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Comparison of the predictive power of beef surface wavelet texture features at high and low magnification

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A B S T R A C T

Beef *longissimus dorsi* surface texture is an indicator used in predicting beef palatability by expert graders. Computer vision systems have previously used imaging at normal view to develop surface texture features with some success. Good models of beef overall acceptability using imaging at high magnification have been recently developed. As a comparison the same surface texture features were computed from the corresponding images at normal view and used to model overall acceptability. Both sets of texture features were also combined with muscle colour and marbling features and used to model overall acceptability. Models using texture features alone were more successful at normal modality. However colour and marbling features combined much better with texture features at high modality to yield the most accurate model of overall acceptability ($r^2 = 0.93$). Accurate Partial Least Squares Regression (PLSR) models were computed at both modalities with and without inclusion of colour and marbling features. Addition of squared terms to the models failed to improve accuracy.

1. Introduction

The surface texture properties of beef *Longissimus Dorsi* (LD) muscle are used by United States Department of Agriculture (USDA) expert graders as part of their palatability assessment after carcass quartering (USDA, 1997). Surface texture is a vitally important palatability indicator as it will reflect the amount of connective tissue in the muscle. Connective tissue is known to increase the toughness of beef (Li, Zhou, & Xu, 2008; Swatland, 2006). A fine texture indicates low connective tissue content while a coarse texture indicates high content (Li, Tan, & Shatadal, 2001). Surface texture will also reflect muscle fibre bundle size (Li et al., 2001). There are a number of essential problems with expert grading of surface texture properties. Firstly the judgement of expert graders suffers from subjectivity and inconsistency, secondly the muscle surface can only be examined unmagnified leading to some finer details being missed, thirdly the human grader has limited means of perceiving and analysing texture. A computerised vision system can avoid these problems and give better judgements of palatability based on surface texture.

There are other palatability indicators used by USDA graders in forming their judgement such as LD colour and marbling, skeletal maturity and ribeye firmness (USDA, 1997). The same problems of subjectivity, inconsistency and limitation of perception and analysis arise with expert grading of these properties. Of these indicators LD colour and marbling are easily measured with any vision system that measures surface texture. Thus the computer vision system can easily combine surface texture features with LD colour and marbling when making a palatability judgement. These three indicators are linked to tenderness, juiciness and flavour (USMEF, 2007) which are the three most important aspects of palatability (Warriss, 2000).

Previous studies with such computer vision systems have shown that surface texture properties of meat images can form a large part of a predictive model accounting for a substantial proportion of tenderness variability (Chandraratne, Samarasinghe, Kulasiri, & Bickerstaffe, 2006; Li, Tan, Martz, & Heymann, 1999; Tian, McCall, Dripps, Yu, & Gong, 2005). Typically meat surface texture has been expressed using classical algorithms such as pixel co-occurrence, difference histograms and run lengths (Chandraratne et al., 2006; Li et al., 1999; Tian et al., 2005). The advantage of perceiving texture in these ways is that they immediately make sense and can be easily understood by observation of an image. However analysis by Jackman, Sun, Du, Allen, and Downey (2008) and Huang et al. (1997) demonstrated that the wavelet transform is a superior means of expressing meat surface texture than classical algorithms. The wavelet transform imagines a texture greyscale image as a two dimensional wave of limited duration with the pixel grey

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level being the height of the wave at that point. The shape of the wave can broken down into fundamental elements called wavelets which when added together recreate the wave. Using a small subset of these wavelets a very close approximation of the original wave is possible. One such subset is dyadic scales (scales of 2^k). Thus the wavelet transform can compress image data into a relatively small number of features without substantial loss of information. Hence wavelets can provide highly efficient texture analysis. The mathematical foundations of wavelets are given by Kaiser (1994). The benefits of applying a wavelet transform to food quality inspection data are discussed in detail by Singh, Choudhary, Jayas, and Paliwal (2008). The Federal Bureau of Investigation (FBI) in the USA applies the wavelet transform to compress fingerprint images without substantial decline in fingerprint image quality. Wickerhauser (1994) explains this in some more detail.

Previous studies used imaging at normal view to generate the surface texture features. It was proposed by Li et al. (2001) that more useful surface texture features could be found at higher magnifications as this would allow a more detailed view of the muscle fibre bundles. On the basis of this proposal surface texture features of images at high magnification rather than normal view were used by Jackman et al. (2008) to develop predictive models of beef palatability without and in combination with *L. Dorsi* (LD) colour and marbling features. Models produced using the surface texture features at high magnification proved very successful at modelling important palatability measurements.

Jackman et al. (2008) used a corresponding image at normal view to evaluate LD colour and marbling features for each sample. This image can also be used for surface texture analysis as described by Jackman, Sun, Du, and Allen (2009) in similar work where high magnification images were not available for all samples. Hence by extracting the same surface texture features from these corresponding normal view images as were extracted from the high magnification images a comparison can be made of the predictive power of surface texture features at normal view and high magnification. Some of the previous studies (Jackman et al., 2008, 2009; Li et al., 1999; Tian et al., 2005) have shown how surface texture features can combine effectively with LD colour and marbling in modelling palatability. Hence the predictive power of both sets of texture features should also be evaluated in terms of how well they combine with LD colour and marbling features.

2. Materials and methods

2.1. Sample preparation

Thirty two heifers approximately two years old from a pilot scale abattoir (Meat Industrial Development Unit, Teagasc Ashtown Food Research Centre, Dublin) were prepared and slaughtered in the same way as described by Du, Sun, Jackman, and Allen (2008). Sixteen carcasses were then chilled at ≈2 °C for 2 days. One side of the remaining 16 were then chilled at ≈−5 °C for 2 days and the other at ≈5 °C also for 2 days. This effectively produced 48 samples. A steak for computer vision analysis and a duplicate for sensory panel assessment were excised from each sample. The steaks for sensory panel assessment were vacuum packed and aged for a further 12 days, after which they were transferred to a −20 °C freezer for storage.

2.2. Image acquisition and processing

The acquisition system and procedure for imaging at normal view is the same as described by Jackman et al. (2009). For imaging at high magnification a telescope (CFM2, Infinivar, Boulder, CO, USA) was attached to the camera. This telescope offers 6.4 times magnification. High magnification images of 5 spots on the LD muscle were taken. Image acquisition was in RGB compressed TIFF form (Tag Image File Format). Images were decompressed into BMP form (Bitmap) with conversion software Optimas (Meyer Instruments, Houston, TX, USA, www.meyerinst.com) before analysis in Matlab (Mathworks, Natick, MA, USA, www.mathworks.com). A greyscale was used to reveal surface texture. The greyscale chosen was colour saturation as this was previously found to be highly effective for beef by Li et al. (2001). To create this greyscale each image was transformed into the HSI colour space, with the second channel in the image being the colour saturation. Each image at high magnification was trimmed into 512 × 512 size for wavelet analysis. The normal view images could not be trimmed to 512 × 512 size as this would go beyond the edges of the muscle. Thus the nearest dyadic scale was used. Hence each image at normal view had a window of 256 × 256 size on the centre of the LD muscle extracted. Cropping the high magnification images to 256 × 256 size was not performed as this would reduce the area of muscle examined possibly reducing the representivity of the data. Fig. 1 shows a saturation image at normal view and Fig. 2 illustrates a saturation image at high magnification from the same sample. The image acquisition system failed for 2 samples thus reducing the sample number to 46.

2.3. Sensory property evaluation

Sensory panel assessment was carried out on the 14-day aged steaks in the same manner as described by Jackman et al. (2009). A steak was cooked to 71 °C internal temperature in an electric grill (HB 90420, Siemens-Electerogerate, GmbH, Munich, Germany). Square pieces 12.5 mm in dimension were cut from the steak and served to eight in house panellist's who evaluated overall acceptability. The sum of acceptability scores for each sample was used for data analysis.

2.4. Data processing

Partial least squares regression (PLSR) predictive models were generated for overall acceptability with Unscrambler (Camo Software, Woodbridge, NJ, USA, www.camo.com). The models were validated by full cross validation. The models used the Symlet (Symmetric modification of the Daubechie wavelet) to express sur-

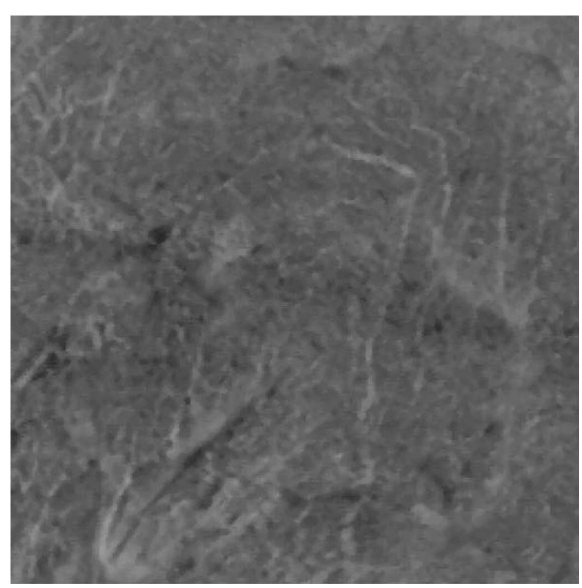

Fig. 1. A saturation channel image at normal view.