Journey Toward Off-Ground Harvest
Session Speakers

Sebastian Saa, ABC
Brian Wahlbrink, Sperry Farms
Chris Simmons, UC Davis
Ted DeJong, UC Davis
Patrick Brown, UC Davis
Michael Coates, Plant and Food Research Australia
Zhongli Pan, UC Davis
REDUCE DUST DURING ALMOND HARVEST BY 50%
Harvest workgroup funded initiatives in 2019

• Off-ground Harvest of Almonds: Techno-economic Cost and Benefit Analysis with Analysis of Barriers to Adoption (Dr. Simmons)
• Orchard configurations appropriate for off-ground harvest (Dr. Ted DeJong)
• Quantitative and qualitative impacts of windfall on almond yield and quality (Dr. Patrick Brown)
• Handling Fresh Harvested Almond (Dr. Coates, Dr. Donis-Gonzalez, and Dr. Reza Ehsani)
• Efficient Drying of Off-ground Harvested Almonds without Quality Concerns (Dr. Pan)
Technoeconomic assessment of potential off-ground harvesting practices in the California almond industry

Christopher Simmons, PhD
Department of Food Science and Technology
University of California, Davis
Assumptions

Model developed for a hypothetical orchard

- 100 acre orchard
- >4 years old
- 2200 lb/acre yield
- $2.50/lb selling price
- 1% windfall
- Conventional sanitation, fertilization, irrigation, pest management, pruning, pollination etc. agree with existing cost study
Expected effects

- Losses due to windfall; may be affected by:
  - Region
  - Variety
  - Harvest schedule

- Harvesters; effect currently unknown; rental cost will be affected by:
  - Capital cost
  - Fuel/labor demand/cost
  - Lifespan/depreciation
  - Maintenance cost

- Cultural practices:
  - Fewer pest control measures needed
  - Less stringent leveling needed

- Harvest operations:
  - Blowing/sweeping are avoided
  - Pickup may be avoided

Change in net return per acre above total costs relative to conventional practices ($/acre)

- (undesirable)
- (?)
- (desirable)
In-orchard drying scenarios

POLYMERIC SOIL STABILIZATION
-1,830

ENZYMATIC SOIL STABILIZATION
-1,378

NO SOIL STABILIZATION
+75

Change in net returns above total costs ($/harvested acre)

-2000 0 +100
Drying lot scenarios

ADD 6 MIL TARP

ADD ENZYMATIC STABILIZER

ADD 1.25 MIL TARP

BARE SOIL

CHANGE IN NET RETURNS ABOVE TOTAL COSTS ($/HARVESTED ACRE)

-100 -17 -4 +13 +24 +100 +86 +115 +175 +173 +178 +200

ADD POLYMERIC STABILIZER

7-acre lot

6-acre lot

5-acre lot
CHANGE IN NET RETURNS ABOVE TOTAL COSTS ($/HARVESTED ACRE)

Grower acquires new land

Grower uses existing marginal land

-100

-74 -61

-36 -25

-11 +28

+18 +51

+2 +11

+47 +75

+127 +137

+116

7-acre lot

6-acre lot

5-acre lot

+200

-100
### Lot drying scenarios

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**LOT SIZE AND DUST CONTROL TREATMENTS MUST BE FINELY TUNED TO QUANTITY OF ALMONDS**
Mechanical drying scenarios

23.9% INITIAL MOISTURE

25% INITIAL MOISTURE

17.9% INITIAL MOISTURE

21.9% INITIAL MOISTURE

Change in net returns above total costs ($/harvested acre)
Questions and next steps

What is the true cost of an off-ground harvester?
• Depreciation and capital recovery
• Fuel and labor efficiency
• Maintenance
• Cost to produce, competition and penetration pricing

What will be the cost of mechanical drying at scale?
• Predicting supply versus demand
• Potential for economy of scale

How much dust is mitigated under each harvesting scenario?
Orchard configurations appropriate for off-ground harvest

Ted DeJong
Plants, nature’s original solar energy collectors

- Theoretically, maximum solar energy collection will occur when orchard cover is complete.
Light interception (that drives photosynthesis) is related to maximum crop yield.

The objective of any orchard system is to harvest the sun’s energy.

Lampinen et al. 2012
Adapting almond orchard systems to accommodate off-ground harvest

• Moving to off-ground harvest will require a change in mind-set prior to planting a new orchard.
  – Rather than primarily thinking mainly about choosing a density to maximize yield and accommodate your irrigation system and operation of orchard equipment, the type of harvesting equipment that will be used becomes a primary consideration.
  – The orchard configuration must accommodate a specific type of off-ground harvesting equipment.
    • Over-the-row type of harvester used in high-density olives.
    • A Tenias type of over-the-row harvester that can accommodate medium sized trees
    • A side-by-side shake-catch harvester similar to what is used in prunes and pistachios
    • A wrap-around shake-catch harvester like those initially developed in the 70’s
What about the super high-density systems?
Based on a simple application of Bruce Lampinen’s light studies it appears highly unlikely that these systems can be as productive as our nearly “full canopy” systems because of low total light interception.

However, the Spanish argue that there is increased canopy exposure to this lateral light and, that because the canopies are thinner, spurs are more effectively exposed to light. This needs further study.

Can healthy spur populations be maintained with less total light, if the light is distributed more uniformly through the canopy?
The systems that the Spanish are developing for almonds are an adaptation from what they promote for peaches and apples. But in growing peaches and apples growers are concerned with good distribution of light within the canopy to enhance uniform fruit quality. This is not an issue with almonds. The hedgerow systems are also suited well for hand harvest of fruit and for locations where there are a lot of cloudy days so the incoming radiation is mainly in the form of diffuse light rather than direct light. Neither of these pertain to growing almonds in California.
Adapting almond orchard systems to accommodate off-ground harvest

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    • A wrap-around shake-catch harvester like those initially developed in the 70’s
Each of the off-ground harvesting systems have their advantages and disadvantages but they all essentially require trees and orchard canopies to be smaller than most California almond orchards are today.

- For numerous reasons it is not feasible to limit tree size to accommodate harvester limitations by pruning alone.
- In the past rootstocks have often been chosen for their ability to enhance tree vigor and mature tree canopy size.
- Moving to off-ground harvest will necessitate selection of rootstocks to limit tree size like has been occurring if fruit crops to decrease ladder work.
- To effectively move to off-ground harvest the almond industry will need size-controlling rootstocks.
- I believe the industry urgently needs to test as many size-controlling rootstocks as are available for other Prunus crops that are likely to be compatible with almond.
- There are a number of newer size-controlling peach rootstocks available but their suitability for almond production has never been thoroughly tested.
- A major issue with size-controlling rootstocks will likely be anchorage. Many dwarfing rootstocks for fruit trees have relatively poor anchorage. (Apple trees on M9 rootstock require secondary support to stay upright.)
Windfall – The Off Ground Journey

Patrick H. Brown, Ricardo Camargo
Gustave Cirhigiri
QUANTITATIVE OUTCOMES

• How Much Windfall Occurs
• When Does Windfall Occur
• Effect of location, cultivar and date

QUALITATIVE OUTCOMES

• Determine effect of windfall date on quality of final harvest.
• Determine effect of harvest date on nut quality
MORE ABOUT THE ORCHARDS

61 orchards total. Single dot may represent multiple fields.

280 sites
>12,000 windfall measurements
THE ORCHARDS

- Each barcode must be **pictured weekly** for density count from 5%-95% Hull Split
- Multiple locations on a transect in each orchard

- Orchards sampled **in transect**
- Three reps per variety present
- Eight photo frames per rep
  - 4 Along row (0°)
  - 4 Across rows (90°)
EXAMPLE QUANTITATIVE OBSERVATIONS (LOW WINDFALL 0-0.1% 2-3 LBS)

2 Weeks prior to harvest

1 Week prior to harvest

After Shake 9/23/19

Across rows (90°)

Across rows (90°)

Across rows (90°)
EXAMPLE QUANTITATIVE OBSERVATIONS (HIGHEST WINDFALL SITE 1-1.2%, 20-30 LBS @ 2 WEEKS)

- 2 Weeks prior to harvest
- 1 Week prior to harvest
- After Shake 9/23/19

Across rows (90°)
COUNTING NUTS USING ARTIFICIAL INTELLIGENCE

After Shake 9/23/19

2 Weeks prior to harvest

1 Week prior to harvest

A WORK IN PROGRESS!
Quality of Nuts if left on ground 6 (T-6), 4 (T-4), 2 (T-2), and 0 (T-0) week(s) before harvest, while being exposed to standard orchard conditions.

Measurements made on nuts collected just prior to normal shake.

QUALITY PARAMETERS BEING MEASURED

External
- Moisture content
- Insect damage
- Kernel color

Internal
- Aflatoxin Levels
- Free Fatty Acids (FFA)
- Peroxide Values
## Qualitative Experimental Design

### Randomized Complete Block Design

- **Goal**: Determine the effect of pre-harvest incubation times of nuts on orchard floor on quality.
- **Locations**: Kern county (Bakersfield) and Butte County (Chico).
- **Replications**: 6 replications with 6 pseudo-replications made of 6 trees each (20 nuts/tree).
- **Measurements**: Continuously monitored soil and air temperature and soil moisture.
- **Quality parameters**: Moisture, insect damage, molds, aflatoxin test, free fatty acids, peroxide values, kernel size, weight, color, shape, and percentage of blanks.

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<td>Bakersfield</td>
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<tr>
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<td>July 3rd</td>
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<td>T4=4weeks pre-harvest</td>
<td>July 17th</td>
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<tr>
<td>T2=2weeks pre-harvest</td>
<td>August 2nd</td>
</tr>
<tr>
<td>T0= Control at harvest</td>
<td>August 17th</td>
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</table>
Preliminary analysis of composite samples from Bakersfield shows Moisture and FFA percentages gradually decreasing from T-6 (6 weeks before harvest) to T-0 (nuts at harvest) while aflatoxin concentration and peroxide value remained constant.
POSSIBLE ADDITIONS TO THE PROJECT

NOW INCIDENCE IN RELATION TO EARLIER HARVEST.

PERFORM NOW COUNTS AT SELECTED ORCHARDS
6 WEEKS (T-6), 4 WEEKS (T-4), 2 WEEKS (T-2), AND 1 (T-1) WEEK(S) PRIOR TO HARVEST.

GROWERS WITH HIGH NOW INCIDENCE ORCHARDS ARE ENCOURAGED TO PARTICIPATE.
Magnitude and Quality of Windfall Nuts

• Preliminary analysis shows windfall from zero to 1% percentage, with the majority of sites showing <0.4% (0-15 lbs.)
• Fruit falling before 4+ weeks of normal harvest are very poor quality.
• Quality and size of kernels is not compromised at 2-4 weeks early shake.
• Kernel moisture is 10-15% higher at > 2 weeks early shake
• The potential for NOW and Hull Rot is greatly increased with fruit maturity.
• Analysis of regional and cultivar data is continuing.
• Repeat studies in 2020 with added 1) high aflatoxin sites and 2) high NOW/HR sites will be conducted.
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UC Davis

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Drying Fresh Almonds

**Batch**

Establishing the minimum requirements (flowrate, temperature and time) that allow almond fruit to dry in batches without effecting the quality of the fruit.

**Stockpile**

Establish how stockpiles can be utilized to dry fruit outside of the orchard.
Drying

1. Providing enough airflow to remove the water coming from the fruit.

2. Keep the air warm enough that moisture keeps moving through the fruit.

Fruit that takes 3-10 days to dry in a tree row, can take 2-3 weeks to dry in a stockpile or batch dryer with evaporative cooling caused by insufficient air flow.

Manage evaporative cooling
Drying

Harvest time variability for each cultivar

Day 1
20% MC
(kernel)

Day 10
10% MC
(kernel)

Additional resources:
• Forced Air
• Heat

Additional resources:
• Ambient air
Batch Drying

Lots of nuts are batch dried:
Walnuts, macadamias, pistachios, peanuts ….

We are in the process of establishing almond parameters so these machines can be tuned to dry almonds. Example:

Variety: ‘Carmel’
Initial kernel MC: ~10%
Final kernel MC: ~4%
Air Temp. 52°C (80°F)
~5200 ft³ of almond fruit
15 kW fan
Batch Drying

UC Davis batch dryer

- ~750 lbs. of fruit per bin (340 kg dry)
- Air flow of 23-25 cfm/ft³ (~1 m³/s/m³)
- Heat capacity of 50°C (122°F)

Variety: ‘Aldrich’
Initial MC: 8% Kernel
Final MC: 4.5% Kernel
Stockpile Drying

Kernel MC ~5%
Standard stockpile

Kernel MC <10%
Stockpile tunnel
(natural convection)

Kernel MC 10-15%
Stockpile tunnel
(mechanical air)

Kernel MC >15%
Stockpile tunnel
(mechanical air)
(additional heat)

This is currently the direction the research is going, but it is still preliminary.
Stockpile Drying

Variety: ‘Monterey’
~5000 kg dry (11000 lbs. of fruit)
Stockpile Drying

Variety: ‘Monterey’
Initial MC: 12.6% (Kernel)
Final MC: 4.5% top, 6% mid, 6.5% bottom (Kernel)
Comments

Batch

• Working to establish the minimum requirements to dry fruit in batches without damaging the fruit.

Stockpile

• Orient the stockpile perpendicular to the wind.
• Thermal mass can keep fruit from over drying.
• Mechanical air needs to be high volume, low velocity.
• Most growers have not allowed space to stockpile (CA).
  • This could potentially be a roll for the handlers.
Thank you

Industry
Nickels Soil Lab (USA)
Century Orchard (AU)
Walker Flat Almonds (AU)

Students / Staff
Calos Orozco (UCD)
Lucia Felix (UCD)

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Efficient Drying of Off-ground Harvested Almonds without Quality Concerns

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Questions About Drying of Off-ground Harvested Almonds

- What is the highest temperature that can be used for drying?
- Will high drying rate cause quality deterioration?
- Will the harvest moisture affect dried almond quality?
- Will different varieties of almonds perform differently during drying?
- How much does it cost to dry the almonds?

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<th>Equipment</th>
<th>Location</th>
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<td>Benchtop Dryer</td>
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<td>Column dryer</td>
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<td>Tunnel Drying at Campos Brothers</td>
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<td>Stadium Drying at Emerald Farm</td>
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Trailer Drying at West Valley Co.
Objectives

- Investigate characteristics of off-ground harvested vs. conventionally harvested almonds
  - Initial moisture content of different components (hull, shell, kernel) and distributions
  - Dimensions and aerodynamic properties
  - Insect damages

- Determine the drying performance and product quality for different varieties with different drying conditions and methods

- Build drying kinetic models for predicting drying time, energy consumption and drying cost
Quality Evaluation

- Insect damage
- Moisture content
- Product color
- Cavity
- Concealed damage (Color development scores were graded after roasting (275 °F, 90 mins))
- Peroxide value (PV) and free fat acid (FFA)

Insect damaged almonds

Cavity determination

Score 1 2 3 4 5

Example

Color development score grading reference

Color measurement

Oil extraction device

PV and FFA measurement device
Drying Performance Evaluation

- Drying time and rate
- Drying Model
  - Page model
- Energy consumption
- Cost estimate
1. Development of Effective Drying Methods for Off-Ground Harvest Almonds

- Benchtop and pilot scale drying
Tests of Benchtop and Pilot Scale Drying

- Hot air drying study: two different dryers
- Variety: Nonpareil, Monterey, and Fritz from Nickels Soil Lab
- Temperature: 45, 50, 55, and 60°C
- Air velocity: 1 and 2 m/s
- Column Height: 0, 2, 4, and 6 ft
Characteristics of Almonds from Off-Ground and Conventional Harvest

- Less insect damage and cleaner from off-ground harvest

<table>
<thead>
<tr>
<th>Variety</th>
<th>Days on ground</th>
<th>Insect infestation (%) Conventional</th>
<th>Off-ground</th>
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<tr>
<td>Nonpareil</td>
<td>11</td>
<td>6.3</td>
<td>3.3</td>
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<tr>
<td>Monterey</td>
<td>14</td>
<td>11.4</td>
<td>6.3</td>
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<tr>
<td>Fritz</td>
<td>9</td>
<td>4.5</td>
<td>2.5</td>
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Percentage of insect infestation for different varieties

- Monterey - largest length and width
- Fritz – smallest in length and width
- Nonpareil - smallest thickness

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<thead>
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<th>Variety</th>
<th>Category</th>
<th>Axial dimension (mm)</th>
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<td>length</td>
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<td>Nonpareil</td>
<td>In-hull</td>
<td>37.53±2.71</td>
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<tr>
<td></td>
<td>In-shell</td>
<td>33.63±2.43</td>
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<td></td>
<td>kernel</td>
<td>24.47±1.60</td>
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<td></td>
<td>hull</td>
<td>38.13±2.57</td>
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<td>Monterey</td>
<td>In-hull</td>
<td>38.27±3.22</td>
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<td>In-shell</td>
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<td>hull</td>
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Appearance

Off-ground harvest almonds

Conventional harvest almonds
## Initial Moisture Content of Almonds

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<th>Variety</th>
<th>Overall (%)</th>
<th>Average, min and max initial moisture contents (% wb)</th>
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<th>In shell</th>
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<td>Shell</td>
<td>Kernel</td>
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<td>20.9</td>
<td>23.7 (13.3-46.9)</td>
<td>9.2 (5.4-16.5)</td>
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<td>19.8 (12.2-51.9)</td>
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<td>Fritz</td>
<td>20.8</td>
<td>27.1 (12.4-55.7)</td>
<td>15.3 (8.5-26.6)</td>
<td>13 (3.6-32.5)</td>
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Drying Performance and Product Quality from Benchtop Drying

- Drying time ↓ as the temperature and air velocity ↑
  - 2 h (45°C, 1 m/s) vs. 0.75 h (60°C, 2 m/s)
- In-shell almonds dried faster and more uniformly than in-hull almonds

Drying performance of benchtop drying at different conditions (Nonpareil)

<table>
<thead>
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<th>Air velocity (m/s)</th>
<th>Temp (°C)</th>
<th>Initial MC (%)</th>
<th>Final MC (%)</th>
<th>Drying time (h)</th>
<th>Overall drying rate (kg/h-kg)</th>
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<td>Ave</td>
<td>Std</td>
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<td></td>
<td>60</td>
<td>15.85</td>
<td>0.35</td>
<td>11.60</td>
<td>0.71</td>
</tr>
</tbody>
</table>
Almond Quality from Benchtop Drying

- No significant changes
  - Color
  - Cavity
- PV and FFA
  - Much lower than the industry standards: (5 meq O₂/kg oil and 1.5%)

Final product kernel whiteness index at different temperature levels at 1 m/s (left) and 2 m/s (right) (Nonpareil)

Peroxide value (left) and free fatty acids (right) of almonds after benchtop drying (Nonpareil)
Concealed Damage from Benchtop Drying

- Color development
  - Slightly higher color development scores than conventional and column drying
- Air velocity had some effect on the color scores of some samples

Concealed damage grading reference

<table>
<thead>
<tr>
<th>Score</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Example</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Concealed damage of benchtop drying at 1 m/s (Nonpareil)

Concealed damage of benchtop drying at 2 m/s (Nonpareil)
Drying Performance and Product Quality of Column Drying

- Drying time↓ as the temperature and air velocity↑
  - 4.5 h (45°C, 1 m/s) vs 2.5 h (60°C, 2 m/s)
- Overall drying rate and final moisture content uniformity varied at different heights
  - Slower drying and more uniform MC at the column top than at the bottom
- No color change (kernel whiteness) or cavity developed after drying
- Similar trends were found for other varieties.

Drying curves under different temperatures and air velocities of column drying for Nonpareil
Concealed Damage from Column Drying

- No concealed damage for both conventional and column drying
- Color development scores of column drying were similar or lower than conventional drying
- Air velocity had significant impact
  - Air velocity of 1 m/s had significantly lower scores (vs. conventional drying)

Color development (CD) scores of column drying (Nonpareil)
Oil Quality after Column Drying

- Peroxide value (PV) and free fatty acid (FFA) amount of almonds after column drying were much lower than the upper limit of industrial standard.
- No apparent trend was observed for the influence of drying air temperature and air speed on the PV and FFA of dried almonds.
- No significant difference was found for PV and FFA of almonds at different locations in the column dryer.
Drying Kinetics Modeling of Almonds and Energy Consumption of Column Drying

- The Page model was used to simulate the drying kinetics of almonds with good fits ($R^2 > 0.99$)
  
  \[ MR = \exp(-kt^n) \]

- The drying time decreased with the increase of drying air temperature and air speed

- Specific energy consumption of almond drying increased with temperature and air speed

- Drying at 55°C led to relatively short drying time and low energy cost

- Optimum drying conditions varied with the almond variety

<table>
<thead>
<tr>
<th>Air velocity (m/s)</th>
<th>Temp (°C)</th>
<th>Initial MC$_{wb}$ (%)</th>
<th>Final MC$_{wb}$ (%)</th>
<th>Drying time (h)</th>
<th>Specific energy consumption (MJ/kg)</th>
<th>Energy cost (¢/lb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>45</td>
<td>20.77</td>
<td>11.98</td>
<td>5.32</td>
<td>9.26</td>
<td>1.8</td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>20.77</td>
<td>11.98</td>
<td>5</td>
<td>10.91</td>
<td>3.4</td>
</tr>
<tr>
<td></td>
<td>55</td>
<td>20.77</td>
<td>11.98</td>
<td>4.55</td>
<td>11.95</td>
<td>2.1</td>
</tr>
<tr>
<td></td>
<td>60</td>
<td>20.77</td>
<td>11.98</td>
<td>4.2</td>
<td>12.86</td>
<td>3.6</td>
</tr>
<tr>
<td>2</td>
<td>45</td>
<td>20.77</td>
<td>11.99</td>
<td>5.25</td>
<td>17.22</td>
<td>2.3</td>
</tr>
<tr>
<td></td>
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<td>20.77</td>
<td>11.97</td>
<td>4.4</td>
<td>18.32</td>
<td>3.8</td>
</tr>
<tr>
<td></td>
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<td>20.77</td>
<td>11.97</td>
<td>3.78</td>
<td>19.05</td>
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</tr>
<tr>
<td></td>
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<td>20.77</td>
<td>11.93</td>
<td>3.2</td>
<td>18.88</td>
<td>3.7</td>
</tr>
</tbody>
</table>
Terminal Velocity and Dimension for Sorting

- Mis-classification error rate for the dimension separation: 15% to 23% hulls in the in-shell almonds.
- Mis-classification error rate for the dimension separation: 4% to 10% hulls in the in-hull almonds.
- A potential to sort in-hull almonds, in-shell almonds and hulls to improve drying energy efficiency and moisture uniformity.
2. Performance Evaluation of Commercial Dryers for Drying Off-Ground Harvest Almonds
Commercial Drying of Off-Ground Harvesting

- Commercial drying systems
  - Tunnel dryer
  - Stadium dryer
  - Trailer
- Almond varieties
  - Independence (ID)
  - Monterey (MT)
  - Fritz (FR)

Off-Ground harvesting at JY Farm

Off-Ground harvesting at Emerald Farm

Tunnel Drying at Campos Brothers

Stadium Drying at Emerald Farm

Trailer Drying at West Valley Co.
Characteristics of Off-Ground Harvested Almonds

- Compared with conventional harvest
  - Much cleaner due to less dust, rocks, and branches
  - Much less insect damage
- Large hull fraction
  - Does not need to be dried if separated before drying
- Bulk density (kg/L)
  - Independence (0.32), Monterey (0.29), and Fritz (0.38)

Fraction weight ratio of almonds from off-ground harvest

<table>
<thead>
<tr>
<th>Variety</th>
<th>Orchard</th>
<th>Weight ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Hull</td>
</tr>
<tr>
<td>Independence</td>
<td>J.Y.</td>
<td>0.32</td>
</tr>
<tr>
<td>Monterey</td>
<td>Emerald</td>
<td>0.16</td>
</tr>
<tr>
<td>Fritz</td>
<td>Emerald</td>
<td>0.12</td>
</tr>
<tr>
<td>Monterey</td>
<td>Baker</td>
<td>0.14</td>
</tr>
</tbody>
</table>

Insect damage comparison

<table>
<thead>
<tr>
<th>Variety</th>
<th>Orchard</th>
<th>Insect Infestation (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Conventional</td>
</tr>
<tr>
<td>Independence</td>
<td>J.Y.</td>
<td>10.0</td>
</tr>
<tr>
<td>Monterey</td>
<td>Emerald</td>
<td>9.1</td>
</tr>
<tr>
<td>Fritz</td>
<td>Emerald</td>
<td>7.7</td>
</tr>
<tr>
<td>Monterey</td>
<td>Baker</td>
<td>2.0</td>
</tr>
</tbody>
</table>
Moisture Content Characteristics before Drying

Moisture content distribution before ambient air drying (tunnel drying)

Moisture content distribution before hot air drying (tunnel drying)

Average moisture content (tunnel drying)

<table>
<thead>
<tr>
<th>MC&lt;sub&gt;wb&lt;/sub&gt; (%)</th>
<th>Ambient Air</th>
<th>Hot Air</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>In hull</td>
<td>In shell</td>
</tr>
<tr>
<td>Whole Almond</td>
<td>36.3</td>
<td>13.2</td>
</tr>
<tr>
<td>Kernel</td>
<td>12.9</td>
<td>12.2</td>
</tr>
</tbody>
</table>
Drying Characteristics of Commercial Drying

Whole almond MC profile (tunnel drying)  Whole almond drying rate (tunnel drying)

Kernel MC profile (tunnel drying)  Kernel drying rate (tunnel drying)

RH during ambient air drying (tunnel drying)  RH during hot air drying (tunnel drying)
Performance of Commercial Dryers

- Drying conditions (temperatures at air inlets)
  - Tunnel Drying (ID)
    - Ambient air (AA) and 1 m/s
    - Hot air (HA), 46°C (115°F) and 1 m/s
  - Stadium Drying (MT and FR)
    - 35°C (95°F) and 0.7 m/s
  - Trailer Drying (MT)
    - 43°C (110°F) and 54°C (130°F)
  - Performance evaluation
    - Energy costs calculated based on reference rates
    - Energy costs of tunnel and stadium drying were lower than 5 cents/lb. (trailer feedstocks little bit too dried)

<table>
<thead>
<tr>
<th>Drying condition</th>
<th>Variety</th>
<th>Initial MC (%)</th>
<th>Final MC (%)</th>
<th>Drying time (h)</th>
<th>Energy Cost (cents/lb)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Whole</td>
<td>Kernel</td>
<td>Whole</td>
<td>Kernel</td>
</tr>
<tr>
<td>Tunnel (ambient)</td>
<td>ID</td>
<td>42.3</td>
<td>14.4</td>
<td>16.8</td>
<td>7.8</td>
</tr>
<tr>
<td>Tunnel (115°F)</td>
<td>ID</td>
<td>37.6</td>
<td>12.9</td>
<td>12.5</td>
<td>5.8</td>
</tr>
<tr>
<td>Stadium (95°F)</td>
<td>MT</td>
<td>24.4</td>
<td>12.7</td>
<td>7.8</td>
<td>3.9</td>
</tr>
<tr>
<td>Stadium (95°F)</td>
<td>FR</td>
<td>44.3</td>
<td>17.7</td>
<td>6.5</td>
<td>3.8</td>
</tr>
<tr>
<td>Trailer (110°F)</td>
<td>MT</td>
<td>21.1</td>
<td>7.8</td>
<td>8.3</td>
<td>4.8</td>
</tr>
<tr>
<td>Trailer (130°F)</td>
<td>MT</td>
<td>21.1</td>
<td>7.8</td>
<td>7.8</td>
<td>4.1</td>
</tr>
</tbody>
</table>

[1] cent/lb of dried almond kernels, energy cost only
Moisture Content Characteristics after Commercial Drying

Average moisture content after drying (tunnel drying)

<table>
<thead>
<tr>
<th>MC&lt;sub&gt;wb&lt;/sub&gt; (%)</th>
<th>Ambient Air</th>
<th>Hot Air</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>In Hull</td>
<td>In Shell</td>
</tr>
<tr>
<td>Whole Almond</td>
<td>14.5</td>
<td>7.4</td>
</tr>
<tr>
<td>Kernel</td>
<td>8.1</td>
<td>6.8</td>
</tr>
</tbody>
</table>
Quality of Almonds from Commercial Drying

- **Color**
  - Represented by kernel whiteness index
  - No change vs. fresh control (Control)
  - No significant difference vs. conventional harvest and drying (Conv)

![Kernel whiteness index (tunnel drying)](image)

![Kernel color after commercial drying](image)
Quality of Almonds after Commercial Drying (Continued)

- **Cavity**
  - No cavity observed for all samples

- **Color development score for concealed damage evaluation**
  - Color development scores were similar for different conditions (Conv, AA, and HA)

<table>
<thead>
<tr>
<th>Score</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Example</td>
<td><img src="image1.png" alt="Example Image" /></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Color development score grading reference

![Bar Chart](image2.png)

Concealed damage of almonds after commercial drying

Suture of almonds after commercial drying
Quality of Almonds from Commercial Drying (Continued)

- Peroxide value
  - Slightly increased but much less than industrial standard (5 meq/kg)
- Free fatty acid
  - Slightly increased but much less than industrial standard (1.5%)
Conclusions

• Almonds from off-ground harvest vs. conventional harvest
  – Less insect damage
  – Cleaner
  – Slight change in oil quality for high temperature commercial drying

• Hot air drying
  – No cavity
  – No significant kernel color change
  – No significant concealed damage
  – Initial moisture and drying conditions did not show significant effect
  – Recommend conditions: up to 60°C and 2m/s

• Energy cost: 0.23 to 5 cents per pound almond

• Sorting for reducing energy cost
Acknowledgement

• Food Processing Research Group
  – Ragab Khir, Yi Shen, Chang Chen, Zhaokun Ning, Xingzhu Wu,
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  – Guangwei Huang and Sebastian Saa

• Collaborators
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  • Emerald Farm
  • West Valley Hulling Company
  • Wizard Manufacturing Inc.
  • Nickels Soil Lab

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