FRACTAL FEATURE ANALYSIS OF BEEF MARBLING PATTERNS

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Abstract: The purpose of this study is to investigate fractal behavior of beef marbling patterns and to explore relationships between fractal dimensions and marbling scores. Authors firstly extracted marbling images from beef rib-eye cross-section images using computer image processing technologies and then implemented the fractal analysis on these marbling images based on the pixel covering method. Finally box-counting fractal dimension (BFD) and informational fractal dimension (IFD) of one hundred and thirty-five beef marbling images were calculated and plotted against the beef marbling scores. The results showed that all beef marbling images exhibit fractal behavior over the limited range of scales accessible to analysis. Furthermore, their BFD and IFD are closely related to the score of beef marbling, suggesting that fractal analyses can provide us a potential tool to calibrate the score of beef marbling.

Key words: beef marbling, fractal, fractal dimension, image processing

1. INTRODUCTION

The beef marbling score, a dominant indicator in deciding beef quality in most current beef quality grading systems (Chen and Ji 2006), is a measurement of the abundance levels of intramuscular fat on the cross-section of the longissimus dorsi muscle (rib-eye) between the 12th and 13th or 6th and 7th ribs. In order to determine the beef marbling scores, the content and distribution of marbling flecks in the rib-eye region have to be taken into account. However, most studies on automatic grading techniques of beef marbling only pay attention to determining the grade of beef marbling in terms of variables such as the ratio of the area of fat regions over the entire beef rib-eye cross-section (abbreviated as fat ratio), the circumference of the fat regions, the number of fat particles and so on (Kuchita and others 1993, Shiraniata and others 1996, Jeyamkondan and others 2000). These feature quantities, in fact, are only associated with the overall fat content; not the distribution of fat flecks. Unfortunately, the differences in eating quality of beef can be attributed to not only the total fat content but also the fat distribution within the muscle (Albrecht and others 1996). Moreover, as previously indicated in beef studies (Kuchida and others 1992, Kurosawa and Nakanishi 1995, Shiraniata and others 1996), a considerable error would occur in grading beef marbling if the scores were evaluated only in terms of the above variables. A few of studies have focused on the distribution of intramuscular fat flecks. Yoshikawa and others (2000) proposed to use run length processing as a tool which takes into account the spatial information on the distribution of fat particles. Shiranita and others (2000) employed the amount of scatter of the distribution of marbling to take into consideration the geometry and location of fat flecks in the rib-eye region. As a further improvement of this approach, it is necessary to pay much attention to characterization of the geometric structure of the beef marbling so as to find out a more useful and appropriate feature quantity by which the overall distribution of fat particles over the cross-sectional rib-eye region can be identified correctly.

The concept of fractal geometry, which was created by Mandelbrot (1983), provides an excellent explanation of erratic natural patterns and many other natural phenomena. Its application to many fields in science and engineering has made a great progress in recent years. For example, many investigators employed fractal concept in the graphical simulation of natural phenomena like trees, clouds and so on (Huan and others 1997, Zhang and others 2000). In addition, other authors found that geometric characteristics of natural patterns can be described based on the fractal; and the recognition of human face, the letters, leaf and fingerprint etc., complex, irregular natural patterns, could be carried out by analysing fractal features (Zhang and others 1995, Borkowski 1999, Chen and Qi 2000, Yuan and others 2002).

The fractal dimension is a primary tool describing the fractal features, which can be employed to quantitatively measure the irregular degree, complexity and fragmentation of a set or pattern. Tian and others (2003) pointed out that the box-counting dimension values can be used to effectively characterize the spatial occupation degree of the crevices in grassland. Lian (2001) proposed that the box-counting dimension can reflect the spatial occupation degree of the Carpinus pubescence population, while the information dimension can quantify the variation degree of pattern intensity and the unevenness of individual distribution. Therefore, supposing that the beef marbling pattern is fractal, it is possible to use the fractal dimension to quantitatively describe the geometric features of distribution and amount of fat flecks.

Many methods including varying megascopic degree, interrelation function, distribution function and spectrum function etc. have been proposed for estimating the fractal dimension and analysis of the fractal features (Chen 1999; Sun 2004). From amongst these methods, the box-counting approach based on varying megascopic degree, although not quite exact, is the simplest to undertake using a personal computer, and it appears to be more suitable for the estimation of fractal dimensions (Tanaka and others 1999). Therefore, most researchers employ this method for the fractal analysis of a fractal pattern.

This study attempts to demonstrate that beef marbling exhibits fractal behaviour and to relate the fractal dimensions with beef marbling scores. Three aspects of this problem have to be addressed. The first question involves in the extraction of the beef marbling from sample images by image processing technologies. The second problem relates to the application of the method of varying megascopic degree to measure BFD and IFD of beef marbling images. Finally, the third aspect of this study discusses relationships between the score of beef marbling and fractal dimensions.

2. MATERIALS AND METHODS

2.1 Hardware

The computer used in this study was a 1.8GHz PC equipped with a 40 GB hard drive, 256 MB of RAM. The actual images of beef rib-eye cross-section were selected by a digital camera, with a resolution 2048 by 1536 pixels and output in RGB format.

2.2 Image samples

One hundred and thirty-five images of beef rib-eye cross-section captured in a factory in Shandong Province, China, were used for the fractal analysis and discussion of the relationship between fractal dimensions and marbling scores. A three-graders panel was established to assign marbling scores based on four official China standard pictures with marbling scores ranging from 1 to 4 (Showed as Fig. 1) . All images were digitized to 528×256 (W×H) pixels.

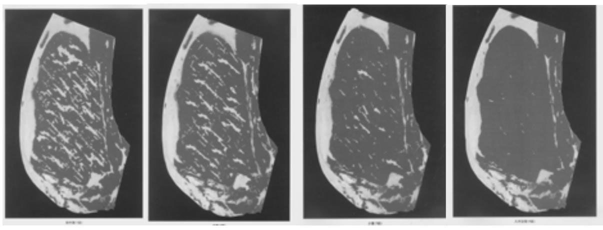

Fig. 1: BMS images from China

2.3 Pre-processing of images

The image pre-processing refers to the segmentation of marbling, involving removal of the background, segmentation of the rib-eye area and extraction of marbling. These operations were presented in detail by Chen and others (2007).

2.4 Examination of the fractal dimensions

2.4.1 Box-counting fractal dimension

The pixel covering (Feng and Zhou 2001) was applied to the measurement of box-counting fractal dimension based on the changing megascopic degree. Its primary principle is that a big rectangle is firstly used to cover the given pattern, a pre-processed image of marbling (In fact, it is expressed as a pixel matrix in computer), then the rectangle is divided into many small grids with a given side length r ($r \leq$ W and $r \leq$ H), which, in general, is named as box (sub-matrixes) and r refers to the length scale. Finally, the number of boxes which covers any part of the given pattern is recorded by counting the sub-matrixes which do not equal to zero and note it with $N(r)$. By changing the length scale r and counting the "un-empty" boxes, two data arrays can be derived. According to the box-counting method, if the data arrays fit the following relationship:

$$N(r) \propto (1/r)^{D_B} \quad (1)$$

Then the given pattern is designated a fractal object and D_B is defined the box-counting fractal dimension. Usually, the above relationship is transformed into a logarithm equation:

$$\ln[N(r)] \propto D_B \ln(1/r) \quad (2)$$

Thus, the BFD can be obtained by fitting the values of r and $N(r)$ to Equation 2 by the regression analysis.

2.4.2 Information fractal dimension

When estimating the box-counting fractal dimension, we only pay attention to the fact that the box is empty or not. According to the definition of information fractal dimension, how much information is included in a box has to be taken into account for the measurement of IFD. After being binarized, a beef marbling image is saved in computer by means of data matrix consisting of *1* and *0*, which represents a pixel of marbling and a pixel of lean meat, respectively. Further *1* also represents one information unit of marbling. Therefore, the fat information amount included in one box can be determined by simply counting the number of *1s* in one sub-matrix. According to Zhu and others (2005), to estimate IFD, the given pattern was firstly covered with a big rectangle, and divided into many small grid boxes of size *r*. Then the number of *1*s in the matrix, *N,* and the number of *1*s in a sub-matrix N_i were also recorded. According to the definition of IFD, the distribution density of information and information amount in a small grid or box are, respectively, defined as:

$$Pi = \frac{N_i}{N} \quad (3)$$

$$I_i = -P_i \ln P_i \quad (4)$$

The total information of marbling is given by the following equation:

$$I(r) = \sum_{i=1}^{N(r)} P_i \ln P_i \quad (5)$$

Where Pi — distribution density of information

. I_i — information amount in a small rectangle or box

$I(r)$ — total information of marbling under a given length scale, *r*

$N(r)$ — the number of sub-matrix which dose not equal to zero.

By varying the length scale *r*, different $I(r)$ values can be obtained; and if the relationship between *r* and $I(r)$ follows:

$$I(r) \propto (1/r)^{D_i} \quad (6)$$

Then the given pattern may be regarded as a fractal object with D_i representing the IFD. The values of *r* and $I(r)$ were fitted to the linearised form of Equation (6) to deduce D_i:.

$$ln[I(r)] = k - D_i ln(r) \quad (7)$$

Where *k* is a constant.

3. RESULTS AND DISCUSSION

3.1 Box-counting fractal dimension

To begin with, an arbitrary picture taken randomly from one hundred and thirty-five samples was chosen as an example for executing a fractal analysis. Then similar analyses have been made for the remaining samples but they are not shown here for simplicity. Fig. 2 shows this image and its pre-processed image obtained by the method described above is shown in Fig. 3 (For visualization clarity, here shows its grey level image).

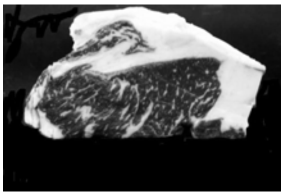

Fig. 2: An original image of sample

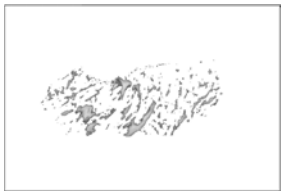

Fig. 3: The pre-processed image

Fig. 4 shows the graph of ln $N(r)$ versus ln(r), for the pre-processed image. The plot can be divide into three sections based on observation: the plots can be considered to be linear in the length scale intervals covering [1,11] and [12,116] pixels, whereas it is curved when r>116 pixels. The regression analyses also show that ln $N(r)$ is highly significantly linearly correlated with ln(r) in the two intervals: [1, 11] and [12, 116] pixels (Significant level α=0.01). Thus, the totall number of "un-empty" boxes as a function of length scale of the fractal analysis satisfies a power law behaviour shown in Equation. (1), indicating that this image of beef marbling is scale-free and can be characterized by multi fractal in the interval r = [1, 116] pixels. The corresponding BFDs obtained from slopes gave values 1.3463 in interval r = [1, 11] pixels and1.5226 in r = [12, 116] pixels. Afterward, the other one hundred and thirty-four samples were subjected with the above fractal analysis and also demonstrated the same multi fractal feature in the interval r = [1, 11] and r = [12,116] pixels. Their BFDs range from 1.0888 to 1.8181 in the box size [12, 116].

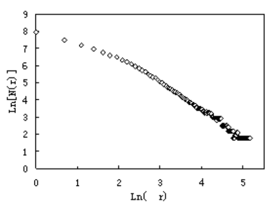

Fig. 4: Plot of $\ln[N(r)]$ versus $\ln(r)$ for the image shown in Fig. 3

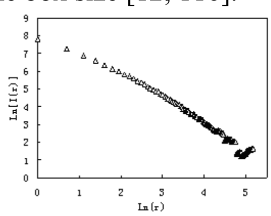

Fig. 5: Plot of $\ln[I(r)]$ versus $\ln(r)$ for the image shown in Fig. 3

Especially, four parameters: ratio of fat area to l.d. muscle area (RFA), total number of fat flecks (TNFF), number of big fat flecks (NBFF, refers to these that their areas determined by pixel count are bigger than the average area of all fat flecks) and number of small fat flecks (NSFF, whose areas determined by pixel count are smaller than the average area of all fat flecks) were calculated for every image. After making a comparison, we found that the images which have the same total amount of marbling have different BFDs due to difference in the distribution of marbling. For example, for two images which have fat area ratio, 0.1340 and 0.1339, respectively, their BFDs are 1.6067 and 1.7643 respectively. The former has the TNFF 249, NBFF 80 and NSFF 169 while the latter has TNFF 293, NBFF 46 and NSFF 247. Obviously, the former's TNFF is less than the latter and its NBFF is more than the latter's, suggesting that marbling in the image with lower dimension is more concentrative than that with higher dimension.

3.2 Information fractal dimension

The image shown in Fig. 3 was also subjected to the determination of IFD and fractal analysis. The decrease in total information of marbling [$I(r)$] as the length scale *(r)* increases, is plotted in Fig. 5 in order to correlate the ln *I*(*r*) with ln (*r*). It is clear from Fig. 5 that ln *I(r)* — ln *(r)* dependence also consists of two lines and one curve. Further regression analyses also justify the two significant linear relationships between the ln *I(r)* and *ln* (*r*) in intervals [1, 17] and [18, 116] pixels (α = 0.01), indicating that the beef marbling pattern is multi fractal in a given interval *r* = [1, 116] pixels with slopes 1.5123 and 1.5609 in intervals [1, 17] and [18, 116] pixels, respectively. Similarly, the fractal analysis of all other samples show that beef marbling is a fractal object over two specific length scale intervals: [1, 17] and [18,116] pixels, with IFDs ranging from 1.0843 to 1.956 in the interval [18, 116].conference is agriculture-oriented and targeted participants are from government, institutes and large companies, industrial districts, clusters and regional development agencies and consultants all over the world.

3.3 Relationships between fractal dimensions and beef marbling scores

Descriptive analysis for BFD and IFD data of all beef images was carried out. The effect of marbling score on the BFD and IFD was examined by means of an ANOVA. Pearson's correlation coefficients were calculated in order to evaluate the relationship between the BFD and IFD of beef marbling and its score to study weather the score of beef marbling could be predicted from the BFD or IFD value.

BFDs of all beef marbling images in intervals [1,11] and [12,116] pixels were plotted against marbling score in Fig. 6 and Fig. 7, respectively. BFDs for different marbling scores were significant distinct from each other as observed from Fig. 6 and Fig. 7 although there are questions of a little overlap between the BFD values of adjacent score of beef marbling. There was a visible decrease in the BDF values with the increase in marbling score from 1 to 4. The beef marbling having higher BFD value showed lower score. This fact suggested that the more abundant the beef marbling is, the higher its BFD value is. A correlation analysis was applied to analyze the relationship between beef marbling scores and its BFD values. Our results indicated those BFD values of beef marbling in intervals [1,11] and [12,116] pixels were significant correlated to beef marbling score at the 0.01 level, respectively.

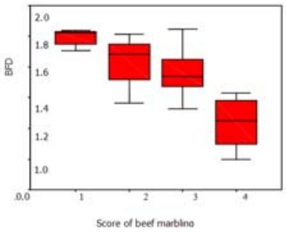

Fig. 6: Variation in BFD in interval [1,11] pixels with Score of beef marbling

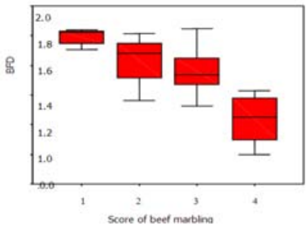

Fig. 7: Variation in BFD in interval [12,116] pixels with Score of beef marbling

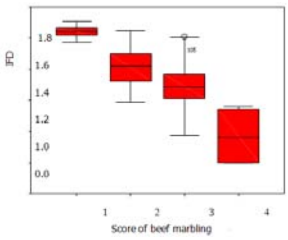

Fig. 8: Variation in IFD in interval [1,17] pixels with Score of beef marbling

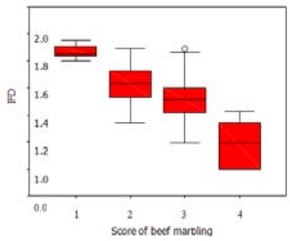

Fig. 9: Variation in IFD in interval [18,116] pixels with Score of beef marbling

Similar results could be obtained from Fig. 8 and Fig. 9 illustrating the variations of IFD values in intervals [1,17] and [18,116] pixels as beef marbling scores change, respectively. IFD also showed significant correlation with Beef marbling scores at the 0.01 level.

For comparison, marbling features including RFA, TNFF, NBFF and NSFF were calculated. Note that all the features were normalized with respect to l.d. muscle area. The mean, SD and simple correlation coefficients of each predictor with beef marbling score were listed in Table 1. Correlation coefficient is a measure of the linear association between two variables. All feature parameters of beef marbling significantly correlated with beef marbling score ($P < 0.01$). RFA showed the highest correlated with marbling score (r=0.661). The BFD has slightly higher correlation with marbling score in smaller length scales [1,11] pixels (r = 0.628) than in more one [12, 116] (r = 0.560). The IFD has also slightly higher correlation with marbling score in smaller length scales [1,17] pixels (r = 0.644) than in more one [18,116] (r = 0.592). although the correlation coefficients between BFD and IFD and marbling score are lower than that between RFA and marbling score, both BFD and IFD in smaller length scales have higher correlation with marbling score compared with TNFF (r = 0.608), NBFF (r = 0.582) and NSFF (r = 0.574), which are useful in predicting beef marbling score. This suggested that BFD and IFD of beef marbling image are potential indicators which could be used in predicting marbling scores.

Tab. 1 Means, Standard deviations and correlation coefficients of BFD, IFD, RFA, TNFF, NBFF and NSFF with beef marbling score

Variables	Means and Standard deviations				Correlation coefficients
	No. 1	No. 2	No. 3	No. 4	
BFD*	1.7792±0.0042	1.6327±0.1077	1.5300±0.1138	1.1859±0.1749	0.628**
BFD**	1.7893±0.0054	1.6340±0.1287	1.5548±0.1125	1.2333±0.1809	0.560**
IFD*	1.8415±0.0046	1.6184±0.1182	1.4843±0.1480	1.1716±0.1698	0.644**
IFD**	1.1813±0.0058	1.6312±0.1439	1.5147±0.1541	1.1938±0.1879	0.592**
RFA	0.1662±0.0034	0.1458±0.0039	0.0085±0.0042	0.0025±0.0012	0.661**
TNFF	360±82	316±87	213±84	67±40	0.608**
NBFF	57±12	57±14	36±17	13±5	0.582**
NSFF	304±91	259±83	174±75	54±35	0.574**

BFD* in intervals [1,11]; BFD** in intervals [12,116]; IFD* in intervals [1,17]; IFD** in intervals [18,116]

**P<0.01

4. CONCLUSIONS

The beef marbling is significantly characteristic of the fractal in given intervals. The multi fractal characterization of beef marbling image implies the existence of more complex distributions of marbling within the image, indicating there is marked variation in local density of marbling.

Both BFD and IFD of beef marbling images are significantly correlated with beef marbling score. BFD and IFD in smaller length scales showed higher correlation with marbling score than TNFF, NBFF and NSFF. Fractal dimensions over a specified interval are potential parameters for reflecting the abundance degree of beef marbling.

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