Effect of post-harvest processes and storage conditions on aging and quality of fruit nuts

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ABSTRACT
Nuts are harvested in-hull and usually left on the ground or dried on-farm until the moisture content of kernel reduces to optimum processing level. The damages on kernel during and after the harvest due to on-ground exposure to weather and storage in high humidity and high temperature environment can be significant in nut kernels such as almonds and macadamia. Previous works on quality degradation of nut kernel showed that high quality of kernel prior to packaging and storage can lead to longer shelf-life of products. While prolonged storage and aging of nuts may adversely affect the quality parameters such as texture, colour, taste and flavour. Moreover, harsh and uncontrolled storage environment (i.e., high humidity and temperature) would accelerate the rate of quality degradation. The proposed study aims to monitor the aging process by defining the quality losses including the effects such as keeping kernels in shell and exposure to the environmental factors during on-ground and storage conditions. To create faster aging process, three different relative humidity of 50, 70 and 90% at 40°C were applied. The quality parameters including the size, moisture content, colour changes (darkening), and texture were evaluated.

KEYWORDS: Nut kernel, Post-harvest, On-farm storage, Relative humidity, Temperature, Quality loss.

INTRODUCTION
The almond and macadamia kernel quality changes with various factors including the harvest condition (dry and wet), environmental factors during the harvest and stockpiling, post-harvest operations, storage methods and its corresponding conditions (Garcia-Pascual et al. 2003, Borompichaichartkul et al. 2009, Le Lagadec 2009, Piscopo et al. 2010, Walton and Wallace 2011, Jagadeesan and Nayak 2017). High temperature and humid environment after harvest can have direct influence on quality of nut such as flavour, appearance, texture, nutritional values and moisture content (Vanhanen and Savage 2006, Yahia 2011). Study of nut quality after harvest and during storage showed that higher temperature conditions can reduce the crispiness, increase moisture content, and change the oiliness along with sweetness resulting in development of rancidity (Özdemir and Devres 1999, Kader 2013). To investigate the optimum harvest and post-harvest operations it is crucial to develop knowledge on fruit properties and
effects of changes in environment on quality characteristics of nut. Almonds are harvested during hot summer in Australia and are left on orchard ground until the kernel moisture content drops to 7%. The fruit is then stockpiled until further processing and storage (Micke 1996). The stockpiling of wet fruit in hot and rainy condition could create hot and damp environments for fruit resulting in loss of colour, flavour and increased chance of condensation (Gouk 2012).

Macadamia are harvested during summer in Australia after fruit fall from the tree. Depending on the variety and harvest season conditions the fruit could be left on the ground for several days exposed to hot sun and wet conditions (Wilkinson 2005) or kept in on-farm silos which could create relative humidity of 80-85% (Winks 1998, Walton and Wallace 2011). Kernel moisture content at the time of harvest is greater than 20% which needs to be reduced as soon as possible after the harvest to reduce the risk of deterioration. The recommended macadamia moisture content for cracking operation is 1.5-6.5% (Braga et al. 1999).

The effects of moisture content on mechanical properties of nut has been studied previously (Braga et al. 1999, Altuntas and Erkol 2011, Shirmohammadi and Fielke 2017). The study has shown reduction in rupture force required to break the kernel as the water activity increases (Yanniotis et al. 2013) leading to lower crispiness and brittleness of kernel. This study aims to explore the effects of high humidity and temperature during harvest and on-farm storage conditions on the almond and macadamia kernel quality.

**MATERIAL AND METHOD**

**Sample and treatment**

Samples of in-shell almond kernel and macadamia were purchased from producers during 2017-2018 harvest season. Samples were raw (unpasteurised) and no treatment or any drying technique was applied on them prior to the testing. Physical properties including length, width, thickness and mass were recorded for each sample batch. Moisture content (% wet basis) of samples (3 kernels in each sample) were determined using oven drying operated at 103°C for 48 hours.

To study the effects of hot and humid conditions on physical and mechanical properties of kernel samples, in-shell macadamia and almond kernel were stored in incubator at 40°C and relative humidity (RH) range of 50, 70 and 90% for period of 2, 5 and 7 days. After each stage, samples were removed and their moisture content, size, colour and texture were recorded.

**Physical properties**

Physical properties of kernel were determined by measuring the length, width, thickness and mass of each kernel. The data was used to calculate the arithmetic mean diameter (mm) and geometric diameter (mm) for almond and macadamia kernels. The following equations were used:

\[
\text{Arithmetic Mean Diameter (mm)} = \frac{L + W + T}{3} \quad \text{Eq 1}
\]

\[
\text{Geometric Diameter (mm)} = (LWT)^{1/3} \quad \text{Eq 2}
\]

Sample colours were recorded by processing images of products obtained from an Olympus SZX7 microscope with a fixed light source. The images were then processed in MATLAB (Mathworks, Natick, MA) to determine the L*, a* and b* values.

**Mechanical properties**

Textural properties of samples were determined using a mechanical tester (Shimadzu EX-LZ, Kyoto, Japan) with 500 N load cell and a sharp end indenter. Testing was conducted at 1 mm/s speed on almond kernel by placing samples on the platen on the flat side and applying load in vertical direction. For macadamia samples kernels were shelled and half of each kernel was used in loading test by placing samples on the flat side. Mechanical parameters including stiffness and toughness were calculated using the following formula:

\[
\text{Stiffness (N/mm)} = \frac{\text{Yield Force (N)}}{\text{Displacement (mm)}} \quad \text{Eq 3}
\]
Yield force and displacement were considered as the peak force value in the force-deformation curve obtained from the mechanical tester (Yannioti et al. 2013).

RESULTS AND DISCUSSION
Changes in physical properties of samples were recorded before and after each period of treatment (Table 1). The geometric diameter was 14.7 mm for fresh almond kernels which reduced to 13.27, 13.51 and 13.68 mm after 2 days at 50%, 70% and 90% humidity, respectively at 40°C. For macadamia kernels the geometric diameter increased after 2 days for all three relative humidity values tested. For all samples mass reduced due to moisture loss in hot environment in the incubator.

<table>
<thead>
<tr>
<th>RH (%)</th>
<th>Time (day)</th>
<th>Mass (g)</th>
<th>Arithmetic diameter (Da) (mm)</th>
<th>Geometric diameter (GDM) (mm)</th>
<th>RH (%)</th>
<th>Time (day)</th>
<th>Mass (g)</th>
<th>Arithmetic diameter (Da) (mm)</th>
<th>Geometric diameter (GDM) (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td>1.7 ± 0.27</td>
<td>15.4 ± 0.62</td>
<td>14.7 ± 0.7</td>
<td>0</td>
<td>3.0 ± 0.44</td>
<td>17.8 ± 0.87</td>
<td>17.6 ± 0.87</td>
<td></td>
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<tr>
<td>50</td>
<td>2</td>
<td>1.3 ± 0.11</td>
<td>14.2 ± 0.34</td>
<td>13.27 ± 0.44</td>
<td>0</td>
<td>3.9 ± 0.74</td>
<td>19.7 ± 1.47</td>
<td>19.5 ± 1.40</td>
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<td>5</td>
<td>1.6 ± 0.27</td>
<td>13.7 ± 0.48</td>
<td>12.84 ± 0.32</td>
<td>0</td>
<td>3.1 ± 0.37</td>
<td>17.6 ± 1.06</td>
<td>17.5 ± 0.91</td>
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<tr>
<td></td>
<td>7</td>
<td>1.3 ± 0.10</td>
<td>14.4 ± 0.43</td>
<td>13.41 ± 0.36</td>
<td>0</td>
<td>3.7 ± 0.48</td>
<td>19.5 ± 1.21</td>
<td>19.5 ± 1.17</td>
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<tr>
<td>70</td>
<td>2</td>
<td>1.3 ± 0.13</td>
<td>14.4 ± 0.51</td>
<td>13.51 ± 0.47</td>
<td>50</td>
<td>3.7 ± 0.58</td>
<td>19.3 ± 0.69</td>
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<tr>
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<td>5</td>
<td>1.4 ± 0.23</td>
<td>14.3 ± 0.55</td>
<td>13.32 ± 0.29</td>
<td>50</td>
<td>3.8 ± 0.48</td>
<td>18.9 ± 1.76</td>
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<tr>
<td></td>
<td>7</td>
<td>1.3 ± 0.11</td>
<td>14.5 ± 0.53</td>
<td>13.31 ± 0.40</td>
<td>50</td>
<td>3.4 ± 0.71</td>
<td>17.8 ± 1.41</td>
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<tr>
<td>90</td>
<td>2</td>
<td>1.4 ± 0.1</td>
<td>14.5 ± 0.6</td>
<td>13.6 ± 0.4</td>
<td>70</td>
<td>3.3 ± 0.65</td>
<td>18.5 ± 1.7</td>
<td>18.3 ± 1.7</td>
<td></td>
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<tr>
<td></td>
<td>5</td>
<td>1.3 ± 0.12</td>
<td>13.8 ± 0.56</td>
<td>13.22 ± 0.48</td>
<td>70</td>
<td>3 ± 0.76</td>
<td>17.7 ± 1.32</td>
<td>17.5 ± 1.31</td>
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<tr>
<td></td>
<td>7</td>
<td>1.3 ± 0.12</td>
<td>14.0 ± 1.31</td>
<td>13 ± 0.5</td>
<td>90</td>
<td>3.1 ± 0.52</td>
<td>17.7 ± 1.54</td>
<td>17.5 ± 1.5</td>
<td></td>
</tr>
</tbody>
</table>

Moisture content changes are presented in Figure 1. Initial moisture content of almond and macadamia were 7.4% (±0.05) and 7.5% (±0.02) for almond and macadamia samples, respectively. As time in hot and humid environment increased, almond kernels absorbed more water.

![Figure 1](image-url)  
*Figure 1: Changes in moisture content of samples over 2, 5 and 7 days of treatment at 50, 70 and 90% relative humidity at 40°C for (a) almond and (b) macadamia samples.*

**Effects of aging on colour**
Figure 2

(a)

(b)
Figure 2 shows the summary of colour values determined for samples under humidity of 50 and 90%. The lightness (L*) value reduced both in macadamia and almond and indicated a slight drop over time for both the samples.
The duration of hot and humid treatment affected the $L^*$, $a^*$, and $b^*$ values for both samples. For almond kernel redness value increased as the duration of hot and humid treatment increased. The yellowness value reduced for 90% humidity treatment.

Figure 2: Summary of color reading for (a) almond lightness, (b) macadamia lightness and (c) almond and macadamia Chroma values.
Figure 3: Values and $a^*$ (redness) and $b^*$ (yellowness) determined for samples

**Texture**

Values of force required to break the kernel is presented in Figure 4. Values of force reduced as the length of exposure in hot and humid environment increased. For fresh macadamia kernel, average values of force and deformation at yield point were 51 N and 6.1 mm. As the kernel aged, force required to break the kernel reduced from 53N to 29 and 28.9 N for 50% RH and from 46 N to 43 and 39 N for 70% RH and from 44 N to 40 and 32 N at 90% RH for 2, 5 and 7 days, respectively. For almond kernels, force required to break the fresh samples was 54 N and changed to 51, 50, 49 N for 50% RH and 46, 43 and 41N for 70% RH and 57, 60 and 59 N at 90% RH for 2, 5 and 7 days, respectively. Previous study on almond varieties and water activity showed loss of brittleness and higher plasticity as the kernel absorbed moisture (Yanniotis et al. 2013).

Figure 4: Force required to break the kernel (a) almond and (b) macadamia

Values of stiffness and toughness for tested samples in exposure to heat and humidity. For Macadamia kernel, toughness values reduced as it aged in humid environment. For almond kernel, however, less clear pattern was observed at 70% relative humidity.
Table 2: Summary of mechanical properties tested

The stiffness values increased for almonds at 50 and 70% humidity (Table 2). However, the values for 90% relative humidity incubation test reduced as kernel aged which can be related to the combined effects of exposure to heat and humidity. For Macadamia kernel, toughness values reduced as it aged in humid environment. For almond kernel, however, less clear pattern was observed at 70% relative humidity.

<table>
<thead>
<tr>
<th>Condition (RH% - 40°C)</th>
<th>Time (day)</th>
<th>Stiffness, N/mm ± SD</th>
<th>Toughness, N.mm ± SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fresh</td>
<td>2</td>
<td>20.08 ± 3</td>
<td>73.69 ± 25</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>20.96 ± 3.23</td>
<td>68.64 ± 28</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>21.63 ± 2.6</td>
<td>57.39 ± 18</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Condition (RH% - 40°C)</th>
<th>Time (day)</th>
<th>Stiffness, N/mm ± SD</th>
<th>Toughness, N.mm ± SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fresh</td>
<td>2</td>
<td>10.12 ± 1.6</td>
<td>142.65 ± 26</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>10.06 ± 2.2</td>
<td>43.55 ± 12</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>10.03 ± 2</td>
<td>42.48 ± 12</td>
</tr>
</tbody>
</table>

Table 2: Summary of mechanical properties tested

Figure 5 shows the deformation at yield point versus the moisture content of kernel. The results for almond kernels show an increasing pattern of deformation from 2.98 mm for fresh to 4.44, 4.58 and 4.15 mm for 2, 5 and 7 days at 90% RH and 40°C. The results for macadamia showed less clear pattern which could be related to the effects of shell layer balancing the moisture transfer.

CONCLUSION AND FUTURE WORK

Test results showed effects of aging on nuts in humid and hot environment. The lightness value reduced for both the samples as kernels turned to darker colour. Force required to break the kernel reduced as aging progressed and larger deformation was required at the rupturing point. The results of this study showed the effects of environmental factors that can reduce the marketability of nut products by changing the textural and physical properties of products. The next step will be investigating the effects of these factors for a range of temperatures and the changes in chemical composition of products such as peroxide value and antioxidant values of nut kernels.
The possible effects of hull and shell layer on balancing the humidity and the moisture equilibrium inside the shell cavity will need to be investigated to address the in-field stockpiling and storage on quality of kernels.

REFERENCES


