Characteristics of California Almonds

December 8, 2015
Speakers

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The Chemistry of Almond Flavor

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University of California Davis
What is an Almond?

- An almond (Prunus dulcis), botanically, is the seed (fruit) of a drupe
  - Not a true nut
  - A member of the rose family and is related to peaches, plums, apricots and cherries
  - Native to the Middle East and South Asia
- Consumed since the Early Bronze Age (3000-2000 BCE)
- Convenient, dense source of energy that naturally stores well
  - Consumption is associated with a reduced risk of CVD
Almond Composition

- Almonds are composed of:
  - Fat (~51-60%)
  - Protein (~21%)
  - Carbohydrate (11%)
  - Varies depending upon the cultivar
- Almond fat is composed of triglycerides
  - A triglyceride is 3 fatty acid molecules attached to a molecule of glycerol
Lipid Composition of Almonds

- Fatty acids can be saturated (no double bonds) or unsaturated (double bonds)
- The primary fatty acids in almonds are:

<table>
<thead>
<tr>
<th>Name</th>
<th>Number of Carbons:Double bonds</th>
<th>Percent in Almond Oil</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oleic</td>
<td>18:1</td>
<td>60-75%</td>
</tr>
<tr>
<td>Linoleic</td>
<td>18:2</td>
<td>19-30%</td>
</tr>
<tr>
<td>Palmitic</td>
<td>16:0</td>
<td>0.5-8%</td>
</tr>
<tr>
<td>Stearic</td>
<td>18:0</td>
<td>1-3%</td>
</tr>
</tbody>
</table>

- “Heathy fats” – primarily unsaturated
What is Flavor?

• Flavor is a composite quality:

• A combination of sensations from taste buds in the mouth and odor receptors in the nose
  – Taste: The human tongue can distinguish 5 basic flavors: sweet, sour, salty, bitter, and savory
  – Aroma: hundreds of aroma molecules

• Taste is also influenced by:
  – Chemical irritation: peppers, burning, etc.
  – Temperature sensation
Raw Almond Taste

- Almonds are composed mainly of fat, protein, sugars and fiber
  - Primary drivers of almond taste
- A bitter compound called amygdalin and astringent tannins (skin)
  - Sweet almonds varieties contain very low levels of amygdalin
- Fat creates a rich taste, and lack of acid enhances sweetness of starch and sugar in almonds

<table>
<thead>
<tr>
<th>Macronutrient</th>
<th>Range in CA-grown almonds (% g/g almond)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lipids</td>
<td>35-66</td>
</tr>
<tr>
<td>Protein</td>
<td>16-23</td>
</tr>
<tr>
<td>Sugars</td>
<td>2.1-7.4</td>
</tr>
<tr>
<td>Fiber</td>
<td>11-14</td>
</tr>
</tbody>
</table>
Almond Taste & Bitterness

• Raw almonds are subjectively characterized into three phenotypes:
  • Non-bitter
    – Sweet snacking almonds (nutty flavor)
  • Semi-bitter
    – Often used in processing for their “marzipan-like taste”
  • Bitter
    – Determined by the content of the cyanogenic glycoside amygdalin
    – Bitter almonds contain 3-5% amygdalin and develop a cyanide aroma when moist
Characterizing Amygdalin Levels in California Almonds

- Non-bitter (10 commercial CA varieties)
  - 2.16-157.44 ppm
- Semi-bitter (4 varieties)
  - 523.50-1,772.75 ppm
- Bitter (6 varieties)
  - 33,006.60-53,998.30 ppm

We can now use amygladin levels to distinguish almond classification

Lee et al., J. Ag. Food Chem., 2013, 61, 7754-59
Amygdalin & Benzaldehyde

- Benzaldehyde is generated by the disruption of almond tissue (e.g. chewing) which enables the amygdalin to come into contact with hydrolytic enzymes to form hydrogen cyanide and benzaldehyde.

Benzaldehyde = amaretto aroma
Odor Threshold = 0.5 ppm

Bitterness = Combination of amygdalin levels and enzymatic hydrolysis rates
Aroma

• Aroma is based on the sense of smell
• Aroma involves chemoreception
  – the ability of the receptors in the nose to detect specific chemical compounds
• This stimulation results in the perception of aromas
• Aroma (smell) involves detection of hundreds of volatile compounds

https://www.rci.rutgers.edu/~uzwiak/AnatPhys/ChemicalSomaticSenses.htm
Almond Aroma = Volatile Molecules

- The aroma chemicals in almonds are volatiles
- Small and uncharged molecules that can easily move through the air
- This allows them to rise with the breath into the nasal passageways
- Each with different potency or odor threshold
- Warmer temperatures increases volatile
- Roasting creates and releases news aromas
Almond Aroma

- Will depends on whether almonds are raw or roasted
- When almonds are roasted they undergo many chemical reactions that lead to the creation and release of new volatile compounds
  - Development of brown pigments
- This happens through a series of chemical reactions generated through **Maillard Browning** reactions
- A reaction between a sugar and amino acid
Characterizing Volatile Aroma Compounds in Almonds

- With support of the ABC we developed a HS-SPME GC/MS method to measure a broad range of volatile compounds in raw and roasted almonds
  - Few studies on almonds volatiles before 2014
    - Little varietal information/incomplete characterization/solvent extraction
  - Characterize volatiles in:
    - Raw almonds
    - Roasted almonds
    - Stored almonds

Xiao et al., 2014; Food Chemistry, 151, 31–39
HS-SPME GC/MS Analysis of Almonds

• Head Space Solid Phase Micro-Extraction (HS-SMPE)
  – Traps the volatile molecules on a fiber

• Gas Chromatography with Mass Spectrometry (GC/MS)
  – GC separates the volatiles and the MS measures their gives us a picture and mass of the compound
GC/MS Chromatogram

- Picture of the volatiles in the sample
- Viewed as peaks that correspond to the individual volatile compounds
- Peak Identification:
  - Comparison of the $t_R$ and mass spectra (MS) with standards
  - Comparing $t_R$, MS and Kovats Index with NIST MS library's with 80% cut-off (no standard)
Volatiles Identified in Raw Almonds

• Identified: 13 carbonyls, 1 pyrazine, 20 alcohols, and 7 additional volatiles

• Key Compounds
  – Benzaldehyde, the breakdown product of amygladin, was the predominant volatile in raw almonds (2,934.6 ± 272.5 ppb)
    • Almond-like aroma
  – Hexanal (422.6 ± 97.9 ppb)
    • Fruity/green (cut grass)
  – 2-phenylethanol (6.2 ± 0.6 ppb)
    • Floral
  – Limonene (16.6 ± 0.5 ppb)
    • Pine/citrus

Xiao et al., J. Food Chemistry 151 (2014) 31-39
Volatile compounds were identified in roasted almonds and include:

- Ketones, aldehydes, pyrazines, alcohols, aromatic hydrocarbons, furans, and pyrroles
- These volatile compounds are generated through the Maillard reaction and via lipid oxidation (kernels are 48-67% oil)
- Pyrazines, furans and alcohols are key components of roasted almond flavor
  - Pyrazines: Maillard sugar-amine reactions and Strecker degradation
  - Furan-containing compounds: thermal degradation of sugars
  - Alcohols and aldehydes: lipid oxidation
## Volatiles in Fresh Roasted Almonds

<table>
<thead>
<tr>
<th>Acids</th>
<th>Alcohol</th>
<th>Ketones</th>
<th>Esters</th>
<th>Sulfur Compounds</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acetic acid</td>
<td>vinegary, sour</td>
<td></td>
<td></td>
<td>Methanethiol</td>
</tr>
<tr>
<td>Butanoic acid, 3-methyl-</td>
<td>sweaty</td>
<td></td>
<td></td>
<td>sulfur, gasoline, garlic</td>
</tr>
<tr>
<td>1-Pentanol, 2-methyl-</td>
<td>pungent</td>
<td></td>
<td></td>
<td>Dimethyl sulfide</td>
</tr>
<tr>
<td>1-Butanol</td>
<td>medicine, fruit, wine</td>
<td></td>
<td></td>
<td>Disulfide, dimethyl</td>
</tr>
<tr>
<td>1-Butanol, 2-methyl-</td>
<td>malt</td>
<td></td>
<td></td>
<td>Methylthio-2-propanone</td>
</tr>
<tr>
<td>1-Pentanol, 3-methyl-</td>
<td>pungent</td>
<td></td>
<td></td>
<td>Methional</td>
</tr>
<tr>
<td>1-Pentanol</td>
<td>fruit</td>
<td></td>
<td></td>
<td>Ethanol, 2-(ethylthio)-</td>
</tr>
<tr>
<td>Acetoin</td>
<td>butery, cream</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2-Propanol, 1-chloro-</td>
<td></td>
<td></td>
<td></td>
<td>Methanethiol</td>
</tr>
<tr>
<td>3-Pentanol</td>
<td>green, herbal</td>
<td></td>
<td></td>
<td>sulfur, gasoline, garlic</td>
</tr>
<tr>
<td>1-Hexanol</td>
<td>resin, flower, green</td>
<td></td>
<td></td>
<td>Dimethyl sulfide</td>
</tr>
<tr>
<td>(S)-(+)2-Chloro-1-propanol</td>
<td>pleasant, alcohol-like</td>
<td></td>
<td></td>
<td>Disulfide, dimethyl</td>
</tr>
<tr>
<td>1-Octen-3-ol</td>
<td>moss, nut, mushroom</td>
<td></td>
<td></td>
<td>Methylthio-2-propanone</td>
</tr>
<tr>
<td>1-Heptanol</td>
<td>herb</td>
<td></td>
<td></td>
<td>Methional</td>
</tr>
<tr>
<td>2,3-Butanediol, [S-(R*,R*)]-</td>
<td>Fruity</td>
<td></td>
<td></td>
<td>Ethanol, 2-(ethylthio)-</td>
</tr>
<tr>
<td>1-Octanol</td>
<td>chemical, metal, burnt</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Propylene Glycol</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phenylethyl Alcohol</td>
<td>floral, hyacinth/gardenia</td>
<td></td>
<td></td>
<td>Methanethiol</td>
</tr>
</tbody>
</table>

| Terpenes | | | | |
| Alpha Pinene | pine, terpentine | | | sulfur, gasoline, garlic |
| D-Limonene | Fruity, citrus | | | Dimethyl sulfide |

<table>
<thead>
<tr>
<th>Ketones</th>
<th>Esters</th>
<th>Sulfur Compounds</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acetone</td>
<td>pungent, solvent</td>
<td>Methanethiol</td>
</tr>
<tr>
<td>2-Butanone</td>
<td>sharp, sweet, butterscotch</td>
<td>sulfur, gasoline, garlic</td>
</tr>
<tr>
<td>2-Pentanone</td>
<td>pungent, nail polish</td>
<td>Dimethyl sulfide</td>
</tr>
<tr>
<td>2,3-Pentanedione</td>
<td>cream, butter</td>
<td>Disulfide, dimethyl</td>
</tr>
<tr>
<td>3-Penten-2-one</td>
<td>fruity, fish</td>
<td>Methylthio-2-propanone</td>
</tr>
<tr>
<td>2-Heptanone</td>
<td>cheesy, banana, fruity</td>
<td>Methional</td>
</tr>
<tr>
<td>Acetic acid, methyl ester</td>
<td>glue, nail polish remover</td>
<td>Ethanol, 2-(ethylthio)-</td>
</tr>
<tr>
<td>Ethyl acetate</td>
<td>fruity, glue, nail polish</td>
<td></td>
</tr>
</tbody>
</table>
# Volatiles in Fresh Roasted Almonds

<table>
<thead>
<tr>
<th>Type of Compound</th>
<th>Compound Name</th>
<th>Descriptor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pyrazine</td>
<td>2,5 Dimethyl pyrazine</td>
<td>Earthy, nutty, roasted nut, cocoa, roast beef</td>
</tr>
<tr>
<td></td>
<td>Methyl Pyrazine</td>
<td>Popcorn</td>
</tr>
<tr>
<td></td>
<td>Pyrazine, 2-ethyl-5-methyl-</td>
<td>fruity, sweet</td>
</tr>
<tr>
<td></td>
<td>Pyrazine, trimethyl-</td>
<td>roast, potato, must</td>
</tr>
<tr>
<td></td>
<td>Pyrazine, 2-ethenyl-6-methyl-</td>
<td>earthy</td>
</tr>
<tr>
<td></td>
<td>Pyrazine, 3-ethyl-2,5-dimethyl-</td>
<td>Brothy, roast, potato</td>
</tr>
<tr>
<td></td>
<td>Pyrazine, 2,3-dimethyl-</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pyrazine, 2,6-diethyl-</td>
<td>tobacco</td>
</tr>
<tr>
<td></td>
<td>Furfural</td>
<td>bread, almond, sweet</td>
</tr>
<tr>
<td></td>
<td>3-Furaldehyde</td>
<td>bread, almond, sweet</td>
</tr>
<tr>
<td></td>
<td>2-Acetyl-1-pyrroline</td>
<td>Buttery popcorn</td>
</tr>
<tr>
<td></td>
<td>Pentyl Oxirane</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2-Pentyl Furan</td>
<td>green bean, butter</td>
</tr>
<tr>
<td></td>
<td>Furaneol</td>
<td>caramel</td>
</tr>
<tr>
<td></td>
<td>Pyrrole</td>
<td>nutty</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Type of Compound</th>
<th>Compound Name</th>
<th>Descriptor</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Propanal</td>
<td>pungent, solvent</td>
</tr>
<tr>
<td></td>
<td>Propanal, 2-methyl-</td>
<td>cooked, caramel</td>
</tr>
<tr>
<td></td>
<td>Butanal</td>
<td>green, pungent</td>
</tr>
<tr>
<td></td>
<td>Butanal, 2-methyl-</td>
<td>cocoa, pungent</td>
</tr>
<tr>
<td></td>
<td>Butanal, 3-methyl-</td>
<td>malt</td>
</tr>
<tr>
<td></td>
<td>Pentanal</td>
<td>almond, malt, pungent</td>
</tr>
<tr>
<td></td>
<td>Hexanal</td>
<td>grass, green, tallow, fat</td>
</tr>
<tr>
<td></td>
<td>2-Butenyl, 2-methyl-</td>
<td>green, fruit</td>
</tr>
<tr>
<td></td>
<td>Heptanal</td>
<td>fat, citrus, rancid</td>
</tr>
<tr>
<td></td>
<td>Octanal</td>
<td>Citrus-like, soapy</td>
</tr>
<tr>
<td></td>
<td>Nonanal</td>
<td>Soapy, citrus-like</td>
</tr>
<tr>
<td></td>
<td>Decanal</td>
<td>Soapy, citrus-like, tallow</td>
</tr>
<tr>
<td></td>
<td>Benzaldehyde</td>
<td>almond, sweet</td>
</tr>
<tr>
<td></td>
<td>Benzeneacetaldehyde</td>
<td>pungent, phenolic</td>
</tr>
<tr>
<td></td>
<td>2-Decenal, (Z)-</td>
<td>tallow, fat</td>
</tr>
</tbody>
</table>
Volatiles Change with Roasting Time/Temp

<table>
<thead>
<tr>
<th>possible compounds</th>
<th>raw</th>
<th>28 min</th>
<th>33 min</th>
<th>38 min</th>
<th>increase&lt;sup&gt;a&lt;/sup&gt; (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>aldehydes and ketones</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>butanal</td>
<td>19.6 ± 2.7</td>
<td>27.6 ± 1.5&lt;sup&gt;a&lt;/sup&gt;</td>
<td>29.3 ± 0.6&lt;sup&gt;a&lt;/sup&gt;</td>
<td>40.8 ± 2.1&lt;sup&gt;a&lt;/sup&gt;</td>
<td>67&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>2-methylbutanal</td>
<td>14.3 ± 0.3</td>
<td>146.6 ± 25.7&lt;sup&gt;a&lt;/sup&gt;</td>
<td>500.3 ± 241.1&lt;sup&gt;a&lt;/sup&gt;</td>
<td>657.3 ± 275.0&lt;sup&gt;a&lt;/sup&gt;</td>
<td>3021&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>1-methylbutanal</td>
<td>32.4 ± 0.5</td>
<td>911.4 ± 50.9&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2867.4 ± 71.1&lt;sup&gt;a&lt;/sup&gt;</td>
<td>4268.9 ± 381.8&lt;sup&gt;a&lt;/sup&gt;</td>
<td>8167&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>2,3-butanedione</td>
<td>8.0 ± 0.3</td>
<td>100.3 ± 0.8&lt;sup&gt;a&lt;/sup&gt;</td>
<td>163.7 ± 1.3&lt;sup&gt;a&lt;/sup&gt;</td>
<td>226.3 ± 13.7&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1940&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>pentanal</td>
<td>50.4 ± 5.7</td>
<td>223.0 ± 8.6&lt;sup&gt;a&lt;/sup&gt;</td>
<td>169.0 ± 5.1&lt;sup&gt;a&lt;/sup&gt;</td>
<td>264.1 ± 15.9&lt;sup&gt;a&lt;/sup&gt;</td>
<td>334&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>hexanal</td>
<td>422.6 ± 97.9</td>
<td>983.0 ± 133.7&lt;sup&gt;a&lt;/sup&gt;</td>
<td>689.0 ± 78.1&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1140.8 ± 3.8&lt;sup&gt;a&lt;/sup&gt;</td>
<td>122&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>2-heptanone</td>
<td>50.0 ± 4.7</td>
<td>72.0 ± 7.5&lt;sup&gt;a&lt;/sup&gt;</td>
<td>71.0 ± 6.3&lt;sup&gt;a&lt;/sup&gt;</td>
<td>123.6 ± 3.0&lt;sup&gt;a&lt;/sup&gt;</td>
<td>78&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>heptanal</td>
<td>40.5 ± 8.9</td>
<td>75.2 ± 16.2&lt;sup&gt;a&lt;/sup&gt;</td>
<td>57.1 ± 4.0</td>
<td>114.8 ± 3.0&lt;sup&gt;a&lt;/sup&gt;</td>
<td>103&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>2-hexanal</td>
<td>[almond/green leaf]</td>
<td>ND&lt;sup&gt;b&lt;/sup&gt;</td>
<td>14.6 ± 2.7</td>
<td>11.3 ± 2.2</td>
<td>14.1 ± 2.7</td>
</tr>
<tr>
<td>2-methylfuran-3-one</td>
<td>[rummy/nut]</td>
<td>ND&lt;sup&gt;b&lt;/sup&gt;</td>
<td>15.4 ± 1.3</td>
<td>86.3 ± 4.2</td>
<td>128 ± 11.0</td>
</tr>
<tr>
<td>3-hydroxybutan-2-one</td>
<td>[buttery]</td>
<td>ND&lt;sup&gt;b&lt;/sup&gt;</td>
<td>22 ± 0.2</td>
<td>3.0 ± 0.1</td>
<td>3.8 ± 0.6</td>
</tr>
<tr>
<td>octanal</td>
<td>25.2 ± 4.7</td>
<td>31.1 ± 7.3</td>
<td>18.5 ± 6.3</td>
<td>42.0 ± 3.0</td>
<td>21&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>1-hydroxypropan-2-one</td>
<td>1.3 ± 0.0</td>
<td>9.0 ± 0.9&lt;sup&gt;a&lt;/sup&gt;</td>
<td>11.0 ± 0.0&lt;sup&gt;a&lt;/sup&gt;</td>
<td>13.7 ± 3.0&lt;sup&gt;a&lt;/sup&gt;</td>
<td>771&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>(Z)-2-heptenal</td>
<td>19.1 ± 0.9</td>
<td>65.6 ± 13.2&lt;sup&gt;a&lt;/sup&gt;</td>
<td>36.5 ± 4.6</td>
<td>61.9 ± 1.6&lt;sup&gt;a&lt;/sup&gt;</td>
<td>186&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>nonanal</td>
<td>36.6 ± 4.9</td>
<td>55.9 ± 13.3</td>
<td>34.6 ± 4.0</td>
<td>70.5 ± 18.9</td>
<td>47&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>(E)-2-octenal</td>
<td>7.3 ± 0.9</td>
<td>12.5 ± 2.1</td>
<td>8.3 ± 0.1</td>
<td>15.9 ± 2.0</td>
<td>67&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>furfural</td>
<td>[brown/caramel]</td>
<td>ND&lt;sup&gt;b&lt;/sup&gt;</td>
<td>103.2 ± 8.7&lt;sup&gt;a&lt;/sup&gt;</td>
<td>366 ± 13.2&lt;sup&gt;a&lt;/sup&gt;</td>
<td>460.0 ± 21.4&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>decanal</td>
<td>[aldehyde]</td>
<td>ND&lt;sup&gt;b&lt;/sup&gt;</td>
<td>6.9 ± 2.3</td>
<td>5.0 ± 1.6</td>
<td>4.6 ± 1.0</td>
</tr>
<tr>
<td>benzaldehyde:</td>
<td>[almond/marzipan]</td>
<td>2934.6 ± 272.5</td>
<td>368.8 ± 41.2&lt;sup&gt;a&lt;/sup&gt;</td>
<td>246.7 ± 53.0&lt;sup&gt;a&lt;/sup&gt;</td>
<td>331.9 ± 63.4&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>(Z)-2-nonenal</td>
<td>[green]</td>
<td>ND&lt;sup&gt;b&lt;/sup&gt;</td>
<td>ND</td>
<td>ND</td>
<td>53.1 ± 7.7</td>
</tr>
<tr>
<td>2-phenylacetaldhey</td>
<td>[honey/floral]</td>
<td>ND&lt;sup&gt;b&lt;/sup&gt;</td>
<td>107.5 ± 20.7</td>
<td>284.0 ± 22&lt;sup&gt;a&lt;/sup&gt;</td>
<td>491.3 ± 45.4&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

- Generated through lipid oxidation and the Maillard reaction
- Most compounds increase with roasting (exception is benzaldehyde)
Volatiles Change with Roasting Time/Temp

Roasted Nutty Flavors

<table>
<thead>
<tr>
<th>Compound</th>
<th>raw</th>
<th>28 min</th>
<th>33 min</th>
<th>38 min</th>
<th>Increase (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pyrazine</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2-methylpyrazine</td>
<td>ND</td>
<td>4.1 ± 0.3*</td>
<td>21.5 ± 0.6***</td>
<td>26.5 ± 1.8***</td>
<td>New</td>
</tr>
<tr>
<td>2,5-dimethylpyrazine</td>
<td>11.4 ± 0.5</td>
<td>16.2 ± 0.6***</td>
<td>53.3 ± 0.3***</td>
<td>66.5 ± 0.4***</td>
<td>298</td>
</tr>
<tr>
<td>2,6-dimethylpyrazine</td>
<td>ND</td>
<td>ND</td>
<td>2.8 ± 0.4**</td>
<td>4.2 ± 0.6***</td>
<td>New</td>
</tr>
<tr>
<td>2-ethylpyrazine</td>
<td>ND</td>
<td>ND</td>
<td>2.6 ± 0.1***</td>
<td>3.2 ± 0.1***</td>
<td>New</td>
</tr>
<tr>
<td>2,3-dimethylpyrazine</td>
<td>ND</td>
<td>ND</td>
<td>1.0 ± 0.1***</td>
<td>1.4 ± 0.1***</td>
<td>New</td>
</tr>
<tr>
<td>2-ethyl-6-methylpyrazine</td>
<td>ND</td>
<td>ND</td>
<td>1.7 ± 0.1***</td>
<td>2.2 ± 0.0***</td>
<td>New</td>
</tr>
<tr>
<td>trimethylpyrazine</td>
<td>ND</td>
<td>ND</td>
<td>4.5 ± 0.3***</td>
<td>6.1 ± 0.2***</td>
<td>New</td>
</tr>
</tbody>
</table>

- Six new pyrazines were identified in roasted almonds
  - 2-methylpyrazine likely occurred nonenzymatic browning during drying
- Generated through the Maillard reaction
- Most have low odor thresholds and increased with the degree of roast
Rancidity Another Source of Volatiles

- Rancidity is the unpalatable odor and flavor of deteriorating edible fats and oils in foods
- Problem that can develop with storage of almonds
- Rancidity occurs via two chemical reactions:
  - Oxidation
    - Oxygen attack of the triglycerides at double bonds
  - Hydrolysis
    - Addition of water across triglycerides and release of Fatty acids (FFAs)
Rancidity in Almonds

• Rancidity in almonds occurs primarily via the oxidation of oleic [18:1] and linoleic [18:2] acids
  – Double bonds
  – Initiated by exposure to heat (e.g. pasteurization, blanching, roasting, etc.), or oxygen exposure (e.g. during storage)

• Primary lipid oxidation products include:
  – Lipid hydroperoxides and conjugated dienes

• Secondary lipid breakdown products include:
  – Volatile compounds
    • Aldehydes (hexanal), ketones, off-odors
Accelerated Shelf-life Storage & Rancidity

- Nonpareil almonds were roasted at 60 min (240°F) light roast or 20 min at 315°F dark roast
- Almonds were stored at 39 + 2ºC and RH Humidity of 15 + 3%
- Almonds were stored in open bags to maximize oxidation during storage
- On-going
Monitoring Rancidity

- Goal of the Study:
- Primary Oxidation Products
  - Peroxide Value
- Secondary Oxidation Products
  - Volatiles by GC-MS
- Hydrolytic Rancidity
  - Free Fatty Acids
- Sensory Measures
  - Consumer Acceptance
  - Descriptive Analysis
# Volatiles Associated with Lipid Oxidation in Almonds

<table>
<thead>
<tr>
<th>Type of Compound</th>
<th>Name of Compound</th>
<th>Descriptor</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Aldehydes</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pentanal</td>
<td>almond, malt, pungent</td>
<td></td>
</tr>
<tr>
<td>Hexanal</td>
<td>grass, green, tallow</td>
<td></td>
</tr>
<tr>
<td>4-Pentenal</td>
<td>strawberry, fruit, tomato</td>
<td></td>
</tr>
<tr>
<td>Heptanal</td>
<td>fat, citrus, rancid</td>
<td></td>
</tr>
<tr>
<td>Octanal</td>
<td>Citrus-like, soapy</td>
<td></td>
</tr>
<tr>
<td>Nonanal</td>
<td>Soapy, citrus-like</td>
<td></td>
</tr>
<tr>
<td>2-Octenal, (E)-</td>
<td>fruity, soap, fatty</td>
<td></td>
</tr>
<tr>
<td>Decanal</td>
<td>Soapy, citrus-like, tallow</td>
<td></td>
</tr>
<tr>
<td>2-Decenal, (Z)-</td>
<td>tallow, fat</td>
<td></td>
</tr>
<tr>
<td>2-Heptenal, (Z)-</td>
<td>soap, fat, almond</td>
<td></td>
</tr>
<tr>
<td><strong>Ketones</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2,3-Pentanedione</td>
<td>cream, butter</td>
<td></td>
</tr>
<tr>
<td>2-Heptanone</td>
<td>cheesy, banana, fruity</td>
<td></td>
</tr>
<tr>
<td>2-Octanone</td>
<td>herb, butter, resin</td>
<td></td>
</tr>
<tr>
<td>1-Hepten-3-one</td>
<td>mushroom</td>
<td></td>
</tr>
<tr>
<td>3-Octen-2-one</td>
<td>nut, crushed bug</td>
<td></td>
</tr>
<tr>
<td>2-Propanone, 1-(acetyloxy)-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3-Heptanone, 2-methyl-</td>
<td>fruity</td>
<td></td>
</tr>
<tr>
<td>trans-3-Nonen-2-one</td>
<td>fruity, brandy, mushroom</td>
<td></td>
</tr>
<tr>
<td><strong>Esters</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acetic acid, octyl ester</td>
<td>fruity</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Type of Compound</th>
<th>Name of Compound</th>
<th>Descriptor</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Oxiranes/Heterocycles</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2-n-Butyl furan</td>
<td>spicy</td>
<td></td>
</tr>
<tr>
<td>Oxirane, pentyl-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oxirane, hexyl-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2(3H)-Furanone, 5-ethylidihydro-</td>
<td>spice</td>
<td></td>
</tr>
<tr>
<td>2H-Pyran-2-one, tetrahydro-6-methyl-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2(3H)-Furanone, dihydro-5-propyl-</td>
<td>nut, fat, fruit</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Type of Compound</th>
<th>Name of Compound</th>
<th>Descriptor</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Alcohols</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1-Butanol</td>
<td>medicine, fruit, wine</td>
<td></td>
</tr>
<tr>
<td>1-Butanol, 2-methyl-</td>
<td>malt</td>
<td></td>
</tr>
<tr>
<td>1-Pentanol</td>
<td>fruit</td>
<td></td>
</tr>
<tr>
<td>3-Octen-1-ol, (E)-</td>
<td>melon, earthy</td>
<td></td>
</tr>
<tr>
<td>1-Octen-3-ol</td>
<td>moss, nut, mushroom</td>
<td></td>
</tr>
<tr>
<td>1-Heptanol</td>
<td>herb</td>
<td></td>
</tr>
<tr>
<td>1-Octanol</td>
<td>chemical, metal, burnt</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Type of Compound</th>
<th>Name of Compound</th>
<th>Descriptor</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Acids</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acetic acid</td>
<td>vinegar, sour</td>
<td></td>
</tr>
<tr>
<td>Pentanoic acid</td>
<td>sweaty, pungent, putrid</td>
<td></td>
</tr>
<tr>
<td>Hexanoic acid</td>
<td>sweaty, pungent</td>
<td></td>
</tr>
<tr>
<td>Butanoic acid, 3-methyl-</td>
<td>sweaty</td>
<td></td>
</tr>
</tbody>
</table>
Comparison of Volatiles in Stored Almonds

. (▪ Just roasted ▪ 3 months storage ▪ 6 months storage)
Increases in Aldehydes During Storage (39°C)

Tallow, fat, rancid, soapy, green, citrus
Effectivity of PV as an Indicator of Rancidity

![Graph showing Peroxide Values and Hexanal Content for Dark Roasted Almonds]

- **PV**
- **Hexanal**
- 5 Millieq PV
- Still considered acceptable by Industry standards
Effectivity of FFA as an Indicator of Rancidity

- Slower to indicate significant changes
- does not follow hexanal
- May not be very useful
Conclusions

- Almond flavor is a composite quality that involves taste (fat, sugar, proteins, amygdalin, tannins) and volatiles (especially benzaldehyde).
- Flavor is influenced by roasting (development of pyrazines) and storage (lipid oxidation products).
- Changes in volatile aroma compounds may be the earliest indicators of quality losses, shelf life limits, and abuse.
- HOWEVER
  - Quantifying volatiles does not necessarily indicate the actual flavor of the almonds
    - Sensory thresholds
    - Concentration dependency of the various flavor attributes
    - Suppression/enhancement due to compounding effects of multiple molecules in the profile
    - Furthermore, knowing how the flavor is described does not indicate consumer ACCEPTANCE of products.
- There is a need for a comprehensive analysis to connect chemical measures with sensory data
  - Poster #32
- This research is underway in conjunction with the National Foods Lab.

Poster #32
Acknowledgements
Advancing Knowledge a Team Effort

- UC Davis
  - Cristian Rogel Castillo, PhD candidate
  - Arunwong Opastpongkarn, BS student
  - Tom Gradziel, PhD

- Food Safety and Measurement Facility

- Almond Board of California
  - Guangwei Huang, PhD
  - Karen Lapsley, PhD

- Agilent Technologies

- Phil Wilie, PhD

- John Kinsella Endowment
Profiling Sensory Differences in Almond Varieties

Dr Dawn Chapman & Dr Ellie King

The National Food Lab, Livermore CA
Content

- Capabilities of The NFL
- Methodology – Descriptive Analysis
- Results
- Key Findings
The NFL Overview

What We Do

The NFL is a food and beverage consulting and testing firm providing creative, practical and science-based solutions for the following areas:

Product and Process Development
Safety and Quality
Sensory and Consumer Research
Who We Are

• Privately held company; over 35 years in operation
  – Technology & Product Design Centers located in the San Francisco Bay Area
  – Heritage in food safety, process validation and commercialization across product development continuum

• ≈ 150 employees
  – Highly experienced subject matter experts
  – 80+% of staff have BA/BS – 1/3 with Masters/PhD
Sensory Evaluation

Our Approach:

- Tap into our pool of 45 highly trained panelists with an average of 5 years of experience.
  - These are not Consumers and they do not provide their liking or opinions.
  - Skilled at describing sensory characteristics and intensity ratings of a wide variety of products.
  - Screened for olfactory & gustatory acuity and ability to describe flavor nuances.
  - Extensively screened and provided with 3+ months of training before qualification.
- Overseen by experienced panel leaders
  - Advanced degrees (Master’s or Ph.D. in Sensory Science)
Previous Almond Sensory Work

- **2006 – Sensory Spectrum – Almond Lexicon**
  - 36 samples representing 20 almond varieties used to develop lexicon
  - 86 attributes:
    - 15 appearance terms
    - 9 aroma terms
    - 36 flavor terms
    - 3 basic taste terms
    - 4 chemical-feeling factor terms
    - 19 textural terms
  - A large number of attributes used (entire overview of almond sensory profiles)
  - Limited examples of reference standards to use for translation and training
  - Extensive sample preparation
  - No statistics or mapping

- **2013 – UC Davis, Hildegard Heymann – develop a simple sensory analysis procedure**
  - 14 varieties – raw, pasteurized and roasted; shelled or unshelled; whole, sliced & diced
  - 31 attributes:
    - 4 appearance terms
    - 13 aroma/flavor terms
    - 3 basic taste terms
    - 11 texture terms
Background & Objectives

Background:
• The Almond Board of California was interested in understanding the variability in different almond varieties.
• The NFL conducted sensory descriptive analysis on 13 almond varieties from various Californian growing counties (43 almond samples in total).

Objectives:
• To describe the appearance, aroma, flavor and texture of 43 almond samples using trained sensory panelists.
• To create a sensory map to differentiate almond varieties based on their sensory profiles.
Product Descriptions

- 13 varieties (43 samples total)
- Raw and unpasteurized – Samples were sorted and dusted before evaluation.

<table>
<thead>
<tr>
<th>Variety</th>
<th>Number of samples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aldrich</td>
<td>4</td>
</tr>
<tr>
<td>Butte</td>
<td>4</td>
</tr>
<tr>
<td>Butte Padre</td>
<td>3</td>
</tr>
<tr>
<td>Carmel</td>
<td>2</td>
</tr>
<tr>
<td>Fritz</td>
<td>4</td>
</tr>
<tr>
<td>Indendence</td>
<td>1</td>
</tr>
<tr>
<td>Mission</td>
<td>4</td>
</tr>
<tr>
<td>Monterey</td>
<td>4</td>
</tr>
<tr>
<td>Nonpareil</td>
<td>4</td>
</tr>
<tr>
<td>Padre</td>
<td>1</td>
</tr>
<tr>
<td>Price</td>
<td>4</td>
</tr>
<tr>
<td>Sonora</td>
<td>4</td>
</tr>
<tr>
<td>Wood Colony</td>
<td>4</td>
</tr>
<tr>
<td>TOTAL</td>
<td>43</td>
</tr>
</tbody>
</table>
Methodology – Descriptive Analysis

- Descriptive testing was conducted by The National Food Lab using trained panelists.
- 10 panelists, 2 replications.
- Panelists participated in three 2-hour orientation sessions to discuss the samples and review the references.
- Samples were identified by 3-digit codes and were served in a randomized and balanced order.
- Panelists rated attribute intensities on 15-point line scales.
Key Sensory Attributes

- Aroma and Flavor
  - Total Aroma/Flavor Intensity
  - Sweet *
  - Bitter *
  - Sweet Aromatic (non-fruity)
  - Marzipan/Benzaldehyde
  - Fruity/Sour
  - Hay
  - Unripe/Beany
  - Woody
  - Musty/Earthy
  - Total Off Aroma/Flavor
    - Rubber/Medicinal
- Appearance
  - Average Darkness of Color
  - Diversity of Color
  - Average Length
  - Diversity of Shape/Size
  - Appearance of Ridges/Veins
- Texture – Initial (first 3 chews)
  - Hardness
  - Fracturability
  - Crunchy
  - Denseness
  - Roughness
- Texture – Chewdown
  - Chewiness
  - Cohesiveness of Mass
  - Moistness of Mass
  - Mealy Mouthcoating
  - Awareness of Skins
- Texture – Residual
  - Amount of Residual Particulate
  - Residual Toothpack
  - Astringent

* Flavor only
Flavor Profile

- Total Flavor Intensity **
- Sweet taste **
- Sweet Aromatic flavor **
- Marzipan/Benzaldehyde flavor
- Hay flavor **
- Woody flavor **
- Musty/Earthy flavor **

* 90% Confidence Level (Duncan’s)
** 95% Confidence Level (Duncan’s)
NSD: Not Significantly Different
Four Sensory Dimensions* Define the Perceptual Space for Raw Almonds

- Although appearance was a key differentiator of the samples, it was removed from further data analysis.

<table>
<thead>
<tr>
<th>Moist/Cohesive to Crunchy/Hard</th>
<th>Total Flavor</th>
<th>Awareness of Skins/ Rough</th>
<th>Marzipan/ Benzaldehyde to Hay flavor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crunchy</td>
<td>Hay aroma</td>
<td>Awareness of Skins</td>
<td>Hay flavor</td>
</tr>
<tr>
<td>Fracturability</td>
<td>Total Flavor intensity</td>
<td>Roughness</td>
<td>Opposing: Marzipan/ Benzaldehyde flavor</td>
</tr>
<tr>
<td>Hardness</td>
<td>Sweet taste</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Opposing:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moistness of Mass</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cohesiveness of Mass</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* A sensory dimension consists of sensory attributes that are related statistically, and tend to rise and fall together. They are determined by Principal Component Analysis, a data reduction technique that identifies key dimensions to describe the sensory differences among samples. The above 4 dimensions reflect 90% of the sensory variability within this sample set.
Perceptual Map of Dimensions 1 and 3 (Texture)

High Awareness of Skins/Rough

Low Awareness of Skins/Rough

D3 (14%)

D1 (45%)

High Moist/Cohesive

High Crunchy/Hard

buttes

Carmel

Monterey

Mission

Indendence

Price

Wood Colony

Sonora

Butte

Butte Padre

Nonpareil

Radich

Padre
Perceptual Map of Dimensions 1 and 3 (Texture)
Perceptual Map of Dimensions 2 and 4 (Flavor)

- High Hay flavor
- High Marzipan/Benzaldehyde flavor
- Low Total Flavor
- High Total Flavor
- D4 (13%)
- D2 (18%)

Points labeled:
- Aldrich
- Butte
- Butte Padre
- Carmel
- Fritz
- Independence
- Mission
- Monterey
- Nonpareil
- Price
- Sonora
- Wood Colony

Flavors:
- High Hay flavor
- High Marzipan/Benzaldehyde flavor

Legend:
- Purple: Aldrich
- Red: Butte
- Green: Butte Padre
- Purple: Carmel
- Blue: Fritz
- Pink: Independence
- Pink: Mission
- Blue: Monterey
- Red: Nonpareil
- Orange: Price
- Green: Sonora
- Grey: Wood Colony
Perceptual Map of Dimensions 2 and 4 (Flavor)
### Sensory Dimensions by Liking Segment & Product

<table>
<thead>
<tr>
<th>Almond Varieties</th>
<th>“Moist/ Cohesive”</th>
<th>“Crunchy/ Hard”</th>
<th>“Total Flavor”</th>
<th>“Awareness of Skin/Rough”</th>
<th>“Marzipan/ Benzaldehyde flavor”</th>
<th>“Hay Flavor”</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aldrich</td>
<td>Mid</td>
<td>Mid</td>
<td>High</td>
<td>Low</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Butte</td>
<td>Mid-High</td>
<td>Low-Mid</td>
<td>Low-Mid</td>
<td>Mid</td>
<td>Low-Mid</td>
<td>Mid-High</td>
</tr>
<tr>
<td>Butte Padre</td>
<td>Mid</td>
<td>Mid</td>
<td>Mid</td>
<td>Mid-High</td>
<td>Low-Mid</td>
<td>Low-Mid</td>
</tr>
<tr>
<td>Carmel</td>
<td>Mid</td>
<td>Mid</td>
<td>Mid</td>
<td>Mid</td>
<td>Mid</td>
<td>Mid</td>
</tr>
<tr>
<td>Fritz</td>
<td>High</td>
<td>Low</td>
<td>Mid</td>
<td>Mid</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Indendence (n=1)</td>
<td>Low-Mid</td>
<td>Mid-High</td>
<td>Mid</td>
<td>High</td>
<td>Mid</td>
<td>Mid</td>
</tr>
<tr>
<td>Mission</td>
<td>Mid</td>
<td>Mid</td>
<td>Low-Mid</td>
<td>Mid</td>
<td>Mid-High</td>
<td>Low-Mid</td>
</tr>
<tr>
<td>Monterey</td>
<td>Mid-High</td>
<td>Low-Mid</td>
<td>Mid</td>
<td>Mid</td>
<td>Mid</td>
<td>Mid</td>
</tr>
<tr>
<td>Nonpareil</td>
<td>Mid-High</td>
<td>Low-Mid</td>
<td>Mid-High</td>
<td>Low</td>
<td>Low</td>
<td>High</td>
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<tr>
<td>Padre (n=1)</td>
<td>Low</td>
<td>High</td>
<td>Low</td>
<td>Mid</td>
<td>Low</td>
<td>Mid</td>
</tr>
<tr>
<td>Price</td>
<td>Mid</td>
<td>Mid</td>
<td>Mid</td>
<td>Mid</td>
<td>Mid</td>
<td>Mid</td>
</tr>
<tr>
<td>Sonora</td>
<td>Low-Mid</td>
<td>Mid-High</td>
<td>Mid</td>
<td>Mid</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Wood Colony</td>
<td>Mid</td>
<td>Mid</td>
<td>High</td>
<td>Mid</td>
<td>Mid</td>
<td>Mid</td>
</tr>
</tbody>
</table>

- **High intensity**
- **Low intensity**
- **High variability**
Key Findings

- We found differences in the sensory profiles of 13 almond varieties.
  - Fritz had a different sensory profile to the other almond varieties and high consistency lot-to-lot. It was the most moist and cohesive sample, and was high in Marzipan/Benzaldehyde flavor.
  - Butte & Monterey had similar sensory profiles, however, they both had a high level of lot-to-lot variation.
  - Butte Padre, Price, Sonora and Wood Colony were similar in texture profile, but had flavor profile differences.
  - Independence was very high in Awareness of Skins/Rough, but only one sample was assessed for this variety.

- Lot-to-lot variability exists to a larger extent for some varieties than others, in particular Aldrich, Butte, Monterey and Wood Colony.
Next Steps

• Relate the sensory profiles to the analytical measures conducted in Alyson Mitchell’s laboratory at UC Davis.

• Collect consumer findings to understand which dimensions are most important to focus on for consumer liking of raw almonds.

• Are these findings stable over years?

• These sensory differences can then be translated and presented to Food Manufacturers and Retailers, to aid discussions around which almond products would best serve the purposes of the end-product.
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Descriptive Analysis and Consumer Testing of Almond Texture

Presented by Zata Vickers
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Objectives

- to measure sensory texture attributes of five types of almonds conditioned at 4 different moisture levels
- to measure liking of a subset of these products
- to compare the sensory texture measurements with consumer liking ratings and with moisture.
Descriptive Analysis

- 13 panelists
- Trained
  - Selected appropriate texture attributes
  - Established appropriate eating techniques
  - Practiced rating -- with feedback
Descriptive Analysis

- **Almonds tested:**
  - 5 almonds
    - Raw whole
    - Dry Roasted whole
    - Blanched whole
    - Blanched sliver
    - Sliced
  - 4 moistures
    - Very low (LL)
    - Low
    - Normal (Norm)
    - Adjusted Higher (High)
Descriptive Analysis

• Sensory procedure
  – Rated 20 samples twice over 5 sessions
  – Balanced for position and carryover
  – Rated each sample for 17 texture attributes
Lexicon

• **Surface**
  – Powdery/Fuzzy
  – Macro-roughness
  – Loose particles
  – Oiliness

• **First bite (with Molars)**
  – Hardness to split/crack
  – Crispness
  – Number of Pieces
  – Hardness to grind pieces

• **Chewdown**
  – Number of chews to bolus
  – Moistness of Mass (5 chews)
  – Cohesiveness of mass
  – Particulate mass (at swallowing)
  – Fibers between teeth
  – Crunchiness
  – Persistence of crunch
  – Number of swallows

• **Residual**
  – Toothpack
  – Loose particles
  – Fatty/oily film
Each attribute was rated on a 20-point scale

Moistness
Descriptive Analysis Results

- Used Principal Components Analysis (PCA) to make summary plots
  - Similar products are positioned close to each other
  - Axes represent latent (more basic, summary) variables
Blanched almonds are more moist and have more fatty film.

Whole almonds are harder, take more chewing.

Unblanched almonds are more powdery, have more loose particles and more surface roughness.
Whole almonds only

Component 1 (36%)
Component 2 (29%)

-2 -1.5 -1 -0.5 0 0.5 1 1.5 2

-2 -1.5 -1 -0.5 0 0.5 1

Blanch Whole Low
Blanch Whole LL
Blanch Whole High
Blanch Whole Norm
Blanch Whole LL
Blanch Whole Low

More dry

Blanched

Whole almonds only
PCA plot whole almonds only

Component 2 (29%)

Component 1 (36%)

- Powdery, macroroughness
- Cohesive mass
- Fatty film, moist
- Blanch Whole High
- Blanch Whole Low
- Blanch WholeLL
- Blanch Whole Norm
- Blanch Whole Low
- DryR High
- DryR Low
- DryR LL
- DryR Norm
- Raw High
- Raw Low
- Raw LL
- Raw Norm

Hard, crisp, crunchy

Hardness to split
Crispness
Persistence of crunch
Moistness of mass
Cohesiveness of mass
Fibers between teeth
Residual particles
Powdery, macroroughness
Loose particles
Moistness
Hardness to grind
Number of pieces
Number of chews
Fat film

Component 2 (29%)

Component 1 (36%)
PCAP plot whole almonds only PCs 1 & 2

Component 1 (36%)
Component 2 (29%)

- Powdery, macroroughness
- Cohesive mass
- Fatty film, moist
- Hard, crisp, crunchy
- More dry
- Water
- Moisture content
- Water activity
- Cohesiveness of mass
- Moistness of mass
- Fatty film
- Moiство
- Fibers between teeth
- Loose particles
- Residual particles
- Crispness
- Persistence of crunch
- Moistness of mass
- Cohesiveness of mass

Blanch Whole Low
Blanch Whole High
Blanch Whole Norm
Blanch Whole LL
Blanch Whole High
Blanch Whole Low
Raw Low
Raw High
Raw Norm
DryR Low
DryR High
DryR Norm
DryR LL

Consumer test

• 113 panelists
  – that had consumed almonds in the last month
  – no food allergies

• Whole almonds that spanned the range of the PCA space
Selected for consumer test

Component 1 (36%)
Component 2 (29%)

-2 -1.5 -1 -0.5 0 0.5 1 1.5 2

Whole almonds only

-2 -1.5 -1 -0.5 0 0.5 1 1.5 2

-2 -1.5 -1 -0.5 0 0.5 1 1.5 2

Blanch Whole
Normal

Blanch Whole High

Blanched

Blanched Whole 48

More dry

MONTEREY 48

DRY RN

DryR Low

DryR Norm

Raw LL

Raw Low

DryR High

Raw Norm

Raw High

Blanch Whole

Raw Low

DryR Low

DryR Norm

DRY RN

MONTEREY 48

Component 1 (36%)
Component 2 (29%)
Consumer test

• 113 panelists
  – that had consumed almonds in the last month
  – no food allergies

• 8 whole almonds that spanned the range of the PCA space

• Place the sample in their mouth, bite down and chew with their molars
  – Rated
    • Liking (overall, flavor, texture)
    • Hardness, crispness, crunchiness, toothpacking
Texture Liking matches overall liking
PCA for 8 whole almonds in the consumer test  Components 1 & 2

Component 1 (37 %)

Component 2 (13%)

Blanch Whole High

Blanch Whole LL

DryR high

DryR low

DryR Norm

Fibers between teeth

Cohesiveness of mass

Number of chews

Texture Liking

Crispness

Persistence of crunch

Hardness to grind

Hardness to split

Residual particles

Particle mass

Cohesiveness of mass

Fatty film

Loose particles

Toothpack

Fibers between teeth

Fatty film

Component 1 (37 %)
Water activity vs. crunchiness
Summary

- sliced and slivered almonds had less hardness and less crunchiness than whole almonds
- Crispness, hardness, crunchiness, and persistence of crunch decreased with increasing moisture content
- Consumer texture liking ratings were highly positively correlated with crispness, crunchiness, and persistence of crunch.
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