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# APPLICATION OF MACHINE VISION TO PUP LOAF BREAD EVALUATION

I.Y. Zayas and O.K.Chung
USDA-ARS, Grain Marketing Research and Production Center, Manhattan, KS 66502
tel.913-776-2758; FAX 913-776-2792; e-mail izayas@ksu.ksu.edu.

## ABSTRACT

Intrinsic end-use quality of hard winter wheat breeding lines is routinely evaluated at the USDA, ARS, USGMRL, Hard Winter Wheat Quality Laboratory. Experimental baking test of pup loaves is the ultimate test for evaluating hard wheat quality. Computer vision was applied to developing an objective methodology for bread quality evaluation for the 1994 and 1995 crop wheat breeding line samples. Computer extracted features for bread crumb grain were studied, using subimages (32x32 pixel) and features computed for the slices with different threshold settings. A subsampling grid was located with respect to the axis of symmetry of a slice to provide identical topological subimage information. Different ranking techniques were applied to the databases. Statistical analysis was run on the database with digital image and breadmaking features. Several ranking algorithms and data visualization techniques were employed to create a sensitive scale for porosity patterns of bread crumb. There were significant linear correlations between machine vision extracted features and breadmaking parameters. Crumb grain scores by human experts were correlated more highly with some image features than with breadmaking parameters.

## INTRODUCTION

Automation of bread quality assessment is important for industrial baking companies as well as for research laboratories. Definition of good and bad bread crumb grain is vague and relative to many social, cultural and regional factors besides baking technological factors. The development of an objective method of bread crumb grain evaluation with use of computer vision technique started at USDA, ARS - U.S. Grain Marketing Research Laboratory (USGMRL) in 1992. Studies were carried out for one-pound loaf breads (Zayas 1993, Zayas et al. 1993) and for pup loaf breads (Zayas et al. 1995). Several groups of scientists have been working during the last several years on an application of digital imaging to bread crumb grain (Batchelor 1993, Bertrand et al.1992, Wang and Coles 1993 a,b and 1994, Sapirstein et al. 1994, Rogers et al. 1995). The problem of bread crumb evaluation of industrially baked breads and breads baked at the Hard Winter Wheat Quality Lab, USGMRL (HWWQL), has different aspects of assessment. Bread assessment at the HWWQL mainly addressed evaluation of breadmaking potential of breeders' samples. Since no large quantity of flour is available, bread is made on a small scale of pup loaves, using 100 g flour per loaf. The crumb grain evaluation study of pup loaves started with the 1994 crop samples and continued with the 1995 harvest breeding line samples. The database of two-year results has been expanded to contain enough observations to represent the full spectrum of five grades of bread crumb scores determined by human experts.

## EQUIPMENT

Bread slice images were acquired using a UMAX UC630 color scanner interfaced to a compatible 486/PC through a SCSI interface card with 85 dpi (512x512 pix) and 8 bits per pixel (256 grey levels). Bread slice images were acquired, stored and analyzed, using a Kontron Image Processing System (KIPS), Kontron IBAS software, and a SUN-3/160C work station with a Unix operating system. Image analysis and data analysis were performed using MATLAB (Matlab 1993) and SAS software (SAS 1993) installed on a Sparc Classic with 96MB RAM.

## MATERIAL AND METHODS

### MATERIAL

#### BREAD CRUMB

Crumb grain may be defined as the soft interior portion of bread that is enclosed within an exterior crust (Pyler 1994). Cell structure is the crumb grain that is exposed when a loaf of bread is sliced. Bread slices show a wide range in cell size and shape within a slice and a loaf. Thickness of the cell walls affects grain character greatly. Thin cell walls are prevalent in fine texture crumbs, and thick cell walls may be found in coarse crumbs. Crumb grain of the cut slices of bread loaves were graded by human experts. The description for "outstanding and excellent" grade (5) was for bread crumb grain of very fine, elongated cells uniformly layered in with light, lacy, and very thin cell walls; "satisfactory" grade (4) was for bread crumb grain of fine, elongated cells slightly irregularly layered in with light, lacy, and thin cell walls; "questionable" grade (2) was for bread crumb grain of somewhat open, mostly round and coarse cells irregularly sized and shaped with thick cell walls; and "unsatisfactory" grade (0) for bread crumb grain of very coarse, very round cells extremely irregularly sized and shaped with very thick cell walls.

Experimentally baked pup loaves (100-g flour) of hard winter wheat breeding lines were studied. All baking experiments were replicated twice. The laboratory control flour loaves, baked the same day with other experimental flour samples, were also included in the database. The images were collected for representatives of five crumb grain scores, as graded by human expert. Number of loaves in Score 1 grade (CRGRAIN1) was 127, 176 in Score 2 grade (CRGRAIN2), 221 in Score 3 grade (CRGRAIN3), 218 in Score 4 grade (CRGRAIN4), and 17 in Score 5 grade (CRGRAIN5). Human expert scores, which categorized loaves into different grades, were included. Baking parameters such as flour protein and moisture content, loaf weight, and loaf volume (Table 1) were included in the database together with digital image features.

**IMAGE ANALYSIS**

The images of bread slices were subimaged by 32x32 pixels, means and standard deviations were computed. MATLAB software was used for image feature extraction and data visualization. Figure 1A shows grids positioned around the vertical axis of symmetry and horizontal axis. The vertical axis of symmetry for a slice was determined automatically, its position was determined in relation to slice boundaries. The horizontal axis was set in relation to the base line of the slice, on the level of the upper edge of the baking pan. The grid of 30 subimages was built around these axes. Individual subimage features and derived composed features for a slice and a loaf were calculated.

Binarized images of six gray level settings assessing area of bread crumb with holes of different depth (acr1-acr6) are shown in Figure 2. The binarized image resulting from thresholding at 205-255 gray level (acr1) picked up holes with shallow fine pattern with coarse image texture parts excluded. The binarized image of slightly deeper holes with coarser part still excluded, resulted from thresholding at 195-255 gray levels (acr2). The binarized image of deeper holes with exclusion of shallow holes resulted from thresholding at 185-211 gray levels (acr3). The binarized image of even deeper holes, with exclusion of upper levels of the same holes, resulted from thresholding at 145-173 (acr4). The same may be said about images resulted from thresholding at 105-160 (acr5). The binarized image showing all slice area with exclusion of deep holes which were through or nearly through slice resulted from thresholding 105-255 (acr6). Thus, there were similarities between acr1 and acr2, and between acr4 and acr5; acr6 was quite different from all other images.

Bread crumb area for these binarized images, six per a slice, was calculated for the percent of the whole slice area. Plots of these six values (PACR) are shown in Figures 1D. The same values for six different slices are shown in Figure 4. The values of PACR are expressed in percents.

Several shape and size features for a whole slice were determined using Kontron image processing software and are shown in Table I. The features were height (FERETY), width (FERETX), maximum size (DMAX), minimum size (DMIN) of a bread slice, perimeter of bread slice (PERIM), which is the sum of all the pixels on a boundary of a slice, and convex perimeter (CPERIM), which is equivalent to the length of a string around the outside of a slice. Several derived shape descriptors were computed. They were aspect ratio (FSHAPE), symmetry of a slice (SYM), smoothness of a slice outline (SHA), slice area (SA), and crust area (CRA).

## DATA ANALYSIS AND RESULTS

Several approaches were used to make bread crumb grain assessment and classify bread slices in five categories, as established by the score system used at USGMRL, HWWQL. In this study three different alternative or supplemental tools for crumb grain assessment were developed to help users assess bread crumb grain.

<u>ASSESSMENT of BREAD CRUMB by SUBIMAGE FEATURES</u>

The developed software tools give a user the possibility of assessing bread slice crumb with glance on the plots of subimage features to get information on how coarse or fine parts of the slice are distributed or what percent of these subimages are present on a slice. The image of each slice may be recalled and labeled with a choice of related features recalled from the database to assess crumb grain:

1) topologically;
2) indirect evaluation of depth of holes, and
3) percent of subimages of fine and coarse texture present on different parts of a slice

Occurrence of coarse crumb grain, depending on the location on a bread slice, impacts human expert judgement. Scores may vary, depending on the part of the slice where holes could be found, such as central, top, or peripheral. The bar chart in the right top corner (B) of Figure 1 shows a 30 bar plot, representing composite subimage values (CASU). This plot (Fig. 1B) shows subimage texture in relation to the location on the slice: subimages 1-6 are on the top of the slice; subimages 7-10 are on the upper top of central part; subimages 11-18 and 20 and 21 are located on the central part; 19, 22, and 23-30 are located on the bottom part of the slice (Fig. 1A).

The bread slice, shown on the left side (Fig. 1A) has relatively uniform image texture except for one small deep hole in subimage 17 and slightly coarser texture in subimages 3, 5, 6, 9 and 27 (Fig. 1B). Such a plot may be helpful to human expert to differentiate between holes which occured because of molding defects or those which occurred in specific parts of the slice vs. defects, which may actually occur due to differences in wheat quality. This evaluation may be done without looking at the actual slice.

The plot on Figure 1C shows the percent of one of the six ranges of fine and coarse texture subimages present on the different parts of a slice. The entire population of subimages was ranked and divided in six ranges and assigned to new variables (COFITM). These variables were determined as a percent of subimages, which fall into a specified range of coarseness under the name of COFITM1-COFITM6.

A comparison of different classes by distribution of COFITM is shown in Figure 3. In this procedure, the class categorization was determined by five ranges of variable composite per slice (SCSTM). Distribution of COFITM for the best Class"5" shows a pronounced peak of COFITM1 and a short tail to the right with absent COFITM3 in case of L11s5 or a very small percent of COFITM3 present in case of slice L10s5. This distribution may be interpreted as very uniform, because only COFITM1 (fine) and a small percent of COFITM2 (medium coarse) were present with COFITM1 domineering. In Class "3" COFITM had a long right tail with all COFITM being represented, which can be interpreted as an absence of uniformity of crumb grain. Both representatives of Class 3 have subimages of fine tight porosity and some medium coarse and deep holes through. Subimages 1, 2, 4, 5 of L9s5 have fine tight porosity. Subimages 6, 7, 8, 13,14,17 and 18 have a medium coarse pattern. Subimages 24 and 28 have a deep hole. In other words, slices shown in Figure 3, have diversity of crumb porosity which is reflected in growth of COFITM3-COFITM6. The major peak was still in COFITM1, but also a second small peak may occurred in COFITM6 (L15s5). This figure also showed diminishing presence of COFITM1 and growth of COFITM2 with a more flat curve with a shift of maximum in area of COFITM2. Distribution of Class "1" showed the peak growth in COFITM6 and COFITM4, COFITM5. The major peak is still occurred in COFITM1 or more often in COFITM2 with a flatter curve and shift of maximum in area of COFITM2. The slices of Class "1" have a smaller presence of fine porosity pattern and more of subimages of medium coarse and coarse with deep holes. For example, L22s5 has subimages of fine porosity 1, 4, 7, 8, 11, 12, 15 ,16 and 21; subimages of coarse porosity are represented by subimages 23, 24, 28 and 29. Thus, slices with fine crumb grain had higher values on the the left (COFITM1, COFITM2) and a pronounced peak on the left of the distribution curve. As crumb grain increased coarseness, the general shape of curve became more flat, with decreasing values on the left and increasing values in the middle and further growth of the peaks on the right (COFITM6), as shown in Figure 3. The human expert scores (CRGRAIN) are shown together with machine scores (SCSTM) for additional information; in some cases (L9s5, L15s5, and L52s5) they are close to each other.

## ASSESSMENT by PERCENT of SLICE AREA, DETERMINED BY THRESHOLDING

Evaluation of bread slice crumb grain was carried out by computed features, based on the settings of six gray level thresholds to illustrate the pattern of porosity (PACR1-PACR6). Figure 1D and Figure 4 show all six PACR values for a slice. Figure 4 illustrates comparison of representatives of classes, categorized by composite values per slice (SCSTM), using PACR values. Plots of PACR values have definite specific patterns for each class. Class "5" has pronounced PACR2 with a peak of about 60% and PACR1 with a peak of about 40%, which was very close to PACR3. Class "3" has a tendency to have smaller values of PACR1 and PACR2, but higher values of PACR4 and PACR5 in comparison with Class "5". Class "1" shows increasing values of PACR4 and PACR5 in comparison with Class "3". The shape of the curve connecting PACR1 to PACR4 became more flat, when crumb became more coarse.

ASSESSMENT by KOLMOGOROV-SMIRNOV COEFFICIENT

Crumb grain was assessed by comparison of slices to the reference slice. Similarity between slices was evaluated by Kolmogorov-Smirnov statistics of SAS Procedure NPAR1WAY. Kolmogorov-Smirnov statistics evaluate a distance between two cumulative frequency curves. The slice chosen as a reference slice, was evaluated by human expert as CRGRAIN 5, the highest rank for crumb grain scores. The rest of the slices were compared with the reference slice. Figure 5 shows comparison by the Kolmogorov-Smirnov coefficient (KSa). Smaller values of KSa indicate more similarity in crumb grain texture with fine and more regular porosity patterns. Higher values of KSa describe crumb grain with much coarser and irregular porosity than the reference slice. Figure 5 provides additional information on human expert score CRGRAIN and CLASS category determined by machine vision computed scores (SCSTM). The image of slice 1 of loaf No. 104 (L104S1), had fine and small porosity, much smaller than the reference slice (L368S7), which was the 7th slice of loaf No. 368. The slice L104S1 had a KSa value of 1.68. The 5th slice of loaf No. 12 (L12S5) showed more similarity with the reference slice and had a lower KSa value of 0.90. Slice 5 of loaf No. 13 (L13S5) and slice 5 of loaf No. 588 (L588S5) showed KSa values of 1.03 and 3.36, respectively. Even though the L51S5 with KSa 2.25 was graded with CRGRAIN score of 3 by human experts, the machine vision score (SCSTM) categorized it as CLASS 2. Both L13S5 and L51S5 were graded by human experts with CRGRAIN score of 3. However, the machine vision scores SCSTM categorized the L51S5 as CLASS 2. In the case of slice L12S5 the machine vision score was 4, though the human expert score CRGRAIN was 3. Machine vision classification of slices presented in Figure 5 seems to be reasonable according to visual judgement.

CORRELATION

The linear relationship between computer extracted features from bread slice images and subimages, human expert scores and breadmaking parameters was evaluated by Pearson's correlation coefficients (SAS Procedure CORR). Most image features PACRs showed higher correlation with breadmaking features and human expert crumb grain scores (CRGRAIN) than with features extracted from subimages COFITMs (Table II). Linear correlation coefficient (r) for CRGRAIN was 0.43 with PACR6, 0.35 with COFITM1 and 0.34 with both PACR2 and SA (Table II). The porosity pattern features (PACR1, PACR2, PACR3), one of the bread slice shape and size features (SHA-smoothness of slice outline), and one of the subimage features (COFITM1) were correlated positively with crumb grain scores (CRGRAIN) by human experts and bake mix time (MIXTIME) but negatively with four protein contents (PROTEIN), bake water absorption (ABSORP), loaf volume (LOAFVOL), loaf weight (LOAFWT), and proof height (PROFHT) of fermented dough. However, another subimage feature, COFITM2, was correlated negatively with CRGRAIN and MIXTIME but positively with other breadmaking parameters.

The area of slice (SA) was correlated positively with all parameters except for LOAFWT, and the area of crust (CRA) was also correlated positively with all but CRGRAIN. CRGRAIN was positively correlated with MIXTIME ($r=0.37$), LOAFVOL ($r=0.35$), and PROOFHT ($r=0.31$) among bread making parameters; and PACR6 ($r=0.43$), COFITM1 ($r=0.35$), PACR2 ($r=0.34$) and SA ($r=0.34$) among the image features. PROTEIN was correlated negatively with PACRs ($r=-0.47$ to $-0.51$), SHA ($r=-0.48$), and COFITM1 ($r=-0.41$), SHA ($r=-0.48$), and COFITM1 ($r=-0.41$), and positively with SA, CRA, and COFITM2 ($r=0.31$ to $0.49$). ABSORP showed "r" values ranging from -0.41 to - 0.49 with PACRs, COFITM1 and SHA, and from 0.18 to 0.38 with SA, CRA, and COFITM2. Among the image features the area of slice (SA) showed the highest "r" values with MIXTIME ($i=-0.38$), LOAFVOL ($r=0.74$), and PROOFHT ($r=0.66$), and COFITM1 showed the highest "r" values with ABSORP ($r=-0.49$) and LOAFWT ($r=-0.46$). Among the image features and breadmaking parameters, PACR6 was the one which was most highly correlated with the CRGRAIN values.

## CONCLUSIONS

Machine vision evaluation of bread crumb was successfully applied to a massive database of pup-loaves with five classes. Bread crumb grain of pup loaves was assessed using different approaches for data analysis. Emphasis was put on developing data analysis visualization tools. Developed software tools give a user the possibility of assessing topologically crumb grain of the slice as a support tool for human experts to gain information from different parts of the bread slice. Ranking procedures for crumb grain evaluation were successfully done by different methods, based on subimage sampling and several gray levels thresholding, indicating the depth of the holes. Evaluation by comparing a slice to the reference slice, using Kolmogorov-Smirnov coefficient, provided another sensitive alternative for ranking evaluation. Presenting results of computer evaluation in the form of images and graphs may become useful tools to help or supplement subjective human judgement for bread crumb grain evaluation.

Linear correlation analysis showed that some image computed features were correlated on a higher level with bread making features than human expert scores. The best correlation coefficients ranged from 0.7 to 0.4. The best correlation score was

0.74 for area of slice (SA) and loaf volume (LOAFVOL).

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## LITERATURE CITED

BATCHELOR, B. 1993. Automated inspection of bread and loaves. SPIE Proc., Machine Vision Architectures, Integration and Applications, 2064:124-134.

BERTRAND, D., LEGUERNEVE, C., MARION, D., DEVAUX, M.F., and ROBERT, P.1992. Description of the textural appearance of bread crumb by video image analysis. Cereal Chem. 69(3):257-261.

MATLAB REFERENCE GUIDE. 1993. The Math Works, Inc. Natick, MA.

MORRISON, D.F. 1985. Multivariate statistical methods. McGraw-Hill Book Company. New York, NY.

PYLER, E. J. 1994. Bakers Handbook. Sosland Publishing Co. Kansas City, MO.

ROGERS, D., DAY, D.D., and OLEWNIK, M.C. 1995. Development of an objective crumb-grain measurement. Cereal Food World 40(7):498-501.

SAPIRSTEIN, H.D., ROLLER, R., and BUSHUK, W. 1994. Instrumental measurement of bread crumb grain features by digital image analysis. Cereal Chem.71(4):383-391. .

SAS USER'S GUIDE. 1993. Version 6.09 edition. SAS Institute, Cary, NC.

WANG, J., and COLES, G.D. 1993. Image processing methods for determining bread texture. Proceedings of the first New Zealand Conference on Image and Vision Computing. Auckland. pp. 125 - 132.

WANG, J., and COLES, G.D. 1993. A new method of objective measurement of bread crumb texture. Proceedings of the second New Zealand Conference on Image and Vision Computing. Palmerston North.

WANG, J., and COLES, G.D. 1994. Objective measurement of bread crumb texture. SPIE Proc., Optics in Agriculture, Forestry, and Biological Processing, 2345:85-91.

ZAYAS, I.Y. 1993. Potential of digital imaging for bread crumb grain evaluation. Cereal Food World, 38(10):760-766.

ZAYAS, I.Y., STEELE, J.L., WEAVER, G., and WALKER, D.E. 1993. Breadmaking factors assessed by digital imaging. SPIE Proc., Machine Vision Architectures, Integration and Applications, 2064:135-151.

ZAYAS, I.Y., CHUNG, O.K., and CALEY, M.S. 1995. Neural network classification and machine vision for bread crumb grain evaluation. Machine Vision Applications, Architectures, and Systems Integration, SPIE International Symposium, Philadelphia, PA, 22-26 October, Proceedings SPIE 2597:292-308.

**Table I**
**Breadmaking Quality Parameters and Image Features of Bread Crumb and Slice Shape.**

| No. | FEATURE | DESCRIPTION |
|---|---|---|
| | | **BREADMAKING QUALITY PARAMETERS** |
| 1. | CRGRAIN | Human expert score of crumb grain |
| 2. | PROTEIN | Flour protein content (% on 14% moisture content basis) |
| 3. | ABSORP | Water absorption (% flour weight) |
| 4. | MIXTIME | Mixing time (min) |
| 5. | LOAFWT | Loaf weight (g) |
| 6. | LOAFVOL | Loaf volume (cc) |
| 7. | PROOFHT | Proof height of dough (cm) |
| | | **IMAGE TEXTURE FEATURES** |
| 8. | CASUTM | Composite of average and standard deviation per subimage |
| 9. | COFITM | Percent of coarse and fine subimages per slice |
| 10. | SCSTM | Score of slice based on CASUTM |
| 11. | FSHAPE | DMAX/DMIN[a] |
| 12. | SYM | FERETX/FERETY[b] |
| 13. | SHA | CPERIM[c]/PERIM[d] |
| 14. | CRA | Area of crust |
| 15. | SA | Area of slice |
| 16. | ACR1 | Area of crumb, grey levels 205-255 |
| 17. | ACR2 | Area of crumb, grey levels 195-255 |
| 18. | ACR3 | Area of crumb, grey levels 185-211 |
| 19. | ACR4 | Area of crumb, grey levels 145-173 |
| 20. | ACR5 | Area of crumb, grey levels 105-160 |
| 21. | ACR6 | Area of crumb, grey levels 105-255 |
| 22. | PACR1 | Percent area of crumb, grey levels 205-255 |
| 23. | PACR2 | Percent area of crumb, grey levels 195-255 |
| 24. | PACR3 | Percent area of crumb, grey levels 185-211 |
| 25. | PACR4 | Percent area of crumb, grey levels 145-173 |
| 26. | PACR5 | Percent area of crumb, grey levels 105-160 |
| 27. | PACR6 | Percent area of crumb, grey levels 105-255 |
| 28. | KSa | Kolmogorov-Smirnov coefficients |

[a] DMAX-maximum slice size, DMIN-minimum slice size.

[b] FERETX-slice width, FERETY-slice height.

[c] CPERIM-perimeter equivalent to the length of a string around the outside of a slice.

[d] PERIM-sum of all pixels on a boundary of a slice.

**Table II**

**Linear Correlation Coefficients Between Image Features and Breadmaking Parameters Using Database of the 4th and 5th Slices (n=1378).**

| | CRGRAIN | PACR1 | PACR2 | PACR6 | SHA | SA | CRA | COFITM1 | COFITM2 |
|---|---|---|---|---|---|---|---|---|---|
| CRGRAIN | 1.00 | 0.28 | 0.34 | 0.43 | 0.26 | 0.34 | -0.18 | 0.35 | -0.24 |
| PROTEIN | -0.06 | -0.50 | -0.51 | -0.47 | -0.48 | 0.31 | 0.49 | -0.41 | 0.38 |
| ABSORP | 0.05 | -0.41 | -0.43 | -0.44 | -0.41 | 0.18 | 0.31 | -0.49 | 0.38 |
| MIXTIME | 0.37 | 0.26 | 0.29 | 0.24 | 0.25 | 0.38 | 0.02 | 0.30 | -0.29 |
| LOAFVOL | 0.35 | -0.29 | -0.28 | -0.27 | -0.33 | 0.74 | 0.44 | -0.19 | 0.11 |
| LOAFWT | -0.13 | -0.37 | -0.38 | -0.32 | -0.22 | -0.20 | 0.03 | -0.46 | 0.42 |
| PROOFHT | 0.31 | -0.36 | -0.34 | -0.26 | -0.34 | 0.66 | 0.39 | -0.21 | 0.16 |

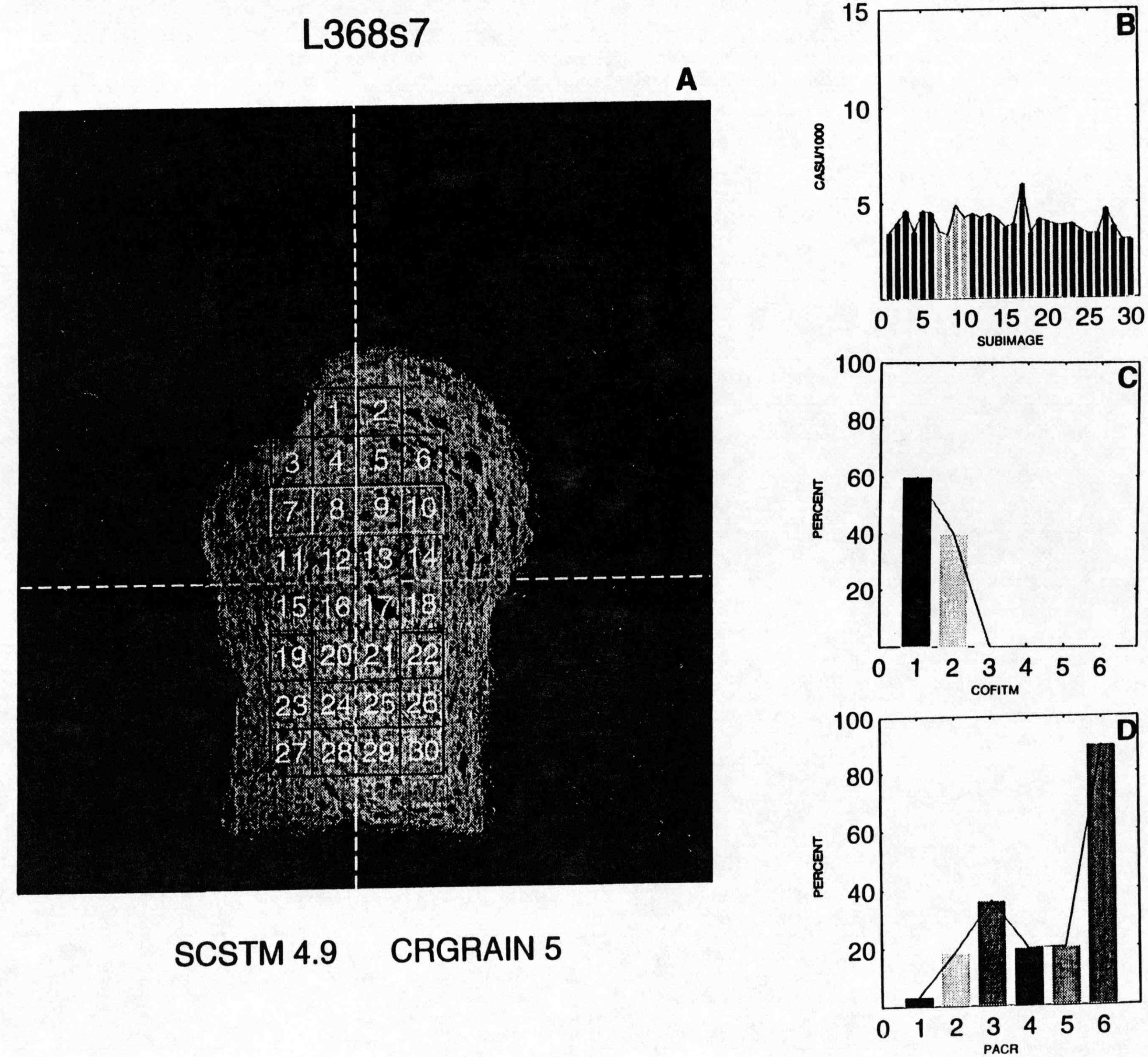


Figure 1. Bread slice (A) with plot (B) of subimage texture from different parts of the slice (CASU), plot (C) of percent of coarse and fine subimages present on the slice (COFITM) and plot (D) of features (PACR) determined by gray level settings.

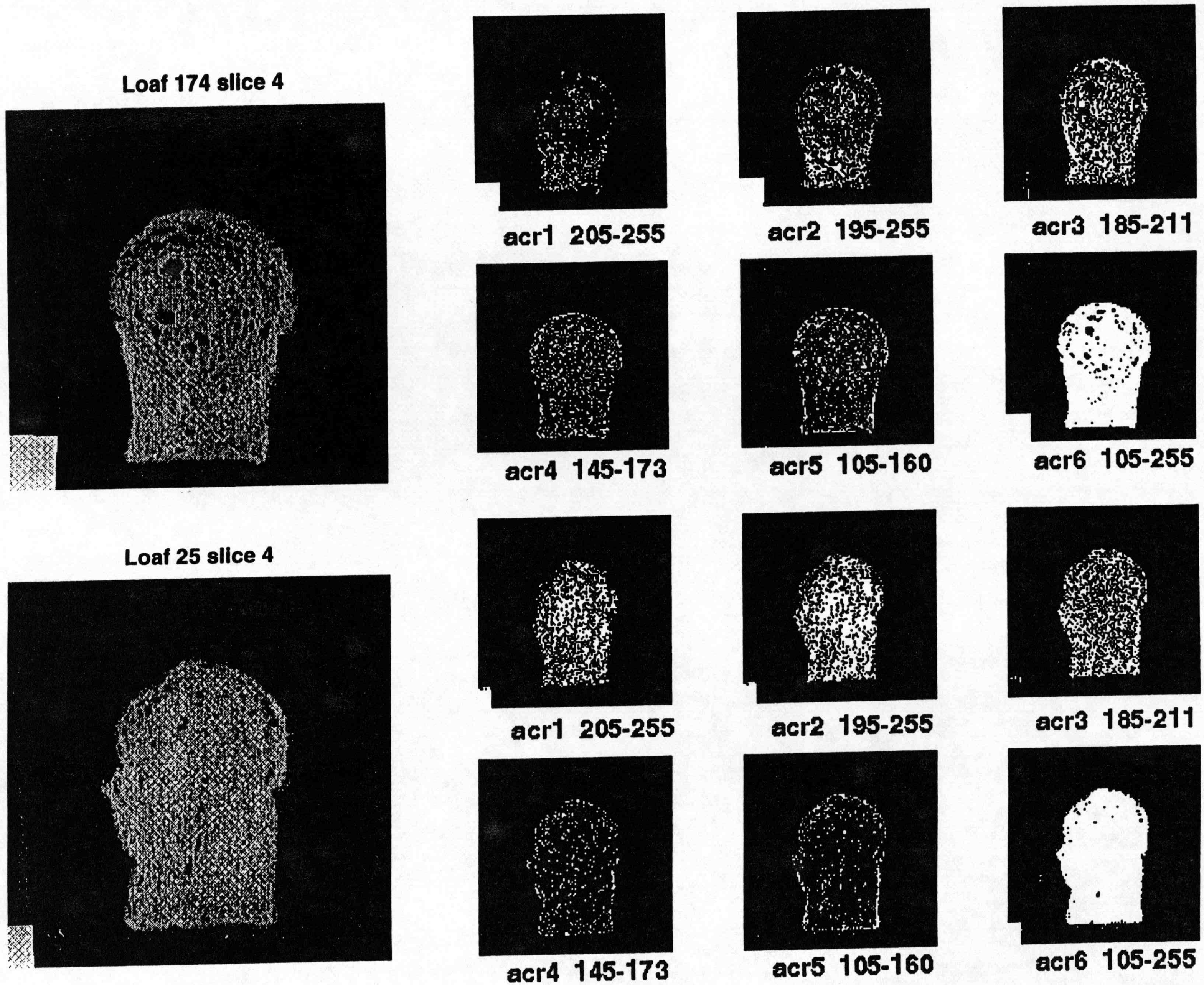


Figure 2. Bread slices and crumb area with six binary gray level settings.

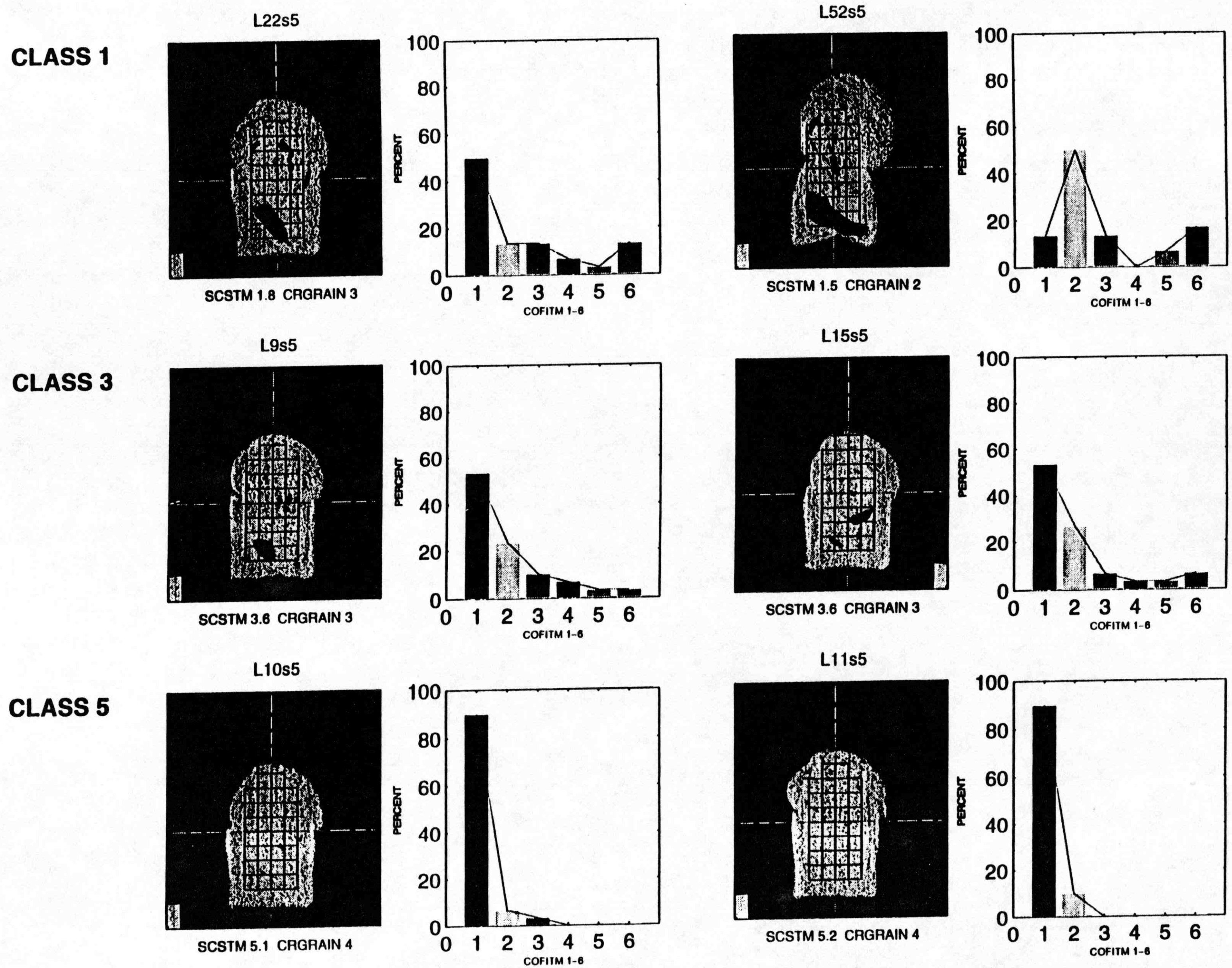


Figure 3. Comparison between classes determined by computer scores (SCSTM) with plot of percent of coarse and fine subimages present on the slice (COFITM).

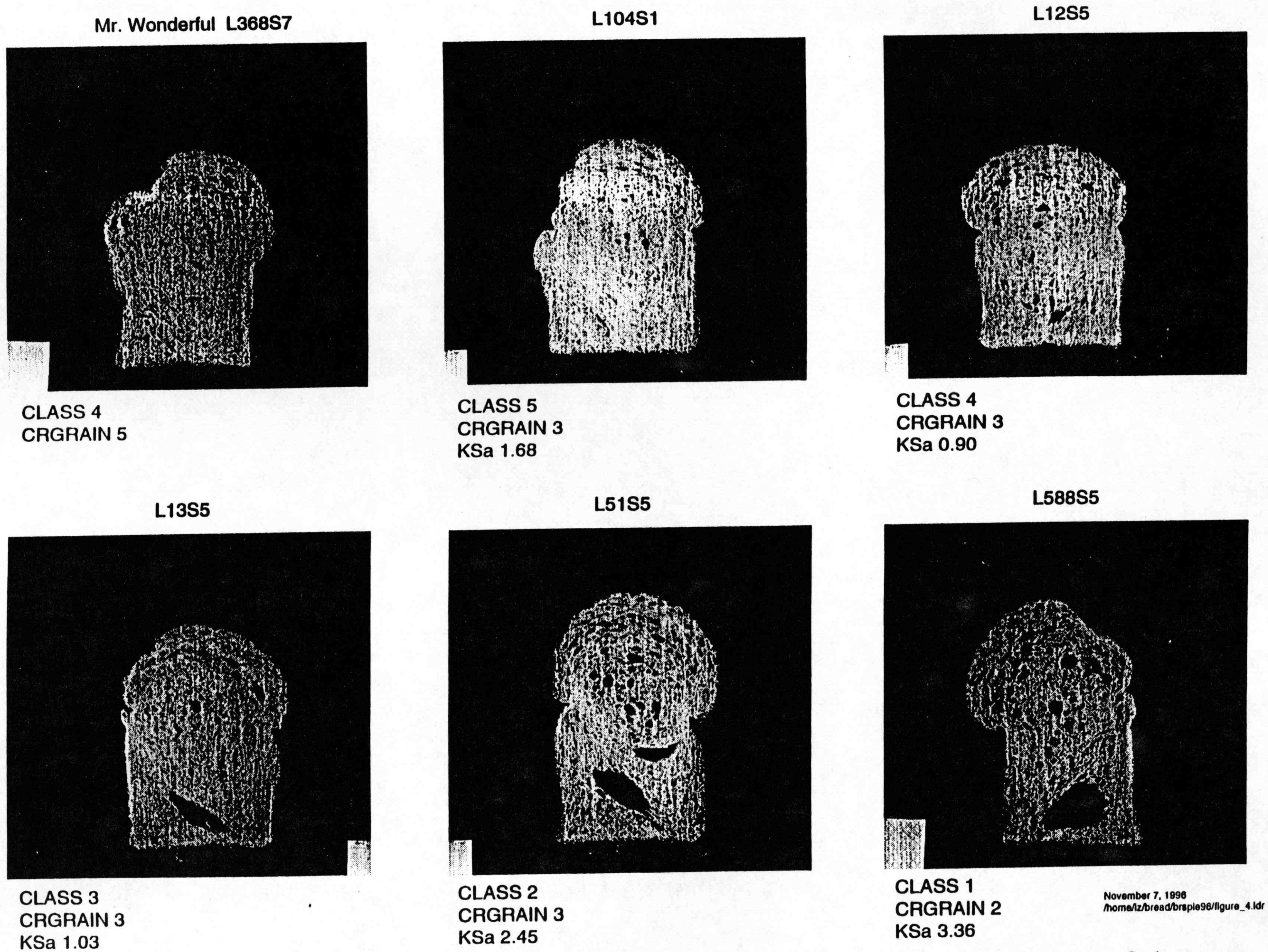


Figure 4. Evaluation of crumb grain by comparison of slices of different crumb grain with the reference slice by Kolmogorov-Smirnov coefficients (KSa), with human expert scores (CRGRAIN) for classes determined by machine vision score (SCSTM).

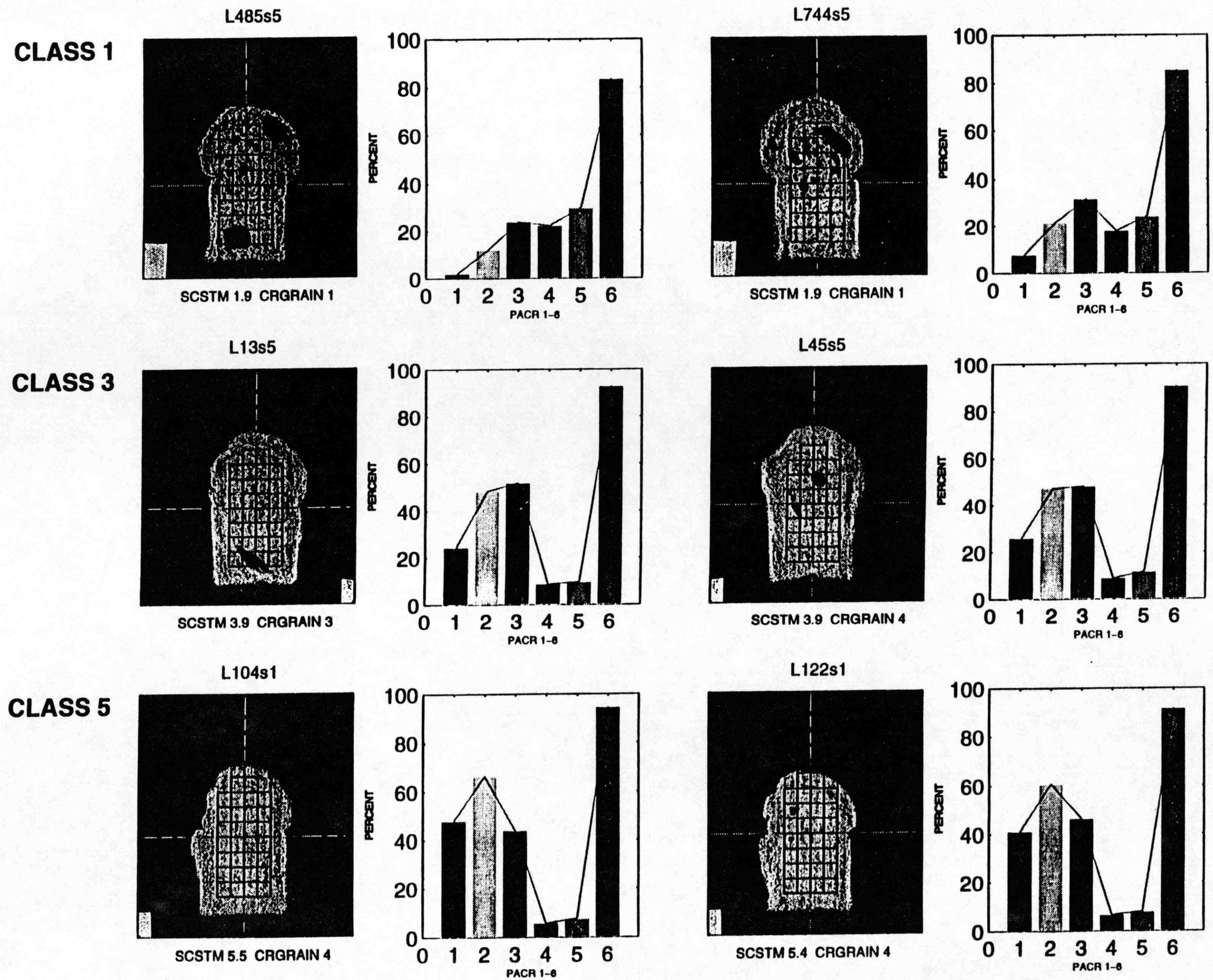


Figure 5. Bread Slices evaluated by percent of slice area determined by different gray level settings.

November 7, 1996
/home/lz/bread/brspie96/figure_5.ldr