SENSORY AND ANALYTICAL: WHERE SCIENCE MEETS ART

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

- **Steve Lindsay**, Almond Quality Food Safety Committee, moderator
- **Guangwei Huang**, Almond Board of California
- **Ellie King**, MMR Research Worldwide
- **Alyson Mitchell**, UC Davis

Dr Ellie King
MMR Research Worldwide, Inc., Pleasantville NY

Sensory: Dr Dawn Chapman
Covance Food Solutions, Livermore CA

Chemistry: Dr Alyson Mitchell
UC Davis, Davis CA
Content

• About MMR

• Background & Objectives

• Methodology

• Results

• Key Findings
MMR has 4 Sensory Science Centres in the UK, US, Singapore & China

Over 25 years experience and 15 trained sensory panels globally

Each location is **purpose built** and fitted with:

- A kitchen/preparation area
- Large training/discussion rooms
- Light, temperature and odor controlled booths equipped with tablets

There are 3 **sensory descriptive analysis panels** in Pleasantville, NY and on-site client panels in the US:

- The first US panel was established in 2011
- These sensory panels consist of 10-15 panelists, who are screened, trained and calibrated to evaluate a **wide range of food, drinks, personal and household care** products

MMR also has a team of **8 statisticians** all experts at analyzing and modeling sensory panel data, with consumer and or analytical data.
Background & Objectives

Background:

- Almond Board of California is interested in better understanding the sensory profiles and chemical composition of raw almond varieties
- 10 raw almond varieties were analyzed over two seasons, using sensory descriptive analysis and chemical analyses

Objectives:

- To determine the sensory signatures of raw almond varieties
- To relate the sensory and chemical analyses and identify trends across the two growing seasons

<table>
<thead>
<tr>
<th>Almond Varieties</th>
<th>2015-16 season</th>
<th>2016-17 season</th>
<th>Trends over 2 seasons</th>
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<tbody>
<tr>
<td>Monterey</td>
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<td>Wood Colony</td>
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<tr>
<td>Aldrich</td>
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<td>Padre</td>
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<td>0</td>
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<tr>
<td>Carmel</td>
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<td>4</td>
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<tr>
<td>Butte</td>
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<td>Price</td>
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<tr>
<td>Nonpareil</td>
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<td>4</td>
<td>x</td>
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<tr>
<td>Sonora</td>
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<td>4</td>
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<tr>
<td>Independence</td>
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<td>4</td>
<td>x</td>
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<tr>
<td>Butte/Padre</td>
<td>3</td>
<td>4</td>
<td>x</td>
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<tr>
<td>TOTAL</td>
<td>42</td>
<td>40</td>
<td>10 varieties</td>
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</table>

Raw and unpasteurized – samples were sorted and dusted before evaluation
Methodology – Descriptive Sensory Analysis

- Descriptive testing was conducted by Covance (formerly The National Food Lab) using trained sensory panelists
- 10 panelists, 2 replications
- Panelists participated in up to 3 orientation sessions to discuss the samples and review the references
- Samples were blinded using 3-digit codes and served in a randomized and balanced order
- Panelists rated attribute intensities on a 15-point modified Universal line scale
- 40 sensory attributes were evaluated across all modalities

- **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

- **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
Methodology – Chemical Analyses

- 11 physical measures
- 9 vitamins and metals
- **Gas Chromatography** – measured at UC Davis:
  Headspace Solid-Phase Microextraction Gas Chromatography/Mass-Spectrometry (HS-SPME-GC/MS)
  - 52 volatile compounds, most confirmed with authentic standards
  - 2 replicates

http://www.elcalabs.com/GCMS.html
Descriptive Sensory Results
(2015/16 and 2016/17 seasons)
Sensory profiles of raw almonds across 2 growing seasons

- Total Aroma Intensity (O)
  - Fruity/Sour (O)
  - Hay (O)
  - Unripe/Beany (O)
  - Rubber/Medicinal (O)
- Hardness (T)
- Fracturability (T)
- Crunchy (T)
- Roughness (T)

- Total Flavor Intensity (F)
  - Sweet (F)
  - Sweet Aromatic (F)
  - Marzipan/Benzaldehyde (F)
  - Woody (F)
- Chewiness (T)
- Cohesiveness of Mass (T)
- Moistness of Mass (T)
- Mealy Mouthcoating (T)

2015/16

- PC1 (41%)
- PC2 (16%)

2016/17

- PC1 (53%)
- PC2 (15%)

Monterey
Wood Colony
Aldrich
Price
Nonpareil
Sonora
Mission
Butte
Butte/Padre
Padre
Independence
Carmel
Butter/Padre
Sweet Aromatic (F)
Key difference among samples is driven by TEXTURE (Hardness).

Sonora tends to be high in Crunchy & Fracturability in 2015/16 season.

Independence tends to be high in Hardness, Fracturability, Crunchy & Astringent across both seasons.

Woody Colony tends to be high in Hardness, Fracturability, Crunchy & Astringent in 2016/17 season.

Hardness, Fracturable, Crunchy, Astringent
Key difference among samples is TEXTURE (Hardness to Chewiness)

Fritz tends to be high in Moistness, Chewiness & Sweet across both seasons

Monterey tends to be high in Moistness, Chewiness & Cohesiveness of Mass across both seasons
Samples further differentiated by FLAVOR (Hay/Woody and Marzipan)

- **Butte/Padre** tends to be high in **Hay, Fruity/Sour, Woody** in 2016/17 season
- **Nonpareil** is high in variability in 2016/17; some samples tends to be more **Sweet**
- **Butte** tends to be low in aroma/flavor in 2015/16 season
- **Carmel** tends to be fairly high in Marzipan/Benzaldehyde in 2016/17 season
- **Aldrich** tends to be high in Hay, Unripe/Beany, Sweet aromatic in 2015/16 season & highest in Marzipan/Benzaldehyde in 2016/17 season

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- **Hay, High aroma/flavor**
- **Woody/Hay, High aroma**
- **Marzipan, High flavor**

- **Sonora**
- **Independence**
- **Wood Colony**
- **Fritz**
- **Monterey**
- **Nonpareil**
- **Aldrich**
- **Carmel**
- **Butte/Padre**

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2015/16

- Total Aroma Intensity (O)
- Fruity/Sour (O)
- Hay (O)

2016/17

- Woody (F)
- Total Flavor Intensity (F)
- Sweet (F)
- Sweet Aromatic (F)
- Marzipan/Benzaldehyde (F)

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**Aroma Intensities**

- Total Aroma Intensity (O)
- Fruity/Sour (O)
- Hay (O)
- Unripe/Beany (O)
- Rubber/Medicinal (O)

**Flavor Intensities**

- Total Flavor Intensity (F)
- Sweet (F)
- Sweet Aromatic (F)
- Marzipan/Benzaldehyde (F)
- Woody (F)

---

**Textual Content**

- Butte/Padre tends to be high in **Hay, Fruity/Sour, Woody** in 2016/17 season
- Nonpareil is high in variability in 2016/17; some samples tends to be more **Sweet**
- Butte tends to be low in aroma/flavor in 2015/16 season
- Carmel tends to be fairly high in Marzipan/Benzaldehyde in 2016/17 season
- Aldrich tends to be high in Hay, Unripe/Beany, Sweet aromatic in 2015/16 season & highest in Marzipan/Benzaldehyde in 2016/17 season

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**Key Points**

- **Sonora**
- **Independence**
- **Wood Colony**
- **Fritz**
- **Monterey**
- **Nonpareil**
- **Aldrich**
- **Carmel**
- **Butte/Padre**

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**Aroma Attributes**

- Total Aroma Intensity (O)
- Fruity/Sour (O)
- Hay (O)
- Unripe/Beany (O)
- Rubber/Medicinal (O)

**Flavor Attributes**

- Total Flavor Intensity (F)
- Sweet (F)
- Sweet Aromatic (F)
- Marzipan/Benzaldehyde (F)
- Woody (F)
Padre, Sonora and Mission have no distinct sensory profiles.

Total Aroma Intensity (O) - Fruity/Sour (O) - Hay (O)

Total Flavor Intensity (F) - Sweet (F) - Sweet Aromatic (F) - Marzipan/Benzaldehyde (F)

Hardness (T) - Fracturability (T) - Crunchy (T) - Roughness (T)

Total Aroma Intensity (O) - Hay (O) - Fruity/Sour (O)

Total Flavor Intensity (F) - Woody (F) - Hay (F) - Sweet (F)

Hardness, Fracturable, Crunchy, Astringent

PC1 (41%) - PC2 (16%)

Wax, High aroma/flavor

PC1 (53%) - PC2 (16%)

Wood, Low aroma/flavor

Flavors tend to be more variable across seasons, whereas textures are more consistent.
Relating Sensory & Chemical Analyses
(2015/16 and 2016/17 seasons)
Descriptive sensory profile of 2015/16 and 2016/17 seasons

PCA plot showing the distribution of sensory attributes for the two seasons.
Mapping the relationship of physical measures, vitamins & metals on the sensory space

### 2015/16
- Total Aroma Intensity (O)
- Fruity/Sour (O)
- Hay (O)
- Total Flavor Intensity (F)
- Sweet (F)
- Sweet Aromatic (F)

### 2016/17
- Potassium (mg/100g)
- Marzipan/Benzaldehyde (F)
- Phosphorus (mg/100g)
- Cohesiveness of Mass (T)
- Moistness of Mass (T)

### Physical Measures & Vitamins
- Calcium (mg/100g)
- Iron (mg/100g)
- Zinc (mg/100g)
- Phosphorus (mg/100g)
- Copper (mg/100g)
- Iron (mg/100g)

### Vitamins & Metals
- α-Tocopherol (mg/100g)
- MUFA (%)
- PUFA (%)
- SAFA (%)
- $\alpha$-Tocopherol (mg/100g)

### Nutrients
- Moisture (%)
- Protein (%)
- Ash (%)
- Magnesium (mg/100g)
- Iron (mg/100g)
- Copper (mg/100g)
- Zinc (mg/100g)
- Phosphorus (mg/100g)
- Magnesium (mg/100g)

### Sensory Attributes
- Hardness (T)
- Fracturability (T)
- Crunchy (T)
- Roughness (T)

### Additional Attributes
- Mealy Mouthcoating (T)
- Astringent (T)
- Amt of Residual Particulate (T)
- Moistness of Mass (T)

### Graphical Representation
- PC1 (41%)
- PC2 (16%)

### Additional Measurements
- Total Aroma Intensity (O)
- Fruity/Sour (O)
- Hay (O)

### 2016/17
- Total Aroma Intensity (O)
- Fruity/Sour (O)
- Potassium (mg/100g)
- Marzipan/Benzaldehyde (F)

### Graphical Representation
- PC1 (53%)
- PC2 (15%)
Mapping the relationship of volatile compounds on the sensory space
Marzipan/Benzaldehyde flavor is driven by benzaldehyde, amygdalin, phenylethyl alcohol & benzyl alcohol across the 2 seasons.
Marzipan/Benzaldehyde flavor is positively correlated with Benzaldehyde & Amygdalin.

**2015/16**

**Benzaldehyde**

- Correlation: $r = 0.72$

**Amygdalin**

- Correlation: $r = 0.90$

**2016/17**

**Benzaldehyde**

- Correlation: $r = 0.92$

**Amygdalin**

- Correlation: $r = 0.96$
Chewiness is driven by the presence of Moisture across the 2 seasons.

2015/16
- Total Aroma Intensity (O)
- Unripe/Beany (O)
- Fruity/Sour (O)
- Hay (O)
- Rubber/Medicinal (O)

2016/17
- Total Flavour Intensity (F)
- Sweet (F)
- Sweet Aromatic (F)
- Woody (F)
- Chewiness (T)
- Cohesiveness of Mass (T)
- Moistness of Mass (T)

Ahimsa
- Hardness (T)
- Fracturability (T)
- Crunchy (T)
- Roughness (T)
- Mealy Mouthcoating (T)
- Astringent (T)

Ahimsa
- Zinc (mg/100g)
- Iron (mg/100g)
- Copper (mg/100g)
- Ethenyl Acetate
- 2-Butanone
- 1-Butanol
- 3-Hexanol
- Acetoin
dihydro-3-methyl-2(3H)-Furanone
- Marzipan/
Benzaldehyde (F)
- Sugars (%)
- PUFA (%)
- Magnesium (mg/100g)
- Moisture (%)
- Total Aroma Intensity (O)
- Fruity/Sour (O)
- Marzipan/
Benzaldehyde (F)
- Cohesiveness of Mass (T)
- Moistness of Mass (T)
- PC2 (16%)
- PC1 (41%)
- PC2 (15%)
- PC1 (53%)

2015/16
- 1-Propanol
- Hexanal
- Furfural

2016/17
- Hexanal
- Furfural
- Copper (mg/100g)
- Ahimsa
- Magnesium (mg/100g)
- Cinnamaldehyde (F)
- 3-(methylthio)-1-Propanol
- Phenylethyl Alcohol
- 2,3-Butanediol
- 1-Propanol
- Ethyl Acetate
- 2-Butanone
- 1-Butanol
- 3-Hexanol
- Acetoin
dihydro-3-methyl-2(3H)-Furanone
- Marzipan/
Benzaldehyde (F)
Chewiness is positively correlated with Moisture

2015/16

2016/17

$r = 0.74$

$r = 0.87$

Monterey

Wood Colony

Independence

Price
Conversely, Fracturability is driven by the absence of Moisture and the presence of Phosphorus across the 2 seasons.
Fracturability is negatively correlated with Moisture

2015/16

Fracturability (T) vs Moisture (%)

Fracturability (T) vs Moisture (%)

2016/17

Fracturability (T) vs Moisture (%)

Fracturability (T) vs Moisture (%)
Sweetness is related to Sugars in 2015/16, but not in 2016/17.
Sweetness is positively correlated with Sugars in 2015/16, but shows no relationships in 2016/17.

2015/16: \( r = 0.61 \)

2016/17: \( r = 0.27 \)

No relationship
Climate differences may account for seasonal variation among varieties

- Samples grown in Central Valley, CA
- Temperature was similar across the 2 growing seasons – 2016/17 is slightly colder than 2015/16
- 2016 growing season was much wetter than 2015/16
Product Descriptions
Aldrich – high in flavor & marzipan/benzaldehyde, sweeter

**Sensory**

- Total Flavor Intensity (F)
- Marzipan/Benzaldehyde (F)
- Woody (O)
- Sweet Aromatic (F)
- Awareness of Skins (T)

**Chemistry**

- Amygdalin
- Benzyl alcohol
- Sugars %
- Ethyl Acetate
- Acetoin
- Prenol

**Significant at 95% within each growing season:**

- 2015/16
  - Has more
  - Has less

- 2016/17
  - Has more
  - Has less
Nonpareil – uniform with lighter color and ridges/veins, sweeter

**Sensory**
- Appearance of Ridges/ Veins (Ap)
- Diversity of Color (Ap)
- Sweet (F)
- Fruity/Sour (O)
- Hay (O)
- Unripe/Beany (O)
- Average Darkness of Color (Ap)
- Roughness (T)
- Astringent (T)

**Chemistry**
- Phosphorus
- 3-methyl-2-Butenal
- Sugars %
- MUFA %
- 2-butoxy-Ethanol
- Dietary Fiber %
- Insoluble Fiber %
- Ash %
- Manganese
- Toluene
- Nonanal
- 1-Octanal
- Benzeneacetaldehyde
- 5-ethylidihydro-2(3H)-Furanone (3H)-Furanon
- 2-methyl-3-Pentanol
- cis-Linaloloxide
- Cohesiveness of Mass (T)
- 1-Butanol
- 2-Butanol
- Isopropyl Alcohol
- Benzyl alcohol

Significant at 95% within each growing season:
- ↑ Has more
- ↓ Has less
Key Findings
Key Findings – Varietal Sensory Profiles

More consistent sensory profiles across seasons:

- **Aldrich** – high in flavor & marzipan/benzaldehyde, sweeter
- **Fritz** – darker, moist, chewy & marzipan/benzaldehyde
- **Wood Colony** – hard, fracturable, crunchy & astringent
- **Independence** – ridges/veins, hard, rough & fracturable
- **Sonora** – larger & lighter-colored, sweet & hay aromas, crunchy
- **Butte** (2015/16) – low aroma & flavor
- **Price** – intermediate sensory profile
- **Mission** (2015/16) – intermediate sensory profile

Higher variability in sensory profiles among samples/ across seasons:

- **Monterey** – high in moistness, roughness, & chewiness
- **Carmel** – woody & marzipan/benzaldehyde flavors, toothpacking
- **Butte/Padre** – smaller with fruity/sour aroma
- **Nonpareil** – uniform with lighter color and ridges/veins, sweeter
- **Padre** (2015/16) – intermediate sensory profile
Key Findings – Sensory & Chemical Data

- Sensory & chemical differences between almond varieties are greater than variation among replicates/samples.

- There is high seasonal variation within variety, seen both in the chemical and sensory data.

  - Flavors tend to be more variable across seasons, whereas textures are more consistent.

  - Climate differences may account for seasonal variation among varieties – 2016/17 was a wetter season than 2015/16.

- Key differences in the sensory profile of the 13 raw almond varieties are found in texture – hardness/fracturability/crunchy vs. moistness of mass/chewiness/-cohesiveness of mass.

  - Appears to be driven by moisture content.

- Almond samples are further differentiated by flavor – hay/woody vs. marzipan/benzaldehyde.

  - The perception of marzipan/benzaldehyde is highly correlated to amygdalin and benzaldehyde.
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Thank you!
Understanding the Chemistry and Aroma of California Almonds

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The Almond Conference
Sacramento CA Dec 5-7th
Flavor

• Flavor is the sensory impression of a food
• Composite quality involving the sensations of aroma, taste, chemical irritation, as well as temperature, texture and sound
• Taste: Humans can distinguish 5 basic flavors
  • Sweet, sour, salty, bitter, and savory (umami)
  • Reactions with taste receptors on the tongue
• Aroma: Involves the interaction of volatile molecules with olfactory receptor neurons located in the nasal passageways
Raw Almond Flavor

- Taste
- Aroma
Raw Almond Taste

Fat, protein, sugars and starch
- Fat creates a rich taste, and lack of acid enhances sweetness of the sugar in raw almonds
- Fats, protein and sugars are similar in CA almond varieties
- Contribution to taste will be similar in all varieties

Bitterness
- Bitterness is derived from *amygdalin*
- Almonds can be classified based upon their level of bitterness

Astringency
Derived from tannins located in the skin
- 2.1 mg/g skin
- *isorhamnetin-3-O-rutinoside*, *catechin*, *epicatechin*, *kaempferol-3-O-rutinoside* etc.,
- Bolling et al., J. Food Science 2009

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<thead>
<tr>
<th>Macronutrient</th>
<th>Range in CA-grown almonds (% g/g almond)</th>
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<tbody>
<tr>
<td>Lipids</td>
<td>44.7-54.1</td>
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<tr>
<td>Protein</td>
<td>18.5-24.0</td>
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<td>Sugars</td>
<td>7.9-16.0</td>
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<tr>
<td>Fiber</td>
<td>9.4-15.1</td>
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</tbody>
</table>

Yada et al., J. Food Composition Analysis 2013 (30) 80-85
Lipid Composition of Almonds

• The primary fatty acids in almonds are “Heathy fats”
  • Unsaturated fats
• Oleic (18:1, 62–80%) and linoleic acid (18:2, 10–18%)
• Create a rich taste in almonds, carry volatile aroma compounds
• When oxidized create off odors

<table>
<thead>
<tr>
<th>Name</th>
<th>Number of Carbons:Double bonds</th>
<th>Percent in Almond Oil</th>
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</thead>
<tbody>
<tr>
<td>Oleic</td>
<td>18:1</td>
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<tr>
<td>Linoleic</td>
<td>18:2</td>
<td>10-18%</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>
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</table>
Almond Bitterness (Phenotypes)

- **Non-bitter (Sweet)**
  - Sweet snacking almonds (creamy nutty flavor)

- **Semi-bitter**
  - Often used in processing for their “marzipan-like taste”

- **Bitter**
  - Middle East and Asia
  - Oils and flavorings
  - Contain amygdalin (3-5%) and develop a cyanide aroma when moistened (chewed)
  - Can be toxic
Amygdalin

- A diglycoside (2 sugars attached)
- The disruption of almond tissue (e.g. chewing) enables amygdalin to come into contact with enzymes ($\beta$-glycosidase) and form benzaldehyde and trace levels of HCN

Amygdalin = bitter

Benzaldehyde = amaretto flavor

Chemical defense for the plant
Developed a sensitive method (UHPLC (ESI)-MS/MS) to measure amygdalin in almonds
  • Understand levels in CA varieties and breeding stocks

Commercial non-bitter (sweet) varieties
  • Average amygdalin content 63.13 ± 57.54 mg/kg

Semi-bitter (UCD)
  • Average amygdalin 992.24 ± 513.04 mg/Kg

Bitter (UCD)
  • Average amygdalin 40,060.34 ± 7,855.26 mg/kg

Additional applications alcoholic bitters

USDA recall of almonds
# Amygdalin in California Almond Varieties

<table>
<thead>
<tr>
<th>Flavor</th>
<th>Variety</th>
<th>Amygdalin (mg/kg)</th>
<th>Growing Region</th>
<th>Mean Concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-bitter</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Butte</td>
<td>3.47 ± 0.17*</td>
<td>0.85 ± 0.65</td>
<td>2.16 ± 1.25</td>
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<tr>
<td></td>
<td>Price</td>
<td>7.49 ± 0.06 d</td>
<td>2.49 ± 0.30 b</td>
<td>4.32 ± 2.45</td>
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<tr>
<td></td>
<td>Sonora</td>
<td>1.83 ± 0.18 a</td>
<td>7.08 ± 1.26 b</td>
<td>7.76 ± 6.04</td>
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<tr>
<td></td>
<td>Nonpareil</td>
<td>7.05 ± 0.56 a</td>
<td>12.92 ± 0.57 b</td>
<td>12.23 ± 4.41</td>
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<tr>
<td></td>
<td>Monterey</td>
<td>108.75 ± 1.20 c</td>
<td>44.87 ± 1.12 a</td>
<td>62.47 ± 27.19</td>
</tr>
<tr>
<td></td>
<td>Wood Colony</td>
<td>78.25 ± 8.70 c</td>
<td>81.20 ± 3.71 c</td>
<td>75.03 ± 8.07</td>
</tr>
<tr>
<td></td>
<td>Carmel</td>
<td>75.04 ± 5.89 ab</td>
<td>94.72 ± 5.32 b</td>
<td>76.97 ± 15.22</td>
</tr>
<tr>
<td></td>
<td>Mission</td>
<td>72.47 ± 8.84 a</td>
<td>138.11 ± 6.06 b</td>
<td>89.60 ± 32.34</td>
</tr>
<tr>
<td></td>
<td>Fritz</td>
<td>133.62 ± 8.37 a</td>
<td>130.05 ± 3.38 a</td>
<td>144.87 ± 36.44</td>
</tr>
<tr>
<td></td>
<td>Aldrich</td>
<td>90.06 ± 5.01 a</td>
<td>214.87 ± 11.65 c</td>
<td>157.44 ± 54.01</td>
</tr>
<tr>
<td></td>
<td>All Varieties</td>
<td>63.13 ± 57.54</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Raw Almond Aroma

- Volatile molecules are responsible for the aroma of almonds
- The predominant almond aroma compound is benzaldehyde
  - Cherry, almond flavor
  - Artificial almond aroma
- Comes from the breakdown of amygdalin
Measuring Volatile Aroma Compounds in Almonds

HS-SPME GC/MS

Samples are agitated at 500 rpm and pre-equilibrated at 40ºC for 45 min, after which they were extracted with a 1 cm 30/50um StableFlex DVB/CAR/PDMS fiber exposed for 45 mins at 250 RPM.
Amygdalin and Benzaldehyde in California Almonds

• Strong correlation between amygdalin levels and benzaldehyde levels
Benzaldehyde Flavor and Variety

- Benzaldehyde ranges between 0.587-17.995 mg/kg in commercial almonds

<table>
<thead>
<tr>
<th>Variety</th>
<th>Classification type</th>
<th>Average amygdalin (mg/kg)</th>
<th>Average benzaldehyde (mg/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aldrich</td>
<td>California</td>
<td>76.50 ± 23.99 a</td>
<td>17.995 ± 5886.7 a</td>
</tr>
<tr>
<td>Fritz</td>
<td>California, Mission</td>
<td>59.71 ± 12.37 ab</td>
<td>11.315 ± 2795.5 b</td>
</tr>
<tr>
<td>Padre</td>
<td>California, Mission</td>
<td>53.24 ± 16.74 bc</td>
<td>8.806.8 ± 4101.5 bc</td>
</tr>
<tr>
<td>Monterey</td>
<td>California</td>
<td>46.76 ± 15.21 bc</td>
<td>8.654.3 ± 2137.3 bc</td>
</tr>
<tr>
<td>Wood Colony</td>
<td>California</td>
<td>41.49 ± 14.41 bcd</td>
<td>7.703.4 ± 3394.5 bc</td>
</tr>
<tr>
<td>Mission</td>
<td>Mission</td>
<td>40.24 ± 18.40 cd</td>
<td>6.489 ± 2503.4 cd</td>
</tr>
<tr>
<td>Carmel</td>
<td>California</td>
<td>26.42 ± 14.30 de</td>
<td>5.656.9 ± 1845.3 cde</td>
</tr>
<tr>
<td>Butte</td>
<td>California</td>
<td>18.56 ± 20.77 ef</td>
<td>2.768.3 ± 1783.2 def</td>
</tr>
<tr>
<td>Nonpareil</td>
<td>Nonpareil</td>
<td>9.11 ± 4.42 ef</td>
<td>1.939.5 ± 1318.9 ef</td>
</tr>
<tr>
<td>Sonora</td>
<td>California</td>
<td>5.56 ± 2.20 f</td>
<td>1.936.4 ± 1602.1 ef</td>
</tr>
<tr>
<td>Avalon</td>
<td></td>
<td>3.00 ± 4.17 f</td>
<td>1.179.6 ± 488.1 f</td>
</tr>
<tr>
<td>Independence</td>
<td></td>
<td>2.07 ± 1.66 f</td>
<td>1.062 ± 871.4 f</td>
</tr>
<tr>
<td>Winters</td>
<td>California</td>
<td>1.62 ± 2.10 f</td>
<td>0.730.6 ± 633.3 f</td>
</tr>
<tr>
<td>Price</td>
<td>California</td>
<td>1.77 ± 1.74 f</td>
<td>0.587.7 ± 272.9 f</td>
</tr>
</tbody>
</table>

Samples ~18 months old
Raw Almond Aroma

Literature review

- Volatile compounds identified in raw almonds and reported in 2+ studies
- Benzaldehyde, benzyl alcohol and hexanal are the most widely detected volatiles in raw almonds
- Other key volatiles include: pentanol, hexanol, 2-phenylethanol, 3-methyl-1-butanol, 3-methyl-2-buten-1-ol, and nonenal

<table>
<thead>
<tr>
<th>Type</th>
<th>Compound</th>
<th>Aroma*</th>
<th>Sourceb</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alcohol</td>
<td>1,2-propanediol</td>
<td>nd</td>
<td>2, 3</td>
</tr>
<tr>
<td></td>
<td>1-butanol</td>
<td>medicine, fruit, wine</td>
<td>2, 3, 4</td>
</tr>
<tr>
<td></td>
<td>1-heptanol</td>
<td>herb</td>
<td>2, 7</td>
</tr>
<tr>
<td></td>
<td>1-hexanol</td>
<td>resin, flower, green</td>
<td>1, 2, 3, 7, 4</td>
</tr>
<tr>
<td></td>
<td>1-Nonanol</td>
<td>aldehydic, waxy, citrus</td>
<td>7, 3</td>
</tr>
<tr>
<td></td>
<td>1-octanol</td>
<td>chemical, metal, burnt</td>
<td>2, 3, 7, 4</td>
</tr>
<tr>
<td></td>
<td>1-pentanol</td>
<td>fruity</td>
<td>1, 2, 3, 5, 6</td>
</tr>
<tr>
<td></td>
<td>2-ethyl-1-hexanol</td>
<td>sweet, floral, oily</td>
<td>1, 3</td>
</tr>
<tr>
<td></td>
<td>2-heptanone</td>
<td>cheesy, banana, fruity</td>
<td>1, 2</td>
</tr>
<tr>
<td></td>
<td>2-methyl-1-propanol</td>
<td>wine, whisky</td>
<td>2, 3, 7</td>
</tr>
<tr>
<td></td>
<td>Benzyl alcohol</td>
<td>floral, phenolic</td>
<td>1, 3, 4, 5, 6, 7</td>
</tr>
<tr>
<td></td>
<td>2-phenylethanol</td>
<td>floral, hyacinth/gardenia</td>
<td>5, 7, 6, 1, 3</td>
</tr>
<tr>
<td></td>
<td>3-methyl-butanol</td>
<td>malt</td>
<td>2, 3, 7</td>
</tr>
<tr>
<td></td>
<td>3-methyl-2-Butenol</td>
<td>fruity, alcoholic, green</td>
<td>5, 7, 6, 3</td>
</tr>
<tr>
<td></td>
<td>3-Methyl-3-Butenol</td>
<td>nd</td>
<td>3, 5, 6</td>
</tr>
<tr>
<td>Pyrazine</td>
<td>2-Methylpyrazine</td>
<td>roasted</td>
<td>1, 4</td>
</tr>
<tr>
<td>Acids</td>
<td>Acetic acid</td>
<td>sour</td>
<td>8, 3</td>
</tr>
<tr>
<td></td>
<td>hexanoic acid</td>
<td>sweaty, rancid</td>
<td>2, 3</td>
</tr>
<tr>
<td>Terpenes</td>
<td>alpha-pinene</td>
<td>piny</td>
<td>7, 2</td>
</tr>
<tr>
<td></td>
<td>limonene</td>
<td>orange peel</td>
<td>2, 7</td>
</tr>
<tr>
<td>Aldehydes</td>
<td>Benzaldehyde</td>
<td>sweet, marzipan</td>
<td>1, 3, 2, 7, 5, 6, 4</td>
</tr>
<tr>
<td></td>
<td>heptanal</td>
<td>rancid, pungent</td>
<td>1, 2, 7, 4</td>
</tr>
<tr>
<td></td>
<td>Hexanal</td>
<td>green fatty aldehydic grass</td>
<td>1, 8, 2, 3, 5, 7, 6</td>
</tr>
<tr>
<td></td>
<td>Nonanal</td>
<td>soapy, fatty, rancid</td>
<td>8, 2, 3, 7, 4</td>
</tr>
<tr>
<td></td>
<td>Octanal</td>
<td>soapy, fatty, rancid</td>
<td>8, 2, 7</td>
</tr>
<tr>
<td></td>
<td>pentanal</td>
<td>almond, malt, pungent</td>
<td>1, 2</td>
</tr>
<tr>
<td>Lactone</td>
<td>butyrolactone</td>
<td>creamy, oily, fatty</td>
<td>2, 3</td>
</tr>
<tr>
<td>Alkane</td>
<td>Toluene</td>
<td>painty</td>
<td>4, 7, 5, 6</td>
</tr>
<tr>
<td>Sulfur-containing</td>
<td>Methional</td>
<td>cooked potato</td>
<td>8, 4</td>
</tr>
<tr>
<td>Volatile Aroma</td>
<td>Characteristics</td>
<td>Aldrich</td>
<td>Fritz</td>
</tr>
<tr>
<td>------------------------------------</td>
<td>----------------------------------------</td>
<td>------------------</td>
<td>------------------</td>
</tr>
<tr>
<td>2-methyl-2-butenal</td>
<td>Pungent, green ethereal, sharp nutty</td>
<td>163.2 ± 73.91</td>
<td>155.19 ± 83.44</td>
</tr>
<tr>
<td>3-methyl-2-butenal</td>
<td>Sweet, fruity, brown nutty, almond</td>
<td>93.54 ± 61.85</td>
<td>166.48 ± 86.96</td>
</tr>
<tr>
<td>3-methylbutanal</td>
<td>Alcoholic, fruity, whiskey, banana</td>
<td>20.72 ± 2.62</td>
<td>21.57 ± 4.29</td>
</tr>
<tr>
<td>Acetoin</td>
<td>Buttery, creamy-fatty</td>
<td>199.87 ± 30.02</td>
<td>67.4 ± 10.51</td>
</tr>
<tr>
<td>Benzaldehyde</td>
<td>Almond, sweet, marzipan</td>
<td>34506.1 ± 8774.15</td>
<td>16427.9 ± 2412.43</td>
</tr>
<tr>
<td>Benzeneacetaldehyde</td>
<td>Green, sweet floral hyacinth clover</td>
<td>65.29 ± 12.38</td>
<td>36.63 ± 5.67</td>
</tr>
<tr>
<td>Ethyl Acetate</td>
<td>Ethereal, fruity sweet</td>
<td>31.47 ± 6.96</td>
<td>31.76 ± 12.15</td>
</tr>
<tr>
<td>Furfural</td>
<td>Sweet, woody almond fragrant baked</td>
<td>36.26 ± 17.61</td>
<td>54.59 ± 31.01</td>
</tr>
<tr>
<td>Hexanal</td>
<td>Fresh green fatty aldehydic grass</td>
<td>37.21 ± 3.56</td>
<td>40.21 ± 6.48</td>
</tr>
<tr>
<td>2,3-Butanediol</td>
<td>Fruity, creamy buttery</td>
<td>618.11 ± 104.18</td>
<td>779.46 ± 65.2</td>
</tr>
<tr>
<td>1-butanol</td>
<td>Sweet, apricot</td>
<td>39.22 ± 5.53</td>
<td>47.48 ± 6.07</td>
</tr>
<tr>
<td>2,3-Butanediol</td>
<td>Fruity, creamy butterm</td>
<td>173.18 ± 23.89</td>
<td>255.23 ± 24.43</td>
</tr>
<tr>
<td>3-methyl-1-butanol</td>
<td>Fusel oil, alcoholic whiskey, fruity</td>
<td>601.04 ± 140.64</td>
<td>1135.28 ± 154.66</td>
</tr>
<tr>
<td>Benzyl alcohol</td>
<td>Floral rose phenolic balsamic</td>
<td>676.91 ± 101.07</td>
<td>231.59 ± 139.95</td>
</tr>
</tbody>
</table>

Samples ~3 months old
Principal Component Analysis (PCA) Scores Plot

- Based upon the PCA analysis of 52 volatiles in CA almond samples
Benzaldehyde
Benzyl alcohol
Benzene acetaldehyde

3-methyl-1-butanol
Butanol
3-methyl-butanal
Conclusions

- Amygdalin levels correlate with benzaldehyde and are highest in Aldrich and Fritz and lowest in Independence (2016)
- Analysis of volatiles in 3 month old Aldrich, Butte/Padre, Carmel, Independence, Monterey, Nonpareil, Price, Sonora, Wood Colony, Fritz
  - Aldrich has significantly higher levels of levels of benzaldehyde than other varieties and that and Independence has the lowest
- PCA Analysis:
  - Aldrich have the highest levels of volatiles related to almond flavor whereas Independence has more compounds related to creamy, buttery, fruit flavor
  - Cluster analysis indicate that Butte/Padre and Fritz/Carmel are more similar to each other than other varieties and that Nonpareil, Price, Sonora, Wood Colony are similar to each other
- Posters: Wednesday 3:00-5:00 PM
  - Larry Lerno: Volatile Profiling of Raw Almonds #29
  - Kathleen Luo: Chemical Markers Measuring Quality of Moisture Exposed Almonds, #26
  - Kara Nguyen: Nondestructive Classification of Bitterness in Almonds, #28
  - Sean McKeown: In-hull Moisture Content using Microwaves. #27
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• Blue Diamond Almonds
  • W. Scott Moore
  • Brian Dunning

• Agilent Technologies
  • Phil Wylie, PhD
Thank you!
What’s Next

Thursday, December 7 at 1:50 p.m.

• Maximizing Shelf Life – Room 314
• European’s Appetite for Almonds Endures and Grows – Room 306-307
• What’s New in Almond Tree Nutrition and Regulation? – Room 308-309
• Research Update: Irrigation and Harvest – Room 312-313
What’s Next

Wednesday, December 6 at 12:00 p.m.

• Luncheon Presentation – Hall C

The Future of Agriculture: Innovation, Ingenuity, Perseverance
Speaker: Steve Forbes

Luncheon is ticketed and is sponsored by Yosemite Farm Credit