Investigation of Different Post-Harvest Treatments on the Quality of Almond Kernels during Ambient Storage

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Abstract

Maintaining almond kernel quality during and after harvest is crucial in producing premium kernel product for Australian and international markets. In this study, we investigated the effects of different post-harvest treatments on changes in moisture content, texture, colour, nutritional profile and flavour of almond kernels over a storage period of 9 months under ambient conditions. Post-harvest treatments included steam pasteurization, volumetric heating pasteurization, oven roasting and dry roasting, which were compared with raw kernels. Moisture and texture analysis revealed that the average values within each treatment group did not change significantly over 9 months, although the breaking force required to create an initial crack in the kernel structure were markedly lower for Steam Pasteurized (SP) and Oven Roasted (OR) samples after 9 months. Sensory analysis conducted by a trained panel of experts revealed that the chewiness of raw samples increased over time, and both toasted and roasted characteristics were lower. For OR and Dry Roasted (DR) samples the chewiness was low and roasted and toasted properties were higher. Average overall enjoyment score given to samples as a part of sensory testing was higher for Volumetric Heating Pasteurization (VHP) and DR at start of the storage (control) and stayed higher than others after 6 and 9 month of storage. Testing of nutritional content of samples showed changes in alpha tocopherol content in roasted samples. However, DR samples had higher content in comparison with OR samples. Volumetric heating treatment didn’t diminish tocopherol content of samples in comparison with raw samples while the average alpha tocopherol content of SP over first 3 month of storage was lower. Both SP and OR samples showed lower fat percentage in comparison with raw, VHP and DR. A reduction was observed in Lightness (L*) values for all samples tested. Among the tested treatments OR samples had darker kernels and Raw and VHP samples had lightest colours. The testing results showed the potential of volumetric heating pasteurization and roasting in maintaining quality of kernel over bulk storage period.

Introduction

California, Australia and Spain are the major producers of almonds in the world, producing in-shell and kernel products [1]. Australian export almond products include in-shell (32%) and kernel (68%) products exported to Europe (41%), Asia Pacific (33%), Middle East and Africa (13%) and America (12%) [2]. Almond kernel quality is important for Australian products in this competitive export market, and producing continuous and recognised high quality produce is only possible if effective processes and technologies are used, and in-field processing and storage management best practices are applied to maintain kernel quality throughout the supply chain [3]. Therefore, quality evaluation and monitoring is crucial considering the Australian climate and timing for harvest in comparison with northern hemisphere producers. The Australian almond harvest is between February to April each year, whereas Californian, Spanish, Turkish and Iranian harvests start in late August to October each year [4]. Thus, the climate and harvest differences in Australia requires optimum management of kernel quality during post-harvest processing and storage in order to maintain the highest quality produce. Almonds are harvested from the in-hull fruit on the orchard ground. The in-hull fruit is left on the orchard ground for drying for one to two weeks [4] before being piled in field prior to shipment to processing factory. The in-hull fruit can be left in-filed stockpiles or on the factory site for several weeks before being processed [4]. In-hull almond are then processed through hulling and shelling stages (10-15 stages) [5-6].

The final kernel products are then sent for further processing and bulk storage before being sold to national or international customers. Size, shape, colour, taste, nutritional and chemical attributes of almond kernel are the most important parameters of kernel products in export market. The current industrial operation uses steam pasteurization and surface heating (hot air or oven) in reducing the kernel moisture content and roasting. The optimum moisture content of raw kernel is 6% and lower moisture level during storage is favourable [7]. The common steam pasteurization and hot air drying and roasting could results in undesirable quality losses of kernels products. The surface heating could affect the appearance and colour of kernel products [8-11]. Texture and sensory characteristics of kernel also changes during and after heat treatments. Study of cashew nut, pistachio and sesame seed texture showed a reverse relationship between the kernel hardness and roasting temperature [12]. Surface heating and hot air treatments dry the outer layer of the kernel leading to possible case hardening and damaging the texture of product and reducing consumer acceptability of products. Study of macadamia quality after harvest showed that kernel browning due to drying in high RH environment and oxidation due to high oil content of the kernels can rapidly reduce quality of products [13]. Producing high quality nut kernels requires application of best practice drying such as hybrid drying process and monitoring of initial kernel properties including the oil and moisture content.

Heat treatment such as roasting effects the kernel chemical composition by reducing the Peroxide Value (PV) and increasing the Free Fatty Acid (FFA) content [14]. Existing literature reported the effects of increased temperature, storage time and processing (roasting and blanching) on FFA content [15-17]. The oxidation reactions due to environmental factors such as temperature, light or metal ions after harvest and during storage period could result in changes of taste and rancidity development [18]. Volumetric heating pasteurization reported as an alternative operation for optimising the kernel moisture content and pasteurization with less negative effects on kernel quality [19-24]. However, more work is required to monitor the quality changes of VHP treated products in comparison with raw and commercial steam pasteurised products over storage period. This study aims to determine the quality parameters of almond kernel products including Raw, pasteurised and roasted (oven and VH roasted) during 9 month bulk storage period. The study will investigate the effects of different post-harvest treatments on the quality of almond kernels during ambient storage.
treatments including Steam Pasteurization (SP), Radio Frequency pasteurization (RF), Oven Roasting (OR), VH roasting or Dry Roasting (DR) on quality of Nonpareil variety of almonds.

Material and Methods

Almond processing, treatment and storage

Nonpareil Almonds were harvested in the 2016-2017 season from South Australian almond growing regions. Samples of kernels were selected randomly from hulled and shelled kernels. For this study the almond kernels were either Steam Pasteurised (SP), Volumetric Heating Pasteurised (VHP), Oven Roasted (OR), or dry roasted (DR; involving volumetric heating and roasting), and compared with untreated (raw) almonds. Samples of steam pasteurised and oven roasted kernel products were purchased from 206-207 products. Pasteurization and roasting using volumetric heating was conducted at a radio frequency of 27 MHz for 20 minutes at a temperature range of 94-120 °C. Following treatment, the kernels were packed into plastic bags and kept in cardboard boxes and sealed by tape in industrial style bulk storage. Over a 10-month storage period samples were tested at 0, 1, 3, 6 and 9 months from the storage date. The temperature and relative humidity were monitored continuously during storage. Moisture content of samples were determined during the storage period using oven drying at 103 °C. Sample were kept in oven dryer for minimum of 48 h until all moisture was removed and sample weight stayed constant. The following formula was used in determining moisture content:

\[
\% \text{ Moisture Content (MC)} = \frac{W_w - W_r}{W_w} \times 100
\]  

(1)

Where \(W_w\) and \(W_r\) are weight of sample in wet and dry conditions.

Mechanical (texture) properties of almond kernels

A Shimadzu EZ Test mechanical tester fitted with a 500 N load cell was used to measure the force-displacement profiles of the kernels. A flat-ended indenter with a diameter of 6 mm was used for mechanical testing. The force-displacement profiles were then used to calculate the breaking force (N), stiffness (N/mm) and toughness (N.mm) of the kernels. The stress (N/mm² or MPa) and strain required to break the kernel structure were determined using following equations:

\[
\text{stiffness} = \frac{\text{Yield Force}}{\text{Displacement (mm)}}
\]  

(2)

\[
\text{Toughness (N.mm)} = 0.5^* \frac{\text{Force at Yield (N)}}{\text{Displacement at yield (mm)}}
\]  

(3)

\[
\text{Strain} = \frac{\text{Deformation applied (mm)}}{\text{Thickness of kernel (mm)}}
\]  

(4)

Colour measurement of almond kernels

Colour measurements (lightness (L*), redness (a*) and yellowness (b*)) were determined by analysing images of kernels taken using a microscope with top and bottom light sources, and all images were taken in the same lighting conditions. The images were analysed using MATLAB colour reading. From the colour readings the colour differences (ΔE), chroma and browning index (BI) were calculated for each category using the following equations:

\[
E = \sqrt{L^2 + a^2 + b^2}
\]  

(6)

\[
\text{Chroma} = \sqrt{a^2 + b^2}
\]  

(7)

Sensory analysis of almond kernels

A panel of seven assessors experienced in sensory analysis was used to determine the sensory characteristics of the kernels. The survey was designed based on a five choice questionnaire for strongly agree to strongly disagree. The elements questioned included crunchiness, chewiness, roasted, toasted and overall enjoyment. The average results were then used in combination with the texture and nutritional data to evaluate the quality of the kernels treated and stored under different conditions.

Nutritional Content of Almond Kernels

Determination of lipid content

The lipid content in the kernels was determined using a solvent extraction method reported previously [25]. Briefly, freshly ground almond powder (150 mg) was weighed into an amber vial (7 mL) and methanol containing 0.1% BHT (2 mL) and KOH 80% solution (0.5 mL) were added. After sealing the vial, the mixture was vortexed and then placed in an oven at 70 °C for 30 min, with intermittent vortexing every 10 min. The vial was cooled to room temperature, hexane (2.5 mL) was added, and the mixture was vortexed vigorously before the addition of MilliQ water (1.5 mL). The mixture was centrifuged (10 min, 3000 rpm) at 10 °C and the organic phase was transferred to a vial. A second extraction was conducted using hexane (2.5 mL), and the hexane extracts were combined and concentrated under a nitrogen flow. The resulting extract was redissolved in mobile phase (1 mL) and 20 μL of this solution was injected into the HPLC for analysis. To include external standards, varying volume of 1 mg/mL α-tocopherol (0 μL, 5 μL, 10 μL, 20 μL, 30 μL, 40 μL, 50 μL) were spiked into repeated samples of the same amount. The tocopherol content in the kernels was determined using an Agilent 1260 HPLC system fitted with a Agilent ZORBAX Eclipse XDB-C18 column (4.6 x 150 mm), and using a photodiode array detector (PDA) at 292 nm and a fluorescence detector (FLD) at λ\text{ex} = 295 nm and λ\text{em} = 330 nm. The column was held at 30 °C and a mobile phase gradient was employed at a flow rate of 1 mL/min. Mobile Phase A (MPA) consisted of methanol: methyl tert-buty ether (MTBE): H2O (95:4:1 v/v%) and Mobile Phase B (MPB) consisted of methanol: MTBE (10:90 v/v%). The gradient started with 0 % MPB and ramped up to 40 % MPB at 11.5 min. The mobile phase was then immediately switched back to 100 % MPA for 2 min to equilibrate the HPLC system before the next injection. Agilent Open Lab Data Analysis software was used for quantification of the results.

Results and Discussion

Initially, the physical characteristics (mass, dimensions and moisture content) of the kernels were determined following treatment and prior to bulk storage (Table 1). Compared to raw kernels (control), all of the treatments resulted in a reduction in the kernel dimensions and mass, although this was least pronounced for VHP treated samples. The moisture content of the raw kernels (5.96%) was also found to decrease the kernel dimensions and mass, although this was least pronounced for VHP treated samples. The moisture content has previously been reported following SP of kernels, leading to the requirement for further drying processes and a loss of skin quality [26]. Interestingly,
the increase in moisture content for the SP kernels with lower average mass, could suggest that this treatment results in higher water content of kernel that need to be addressed to avoid microbial growth later during long storage of kernels. Additionally, the steam pasteurization has been reported to be effective in eliminating microbial growth (Salmonella Enteritidis) only with high temperature which could cause quality loss and rancidity development [27].

Following these initial measurements the kernels from each treatment group were packaged and stored under ambient conditions for 9 months (from August to April), during which time the temperature and Relative Humidity (RH) were constantly recorded (Figure 1). Almonds in Australia are harvested during hot summer and processed and stored in winter. As it is illustrated in Figure 1, the changes in the RH at the beginning of bulk storage affected the changes in moisture content of kernels. Higher temperature during summer months (September to April) could cause loss of average moisture content. Laboratory environmental conditioning showed that changes in storage RH, temperature and its effects on almond and walnut kernel quality during storage leads to lower moisture content of kernels when stored in higher temperature [28,29].

Changes in sphericity and size of kernel recorded during 9-month storage is shown in (Figure 2 & 3) respectively, shows the variation in kernel size in different sample batches. Sphericity changes of kernel with moisture content is reported in literature is similar to the decreasing trend as moisture content decreased [30]. The effects of heat treatment and oven roasting on sphericity of cashew nut and melon kernel has been studied before indicating the direct relation between moisture content and changes in shape of the kernel that could affect the effectiveness of post-harvest operations on the kernels [31,32].

### Texture and sensory analysis

Force required to break the kernel was determined conducting a uniaxial loading test. (Figure 4) shows the force values for different treated samples. The force required to break Raw and VHP kernels were in same range while the breaking force required for SP was lower than what expected considering the treatment applied. The average breaking force required were 117, 115, 92, 86 and 90 N for Raw, VHP, DR, SP and OR respectively. The average deformation at the breaking point were 1.05, 0.81, 0.55, 1.20 and 0.62 mm for Raw, VHP, DR, SP and OR respectively. With increase in kernel moisture level the observed force required to break, the kernel was lower.

### Table 1: Summary of initial physical properties of kernels recorded prior to packing and storage.

<table>
<thead>
<tr>
<th></th>
<th>Raw</th>
<th>SP</th>
<th>VHP</th>
<th>OR</th>
<th>DR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture content (% w.b.)</td>
<td>5.96%</td>
<td>6.38%</td>
<td>4.13%</td>
<td>2.84%</td>
<td>2.12%</td>
</tr>
<tr>
<td>Thickness (mm)</td>
<td>8.79 ± 0.46</td>
<td>8.18 ± 0.53</td>
<td>8.79 ± 0.42</td>
<td>8.50 ± 0.29</td>
<td>8.62 ± 0.48</td>
</tr>
<tr>
<td>Width (mm)</td>
<td>13.00 ± 0.31</td>
<td>12.06 ± 0.55</td>
<td>12.31 ± 0.42</td>
<td>11.38 ± 0.15</td>
<td>11.63 ± 0.22</td>
</tr>
<tr>
<td>Length (mm)</td>
<td>22.27 ± 0.87</td>
<td>21.10 ± 0.81</td>
<td>21.14 ± 0.80</td>
<td>19.82 ± 0.87</td>
<td>19.26 ± 0.70</td>
</tr>
<tr>
<td>Mass (g)</td>
<td>1.29 ± 0.09</td>
<td>1.11 ± 0.09</td>
<td>1.16 ± 0.05</td>
<td>0.93 ± 0.04</td>
<td>1.0 ± 0.06</td>
</tr>
<tr>
<td>Sphericity (%)</td>
<td>38.08 ± 2.48</td>
<td>32.89 ± 2.57</td>
<td>36.03 ± 2.48</td>
<td>32.25 ± 1.29</td>
<td>33.41 ± 1.81</td>
</tr>
</tbody>
</table>

Figure 1: Temperature and relative humidity changes during the storage period (0 is July and 9 is April).

Figure 2: Moisture content and sphericity changes over 10 month storage period.

Figure 3: The changes in physical properties of kernel during 9-month storage.

Figure 4: Force required to break kernel recorded during storage period.

Values of stiffness (N/mm) and toughness (N.mm) are presented in (Figure 4). A gradual increase was observed in stiffness values from beginning of storage to three months of storage then the values dropped. The stiffness decrease after 9 month of storage and the changes in SP was more obvious with large changes of 124 N/mm in the beginning.
of trial to 22 N/mm after 9 month storage. Interestingly the changes in stiffness values in Raw, VHP and DR followed a similar pattern while the stiffness value for OR samples increased at the last month of storage. The toughness (rupture energy) recorded for Raw and VHP samples were similar at the first month of the storage and after three month the stiffness value for VHP treated samples dropped. The Toughness values recorded for DR and OR samples showed lowest changes over the storage period. The text analysis reported in literature shows that volumetric heating pasteurization could maintain the quality of kernel even if the treatment last for 10, 20 and 30 min while the quality reduces significantly after steam pasteurization [33]. (Figure 4) presents the values of stress and strain for tested samples. The ratio of stress over strain or Elastic modulus (E) was lower for raw and SP and VHP compare to roasted samples at the beginning of the storage period. Reverse relation between Elastic modulus and moisture content of cashew nut and carob pods reported previously [34,35]. The combined effects of changes in force and deformation due to less brittle and more ductile characteristics of kernels at different moisture level has been reported as one of the important factors in developing more effective technologies and reducing unwanted damage on kernel in post-harvest and processing of nut products [6].

The changes in environmental factors including RH, temperature, light and packaging type has shown effects on changes in kernel moisture content which can result in texture changes and chewy characteristics [18].

Figure 7 shows the changes in sensory properties of samples tested in the beginning of trial after 6 and 9 month of storage. The results showed overall lower toasted texture for SP confirming the reduction in stiffness and increase in toughness values. Very similar pattern was observed for samples when roasted characteristic was recorded by the trained panel while for VHP treated samples the toasted characteristic increased and the roasted characteristic reduced slightly. In comparison the chewiness characteristic of VHP, DR and OR samples were lower than Raw and SP. Study of storage effects on shelf life and sensory quality of almond samples during storage shown better quality parameters for fresher products [36]. Texture, appearance and flavour degradation was significantly lower for raw almond kernels packed with oxygen absorber after 4 and 6 months of storage at 20°C and 4°C respectively [37]. Study on shelf life of IR roasted almonds concluded due to flavour loss after 3 month of storage in paper bags at 37±0.5°C and 7-8% RH, IR roasted products are not suitable for sale [36]. In this study, over 9 months of storage roasted and toasted characteristics of samples received lowest average score by the trained panel for Raw, VHP, and SP. While for DR the stale and oiliness and for OR toasted and chewiness had lowest average score.
Changes in tocopherol and fat content

Changes in nutritional content of samples were recorded by testing the vitamin E (tocopherols) and fat content. Both VHP and DR samples maintained the tocopherol content in comparison with the raw kernel while SP and OR samples had lower tocopherol content. Similar study was found when in-shell and roasted kernels stored for 9 month the tocopherol content reduced significantly for the roasted samples while in-shell raw products maintained the quality [38]. Heat treatment through roasting has shown reducing effects on tocopherol content of pine nut, mustard seed extracted oil and soybeans [39-41], the VH process however showed less negative effects on tocopherol content. Changes in saturated and mono-saturated fatty acid in almonds is function of storage/aging length [37]. The existing literature reports a decrease in mono-saturated and increase in saturated fatty acid when almonds are stored for longer period [18-37, 42-44]. However the authors found no previous publication that reported and compared the effects of storage on raw and volumetric heating pasteurized almonds after bulk storage period.

Figure 7 presents the values recorded for fat and total saturates of samples during storage period. The VHP and DR samples maintained similar fat content range to the raw samples while OR and SP samples had lower level. Lower satisfaction due to rancid flavor has been previously reported for almonds stored with oxygen absorber showing the effects of oxidation on quality changes [37]. Study of shelled and roasted almonds during storage showed degradation of flavor as storage continues [38], this study indicated the need for further investigation of effects of processing, storage type and temperature and environmental factors on quality of nut in range of conditions. The results of our experiment showed that there is a difference between products storage quality and shelf life depending on treatment applied. The OR product showed lower nutritional and sensory quality while storing raw and VHP pasteurized product showed better texture and sensory quality. This could indicate the need for optimizing storage of less processed products and processing to roasting as the market demand requires [36].

Colour changes

The recorded values of lightness ($L^*$) and Browning Index (BI) are shown in (Figure 11). The changes in lightness of kernels indicates a darkening trend for all of the samples and OR samples had darkest colour. Although the BI determined for samples didn’t show a significant difference between treatments, the results corresponded with darker colour determined for roasted and steam pasteurised kernels. Study of colour changes of raw and roasted walnut, peanut, almonds and hazelnuts showed better sensory panel acceptance for raw products with lighter colour [45]. The no enzymatic browning occur during steam pasteurization can be the cause of darker skin colour in SP and OR samples [33] while VHP pasteurization and roasting can maintain lighter and natural colour of the kernels.

The values of hue angle and Chroma recorded showed the similarity of VHP treated and raw samples in maintaining the natural color intensity in comparison with the SP and OR samples. The changes in hue angle values for each sample batches over the storage period reported to be indicating the degradation process [46].
Conclusion and Future Work

Results shown in this study indicates the importance of storage and quality loss monitoring for almond kernel products. The changes in quality parameters indicates the need for better process management, minimal post-harvest heat treatment and quality determination during and after harvest. Existing literature on shelf life of roasted products [36] showed faster quality degradation of heat treated products in 3 month storage could illustrate that higher quality can be achieved by storing fresh raw products and further process them to roasted as market demand requires [36,38]. VH pasteurization and roasting showed great potential as an industrial process in maintaining the kernel products quality in comparison with common steam pasteurization. The results showed that better management of quality by storing raw and VHP pasteurized product can be achieved while storing roasted products increases the possibility of product quality loss.

References

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