Plumpness Recognition and Quantification of Rapeseeds using Computer Vision

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Abstract—**The plumpness is an important index of crop seed. However, traditional measurements are time-consuming and labor intensive. The computer vision technology, which may offer more efficient and non-destructive methods for measurement, has recently appeared. But it is very difficult to accurately estimate the plumpness of single seed by the ratio between area and perimeter because of the diversity of rapeseed seed's size. This paper focused on rapeseed seed plumpness recognition and quantification, based on computer vision. A new method, the coefficient of variation of radius (CVR), was used to estimate seed plumpness. The recognition and quantification model for plumpness in single seed were established by using the fuzzy C-means (FCM) clustering and fuzzy math method. The plumpness of the seed is full if plumpness is greater than or equal to 0.6. Some correlative index are calculated and analyzed to verify the validity of this method. The tests show that there is no correlation between plumpness or plumpness ratio, and 1000-seed weight or equivalence diameter. But there are significantly partial correlation between plumpness or plumpness ratio, 1000-seed weight and equivalence diameter. Finally, plumpness ratio index is significantly different among the 12 varieties rapeseed was determined. With the mean value of plumpness ratio of rapeseed variety, the plumpness degree was plotted 10 grades. The results show that the application of computer vision technology is significantly valid for quantitative determination of plumpness in rapeseed seed.**

Index Terms—**Computer vision; rapeseed; plumpness; pattern recognition**

I. Introduction

Rapeseed is one of the most important oil plants and now the largest source of biodiesel production in the world. The seed plumpness grade is not only an important factor affected its vigor, it's also one of the most important indices concerned breeding scientists. However correct measurement for seed plumpness is much more difficult. Currently crop seed plumpness measurement methods are summarized as follows:

(1) Visual measurement method. The seed plumpness is divided into different levels by visual comparison of experts [1, 2]. This method is simple, but there were some questions, such as man-made interference and no norms.

(2) Specific gravity method. Three different concentrations of salt solutions (1.00/1.05/1.10) were used to divide rice seed plumpness [3]. This method is relatively simple and can gain the plumpness of single seed. But there were also some shortcomings, such as more trouble counting and no quantitative measurement.

(3) Water-density method. The water-density of wheat grain was considered the best index to describe wheat grain plumpness [4]. But this method also showed some shortcomings, such as data measurement inconvenience and no quantitative measurement of single seed.

(4) Image processing method. The ratio between area and perimeter was used to calculate the plumpness of seed [5]. This method is only suitable for small changes in crop seed size. The result was also impacted by the size of image resolution. In the same rapeseed variety, there was a relatively large difference for the seed size. The new method was needed to estimate the plumpness of rapeseed seed.

No detailed study concerning plumpness property of rapeseeds has been reported hitherto. The plumpness property must be known to breeding selection of rapeseed seeds for breeding scientists. The plumpness property of rapeseed seeds is currently determined by visual inspection. However, there are some subsistent problems for this visual inspection method. Firstly, this kind of analysis is both labor- and time-consuming. Secondly, there is not a uniform standard. Thirdly, the plumpness property of rapeseed seeds is very difficult to accurately quantify by visual measurement because the size of seeds is too small. This needs a simple and convenient method with quantified evaluation.

Computer vision-based image analysis methods have been investigated as an alternative to realize full automatic measurement of the plumpness property. Numerous studies are being conducted currently on the possibility of using this technique for seed/grain quality estimation, classe identification and biological index evaluation. The morphological and geometrical features were evaluated for maize [6], soybean [6, 7], wheat [8], rice [9] and rapeseed [10, 11]. The geometry, color and texture of kernels were applied to the purpose of identification of weed [12, 13], crop species and varieties [14-24], types of insect and particulate bio-contaminants [25], mechanical damage[26]. Examples of computer vision-based image analysis application to evaluate the biological index of crop seeds are few [27]. Researches based on computer vision technology for rapeseed are mainly focused on seed quality estimation [10, 11, and 24] and varieties identification [22, 23].

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The aim of this work is to establish a fuzzy model to identify and quantify rapeseed seed plumpness. Furthermore, some important biological indices are measured and analyzed in this basis. All tests showed that it was a valid method.

II. Materials and Methods

A. Materials - rapeseed samples

Rapeseed seeds including 12 varieties were obtained from China's five locations (Hunan, Hubei, Shangha, Guizhou, and Gansu province) in September 2006. The 12 varieties were considered as one test, including 2 *Brassica compestris* L., Tainyou 4 (T4) and Tianyou 6 (T6), and 10 *Brassica napus* L., Guiyou 7 (G7), Guiza 2 (G2), Guiza 4 (G4), Qianyou 14 (Q14), Youyan 11 (Y11), Xiangzayou 753 (X753), Xiangzayou 6 (X6), Xiangzayou 743 (X743), Huyouza 1 (H1) and Zhongyouza 11 (Z11). 2000 grains in each variety sample were randomly selected, and divided into 20 portions. Each portion concluded 100 grains, and three photos were taken. Thus, 720 images were obtained, and were randomly divided into two sets, test set 1 and test set 2, by variety. One image of each variety in test set 1 was randomly selected as modeling set, which was used to build fuzzy model.

B. Image acquisition and processing

A Kodak color camera (DX7590, Eastman Kodak, American) with a 1/2.5 inch CCD sensor and 128M SD card was used to take the images of rapeseed samples. The collected images were saved in the JPEG (joint photographic experts group, JPG) format, with a resolution of 2048 × 1536 pixels, and 24-bit color. Camera manual mode was selected and its settings included an aperture (f-number) of F4.0, a shutter speed of 1/400 s, natural color, daylight white balance, center-zone focus, center-weighted light metering, close-up wide, and ISO equivalent of 100.

A tricolor ring light (22 W, ac, color temperature 6500K, Ra>80, EX-D: 3 band Daylight; Model TCL YH22W, China), 184 mm diameter, was fixed in the middle of cylinder lampshade with some diffuse reflection papers.

The rapeseeds were evenly sprinkled on the white background, no adhesion and examined from a distance (lens to objects) of 12.5 cm. A black VCD disc was used as reference for image distortion correction and scale factor calculation. Before rapeseeds image shot, some images were shot with VCD disc at the different direction of scene. Images were copied from the camera to a portable computer.

Image processing was performed using user-written MATLAB® (Version 7.2, The Mathworks Inc., Natick, MA) software, included distortion correction, gray processing, median filter, and segmentation. The gray value of RGB image can be determined by formula (1). A median (median 3 by 3) filter was used to preprocess each image for enhanced visual quality and reduced random noise in the image [28]. Otsu segmentation method was used to separate the object from the background [29].

$$Gray = 0.299 \times R + 0.587 \times G + 0.114 \times B \quad (1)$$

Where, R (Red), G (Green) and B (Blue) were the three color values of the JPG image. R, G, B and Gray ∈ [0, 255].

C. Image analysis and feature extraction

Algorithms were developed to extract some morphologic features, which included equivalent diameter, radius, coefficient of variation of radius, and so on. Image processing and analysis, cluster analysis, and statistical analysis were performed on a HΛSEE portable computer (PM Dothan, 768M, Windows XP sp2).

In order to discuss the performance of this model, some relative indexes would be extracted as follow.

The equivalent diameter (*ED*) can be determined by formula (2).

$$ED = \sqrt{\frac{4 \times SA}{p}} \times SF \quad (2)$$

Where, *SA* is the area of seed image, and *SF* is the scale factor of every pixel in one image.

The 100-seed determination in GB/T 3543.5(1995) was used to measure 1000-seed weight of all relative rapeseed variety by using electron analytical balance (METTLER AE260, Delta Range®) to an accuracy of 0.001g. The result was the average of three repeated measurements.

The plumpness ratio (PR) is the ratio of the number of full seeds and the number of all seeds in an image.

D. Rapeseeds plumpness recognition method

Rapeseed seeds are very small; their diameters are about 2mm [10, 14, and 22]. Conventional methods are time-consuming, hard sledding and not standardized. Usually rapeseed seeds show spherical, and their size is variable even in the same variety. Therefore, we need a new index to eliminate the size effect. Computer vision method is very flexible, convenient and practical. But there are some problems in this method. First the seeds in the image are only two-dimensional projection of their three-dimensional feature. Then the segmented seed boundary is not exact enough and smooth (see Figure 1). In addition, there are always some errors in data processing procedure. That is to say that there is fuzzy information in the whole process. Based on this point, we selected fuzzy information processing method to build fuzzy model to avoid such effect.

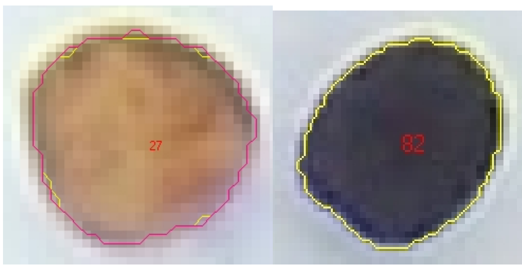


Figure 1. The amplified rapeseed seed image.

For convenience, thereinafter, we suppose that rapeseed seed image had been segmented as Region of Interest (ROI).

1) Seed Area and Centroid Coordinate of ROI

Seed Area (SA) is the number of all pixels for a ROI, namely one seed image. Then, the centroid coordinate of this ROI can be calculated by formula (3) and (4) [30].

$$\bar{x} = \frac{1}{SA} \sum_{(x,y)\in ROI} x \tag{3}$$

$$\bar{y} = \frac{1}{SA} \sum_{(x,y)\in ROI} y \tag{4}$$

2) Euclidean Distance Measure for Radius

The Euclidean distance form center of mass of ROI to boundary point can be calculated by formula (5).

$$R_k = \sqrt{(x_k - \bar{x})^2 - (y_k - \bar{y})^2} \tag{5}$$

Where, k is 1, 2, 3…n. n is the total number of boundary point for ROI.

3) Coefficient of Variation of Radius (CVR)

The coefficient of variation of radius for ROI can be calculated by formula (6) – (8) [30, 31].

$$\bar{R} = \frac{\sum_{i=1}^{n} R_i}{n} \tag{6}$$

$$S = \sqrt{\frac{\sum (R_k - \bar{R})^2}{n-1}} \tag{7}$$

$$CVR = \frac{S}{\bar{R}} \times 100 \tag{8}$$

4) Fuzzy C-Means Clustering

Fuzzy c-means (FCM) is an unsupervised method of clustering which allows one piece of data to belong to two or more clusters. This method (developed by Dunn in 1973 [32] and improved by Bezdek in 1981 [33]) is frequently used in pattern recognition. The algorithm is composed of four steps [see 34, 35].

Thousands of rapeseed seeds, including plump and unfilled selected by experts, were used as the test sample to extract the standard of rapeseed seed plumpness. After being clustered by FCM clustering method, CVR of those seeds were plotted into two parts. And we found that one class's CVR upper limit was 5.66, and another class's CVR lower limit was 5.67.

E. Rapeseeds plumpness quantification model

The value 5.66 of CVR was selected as the standard for rapeseed seed plumpness, namely what CVR is less than or equal to 5.66 is full. But this method only realized the qualitative analysis for rapeseed seed plumpness. We need a more accurate quantitative analysis method. A quantitative analysis model is built by fuzzy math [36]. The quantitative plumpness (*QP*) of rapeseed seed can be calculated by formula (9).

$$QP = \begin{cases} 1 - \dfrac{0.4 \times CVR}{5.66} & CVR < 5.66 \\ 0.6 & CVR = 5.66 \\ 0.9 - \dfrac{0.6 \times CVR}{11.32} & 5.66 < CVR \le 16.98 \\ 0 & CVR > 16.98 \end{cases} \tag{9}$$

Where, $QP \in [0, 1]$.

In this case, we consider that it is not available when the CVR value of seed exceeds the triplication of standard value. When the CVR value of seed is between the standard value and three times of it, the *QP* value of this seed is between 0 and 0.6. Hereinafter, this model was named as FCM model.

F. Statistical analysis

In this study, the correlation coefficient (r) and the partial correlation coefficient were used to measure the degree of association between features. The coefficient of determination (R^2) was interpreted as the proportion of the variability of the dependent features explained by the regression on a feature. Data were analyzed as a differences comparison using ANOVA, and means were separated using Fisher's least significant difference (LSD) at the 1% and 5% significant level. These statistical analyses were performed with the data processing system (DPS, http://www.chinadps.net/index.htm) statistical software [37].

G. The study was realized in four stages

Stage 1 – construction of the recognition and quantificational model of rapeseed seed plumpness using computer vision and fuzzy mathematics methods for the measurement of plumpness of single seed. The results of model identification were compared with the results of three experts by visual measurement for tested its validity to identify rapeseed plumpness. The performance of this model would further be detected by analysis of the expanded boundary curve of rapeseed seed.

Stage 2 – determination of the minimum rapeseed seed sample size of 12 rapeseed varieties for the measurement of plumpness of seeds. The minimum sample size was calculated on the basis of measurement of 100 seeds from the formula (10) [38].

$$n_0 = \frac{t_\alpha^2 \hat{s}^2}{d^2} \tag{10}$$

where t_α is the value of the *t*-Student's variable read from a distribution table for the confidence coefficient 1 – α and *n* – 1 degree of freedom (α = 0.05); $\hat{s}^2$ – variance for sample of size *n*; *d* – maximum error of estimation, i.e., measurement accuracy for particular parameters (*d* = 0.05) [10].

In that part of work, we analyzed also how sample size influences on discrimination of seeds varieties. For analyses of 100, 500, and 1000 seeds dispersion statistics (standard deviation, coefficient of variance, and plumpness ratio) was presented.

Stage 3 –determination of the correlation of some rapeseed seed features and choice of the best indicator for the overall characteristics of the rapeseed seed sample. At this stage all data of test 1, 2, and 1+2 were analyzed together, respectively.

Stage 4 – determination of the grade method of rapeseed seed sample. At this stage three methods (plumpness ratio, plumpness and expert visual measurement) were used to evaluate the quality of rapeseed seed sample and select the best evaluation index.

III. RESULTS AND ANALYSIS

A. Comparisons of CVR and visual measurement method

1) Plumpness indexes analysis

It is generally believed that the ratio of surface area and volume of seed is the best index for the measurement of seed plumpness. But it is very difficult to measure the surface area of seed. Seed image is the projection of its three-dimensional structure in the two-dimensional plane. The ratio of area and perimeter of seed measured by computer vision was considered as a good indicator [5]. The coefficient of variation of radius for seed image was proposed as another indicator. In general, the plumpness of seed is unrelated to seed size. To evaluate the performance of these indicators, the regression analysis of these indicators and seed diameter were conducted for modeling set.

There was a highly significant positive correlation between the ratio of area and perimeter and diameter (see Figure 2). This showed that the value of the ratio of area and perimeter was affected by the seed size. But there was not correlation between CVR or FCM model and diameter (see Figure 3, 4). This showed that the performance of CVR and FCM model was superior to the ratio of area and perimeter. By comparison, there was a more extensive and symmetrical distribution of FCM model than CVR. Obviously, FCM model is a better indicator.

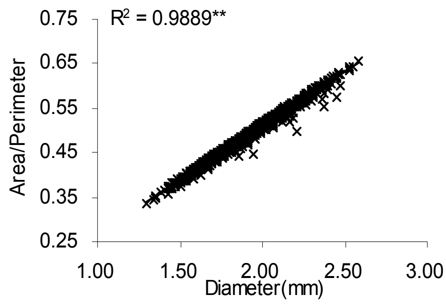


Figure 2. The relationship between diameter and the ratio of area and perimeter. ** shows significance at $p<0.01$.

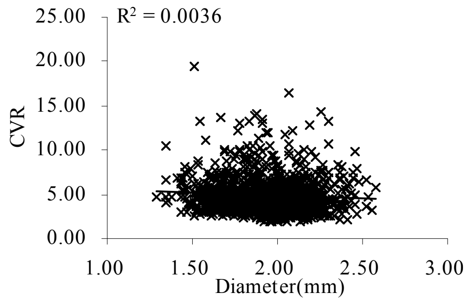


Figure 3. The relationship between diameter and the coefficient of variation of radius

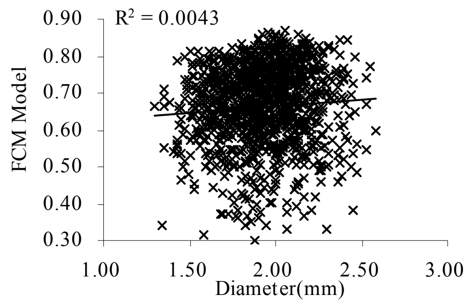


Figure 4. The relationship between diameter and plumpness.

2) The correlation analysis of FCM model and human vision recognition

Analysis of the effects of FCM model and human vision measurement indicated a highly significant positive correlation between the results of FCM model measurement and the results of three experts by visual measurement (see Figure 5). This showed that FCM model had a good performance for the measurement of rapeseed plumpness. But there was large deviation between the results of FCM model and the results of experts 2, 3 and Mean (see Figure 5. b, c and d). This showed that the standard of rapeseed seed plumpness of every expert was inconsistent.

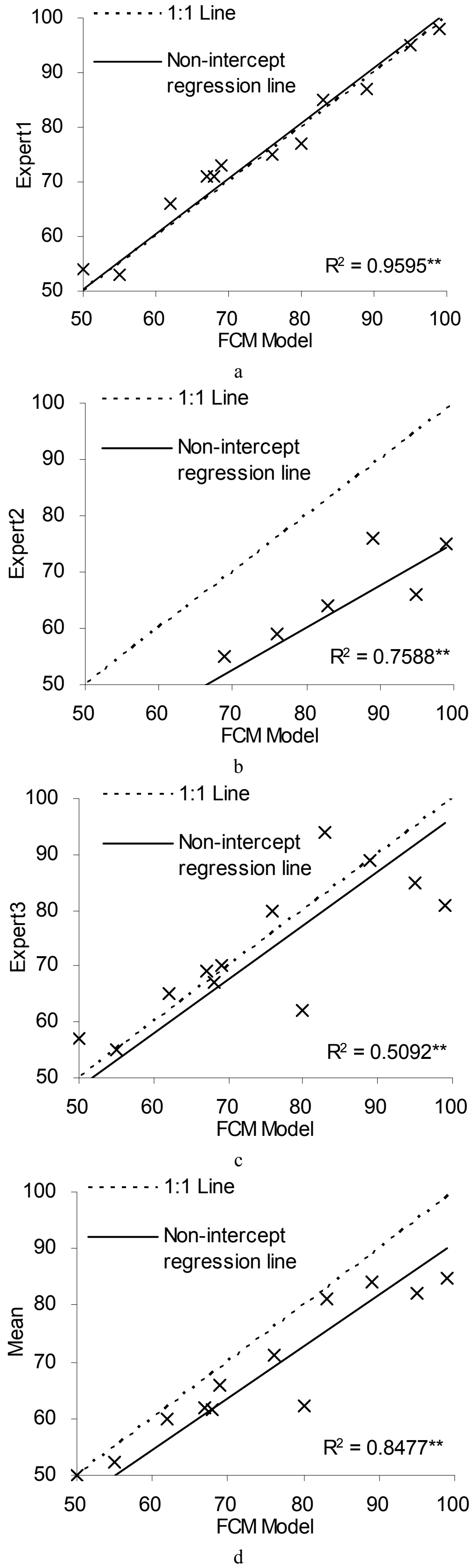


Figure 5. The relationship between the results of FCM model and the results of three experts (a, b, c and d) by visual measurement for rapeseed plumpness. ** shows significance at $p<0.01$. Mean is the average value of three experts' recognition results.

3) Comparisons of FCM model and human vision recognition

The evaluation results of FCM model and three experts, and the average value of three experts' recognition results (expressed by Mean) were presented in figure 6. In addition to G7, the evaluation results of the remaining 11 varieties of expert two were distinctly different to ones of the other two experts and FCM model. This showed the standard of the expert two was clearly stricter than the one of other experts and FCM model.

An analysis of variance (ANOVA) for the results of FCM model measurement and the results of three experts by visual measurement indicated that there were not significantly different among FCM model, Mean, expert 1 and 3, but were significantly different with expert 2 (see Figure 7).

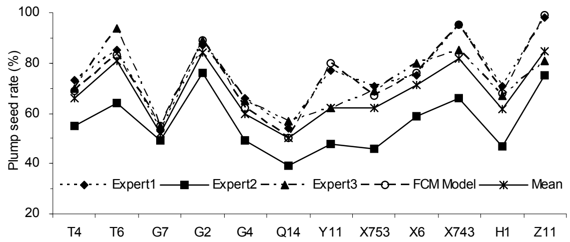


Figure 6. The comparison of the results of FCM model and human vision recognition for seed plumpness in 12 rapeseed varieties. Mean is the average value of three experts' recognition results.

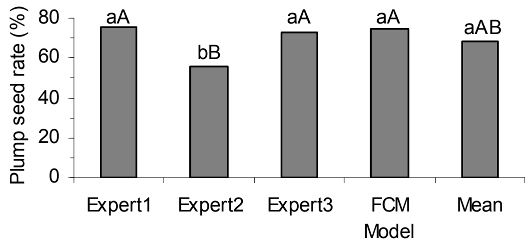


Figure 7. The results of an analysis of variance for the recognition result of FCM model and three experts by visual measurement. Mean is the average value of three experts' recognition results.

For further analysis of FCM model performance, conformity accuracy of plumpness was used as evaluation index. When the result of FCM model was consistent with the result of expert, plump or unfilled seed, it was considered as the accord of the result of two methods. Conformity accuracy of plumpness is the ratio of the number of consistent seed and the total number of a sample. The conformity accuracy of three experts and FCM model, the mean value of three experts' conformity accuracy and the unification, which was the results of three experts with uniform measurement sight, were analyzed using ANOVA.

The conformity accuracy was at between 81% and 98% with average of 90% (see Figure 8, 9). There was not significantly different between Mean and Unification. This showed that the FCM model of rapeseed seed plumpness recognition was effective method.

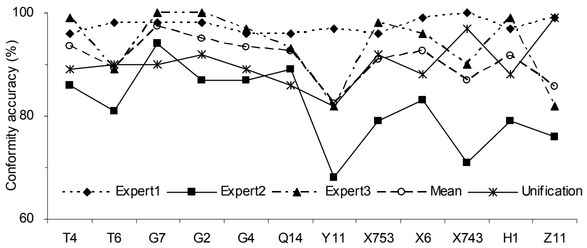


Figure 8. The conformity rate of seed plumpness for the results of FCM model and human vision recognition in 12 rapeseed varieties. Mean is the average value of three experts' recognition results. Unification is the results of three experts with uniform measurement sight.

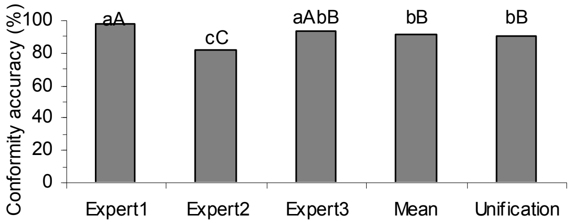


Figure 9. The results of an analysis of variance for the conformity rate of seed plumpness between FCM between and human vision recognition. Mean is the average value of three experts' recognition results. Unification is the results of three experts with uniform measurement sight.

4) Discussions

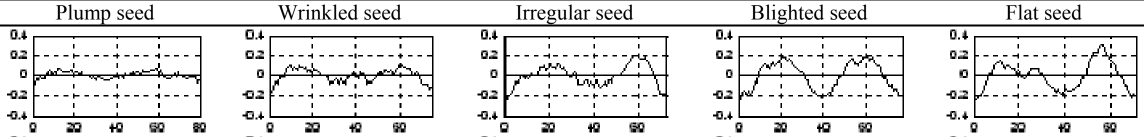
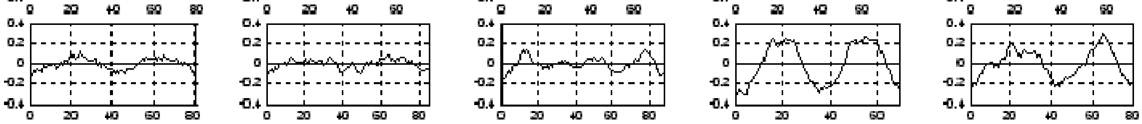
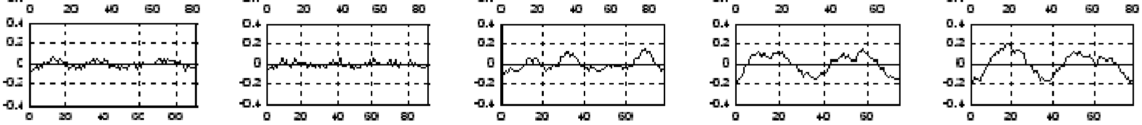
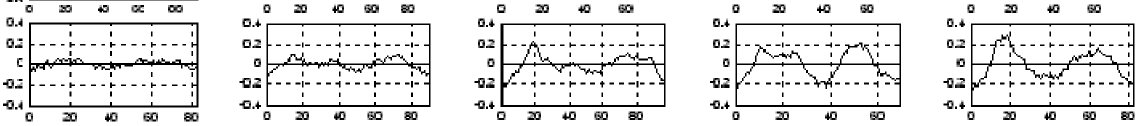
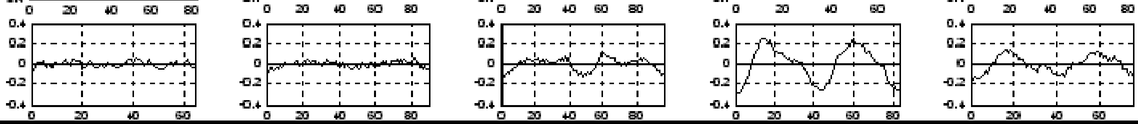
According to the sight of experts, rapeseed seeds were divided into 5 classes, which were plump, wrinkled, irregular, blighted and flat seed (see Table I). The wrinkled, irregular, blighted and flat seed were considered as not full seed by experts. In order to accurately evaluate the performance of FCM model, the expanded boundary curve (EBC) of five classes' rapeseed seed images were extracted as an indicator for analysis, and presented in Table II. To compare expediently the expanded boundary curve of different seed size, the radius was normalized by the ratio of radius minus mean radius and mean radius. The expanded boundary curve of each seed image started and ended at the minimum radius.

TABLE I. IMAGES OF FIVE CLASSES RAPESEEDS FOR DIFFERENT SEED SIZE

No.	Plump seed / Wrinkled seed / Irregular seed / Blighted seed / Flat seed
1	
2	
3	
4	
5	

It was found that the EBC variation range of plump seed was significantly less than one of not full seed. The irregular seed had several corners which were presented as several peaks and valley in EBC of it. The blighted seed was prolate and had two visible apexes. The flat seed had a mixed characteristic of the irregular and blighted seed. The plump, irregular, blighted and flat seeds could be accurately identified by FCM model, but

TABLE II. THE EXPANDED BOUNDARY CURVE OF FIVE CLASSES RAPESEEDS IMAGES

No.	Plump seed / Wrinkled seed / Irregular seed / Blighted seed / Flat seed
1	
2	
3	
4	
5	

x - axis is the number of the boundary point in rapeseed image; y - axis is the ratio of radius minus mean radius and mean radius (Range: -0.4~0.4).

some wrinkled seeds could be falsely distinguished as plump seeds because of the little EBC variation of it. The performance of FCM model for the wrinkled seed depends on the degree of seed shrinkage. In essence, the FCM model is mainly used to detect theses rapeseed seeds with significant morphological change caused by a variety of factors.

B. Sample size determination for measurement of the rapeseed seed plumpness

The mean values of rapeseed seed plumpness for 12 varieties were determined in a statistically reliable way on the basis of at least minimum size sample using formula (10) (see Table III). The least sample size of plumpness was stated for Z11, and the most – for G4. The minimum sample size of Z11 and X743 were similar, and less than 20. The minimum sample size of T4, T6, G2, Y11, and H1 belonged to the same level, less than 40. The minimum sample size of G7, G4, Q14, X753 and X6 belonged to the next level, less than 60. At defined accuracy of the computer vision system calibration the lower standard deviation of a measured parameter, the smaller is the minimum sample size [10].

It was found that plumpness mean values of T6, G7, G2, G4, Q14, X6, X743, H1 and Z11 for sample size of 100, 500 and 1000 seeds were similar, and ones of T4, Y11 and X753 for sample size of 500 and 1000 seeds were similar; so were their standard deviations. However, the range of variation of plumpness was extensive (9.22-25.57%), and it related with the variety characters. This suggests that analysis of the rapeseed plumpness can be performed for sample size of 100 seeds only. The plumpness ratio of G7, G2, G4, Q14, Y11, X753, X743, H1 and Z11 for sample size of 500 and 1000 seeds were similar. This indicates that analysis of rapeseed plumpness ratio can be performed for sample size of around 500 seeds.

C. Applications

1) The coefficient of variation of rapeseed seed features

In 12 rapeseed varieties, the variation coefficient of 1000-seed weight was the largest (see Figure 10). The variation coefficient of plumpness ratio was the second highest, about twice the variation coefficient of equivalence diameter or plumpness. Compared with plumpness, the plumpness ratio can better reflect the seed plumpness characteristic of various rapeseed varieties. In fact, the plumpness only indicates the plumpness characteristics of single seed, but the plumpness ratio can reflect the overall characteristics of the rapeseed seed sample.

TABLE III. EFFECT OF SAMPLE SIZE ON PLUMP FEATURE OF RAPESEEDS FOR 12 VARIETIES

Variety		100	500	1000	n_0	Variety		100	500	1000	n_0
T4	$\overline{x}$	0.61^{b}	0.64^{a}	0.63^{a}	33	Y11	$\overline{x}$	0.65^{b}	0.68^{a}	0.68^{a}	40
	Range	0.00-0.83	0.07-0.84	0.00-0.84			Range	0.33-0.84	0.00-0.86	0.00-0.87	
	SD^{A}	0.12	0.11	0.11			SD^{A}	0.13	0.13	0.13	
	CV^{B}	19.63	16.75	17.57			CV^{B}	20.25	18.78	19.71	
	PR^{C}	0.54^{c}	0.70^{a}	0.65^{b}			PR^{C}	0.68^{b}	0.74^{a}	0.76^{a}	
T6	$\overline{x}$	0.65^{a}	0.65^{a}	0.65^{a}	32	X753	$\overline{x}$	0.61^{b}	0.63^{a}	0.63^{a}	42
	Range	0.18-0.83	0.00-0.83	0.00-0.83			Range	0.00-0.81	0.00-0.84	0.00-0.86	
	SD^{A}	0.12	0.12	0.11			SD^{A}	0.14	0.12	0.13	
	CV^{B}	18.49	19.10	17.53			CV^{B}	22.27	19.70	20.47	
	PR^{C}	0.70^{b}	0.71^{b}	0.73^{a}			PR^{C}	0.62^{b}	0.64^{a}	0.65^{a}	
G7	$\overline{x}$	0.57^{a}	0.58^{a}	0.58^{a}	47	X6	$\overline{x}$	0.63^{a}	0.63^{a}	0.64^{a}	42
	Range	0.00-0.81	0.00-0.83	0.00-o.83			Range	0.05-0.85	0.00-0.86	0.00-0.86	
	SD^{A}	0.14	0.15	0.15			SD^{A}	0.14	0.14	0.13	
	CV^{B}	25.15	25.57	25.04			CV^{B}	21.71	22.35	20.91	
	PR^{C}	0.52^{a}	0.51^{a}	0.51^{a}			PR^{C}	0.64^{b}	0.66^{b}	0.70^{a}	
G2	$\overline{x}$	0.68^{a}	0.69^{a}	0.69^{a}	30	X743	$\overline{x}$	0.72^{a}	0.73^{a}	0.73^{a}	17
	Range	0.13-0.84	0.05-0.86	0.05-0.86			Range	0.33-0.84	0.00-0.85	0.00-0.86	
	SD^{A}	0.12	0.11	0.11			SD^{A}	0.09	0.08	0.08	
	CV^{B}	16.79	16.64	16.46			CV^{B}	12.19	11.62	11.26	
	PR^{C}	0.82^{a}	0.80^{a}	0.80^{a}			PR^{C}	0.88^{b}	0.94^{a}	0.94^{a}	
G4	$\overline{x}$	0.62^{a}	0.61^{a}	0.61^{a}	58	H1	$\overline{x}$	0.63^{a}	0.64^{a}	0.65^{a}	38
	Range	0.00-0.84	0.00-0.85	0.00-0.85			Range	0.10-0.86	0.00-0.87	0.00-0.88	
	SD^{A}	0.16	0.15	0.16			SD^{A}	0.13	0.13	0.13	
	CV^{B}	25.86	25.25	25.31			CV^{B}	20.45	20.92	20.34	
	PR^{C}	0.66^{a}	0.61^{b}	0.62^{b}			PR^{C}	0.67^{b}	0.69^{a}	0.70^{a}	
Q14	$\overline{x}$	0.59^{a}	0.60^{a}	0.60^{a}	44	Z11	$\overline{x}$	0.78^{a}	0.77^{a}	0.78^{a}	12
	Range	0.00-0.83	0.00-0.86	0.00-0.86			Range	0.38-0.87	0.00-0.87	0.00-0.87	
	SD^{A}	0.14	0.14	0.14			SD^{A}	0.07	0.08	0.07	
	CV^{B}	23.80	23.44	22.71			CV^{B}	9.40	10.16	9.22	
	PR^{C}	0.48^{b}	0.56^{a}	0.56^{a}			PR^{C}	0.96^{a}	0.96^{a}	0.97^{a}	

$\overline{x}$ -mean value; $\mathbf{SD^{A}}$ - standard deviation; $\mathbf{CV^{B}}$ - coefficient of variation; $\mathbf{PR^{C}}$ – plumpness ratio; n_0 - minimum sample size calculated according Eq.(10) on the basis of measurements of 100 seeds.

Means and plumpness ratio with the same letter in the same line are not significantly different ($p = 0.05$).

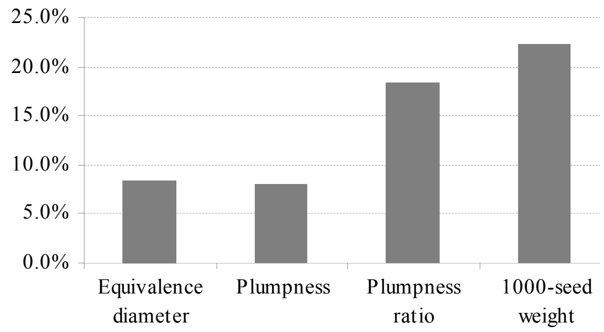


Figure 10. The coefficient of variation of equivalence diameter, plumpness, plumpness ratio and 1000-seed weight in 12 rapeseed varieties.

2) The correlation analysis of rapeseed seed features

There was a highly significant positive correlation between equivalence diameter and 1000-seed weight for test 1, 2 and 1+2 (see Table IV). There was also a highly significant positive correlation between plumpness and plumpness ratio for test 1, 2 and 1+2. But there was no correlation between plumpness or plumpness ratio, and equivalence diameter or 1000-seed weight for test 1, 2 and 1+2. These showed that the 1000-seed weight and the plumpness were two unrelated characteristics. In fact, rapeseed seed can attain plumpness whether the seed is large or not. Similar results were found for wheat grain plumpness [4].

TABLE IV. CORRELATION COEFFICIENT OF 1000-SEED WEIGHT，EQUIVALENCE DIAMETER, PLUMPNESS AND PLUMPNESS RATIO FOR 12 RAPESEED VARIETIES

Test set	r_{ab}	r_{ac}	r_{ad}	r_{bc}	r_{bd}	r_{cd}
1	0.968**	-0.007	-0.055	0.156	0.111	0.966**
2	0.957**	-0.096	-0.047	0.026	0.090	0.789**
1+2	0.962**	-0.052	-0.051	0. 088	0.101	0.863**

Note: *, ** Significantly different from zero at p<0.05 and p<0.01respectively.
a - Equivalence diameter; b - 1000-seed weight; c – Plumpness; d - Plumpness ratio.

3) The partial correlation analysis of rapeseed seed features

In the same plumpness, there was a highly significant positive partial correlation between equivalence and 1000-seed weight (see Table V). This showed that the greater the equivalence diameter of rapeseed seed, the more the 1000-seed weight. In the same equivalence, there was a highly significant positive partial correlation between plumpness and 1000-seed weight. This showed that the higher the plumpness of the rapeseed seed, the more 1000-seed weighed. In the same 1000-seed weight, there was a highly significant negative partial correlation between equivalence and plumpness. This showed that the greater the equivalence diameter of rapeseed seed, the more difficult to attain plumpness.

TABLE V. PARTIAL CORRELATION COEFFICIENT OF EQUIVALENCE DIAMETER, PLUMPNESS AND 1000-SEED WEIGHT FOR 12 RAPESEED VARIETIES

Test Set	$r_{ab \cdot c}$	$r_{ac \cdot b}$	$r_{bc \cdot a}$
1	0.9808**	-0.6339**	0.6452**
2	0.9643**	-0.4167**	0.4080**
1+2	0.9716**	-0.5019**	0.5057**

Note: * * Significantly different from zero at p<0.01.
a - Equivalence diameter; b - 1000-seed weight; c – Plumpness.

In the same plumpness ratio, there was a highly significant positive partial correlation between equivalence and 1000-seed weight (see Table VI). This showed that the greater the equivalence diameter of rapeseed seed, the more the 1000-seed weight. In the same equivalence, there was a highly significant positive partial correlation between plumpness ratio and 1000-seed weight. This showed that the higher the plumpness ratio of the rapeseed, the more the 1000-seed weight. In the same 1000-seed weight, there was a highly significant negative partial correlation between equivalence and plumpness ratio. This showed that the greater the equivalence diameter of rapeseed seed, the less the number of seed that can attain plumpness in rapeseed sample.

TABLE VI. PARTIAL CORRELATION COEFFICIENT OF EQUIVALENCE DIAMETER, PLUMPNESS RATIO AND 1000-SEED WEIGHT FOR 12 RAPESEED VARIETIES

Test Set	$r_{ab \cdot c}$	$r_{ac \cdot b}$	$r_{bc \cdot a}$
1	0.9814**	-0.6484**	0.6526**
2	0.9662**	-0.4595**	0.4645**
1+2	0.9734**	-0.5464**	0.5513**

Note: * * Significantly different from zero at p<0.01.
a - Equivalence diameter; b - 1000-seed weight; c – Plumpness ratio.

In the same plumpness and plumpness ratio, there was a highly significant positive partial correlation between equivalence diameter and 1000-seed weight for test 1, 2 and 1+2 (see Table VII). This showed that the greater the equivalence diameter of rapeseed seed, the more the 1000-seed weight. In the same 1000-seed weight and plumpness, there were significantly negative partial correlation for test set 1 and 2, and a highly significant negative partial correlation for test 1+2, between equivalence diameter and plumpness ratio. This showed that the greater the equivalence diameter of rapeseed seed, the less the number of seed that can attain plumpness in rapeseed sample. In the same equivalence diameter and plumpness, there was a highly significant positive partial correlation between 1000-seed weight and plumpness ratio for test 2 and 1+2. This showed that the higher the plumpness ratio of the rapeseed, the more the 1000-seed weight. In the same equivalence diameter and 1000-seed weight, there was a highly significant positive partial correlation between plumpness and plumpness ratio. This showed the higher the plumpness, the higher the plumpness ratio.

TABLE VII. PARTIAL CORRELATION COEFFICIENT OF 1000-SEED WEIGHT， EQUIVALENCE DIAMETER, PLUMPNESS AND PLUMPNESS RATIO FOR 12 RAPESEED VARIETIES

Test set	$r_{ab\cdot cd}$	$r_{ac\cdot bd}$	$r_{ad\cdot bc}$	$r_{bc\cdot ad}$	$r_{bd\cdot ac}$	$r_{cd\cdot ab}$
1	0.981**	-0.037	-0.180*	0.073	0.147	0.943**
2	0.966**	-0.098	-0.234*	0.076	0.254**	0.742**
1+2	0.974**	-0.073	-0.260**	0.072	0.264**	0.811**

Note: *, ** Significantly different from zero at $p<0.05$ and $p<0.01$ respectively.
a - Equivalence diameter; b - 1000-seed weight; c – Plumpness; d - Plumpness ratio.

4) Rapeseed seed plumpness grade

The evaluation results for 12 rapeseed varieties were basically consistent by three different evaluation methods (see Table VIII). This showed that the fuzzy model was valid and could replace the visual measurement method.

But this digital sort method can not distinguish some similarity of those rapeseed varieties in plumpness degree. From Table 4, we can find that the grade of some varieties in both test set were interleaving by using the plumpness ratio as evaluation index. This showed that those varieties might be similar in plumpness degree.

By comparing (see Figure 11), those varieties' value of plumpness ratio or plumpness were close to each other. The value of plumpness ratio was plotted into 10 parts from 0.5 to 1.0 with interval of 0.05, as grade 10 to 1. In 12 rapeseed varieties, T6 and Y11, X6 and H1, T4 and X753, G4 and Q14, have the same grade.

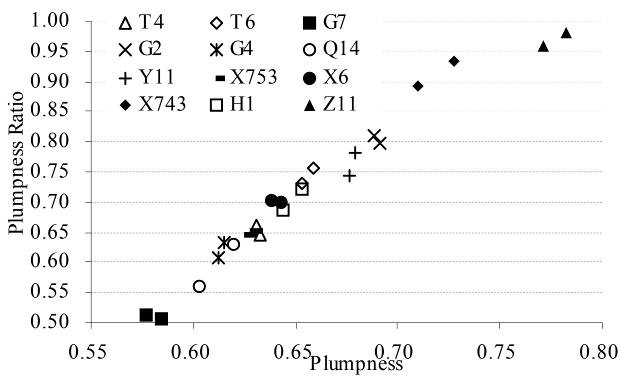


Figure 11. Plumpness and Plumpness ratio for 12 rapeseed varieties in two test sets.

IV. DISCLUSIONS AND CONCLUSIONS

For single rapeseed seed, the value of plumpness can be used as the index for evaluation. But for a rapeseed variety, its mean value for all seeds is not a good index, because it can only indicate part of the characteristics, even cover up the essence. The plumpness ratio, based on sample stat., can present better holistic feature of sample.

This study found that the plumpness ratio was the optimal index to reflect rapeseed variety plumpness. We also discussed the relation among plumpness, 1000-seed weight, equivalence diameter, and plotted plumpness grade. The results showed that it was feasible and valid to obtain rapeseed seed plumpness information by fuzzy processing and computer vision.

The accuracy of this fuzzy model can also partly be affected by some factors, such as seed position and imaging quality. It was assumed that all plump rapeseed seeds were rounded. However, some rapeseed seeds were elliptic or oblate. It can also be affected by some noises near the seed image. Therefore, a good imaging quality can enhance the veracity of recognition result.

This method can also be extended to other crop seed. If the plumpness standard of seed is not a round, a normal model can be used as the template for calculating the CVR. And the fuzzy model also needs to be changed by the acceptance of different crop seed.

To conclude, rapeseed seed plumpness recognition with computer vision is an effective, easy and fast operation to use with individual seed or sample.

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TABLE VIII. PLUMPNESS EVALUATION RESULTS WITH DIFFERENT METHOD IN 12 RAPESEED VARIETIES

Index	Test Set	T4	T6	G7	G2	G4	Q14	Y11	X753	X6	X743	H1	Z11
Plumpness ratio	1	9	5	12	3	10	11	4	8	7	2	6	1
	2	8	4	12	3	11	10	5	9	6	2	7	1
Plumpness	1	8	5	12	3	10	11	4	9	7	2	6	1
	2	8	5	12	3	10	11	4	9	7	2	6	1
Visual method		8	5	12	3	10	11	4	9	7	2	6	1

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