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Prédiction des taux de persillé ou de lipides intramusculaires avec la caméra Q-FOM^{TM}

Prédiction des taux de persillé ou de lipides intramusculaires au niveau de la noix de côte avec la caméra Q-FOM^{TM} sur des carcasses australiennes ou européennes découpées selon différentes méthodes

Mots clés : persillé, lipides, prédiction, industrie, carcasses bovines

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La caméra Q-FOM^{TM} Beef prédit le score de persillé MSA et le taux de lipides intramusculaires que ce soit pour des carcasses australiennes découpées en quartiers aux 10ème-13ème côtes, ou pour des carcasses bovines européennes découpées aux 4ème-6ème côtes.

Résumé

En Australie, l'évaluation de la qualité de la viande bovine est réalisée au niveau de la noix de côte des carcasses selon les normes du « Meat Standards Australia » (MSA) et permet de décrire les caractéristiques de la viande commercialisée. L'une des caractéristiques évaluées visuellement est l'importance du persillé. En Europe, les abattoirs s'intéressent de plus en plus à l'évaluation de ce critère. Ces dernières années, il est devenu de plus en plus important de disposer de technologies de mesure objectives garantissant un classement cohérent, précis et normalisé pouvant être adopté par la filière viande bovine. La caméra Q-FOM^{TM} Beef prédit le taux de persillé et le pourcentage de gras intramusculaire déterminé chimiquement (IMF%). Cet article résume l'exactitude et la précision de la prédiction du score MSA de persillé et du pourcentage de gras intramusculaire par la caméra Q-FOM^{TM} Beef pour des carcasses bovines australiennes, découpées en quartiers aux 10ème-13ème côtes, et pour des carcasses bovines européennes, découpées en quartiers aux 4ème-6ème côtes. La caméra Q-FOM^{TM} Beef prédit le score de persillé MSA avec une précision d'environ 50 points de persillé MSA et le taux d'IMF% avec une précision de 1,3% aux deux sites de découpe des carcasses. Ces résultats sont importants pour les filières bovines européennes et australiennes. La caméra Q-FOM^{TM} Beef est disponible dans le commerce et convient au classement des carcasses dans les chambres froides et en milieu industriel.

Abstract: Prediction of marbling score and intramuscular fat percentage in beef rib eye at quartering sites caudal to the 4th-6th and 10th-13th rib using the Q-FOM^{TM} Beef grading camera

In Australia, quality assessment of the beef rib eye according to AUS-MEAT chiller assessment and MSA standards provides a means of describing saleable meat characteristics. One of the characteristics visually assessed is the amount of marbling. In Europe, a growing interest to evaluate the amount of marbling in beef rib eye is observed among slaughterhouses. Objective measurement technologies ensuring consistent, precise and standardised grading which can be adopted by the beef industry has in recent years become more and more important. The Q-FOM^{TM} Beef camera is an objective equipment that predicts the marbling score and chemical intramuscular fat percentage (IMF%). This paper summarises the prediction accuracy and precision of MSA marbling and chemical IMF% by the Q-FOM^{TM} Beef camera in Australian beef carcasses, quartered at 10th-13th rib, and European beef carcasses, quartered at the 4th-6th rib. The Q-FOM^{TM} Beef is highly accurate and predicts the MSA marbling score with a precision of approximately 50 MSA marbling points and chemical IMF 1.3% at both quartering sites. These results are important for both European and Australian beef industries. The Q-FOM^{TM} Beef camera is commercially available and suited for grading both at grading stations and in chiller.

Keywords : grading, objective measurement technology, meat, quality, beef

I. INTRODUCTION

In Australia, carcass grading is performed by visual assessment of the *M. longissimus thoracis* (rib eye) according to the AUS-MEAT chiller assessment and Meat Standards Australia (MSA) grading standards and includes eye muscle area (EMA), MSA marbling score, AUS-MEAT marbling score, meat and fat colour and subcutaneous rib fat thickness (AUS-MEAT, 2022a). The grading is conducted by accredited graders. AUS-MEAT guidelines states that only carcasses meeting acceptable carcass presentation are to be included in accreditation trials. Carcasses with inadequate ribbing, eye muscle damage, water/blood marks, and ecchymosis are therefore not included in measurement performance evaluation. Development of objective measurement technologies for grading the rib eye traits more consistently have become increasingly important in recent years (Gardner *et al.*, 2021). Stewart *et al.* (2021) demonstrated reliable prediction of rib eye traits in beef carcasses quartered caudal to the 10^{th}-13^{th} rib, and graded in chiller on the morning following slaughter after at least 30 minutes blooming, using a prototype beef grading camera developed by Frontmatec A/S. The prototype (ingress protection IP65) was manufactured to withstand the cold and damp conditions in a slaughterhouse environment. However, operator and camera placement during image acquisition were identified as a potential source of bias, as the prototype camera relied on utilisation of anatomical landmarks (e.g., chine and rib bones) for correct placement of the camera shroud over the grading site. Stewart *et al.* (2021) concluded that significant changes to the prototype grading camera were required for the camera to become a commercially viable product. Frontmatec A/S revised the grading camera and launched the Q-FOM™ Beef grading camera in 2022. In Australia, the Q-FOM™ Beef camera has been recently AUS-MEAT approved for grading beef rib eye caudal to the 10^{th} to 13^{th} rib for MSA marbling score (on a scale from 100 to 1190), AUS-MEAT marbling (from 0 to 9), eye muscle area, meat colour and fat colour (from 0 to 6) (AUS-MEAT, 2023). For such approval, it is required that at least 49%, 79%, and 97% of carcasses must fall within 50, 100, and 200 MSA marbling score points, respectively, of the reference measurements by experts. Stewart *et al.* (2024a) described the precision, accuracy and repeatability of the Q-FOM™ Beef camera in Australian carcasses compiling 12 different research datasets acquired from commercial processing facilities on a diverse range of carcass phenotypes.

European beef carcasses are classified using the EUROP system which provide scores for carcass conformation and fat cover on a 15-point scale. Currently, the EUROP grading system does not include rib eye quality attributes. In addition, ribbing sites are different to those routinely used in Australia with most beef carcasses being quartered at 4^{th}-6^{th} or 7^{th}-9^{th} rib to accommodate different carcass fabrication specifications. This also causes differences in cross-sectional appearance when compared to the 10^{th}-13^{th} ribbing site as well as changes to rib eye shape. Several studies have reported no or negative relationships between EUROP conformation or fatness score and eating quality characteristics such as marbling (Bonny *et al.*, 2016; Liu *et al.*, 2020). Numerous slaughterhouses in Europe are expressing interest in assessing marbling in the rib eye and may already use visual assessment to sort their carcasses to optimise profit and fulfil customer demands.

Chemical IMF% is considered a more objective measure of marbling than visually assessed marbling and is highly correlated with juiciness, tenderness, and overall liking of beef (Cheng *et al.*, 2015), making it a good indicator of overall meat quality (Liu *et al.*, 2020). Moreover, IMF% has comparable precision with MSA marbling when used to predict consumer palatability, indicating that it could displace human assessed marbling scores as an input for eating quality grading (Stewart *et al.*, 2021). Recently, chemical IMF% has been approved as a new trait within the AUS-MEAT beef trading language (AUS-MEAT, 2022a), signalling the importance that the industry places on this trait. However, laboratory analysis is invasive, expensive and laborious and therefore it would be valuable if this trait could be predicted using objective measurement technology such as the Q-FOM^{TM} Beef camera.

The objective of this paper is to summarise the Q-FOM^{TM} Beef grading camera prediction of MSA marbling score and chemical IMF% in Australian beef carcasses, quartered at 10^{th}-13^{th} rib, and European beef carcasses, quartered at the 4^{th}-6^{th} rib.

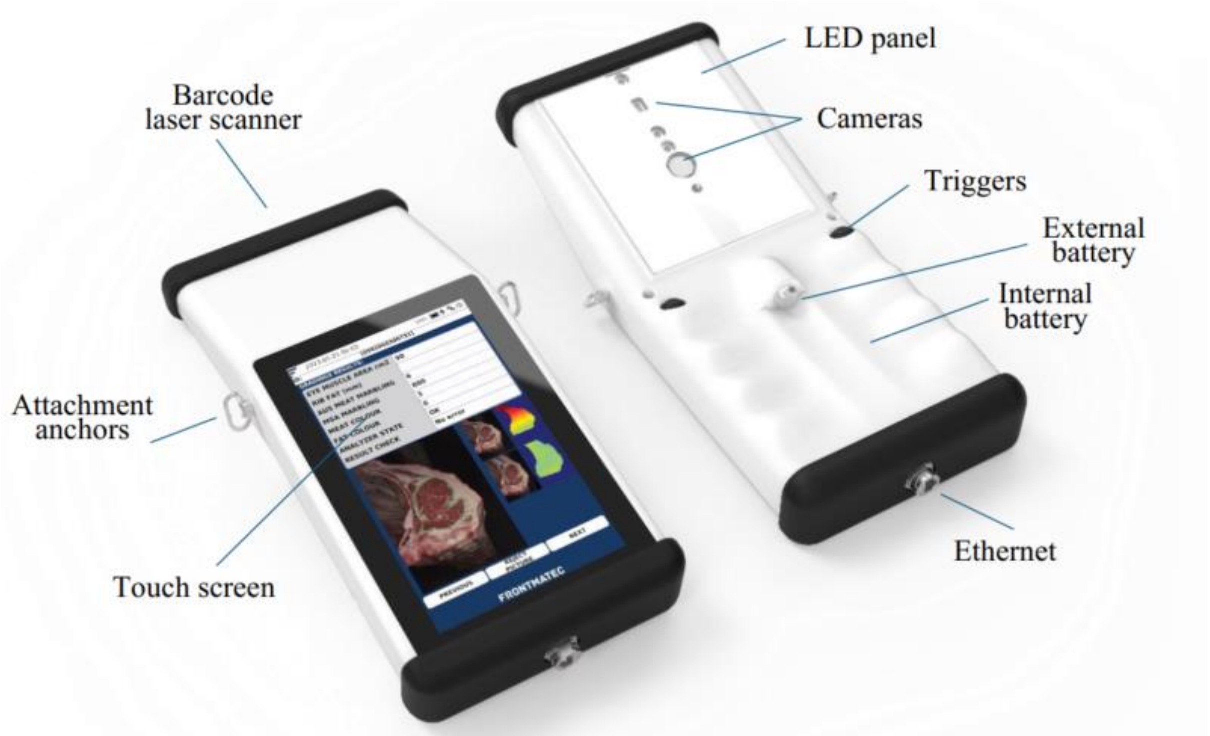
II. MATERIELS ET METHODES

II.1. Device details

The Q-FOM™ Beef camera (Frontmatec A/S, Smørum, Denmark) is an objective vision-based grading equipment (Figure 1).

Images are acquired of the cut surface by a 3D camera in combination with a high resolution 2D camera, that enables correct colour and area representation, whilst maintaining high resolution of the eye muscle area. Two high intensity diffused LED panels are utilised to illuminate the cut surface during image acquisition, minimizing negative effects of ambient light. A depth sensitive viewfinder guides the camera operator to the optimal imaging distance and angle(s), to eliminate camera operator influence on measurements. Prior to grading start-up, a camera self-test is performed using a NIST traceable chessboard target verifying that colour and geometry are unchanged. The grading sequence includes scanning the barcode to identify the carcass, capturing an image of the cut surface, and storing the grading results. This process requires only a few activations of the trigger (Figure 1) and the grading results and rib eye image is presented to the operator within 10 s. The user interface can be configured to fulfill requirements for hot carcass data download to the device and upload of grading results to the processors slaughter database.

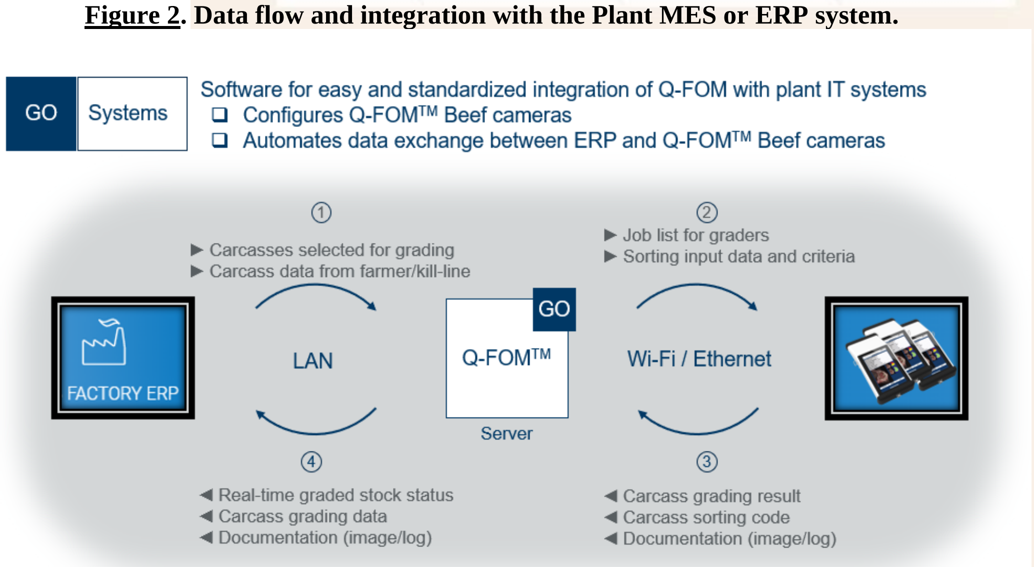
Figure 1. **Q-FOM™ Beef grading camera**



If grading is performed in chillers, a neck strap is attached to the attachment anchors (Figure 1) to avoid that the operator will drop the camera. In this setting the camera is wireless and runs on batteries. If the camera is mounted on a grading station, the camera will be suspended in a hanger and a recoil balancer and wired, which means that the camera will be charging, and data will be transferred constantly.

Camera grading data is uploaded to the processor production database when connected to the network. Grading data and processed images can also be viewed directly on the device. The Q-FOM™ Beef camera can be integrated with the processors Manufacturing Execution System (MES) or Enterprise Resource Planning (ERP) system for data integration (Figure 2).

Figure 2. **Data flow and integration with the Plant MES or ERP system.**



II.2. Animals and sampling

Two trials were used for this study, one conducted in Australia (Stewart *et al.*, 2024a) and one conducted in Europe (Drachmann *et al.*, 2024). At approximately 24 h post-slaughter, beef carcasses were quartered between the 10^{th}-13^{th} rib in Australia and 4^{th}-6^{th} rib in Europe. Carcasses with diverse ranges were targeted to ensure a broad span and good distribution in marbling and IMF%. The European trial included carcasses varying in breed (Holstein dams sired by Angus, Charolais or Danish Blue bulls), age (8-11 months calves and a subset including older carcasses with visible high marbling) and sex (males and females). The Australian trial included carcasses varying in breed and feeding regime (see Stewart *et al.*, 2024a for details). Descriptive statistics on the number of carcasses included in the trials, as well as the average and range of MSA marbling scores and IMF%, are presented in Table 1. Wagyu carcasses were graded approximately 72 h post-slaughter (standard commercial practice). All other carcasses were graded, imaged and sampled for IMF% approximately 24 h post-slaughter. Grading was conducted in-chiller. Prior to grading and image capture, the exposed rib eye muscle was allowed to bloom for 30 minutes to 1 hour. Only carcasses that met acceptable carcass presentation (AUS-MEAT, 2022a) were included in the trials. Carcasses with inadequate ribbing, eye muscle damage, water/blood marks, and ecchymosis were voided, as these factors would interfere with testing the true performance of the camera.

Table 1. Descriptive statistics of reference data for MSA marbling and chemical IMF%

	MSA marbling score					IMF%				
Ribbing site	N	Mean	SD	Min	Max	N	Mean	SD	Min	Max
4^{th}-6^{th}	582	421	147	120	980	397	5.3	4.5	0.9	22.9
10^{th}-13^{th}	2332	445	217	120	1160	653	8.6	5.8	1.2	28.8

In the Australian trial (Stewart *et al.*, 2024a), visual reference grading data of marbling scores was acquired by three graders including a company grader and two industry identified expert graders accredited in both Meat Standards Australia (MSA) grading and in AUS-MEAT chiller assessment (AUS-MEAT, 2022a). In the European trial (Drachmann *et al.*, 2024), MSA marbling score was assessed by a single MSA and AUS-MEAT chiller assessment accredited grader.

After Q-FOM™ image acquisition, samples for chemical IMF% determination were collected using standardised protocols (Drachmann *et al.*, 2024; Stewart *et al.*, 2024a) from the exposed rib eye surface, which was trimmed of secondary muscles, intrusion fat, subcutaneous fat, and connective tissue. Stewart *et al.* (2024a) used laboratory NIR analysis for samples with NIR IMF values around 15% and below and chloroform Soxhlet values for samples with NIR IMF above 15%. Chemical IMF% was reported on a wet matter basis. Drachmann *et al.* (2024) used Soxhlet values for all samples and expressed IMF% as the amount of extracted fat relative to the sample weight.

II.3. Image processing and analysis

The segmentation of the rib eye in the cut graded surface of either the 4^{th}-6^{th} or 10^{th}-13^{th} cut surface was identified using deep learning based semantic segmentation (Ulku & Akagündüz, 2022). A set of calibration parameters recorded during Q-FOM™ manufacturing was used to standardize the image and a subset of the parameters was used to colour, and intensity correct the image. The intensity correction depends on the depth and angle of each point on the cut surface. The eye muscle was further segmented into meat and fat clusters using a Gaussian Mixture Model algorithm and the colour statistics (average colour intensity, etc.) of each of these segmentation clusters was computed. The total fat area in relation to the rib eye area was measured. To quantify the distribution of intramuscular fat the average distance from any point within the segmented rib eye area to any fat pixel was calculated.

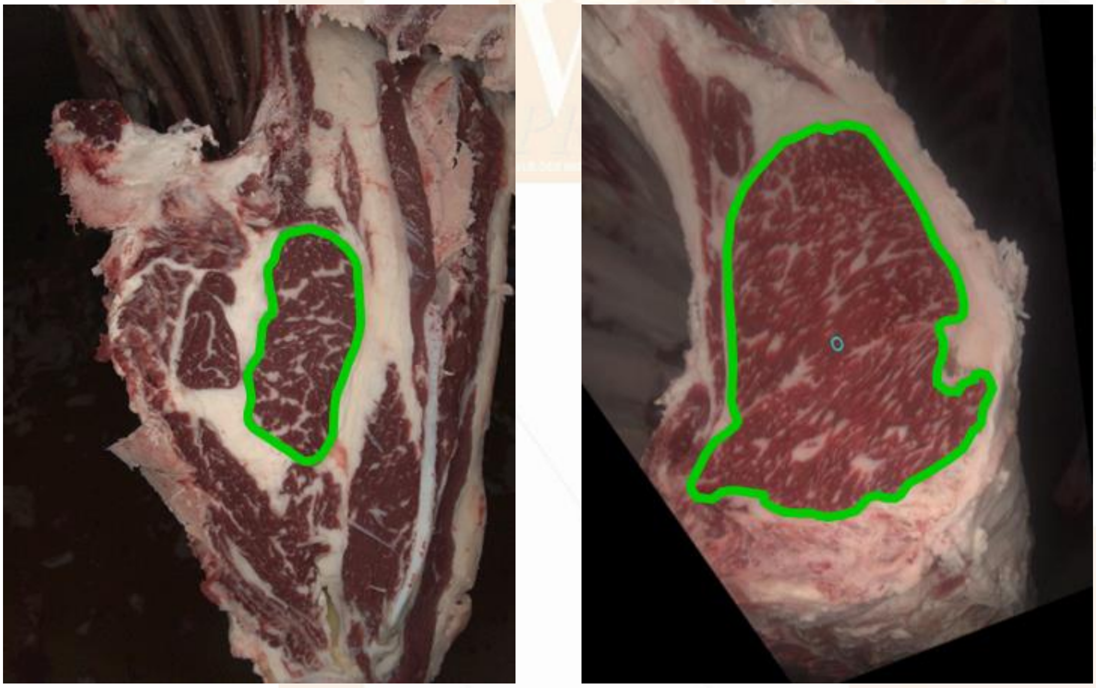
II.4. Statistical analysis

The calibration of MSA marbling and IMF% was performed by multivariate data analysis. The data were centred and scaled to unit variance. Partial Least Squares (PLS) regression was used to predict the traits. Only feature descriptors that correlated with the individual traits and described relevant trait parameters was included in the models. The optimal number of components for each model was selected using five-fold cross-validation in combination with the "One-standard-error rule" (Hastie *et al.*, 2009) to avoid over fitting. The PLS toolbox 8.7.1. (Eigenvector Research, Manson, USA) with Matlab R2021a (Mathworks, Natick, USA) was used for analysis. Limits on certain feature descriptors were applied to match the visual grading scales. The predicted MSA marbling scores were rounded to nearest whole number divisible by 10. Calibration performance was evaluated using the squared Pearson correlation (R^2) and root mean squared error of the cross-validation (RMSECV) for the relationship between actual and predicted values and bias and slope. Maximum and minimum limits on the individual feature descriptors were determined to avoid extrapolating the model beyond the extreme values of the calibration dataset.

III. RESULTATS

The rib eye muscle and the cut surface appearance differ markedly between quartering sites. Rib eye segmentation algorithms were developed specifically for each of the two quartering sites (Figure 3). Marbling score and IMF% were determined in the rib eye muscle.

Figure 3. Rib eye and cut surface appearance at 4th-6th rib (left) and 12th-13th rib (right).



The precision and accuracy of the Q-FOM™ MSA marbling algorithm developed on carcasses quartered either at the 4th-6th or 10th-13th rib are shown in Table 2.

Table 2. Precision and accuracy estimate for the cross-validated Q-FOM™ models predicting rib eye MSA marbling scores at the 4th-6th and 10th-13th rib.

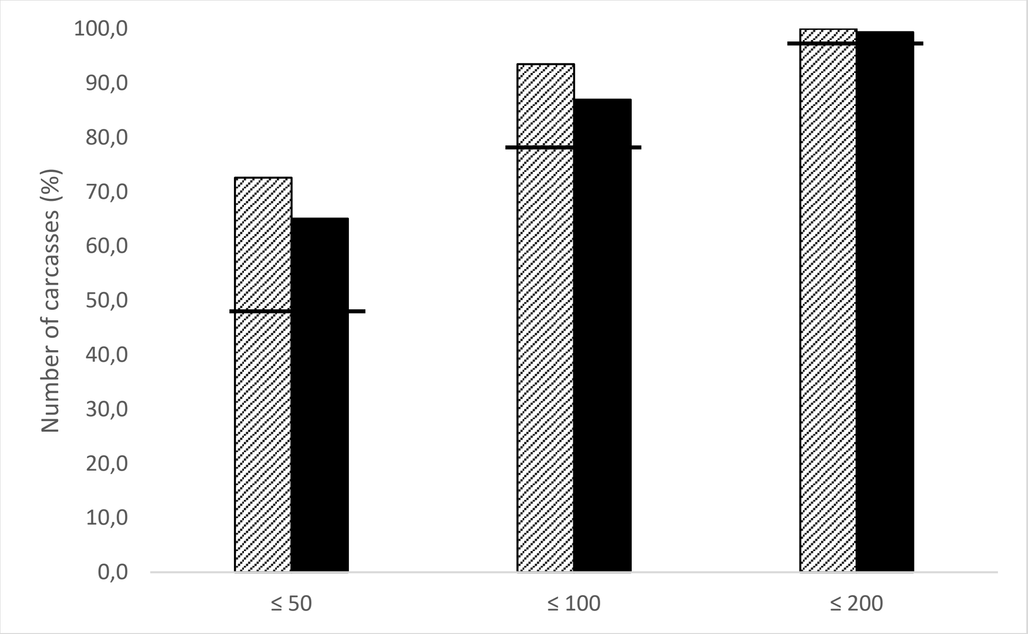
Ribbing site	Model statistics			
	R^2cv	RMSEcv	Slope	Bias
4th -6th	0.87	53.2	0.87	0
10th - 13th	0.95	48.7	0.89	-6.6

The Q-FOM™ demonstrates high level of precision and accuracy at both quartering sites. The Q-FOM™ predicted MSA marbling described 87% and 95% of MSA grader scores using the algorithm developed for the rib eye cut surface at the 4th-6th rib and the 10th-13th rib, respectively. The error of prediction (RMSEcv) was approx. 50 MSA marbling score points for both MSA marbling algorithms. The Q-FOM™ demonstrated a slope of 0.9 with no bias at the 4th-6th rib but a negative bias of 6.6 MSA marbling points when compared to the mean MSA grader scores at the 10th-13th rib (Table 2).

Figure 4 shows the Q-FOM™ camera performance against the AUS-MEAT Language and Standards Committee (AMILSC) approved minimum requirements of accuracy standards for cut surface cameras (AUS-MEAT, 2022b). The recommended accuracy standards for MSA marbling require that at least 49%, 79%, and 97% of carcasses must fall within 50, 100, and 200 MSA marbling score points, respectively, of the expert graders' assessments. The Q-FOM™ MSA marbling score algorithm developed at the rib eye cut surface after quartering at either the 4th-6th or 10th-13th rib fulfills the approval criteria stated by AUS-MEAT.

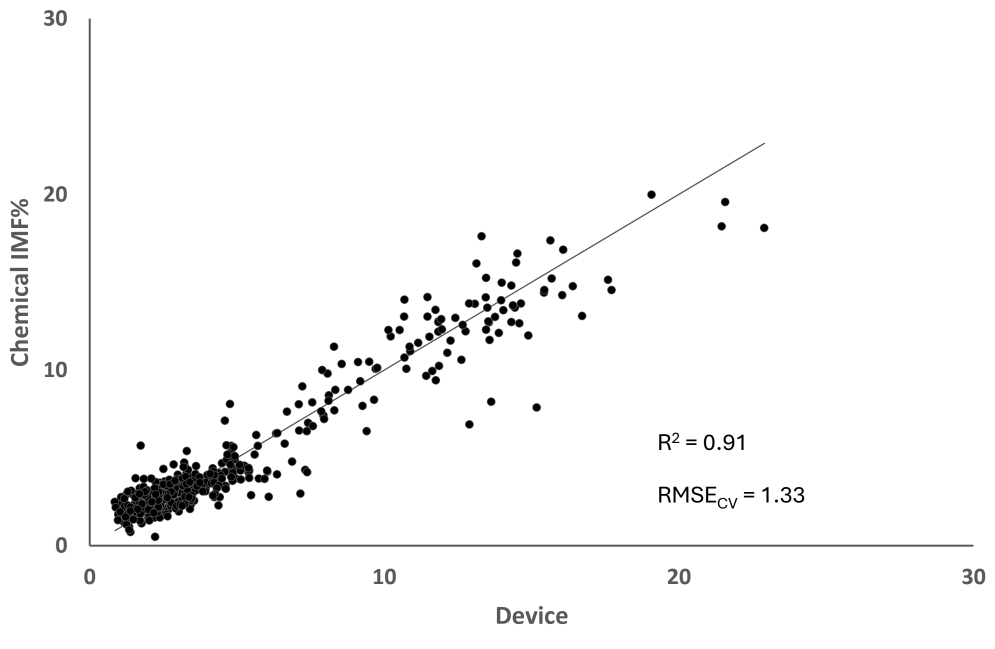
The relationship between IMF% measured by chemical analysis and predicted by Q-FOM™ is shown in Figure 5. A broad IMF range was deliberately selected at both quartering sites (Table 1) to enable development of an IMF% model representing a broad IMF% range. The Q-FOM™ Beef camera predicted IMF% explained 91% and 96% of the variation in chemical IMF% when calibrated on cut surface rib eye quartered at either the 4th-6th rib or 10th-13th rib, respectively. The precision was good and comparable at both quartering sites (RMSEcv=1.3%).

<u>Figure 4</u>. Q-FOM™ MSA marbling performance in relation to the AMILSC approved minimum requirements of accuracy standards for cut surface cameras. Carcasses were quartered at the 4th-6th rib (striped bar) or 10th-13th rib (solid bar). The percent of carcasses required to fulfil the approval criteria is shown by horizontal lines.

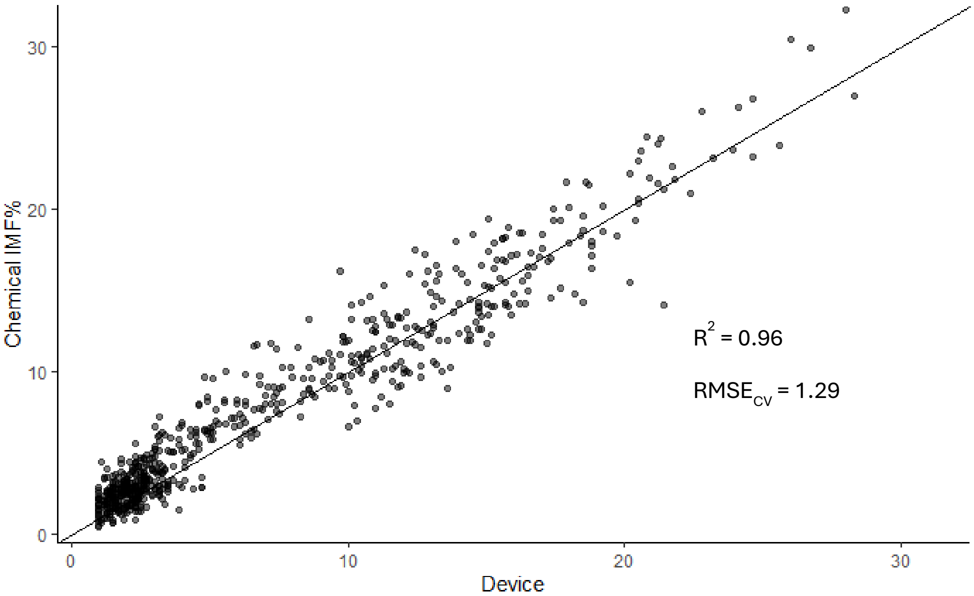


<u>Figure 5</u>. Relationship between chemical IMF% and Q-FOM™ predicted IMF%. The black line is a 1:1 target line and icons represent individual carcasses (4th-6th rib, N=397; 10th-13th rib, N=653). R^2 is the squared Pearson correlation between the actual (Y-axis) and predicted (X-axis) values.

4th-6th rib



10th-13th rib



IV. DISCUSSION

The Q-FOM™ Beef camera eliminates grader-to-grader variation and offers several advantages to the beef value chain. The objective camera solution provides accurate, precise and valuable results on marbling and IMF% in carcasses quartered at both the 4th-6th and the 10th-13th ribs. The use of objective measurement technologies improves consistency in rib eye classification across plants, enables the processors to provide feedback on farm management to producers and to breeding companies on genetic improvement.

Correct segmentation of the rib eye plays an important role in the cameras ability to accurately and precisely predict marbling score and IMF%. The segmentation models are trained to recognise and segment the rib eye and distinguish it from bordering muscles as well as subcutaneous and intermuscular fat. Since the cross-sectional appearance at the two quartering sites are markedly different, individual segmentation algorithms specifically trained on samples representing each of the two quartering sites were developed to optimise the rib eye segmentation quality. Stewart *et al.* (2024a) presents the Q-FOM™ performance against human graders for measurement of the eye muscle area at the 10th-13th rib. Spray chilling causing carcass drip on the cut surface, bone or fat smear and eye muscle damage during the quartering process influences segmentation quality which may result in inaccurate eye muscle area determination and prediction of marbling and IMF%. According to Stewart *et al.* (2024a), processing strategies to ensure high quality quartering must be employed to minimise image rejections and/or manual overwrites and maintain processing efficiency when used under commercial operation.

The Q-FOM™ Beef camera accurately predicts MSA marbling scores at both quartering sites. Although the algorithms explain more than 85% of the variation in the MSA marbling score allocated by visual grading, the coefficient of determination (R^2) was lower for the 4th-6th rib marbling algorithm compared to the 10th-13th rib. A likely explanation is due to the larger phenotypic range in MSA marbling score present in the Australian carcasses compared to European carcasses. Both algorithms show a high level of accuracy with slopes close to 1 (> 0.86) and small prediction errors (RMSEcv) of around 50 MSA marbling points. Considering that the range of MSA marbling score is between 110 and 1190 with increments of 10, the prediction error of 50 seems acceptable. The MSA marbling score algorithm for carcasses quartered at the 10th-13th rib showed a small negative bias (-6.6 MSA marbling points) when compared to the expert MSA graders. The reference MSA marbling scores might be biased due to its human visual source (Jang *et al.*, 2017).

Recently, the Australian meat industry language and standards committee accepted chemical IMF% as an industry trait, reflecting the need for objective reference methods to validate objective measurement technologies (AUS-MEAT, 2022c). The Q-FOM™ performance with regard to prediction of IMF% was highly acceptable at both quartering sites. As for MSA marbling the difference in the observed R^2 value between the two quartering sites may be explained by the difference in the IMF% range between the Australian and European trials. The prediction accuracy was higher for chemical IMF% than for visually assessed MSA marbling score in carcasses quartered at the 4th-6th rib, whereas in carcasses quartered at the 10th-13th rib the prediction accuracy was comparable. In the European trial (4th-6th rib), the MSA marbling score was evaluated by one grader only. This grader was highly experienced in AUS-MEAT chiller assessment and Meat Standards Australia (MSA) grading standards. In the Australian trial (10th-13th rib), the average score from two expert graders and one commercial grader were used as reference. Using experienced MSA graders for both trials eased comparison between the MSA marbling score algorithms. However, the prediction accuracy might have been slightly lower in carcasses quartered at the 4th-6th rib due to the nature of the human visual grading.

Whether IMF% will substitute the evaluation of marbling in commercial production is not yet clear. It seems that the IMF% values may be preferred by breeding companies for genetic improvement, while a marbling score representing the visible amount of marbling may be preferred by the processors for sorting according to product specifications and customer demands. Stewart *et al.* (2024b) recently showed that models transforming chemical IMF% into equivalent MSA marbling scores is possible. This would enable the use of IMF% as an objective reference, whilst minimising industry disruption.

V. CONCLUSION

The Q-FOM™ Beef camera predicts MSA marbling score and chemical IMF% with high accuracy and precision in carcasses quartered at both the 4th-6th rib and the 10th-13th rib, which is important for both European and Australian beef industries. In Australia the Q-FOM™ Beef camera has full AUS-MEAT approval for grading beef carcasses quartered caudal to the 10th-13th rib. Although, no approval criteria for MSA marbling score have yet been defined in Europe, the 4th-6th rib algorithm shows highly acceptable performance when compared to the approval criteria defined by AUS-MEAT. The Q-FOM™ Beef camera is suited for grading both at grading stations and in chillers and is commercially available.

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