Characterisation of macadamia nuts using X-ray microtomography

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Aims

Macadamia nuts are among the most nutritious and highest in monounsaturated oil content among edible nuts¹. They are widely grown in Australia (46 % of total production), United States of America, especially in Hawaii, South Africa and Guatemala². In practice, there are several steps involved in macadamia processing, including sorting and grading, drying, cracking, roasting, packaging and storage. 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, and hence its storage stability. Accurate measures such as kernel volume ratio or shell density could help for improving drying efficiency.

We present a methodology to investigate structural differences between varieties of macadamia nuts in order to understand the factors involved in storage stability. Fresh nuts-in-shell are scanned by X-ray microtomography, and the different parts of the nuts (shell, kernel, tracheids) are segmented by a set of classical 3D image operators. After image segmentation, volumes are determined, and additional weighing of the nuts allows density measurements. These quantities are plotted for several nuts from each variety.

Method

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 then stored in a refrigerator at 4°C until the tomographic acquisition.

Among each of the five nut varieties, three nuts were chosen for scanning and measuring, with an attempt to select over the range of available sizes. This allows to better separate differences between varieties and differences between individual nuts.

The acquisitions were made on a SkyScan 1172 scanner. Radiograms of around 750² 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 750³ pixels, are presented in figure 1, as cross-sections along middle of the nut (approximately). This figure presents the nuts selected from the 246 variety. These nuts have respective total volumes of 5.7, 8.6, and 10.5 cm³ (measured subsequently).

In these images, the darker the voxel, the more attenuating is the associated volume. The annular outer and darker portion is the shell, in which vessels (seen as lighter discs or elongated tubes), or tracheids, are visible. These vessels form a network connected to the top of the nut. The inner round shape is the kernel, which is lighter and therefore less dense than the shell. It is whole in figure 1c), while in the first two images a small fracture is seen in the middle, as water evaporation most often leads to the kernel splitting in two.
Several nuts have been rejected because of defects, mostly consisting in kernel damage.

Each nut was weighed immediately after being taken out of the refrigerator and before being placed in the scanner for acquisition. The acquisition time was about one hour, after which the nuts were weighed a second time to observe water loss, although this second weighing was unfortunately not always performed immediately after the scan (some acquisitions were launched overnight). Finally, the nuts were opened, the kernel and shell separated and weighed independently.

Once the reconstruction was calculated, the 3D images were processed using a series of classical 3D image analysis operations, summarized in figure 2a). Each series of filters is setup so as to extract a particular portion of the nut, presented as columns in the diagram. The leftmost column shows the filters used to extract the tracheids in the shell, the center column for the kernel, and the right column, the nut. It is finally a matter of recombining the results to obtain an image where each portion of the nut is labeled differently. The active surface algorithm used for delimiting the kernel is based on the works of Delingette et al.\textsuperscript{4,5}, and was previously used in a simpler form\textsuperscript{6}.

When each part of the nut has been properly identified, voxel counting allows to accurately measure the different volumes.
Results

The following figures plot the various measures performed on all the selected nuts. Associated with each variety is a symbol (▲, ▲, △, ◇, and ■). The size and darkness of each symbol specifies a size-dependent order to identify individual nuts (larger and darker means bigger volume).

Figure 3a) shows the volumes of the nuts, grouped by variety. They vary roughly between 6 and 13 cm$^3$. These ranges are similar across varieties, but do not reflect all possible sizes as the sets of (arbitrarily chosen) nuts are not representative samples. Nevertheless, this variability insures that specificities in varieties can be distinguished from specificities in size. The second plot, 3b), shows the volumes as a function of density, measured as the mass of the nut before scanning divided by its volume. We can observe in these two plots, representing the same quantities, that there is a general tendency for the nut density to be inversely proportional to their size, i.e. the denser the nut, the smaller it is. The exceptions are the Daddow and 816 varieties. Although the latter seems to have no monotone relation between size and density, the Daddow nuts have the inverse relation, i.e. denser means bigger.

Figure 4 shows the volume ratios. As the tracheid volumes hardly exceed 3% of the total nut volumes, the shell ratios are not presented as they mirror the kernel ratios. Although the variability in each variety makes it difficult to clearly define trends, we notice that on average the Daddow and 246 varieties have a slightly lower kernel ratio compared to the others. As for the tracheid volumes, no clear trend appears. We do observe that the 842 varieties have
a very low amount of tracheids. This space can appear near the top of the nut, but is not always present.

Figure 3. Volumes of the nuts, (a) grouped by variety, and (b) as a function of density.

(a)                                                                   (b)

Figure 4. Volume ratios of (a) the kernels, and (b) the tracheids.

(a)                                                                   (b)

Conclusion

Five varieties of fresh Macadamia nuts were studied using X-ray microtomography, in hopes of observing noticeable differences between varieties. The nuts were weighed and scanned, and the scans processed using 3D image analysis in order to segment the shell, kernel, and tracheids. This allowed to quantify some characteristics, namely volume ratios and densities. In order to insure that any differences observed were the result of the variety and not the individual nut, three nuts from each variety were tested. By the different plots shown in this paper, we observe stronger variations between individual nuts than between varieties. Although some trends can be distinguished, such as the Daddow and 816 nuts not having the same density-volume relation than the other varieties, or the Daddow and 246 nuts having slightly larger shells, these observations must then be correlated with the storage stability of these varieties, which remains to be performed.

References: