MRI texture analysis as means for addressing rehydration and milk diffusion in cereals

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Abstract

Cereals microstructure is one of the primary quality attributes of cereals. Cereals rehydration and milk diffusion depends on such microstructure and thus, the crispiness and the texture, which will make it more palatable for the final consumer. Magnetic Resonance Imaging (MRI) is a very powerful topographic tool since acquisition parameter leads to a wide possibility for identifying textures, structures and liquids mobility. It is suited for non-invasive imaging of water and fats. Rehydration and diffusion cereals processes were measured by MRI at different times and using two different kinds of milk, varying their fat level. Several images were obtained. A combination of textural analysis (based on the analysis of histograms) and segmentation methods (in order to understand the rehydration level of each variety of cereals) were performed. According to the rehydration level, no advisable clustering behavior was found. Nevertheless, some differences were noticeable between the coating, the type of milk and the variety of cereals.

Keywords: Tomography; segmentation; coating; fat level; microstructure.

1. Introduction

Extruded cereals are widely consumed all around the world and are characterized by providing high energy and starch, which is responsible for most of their structural, attributes [1]. Consumers are more and more concerned about a healthy diet; this is why a good content in fiber is not only important in order to obtain a high nutritional quality product also remaining palatable for the consumer. The palatability of a product is much related to its microstructure which will define the rehydration and milk diffusion processes that will take place in this kind of food.

Moisture uptake depends on temperature, on the immersion medium and on the cereal composition and structure [2]. When they are soaked in milk, they may present lost of crispness and organoleptics which are undesirable characteristics for consumers.

MRI is suited as a non invasive tool in order to monitor water and has leads to applications in different areas in agrofood [3-11]. MRI has been chosen by many authors in order to image rehydration in different kind of foods, such as rice or legumes [12-14].

The aim of this work was to monitor rehydration and distribution of milk of several kinds in different prototype cereals, by using MRI techniques applied to hydration levels in real time. In the case of milk, the high water composition, as well as the fat content, allows good signal detection in order to achieve milk mobility and rehydration in cereals.

2. Materials and Methods

2.1. Samples

Different types of prototype cereals were imaged by MRI, at CAI NMR, UCM dependences in Madrid, under static conditions.

Cereals were three different extruded prototypes provided by Nestle, varying the content of fibre as well as the coating of the pellets (Table 1).

Table 1. Cereal varieties and their composition

Variety	Whole Wheat Flour (%)	Oat Bran Concentrate (%)	Wheat bran (%)	Wheat Flour (%)	Corn (%)	Sugar (%)
Var03	80	18	0	0	0	2
Var09	60	0	10	20	18	2
Var14	60	0	0	20	18	2

Each variant were provided as such and coated with syrup composed of sucrose (67%), dextrose (5%) and water (28%).

Two different kinds of milk were tested on each variety, varying their fat content. The first one (A) had 3.6 % of fat; the second one (B) 1.55%. Ten different MRI experiments were performed (Table 2).

2.2. MRI equipment

MRI experiments were performed on a Bruker BIOSPEC 47/40 (Ettlingen, Germany) spectrometer, operating at 200 MHz. All experiments were performed with an actively shielded imaging gradient set and a Radio Frecuence (RF) volume coil with an inner diameter of 3.5 cm. The bore of the magnet is horizontal, 147 cm long and with 40 cm diameter, reduced to 6 cm when the gradients stack in place.

Table 2. Types of samples tested.

Variety	Coating	Milk
Var03	Coated	A
	Coated	B
	Non coated	A
	Non coated	B
Var09	Coated	B
	Non coated	B
Var14	Coated	A
	Coated	B
	Non coated	A
	Non Coated	B

2.3. Sample preparation

In order to acquire images in real time, an injection system was designed by means of a 5 ml syringe, a 10 ml syringe and a 2 mm diameter capillary.

The capillary was placed connecting both syringes and was filled with 5 ml of milk. The 5 ml syringe was pierced on its extreme in order to avoid generating vacuum inside it.

Four or 5 cereals pellets (depending on their size) were placed inside the 5 ml syringe and the 10 ml syringe was filled with air (Figure 1).

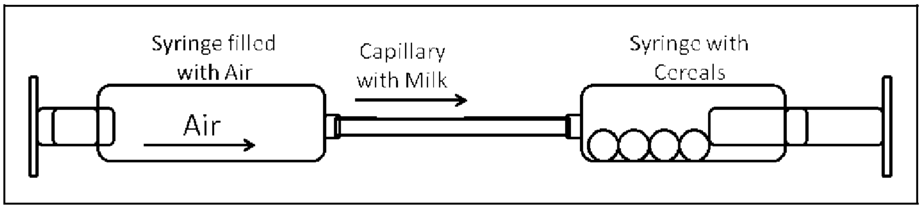


Fig. 1. Scheme of the injection system designed for the experiment

The syringe containing cereals was placed inside the magnet. The one filled with air was placed outside the Faraday cage, with the capillary containing milk connecting them. Before starting the experiment, the air was pushed in order to force the milk to enter in the syringe filled with cereals. From this moment, MR images were taken.

2.4. MRI sequences

MRI experiments were made in 2D Proton Density-weighed, Rapid Acquisition with Relaxation Enhancement (RARE) sequences, targeted at obtaining 15 slices from each image during 60 minutes, every 120 seconds and during 30 minutes, every 60 seconds, depending on the sample.

Sagital images (y-z plane) were obtained from cereals placed with the syringe central axis along the y-axis of the magnet. The MRI sequence parameters were: recovery time (TR) 2000ms, echo time (TE) 10 ms. The Field of View (FOV) was 6 × 3 cm.

2.5. Image processing and data analysis

Image processing was carried out using dedicate routines based on Matlab® 7.0 software and corresponding image analysis toolbox. A combination of textural analysis methods [15-17] and segmentation methods [18,17,19] were implemented.

As a first step, MR images on 16 bits were transformed in 8 bits in order to allow standard image analysis algorithms. For image analysis, the central slice of each time was selected.

In order to segment the image in time, an algorithm was developed by means of a mask (binary image), corresponding to the first time step. This allowed visualizing the cereals and enabled to segment them. By this method it was possible to see in the image the diffusion of the milk inside the cereals along time. Afterwards, the histogram of each image was obtained as well as the average, median and variance of each gray level along time, that shows the infiltration of the milk, and the contours of the milk diffusing through the cereals were displayed. The mask was defined at first step using a polygonal region of interest together with Otsu thresholding.

3. Results & Discussion

MRI images were obtained in real time (example is given Figure 2 for three time steps).

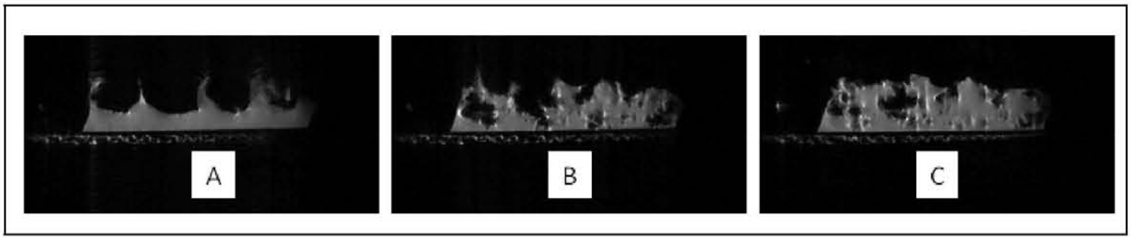


Fig. 2. MR images of the central slice of cereals Var14, coated with milk type A, measured through 40 minutes. A. Image at 0 minutes. B. Image at 20 minutes. C. Image at 40 minutes.

From the segmentation, images of the cereal rehydration were obtained and also their average gray level and their variance were computed (Figure 3) at each time step. Average grey level was computed in order to give an idea of how much each sample was rehydrated while the variance states differences in space at each time step.

In some cases, the first and the second point in average grey level, corresponding to the initial time (the moment just after the injection of the milk and 2 minutes later), showed larger value than the rest of the images. This fact is due to the effect of the movement of the milk through the syringe in the first step, which is very quick as it is impelled by the injection of the air, so these points were removed.

Generally speaking, there is no advisable clustering of behaviours in average grey level due to cereal type or coating (total amount of milk inside the cereals), however there is some clear clues regarding variance since coating seems to provide some clustering effect among samples with higher variances in almost all cases.

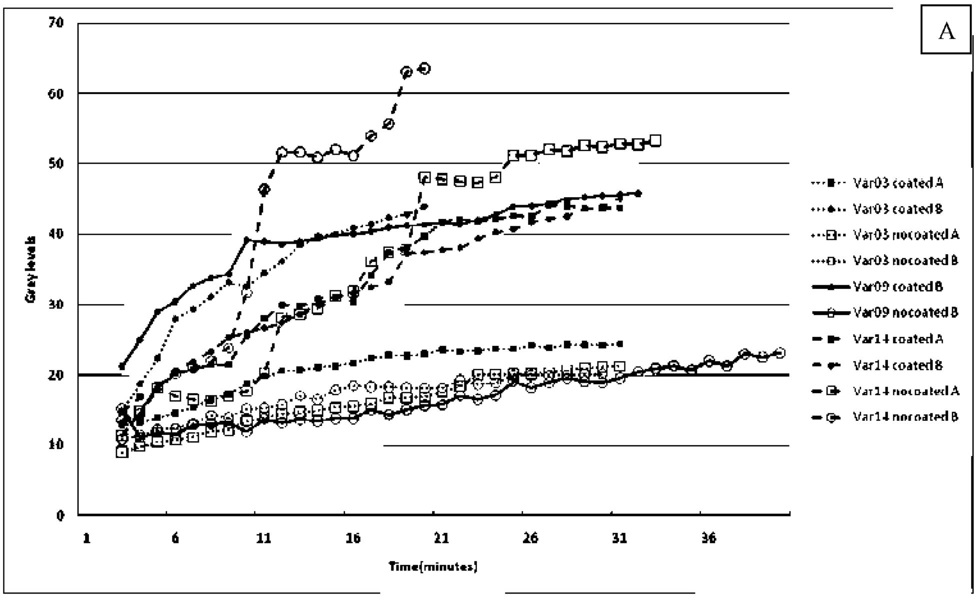
According to average grey level it can be seen that all cereals rehydration was uniform in time (linear time response), except for Var14 non-coated (A and B), which rehydrates uniformly until minute 20 and then presents a step that refers to a quick hydration event.

Lowest differences between coated and non-coated according to average grey level (mean hydration of cereals) are found for Var14 (dashed lines in Figure 3A). This is also true for grey level variance, since all Var14 data are clustered around 90-100 units of variance, the highest values in Figure 3b. This confirms the fact that the addition of fibres seems to refrain the penetration of the liquid in the pellets.

Var09 (solid lines in Figure 3B) present strong differences between coated (variance=90) and non-coated (variance=40) cereals.

Var03 (small dashed line in Figure 3B) series present no differences in grey level variance for milk typed A: coated (variance=63) and no-coated (variance=60), while some differences are appreciated on milk typed B between coated (variance=75) and non-coated (variance=55).

Whenever coating has an effect, grey level variance for coated cereal types is higher than for non-coated which is congruent with the fact that liquid is retained on the external area.



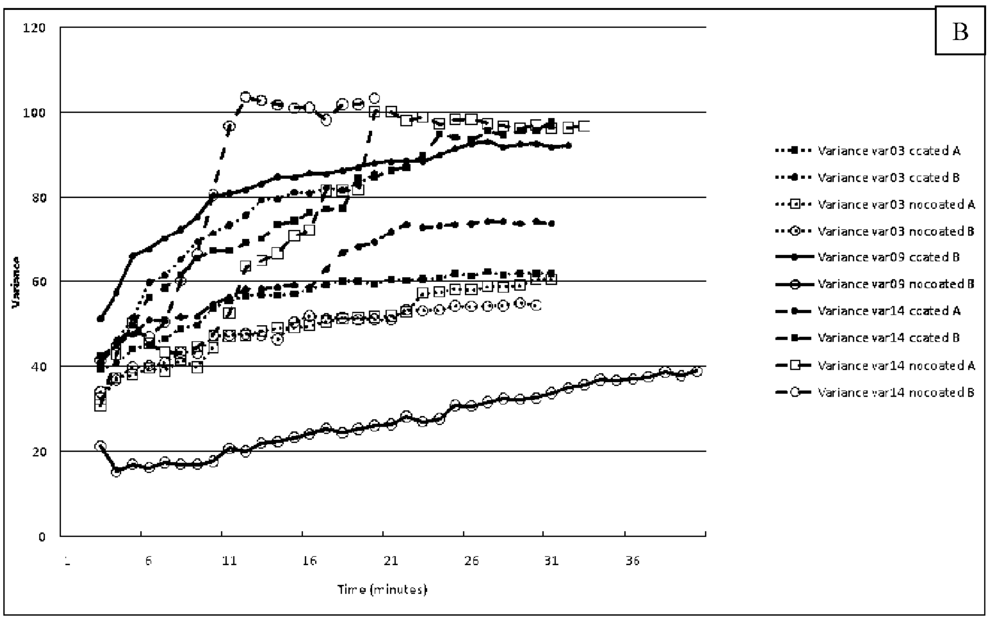


Fig. 3. A. Grey levels of the different varietie;. B. Variance of the different varieties.

4. Conclusion

Differences in hydration uniformity may be assessed by means of changes in grey level variance in MR images. The largest differences are found between cereals Var03 and Var14, being higher the variance for the latter than for the former (90 and 60 aprox. respectively). Besides, difference in grey level variance between coated and non-coated is high for cereals type 09 which refers to coating as having a large effect on this type of cereals. In spite cereal type 03 shows large differences in grey level variances for type of milk and not for coating (higher penetration of milk for milk type B). Another interesting feature for cereal type 03 under milk type A is that it shows poor differences in grey level variance and thus, in this case the effect of coating is very limited.

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