Prospective of Innovative Technologies for Quality Supervision and Classification of Roasted Coffee Beans

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Abstract. *Color sorting is the major procedure employed for establish roast degree of coffee beans. However, color-based procedures have been proven to be ineffective, since coffee beans roasted to different degrees can present the same average readings in light reflectance measurements with significant quality variations. Besides to color, other major changes in beans are volume (swell), mass, form, bean pop and density. Eight samples of arabica coffee from Colombia and Guatemala have been roasted under slightly different conditions of time and temperature in order to obtain the same color classification. Sample analysis of data from nuclear magnetic resonance relaxometry show differences between samples in T1 and T2 parameters at cellular and subcellular level, and image analysis carried out on X-ray µCT* leading to *microestruture images corroborate differences in porosity and fissures presence among them, proving the potentiality of these technological solutions for sensing the microstructure of coffee to provide tools to enhance the roasting process.*

Keywords. food microstructure, multi spectral imaging, X-ray microtomography, nuclear magnetic resonance relaxometry.

Introduction

Color sorting is the major procedure employed for establish roast degree of coffee beans. The external color of the beans (varying from light to dark brown) is assessed in the industry by means of ground beans light reflectance measurement, or just by the visual inspection of the bean color carried out by the roast master (Hernández et al., 2008). Composition of roast coffee varies with the consigned roasting time and temperature. The level of the chemical reactions that occur during this process determines the final flavor quality of the beverage. However, color-based procedures have been proven to be ineffective, since coffee beans roasted to different degrees can present the same average readings in light reflectance measurements with significant quality variations (Franca et al., 2009). Besides color, other major changes in beans are volume (swell), mass, form, bean pop and density.

The main objective of this work is to provide the potentiality of non-invasive technological solutions as multi spectral imaging, X-ray microtomography and nuclear magnetic resonance relaxometry for sensing the microstructure of coffee to provide tools to enhance the roasting process.

Materials and Methods

Coffee beans

Arabica green (crude) coffee samples were randomly selected at Supracafe S.A. Eight samples (200g each) of arabica coffee from Colombia and Guatemala were then separated and oven roasted according to the processing conditions specified in Table 1. The roasting degree was established based on visual inspection of the external color of the beans, since this is the most common procedure employed by the coffee roasting industry. Slightly different conditions of time and temperature were consigned in order to obtain the same ground coffee roast classification by the color disk system Agtron/SCAA (Staub, 1995). Measurements of whole bean roasted coffee were also taken to confirm color variations (see luminosity readings in Table 1) using a Minolta CM-2500D spectrophotometer (400 nm-700nm).

Table 1. Roasting parameters. *Ground coffee score Agtron/SCAA correlation to roasting degree classification in (AGTRON, 2004). **Range of luminosity for roasting degree classification in (Franca et al., 2009).

Origin	**Guatemala**				**Colombia**			
Sample identification	**1.1**	**1.2**	**1.3**	**1.4**	**2.1**	**2.2**	**2.3**	**2.4**
Green beans weight (g)	200	200	200	200	200	200	200	200
Green beans humidity (%)	9.4	9.1	9.1	9.1	9.8	10.1	10.2	10.2
Roasting time (min)	11	12	12	12	12	10	11	9
Roasting temperature (ºC)	180	181	182	180	180	182	182	190
Roasted bean weight (g)	172	172	171	171	169	173	170	172
Weight loss (%)	14	14	14.5	14.5	15.5	13.5	15	14
Agtron scale value (ground color)	# 65	# 65	# 65	# 65	# 65	# 65	# 65	# 65
***Roasting degree classification for #65 Medium-light →ML**	ML	ML	ML	ML	ML	ML	ML	ML
Luminosity (L*)	31.5	31.9	29.4	32.7	33.3	30.7	30.4	31.7
****Roasting degree (luminosity range): Very light (32–35)→VL Light (29–31)→L**	L-VL	L-VL	L	VL	VL	L	L	L-VL

Multispectral imaging

The imaging system consisted of a framegrabber, National 4 Instruments®, and a 3 CCD custom camera, DuncanTech/Redlake MS-3100®, (Redlake Inc., 5 USA) with three band-pass filters centered at 800 nm Infrared (IR), 675 nm Red (R) and 450 nm Blue (B), with a bandwidth of 20 nm. The sample of whole coffee beans from each category, placed in glass crystallizers (volume 20-21 ml and 25 x 40 mm) was illuminated by six 100W halogen lamps for image acquisition.

Nuclear magnetic resonance (NMR) relaxometry

Fifty grams of each coffee sample was sent to the Institute of Food Research at Norwich Research Park (United Kingdom). Under NMR relaxation, the different time constants for the nuclei to return to their thermodynamic rest state after an electromagnetic pulse is applied is measured. The time constants are related to, amongst others, concentrations of the magnetic nuclei but also their mobility. 2-dimensional NMR relaxometry allows the approach to complex microstructured systems by providing detailed "relaxation spectra" giving separate peaks for water in different pores and compartments in microstructured systems. Each peak in the 2D spectrum is characterized by a particular proton longitudinal and transverse relaxation time (T1 and T2 respectively in ms), which differ according to the local water content and size/nature of the pore or compartment. In this study Peak 1 has been selected, extracting parameters Area, T1 and T2.

X-ray µ-CT

Fifty grams of each coffee sample was sent too to the SkyScan Company in Belgium. The SkyScan µCT equipment was used to explore the items from coffee beans. The developed scanning protocol for coffee in order to obtain the right resolution to visualize certain characteristic features of the samples were: 49kV X-ray voltage and 167 µA current in order to obtain good contrast; exposure time 885 ms, rotation step 0.4 degrees and frame averaging 2 for an image pixel size of 6.96 µm.

The technique of X-ray µCT is based on the interaction of X-rays with matter. By using projection images obtained from different angles, a reconstruction can be made of a virtual slice through the object. In this experiment among 1500-2000 different consecutive slices are reconstructed for a 3D visualization of each coffee bean. µCT as non-invasive technique has been applied to the study of the internal 3D structures of coffee beans.

The analysis performed on the reconstructed slice corresponding to the central transverse section of the grain (see Figure 1), using the image processing toolbox of Matlab, allow us after successive image segmentations based on Otsu's method, morphological structuring operations to

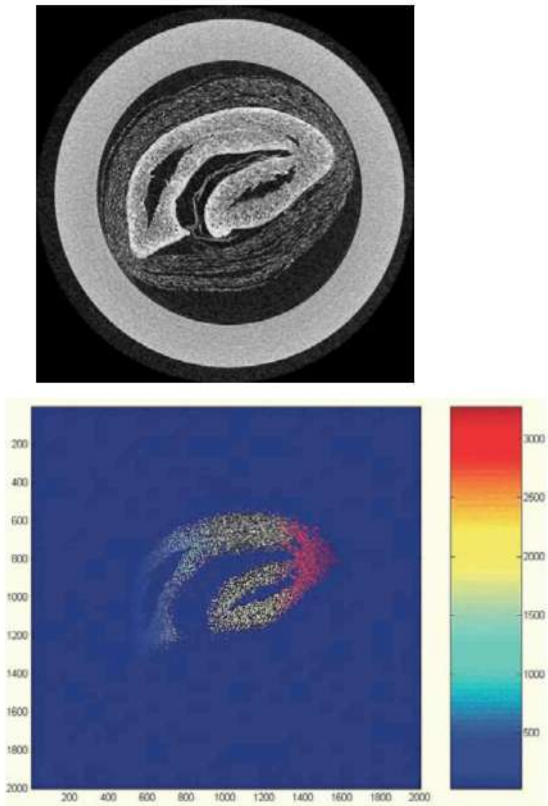

Figure 1. Raw image of the central transverse section of one grain obtained from X-ray µCT (Up). Identification of pores and fissures after image processing (down).

fissures and pores identification and measured a set of properties for each identified region, extracting parameters characterizing internal structure of bean as pores percentage (Pp, %), fissures percentage (Fp, %), pore mean size (Pm, mm^2) and pore median size (Pmd, mm^2).

Results and Conclusions

Multispectral imaging, where R and IR bands correlate with caramelization of sucrose and water content, didn´t provide additional information about samples, as corresponds to the big similarity in roasting degree between them. On the other hand, the PCA analysis (see Figure2) shows that the roasting temperature and time (T-t) treatment affect mainly to Pp and define the first PC (could name it “process axis”), while the relaxation time T1 decreases (r=-0.7) with higher Fp, variables that progress independently of the first ones defining the second PC. The median size of pore and the area or the resonance peak, construct together the PC3 (could name it “intrinsic properties axis”). Analysis on X-ray μ-CT images show that Guatemala coffees tends to open more fissures during roasting and to open higher size pores, behavior more influenced by the origin and variety of raw material than dependent of T-t treatment.

On the other hand, Colombia coffees appear much more sensitive to the process, showing changes in their porosity versus only light differences in the consigned T-t parameters, developing with higher temperatures and shorter times higher porosity than Guatemala coffees. These results indicate that color or weight loss measurements alone are not reliable for roasting quality assessment, since porosity and fissures will influence on diffusivity of gases during whole bean storing and on diffusivity of aroma and soluble compounds in water, and therefore in coffee beverage quality.

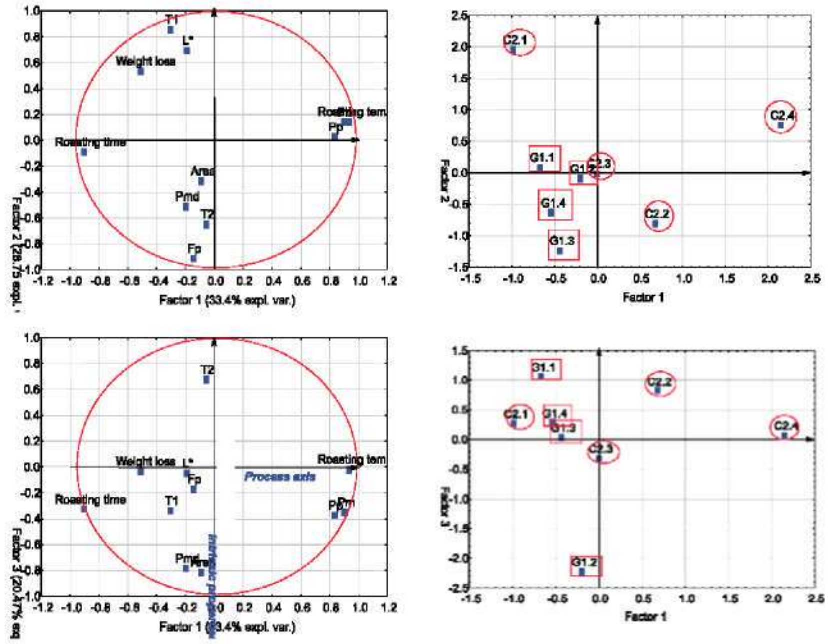

Figure 2. Factor loadings (left) and factor scores (right) for principal components analysis (PCA) results representation.

Acknowledgements

The funding of this work has been covered by LPF-TAGRALIA research group and Technical University of Madrid with the project AL11-PID-30.

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