Validation of an image-analysis-based method of measurement of the overall dimensions of seeds

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Abstract. Due to agricultural producers’ increasing awareness and the introduction of increasingly restrictive crop protection standards, producers have to use new technologies that are safer for consumers and the environment. In order to meet the requirements of these standards, it is necessary to take the physical properties of crops and agricultural raw materials (basic geometric parameters, shape factors, and equivalent spherical diameters) into account when designing machinery for the harvesting, transport, and processing of agricultural produce. When designing machinery, methods used for calculating the strength of the machine construction and the discrete element method (DEM) used in computer simulations of processes involving seeds or particles require the provision of the exact geometrical dimensions of particles and seeds. The aim of the study was to develop a universal method of measurement of the overall dimensions of granular material particles using a widely available application based on image analysis. The study presents the possibility of using a new method of measuring overall dimensions by means of the widely available ImageJ application on a specially designed test facility.

1. Introduction

The construction and operating parameters of functional units in food-processing and agricultural machinery must be adapted to the physical and geometrical properties (the shape and overall dimensions) of seeds, i.e. the length, width, and thickness. The knowledge of the geometric features of caryopses or other plant-derived materials is essential to design the functional units of machinery for the harvesting, cleaning, sorting, grinding, crushing, drying, and transporting of granular materials. The understanding of the geometrical features of granular material is a problem for constructors of agricultural and industrial food-processing machinery. The problem of evaluation of the geometrical features of raw materials also appears in the electromechanical, fuel, and energy industries, where different fractions of kernels, gravel, aggregates, wood waste, etc. are used. It is also necessary to characterise the dimensions of particles to develop models of heat and mass exchange [1], drying, e.g. carrot cubes [2], comminution [3], and grinding [4] materials. Mathematical models of these particles are helpful [5] in these applications. Before making a mathematical model, first, it is necessary to measure the geometric dimensions of raw material particles with adequate accuracy. Although the overall dimensions of granular materials and other particles have been measured for many years to construct machinery [6, 7], it is still necessary to make such measurements as genetically modified cultivars of cereals and many other crop species have been introduced to agricultural production. Traditional methods of measuring the overall dimensions of seeds with classic instruments for linear
measurements are not very efficient. The results do not meet the standards of modern technology due to the low accuracy of measuring instruments. Apart from that, the discrete element method (DEM) used for the calculation and simulation of processes occurring in machines where kernels and particles are involved requires precise geometric models of seeds. Therefore, it is necessary to develop new measurement methods based on image analysis. Modern optical methods based on image analysis such as GrainScan, CVS, and SmartGrain have been described in reference publications [8, 9]. Image analysis has been used many times to identify, measure the overall dimensions and assess the quality of caryopses, tubers, fruit, and vegetables [10-17], identify pests [18], assess the quality of muscles and joints [19, 20], and to evaluate drying processes [21, 22]. Image analysis has also been used to assess the wear of machine parts and subunits [23] and to model the cavitation erosion process [24, 25].

The aim of the study was to develop a universal method of measuring the basic overall dimensions of particles and granular materials with a widely available application based on image analysis.

2. Material and research methods
The research was conducted on seeds of the Antonińskie early winter rye cultivar with a moisture content of 14%. The cultivar can be grown on soils of poorer quality. The seeds for tests were acquired from Centrala Nasienna, Sieradz, Poland, where they were offered for sale as seed material.

The basic geometrical features of the seeds, i.e. the length (the biggest dimension), width (intermediate dimension), and thickness (the smallest dimension) were measured with a digital calliper (SYLVAC MAUa 150 E24-4F, serial number 815003292, measuring range 0-150 mm, measuring accuracy ±0.03 mm) at a specially designed test facility for measuring the overall dimensions of materials. The seed characteristics were measured in three mutually perpendicular planes. The technique of measurements with a calliper is generally known to engineers. The test facility (Figure 1a) consisted of a tripod (1) with a camera holder (2) and a frame (6) enabling placement of glass plates with caryopses (5). In order to measure the length and width of a caryopsis, it needed to be stuck with the furrow up. Then, it was rotated by 90° to measure its thickness. The test facility was illuminated with white light from a source (3) placed above a white background (4) for the best contrast between the examined object and the background. This construction of the test facility guaranteed identical lighting conditions and a constant distance between the plate with granular material and the camera lens.

In one of the test variants, photographs of plates with the granular material or particles were taken with a Sony Alpha a5100 camera (resolution 24.3 Mpix), equipped with a Sony E 16-50 mm f/3.5-5.6 PZ OSS lens, which was placed centrally over the plate with the granular material. The lens was placed 20 cm away from the sample. The distance was determined experimentally by taking a preliminary series of photographs (five photos were taken for each distance adopted in the preliminary test – the distance was changed every 2.5 cm within a range of 15-25 cm). The distance of the lens should be set so that the image is in focus and the whole plate is visible. In order to determine the measuring scale, an object of known diameter, e.g. a one zloty coin, was placed on each plate with granular material or particles. An example of a plate with wheat caryopses and a one zloty coin is shown in Figure 1b.

The basic characteristic dimensions, i.e. the surface area, shape factor, overall dimensions (length, width, and thickness), and equivalent spherical diameter of the granular material were analysed with the free and widely available ImageJ 1.52a application. The program was written in the Java environment and it is supported by all operating systems: Windows, Linux, Android, etc. It allows processing, analysing, and displaying graphic images saved in various formats, e.g. TIFF, JPEG, PNG, GMP, RAM, PNG, etc. and images saved on 8, 16, and 32-bit bitmaps. The application offers various necessary functions such as scaling, cropping, cutting any shape, and rotating the image. This allows processing images by changing their colours, adjusting contrast, isolating the contour and shape of the elements analysed, and measuring linear dimensions (length/width) in two perpendicular directions [26].

The application also enables the correction of the parameters of both 8-bit greyscale images and RGB colour images by smoothing, sharpening, edge detection, median filtering, and thresholding. However, the black and white (B&W) filter is most often used to achieve greater contrast. It enables the distinction of the contours of granular material or particles. The filter facilitates the measurement of quantities analysed. Figure 2a shows an example of the black-and-white filter applied to a plate with Antonińskie winter rye caryopses.
In order to obtain the real dimensions of photographed objects (caryopses) the application needs to be scaled by means of a gauge block with known dimensions – 22.97 mm. Before the dimensions of the caryopses were measured, the diameter of the coin shown in the photo had been selected. Next, each time a dimension was selected, the application automatically converted the pixel value to millimetres. Figure 2b shows the scaling window in the program. In the image of rye caryopses shown in Figure 3a, one pixel was approximately equal to 0.045 mm. Each time the results were exported to an Excel spreadsheet, where the basic statistical indicators were determined.

**Figure 1.** A diagram of the measuring facility (a): 1 – tripod, 2 – camera holder, 3 – source of white light, 4 – white background, 5 – glass plates with caryopses, 6 – frame; (b) a photo of a plate with winter rye caryopses (Antonińskie cultivar) – the caryopses selected for tests are marked with a red box.

**Figure 2.** A view of a plate after analysis of rye caryopses with the black and white filter (a). A view of the program window with settings of the scaling parameters (b).

The measurement of the geometrical features of caryopses or particles (length/width) consisted in using the cursor to select the most distant points on the measurement plane of a caryopsis (particle) in two perpendicular directions. Then the application automatically gave the value of the caryopsis length, width, or thickness. Figure 3a shows an example of measurement of the length of a winter rye caryopsis, whereas Figure 3b shows a measurement of the width. The yellow line shows the measurement plane.
Figure 3. An example of measurement of the length of an Antonińskie winter rye caryopsis (a). An example of measurement of the width of an Antonińskie winter rye caryopsis (b).

The application also enables direct simultaneous measurement of several values. Next, the results are listed in a table. These values can be transferred to any program for statistical analysis. Columns 4 and 5 in Table 1 show the lengths and widths of winter rye caryopses measured with the application. Next, after selecting variables, the surface area and shape factor were automatically measured. The data were saved and exported to an Excel spreadsheet. Ten seeds marked with the red box in Figure 1b were selected as a test sample. The same dimension of each seed was measured with the devices and methods listed above. The procedure gave a set of results consisting of the values of individual geometric features measured with different devices (independent measurements).

3. Results and discussion

Table 1 shows the results of measurements of the surface area, shape factor, length, width, and equivalent spherical diameter of the selected seeds. All these values as well as the mean and standard deviation for the selected ten seeds were calculated in the ImageJ 1.52a program.

Table 1. Example parameters characterising selected winter rye caryopses of the Antonińskie cultivar.

| Seed number | Area [mm²] | Aspect ratio [-] | Length [mm] | Width [mm] | Equivalent spherical diameter [mm] |
|-------------|------------|-----------------|-------------|------------|----------------------------------|
| 1           | 20.459     | 0.305           | 8.690       | 2.756      | 5.104                            |
| 2           | 17.620     | 0.317           | 8.541       | 2.697      | 4.737                            |
| 3           | 22.539     | 0.442           | 8.678       | 2.522      | 5.357                            |
| 4           | 21.345     | 0.381           | 8.594       | 2.918      | 5.213                            |
| 5           | 19.297     | 0.334           | 8.652       | 2.845      | 4.957                            |
| 6           | 19.901     | 0.406           | 8.472       | 2.517      | 5.034                            |
| 7           | 23.984     | 0.393           | 8.655       | 2.508      | 5.526                            |
| 8           | 21.442     | 0.305           | 8.792       | 2.904      | 5.225                            |
| 9           | 17.829     | 0.357           | 8.601       | 2.712      | 4.765                            |
| 10          | 22.139     | 0.303           | 8.506       | 2.698      | 5.309                            |
| Mean        | 20.656     | 0.354           | 8.618       | 2.706      | 5.123                            |
| Standard deviation | 2.043     | 0.049           | 0.096       | 0.157      | 0.255                            |
The mean surface area of the caryopses measured in the ImageJ program was $20.656 \pm 2.043 \text{ mm}^2$. This value was consistent with the results of the research by Guz et al. [27]. The mean shape factor of the Antonińskie winter rye caryopses was $0.354 \pm 0.049$, and the mean equivalent spherical diameter was $5.123 \pm 0.255 \text{ mm}$. These values were greater than those reported by Łukaszczuk et al. [28], who studied seeds of the Gobo rye cultivar and noted a shape factor of 2.7 and an equivalent spherical diameter of 3.9 mm. These differences may have been caused by the fact that a different rye cultivar was used in their study. It is necessary to pay attention to the shape factor, whose value may range from 0 to 1. The closer the value is to 1, the more circular the shape is. On the other hand, the further away the shape factor value is from 1, the more elongated the shape of the caryopsis is.

In order to check the correctness of the method, the length and width of the Antonińskie winter rye caryopses measured with the ImageJ software were compared with the results of measurements with a digital calliper (Figures 4 and 5). The calliper measurements were assumed as a reference for calculation of the relative error. The results of the calliper measurements are shown as orange bars, and the results of the measurements with the ImageJ program are shown as blue bars. The yellow line shows the relative error values [%], whereas the red line shows the mean relative error values [%].

**Figure 4.** A comparison of the length of the Antonińskie winter rye seeds measured with a calliper and with the ImageJ software.

**Figure 5.** A comparison of the width of the Antonińskie winter rye seeds measured with a calliper and with the ImageJ software.
The comparison of the results of measurements made with the software and with the calliper enabled the calculation of measurement uncertainty. The length measurement uncertainty did not exceed 1.0%, because the greatest relative error of measurement No. 4 was 0.88% (Figure 4). The width measurement uncertainty did not exceed 1.5%, because the greatest relative error of measurement No. 3 was 1.48% (Figure 5). These values were acceptable for the process under analysis.

The quick image-analysis-based method of measurement of the overall dimensions of caryopses can be applied when preparing the boundary conditions (the mean dimensions of caryopses and their shape parameters) for simulation tests, or when investigating the effect of the moisture of caryopses or particles on their overall dimensions [29] or surface area [30]. This method can also be used to quickly assess the physical properties and geometrical features of seeds.

4. Conclusions
1. The research proved empirically that the described method is universal and can be used to measure the overall dimensions and geometric features of various types of particles, including granular materials.
2. The maximum differences between the values of the overall dimensions (length and width) of the Antonińskie rye caryopses measured with the ImageJ program at the test facility and the verification measurements determined with the analytical method (digital calliper) amounted to 0.88% and 1.48%, respectively. Therefore, it can be generally concluded that the results of measurements of the geometrical features of the seeds with the ImageJ program at the test facility were characterised by sufficient reliability (accuracy).
3. The image-analysis-based ImageJ application reliably indicated the overall dimensions (length, width) of the seeds shown in the photos.
4. The method can be used in many other fields of science and industry to measure the overall dimensions and shape factors of particles and caryopses, e.g. on the basis of photographs of granular material placed on a glass plate.

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