increased hump height and ossification scores, and decreased marbling scores. Whilst the industry was aware that the eating quality adjustment HGP use in the MSA model was a summation of both the direct and indirect impacts, there were concerns that the changes in indirect carcass traits, and the single HGP adjustment did not account for the differences in the commercial HGP formulations and active ingredient payout periods. The data from the experiments of Packer et al. (2019 and 2018), where feedlot and pasture fed steers were treated with different HGPs, resulted in large differences in carcass traits and eating quality. The diversity of outcomes in both sensory scores and carcass traits provided an ideal opportunity to test the appropriateness of a single HGP adjustment in the MSA beef grading model.

The aim of this paper was to evaluate the potential bias of using a single HGP adjustment in the MSA beef grading model for a range of different HGP implants used during finishing in a feedlot or on pasture. The paper utilized data from two experiments. The first experiment comprised consumer data for different muscles and

ageing periods where different HGP implants were used in feedlot finished steers (Packer et al., 2019). The second experiment comprised consumer data from different muscles and ageing periods where a long acting HGP implant was used in pasture finished steers (Packer et al., 2018). In both experiments, residuals for the MQ4 scores were calculated from the observed MQ4 score minus the predicted MQ4 score using the MSA beef grading model (version 1.7, 2009) for LL-A, LL-P and GM samples, which had been aged for five and 35 days. The total HGP effect on eating quality predicted by the MSA model was calculated from the summation of the direct HGP adjustment and the indirect effects of HGPs on carcase traits.

Material and methods

A detailed description of the trial design, animals, sample preparation and consumer tasting protocol was provided in Packer et al. (2019 and 2018), for feedlot and pasture finishing regimes, respectively. A portion of these results has been presented as a conference paper (Packer et al., 2017).

Live cattle

The experimental design, HGP treatments, feeding regime, slaughter and primal collection procedures of the feedlot experiment were described in detail by Packer et al. (2019). Briefly, 300 crossbred steers (approximately one third *Bos indicus* content) were randomly allocated into three treatment groups; control-feedlot (CON-100-F), oestradiol only 100 day HGP implant (OES-100-F, Compudose 100™, Elanco Animal Health, Indianapolis, IN, USA; 21.1 mg oestradiol-17ß) or a combination of trenbolone acetate and oestradiol HGP implant (TBA+OES-100-F, Component TE-200™, Elanco Animal Health, Indianapolis, IN, USA; 200 mg trenbolone acetate and 20 mg oestradiol). After HGP implantation at induction, steers were fed on a high concentrate ration for 73 days. Data from four steers were excluded from the analysis because the HGP implants were lost, or scar tissue had encapsulated the implant.

Details of the pasture finished experiment were described in detail by Packer et al. (2018). Briefly, 200 crossbred steers of the same breed composition were randomly allocated to two treatment groups; control-pasture (**CON-400-P**) or oestradiol only 400 day HGP implant (**OES-400-P**, Compudose 400™, Elanco Animal Health, Indianapolis, IN, USA; 43.9 mg oestradiol-17ß). The steers were implanted and then finished on pasture for 389 days. Data from ten animals from the OES-400-P group were excluded from the analysis as they had lost their implants during the finishing period.

Slaughter, primal collection and sample preparation

After the respective feedlot and pasture finishing periods, steers were transported to the same commercial abattoir and slaughtered within their finishing regime groups. Carcasses were graded as per MSA grading protocols (MLA, 2020). At boning, the rump primals from both sides (HAM 2110 – Rostbiff), and the striploin primal (HAM 2140 – Striploin) from the left side, were collected from all carcasses (AUSMEAT, 2005). Three days following slaughter, the primal cuts were denuded of fat and epimysium, and the LL-A and LL-P portions along with the GM samples were prepared (each sample being five individual 25 mm × 65 mm × 50 mm steaks). Samples were rotated on position within muscle for the different ageing periods. Samples were aged at 3 °C for five or 35 days before being frozen at −20 °C.

Sensory evaluation

Sensory analysis is described in detail by Watson et al. (2008b) and Anonymous (2008). Briefly, each taste panel session comprised of 60 untrained consumers who assessed a total of 36 sample steaks, balanced for HGP treatments, ageing periods and muscle portions. The feedlot and pasture finished samples were assessed in different tasting sessions.

Samples were grilled to a medium degree of doneness using Silex™ griller (Silex Pty Ltd., Marrickville, Australia), for a set cooking time. Each sample was scored on an anchored 100 mm line for tenderness, juiciness, liking of flavour and overall liking. The four sensory scores were weighted using 0.3, 0.1, 0.3 and 0.3, respectively, and summed to calculate a MQ4 score. The two highest and two lowest sensory scores from each sample were clipped to reduce the standard error of the mean sensory score for each sample (Watson et al., 2008c).

Residual calculation and statistical analyses

The MSA beef grading model (version 1.7, 2009) used HGP treatment, hot carcass weight, hump height, marbling and ossification scores, rib fat depth, ultimate pH and muscle temperature to estimate MQ4 scores for LL-A, LL-P and GM muscle portions at five and 35 days ageing. All carcasses were hung by the Achilles tendon, were steers, and classed as not being milk fed vealer, consigned through a saleyard, or treated with a rinse/flush treatment (MLA, 2020). Residuals were calculated as the observed MQ4 score minus predicted MQ4 score. A positive residual value meant that the MSA model under-predicted eating quality and a negative residual value meant that the MSA model over-predicted eating quality.

Standard deviations for the residuals for the LL-A, LL-P and GM at five and 35 days were calculated. A student's t-test was conducted for each mean residual comparing to a mean of zero, with significance at $P < 0.05$ (Microsoft® Excel 2016).

For both the feedlot and pasture experiments, the bias in the pattern of the residual MQ4 scores was examined by regressing the residual MQ4 scores for each muscle, days aged and treatment subgroups, against predicted MQ4 scores generated by the MSA model. Linear and curvilinear terms for predicted MQ4 scores were tested for each subgroup.

The MSA model was also used to quantify the magnitude of the direct and indirect HGP treatments on predicted MQ4 of the LL-A at the two ageing periods. The single HGP adjustment in the model accounts for the direct HGP impact on eating quality, and the indirect HGP impact accounts for the HGP treatment effects on carcass trait variables. To simplify the output, the LL-A was used as the indicator cut. The direct HGP effect on eating quality was esti-mated at five and 35 days ageing, as well as the indirect HGP effect on mean carcass traits for all treatments. The OES-100-F and TBA+OES-100-F treatment MQ4 scores were compared to CON-100-F for the feedlot samples, and the OES-400-P was compared to the CON-400-P for the pasture samples. The proportions of total HGP effect due to the direct and indirect effects on eating quality were expressed as percentages of the total HGP penalty.

Results

Raw means for carcass traits was used to generate MQ4 scores used in the MSA model (Table 1). Both the feedlot and pasture finished steers treated with HGP implants resulted in heavier carcass weights, larger hump heights, lower marbling and higher ossification scores than the respective control treatments. There was little difference in ultimate pH due to the HGP treatments, though ultimate pH was lower for the feedlot finished carcasses when compared to the pasture finished carcasses.

Fig. 1 displayed the mean residuals and the standard deviations for the LL-A, LL-P and GM samples aged for five or 35 days, from steers finished in a feedlot from the CON-100-F, OES-100-F and TBA+OES-100-F treatments. For the OES-100-F LL samples aged for five days, the MSA grading model predicted mean residuals not different to zero ($P > 0.05$) and under-predicted the 35 day samples ($P < 0.01$). Conversely, the MSA model over-predicted the TBA+OES-100-F LL samples aged for five days ($P < 0.05$), and under-predicted LL-A samples aged for 35 days ($P < 0.01$). For the GM, the MSA model under-predicted all of the OES-100-F and TBA+OES-100-F treatment samples at both five and 35 days ($P < 0.05$).

For the CON-100-F treatment samples, the MSA beef grading model over-predicted the five day LL samples ($P < 0.01$), though the 35 day sample residuals were not different from zero. For the GM samples, the mean residuals for the CON-100-F were the inverse, whereby the mean residual was not different from zero at five days, but the MSA model under-predicted the MQ4 score at 35 days ageing.

Fig. 2 displayed the mean residuals for the LL-A, LL-P and GM samples aged for five or 35 days, from carcasses finished on pasture from the CON-400-P and OES-400-P treatments. For the OES-400-P treatment, the residuals for the five day LL samples were not different from zero ($P > 0.05$), though were under-predicted for the 35 day samples ($P < 0.05$). For the GM, the model under-predicted both the five and 35 day OES-400-P samples ($P < 0.01$). The MSA model over-predicted the CON-400-P LL-P five day samples ($P < 0.05$) and under-predicted the GM 35 day samples ($P < 0.001$).
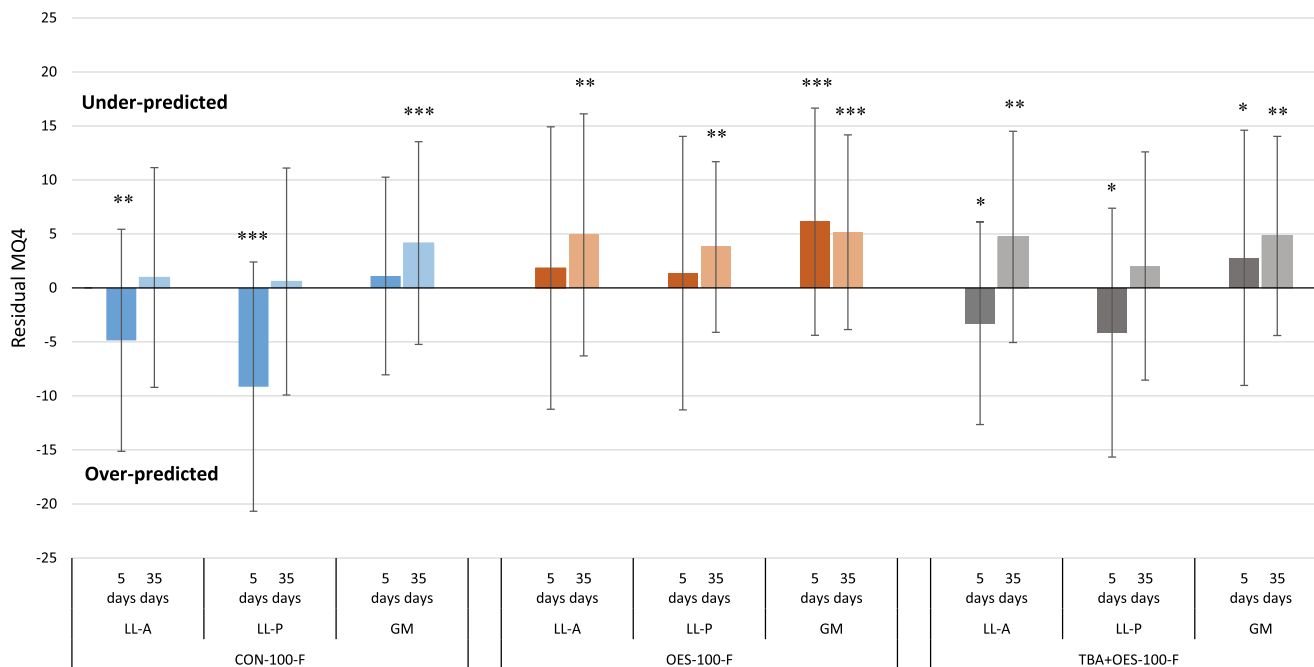
Table 1
Raw means and standard deviation for carcass traits of steers finished in either a feedlot; control (CON-100-F), oestradiol only 100 day Hormonal Growth Promotant (HGP) implant (OES-100-F) and combination trenbolone acetate and oestradiol HGP implant (TBA+OES-100-F), or pasture; control (CON-400-P) and oestradiol only 400 day HGP implant (OES-400-P).

Carcass traits	Feedlot experiment			Pasture experiment	
	CON-100-F (n = 100)	OES-100-F (n = 99)	TBA+OES-100-F (n = 97)	CON-400-P (n = 100)	OES-400-P (n = 89)
Hot carcass weight (kg)	237 ± 16.0	249 ± 16.5	261 ± 14.9	231 ± 12.0	250 ± 13.6
Hump height (mm)	87 ± 9.9	90 ± 10.5	97 ± 9.9	82 ± 8.7	87 ± 9.4
Marbling score[1]	278 ± 50.8	273 ± 50.8	274 ± 53.7	289 ± 60.3	271 ± 60.2
Ossification score[2]	132 ± 11.5	145 ± 13.3	151 ± 17.9	143 ± 14.4	187 ± 37.0
Rib fat (mm)	4.3 ± 1.38	4.1 ± 1.05	3.9 ± 1.01	4.0 ± 1.50	4.2 ± 1.70
Ultimate pH	5.52 ± 0.103	5.53 ± 0.091	5.52 ± 0.081	5.64 ± 0.109	5.62 ± 0.094

[1] Marbling is assessed from the 5th to 13th rib on the carcase which has been allowed to bloom. Marbling is seen as intramuscular deposits of fat within the muscle (m. longissimus lumborum). Meat Standards Australia marble score ranges from 100 (not marbled) to 1 190 (highly marbled), in 10 point increments.

[2] Ossification is a measure of physiological maturity of the beef carcase, through visual assessment of the sacral, lumbar and thoracic vertebrae. Scores range from 100 (no ossification) to 590 (completely fused/ossified), in 10 point increments.

Fig. 1. Raw mean residual meat quality (MQ4) scores (Observed – Predicted MQ4) and standard deviation for the anterior *m. longissimus lumborum* (LL-A), posterior *m. longissimus lumborum* (LL-P) and *m. gluteus medius* (GM) samples at five and 35 days, from steers finished in a feedlot, from three treatments; control (CON-100-F), oestradiol only 100 day Hormonal Growth Promotant (HGP) implant (OES-100-F) and combination trenbolone acetate and oestradiol HGP implant (TBA+OES-100-F). $P < 0.05$, *; $P < 0.01$, **; $P < 0.001$, ***; Indicates significant difference from zero. Sample numbers by treatment, muscle and days aged; **CON-100-F:** LL-A 5 days ($n = 50$); LL-A 35 days ($n = 49$); LL-P 5 days ($n = 49$); LL-P 35 days ($n = 51$); GM 5 days ($n = 98$); GM 35 days ($n = 97$), **OES-100-F:** LL-A 5 days ($n = 51$); LL-A 35 days ($n = 51$); LL-P 5 days ($n = 48$); LL-P 35 days ($n = 47$); GM 5 days ($n = 98$); GM 35 days ($n = 99$), **TBA-100-F:** LL-A 5 days ($n = 45$); LL-A 35 days ($n = 48$); LL-P 5 days ($n = 51$); LL-P 35 days ($n = 48$); GM 5 days ($n = 97$); GM 35 days ($n = 97$).

Analysis of the pattern of the residuals showed that generally there was little relationship between the residual MQ4 scores and the predicted MQ4 scores within HGP treatment, muscle and ageing subgroups. For the feedlot samples, the curvilinear terms for predicted MQ4 were not significant ($P > 0.05$). The majority of subgroups showed no relationship between the residual score and predicted MQ4 scores. The linear term for predicted MQ4 was only significant in two of the six subgroups for both the GM and LL-A, and three of the six subgroups for the LL-P. Even so, the significant regression models only accounted on average for six, 10 and 14% of the variance in the residuals for the GM, LL-A and LL-P, respectively. In all cases where the linear term for the residual versus predicted MQ4 score was significant, the trends were negative, indicating that as predicted MQ4 score increased there was a trend for decreased residuals.

Similar to the feedlot analysis, the curvilinear terms for predicted MQ4 scores for the pasture samples were not significant ($P > 0.05$). The linear regression of residual MQ4 against predicted MQ4 for the GM samples was significant for the OES-400-P treatment, but not the CON-400-P treatment. In both the five- and 35-day-aged OES-400-P GM samples, regression only accounted for 6% of the variance in the residuals. In addition, the slope for these two subgroups was negative, indicating a slight decrease in the size of the residuals with increased MQ4 score. For both the LL-A and LL-P samples the linear regression for residual MQ4 against predicted MQ4 scores was not significant ($P > 0.05$).

Using the LL-A samples as an example, Fig. 3 displayed the direct and indirect impacts of the HGP treatments for the LL-A samples from the feedlot and pasture finished carcasses. The direct effect is the HGP adjustment in the MSA model and the indirect effect accounts for the HGP impacts on carcass traits. The direct HGP effect decreased as samples were aged from five to 35 days. This resulted in an increase with ageing of the relative proportion

of the indirect HGP effects on eating quality through HGP impacts on carcass traits. For the feedlot treatments, the more aggressive TBA+OES-100-F HGP resulted in a greater impact on carcass traits than the OES-100-F treatment, or a larger indirect effect, which accounted for 21% of the total HGP impact at five days, and increased to 32% of the total HGP impact at 35 days. In comparison, the indirect effect of the OES-100-F treatment on carcass traits was 8% at five days and increased to 13% at 35 days. For the pasture HGP treatment, OES-400-P, the longer active payout period equated to larger indirect effects on carcass traits than the OES-100-F treatment in the feedlot. The indirect effect accounted for 14% of total HGP effect at five days and increased to 21% at 35 days.

Discussion

The residuals between predicted MQ4 scores generated by the MSA beef grading model and actual consumer MQ4 scores varied in magnitude and were greater or less than zero, for the HGP treatments from steer carcasses when finished in a feedlot or on pasture. The mean residuals for the majority of the HGP treatment samples were either not different from zero (five out of the 18 treatments) or were positive i.e. the MSA model under-predicted the samples (11 out of the 18 treatments), which has important implications for the Australian beef industry. Whilst the MSA model aimed to generate zero residuals, under-prediction can be considered as providing an additional safeguard to protect the interests of the consumers, rather than if the model had over-predicted and resulted in a more negative eating quality experience than expected. There was a trend for the MSA model to generate positive residuals, or under-predict, for the 35 day and GM samples, which may have resulted from less data underpinning these estimates in the MSA model (version 1.7, 2009). Generation
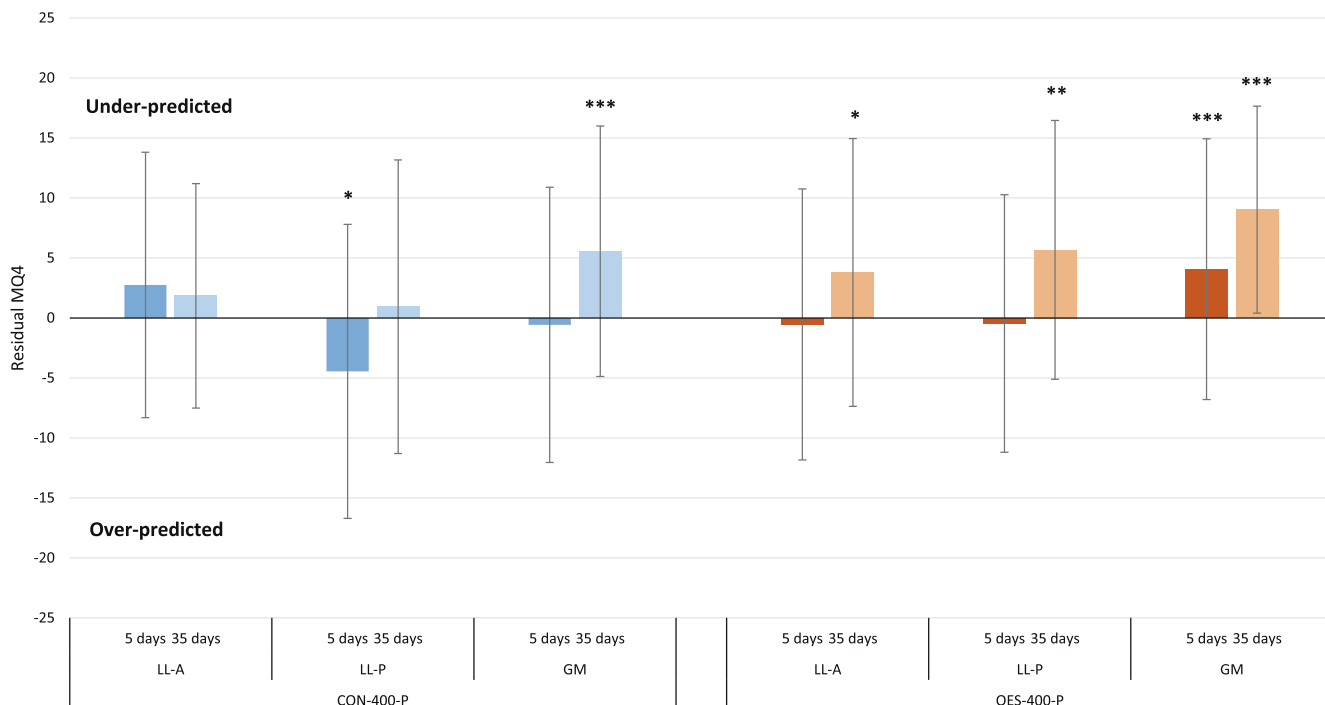
Fig. 2. Raw mean residual meat quality (MQ4) scores (Observed – Predicted MQ4) and standard deviation for the anterior *m. longissimus lumborum* (LL-A), posterior *m. longissimus lumborum* (LL-P) and *m. gluteus medius* (GM) samples at five and 35 days from steers finished on pasture, from two treatments; control (CON-400-P) and oestradiol only 400 day Hormonal Growth Promotant implant (OES-400-P). $P < 0.05$, *; $P < 0.01$, **; $P < 0.001$, ***; Indicates significant difference from zero, Sample numbers by treatment, muscle and days aged; **CON-400-P:** LL-A 5 days ($n = 52$); LL-A 35 days ($n = 44$); LL-P 5 days ($n = 46$); LL-P 35 days ($n = 53$); GM 5 days ($n = 100$); GM 35 days ($n = 100$). **OES-400-P:** LL-A 5 days ($n = 41$); LL-A 35 days ($n = 47$); LL-P 5 days ($n = 45$); LL-P 35 days ($n = 38$); GM 5 days ($n = 89$); GM 35 days ($n = 89$).

Fig. 3. The direct and indirect Hormonal Growth Promotant (HGP) meat quality (MQ4) score impact of oestradiol only 100 day HGP implant (OES-100-F) and combination trenbolone acetate and oestradiol HGP implant (TBA+OES-100-F) vs control (CON-100-F) at 5 and 35 days for the anterior *m. longissimus lumborum* samples from steers finished in a feedlot; and oestradiol only 400 day HGP implant (OES-400-P) vs control (CON-400-P) at 5 and 35 days for the anterior *m. longissimus lumborum* samples from steers finished on pasture. The direct effect is the HGP adjustment in the Meat Standards Australia model and the indirect effect accounts for the HGP impacts on carcass traits. Sample numbers by treatment and days aged: **OES-100-F:** 5 days ($n = 197$); 35 days ($n = 197$). TBA+**OES-100-F:** 5 days ($n = 193$); 35 days ($n = 193$), **OES-400-P:** 5 days ($n = 175$); 35 days ($n = 174$).

of more consumer data from carcasses treated with a range of HGP treatments and different production systems may reduce the residual magnitude for these muscle and ageing combinations. Similarly, consumer sensory testing of a wider range of muscles and longer ageing periods may assist in refining the MSA model to more accurately reflect the ageing potential of HGP treated beef across the carcass.

The lack of significance in most linear models, when the residual MQ4 scores were regressed against predicted MQ4 scores for the various subgroups, indicated there was minimal bias. For

significant regressions, the variance only accounted for less than 14% and 6% for some feedlot and pasture sample models, respectively. This indicated that the MSA model had minimal bias when predicting the eating quality of the LL and GM from animals treated with different HGP formulations, using a single HGP adjustment.

The MSA model is constructed to account for the impact of different HGP implants on eating quality through both the direct impacts on eating quality through a single HGP adjustment, and the indirect impacts on carcass trait variables, such as hot standard

carcass weight, ossification and marbling score. This approach is important as it allows for a customized prediction based on the unique impacts on carcass traits and ultimately eating quality of different HGPs (Packer et al., 2018; 2019). The direct HGP effect, or impact on eating quality over and above variable traits in the MSA model, decreased with ageing as a proportion of total HGP impact. Therefore, the proportion of indirect HGP effects on eating quality, mainly hump height, ossification score and marbling score, ultimately increased with ageing. The more aggressive HGP formulations, i.e. trenbolone acetate combined with oestradiol, resulted in greater impacts on ossification score and hump height, as well as decreased marbling score. In effect, the direct HGP impact for the TBA+OES-100-F HGP treatment accounted for 80% and 70% of the total HGP effect at five and 35 days ageing, respectively, when compared to the OES-100-F treatment, which accounted for eight and 13% of the total HGP effect at five and 35 days ageing, respectively. Similarly, the longer active ingredient payout period of the OES-400-P treatment (circa 400 days) also had a larger impact on carcass traits accounting for 14% to 21% of the total HGP effect when compared to the OES-100-F treatment, which contains the same active ingredient, though had a shorter payout period and only accounted for less than 10% of the total HGP effect. The under and over-prediction observed in this study may mean that the single HGP adjustment for longer ageing periods, as well as the GM, may require further refinement. Further investigation is required across a larger data set of HGP treated animals to evaluate the direct and indirect effects of different HGPs on eating quality.

For the CON-100-F and CON-400-P treatment samples from the feedlot and pasture finished carcasses, the MSA model similarly generated mean residuals, which varied in magnitude, which were greater than or less than zero. In over half the instances, for the different muscle and ageing period combinations, the mean residuals in the control treatments were not different from zero. Despite there being no overall bias in these residuals, they had a similar variance in the residuals between all muscle and ageing combinations. There was a trend for the MSA model to over-predict the LL-P samples and under-predict the 35 day GM samples. The importance of these deviations needs to be assessed against the full MSA database to confirm any adjustments to the individual muscle regressions in the MSA model.

The over-prediction of the five day aged LL samples from TBA +OES-100-F and CON-100-F steers finished in a feedlot, as well as the CON-400-P five day pasture samples, may be caused by a number of factors. Primarily, the MSA model was constructed using a wide range of animal types and production systems to generate the predictive algorithms for the population mean. It is possible that the LL muscles from this subset of animals were different, possibly due to genetics and/or production environment. This highlights the complexity of which a biological prediction model is challenged. Watson et al. (2008a) reported on a larger analysis across all cuts and cooking combinations in the MSA model (version SP2004), stating that only 7% of the residuals were significantly different to a zero mean, with a standard deviation of eight to 10 MQ4 units depending on cut. The standard deviation of the mean residuals reported in this study was between eight and 16 MQ4 points, with an average of approximately 11 MQ4 points, demonstrating the larger variance of residuals within this subsample of animals used in the current study.

Further factors influencing the residual magnitude may include the increase in sample variation with ageing or variation between animals or muscles in postmortem enzyme activity. Postmortem temperature influences proteolysis rate (Thomson et al., 2008) and therefore slight differences in temperature between samples or studies during postmortem ageing may result in different eating quality outcomes. Similarly, differing enzyme levels within a muscle, which could be influenced by genetics or HGP type, may also

have impacted the observed residuals. The lower calpastatin activity within LL feedlot samples from OES-100-F treated carcases, when compared to TBA+OES-100-F carcases, reported by Packer et al. (2019), may explain in part the under-prediction for the OES-100-F samples than the TBA+OES-100-F samples. Thompson et al. (2008a) reported a HGP treatment X *Bos indicus* content interaction which may also explain part of the TBA+OES-100-F over-prediction at five days, though this interaction requires further investigation.

The MSA model has been proven to be a useful commercial tool to predict the eating quality of beef from a large range of Australian beef production systems (Polkinghorne et al., 2008, Watson et al., 2008a). However, as with any prediction model, further data acquisition across a greater range of cattle types, production environments and pathways may reduce residual magnitude. Whilst more data may improve prediction, along with the possible inclusion of more variable traits, residual magnitude will depend on the relationship of a sample population to the mean population in the MSA model. Watson et al. (2008a) and Thompson et al. (2008b) both commented that the model was dynamic and that it can always be improved through additional data sets. Future technologies such as genomics, gene expression or micro RNA could further enhance the MSA model prediction and assist with more accurate animal breeding, management and supply chain decisions.

Conclusion

The residuals between predicted MQ4 scores generated by MSA model beef grading model and actual consumer MQ4 scores were not different from zero or were positive (under-predicted) for the majority of the HGP treatment samples at five and 35 days aging, from steers finished in a feedlot or on pasture. This has important implications for the Australian Beef industry as any under-prediction could be considered a safeguard for the consumer, as it ensured beef products underpinned by the MSA model would be more palatable than the MSA model prediction. The under-prediction of longer aged samples suggests the MSA model may not be fully accounting for the ageing improvements of HGP treated beef. Similarly, the model under-predicted the GM samples, which may be due to less data underpinning these estimates. Some over-prediction was reported for CON-100-F and TBA+OES-100-F LL samples, which may have been influenced by a number of factors including production environment and genetics. Minimal bias was observed when residual MQ4 scores were regressed against predicted MQ4 scores for the various subgroups of muscles, ageing periods and treatments. This indicates that the MSA model does not generate any bias when using a single HGP adjustment to predict different HGP formulations.

The MSA model uses a single HGP adjustment to account for HGP use. This approach allows for a customized prediction of muscles from carcasses treated with different HGP formulations and payout periods, which ultimately have different impacts on carcass traits and eating quality. This was demonstrated by a larger contribution to the total HGP impact being derived from changes in carcass traits associated with the use of more aggressive HGP formulations or formulations with a longer payout period. Whilst in this experiment there was some over- and under-prediction for the HGP treatments by muscle portion and ageing combinations, the single HGP adjustment used in the MSA model in combination with indirect effects from the changes in carcass traits provided reasonable predictions of eating quality for a range of different HGP formulations.

Ethics approval

Ethics approval was granted by the University of New England Animal Ethics Committee (authority number AEC14-045) for

Packer et al. (2019 and 2018). The data from these experiments was used for this study.

Data and model availability statement

Data mentioned in this experiment have not been deposited in an official repository.

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Declaration of Interest

The lead author was an employee of Meat and Livestock Australia at the time of writing this manuscript.

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