Objective on-line assessment of marbling

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Abstract. Visual assessment remains the preferred method for evaluation of marbling in abattoirs. However, visual assessments are compromised by the disadvantages inherent in most systems of subjective evaluation. To that end, several objective measurement technologies have been developed and evaluated for on-line measurement of marbling. Several of these technologies are reviewed in this paper. Of the current suite of technologies, video image analysis and the Danish bioelectrical impedance device offer the most promise in terms of measurement accuracy and suitability for on-line use.

Introduction

Visual assessment of intramuscular fat or marbling on quartered beef carcasses has and continues to be the preferred method for the measurement of this quality trait. Whilst humans can be trained to reliably assess marbling, the fact remains that it is a subjective judgement and consequently, consistency between assessors can often vary. Furthermore, there are other issues associated with subjective beef grading such as the lack of standardisation in assessment procedures and marbling grades between countries and the costs of training and employing graders. In view of these points, there have been several attempts to develop objective technologies for the on-line measurement of marbling.

Before reviewing these technologies, it is pertinent to discuss how marbling should be objectively defined. In quantitative terms, the percentage of chemically extractable intramuscular fat (IMF%) has been one preferred baseline definition. Its selection seems logical given the relationship between marbling content and beef palatability, particularly juiciness and flavour (Smith *et al.* 1984, Perry *et al.* 1999). Whilst the total amount of intramuscular fat is important, there is anecdotal evidence to suggest that the distribution and size of the intramuscular depots may also be relevant particularly in the case of the Japanese market (Harper *et al.* 2001). This qualitative aspect is not reliably captured in a measure of the total intramuscular fat. Its relevance also has implications on the suitability of some of the potential measurement technologies. The use of IMF% has also been challenged on the grounds that it is not congruent with current beef marketing specifications. To that end, at least in Australia, it has been argued that the current visual marbling grades should remain the baseline standard. However, being subjective, the precision with which these standards can be consistently applied in practice is debatable (Markey 2001). Moreover, it should be understood that the correlation between visual marbling scores and IMF% is variable and only modest at best, based on the results of Australian studies (see below). Clearly, there is need to consider an international standard for the objective definition of marbling.

Relationship between subjective assessments of marbling and IMF %

As a benchmark, it is appropriate to firstly examine the relationship between visual marbling scores and IMF%. In studies conducted in the US (Savell *et al.* 1986) and Japan (Cameron *et al.* 1994, Okabe *et al.* 1999), good correlations in the order of 0.87 - 0.89 have been reported. This confers that approximately 75% of the variation in IMF% can be accounted by the visual scores of skilled assessors. In contrast, weak to modest correlations have been found in Australian studies. Using the AUS-MEAT marbling scores, Taylor and Johnson (1992) reported correlations of 0.57 and 0.32 at the 5/6th and 10/11th rib positions respectively. From the large CRC straightbreeding project (n= 7131 progeny), phenotypic correlations of 0.46 - 0.48 between the two traits were found (Reverter *et al.* 2001). In another study (Ferguson unpublished) based on 49 Angus steers fed for 250 days, a higher correlation of 0.71 was obtained.

Some care must be exercised when comparing the results between studies. In particular, criterion such as the correlation coefficient is not the most ideal statistic to compare since its magnitude is inherently affected by the sample variation. The smaller range in IMF% in the Australian studies (2 - 15% Taylor and Johnson 1992; 0 - 10% Reverter *et al.* 2001; 3 - 19% Ferguson unpublished) compared to that observed in the Japanese studies (3 - 38% Cameron *et al.* 1994; 16 - 39% Okabe *et al.* 1999) is certainly one reason for the weaker correlations observed between IMF% and the AUS-MEAT marbling grades. Another critical factor that will influence the relationship is the system of scoring, notably the numbers

of grades and the increments between them and the site of assessment. The USDA system comprises nine grades (six primary grades) and within each grade there are 100 subunits, which are usually scored in 10 unit increments. Consequently, the transition between grades is much smoother compared to the AUS-MEAT marbling grades which are scored as whole scores. The site of assessment varies considerably between countries (*e.g.* 6/7th rib in Japan and 12/13th rib in the US) and assessment site has been shown to influence the strength of association between IMF% and marbling scores (Taylor and Johnson 1992).

Notwithstanding the dimensional difference between a visual score and chemical extraction (ie. two versus three dimensions), it can be seen that the visual scores are generally only moderate predictors of IMF%.

Objective measurement technologies

(i) Video Image Analysis

Of the technologies currently under development, video image analysis (VIA) would appear to offer considerable promise given that the technology essentially emulates what a trained assessor does. In other words, the camera acts as the eye and the computational algorithms simulate the way the brain processes the image to derive a score.

The application of VIA in beef carcass evaluation was first reported in the eighties (Cross 1983; Sorensen 1988). Since then, the technology has been undergoing development in several countries, notably the US, Canada, Denmark and Australia. Two forms of VIA have been developed. The whole carcass system is used on the slaughter-floor to capture images of the lateral view of carcasses or sides. From these, colour and dimensional data are extracted to predict EUROP fat and conformation scores (Sorensen 1988, Borggaard *et al.* 1996) and carcass yield/composition (Ferguson *et al.* 1995, Borggaard *et al.* 1996; Jones *et al.* 1995; Tong *et al.* 1999). The second system, which will be referred to as the chiller assessment system, is used on the chilled quartered side (Tong *et al.* 1999; Markey 2001). Transverse images of the rib section are analysed to derive the marbling grade as well as meat and fat colour scores. In addition, tissue depths and areas can be measured and these have been used to predict carcass yield (Wassenburg *et al.* 1986; Jones *et al.* 1995; Tong *et al.* 1999).

The published results in relation to the performance of VIA to predict either marbling score or IMF% is summarised in Table 1. In some cases, the results pertain to prototype equipment or non-automated component systems that could

Table 1. Summary of results pertaining to VIA assessment of marbling

Study	Sample	Dependent Variable	Performance Criteria
Ferguson *et al.* (1995)[1] VIAscan System	1400 carcasses	AUS-MEAT Marbling Score 10/11th rib	Deviation from the grader's score 71% no difference 98% within 1 score
Jones *et al.* (1995)[1] VIAscan System	327 carcasses	Canadian marble score 12/13th rib	R^2 0.45 – 0.52
Garrard *et al.* (1996) Prototype equipment	60 25 mm steaks	USDA Marbling grade[2] (Range slight – moderately abundant) 12/13th rib	R^2 = 0.84
Tong *et al.* (1999) CVS System	1024 carcasses	N.A.	Repeatability 0.84 – 0.96
Kuchida *et al.* (2000) Prototype equipment	158 carcasses	IMF% (Range 6 – 39%) 6/7th rib	R^2 = 0.96
Markey (2001) VIAscan System	21 VIAscan ribeye images	AUS-MEAT marbling score[3] (Range 0 – 4)	Deviation from the grader's score 39% no difference 91% within 1 score

[1] The system used was an earlier version of the VIAscan chiller assessment system

[2] Scored by a panel of 10 trained assessors

[3] Images were scored by AUS-MEAT chiller assessors in three abattoirs

not be described as readily suitable for abattoir use (*e.g.* Gerrard *et al.* 1995, Kuchida *et al.* 2000). Only the Australian (Ferguson *et al.* 1995, Jones *et al.* 1995 and Markey 2001) and Canadian (Tong *et al.* 1999) chiller assessment systems have been purpose built and tested under abattoir conditions. This is a very important point as experience dictates that the progression from a proof of concept prototype to a commercial technology that functions effectively in abattoir environments is often long and arduous.

With the exception of the study by Jones *et al.* (1995), the results generally indicate that VIA is capable of accurate predictions of visual marbling score. Of course, the level of accuracy that is achievable in this context is constrained by the measurement error inherent in subjective assessment. In view of the limitations of subjective assessments of marbling (Gerrard *et al.* 1996; Markey 2001), the utility of these as the "gold standard" in the evaluation of objective measurement technologies is a source of contention.

In the prediction of IMF%, Kuchida *et al.* (2000) reported that the VIA image ratio of intramuscular fat area to total longissimus was highly correlated with IMF% ($R^2 = 0.96$).

In addition to high measurement repeatability (Tong *et al.* 1999), VIA is the best available technology to objectively define the spatial characteristics of marbling. As mentioned previously, this may be relevant in the case of the Japanese market.

(ii) Near Infrared Spectroscopy (NIRS)

NIRS is based on the principal that the amount of infrared light that is either reflected or transmitted through a compound is directly related to its chemical composition. They are used widely as an analytical tool for the determination of food and grain composition. NIRS has been used successfully to estimate fat and moisture composition of emulsified beef and pork (Lanza 1983) and minced beef patties (Oh and Grobklaus 1995). More recently, it has been evaluated for its ability to predict physical and chemical characteristics (Misumoto *et al.* 1991) and sensory and textural properties (Byrne *et al.* 1998, Rodbotten *et al.* 2000) of beef muscle.

In relation to the prediction of marbling, Mitsumoto *et al.* (1991) reported high correlations (r = 0.89 - 0.97) based on reflectance, transmission or fibre optic NIRS measurements of intact beef muscles (IMF% range 3 - 22%). Rodbotten *et al.* (2000) established slightly lower correlations in their study (r = 0.8) however, the standard error of the estimate (SEE = 1.3) was very similar to that reported by Mitsumoto *et al.* (1991). The SEE is a far more useful statistical criterion than the correlation coefficient when comparing the predictive accuracy between studies (Kempster *et al.* 1982).

Although a NIRS system has been developed for on-line determination of fat and moisture in minced pork and beef (Togersen *et al.* 1999), it is currently not suitable for on-line measurement of marbling in carcasses. The primary limitations are that the equipment is not portable and it is destructive requiring muscle samples to be removed for analysis. However, these limitations may be overcome through the development of NIRS probes, which utilise fibre optic technology. Danish workers (Andersen *et al.* 1993) developed an NIRS probes and reported excellent predictive accuracy (SEE = 0.66) on a small sample (n = 10) of beef loins. It is understood that NIRS probe is also currently under investigation in Australia.

(iii) Ultrasound

Ultrasound has been successfully used in livestock evaluation programs since the late fifties (Thwaites 1984). Being non-invasive, it is ideally suited for the measurement of fat and muscle dimensions, which are useful indicators of carcass composition (Kempster *et al.* 1982). More recently, real-time ultrasound systems have been developed for the measurement of marbling in live cattle (Whittaker *et al.* 1992; Robinson *et al.* 1993; Brethour 1994; Herring *et al.* 1998). Most of these systems utilise image analysis software to extract textural characteristics, which are then used to predict either IMF% or marbling score. In the study by Herring *et al.* (1998), where four systems were evaluated, the SEE ranged from 1.8 - 2.68 for the prediction of IMF%. Given their predictive accuracy, specific systems are now in use as part of beef cattle improvement programs in several countries including Australia.

In contrast, the results when the ultrasound scans are recorded on the hide-on carcass (Whittaker *et al.* 1992) or dressed carcass (Ferguson *et al.* 1992) were not so encouraging. Whittaker *et al.* (1992) attributed this to the loss of capillary blood volume within the muscle following exsanguination. They reasoned that since intramuscular fat is typically concentrated around the blood capillary network, any change to this network, would affect the degree of scattering of the ultrasound pulses. The ultrasound images were then deemed to be less informative by virtue of the reduced scattering effect.

Another ultrasound technology that has been investigated for its application in live animal and carcass evaluation is the measurement of sound velocity. There is approximately a 10% difference (100 m/s) in the speed of sound through muscle and fat tissue (Park *et al.* 1994). Therefore, the time a sound pulse takes to travel a known distance through a mixture of muscle and fat will be directly influenced by the relative proportions of each tissue. The measurement of sound velocity showed considerable promise as a predictor of beef carcass composition (Miles *et al.* 1990; Ferguson 1991). Encouraging results (r = 0.9) were also reported for the prediction of IMF% based on VOS measurements of muscle samples (Robinson *et al.* 1994; Park *et al.* 1994). However, despite the early promise, there were limitations in the application of the technology in commercial situations (Ferguson 1991). In particular, a very high degree of precision is required in the measurement of distance and propagation time such that the combined measurement error should not exceed 0.2% (Ferguson 1991). More specifically in relation to the prediction of marbling in carcasses, the technology would have to be redesigned to allow the transducers to be inserted into the muscle thus ensuring that the only fat depot present in the sound path was intramuscular. With the current design, the transducers are in contact with

the external surfaces of the carcasses, consequently, the velocity measurement will be affected by all the fat depots (ie. subcutaneous + intermuscular + intramuscular) present within the sound path. Given the high degree of predictive accuracy, some thought should be given to establish whether these design issues could be overcome.

(iv) Reflectance probes

Reflectance probes (*e.g.* Hennessy Grading Probe) utilise the difference in optical properties between fat and muscle tissue to derive tissue depth measurements. They have been the preferred measurement technology in pig carcass grading schemes in many countries since the early eighties.

Whilst potentially capable of detecting intramuscular fat in muscle, the results from two studies have been variable. Borggaard *et al.* (1989) using the Danish MQM probe reported a high correlation (r = 0.8) when predicting IMF% in pork loins. In contrast, Chandler *et al.* (1994) could only account for 14% of the variance in IMF% based on Hennessy Grading Probes measurements recorded on beef carcasses. Both authors conceded that probes were limited in this application by the fact that marbling is not distributed homogenously throughout muscle. In other words, sampling error is likely to be high given the small measurement aperture of the probe and the heterogenous distribution of marbling.

(v) Bioelectrical impedance

The measurement principal of bioelectrical impedance (BI) is reliant on the difference in electrical conductivity between muscle and fat tissue. BI has been demonstrated to be an accurate predictor of fat-free muscle mass in live animals and their carcasses (e.g. Berg and Marchello 1994, Marchello and Slanger 1994). Slanger and Marchello (1994) also demonstrated that BI was capable of accurate predictions of IMF% (SEE = 1.0) in beef loins.

The Danish Meat Research Institute have developed a hand-held BI system specifically for the purpose of on-line prediction of IMF% in beef carcasses. The device operates at frequencies ranging from 10 Hz to 150 kHz and has the capacity to adjust for muscle temperature. Results from recent abattoir trials, suggest that very accurate predictions of IMF% (SEE = 1.0 - 1.4) were achievable using the device (Madsen *et al.* 1999, Madsen *et al.* 2001). In the latter study, measurements were taken in loin muscle at the 12/13th rib site and the IMF% ranged 0.5 - 8.5%.

A feature of the device is that there are 12 needle electrodes configured in a 70 mm diameter circle. Impedance measurements are captured between single electrode pairs and there are 50 electrode combinations, which enables the impedance measurement to be derived over the circular plane (70 mm dia.). This enables a larger area within the muscle to be sampled thus partially minimising the influence of heterogeneity in marbling distribution. Another advantage of this device is that the prediction can be made on the hot carcass thereby allowing grading to occur prior to chiller entry.

Conclusions

In the development of objective measurement technologies, the primary performance indicator has traditionally been predictive accuracy. Whilst valid, other criteria such as the costs of the technology and the practical constraints associated with its use in industrial environments must be considered. Whilst it is not possible to fully assess these criteria from the literature, some conclusions can be drawn. VIA would appear to offer advantages over other technologies on a number of fronts. Firstly, accurate and repeatable predictions of marbling score as well as IMF% are possible under commercial conditions. Secondly, VIA can provide some quantification of the spatial characteristics of marbling. Thirdly, in addition to marbling score, other important characteristics such as meat and fat colour can be simultaneously measured.

Of the other technologies, the Danish BI would appear to offer considerable promise if predictions on the hot carcass are desired. The device has been purpose built and is suitable for on-line use.

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