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Morphological analysis of *Coffea arabica* beans roasted by different industrial processes using synchrotron radiation microtomography

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30th Conference
27-31 October
ASIC 2025
Rectory of the University of Lisbon, PORTUGAL

Introduction

Roasting is one of the most important processes in the coffee technology. In facts, thanks to this thermal treatment, the not particularly appealing smell of green coffee beans is transformed into the well-known and highly appreciated roasted coffee aroma. The thermally induced coffee aroma development is accompanied by several bean physical changes ranging from the bean colour and volume up to density to texture modifications. Under typical roasting conditions the beans present an increase up to 100% of volume [1]. This increase in volume is due to the release of water, CO_2 and volatile organic compounds from the beans to the gas phase during the roasting thermal treatment. In parallel, the beans density, typically between 1000 and 1200 kg/m^3 for green beans, may reach values in the range of 400 to 600 kg/m^3 after roasting [2]. Moreover, concerning texture modifications, it is well known that during roasting, coffee beans lose their strength and toughness becoming brittle and fragile [3]. Up to now, conventional 2D microscopic imaging techniques have not yet disclosed differences in coffee bean induced by different industrial roasting processes (see Figure 1), albeit empirically and indirectly detected. Laboratory-based X-ray computed microtomography (μ-CT) has been used to compare the 3D microstructure of green coffee and roasted coffee beans by determining parameters such as porosity, pore volume and pore number distribution as a function of roasting time working with an isotropic voxel resolution of 10 μm [2, 4]. Pore interconnectivity in roasted coffee beans (undefined roasting process) was also studied by laboratory X-ray μ-CT (at 20 μm and 35 μm isotropic voxel) [5]. In this work, synchrotron-based X-ray μ-CT has been applied for the first time to compare roasted coffee beans produced by adopting different industrial roasting processes.

Experimental

Coffea arabica roasted beans from 4 different roasting processes were used (Fig. 1). Sample labelled 497 was produced in an industrial plant following a thermal curve adopted to get medium roasting degree whereas samples labelled 120, 284 and 743 were produced in the same or different industrial plant by following 3 different thermal curves leading to medium roasting degree. Eight beans per process have been characterized by synchrotron based X-ray microtomography (SR μ-CT). The data were collected at the SYRMEP beamline of the Elettra synchrotron light facility in Basovizza (Trieste, Italy) setting an effective pixel size of 2.0 μm. For every bean, 4 different contiguous volumes were scanned allowing to reconstruct a total of 5520 virtual sections (2 μm-thick) (Fig. 2). In Figure 3 a tomographic reconstruction of an axial section (taken in the central part of the bean) is showed. By selecting three different 2D areas (420 x 420 px)) in two sections (section 001 and 600) of two central portion of the bean (Z2.9 and Z5.8) and a 3D cube (252 x 252 x 252 vx) (see Fig.4) processing and analysis protocol was applied to the image data in order to investigate and quantify the cellular morphology.

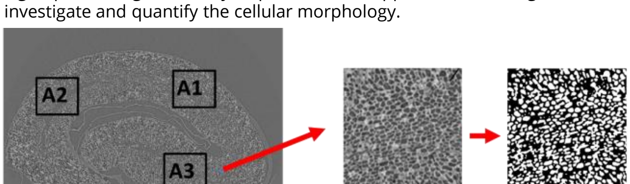
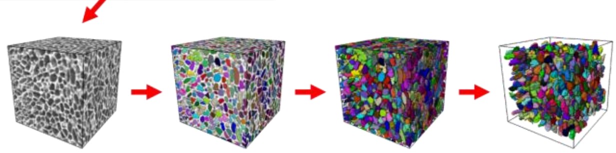


Fig. 4: *Schematic 2D (up) and 3D Image analysis* (down)



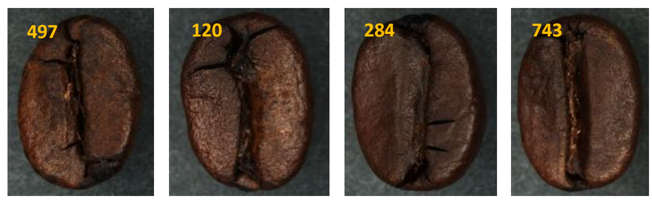


Fig. 1: *Roasted beans from 4 different roasting processes*

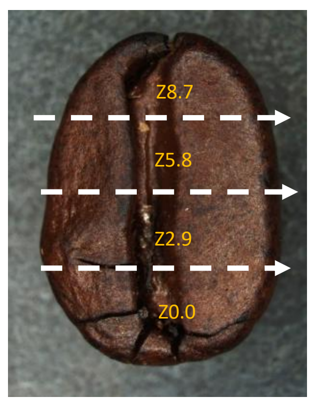


Fig. 2: *Acquisition methodology*

Fig. 3: *Single section (after reconstruction)*

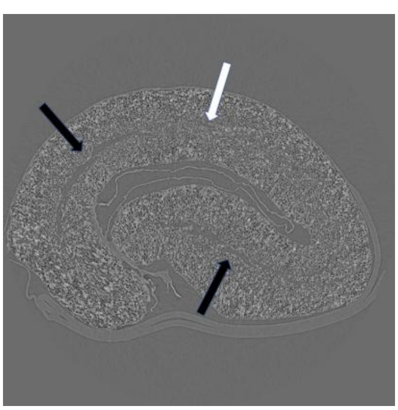


Fig. 5: *Section showing macro-fractures (black arrows) and micro-fractures (white arrow)* .

Results

In the case of the image analysis performed on the reconstructed bean volumes, after segmenting the images, the 'white' areas representing the porous phase, voids or fractures were measured and the porosity parameter has been extracted (expressed as % of the porous phase with respect to the total volume of each VOI). Sample 497 resulted more compact with respect to the others and, in particular, sample 743 resulted to have a higher porosity with larger fractures. Samples 120 and 284 showed an intermediate morphology. However, the image analysis performed on the selected VOIs (accurately chosen to exclude micro- and macro-fractures), did not reveal any significant difference among the samples. It should be emphasized that this last result strongly suggests that the different roasting processes do not influence the cellular structure of the endosperm portion examined. More specifically, the different types of industrial plant, or, for the same industrial plant, the different types of thermal curves, do not alter the size of the endosperm cells. On the other hand, macrofractures of different sizes and spot microfractures (see Figure 5) are clearly visible in the reconstructed bean volumes, especially in the central tissue where cells tend to break first (soft endosperm/embryonic chamber).

Conclusions

Synchorotron radiation X-ray microtomography is a non-destructive technique that has several advantages over other methods, including the ability to image low moisture materials like roasted coffee bean. Here, this 3D imaging technique has been used for the first time to compare roasted coffee beans produced by adopting different industrial roasting processes. The obtained results show that this technique can be extremely useful to differentiate samples at different roasting levels and to individuate and quantify the morphological traits altered by the roasting process. Surprisingly, the endosperm cellular structure is not affected by the different roasting processes. However, both macro- and micro-fractures in soft endosperm/embryonic chamber are strongly and differently induced by the different adopted roasting processes.

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