Colour analysis of rice using flatbed scanning and image analysis

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Abstract

*This paper describes a method for the determination of the colour of raw and processed rice using flatbed scanning (FBS) and image analysis (IA). Colour is one of the key quality attributes of rice and is influenced by processing. The colour of a bulk sample of rice was analysed by imaging a thick layer of rice on the scanner surface and measuring the average RGB colour. The RGB colours were converted to CIE L*a*b* colours after calibration with rice samples measured by a colorimeter using the tristimulus XYZ values. For validation a separate set of rice samples was used. For the determination of the colour of individual rice kernels images were made of a single layer of rice spread on top of the glass plate of the FBS. The measured non-calibrated colour values can be used to detect specific kernels in a rice sample. The FBS method was also used for the determination of the amount of opaque or chalky rice kernels (chalkiness). The results of the determination of the chalkiness are comparable to those obtained by visual inspection using ISO 7301. The FBS-IA method is fast, easy to use and cheap. FBS-IA can monitor colour changes with the same accuracy and better precision than a colorimeter.*

Introduction

Rice is one of the most important cereal grains. It is purchased primarily as milled raw grains by the consumer, and consumed after steaming or cooking. In many countries also parboiled rice is used. Parboiled rice is rough rice that has been gelatinised by soaking and steaming or dry-heating while it was still in the hull, following by drying, removal of the hull and a polishing step. Parboiled rice is clear, vitreous and translucent with a yellow to brown colour. A common problem with parboiled rice is the darkening of the finished product, which affect the consumer acceptability. Processing yields a large variety of rice products. For instance, puffed and popped rice used as traditional breakfast cereals and snack foods. Rice undergo physicochemical changes during processing. Expansion and colour changes are the most obvious changes during heat treatment (hot air, steaming, frying, extrusion). Therefore physical properties as size, shape, appearance and colour are of utmost importance. The colour of rice is usually determined using a colorimeter or colorimetric spectrophotometer [1,2].

Flatbed scanning and image analysis (IA) can be used for the determination of the size distribution and percentage of broken rice kernels [3]. A standard flatbed scanner (FBS), also called desktop scanner was used to obtain images of the rice kernels. The rice is placed on the glass plate of the FBS scanner and covered with a black sheet of paper. A fully automatic procedure was developed using freeware IA software and standard spreadsheet software. FBS scanners are the most versatile and commonly used scanners found in literally all offices and are available at low cost. FBS is robust and independent of external light conditions. The application of FBS for IA has been growing rapidly during the last years. This article presents a method for the determination of the colour of rice using FBS and IA. Beside the bulk colour, determined by imaging a thick layer of rice, also the colour of the individual rice kernels was analysed. This gives information about the homogeneity of the colour which can not be obtained by instrumental methods generally used for rice (e.g. colorimeter). Also specific kernels can be detected. An example is given for chalky kernels. These kernels show whiter opaque regions or are even completely opaque. They contribute to poor milling quality. A FBS method was developed for the determination of the amount of chalky kernels (chalkiness).

The method for the determination of the colour was tested on parboiled and regular-milled white rice and processed rice (puffed and popped) and compared to the analysis using a colorimeter.

Experimental

The experiments were carried using the Agfa Duoscan T1200 flatbed scanner with Agfa Fotolook software (version 3.5). The scanner was used in the reflective mode, 24 bits RGB scale and a resolution of 200 dpi without contrast stretching (full histogram range of 0 to 255) or other corrections (e.g. tone curve, sharpness, flavour). Digital image analysis was made using the Leica Qwin software (version 2.3) under Windows NT on a Dell Precision 420 computer. The method can also be implemented using freeware IA software (e.g. Scion image or Image J). For the determination of the colour of a bulk sample of rice, a plastic sample holder with a size of 4.0 cm by 4.0 cm by 1.5 cm was filled with rice up to a layer of about 1 cm. The sample holder was inverted on the scanner surface within a rectangular hole of 4.0 cm by 4.0 cm of a black sheet of paper covering the total scanner surface (Figure 1). An RGB image was made and the average RGB values of the pixels within an area of 2cm * 2cm in the centre of the sample holder were measured. This was done to exclude edge effects (lower intensity at the edge of the sample holder).

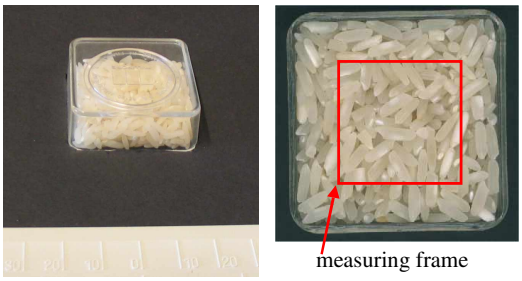

Figure 1. FBS analysis of the bulk colour of a sample of rice: rice kernels in inverted container on the scanner surface (left), FBS image with measuring frame.

For the determination of the colour distribution a single layer of rice was imaged on a black background to facilitate the separation of touching rice kernels [3] a black aluminium sample matrix with holes was used. The rice kernels were identified in the FBS image by preparing a binary image: defining a range of brightness values belonging to the foreground (rice kernels) and rejecting all of the other pixels to the background. This operation

is called thresholding [6] and is quite straightforward for FBS images. Thresholding was performed on the red channel of the RGB colour image. For colour calibration a Minolta colorimeter (Chroma Meter CR300) was used. This colorimeter uses a pulsed Xenon arc lamp filtered to match the CIE standard observer response. It was set at 2^{o} and D65 illuminant condition. The colour (XYZ and L*a*b*) of the bulk sample was measured using the Minolta colorimeter (calibrated using a standard white reflective plate). The rice kernels were placed in a quartz vessel (diameter 4 cm) from which the bottom was placed on top of the measuring head (diameter measuring area = 8mm) of the colorimeter. The vessel was covered with a black opaque plastic cover. Every colour measurement was made in three readings per sample.

Parboiled and regular-milled white rice of different varieties (IR64, Jasmine, Basmati and Arborio) and instant rice with different expansion factors and colour were purchased from commercial markets (see Figure 2). Sub-samples of each type of rice were obtained by using a Retsch PTZ sample divider (sample splitter).

Figure 2. FBS images of a selection of calibration and validation samples used for the determination of the bulk colour.

Results

The FBS method for the determination of the bulk colour was calibrated with rice samples measured by a Minolta colorimeter (Chroma meter CR300). The tristimulus values XYZ measured by the colorimeter and the RGB values measured by FBS were used to calculate the transformation matrix [4]. Rice samples were used for calibration because calibration with photographic paper colour charts resulted in a high systematic error (e.g. calibrated IT8 colour reference charts supplied by the FBS suppliers or a colour checker chart supplied by GretagMacbeth). For calibration of the determination of the bulk colour, 24 samples of parboiled and regular-milled white rice and instant rice were selected with L*a*b* values ranging from 52 to 86, -0.2 to 1.9 and 10 to 16, respectively. For validation a separate set of 10 parboiled rice samples was selected with L*a*b* values ranging from 52 to 69, -0.9 to 4.4 and 8 to 21, respectively. These parboiled samples were obtained under different conditions that were not used for those in the calibration set. FBS images of a selection of these samples are shown in Figure 2. All samples were measured in triplicate with both methods. The results are shown in Figure 3. The correlation between the calculated FBS colour and the colour measured by the colorimeter is reasonable (correlation coefficient of the L*a*b* values are 0.93, 0.88 and 0.76, respectively).

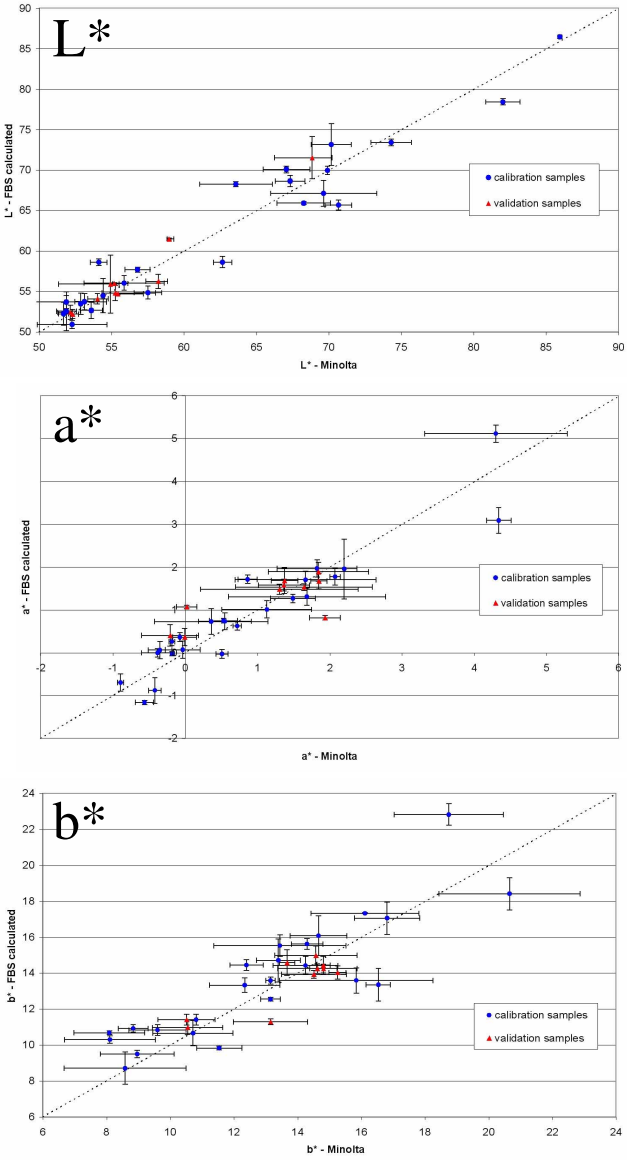

Figure 3. Calibration of FBS with rice samples analysed by Minolta, comparison of CIE L, a* and b* values for calibration and validation samples (error bars: 95% confidence intervals of mean values)*

The difference between the colours determined by FBS and the Minolta colorimeter, expressed as ΔE [4] ranges from 0.4 to 2.6 for the validation samples (parboiled rice). Colour measurements are mainly used to estimate differences between samples (e.g. after treatment). For the calibration and validation samples this was done by calculating the differences between the measured colours of each sample and the colour of plain untreated IR64 rice (regular-milled white rice). The colour differences (ΔE), obtained by FBS and the Minolta colorimeter are compared in Figure 4. The difference between the ΔE values of the parboiled samples used for validation is smaller than 2.

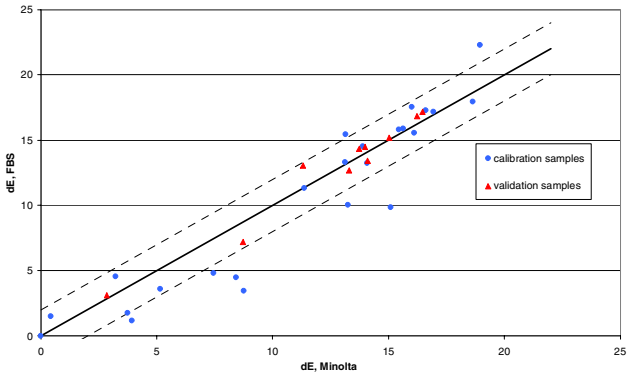

Figure 4. The differences between the colours of each sample and the colour of regular-milled white rice IR64 rice, expressed as ΔE analysed by FBS and Minolta (solid line: y=x; dotted lines y=x±2)

The short-term precision of FBS and the Minolta colorimeter were compared by calculating the standard deviation of the repeatability (S_r) for the L*a*b* values of the calibration and validation samples. The precision parameters calculated by the analysis of variance are listed in Table 2. The precision for the determination of L* is comparable for both methods (no significant difference according to the F-test [5]). For a* and b* of treated rice and b* of untreated rice (regular-milled white rice) a much better precision was obtained by FBS (standard deviation a factor 2-4 lower). The better precision can be caused by the larger surface area measured by FBS (1.6 cm2 compared to 0.5 cm^2).

Table 1. Precision parameters of the determination of the bulk colour of rice by FBS and Minolta colorimeter.

regular-milled white rice of different varieties:

	L*		
	S_r	r	F
Minolta	0.59	1.67	0.7
FBS	0.69	1.96	
	a*		
	S_r	r	F
Minolta	0.09	0.26	1.4
FBS	0.08	0.22	
	b*		
	S_r	r	F
Minolta	0.51	1.43	17.7
FBS	0.12	0.34	

treated rice samples:

	L*		
	S_r	r	F
Minolta	0.79	2.25	1.4
FBS	0.67	1.89	
	a*		
	S_r	r	F
Minolta	0.24	0.68	3.7
FBS	0.12	0.35	
	b*		
	S_r	r	F
Minolta	0.64	1.81	4.1
FBS	0.32	0.89	

Critical value of F for a two-tailed test (P=0.05) is 15.4 for white rice (degrees of freedom = 3) and 2.5 for treated samples (degrees of freedom = 20).

As a measure of the long-term stability of the FBS method, the colour of two rice samples was measured over a period of 1.5 years using an Agfa Duoscan T1200. In this period the flatbed scanner was not re-calibrated (no correction for drift). The analyses were performed in triplicate on the same sub sample of 10 gram. After each replicate the sample was removed from the sample holder and mixed. The results for regular-milled white rice and parboiled rice are plotted in Figure 5. The precision parameters calculated by the analysis of variance are listed in Table 2. The long-term precision is expressed as the standard deviation of the within-laboratory reproducibility (S_{Rw}).and the short-term precision as standard deviation of the repeatability (S_r). The long-term precision is slightly higher than the short-term precision (S_{Rw} is significant higher than S_r according to the F-test for b* of regular-milled white rice and a* of parboiled rice). The colour differences expressed as ΔE, relative to t=0 are smaller than 1.4 for regular-milled white rice and smaller than 0.65 for parboiled rice (95% confidence interval). The standard deviation for L* of regular-milled white rice is higher than for parboiled rice due the inhomogeneous distribution of chalky rice kernels (see Figure 1). The translucent parboiled rice contains a mixture of light and darker coloured kernels resulting in a higher standard deviation for a* and b*.

Table 2. Precision parameters for the determination of the bulk colour by FBS, determined by analysing regular-milled white - and parboiled rice over a period of 1.5 years (57 - 72 analysis per sample).

	regular-milled white rice		
	L*	a*	b*
Mean	68.4	0.054	10.4
S_r	0.44	0.043	0.080
r	1.23	0.123	0.225
S_{Rw}	0.49	0.048	0.121
Rw	1.40	0.135	0.343

	parboiled rice		
	L*	a*	b*
Mean	57.6	0.150	13.2
S_r	0.27	0.067	0.184
r	0.78	0.189	0.520
S_{Rw}	0.29	0.085	0.184
Rw	0.83	0.239	0.520

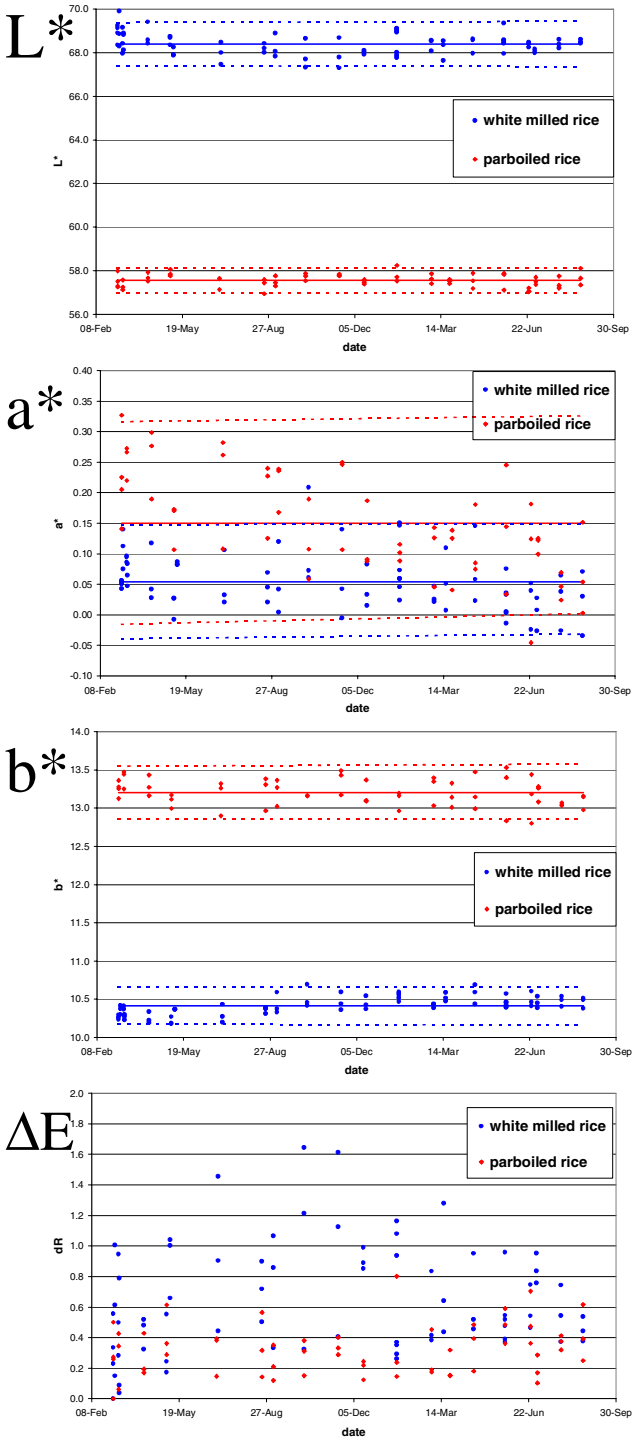

Figure 5. Stability of the determination of the bulk colour of white milled and parboiled rice using FBS : CIE Lab values as function of time (ΔE relative to t=0).

Rice samples with a non-uniform colour (between or within kernels) can be misrepresented by the bulk colour. The bulk colour gives an average colour over an area of 2cm * 2cm. Inhomogeneous samples with a comparable colour of the bulk sample could show clear different colours by eye. An example is given in Figure 6. The variance of the RGB values of the pixels in the images of the bulk colour is influenced by the dark voids between the kernels and will therefore not be suitable to distinguish between homogeneous and inhomogeneous colours.

*Figure 6. Colour images of two instant rice samples with comparable bulk colours. Top : thick layer of rice, bottom rice kernels on a black background (selected area of 4cm * 4cm). The difference between the bulk colour expressed as ΔE is 0.6 (left: L* = 68.8, a* = 0.65, b* =12.5, right: L* = 68.6, a* = 0.52, b* = 13). The difference between the average colour of the rice kernels expressed as ΔE is 3.3 (left: L* = 66.4, a* = -1.43, b* =7.5, right: L* = 68.9, a* = -0.55, b* = 9.5).*

Colour differences of inhomogeneous rice samples can be determined by analysing individual rice kernels. However, these kernels are difficult to detect in the images of the bulk colour. A better separation can be obtained by imaging a single layer of rice kernels on a black background. The rice kernels were identified in the image by thresholding the red channel of the colour image. The colour was measured within the thick central region of the rice kernel to exclude the thin edges with brightness values between the background and the kernel. These edges were removed by erosion of the binary image. This removes a layer of pixels from around the periphery of all kernels. A structuring element with a size of 2 pixels was used for images acquired at 200 dpi. Morphological parameters have to be measured before erosion because erosion causes shrinkage of dimensions of the kernels. Analysis of the colour of individual rice kernels of the two samples shown in Figure 6 resulted in a small difference between the average L*a*b* values (ΔE is 3.3). However the variation of the colour between the kernels in the right image is much higher. The relative standard deviations of the intensity (L*) and saturation (C*) are 2.1 % and 4.0 % for the left image and 4.0% and 9.5% for the right image, respectively. The colour values of individual kernels can not be compared with those of the bulk colour of a rice sample. The black background influences the colour of transparent kernels and the voids influence the bulk colour (high saturation).

Analysis of individual kernels can be used to detect specific kernels in a rice sample. An example is shown in Figure 7. The FBS image shows kernels which are translucent-white, chalky, partly chalky, translucent-coloured (red/yellow and grey). They were selected from a sample of regular-milled white IR64 rice and separated on the scanner surface. The colour of these kernels in the HSI colour space is shown in Figure 8. The HSI values were calculated from the RGB values by using the formulas derived by Tenenbaum, Garvey, Weyl and Wolf [7].

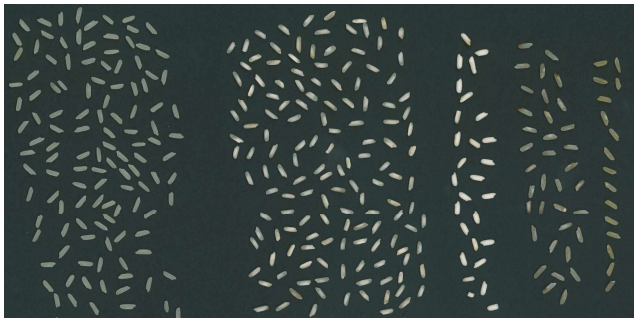

Figure 7 FBS image of rice kernels selected from a sample of regular-milled white IR64 rice, manual divided in translucent white, partly chalky, chalky, translucent red/yellow and translucent grey kernels (from left to right).

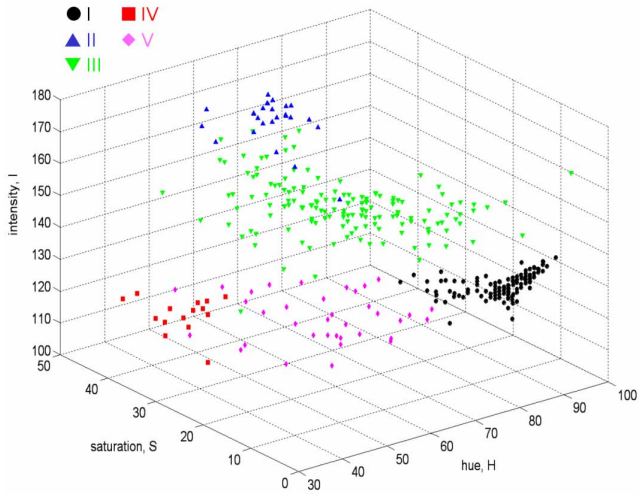

Figure 8 HSI colours measured of kernels selected from a sample of regular-milled white IR64 rice (image shown in Figure 7): I: translucent white (black), II: chalky (blue), III: partly chalky (green), IV: translucent red/yellow (red), V: translucent grey (magenta).

The different rice kernels can be identified by their colour. For white chalky rice kernels higher intensity values were observed than for white translucent rice grains, with highest values for totally chalky grains. Also the colour shifts to red (lower H). This is caused by a decrease of the translucency of the rice grains by which the colour of the black background is less visible through chalky grains. The distribution of the intensity and saturation values is much broader for chalky rice grains than for translucent rice grains (high standard deviation). The colours of red/yellow and grey translucent rice grains are more saturated than white translucent rice grains. The hue of these coloured kernels is lower and the intensities are comparable to white translucent kernels. Kernels can be classified into different quality categories by combining colour, size and shape features. (e.g. damaged kernels which have abnormal shapes, sizes and colours or immature kernels which are small and have a green or white colour).

An example of the detection of specific kernels is the determination of the amount of opaque or chalky kernels (chalkiness). The brightness histograms of the red channel of the colour image of translucent and chalky kernels of regular-milled white Basmati rice are shown Figure 9. The images were obtained using black paper and a black-lined shoebox as background. The black-lined shoebox gives a lower background but not a better separation between transparent and chalky kernels. A threshold level at the intersection of the histograms of transparent and chalky kernels was used to identify the chalky parts and a threshold level between background and translucent kernels was used to identify the total kernel.

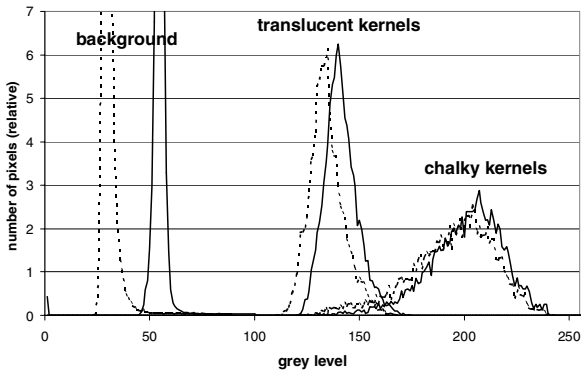

Figure 9 Brightness histograms of FBS images of translucent and chalky kernels of regular-milled white Basmati rice. The images were obtained using black paper (solid lines) and a black-lined shoebox (dotted lines) as background.

The binary image of the total rice kernels was eroded with a kernel size of 2 pixels, to remove the thin edges of the kernels with brightness values between background and kernel. The percentage of chalk of each kernel was calculated as the area of the chalky part within the eroded kernel (Boolean AND operation on binary images of chalky areas and eroded kernels) as a percentage of the area of the eroded kernel. An FBS image of translucent, chalky and partly chalky kernels selected from a sample of regular-milled white Basmati rice is shown Figure 10 (left image). The translucent kernels were placed at the top of the scanner surface and the chalky kernels at the bottom. In between are kernels, which are partly chalky. The right image of Figure 10 shows the chalky parts detected by image analysis. Image analysis without binary erosion as applied by Reece e.a. [9] resulted in about 20% lower areas of chalk: a completely chalky kernel gives approximately 80% chalk. The amount of chalk is generally determined using a subjective visual assessment method (scoring on a 6 or 10 point scale) or a visual selection or appraisal scoring method [9]. In the latter method kernels are selected as chalky when the chalky parts are larger than a predefined percentage of the kernel (classification values of 50% are defined by the USDA (United States Department of Agriculture standards for rice 868, 1995) and 75 % by the Codex Alimentarius using ISO 7301. Visual selection of chalky kernels is very difficult, especially for partly chalky kernels with a percentage chalk around the classification value. Day to day and operator variations are high [9]. The percentage of chalky kernels by image analysis was calculated from the total area of chalky kernels as percentage of the total area of translucent and chalky rice kernels. The distribution of the percentage chalk of kernels regular-milled

Basmati rice is shown in Figure 11. The total amount of chalky kernels (>75% chalk) in the Basmati sample was determined by FBS on 35 % (m/m). This is comparable to visual inspection using ISO 7301.

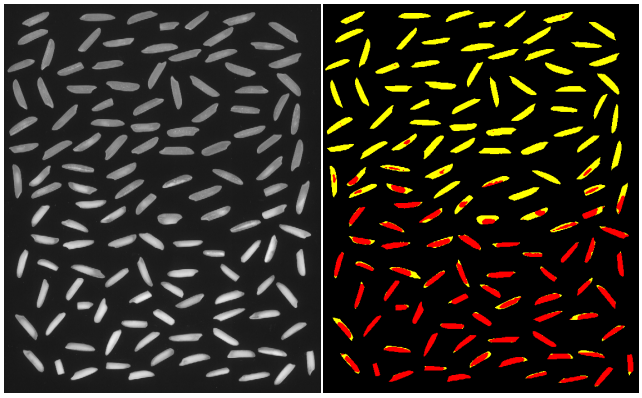

Figure 10 FBS image (left) of translucent and chalky rice kernels of regular-milled white Basmati rice with binary image (right) showing the detected chalky parts in red and translucent parts in yellow (erosion with a kernel size of 2 pixels was used to remove the edges of the kernel).

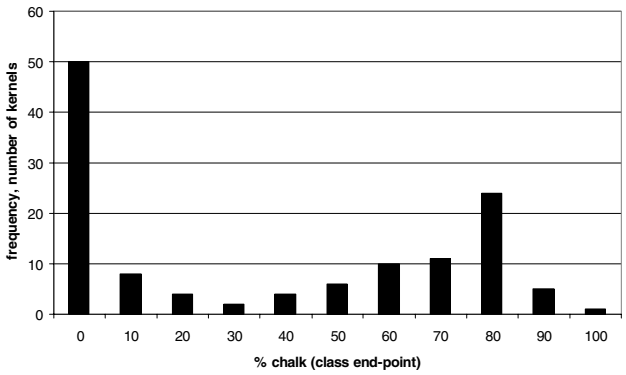

Figure 11 Distribution of the percentage chalk of rice kernels in a sample regular-milled white Basmati rice, determined from the image shown in Figure 10.

The colour analysis was developed on an Agfa Duoscan T1200 FBS. The method can be made scanner independent by using a colour correction method. Images obtained by different scanners could be matched to those obtained by the scanner used for calibration. Shanin e.a. [8] obtained good results for the FBS analysis of the colour of grains of lentils and peas by using standard colour chart - histogram matching based mapping functions.

Conclusion

The colour of rice can be analysed by flatbed scanning and image analysis (FBS-IA). This method is fast, easy to use and cheap. The colour of a thick layer of rice, the so-called bulk colour provides an objective assessment of the rice colour using the CIE L*a*b* colour space. FBS-IA can monitor colour changes with the same accuracy and better precision than a colorimeter. Beside the bulk colour also the colour of individual rice kernels can be measured. The measured non-calibrated colour values can be used to detect specific kernels in a rice sample or to determine the homogeneity of the colour. The results of the determination of the chalkiness of rice by FBS are comparable to those obtained by visual inspection using ISO 7301.

The method for the determination of colour can be incorporated into the FBS-IA method used for the determination of shape, length, width, density and number of broken rice kernels. FBS-IA allows visualisation and quantitative measurement of physical properties of rice. FBS-IA can also be used for the characterisation of other cereal grains and their products such as breakfast cereals, snacks, dry pasta and meals [10].

References

[1] A.B. Blakeney and L.A. Welsh, Objective measurement of rice grain color and gloss, Cereal Foods World, 33 (8), pg 679-679 (1988).

[2] P.W. Gras, M.L. Bason and L.A. Esteves, Evaluation of a portable colour meter for assessment of the colour of milled rice, Journal of stored Product Research, 26 (2), pg 71-75 (1990).

[3] G. van Dalen, Determination of the size and size distribution of rice and percentage of broken kernels using flat bed scanning and image analysis, Food Research International, pg 51-58 (2004).

[4] G. Wyszechi and W.S. Stiles, Color Science: Concepts and Methods, Quantitative Data and Formulae, John Wiley & Sons Inc., New York, USA (1982)

[5] J.C. Miller. and J.N. Miller, Statistics for analytical chemistry, Ellis Horwood Limited, Chisester, John Wiley & sons, New York, pg 60-62 (1988)

[6] Russ, J.C., The image processing handbook, 3e edition, CRC press, Florida, USA (1999)

[7] Palus, H., Representations of colour images in different colour spaces, The colour image processing handbook, editors Sangwine, S.J. and R.E.N. Horne, Chapman & Hall, London, 67-92 (1998)

[8] M.A. Shanin. and S.J. Symons, Color calibration of scanners for scanner-independent grain grading, Cereal Chemistry, 80 (3), pg 285-289 (2003)

[9] J.E. Reece and A.B. Blakeney, Image analysis for the assessment of chalk in milled rice, Proceedings of the 43rd Australian Cereal Chemistry Conference, Cereal Chemistry Division of the Royal Australian Chemical Institute, North Melbourne, pg 21-24 (1993)

[10] Instrumental colour and size grading of pulse grains, Proceedings of the World Congress of Computers in Agriculture and Natural Resources, Brazil, pg 107-113 (2002)

Author Biography

Gerard van Dalen has been working in Unilever Research Vlaardingen for 26 years and was manager for 12 years of the Atomic and Vibrational Spectroscopy unit. He is currently involved as a research scientist in the application of IA techniques for advanced imaging techniques (2D, 3D and 4D) to obtain quantitative information of the micro and macro structure, composition, texture, size, shape, colour and appearance of foods, detergents and related products. He is author of 20 papers on Spectroscopy, Microscopy and Image Analysis.