X-ray CT applications to reveal physical defects of onion during storage

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Abstract. Inappropriate conditions of storage may result in physical defects that are sometimes visually undetectable. X-ray CT is a non-destructive instrument that has been widely implemented to identify sound and/or defect structures of many products, but only a little used for onion. In this study, the structure change of local onion during storage were imaged and characterized. To see the X-ray CT utilization, Onion harvested from a local farm was, for the first step, stored in an extreme condition potentially causing physiologically structure damage. X-ray CT scanning of intact onion was performed at low resolution to see the structure difference at the pre- and post-storage condition. Image processing was conducted to observe the change of the physical parameters. From the result, X-ray CT depicted spatially structural deformation of onion after a short-term storage period. Onion generally underwent shrinkage marked by the decrease in the cross-section area and the increase in air spaces between the fleshy leaves. This result was also in line with the decrease in weight and moisture content with respect to the storage conditions. This study concludes that X-ray CT has a high potential to reveal the physical defects of local onion affected by inappropriate storage conditions.

1. Introduction

Onion is one of Indonesia's horticultural commodities with high sales and economic value. Onion has many benefits, such as the traditional ingredients of cooking and medicine. In Indonesia, there are several onion production centers, including Brebes, Nganjuk, Cirebon, East Lombok, Tegal, Probolinggo, and Malang. Based on data from Badan Pusat Statistik in 2021[1]. Indonesia's onion production reached 2 million tons an increase from 2020 of 1.82 million tons. Central Java, the largest onion production center in Indonesia in 2021, production of onions reached 0.56 million tons, which decreased from 0.61 million tons in 2020 and was followed by East Java and West Nusa Tenggara. Several varieties of onions in Indonesia are Bima Brebes, Medan, Maja Cipanas, Keling, Ampenan, Sumenep, Kuning, Timor, and Lampung[2].

In the harvest, onions tend to be abundant, but during the off-season, there is very little supply that requires imports from abroad. The red onion bulbs are not durable and are easily damaged because they have a high-water content[3]. Some farmers choose to store their crops for a certain period, waiting for an increase in selling prices. However, these farmers face two significant risks: storage costs and a lack of adequate storage space. To prevent stored onions from spoiling, it is essential to monitor environmental parameters like temperature and humidity. In Indonesia, onion storage methods remain relatively basic, involving hanging or placing the onions in an area covered by tarpaulin, making it challenging to control conditions such as temperature [4].

The anatomy of onions ranges from macrostructures to microstructures. Macrostructures consist of visually visible parts (>100 μm), such as fruit flesh and skin, while microstructures consist of visually invisible parts (<100 μm), such as cells, pores, and cell walls [5]. To date, the structure of onions on a macro or micro scale has not been comprehensively characterized, quantified, and visualized, which can help explain storage breakdown of onion, depending on environmental conditions.

X-ray computed tomography (CT) is a non-destructive evaluation device used to identify the internal structure of a product. The advantage of X-ray CT is that it is capable of quantifying and visualizing the internal structure of the product in 3 (three) dimensions [6][7]. This makes it possible to see and quantify the characteristics of the physical defects of onions both internally and externally so that they can quantize physical parameters such as surface area, volume, number of layers on the tissue (macroscale), pore network, pore size, and pore connectivity (microscale)[8].

Given that onions have such a high potential in Indonesia, a method is needed to reveal the physical breakdown of onions during storage. This study aims to apply X-ray CT as a non-destructive evaluation technology to characterize and visualize onion structure changes before and after storage.

2. Materials and Methods

2.1 Onion samples

Onions without physical damages from a traditional market around Yogyakarta, Indonesia were chosen and transported to Laboratory at Faculty of Agricultural Technology, Universitas Gadjah Mada for treatments. The onion was exposed to the condition of different relative humidities with salt solution of sodium chloride and potassium nitrate (76% and 96 %) at temperature (5^{o}C, 20^{o}C, 35^{o}C) for one month. X-ray computed tomography (CT) images of the onion at initial and final conditions were taken to see the physical change of onion visually invisible.

2.2 X-ray CT imaging

Initial and final conditions of onion were imaged with Nanotom system at X-ray CT Lab, Cikarang, Indonesia. Low-resolution setup (75 µm) with a voltage of 100 kV and a current of 250 µA was chosen to accommodate the intact part of the onion organ, approximately lasting for 21 min per scan. The setup also enabled the X-ray photon to propagate through soft tissue of onion, presenting the CT images with tissue density differences in the intact onion with varying gray values. This is crucial to visualize details of intact onion anatomy so that the structural changes of initial and final condition are detectable.

Radiographic images produced during the scanning were reconstructed using Phoenix software to produce the stuck of X-ray CT image slices (**Figure 1**).

2.3 Image processing

Image processing was performed to analyse the change of onion internal structure. To do so, the onion CT images were initially filtered to minimize some noises. Subsequently, the filtered images were segmented using Otsu's method where the tissue fraction of onion was marked as 1 (white pixels) and the air fraction was 0 (black pixels). To have a mask, the binarized image was duplicated and the whole air fraction of the one image was closed by implementing 'fill hole' operation. Void space fraction (ε, %) was computed based on the following formula:

$$\varepsilon = \left(1 - \frac{X_{wp}}{X_m}\right) x100 \quad (1)$$

where X_{wp} is the pixel number of solid fraction in the binarized image and X_m is the pixel number of the mask.

2.4 Physical parameter analysis

Firmness and moisture content closely related to the physical structure of biological materials were analyzed to verify the structure changes of onion organ imaged from X-ray CT. The analyses were performed before and after storage with three replicates of onion per treatment. For the moisture content, onion was cut into small pieces, weighted, and put in an oven to remove the water so that the solid and water fraction can be known to calculate the moisture content in wet basis (%) as written in **Formula 2**.

$$M = \frac{m_o - m_t}{m_o} x100 \quad (2)$$

where m_o is a total sample mass of sliced onion (gr) as m_t is a solid mass of the sample (gr).

Firmness was measured using a texture analyzer where a probe was used to press the center of the onion. The onion placed on the test table and then subjected to pressure with the probe until it pierced into the bulb. The probe used was the TA39 probe, which has a diameter of 2 mm with a circular cross-section. The firmness data were collected before and after storage.

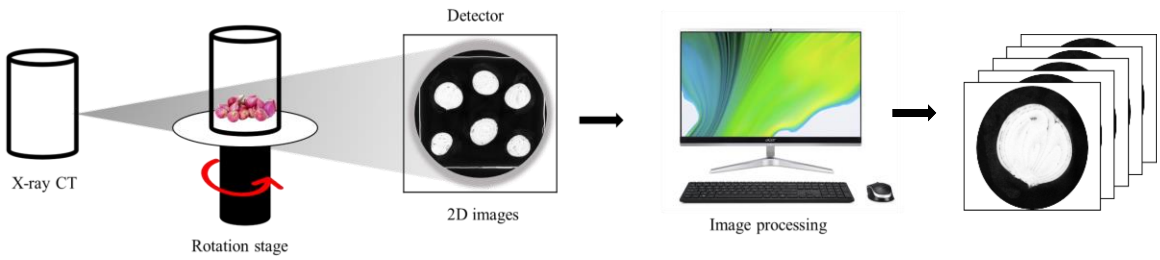

Figure 1. Schematic of X-ray computed tomography imaging.

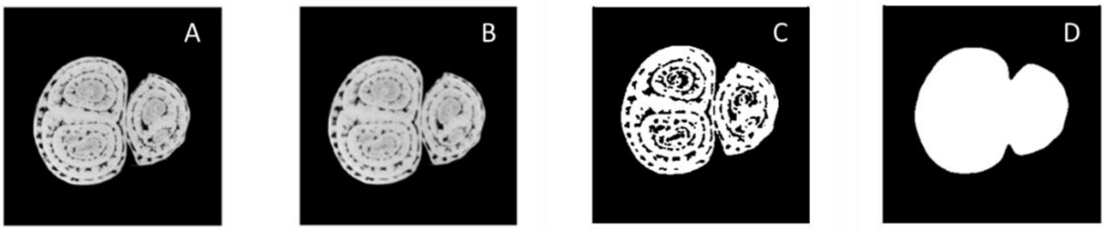

Figure 2. Image processing steps. (A) original X-ray CT image slice, (B) filtered CT image, (C) binarized CT image, and (D) mask of the CT image.

3. Results and discussion

Storage is a crucial step of onion postharvest handling to maintain the quality and control the market price[9]. Storage conditions also have an important in onion physiology, having affected the physicochemical and photochemical properties of onion during storage[10]. An improper condition of storage may result in quality degradation generally marked by weight loss and physical defects. This quality degradation is sometimes visually undetectable.

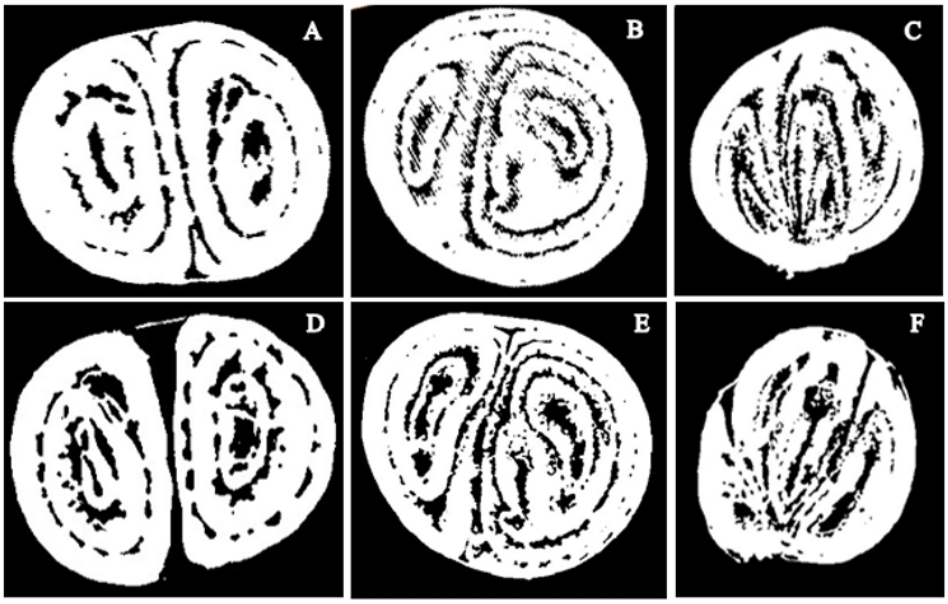

Figure 3. Physical changes of the onion tissue at initial (A-C) and final (D-F) condition under (A and D) 5°C, (B and E) 20°C, and (C and F) 35°C storage temperature depicted non-destructively using X-ray CT. Black areas inside the onion represent the void/air spaces between the tissue layers.

Virtual geometry of onion generated from X-ray CT image enabled to show internal and external structure transformation of onion at initial and final storage conditions (**Figure 3**). Tissue deformations occurred inside the onions during storage, creating bigger void spaces between the tissue layers. The deformation magnitude depends on the initial void spaces. As the spaces were small at primary condition, void space development was greater at final condition (**Figure 3A, B, D and E**). Onions have reduced quality and water holding ability which allows larger pores to be formed. In addition, temperature and humidity, initial quality, and storage method also affect the increased porosity of onion. The void space fraction of onion did not develop significantly as it was already high at the primary condition even though the temperature was high (35°C) (**3C and F**).

Analysis of void space fraction based on CT image processing confirms the onion geometry (**Table 1**). This result showed that temperature affect the void space development between the layer as the low relative humidity (76 %) contributed more.

Table 1. Void space (%) between onion tissue layer at initial and final condition of storage (standard deviation of three replicates given behind the ± sign).

Storage temperature	Void space (%)	
	Initial condition	Final condition
5 °C	8,90 ± 1,7	18,60 ± 2,15
20 °C	9,99 ± 3,66	18,85 ± 1,87
35 °C	16,35 ± 1,09	20,18 ± 2,27

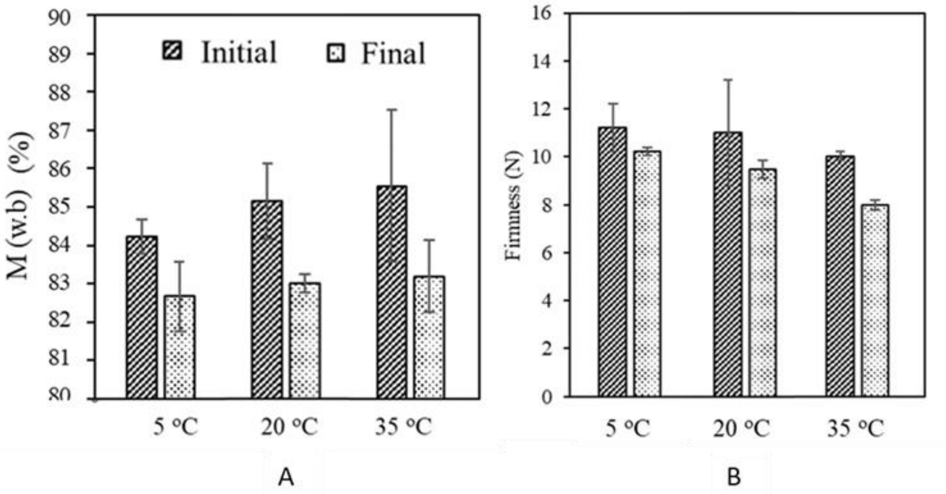

Figure 4. Physical parameter changes of (A) moisture content and (B) firmness between the initial and final conditions of storage

Moisture content and firmness analysis provided a bit different result from the onion organ visualization while the storage temperature affected the bigger difference between the initial and final onion condition (**Figure 4A and B**). This might be due to the moisture content and firmness are more related to the tissue density [11], represented by grayscale intensity of the onion CT images. During the storage, the water content might diffuse from each tissue layers and evaporated through the void spaces. The tissues that underwent the water content loss became less dense, typically could be recognized by grayscale intensity of the CT image. Loss of water content is caused by transpiration, respiration, decay, and sprouting [12]. In the next study, grayscale intensity should be taken into account into the analysis to see the correlation between the moisture content and firmness versus grayscale intensity.

4. Conclusions

X-ray CT is a potential instrument to investigate the quality loss of onion during storage as many quality losses occur inside the product visually invisible. Its non-destructive feature enables to calculate and visualize the physical structure change inside the product. In the next study, model predictions of the structure change can be developed.

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