Int. Agrophysics, 1999, 13, 133-140

COMPUTER SYSTEM FOR ANALYSIS OF X-RAY IMAGES OF WHEAT GRAINS (a preliminary announcement)*

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Accepted April 1, 1998

A b s t r a c t. Main elements of a computer system for analysis of X-ray images of wheat grains are outlined in the paper. In particular a specially developed software package (named GRAINS) for visualisation of grain images and for aiding kernel quality assessment analyses is presented. The package works in Windows 95 programming environment and has a menu driven user interface so enabling quick and easy access to all program functions. The program workplace enables simultaneous display of va- rious objects processed in the package, i.e., images, graphics, text documents, and spreadsheets. Main program capabilities include: loading and displaying X-ray grain images, measurements of main geometrical features and statistical parameters of grain images, quantitative assessment of the quality of grain kernels by calculating positional damage indices, and generation of binary and text report files.

K e y w o r d s: wheat grain, X-ray imaging, image analysis, damage indices

INTRODUCTION

Wheat grain is one of the most valuable plant materials containing high proportions of nutritional components. Unfortunately, during harvesting and post-harvesting processing, it is subjected to damage both of a mechanical and thermal nature. This damage, which is frequently difficult to notice by a naked eye, can cause detrimental effects on the physical and biological properties of grain. Damaged kernels absorb moisture more intensively and have lower mechanical strength than the undamaged kernels (e.g., they crumble easily). Thus, careful choice of the parameters which characterise grain processing technology is of major importance if losses due to low quality of this cereal are to be minimised. This aim, however, can only be achieved if objective and precise methods for identification of internal grain structure are available.

One of the techniques which provides high quality visualisation of the internal kernel structure is a soft X-ray photograph. This technique is particularly useful in detecting internal damage of the photographed kernels since the X-rays are absorbed to a different extent by the damaged and undamaged endosperm [6,7,10]. Moreover, X-raying of kernels is non-destructive and is considerably cheaper than other more sophisticated imaging techniques like Magnetic Resonance Imaging (MRI), scanning microscopy or laser technology. It has to be stressed, however, that sole visualisation of the kernels, irrespective of the technique used, does not provide quantitative evaluation of the overall quality of the kernel, e.g., geometric parameters of internal grain features, their quantity and distribution within the structure etc. In order to carry out accurate grain quality assessment specialised image processing and analysis methods need to be

*Paper presented at 6 ICA

employed for detection, measurement, and interpretation of kernel X-ray images. For several years, image processing techniques have become particularly attractive because they can be implemented cost effectively on desktop computers. These techniques offer a new powerful tool which, in the case of grain quality analysis, can bring considerable improvements in terms of analysis quality, shorter processing time and lower number of skilled personnel involved. Moreover, determination of some important features of grain images, too cumbersome for analysis with the use of "manual" methods, has been made possible.

This paper outlines the main elements of a complete computer system for analysis of X-ray images of wheat grains, which was developed jointly by the Institute of Agrophysics of the Polish Academy of Sciences in Lublin and Institute of Electronics, Technical University of Łódź. In particular the software program, written in Łódź, specially designed for visualisation and analysis of grain images is presented in more detail.

PROGRAM DESCRIPTION

Major parts of a computerised system specially developed for analysis of wheat grain kernels are visualised in Fig. 1. The soft X-ray apparatus ELEKTRONIKA Model 25 of Russian make is used for grain X-raying. Each X-ray exposure lasts exactly one minute. Precise timing of the exposure is critical for obtaining good quality pictures in which image contrast is maintained at the same level. For each X-ray exposure 10 to 12 grain kernels are evenly positioned (groove down) in the cassette as shown in Fig. 1. The images of grains are obtained in the form of photograms of size 18 x 13 cm in which the grains are magnified 5 times. The photograms are then scanned by a Hewlett-Packard table photo-scanner ScanJet 4C equipped with a transparency adapter. The scanner provides 400 dots per inch (dpi) scanning resolution and 8 bit grey scale image digitisation. It produces files in the Windows Bitmap graphics format which are transferred to the IBM PC compatible computer. This X-raying and photo-scanning procedure provides a sufficient resolution (both spatial and grey scale) for reflecting distinct features important for accurate characterisation of kernel damages. A single grain kernel is depicted by approximately 10000 image picture elements (pixels) each assuming one of 256 discrete grey values (with 0 corresponding to black and 255 to white).

Quantification of grain cracks is the most difficult problem in grain quality evaluation. This is due to a rich variety of damage types the kernel can suffer. Some of the damages are well defined (usually perpendicular to the groove) whereas others can form a network of tiny narrow cracks running in arbitrary directions and crossing each other.

Irrespective of the above mentioned problems in quantitative assessment of grain quality a number of measures (damage indices) were

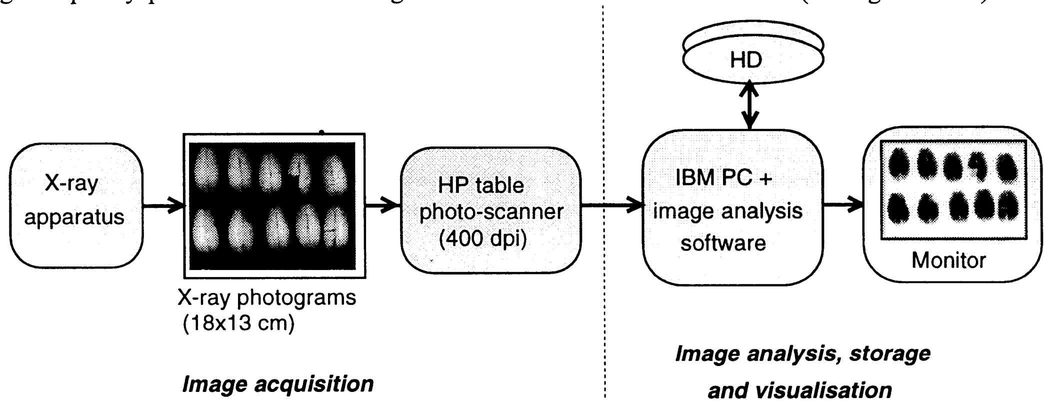

Fig. 1. Computer system for analysis of X-ray images of grains.

proposed for this task [1]. Some of these measures termed *positional damage indices* (PDI) have been worked out to take into account not only the extent of the damage but also the position it occurs relative to the germ [2]. Yet, another method for grain quality evaluation was proposed which accounts both for the localisation and the severity of the damage [4,5]. This method relies on superimposing a rectangular grid onto the area of the grain image and evaluating endosperm quality in each of the so generated grain image zones. The number of rows and columns defining the number of analysis zones can vary according to the requirements. Each of the analysis zone is assigned its corresponding weight characterising its position and importance in the grain kernel (e.g., for projection A, see Fig. 2, larger weights are assigned to zones nearest to the germ). Also, each zone is given "a mark" reflecting the damage severity. Different types of damage indices can be defined depending on distribution of weights in the grid, e.g., overall index (all weights equal to 1), positional index (accounting for damage localisation), mixed indices, etc.

The software package, called GRAINS, was specially developed for aiding analysis procedures required for evaluation of endosperm cracks (including computations of the PDI indices). The package also provides many other features facilitating visual inspection of the grain structure, computations of geometrical and statistical parameters of grain images and generating report files with analysis results. GRAINS is a menu driven program and works on IBM PC compatible machines in the Windows programming environment (either Windows 3.1 or Windows 95) [8]. The intention of the program authors was to include, in the offered program package, the main commands specific to evaluation of wheat grain quality whereas leaving out general purpose image processing commands which are supported in other popular and commercially available packages like: Adobe Photoshop, Photo Styler etc.

The view of the main program window, as it appears after GRAINS is started, is shown in Fig. 3. The main menu bar contains names of the pull-down menus grouping all commands available in the program. The main

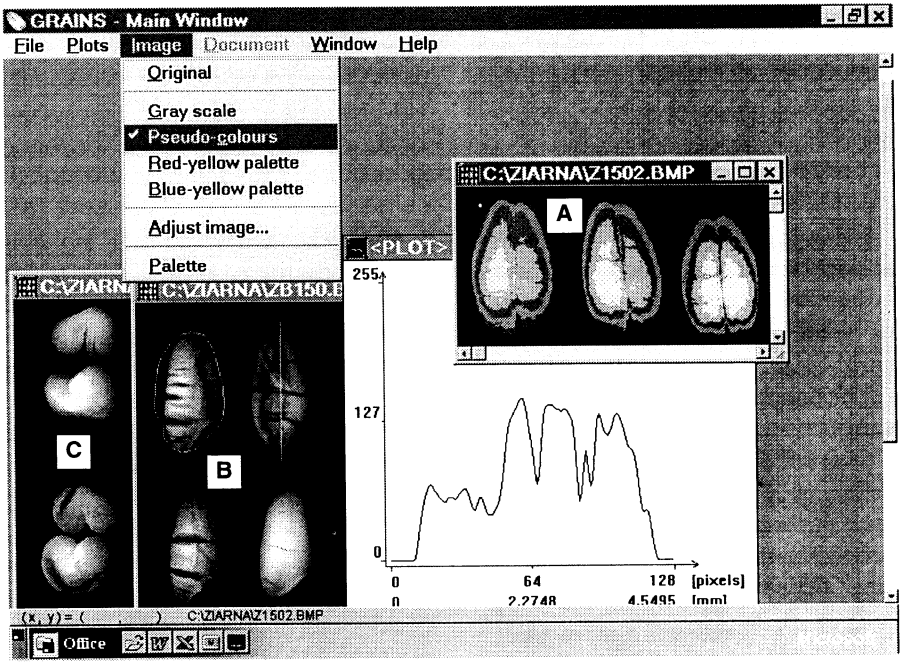

Fig. 2. View of GRAINS window including three (A,B,C) kernel projections. Projection A is displayed in pseudo-colours.

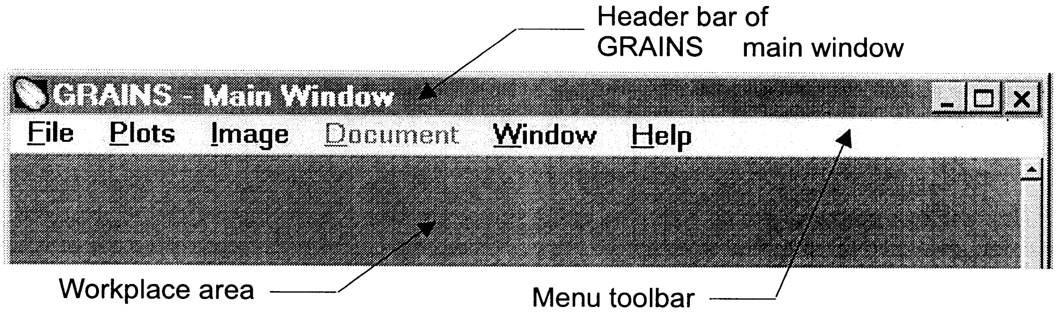

Fig. 3. A fragment view of GRAINS main window.

command groups are: "File", "Plots", "Image", "Document", "Window", and "Help" (further on "Arial font" will be used when referring to program command names or other program elements).

The "File" menu, following the Windows programming conventions, groups commands for manipulating data files, of which GRAINS contains commands for loading image files, opening new documents, and storing analysis data.

The "Plots" menu is activated once an image window is opened in the GRAINS workplace and contains commands for detecting boundaries of grain kernels and commands for generating plots based on the image information, e.g., axonometric projections, image brightness profile plots and image scaling procedures (for scaling image objects to their real size units).

The "Image" menu groups commands for changing attributes of the displayed grey-scale X-ray image in order to make it most convenient for user visual inspection, i.e., image pseudo-colouring, choice of colour palette, and image contrast/brightness manipulation is possible.

The "Document" menu contains key program commands associated with kernel analysis, i.e., measurements of main geometrical and statistical parameters of individual kernels, inspection and evaluation of grain internal structure quality, and commands for editing the document window where the analysis results are stored.

"Window" and "Help" menus, available in GRAINS, offer standard functions similar to other programs working in the Windows environment.

Complete analysis procedure of an individual grain kernel, using commands available in GRAINS, can be split up into the three following stages:

- detection of grain boundary in an image,
- calculations of main geometrical and statistical parameters of the grain image object,
- computations of damage indices.

These three main program features will be described in the remaining part of this text.

GRAINS supports procedures for display and analysis of grain kernels scanned in three different projections termed A, B, and C. Figure 3 shows the program window with the "Plots" menu activated and a number of preloaded image windows each containing different grains projections. The procedure of detecting grain boundary, for projection A, relies on pointing, with a mouse controlled cursor, the terminating points of the grain groove (for B, C projections indication of any point lying in the proximity of kernel centre will suffice). Each of this pointing scheme (commands "Contour A, B, C" respectively in the "Plots" menu) initiates a procedure for automatic detection of the kernel boundary.

A special contour extraction technique called active contour model (popularly termed snake) has been employed for detection of grain boundaries. The reason for this is that image regions representing grain boundaries are poorly defined (non-uniform brightness, kernel-fragmentation). An interested reader may wish to study more details about snakes. This clever contour finding method was originally proposed in [3] and, recently, authors of this paper have reported modifications to the original method in [9]. Figure 2 illustrates example contours (closed white curves) indicating boundaries of grain image object obtained with the use of the snake algorithm. Note also the displayed brightness profile window containing an image brightness plot corresponding to a user-defined line fragment positioned in the area of the B-projected kernel.

Once, the boundary of the analysed kernel has been determined further analysis procedures available in the "Document" menu are being enabled in the program.

First, geometrical and statistical parameters of image grain object can be determined. Figure 4 views results of such an analysis, initiated with the "Insert" GRAINS... command, along with a list of "Document" menu group. Analysis results of each single kernel are inserted into the "Document" window. These results are structured as follows. First, there is a number of text lines with labelling information and comments provided by the program user as shown in the Fig. 4. Below, an image fragment containing the analysed kernel is displayed. On its right hand side a list of geometrical parameters and their computed values are displayed. Further below, histogram and cumulative histogram diagrams corresponding to the image area marked in white are plotted. Finally, in the lower right hand corner of the "Document" window values of the computed statistical parameters of the analysed image fragment are listed out. Every consecutive analyses of other grains will be appended to the "Document" window. The "Mark/unmark fragment" and "Delete Marked" commands allow editing the "Document" window according to user requirements. They are two possible ways of storing the analysis data. User can either choose storing the data originally as it is displayed in the "Document" window or choose storing an abbreviated version of it in the form of a text file report. In the latter case no graphic information (i.e., images, diagrams) is stored.

The most important feature of GRAINS package is that it provides a means for aiding the calculation of kernel damage indices according

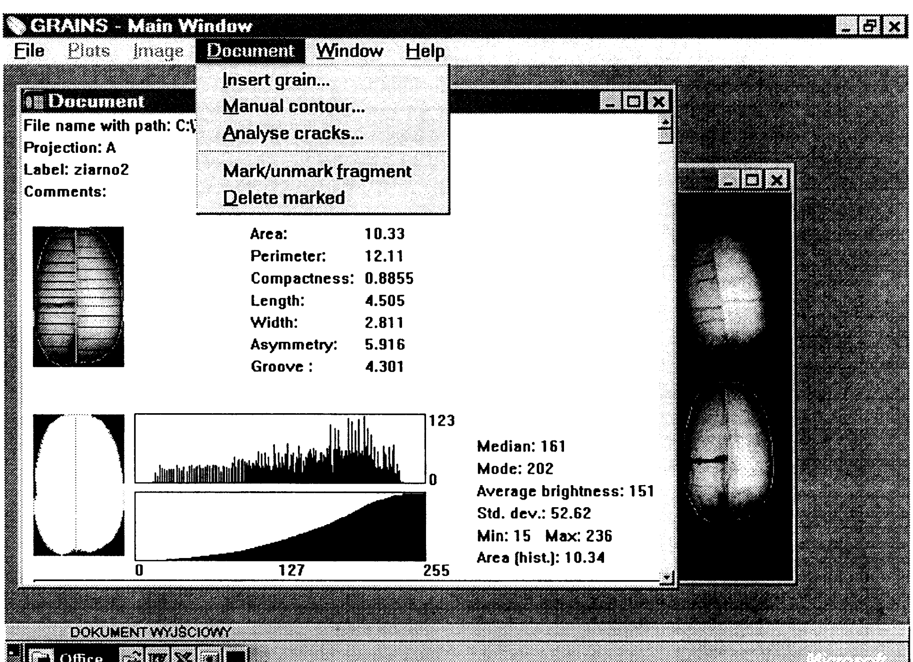

Fig. 4. A view of the "Document" window with geometrical and statistical parameters listed out (more explanations in the text).

to the method proposed in [4,5]. This program function is initiated with the "Analyse cracks..." command from the "Document" menu. At the start a program window called "Cracks" is displayed (see Fig. 5). In the left hand part of this window an enlarged view of the analysed kernel is displayed (i.e., in one of the supported projections A, B, or C). The right hand part of the "Cracks" window contains different groups of text fields, radio and other control buttons the control of damage index calculation procedure. A rectangular grid is superimpose onto the enlarged kernel image. The number of rows and columns of this grid is user defined but still monitored by the program, e.g., for projection A the maximum number of rows and columns is 14 and 4, respectively. Note, in the upper left hand corner of each grid cell there is a digit displayed. This is the "mark" (integers from 0÷9) the user can assign to the corresponding kernel rectangular fragment which reflects its damage state, with 0 indicating no damages and 9 reserved for the largest damage. The "marking" processes can be carried out first by selecting the marked cell (with the mouse button) and then by clicking the button the required number of times so setting the mark.

Calculations of four types of damage indices are supported by the program procedure. Choice of the particular index is available by picking one of the respective radio buttons located in the right hand side of the "Cracks" window. Damage index type is specified by pre-assigning specific weight values to each row of the analysing grid. For the "overall" damage index all weights are equal to one. The other possibility is to choose these weights arbitrarily according to user preferences ("user defined").

The remaining two types of indices, available in the program, are the positional indices

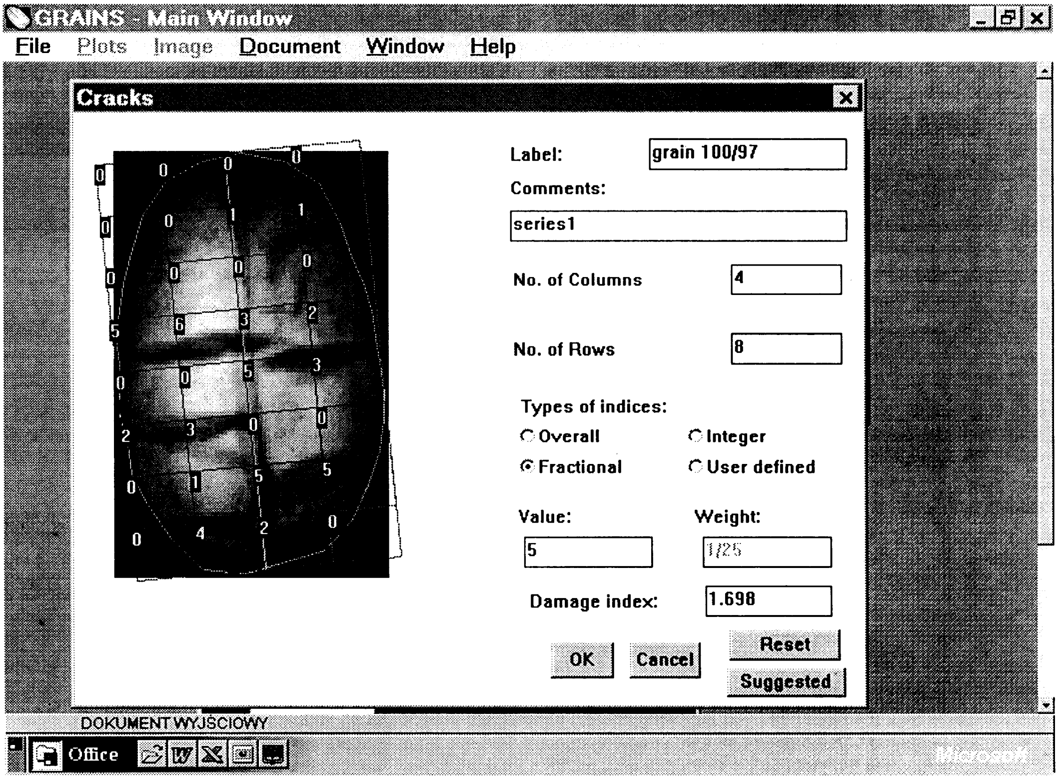

Fig. 5. View of the "Cracks" window (comments in the text).

which weight the position of damage in proportion to the distance it appears from the grain germ. The closer the position of the damage to the germ the larger the weight (i.e., the relative importance) of this damage. The so called "integer" positional index assigns weights to N column grid according to the formula $w_i = (N+1)^i$ where i is the number of the current grid row starting from the row farthest from the germ for which i=0. On the other hand the so called fractional positional index pre-defines weights according to the rule $w_i = 1/(N+1)^{(i+1)}$. Here, on the contrary, the rows are counted up in the opposite direction (i.e., beginning from the germ part of the grain) and starting from i=0.

The final values of the positional damage indices (PDI) are calculated according to the following formula [4,5]:

$$PDI = \sum_i \sum_j w_i b_{ij}$$

where i,j are the co-ordinates of grid rows and columns, respectively, w_i is the weight value assigned to the i-th grid row, and b_{ij} is the user marked kernel damage at grid co-ordinate i,j.

Completion of the grain damage evaluation procedure inserts automatically the computed PDIs and the user marked pattern of kernel damages into the program "Document" window. All the data inserted into the "Document" window can be stored as disk files. These files can be re-loaded back to the program workplace either for editing or appending analysis data created at later analysis sessions.

SUMMARY AND CONCLUSIONS

A complete computer system and a specialised software package for aiding quality assessment of wheat kernels has been presented. Analysis procedures are based on computer image processing techniques applied to X-ray images of grains [8]. These techniques proved viable in the task of kernel quality evaluation in many respects. They are precise, objective, relatively cheap and yield much faster throughput analysis. Moreover, they are flexible as the developed software package, with minor alterations, can be employed for quality inspection of other cereals (e.g., corn, soy, bean seeds) and other biological materials (e.g., granules of yeast, and sections of plant stems).

The staff from the Institute of Agrophysics in Lublin, who currently test the program, expresses the view that GRAINS is extremely useful for analysis of short series of wheat kernels. In particular GRAINS turned out to be very useful in speeding up the studies on moisture treatment of wheat grain and its effects on endosperm damage [10].

There are many elements of the system that can still be improved and extended. Firstly, an attempt will be undertaken to achieve fully automatic detection of endosperm cracks and their quantification (e.g., with the use of artificial intelligence paradigms). Secondly, 3-D reconstruction of kernels from their 2-D projections and calculation of the corresponding 3-D damage indices is envisioned.

ACKNOWLEDGEMENTS

This work was carried out as a part of the research project No. 5P06F01209 sponsored by the State Committee for Scientific Research in 1996.

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