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X-ray microtomography of macadamia nuts

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Abstract

Several varieties of macadamia nuts are studied using X-ray microtomography, in order to determine a link between structural properties and storage stability. Fresh nuts-in-shell (NIS) of the predominantly grown hybrid varieties (A38, 816, 842, Daddow and 246) are scanned, the 3D tomographic reconstructions are then segmented, i.e. pixels labelled either as shell, void (inner and outer), and kernel. The automatic segmentation process consists in two steps: positioning of markers that identify each of these regions (by labelling pixels that are certain to belong to the region), and delimitation of these regions. The first step is performed with typical image processing operators (thresholding, connected component analysis, distance transform), while the second step uses the watershed algorithm. Once all regions are identified, pixel counting provides measures of volumes for each region, which, coupled with weighing, gives densities. We show that from physical quantities such as kernel volume percent or shell density, two main classes of nuts can be derived. A relationship between these observations and the behaviour of the nut varieties considered by this study during postharvest operations is discussed and further research work is proposed.

Key-words: Macadamia nut, shell density, kernel volume ratio, X-ray microtomography

1. Introduction

Macadamia nuts are among the most nutritious and highest in monounsaturated oil content among edible nuts (AMS, 2009). They are widely grown in Australia, United States of America, especially in Hawaii, South Africa and Guatemala (USDA, 2008). According to World Horticultural Trade & U.S. Export Opportunities (2002), Australia is the biggest macadamia producer and exporter, accounting for 46 % of total macadamia world production. In practice, there are several steps involve in macadamia processing including sorting and grading, drying, cracking, roasting , packaging and storage respectively. Drying is a very crucial step as it needs to preserve macadamia quality as well as enhance storage stability through the reduction of water activity. It is obvious that physical properties of the nut contribute to its drying characteristics. Accurate measures such as kernel volume ratio or shell density could help for improving drying efficiency.

It is largely admitted that for a complete understanding of their thermal and mechanical behaviour, a clear relation has to be established between the structure and the properties of the cellular materials. The understanding of this relation allows much better modelling methods to be proposed. X-ray tomography has appeared recently to be a very powerful tool allowing to characterise the microstructure and also the deformation modes of cellular materials (Maire *et al.*, 2001), and in the past decade of food products (Lim and Barigou, 2004; Falcone *et al.*, 2005; Bellido *et al.*, 2006; Haedelt *et al.*, 2007; Léonard *et al.*, 2008; Pareyt *et al.*, 2009; Frisullo *et al.*, 2010; Primo-Martín *et al.*, 2010; Pittia *et al.*, 2011; Sozer *et al.*, 2011).

Hence this study has focused on determination of the effects of seed volume ratio and shell density on drying characteristics and vice versa. The aims of this study were as follows:

a) to develop X-Ray tomography method for determination of microstructure of macadamia nuts
b) to determine the physical properties of macadamia nut in shell including shell density and seed volume ratio

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c) to evaluate the impact and consequences of those physical properties on drying characteristics of macadamia nut.

2. Materials and methods

Fresh macadamia nuts-in-shell (NIS) the predominantly grown hybrid varieties A38, 816, 842, Daddow and 246 were harvested in May-July 2011 in various plantations situated in northern New South Wales, (Australia). They were frozen down to -20 °C, transported to the UNSW in Sydney and stored at that temperature until used. They were thawed overnight in a refrigerator at 4 °C and equilibrated with ambient temperature of the laboratory (about 24 °C) prior to drying.
Drying was performed in thin layer in a cabinet dryer at 30 °C and 40% relative humidity (RH) until a moisture content of about 11% wet basis was reached. The samples were then vacuum-packed and sent to the University of Liège where they were subjected to X-ray microtomography.

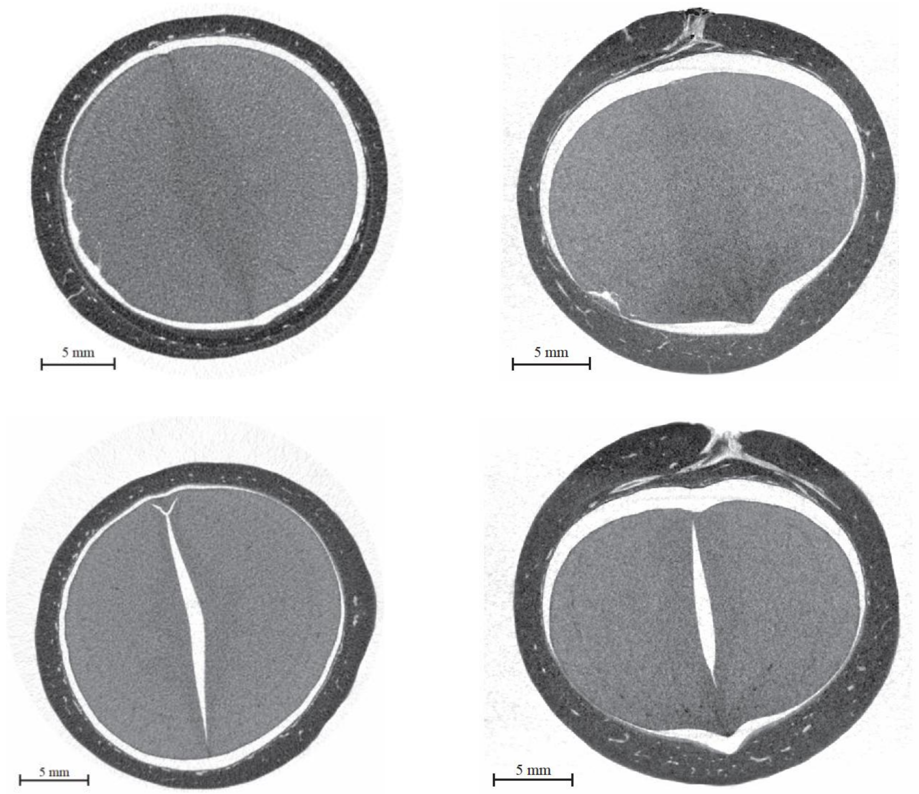

Figure 1. Axial (left) and coronal (right) cross-sections from two tomographic reconstructions of macadamia nuts-in-shell. The nuts are of the 816 and 842 varieties, for the top and bottom images respectively.

The acquisitions were made on a SkyScan 1172 scanner. Radiograms of around 750^2 pixels, with 34.56 µm/pixel, were acquired over 360°, at 0.1° intervals. The X-ray source was set to 60 kV. Tomographic reconstruction was performed using SkyScan's Nrecon software, making use of their integrated ring artefacts reduction, beam-hardening correction, and misalignment compensation. Illustrations of the resulting 3D reconstructions, each containing around 750^3 pixels, are presented in figure 1, as cross-sections along middle of the nut (approximately), in two perpendicular directions. The top two cross-sections are from a nut of the 816 variety, while the bottom two are from a 842 variety. In these images, the darker the pixel, the more attenuating is the associated volume. The annular outer and darker portion is the shell, in which vessels (shown as lighter discs or elongated tubes) are visible. These vessels form a network connected to the top of the nut. The inner circular shape is the kernel, which is lighter and therefore less dense than the shell. It is whole in the first example, while in the second a large fracture nearly splits it in two. A source of measurement error, that will be discussed in the next section, can be seen in the 816 variety, on the top right image: a portion of the kernel has adhered to the inner surface of the shell, and separated from the rest of the kernel.

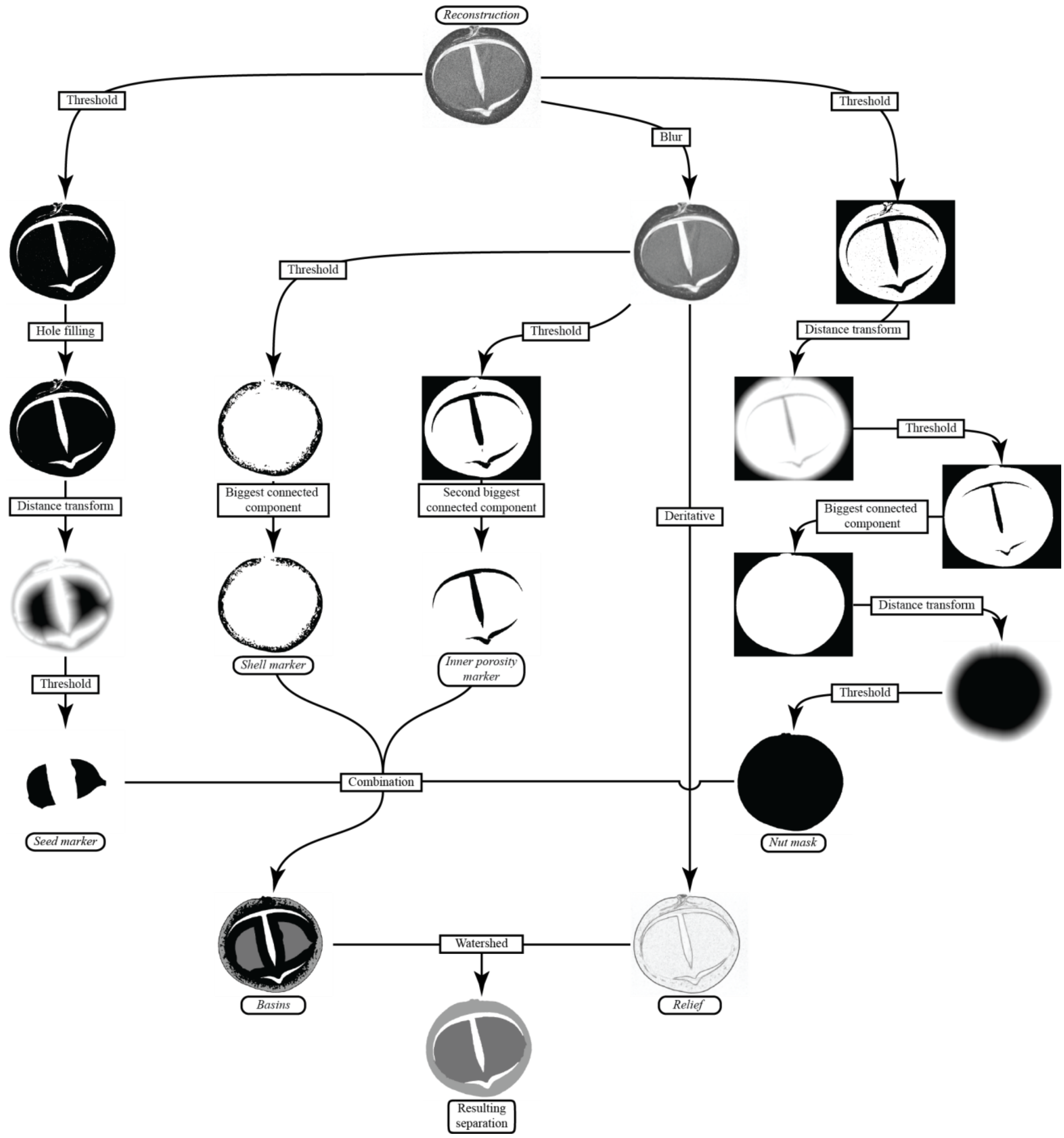

Figure 2. Diagram showing the image processing steps taken to separate the four regions.

In order to determine quantities such as shell density, the components of the nut must be segmented. Four regions were defined in the images: exterior, shell, inner porosity, and kernel. For the separation of these regions, a watershed approach was chosen.

The watershed transfom is a region-based segmentation originally proposed by Lantuéjoul (1978), and is a common segmentation approach in greyscale mathematical morphology. Typically defined in flooding semantics (Soille, 1999), the principle is to consider the image as a relief, and find the crest lines between basins, or local minima. In our case, we considered the gradient of the image as the relief, and the basins were defined by markers of each region. These markers consisted in pixels that were certain to be contained in that region. The automatic procedure is summarised by the diagram of figure 2. All methods are well-established image processing operators that can be found in (Soille, 1999), and are applied in 3D on the tomographies.

3. Results and discussion

Results of this process are shown in figure 3, for a nut of the 816 variety. The top cross-section passes through the fracture that splits the kernel in two halves, which is why it appears as though a huge fraction of the kernel is missing. The four regions defined previously appear as different colours in the right images. The shell region, shown in purple, also contains the vessels, and will thus be integrated into the volume and density measurements for the shell.
Table 1 gives the volumes of the tested nut of each variety. Nut volume is the combined volumes of shell, inner void, and kernel. This quantity in itself is not that relevant, as strong variations in size exist among the varieties.
The ratio of kernel volume to nut volume and shell density are plotted in the graphs of figure 4. Volume ratios vary from 39.5 % to 47.1 %. Two families can be identified, one below 42 % and one above 45 %. Such noticeable separation cannot be observed in the inner void ratio (not presented here), as it exhibits an even distribution between 6.5 % and 14.7 %.

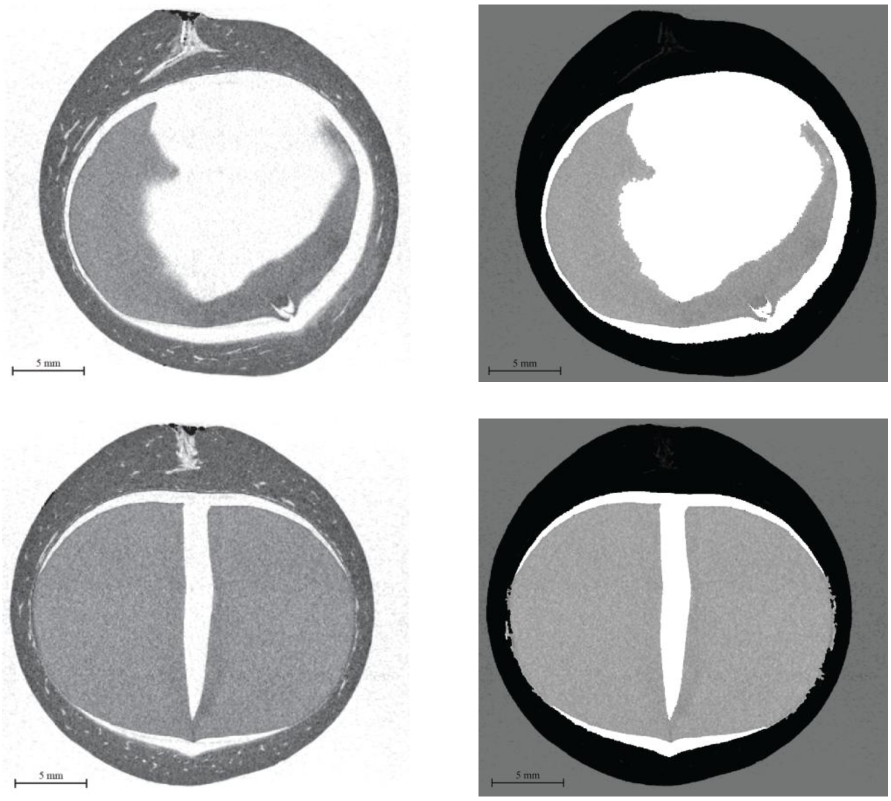

Figure 3. Result of the segmentation on a nut of the 816 variety. The top and bottom rows show coronal and sagittal cross-sections respectively, while the right images shows the pixel classification, where yellow, purple, turquoise and red are respectively exterior, shell, inner void, and kernel.

Variety	**246**	**842a**	**842m**	**816a**	**816T**	**A38**	**Daddow**
Nut volume (cm^3)	6.56	7.43	7.34	7.14	7.59	6.94	6.92

Table 1. Total nut volume for a nut of each variety.

Variations up to 8 % can be observed in the shell densities, the highest differences being between the 842 variety and the others. Apart from 816T, similarities with the kernel volume ratio are observed, namely the fact that the 246 and Daddow varieties are found on one end on the range, and 842 on the other. The lowest values of kernel volume ratio and shell density were found for the Daddow variety that is known for not being susceptible to kernel discoloration. Finally, it is interesting to note that nuts from the same group but from different batches (842 and 816) have nearly identical shell densities.

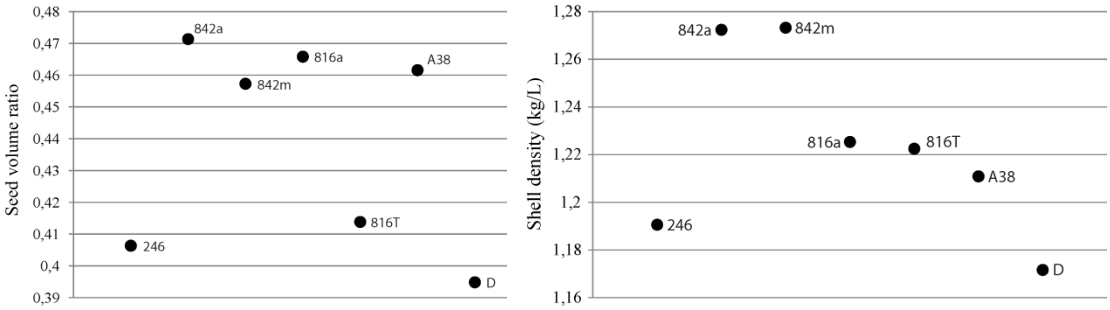

Figure 4. Significant measures for each variety. Left : ratio between kernel volume and nut volume. Right: shell densities.

Some caution is to be taken with these measures, as errors of up to 5 % can be expected, mainly from two different sources. The first is from the segmentation process. Inaccuracies, such as the ones seen in the bottom right image of figure 3, on the left a right sides, arise in between the kernel and the shell, when they are in contact. As the vessels in the shell are found very close to its interior boundary, when the seed is in contact with this boundary, the highest contrast is found around the vessel, and thus the portion of the shell in between the vessels and the kernel will be wrongly assigned the seed region. An annular region of the shell around the kernel is thus wrongly assigned. If we consider the worst case scenario (where the entire lower part of the kernel touches the shell) to add an average layer of 7 pixels to the kernel on half of its surface, this would add 4.7 % to the kernel volume. Although this is a high upper bound, the segmentation is the most significant source of error. The other main source of error if the weighing. It is not due to the scale, as it measures 4g of shell to a precision of ± 0.5 mg, but what is weighed. Indeed, not only do the kernel and shell seemed joined in the images, they physically adhere to each other, so much that portions of the kernel remains on the inner surface of the shell upon opening. Although as much as possible is scraped off, this can add up to 10 mg to the weight of the shell, introducing at most 0.25 % error in the weight. Of course, this is to be put in perspective with the segmentation error upper bound mentioned previously.

4. Conclusions

Microtomographic acquisitions followed by image analysis on different varieties of macadamia nuts were performed in order to extract measures of kernel volume ratios and shell densities, and eventually determine a relation with shelf life.

The process of 3D acquisition allows an accurate assessment of the volumes of the different components of the macadamia nuts. However, noise and insufficient contrast between the shell and the seed forbids a simple thresholding technique to separate the two in the images. A watershed approach based on the image gradients proves to be a viable solution, but is not free of errors. The vessels inside the shell, in proximity with the inner border, introduce a certain amount of error in the segmentation (at most a few percent of the volume).

The computed volumes and densities have shown a particular order amongst the types of nuts. Two classes are evident when examining the seed volume ratio, for instance, and a similar order is seen in the shell densities, which might be linked to kernel discoloration susceptibility.

As future work, a more accurate picture of the variations inside each type would be necessary. This will require a larger number of samples and also various moisture contents, including freshly harvested nuts. For the time being, three types have had two nuts processed in the same way. They show differences in volume ratio of 2 to 3 %, and differences in density of around 0.5 %.

References

AMS [Australian Macadamia Society] (2009) http://macadamias.org/refs/730. *Accessed December 2009*

Bellido, G.G., Scanlon, M.G., Page, J.H., Hallgrimsson, B. 2006. The bubble size distribution in wheat flour dough. Food Res. Int. 39. 1056-1066.

Falcone, P.M., Baiano, A., Zanini, F., Mancini, L., Tromba, G., Dreossi, D., Montanari, F., Scuor, N., Del Nobile, M.A. 2005. Three-dimensional quantitative analysis of bread crumb by X-ray microtomography. J Food Sci. 70. E265-E272.

Frisullo, P., Licciardello, F., Muratore, G., Del Nobile, M.A. 2010. Microstructural characterization of multiphase chocolate using X-Ray microtomography. J. Food Sci. 75. E469-E476.

Haedelt, J., Beckett, S.T., Niranjan, K. 2007. Bubble-included chocolate: Relating structure with sensory response. J Food Sci. 72. E138-E142.

Lantuéjoul C. 1978. La squelettisation et son application aux mesures topologiques de mosaïques polycristallines. PhD thesis, Ecole des Mines, Paris, France.

Léonard, A., Blacher, S., Nimmol, C., Devahastin, S. 2008. Effect of far-infrared radiation assisted drying on microstructure of banana slices: An illustrative use of X-ray microtomography in microstructural evaluation of a food product. J. Food Eng. 85. 154-162.

Lim, K.S., Barigou, M. 2004. X-ray micro-computed tomography of cellular food products. Food Res. Int. 37, 1001-1012.

Maire E, Buffière J.Y, Salvo L, Blandin J.J, Ludwig W, Létang J.M. 2001. On the application of x-ray microtomography in the field of materials science. Adv. Eng. Mater. 3, 539–546.

Pareyt, B., Talhaoui, F., Kerckhofs, G., Brijs, K., Goesaert, H., Wevers, M., Delcour, J.A. 2009. The role of sugar and fat in sugar-snap cookies: Structural and textural properties. J. Food Eng. 90. 400-408.

Pittia P., Sacchetti G., Mancini L., Voltolini M., Sodini N., Tromba G., Zanini F. 2011. Evaluation of Microstructural Properties of Coffee Beans by Synchrotron X-Ray Microtomography: A Methodological Approach. Food Sci. 76. E222-E231.

Primo-Martín, C., van Dalen, G., Meinders, M.B.J., Don, A., Hamer, R.H., van Vliet, T. Bread crispness and morphology can be controlled by proving conditions. Food Res. Int. 43. 207-217.

Soille P. 1999. Morphological Image Analysis. Springer-Verlag, ISBN 3-540-65671-5.

Sozer, N., Dogan, H., Kokini, J.L. 2011. Textural properties and their correlation to cell structure in porous food materials. J. Agr. Food Chem. 59. 1498-1507.

USDA [United State Department of Agriculture], 2008. http://www.fas.usda.gov/

USDA [United State Department of Agriculture], 2002. World Horticultural Trade & U.S. Export Opportunities in U.S. horticultural report.