

MOBILE PHONE DIGITAL IMAGE METHOD DESIGNED FOR EFFICIENT DURUM
WHEAT FLOUR CHARACTERIZATION.

Angel López Molinero

E-mail address : anlopez@unizar.es

Nanosensors and Bioanalytical Systems group (N&SB). <https://gba.unizar.es>

Analytical Department, Faculty of Sciences, University of Zaragoza, s-50009 Zaragoza,
Spain

ABSTRACT

The characterization and counting of foreign bodies and impurities in flours and semolina from wheat are decisive analytical parameters of safety and quality which should be evaluated in a context of efficiency and low cost. Moreover, their recognition and counting are required by the regulatory and quality norms of the sector. International standards such as UNI 10941:2001, could be applied but it has subjective appreciations. In this paper, a new analytical semi-automatic method based on digital images is assessed and proposed. The main features of the method were based on the use of representative sample images that could be taken in controlled illumination conditions by a Smart-phone. The images were then analyzed by a macro-script adapted to the free software FIJI-ImageJ of image processing. By changing the image color format to grey and its contrast, a threshold intensity, or cutoff, was selected to distinguish between foreign bodies from the rest of the product. And the number of particles was counted. Finally, four different fractions of components in the product were recognized which characterized the type of the product. The estimated processing time was less than 60 s.

The method has been validated against 14 reference samples that were previously studied by the standard UNI 10941:2001. These samples presented: low, medium and high particle content, as well as different background color of the matrix product: from white to yellow. The results were obtained with an average of 6 ROIs taken in different locations of the same digital image. Figures of merit of the procedure such as the biases presented relative differences of less than $\pm 20\%$, against reference values in the worst case. The reproducibility of the measurements, examining different locations, is better than 30-40% RSD. Likewise, the reproducibility in the same ROI but with short scans in the threshold of selection produced response ranges of less than 30% RSD. These parameters are consistent with those of prevalence in the sector and this type of products

Key words: Digital image, Mobile phone recognition, Counting, Extraneous bodies, Flour semolina wheat.

1. Introduction

Flour and semolina obtained by grinding of durum wheat cereal, *Triticum Durum* Desf., are principal ingredients in preparation of basic and appreciated foods such as paste and pastry. High levels of homogeneity and quality are essential for its use. International recommendations and rules about their composition and quality parameters are collected and detailed in the Codex Alimentarius Guide ¹. These guides are usually incorporated into the countries legislation which is the case of European Legislation ². Inspection and recognition of foreign bodies and contaminating residues are decisive parameters related to the safety and quality of these products. They can be considered elements outside the main product that could be interpreted as defects ³. In general, the presence of foreign bodies in foods is an analytical determination of such importance that the FDA has established strict requirements with quantitative criteria based on a maximum proportion of allowed defects, named as defect action levels, DALs, ⁴ even if they do not pose a health risk.

In the case of flour, also the presence of the bran is of particular interest for the ascription to different types or classes. This component comes from the shell of cereal grains that has not been completely ground. And although it does not affect their nutritional properties, it could be considered another imperfection that affects their commercial appreciation.

All of aforementioned arguments introduces a needs for a quantitative control of foreign bodies and bran with high levels of efficiency. This process deals with observing particles of small size [lengths between: 0.1-0.5 mm; area: $9 \cdot 10^{-3}$ - $2 \cdot 10^{-1}$ mm², irregular in size and inhomogeneous color. They tend to emerge such as a more or less dark hue scattered over a surface of predominant white-yellowish color consequence of the cereal matrix.

Official methods of determination like the one compiled by FAO, FDA and AOAC are an important option. They are designed for the routine control of production with specific proposals focused on the isolation and determination of foreign particles. Among the most highlighted the proposed by the AOAC ⁵ and the International American Association of Cereals Chemists, AACC, ⁶ should be mentioned. They can be classified into two types: classical or advanced methods. Firstly, Classical methods include separation, filtration, flotation and sedimentation procedures. They are based on differences in size, density and solubility of the foreign particles in distinct solvents. And secondly, advanced and instrumental methods have been implemented with X-ray examination, ultraviolet light, and qualitative and quantitative microscopy observation and measurement. These procedures are usually combined with selective digestion and solubilization procedures by organic solvents and enzymes.

Alternative methods proposed by technical standards, such as the UNI 10941:2001 norm, have gained acceptance and they are of common use in manufacturing with broad consensus in trade ⁷. The previously mentioned standard is based on visual observation of the sample with the naked eye for the identification and counting of foreign matter and bran particles in durum wheat flour and semolina. The observer usually requires magnifying glasses, subdivides the test area into smaller sections and then proceeds to the count in the individual zones. Conditions of homogeneity in lighting and product dispersion are always necessary and partial results are added to derive the final conclusion. In general, this method can produce answers with low reproducibility and uncertainty ranges of 20-50% RSD.

The standard norm could be considered as a laborious procedure. However, the main disadvantage is that the results lack an objective contrast that could facilitate the verification and traceability of products between parts. Furthermore, it is based on a methodology that is unsuitable for the rapid processing of samples and results.

Recently, new spectral methods for wheat characterization by NIR ⁸ are qualified of high productivity. Also approaches based on artificial vision ⁹ with digital images are being considered as ideal procedures in food control ¹⁰ or classification as in the differentiation of natural unprocessed teas ¹¹. It is evident that new analytical procedures should favour the productivity with control tests that provide verifiable data with fast communication and acceptance of results. This scheme has been applied in the evaluation of the appearance of cereal grains ¹². The detection and counting of pulses pest by digital images with the software ImageJ has also been published ¹³.

In line with the aforementioned publications, this work proposes a fast efficient method of digital image analysis that allows the counting of particles in a semi-automatic way with the image processing platform, Fiji, variant of the ImageJ software ¹⁴. The principal features are based in the image capture of a representative sample with a high resolution Smart-phone camera followed by the selection of the color threshold that differentiates between the particles of interest and others that are not required.

The method has been evaluated with reference samples that presented a wide range of foreign bodies and which were previously counted by the standard UNI 19041:2001. The comparison showed a reasonable congruence with differences between the reference and predicted values below the 30-40% range. At the same time this alternative simplified and speeded up the procedure.

2. Material and methods.

2.1 Illumination box

An illumination box made of cardboard was prepared. White mid-height PE sheets were

placed inside it to support a LED lighting strip and to produce a reflective well illuminated space. The tray with the sample was placed at the bottom. The digital camera, or Mobile-phone, was positioned on the upper cover as can be seen in Figure 1.

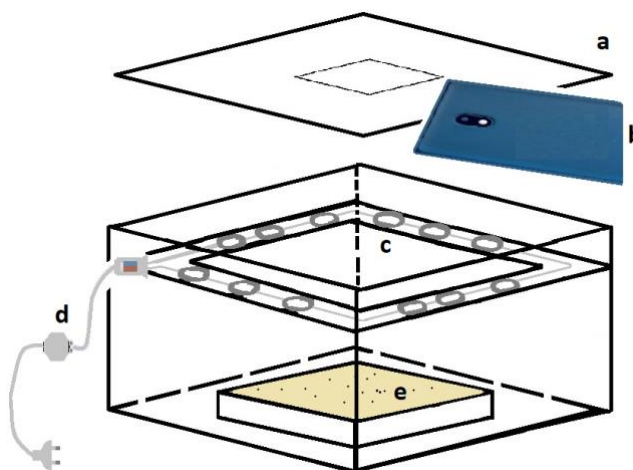


Figure 1: Main features and components of the illumination box
a) Upper cover with opening. b) smart-phone, c) strip of LEDs, d) electric connections, e) samples support.

2.2 Illuminant

Alverlamp commercial LED strip, 14.4 watts, working in the cool white light mode, 4000K.

2.3 Sample tray

It was prepared using a 3-D printer with PolyLactic acid, PLA, of 15x20 x2.5 cm, which makes it possible to deposit up to 400 g of sample. It was adapted to a matte black color.

The sample in the tray was flattened using a ruler until it presented a smooth, homogeneous surface without accumulations.

2.4 Samples

Flour and semolina samples were obtained from durum wheat (*Triticum wheat*) milled in an industrial procedure. In this process the grain was cleaned, tempered, grinded and finally cleaned of seed coats. The variety of Durum Wheat was harvested in Aragon, Spain, and principally destined for the production of high-quality pasta products.

2.5 Image

Images in 'jpg' format were taken with a Redmi Smartphone, model Note 8T, equipped with a 48 MPixels HR camera. Focusing was carried out by capturing the entire sample tray and a full digital image of the sample was obtained.

The images were calibrated [pixels / cm] taking as reference the dimensions of the sampling tray. After scaling, Regions (areas) of Interest were selected and cropped - ROIs - 10x10 cm in size - in different locations of the full digital image of the sample.

2.6 Macro-script

A macro-program was designed and written in Java 4 for the counting purpose. The counting process was performed on the Fiji platform, variant of the ImageJ software. The flow chart in Figure 2 describes and highlights the main aspects.

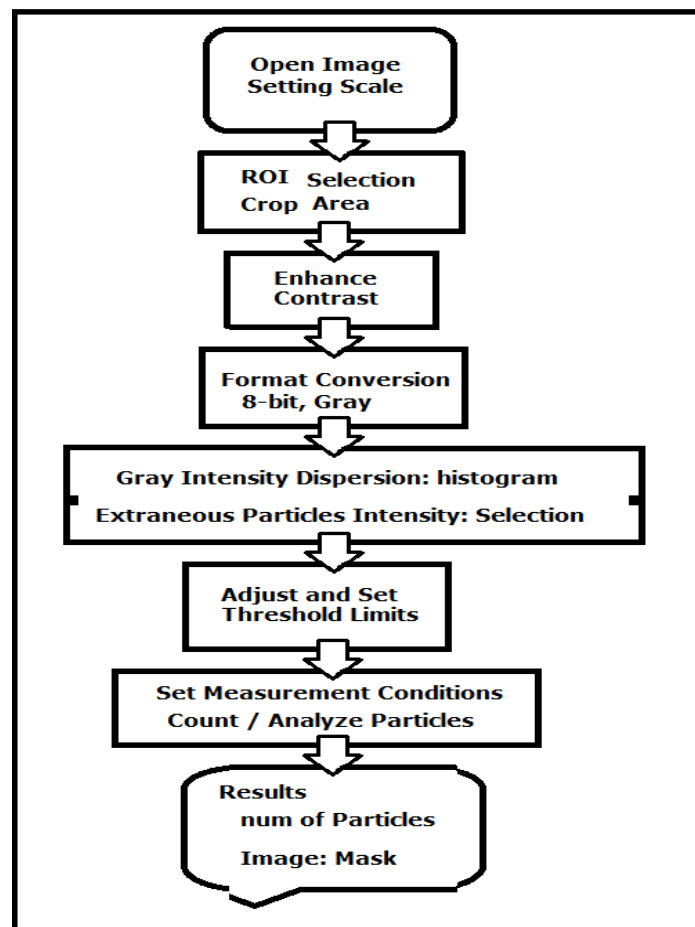


Figure 2: Flow chart of the main action of the macro-script program

3 Results and discussion

3.1 Conditions in the digital process

Smartphones and Compact cameras were used throughout. Minimum resolution in the images was evaluated with a camera of 12 MPixels [MP]. Subsequent work, however, will be presented with Smartphones at 40 MP resolution. Focus was always manual with full capture of the sample tray.

The illumination was produced with panchromatic white light of: warm, neutral and cold type. Best conditions were achieved with cool 4000K white LED light. Monochrome LED lights: red, green, blue, for compensating the effects of the matrix-background color were also examined.

The main conditions in the image pre-processing were studied and set at the following values: - image size was scaled [from pixels] to basic units, cm. – image contrast increased at a value of 0.2%. This means the number of pixels that can become saturated at maximum intensity. - format image conversion: from color[RGB] to an 8-bit grey format. This last format reduced the influence of the background matrix color. The format change was completed in automatic mode with a direct transformation algorithm: $I_{\text{grey}} = R + G + B / 3$ which produced a grey image with intensities scaled between: 0-255 ru (relative unit), where value 0 is associated with black and 255 with white. In this context, the background matrix color of the flour appeared with high values of intensity. Foreign bodies were observed as a dark grey-black color and consequently had low intensity values.

Other treatments for the elimination of the matrix-background color, such as the separation and selection of R G B layers of the image, or the use of optic filters, were studied but they did not improve the results of the grey transformation.

The differentiation of the foreign particles from the rest of the components was achieved by selecting a range of cutoff values in grey intensity: min-max. The typical range was: 0-40 ru. The '0', minimum value was always maintained but the maximum value of the range was selected according to the appearance in each sample. Under the conditions of our experiments, usual maxima were in the interval of 38-39-40-41 ru. In general, it is recommendable to scan the threshold value around a central value or criterion. In this way the reliability of the results was increased. The process only allowed the selection of only pixels included in the grey intensity range: min-max, and the exclusion of the rest. It was programmed with the Threshold option implemented in the software.

Other conditions, such as those related to the analysis and measurements parameters were programmed at convenience. Thus, particle sizes with area ranges between 0.01 - 0.2 mm² [min-max] and diameter 0.1-0.5 mm could be selected.

3.2 Image processing.

The actions of the image analysis, see Figure 2, were sequentially and automatically executed by a program developed by us, as a macro-script in Java 4.1, and adapted to FIJI Software.

The main results of the application of the program over a reference image can be seen in Figure 3. It shows the full digital of the cuvette with the sample, Figure 3-A, in the illumination box. The region of interest or ROI, was selected and cut, with an area of 10x10 cm, such as in Figure 3-B. The contrast was then increased [Figure 3C] and subsequently converted to grey format [Figure 3D].

The enlargement of the last figure, such as in Figure 4, allowed the identification of different particles dispersed over the matrix of the product. Their levels of the grey intensity were a feature with potential of discrimination.

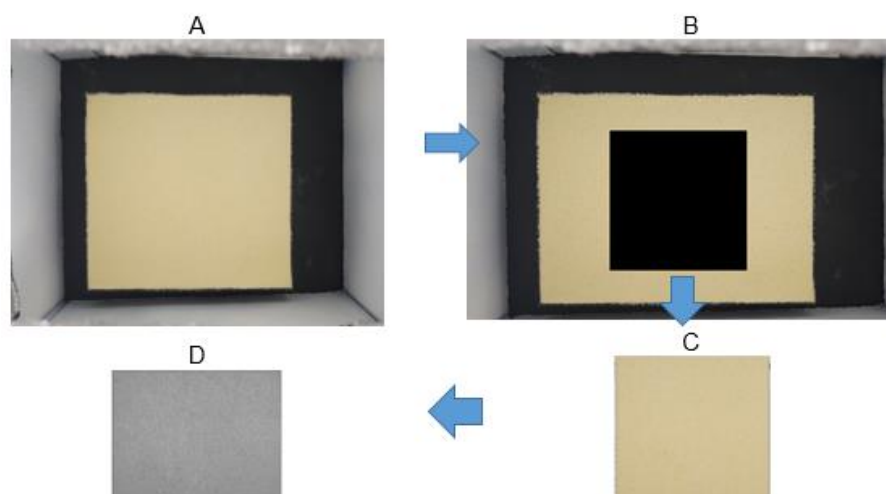


Figure 3:
Results of the application of the macro-script over the sample image: A- Sample image in the cuvette, inside the light box. B- Selection and cut of a Region of Interest. C-Contrast increase and D- image conversion from color to grey format.

The profile of the grey intensity of the pixels along a passing line through

representative zones, [see Figure 4] made it possible to recognize four different types of values and consequently of four different types of component:

- [i] Values of grey intensity in the range 150-170 ru. They represented a constant level in the image that is maintained from the left to the right, which could be associated with the intensity of the background or the predominant matrix-component of the product.

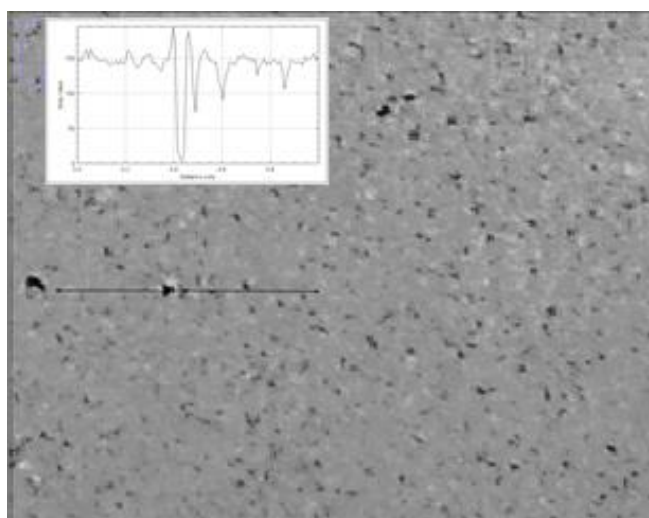


Figure 4.
Enlargement of Figure 3D with a 200% ratio increase. In the inlet: grey intensity profile along the representative line crossing the image.

- [ii] Decreasing peaks with minimum grey intensity that arrived at 0 ru, black. This low intensity is associated with foreign bodies and extraneous particles.
- [iii] Other decreasing peaks with similar profiles to the previous one, but with minimum grey intensity higher than 50 ru. These values might be associated with particles lighter than the foreign bodies [0-40 ru] but darker than the predominant matrix [$< 150-170$ ru].
- [iv] Pixels of high grey intensity with values greater than 170. They were in low proportion and located in the proximity of the foreign particles. They were clearer than the matrix of the product and might be interpreted as a white fraction of the product or also as simple effects produced in the capture of the image.

The above identification could explain the different components in the product. Thus the first type of values [i] would be associated with the major fraction of the product.

The minimum grey intensity [ii] would correspond to the fraction of foreign bodies.

On the other hand, the pixels with intermediate grey intensities [III] might be associated with wheat germ and other oxidized fractions of the main product. According to the evaluation criteria they would not be associated with foreign particles.

And finally, the greatest intensity values [iv] identify very clear compounds that might be considered internal fractions of the cereal grains. These values could also be produced by a reflection light effect in zones close to the foreign particles.

3.3 Quantitative dispersion and distribution.

The previous information was completed with the histogram of the grey intensities for all the pixels, that is for the full image.

Figure 5 plots the count or number of pixels for each value of grey intensity.

The results showed that the majority of pixels appeared in the grey intensity range 90-193 ru, with 152 ru as the modal intensity.

These pixels represented the major fraction, 'MF', of components of the product and are certainly correlated with the intensity of the background color previously described in the Figure 4, as the fraction of values [i].

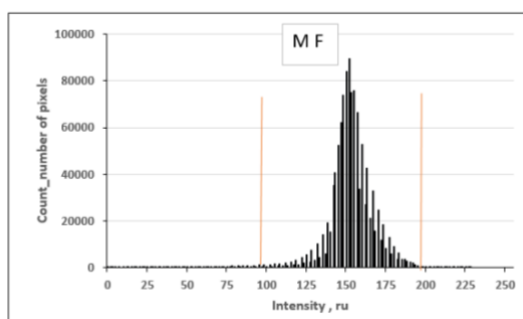


Figure 5
Histogram. Count of pixels for each grey intensity value, in the scale 0-255 ru, and for all the pixels of the ROI.

The abundance of these pixels was 98.92% of the total number of pixels.

On the other hand, the ratio of pixels with grey intensity lower than 90 ru accounts for 0.78% of the total. Pixels with intensity values greater than 193, only represent 0.30% of the total.

The change in the variable of the histogram to logarithmic scale [$\log[\text{count}]$] made it possible to appreciate other minor components, especially important with grey intensity lower than 90 ru.

In this range, the Figure 6 differentiated two zones. A lower zone, characterized by a

grey range 0-40 ru, which would be a fraction of pixels with the features of the extraneous and foreign particles, 'EP F'. That is to say, it would coincide with the decreasing peaks of Figure 4, which had values [ii].

And the second zone would correspond to the grey range 50-90 ru. These pixels were identified as an Intermediate fraction of pixels, 'I F', and might be associated with values of the type [iii], according to Figure 4.

Furthermore, it is possible to identify a fraction of pixels with grey intensity greater than 195 ru which has a fraction of lighter colors, 'H F', and which were coincident with the pixels of the type [iv] defined in Figure 4.

In general terms, the fractions of pixels identified in both histograms, Figs 5-6, including the full image were coincident with the component differentiated in Figure 4. These fractions can be summarized as:

I. Major Fraction, 'M F', with grey values in the range 90-195, and maximum intensity at 152 ru which could due to the background-matrix color of the predominant product.

II. Fraction of Extraneous and Foreign Particles, 'EP F', with grey values in the range 0-40 ru and mode value of 38 ru. This is a fraction of grey intensity close to black. The grey limits of this fraction are the key to deducing the appropriate number of extraneous particles, especially the value of the upper limit. In general, it was found that an inflection or transition zone was located between the fractions EP F and the intermediate fraction, IF, of the histogram [logarithm], as can be seen in Figure 6. Consequently, the maximum grey intensity of the EP Fraction could be taken as the largest intensity or cut off, 'I C', for the identification and counting of foreign particles.

In images with low resolution, a range of cutoff values around the critical intensity can be selected: $IC \pm IC \times 5\%$. It will therefore produce a realistic answer as an interval of particles.

III. Fraction of Intermediate pixels, 'I F', with intensities in the range (>40) 43-90. It represents a fraction formed by components such as wheat germ and others oxidized products. They could appear as artifacts and they should be avoided because they could be included as foreign particles.

IV. Fraction 'H F' of particles with intensities greater than 193 ru which were associated with particles of a lighter tone and little abundance.

These results also produced relationships of consistence and Quality Control between the areas of the different fraction of components. Furthermore, it could represent an estimation of their relative composition. In general, the pixels of the major fractions are in the order of 90-95% of the total area of the image. Minority fractions EP F and I F represented ratios in the order of 1.5 and 3.0% respectively.

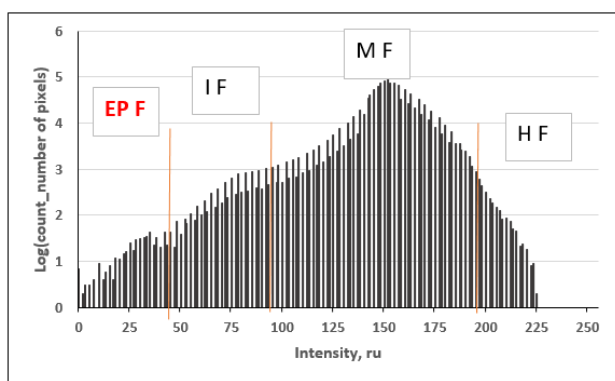


Figure 6

Histogram with the logarithm of the number of pixels that present an intensity of grey, for all the pixels of the ROI. Logarithmic distribution of the pixels of the entire ROI.

The procedure is therefore proposed, with standardized illumination and calibrated dimensions, for the identification of different fractions and also the evaluation of a ratio composition given in terms of area. And although it cannot describe the real composition, in mass, it established an index of coherence and Quality Control between the different fractions, as well as between different types of products.

3. 4 Application to reference samples.

The method was studied and applied to 14 reference and representative samples of flour and semolina productions ready to make paste for cooking. They had different matrix-background color (from predominantly white to yellow) and number of foreign particles. In a previous process they were evaluated by the UNI 1705:2001 visual method which produced a range between 39-129 particles.

The results obtained using the proposed digital method are gathered in Table 1.

They were reached from representative and homogenized samples which were captured in a full digital image, such as in Figure 3. Afterwards, six different ROIs were selected from distinct locations of the same digital image. In each ROI the number of particles were counted at three threshold values, i.e.: Critical Intensity CI, CI+5%CI and CI-5%CI. That is, each ROI was characterized by its mean. And, the final count was deduced as the mean of the 6 (means) ROIs.

Sample	Number of particles	
	Mean(6)	% DSR
1	32	20
2	74	12
3	125	14
4	90	31
5	80	30
6	93	12
7	79	25
8	92	24
9	76	12
10	115	8
11	81	21
12	91	15
13	76	14
14	85	23

TABLE 1: Number of particles and reproducibility of the counting process

This scheme provided a more verifiable and reliable dispersion of results.

~~The differences between the results were lower than 10-20%.~~ The homogeneity of the sample and the resolution in the image were factors which influenced the range of dispersion.

In this context, the comparison between the results of the new digital method and the visual standard procedure, by the test t in the paired t-test scheme, showed that both methods were statistically comparable, at P=0.05. That is, the differences between the means, of the digital image method vs. the visual method, showed that the null hypothesis could be maintained: the methods didn't show significant differences at one way because: $\text{abs}(t_{\text{exp}}) = 1.615$ was lower than ' $t_{\text{critical}} = 1.771$ '. And neither did they at two ways: $t_{\text{critical}} = 2.160$. Always at P=0.05.

The comparison of results, by a linear regression, gathered in Figure 7, between the count

obtained by the visual method and that obtained by the digital method showed a high correlation between methods, with $R^2 > 0.91$.

Also, the comparison of their regression coefficients, against the theoretical

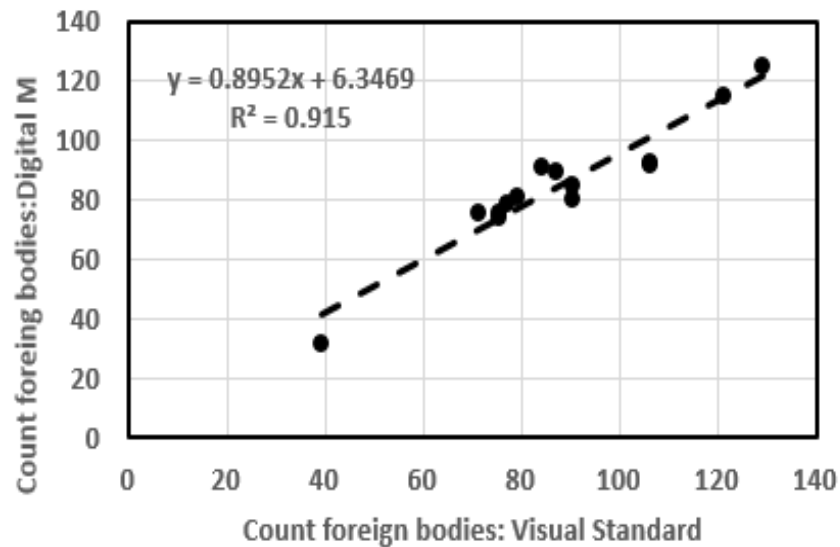


Figure 7.

Comparison and correlation between the results of the count of foreign and extraneous particles by the new digital method vs. the obtained by the visual standard UNI 2087:2001.

or expected values of 1.0 as the slope and of 0.0 as the ordinate, according to the test t, at level of 95% confidence, showed that the differences could be justified by a random dispersion and there were not proportional nor additives interferences between methods.

That is, both statistical comparisons were coincident and showed a high level of confidence that results were not affected by any systematic error.

The reproducibility of the digital method is maximum if the same ROI image is replicated while maintaining the threshold value.

~~The change of the cutoff value in the threshold for the analysis of particles, in a range $\pm 8\%$, could produce a variation in the mode response of less than 20%.~~

Under the conditions proposed, and applied such is described in Figure 2, the image processing time can be estimated to be less than 60 s. The manual method, however, requires more than 6 min per sample. In addition, the digital procedure could be automatically integrated in a traceability process that fits into the quality assurance programs of the international standards such as ISO 9001 and 17025.

Conclusions

Rapid analytical control for characterization and counting of foreign bodies in flour and semolina from durum wheat were carried out for first time using digital images. Under reference conditions, the images did not exhibit the influence of the base color of the product and selection of a cut-off grey intensity in the pixels, or threshold value,

differentiated between foreign bodies from the rest of the product. Moreover, it was kept practically permanent between batches of samples.

The process was implemented and speeded up in the free software FIJI-Image J. The operation time was significantly reduced to less than 60 s and reproducibility was established in the range 10-30% RSD.

Furthermore, the pixels selection identified four different fractions in the product: Extraneous, Intermediate, Major and High components. The ratio between them would provide new parameters of coherence and quality control in the products

This procedure afforded results with efficiency at low cost and allowed objective evidences for the comparison and contrast of results between different stakeholders.

Conflicts of interest

The author declares that he had not competing interests that could influenced the results and research reported in this paper.

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