MAXIMIZING SHELF LIFE

2017 THE ALMOND CONFERENCE

Room 314 | December 6, 2017
CEUs – New Process

Certified Crop Advisor (CCA)
- Sign in and out of each session you attend.
- Pickup verification sheet at conclusion of each session.
- Repeat this process for each session, and each day you wish to receive credits.

Pest Control Advisor (PCA), Qualified Applicator (QA), Private Applicator (PA)
- Pickup scantron at the start of the day at first session you attend; complete form.
- Sign in and out of each session you attend.
- Pickup verification sheet at conclusion of each session.
- Turn in your scantron at the end of the day at the last session you attend.

Sign in sheets and verification sheets are located at the back of each session room.
AGENDA

• Guangwei Huang, Almond Board of California, moderator
• Ron Pegg, University of Georgia
• Kenneth Marsh, Kenneth S. Marsh & Associates
MAXIMIZING SHELF LIFE OF YOUR ALMONDS

Ronald B. Pegg
Department of Food Science & Technology
December 6, 2017
What is shelf life (SL)?

SL is a finite length of time ($t$) after production and packaging during which the food product retains a required level of quality under well-defined storage conditions.

Basically, there are 2 possibilities for a product to become unacceptable during storage ...

(1) the development of a risk for consumer dissatisfaction due to poor quality appearance, low sensory, and/or nutritional quality of the product (e.g., lipid oxidation);
(2) mainly associated with safety issue potentially leading to a risk for consumer health.
\( \Lambda = \) parameters such as T, RH, packaging type, # of films & thicknesses, \( O_2 \) level …

- The concept of an acceptability limit (\( I_{lim} \)) discriminates products that are still acceptable for consumption (\( SL \)-in food) from the no longer acceptable ones (\( SL \)-out of food).
- Despite its intuitive nature, it is a shadowed boundary that is difficult to be defined.

Sensory analysis is one of the most suitable processes for measuring oxidative damage and determining the shelf-life (SL) of foods, but it is an expensive and time-consuming methodology.

Lipid oxidation is one of the most common causes of deterioration in the sensory and nutritional quality of nuts.
Variables affecting consumer acceptance or rejection of stored almonds.
Almonds are susceptible to...

- Microbial spoilage ... mold
- Oxidation
- Textural degradation
Nuts are protected from light and humidity inside their shells, and they can be conveniently stored for a long time.

The pellicle that covers the nuts is rich in phenolic compounds that confer extra protection against oxidative damage.

For economic reasons, however, a great % of nuts sold in the market are out of their shell and exposed to light, oxygen, and elevated temperatures.
Solutions...

- Microbial spoilage ... mold  ➔  Reduce moisture content to 4-6%
- Oxidation  ➔  Nitrogen flush, vacuum package
- Textural degradation  ➔  Protect against too high/too low RH

What is needed to achieve this?

$
Factors that Affect Shelf Life

- Almonds are relatively low-moisture, high-oil-containing nuts with a long shelf life when properly handled.
- Almond quality and shelf life can be influenced by three general factors: the *product characteristics*, the *environment* during distribution and storage, and the *package*.
- These factors interact in many ways to influence almond quality and to impact shelf life.
- Shelf life guidance for almonds must specify the product and the storage conditions.

<table>
<thead>
<tr>
<th>Product characteristics</th>
<th>Environment</th>
<th>Package</th>
</tr>
</thead>
<tbody>
<tr>
<td>Composition; Water activity; Form.</td>
<td>Temperature; Humidity; Oxygen; Processing conditions; Insects, pests, microorganisms.</td>
<td>Physical protection; Moisture barrier; Gas barrier.</td>
</tr>
</tbody>
</table>
ABC Recommendations - Storage Conditions and Handling Practices

• Storage for all almond forms in cool and dry conditions (<50°F/<10°C and <65% relative humidity) is recommended.
• The optimal goal of the recommended storage conditions is to maintain <6% MC, which helps preserve shelf life.
• A cool temperature of <50°F/<10°C is optimal, but a higher temperature that does not stimulate insect activity may work as well to control moisture migration (and also minimize lipid oxidation).
• Almonds are a shelf-stable nut that can have more than two years of shelf life when stored at the recommended conditions.

High Quality → Moisture <6%, a_w 0.25-0.35, Free fatty acids <1.5%, PV <5 meq/kg
Knowledge of T, RH, and $a_w$ levels can aid in the selection of a package with the correct barrier properties to optimize quality and shelf life.

LOx is lowest at $a_w$s of ~0.2 to 0.4

source: www.aqualab.com
Lipid Oxidation

- Lipid oxidation (lipox) is a complex series of undesirable reactions that cause the breakdown of fats and oils.

- In almonds, the oxidation reactions lead to a loss of quality as the nuts develop “rancid” flavors and odors.

- During lipox, O₂ reacts spontaneously with the fatty acids in fats to form primary breakdown products (e.g., peroxides, conjugated dienes) and, as oxidation progresses, secondary products (e.g., volatile aldehydes, ketones) are formed that give rise to off-flavors and off-odors.

- Oxidation can be measured by testing for the presence or accumulation of one or more of these primary and secondary products.
Several simple chemical tests based on spectrophotometry or titration can be used to track lipid oxidation in nuts.

- Peroxide value (measure hydroperoxide formation), 1°
- TBARs (2-thiobarbituric acid reactive substances), 2°
- $p$AV (para-anisidine value), 2°
- Hexanal formation by HS-SPME-GC, 2°
- Tocopherol (vitamin E) analysis

What about the impact of relative humidity (RH)?

- Consumers rejected nuts after 12 days
- PV = 18.8 meq. active O$_2$/kg oil
- pAV = 7.68
- Hexanal = 49 μmol/100 g oil
Volatile Reaching our Nose

- Hexanal is an important secondary product of lipox of linoleic acid.
- It is a volatile aldehyde with a “fatty, green, grassy” note.
- It forms as almonds oxidize during storage; it can be measured and used as an indicator of oxidative rancidity.
- Other volatile compounds exist in raw, roasted, and stored almonds.
- Emerging research is showing that selected volatiles other than hexanal might be sensitive markers of early oxidation in almonds.
Headspace — Solid Phase Microextraction — Gas Chromatography — Mass Spectrometry Analysis
12 mo - Roasted Almond Sample in a PP Bag @35 °C/65% RH
Moisture Migration

The difference between the relative humidity (RH) of the surrounding environment and water activity \((a_w)\) of the food determines whether a food gains or loses moisture during storage.

- RH > \(a_w\), then food will absorb moisture from the air.
- RH < \(a_w\), then the food will lose moisture.
- At equilibrium, RH = \(a_w\).

\(a_w\) is the vapor pressure of water above a sample \((P)\) divided by that of pure water at the same T \((P_o)\):

\[ a_w = \frac{P}{P_o} \]
Crispness scores drop when a critical moisture ($a_w$) is reached

Method for Texture & Sound Analysis

• Texture analysis can be performed using a Texture Technologies TA-XT2i texture analyzer.

• The fracturability of whole almonds can be evaluated using the texture analyzer with a compression disk.

• The audio can be recorded during texture analysis and analyzed to provide a more complete fracturability profile.
Description of textural factors extracted from the force/displacement curves

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Textural association</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of force peaks (FP)</td>
<td>Crispness, Brittleness</td>
</tr>
<tr>
<td>Average gradient (AG)</td>
<td>Chewiness</td>
</tr>
<tr>
<td>Average drop-off (AD)</td>
<td>Crispness, Brittleness</td>
</tr>
</tbody>
</table>
# Study Design

The effects of environmental storage conditions on roasted and raw almond quality characteristics were investigated with an incomplete factorial design (n = 25) over 16-mo and 24-mo, respectively.

Samples were analyzed at 2-mo intervals until consumer rejection or conclusion of the study, and compared to baseline values.
Rejection timeline for raw and roasted almond samples

Rejection timeline (mo) for all samples

<table>
<thead>
<tr>
<th></th>
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<th>2</th>
<th>4</th>
<th>6</th>
<th>8</th>
<th>10</th>
<th>12</th>
<th>14</th>
<th>16</th>
<th>&gt;&gt; 24</th>
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<td>35/65</td>
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<td>25/65</td>
<td>15/50</td>
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<tr>
<td>UC</td>
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<td>4/90</td>
<td>15/65</td>
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<td>4</td>
<td>6</td>
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<td>&gt;&gt; 24</td>
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<tr>
<td>HBB</td>
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<td></td>
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</tr>
<tr>
<td>(Roast PPB)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>35/65</td>
<td>35/50</td>
<td>25/65</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Roast HBB)</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
</tbody>
</table>

Samples that were not rejected

<table>
<thead>
<tr>
<th>Sample</th>
<th>Rejection Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>A 25/50</td>
<td>22.5%</td>
</tr>
<tr>
<td>A 15/50</td>
<td>10.0%</td>
</tr>
<tr>
<td>A 4/90+</td>
<td>12.7%</td>
</tr>
<tr>
<td>C 25/50</td>
<td>18.6%</td>
</tr>
<tr>
<td>C 15/65</td>
<td>20.6%</td>
</tr>
<tr>
<td>C 15/50</td>
<td>8.9%</td>
</tr>
<tr>
<td>C 4/90</td>
<td>9.8%</td>
</tr>
<tr>
<td>D 25</td>
<td>2.9%</td>
</tr>
<tr>
<td>D 15</td>
<td>7.9%</td>
</tr>
<tr>
<td>D 4</td>
<td>5.9%</td>
</tr>
</tbody>
</table>

Shelf-life:
HBB >> PPB > UC
At 35 °C, roasted > raw
Summary

Chemical
• ↑ values → ↓ overall acceptability and ↑ rejection rate
• Univariate analysis revealed ...
  • Overall acceptability: $a_w >$ FFAs > PVs
  • Rejection rate: FFAs > PVs

Textural
• ↑ FPs, ADs → ↑ overall acceptability and ↓ rejection rate
• ↑ AGs → ↓ overall acceptability and ↑ rejection rate
• Univariate analysis revealed ...
  • FPs > ADs
Overall Study Conclusions

• For both raw and roasted almonds, an interaction of chemical and textural parameters predicted shelf life.

• Both temperature and humidity are important to regulate during storage ...
  – Almonds stored at higher $T_s$ degraded more rapidly than counterparts at lower $T_s$.
  – Almonds stored at higher $\%RH$ degraded more rapidly than counterparts at lower $\%RH$

• Using univariate analysis, $a_w$ and $MC$ were determined to be the better predictors of overall acceptability and rejection rate.
Acknowledgments

Almond Board of California
Guangwei Huang
Karen Lapsley
Managing Moisture to Maximize Shelf Life of Almonds

Kenneth S. Marsh, PhD, CPP, CFS
Kenneth S. Marsh & Associates, Ltd.
www.drkenmarsh.com
42nd Almond Annual Conference
Sacramento Convention Center
December 6, 2017
Shelf Life

• Time after production that a food product remains acceptable

• Factors effecting shelf life:
  – Product
  – Processing
  – Packaging
  – Storage environment
  – Company standards
Some Comments

- Safety is mandatory; quality is optional
- Definition of acceptability is important
- Multiple degradation - pick most critical
- Packaging contains, protects, presents
- Distribution plays an important role

- Modeling lets you “try” alternatives
Almond Package Examples from China Market
Local Packages and Dates

- Best before 1/15/19
- Best before 10/22/18
- Best by 7/6/18
- Sell before 4/4/18
- Best by 7/2018
- Best by 7/2018
- Best by 5/12/20
### Claimed Best by Quality Remaining (months) for Some Commercial Almond Products

<table>
<thead>
<tr>
<th>Package – from “Best by:” and “Sell by” dates</th>
<th>Ambient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Almonds in PETE tub</td>
<td>6</td>
</tr>
<tr>
<td>Almonds-All Natural - in pouch (suggest fridge)</td>
<td>9</td>
</tr>
<tr>
<td>Trail Mix - clear stand-up pouch</td>
<td>9</td>
</tr>
<tr>
<td>100 Calorie Almonds – pouch-in-box</td>
<td>12</td>
</tr>
<tr>
<td>Wasabi-Soy Almonds - foil stand-up pouch</td>
<td>14</td>
</tr>
<tr>
<td>Whole Natural - in can</td>
<td>19</td>
</tr>
</tbody>
</table>
Shelf Life Modeling

- Product parameters: initial moisture, critical moisture, moisture isotherm that defines moisture impact.
- Packaging parameters: WVTR, thickness, area, net weight
- Environmental parameters: Temperature, relative humidity

Assumed in 12 oz. package of OPP25/ink/adh/EVOH50 – WVTR 0.258
Shelf Life Model

Shelf Life = \frac{\ln \left( \frac{M_e - M_i}{M_e - M_c} \right)}{\left( \text{WVTR} \times \left( \frac{A}{100} \times W_s \right) \times \left( \frac{P_o}{b} \right) \right)}

Me, Mi, Mc = equilibrium, initial, critical moistures
WVTR = Water Vapor Transmission Rate
Ws = Weight solids
A = Area of package
Po = Saturated vapor pressure
b = slope isotherm
Estimation of Shelf Life Potential Based on Moisture Adsorption

• Estimation assumption – Shelf life is defined by moisture content:
  – Initial moisture: 5.0%  
  – End moisture: 6.0%

  12 oz. package

  OPP25/ink/adh/EVOH50 – WVTR 0.258

  Same size flexible pouch

Note: Almonds are both moisture and oxygen sensitive. Shelf life is determined by that parameter that makes the product unacceptable first, and can be packaging dependent. If you use an excellent moisture barrier, rancidity can be the critical factor.

Oxidation is complex, based on history and harder to model.
Obtaining Equilibrium Moisture and Slope from Moisture Adsorption Isotherms

MOISTURE MIGRATION AND MANAGEMENT

Relative Humidity and Moisture

Almonds can pick up or lose moisture depending on their initial moisture content and the relative humidity of the surrounding environment — called moisture migration. Unharnessed moisture migration in almonds may affect texture, microbial stability and the rate of various reactions that impact shelf life. When almonds pick up moisture (adsorption), they may lose some of their crunch; most may start to turn, and fat oxidation increases. Moisture loss adsorptions may lead to some desirable changes, such as more caramelized, but at very low moisture limits, oxidation also increases.

Moisture migration occurs until equilibrium within the system is reached; almonds in high-humidity environments will generally pick up moisture, especially at ambient and higher temperatures. Stopping moisture migration requires either a moisture barrier package and/or reducing the humidity of the environment.

The effects of environmental RH on almond moisture levels are expressed by water suction isotherms. As shown from almond adsorption at a range from 20 to 60% RH, almonds will retain moisture levels from 2 to 6% RH. At these levels, almonds are less prone to biological or chemical reactions. Moisture levels less than 4% RH are often not achieved at environmental conditions of 30 to 64% RH. During storage, managing environmental humidity is key to preserving almond quality. It is critical to maintain a dry environment if the moisture levels in almonds will not fluctuate over storage.

Studies at the University of California, Davis, indicate that different varieties or sizes of whole almond kernels and packaged or unpackaged almonds interact similarly with environmental RH, but roasted and blanched almonds interact differently.

Relative humidity fluctuations will affect almond moisture changes, which will impact texture quality. This online moisture and texture model demonstrates the effects of environmental RH on almond moisture content and the impact on texture properties.

To use the online moisture and texture model, click the image below.

### WVTR of Packaging Materials Used by Almond Stakeholders

<table>
<thead>
<tr>
<th>Package</th>
<th>g/100in²/day</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.25 mil NA940 – LLDPE</td>
<td>0.88</td>
</tr>
<tr>
<td>OPP25/ink/adh/EVOH50</td>
<td>0.258</td>
</tr>
<tr>
<td>48gaPET/DL/48gaVMPET/DL/320gaLLDPE</td>
<td>0.18</td>
</tr>
<tr>
<td>Nylon (MVTR from spec sheet)</td>
<td>0.077</td>
</tr>
<tr>
<td>PP/ink/adh/MPET/adh/PE</td>
<td>0.05</td>
</tr>
<tr>
<td>76gaOPP/DL/48gaVMPET/DL/160gaLLDPE</td>
<td>0.05</td>
</tr>
<tr>
<td>Foil</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>48gaPET/12#PE/.000285Foil/12#PE/150gaLLDPE</td>
<td>0.0006</td>
</tr>
</tbody>
</table>

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Time to attain 6% moisture for Monterey Raw Unpasteurized at (25°C/65%RH)

<table>
<thead>
<tr>
<th>Package</th>
<th>Shelf Life-days</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Packaging Film</td>
<td>3</td>
</tr>
<tr>
<td>1.25 mil NA940 – LLDPE</td>
<td>88</td>
</tr>
<tr>
<td>OPP25/ink/adh/EVOH50</td>
<td>94</td>
</tr>
<tr>
<td>48gaPET/DL/48gaVMPET/DL/320gaLLDPE</td>
<td>134</td>
</tr>
<tr>
<td>Nylon (MVTR from spec sheet)</td>
<td>314</td>
</tr>
<tr>
<td>PP/ink/adh/MPET/adh/PE</td>
<td>484</td>
</tr>
<tr>
<td>76gaOPP/DL/48gaVMPET/DL/160gaLLDPE</td>
<td>484</td>
</tr>
<tr>
<td>Foil</td>
<td>years</td>
</tr>
<tr>
<td>48gaPET/12#PE/.000285Foil/12#PE/150gaLLDPE</td>
<td>years</td>
</tr>
</tbody>
</table>
## Effects of Relative Humidity and Temperature to attain 6% (months)

<table>
<thead>
<tr>
<th>Product</th>
<th>10°C/65%</th>
<th>15°C/50%</th>
<th>15°C/65%</th>
<th>25°C/65%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monterey-Raw pasteurized</td>
<td>23.2</td>
<td>stable</td>
<td>12.6</td>
<td>28.0</td>
</tr>
<tr>
<td>Monterey-Raw unpasteurized, no package</td>
<td>3 days</td>
<td>stable</td>
<td>3 days</td>
<td>3 days</td>
</tr>
<tr>
<td>Monterey-Raw unpasteurized</td>
<td>14.7</td>
<td>stable</td>
<td>13.3</td>
<td>9.9</td>
</tr>
<tr>
<td>Monterey-Raw blanched</td>
<td>37.9</td>
<td>stable</td>
<td>68.9</td>
<td>stable</td>
</tr>
<tr>
<td>Nonpareil-Raw pasteurized</td>
<td>stable</td>
<td>stable</td>
<td>stable</td>
<td>stable</td>
</tr>
<tr>
<td>Nonpareil-Raw unpasteurized</td>
<td>30.7</td>
<td>stable</td>
<td>29.0</td>
<td>stable</td>
</tr>
<tr>
<td>Carmel-Raw pasteurized</td>
<td>stable</td>
<td>stable</td>
<td>stable</td>
<td>stable</td>
</tr>
<tr>
<td>Carmel-Blanched</td>
<td>stable</td>
<td>stable</td>
<td>stable</td>
<td>stable</td>
</tr>
</tbody>
</table>

Assumed in 12 oz. package of OPP25/ink/adh/EVOH50 – WVTR 0.258
Attaining 6% moisture under accelerated conditions (months)

<table>
<thead>
<tr>
<th>Product</th>
<th>10°C/75%</th>
<th>15°C/75%</th>
<th>25°C/75%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monterey-Raw pasteurized</td>
<td>7.8</td>
<td>6.5</td>
<td>4.8</td>
</tr>
<tr>
<td>Monterey-Raw unpasteurized</td>
<td>5.8</td>
<td>4.8</td>
<td>3.1</td>
</tr>
<tr>
<td>Monterey-Raw blanched</td>
<td>10.2</td>
<td>8.2</td>
<td>7.2</td>
</tr>
<tr>
<td>Nonpareil-Raw pasteurized</td>
<td>9.2</td>
<td>7.5</td>
<td>5.1</td>
</tr>
<tr>
<td>Nonpareil-Raw unpasteurized</td>
<td>8.9</td>
<td>7.2</td>
<td>4.8</td>
</tr>
<tr>
<td>Carmel-Raw pasteurized</td>
<td>12.3</td>
<td>8.9</td>
<td>6.1</td>
</tr>
<tr>
<td>Carmel-Blanched</td>
<td>18.8</td>
<td>11.6</td>
<td>8.9</td>
</tr>
</tbody>
</table>

Assumed in 12 oz. package of OPP25/ink/adh/EVOH50 – WVTR 0.258
Other Shelf Life Impact Factors

• Larger size – area goes up as square, volume as cube → longer shelf life. Note: Bulk packaging does not fit model. It’s longer!

• Better barrier usually increases shelf life

• Faster distribution reduces requirement

• Oxidation is a function of history/product handling in addition to barrier and package size.
Model Capabilities

• Shelf life v. Barrier or Barrier v. Shelf life
• Area/net wt. or Volume v. Shelf life
• Initial or Critical moisture v. Shelf life
• Moisture level v. Storage time
• Shelf life v. Temperature
• Available Shelf life in real world conditions
# Impact of Initial and End Moisture Levels, and Relative Humidity (Monterey Raw Unpasteurized)

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<th>Mc</th>
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Shelf Life Verify

- Shipping tests
- Storage tests
- Accelerated tests
  - Temperature
  - Permeability

- Models can improve choices for testing
“Proposal” System

- **Products Released On Properties Obviously Selected for Additional Life**
- Record temperature/RH in real time
- Use information to calculate available shelf life remaining
- Ship on the basis of shortest available shelf life
- For normal shipments - this defaults to FIFO
- For abused shipments, it would add profits
Thank you!
What’s Next

Almond Stage Presentation at 3:00 p.m.
• How Important is the Quality of Data from In-Field Sensors in Making Accurate Navel Orangeworm Treatment Decisions in Almonds?, presented by Semios

Almond Stage Presentation at 3:30 p.m.
• Navigate Your Utility Bill, presented by Coldwell Solar

3:00 p.m. – 5:00 p.m. Coffee Break is sponsored by Actagro