Journey Toward Off-Ground Harvest

california almonds
Almond Board of California

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)**



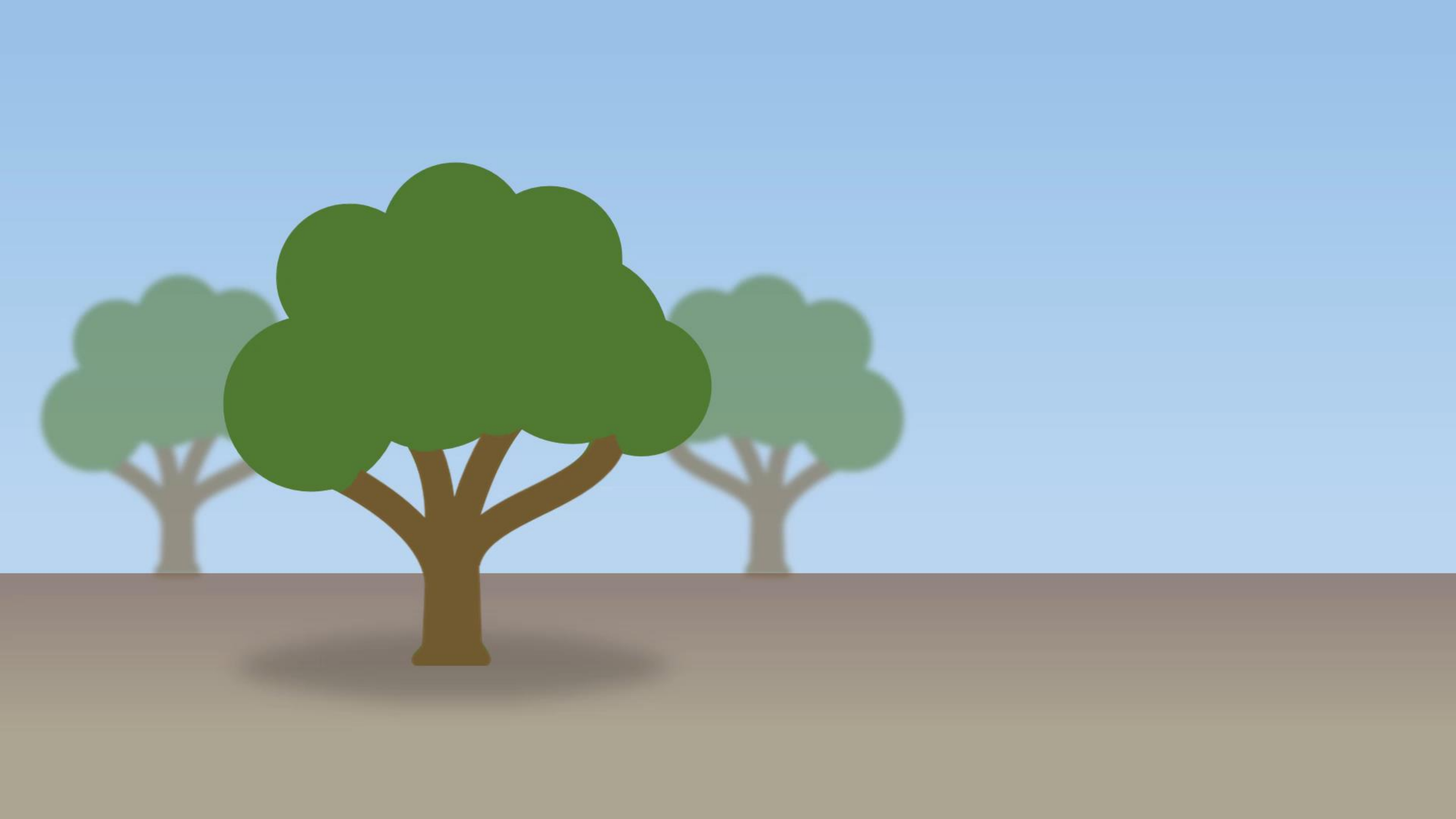
Technoeconomic assessment of potential off-ground harvesting practices in the California almond industry

Christopher Simmons, PhD

Department of Food Science and Technology

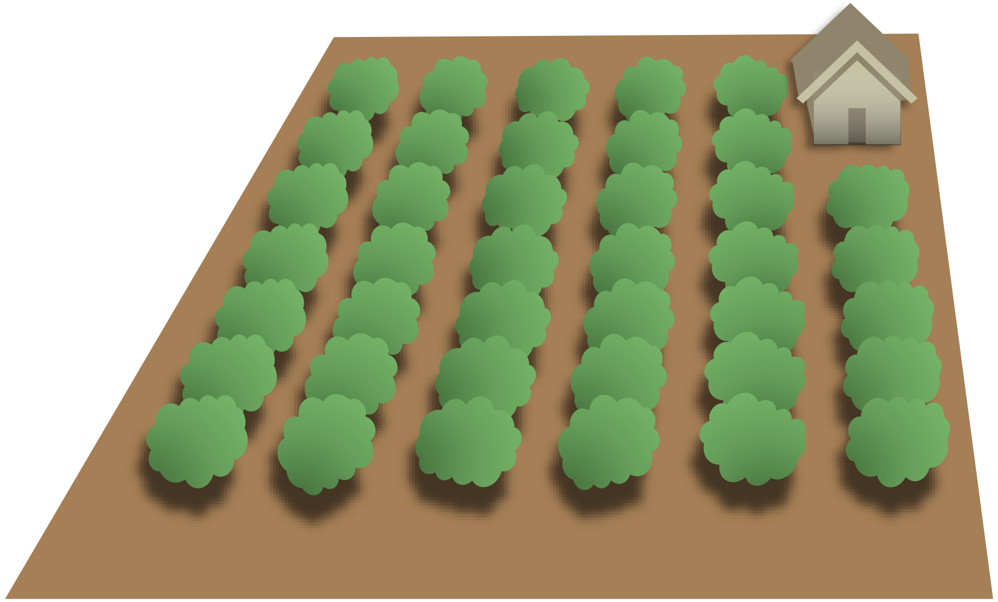
University of California, Davis

california almonds
Almond Board of California



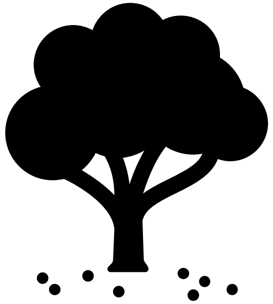
Assumptions

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

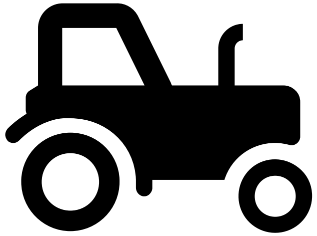
Expected effects



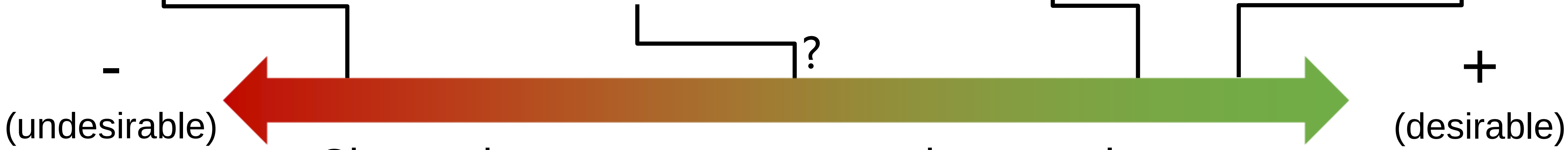
Losses due to windfall; may be affected by
- Region
- Variety
- Harvest schedule

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

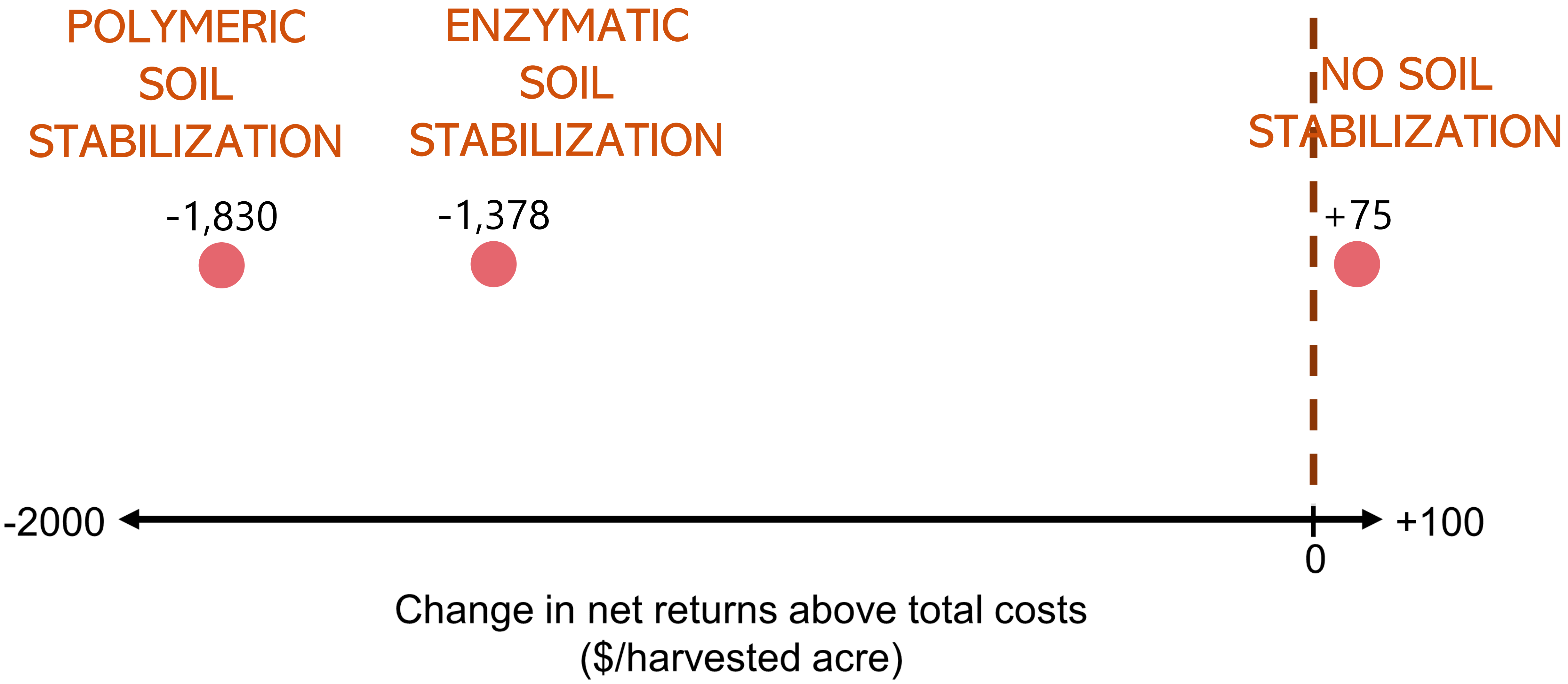


Harvest operations
- Blowing/sweeping are avoided
- Pickup may be avoided

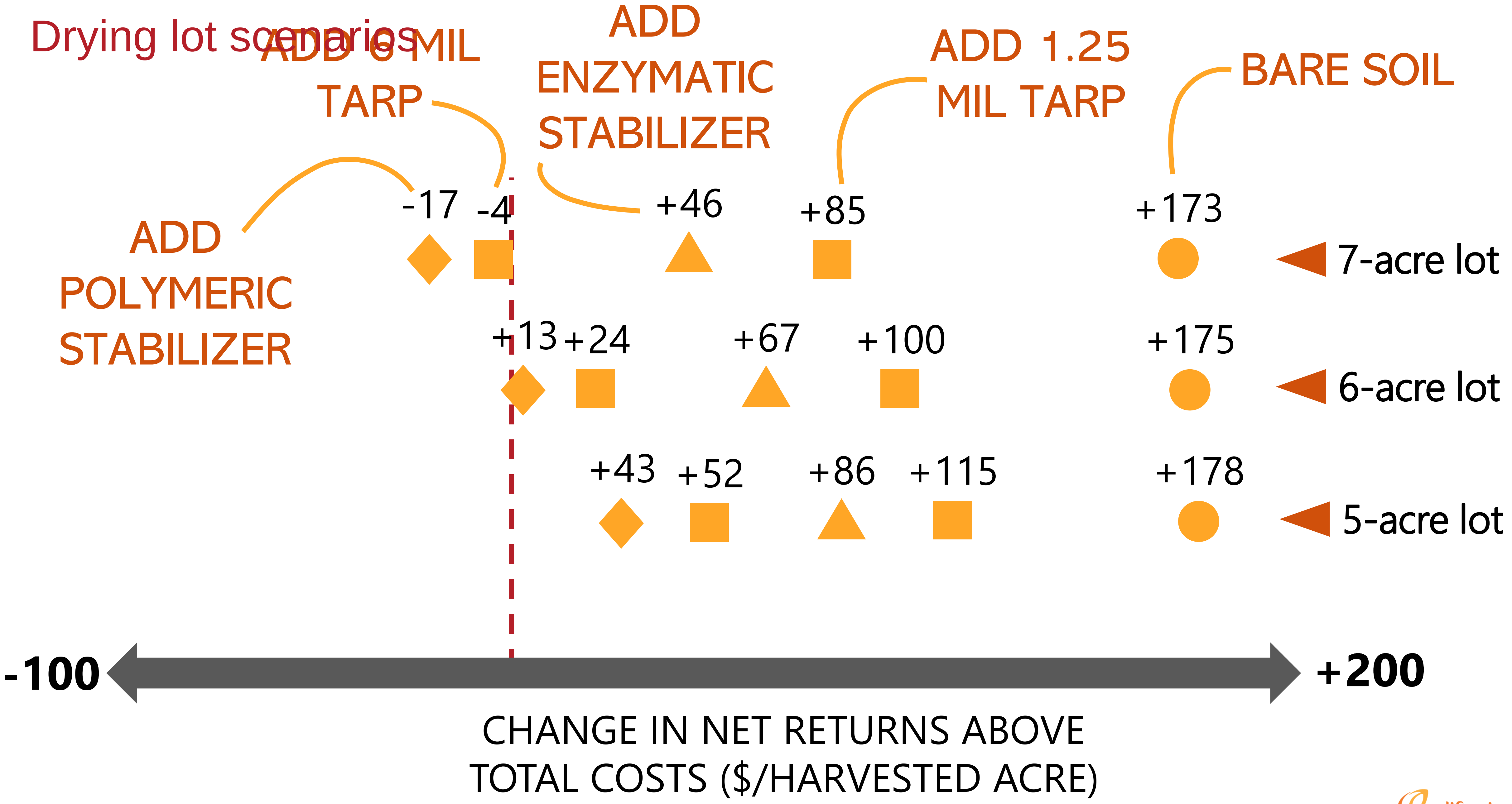


Change in net return per acre above total costs relative to conventional practices ($/acre)

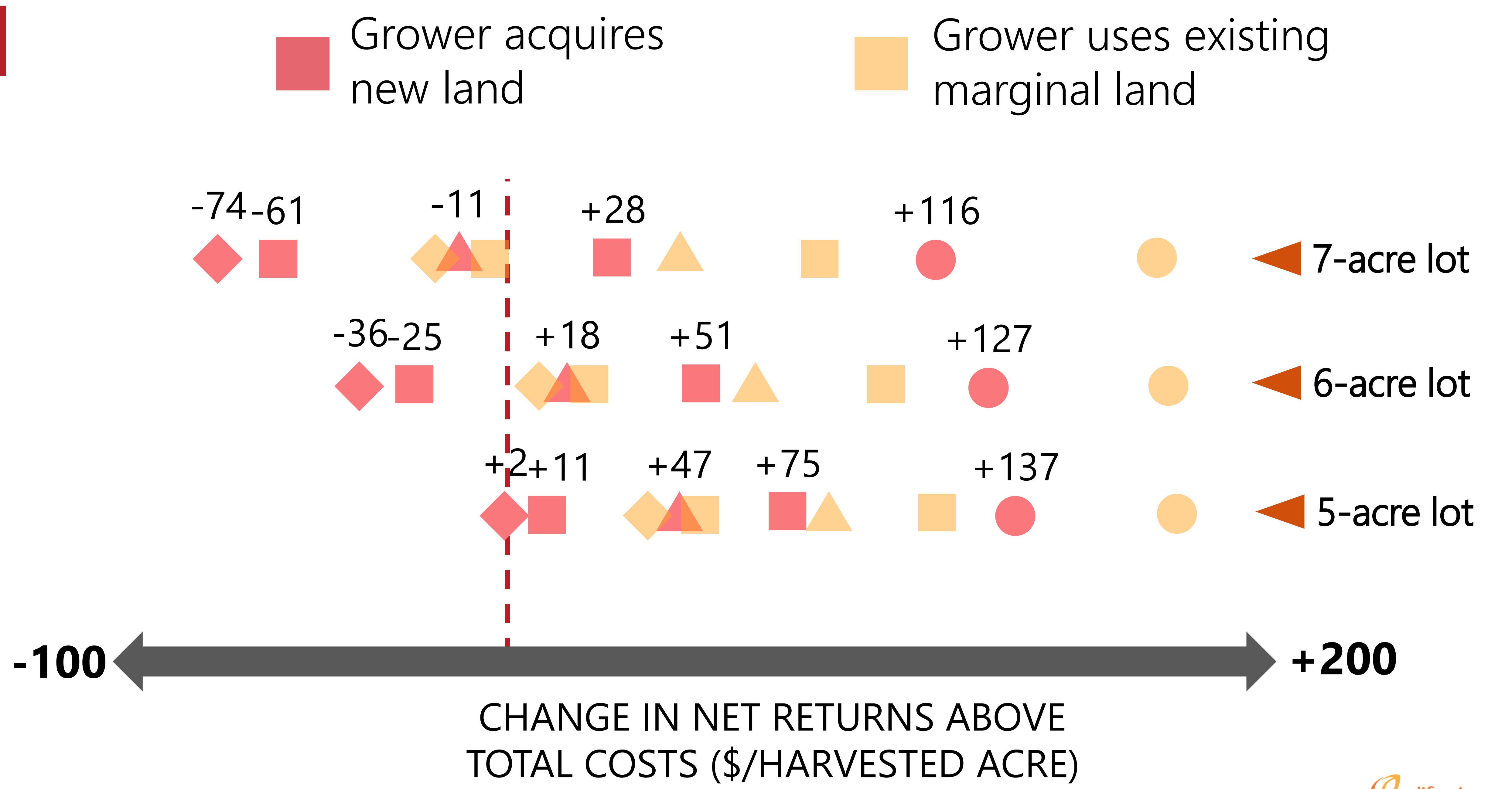
In-orchard drying scenarios



Drying lot scenarios



california almonds Almond Board of California



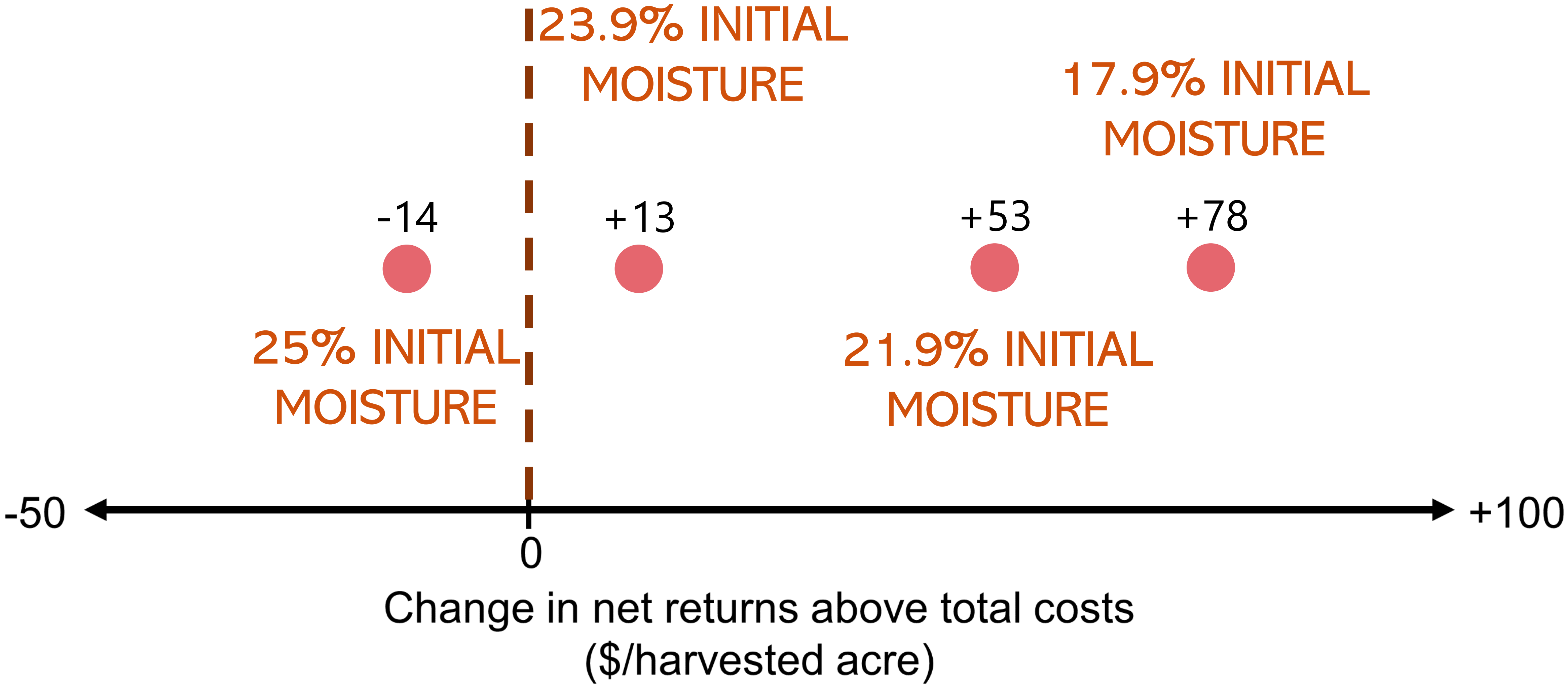
Grower acquires new land
Grower uses existing marginal land
-74
-61
-11
+28
+116
7-acre lot
-36
-25
+18
+51
+127
6-acre lot
+2
+11
+47
+75
+137
5-acre lot
-100
+200
CHANGE IN NET RETURNS ABOVE TOTAL COSTS ($/HARVESTED ACRE)

Lot drying scenarios

		Yield (Pound/Acre)						
Lot size	Soil stabilization	1000	1400	1800	2200	2600	3000	3400
5	none	-25.00	48.00	120.00	192.00	265.00	337.00	410.00
6	none	-35.00	37.00	109.00	182.00	254.00	326.00	399.00
7	none	-46.00	26.00	98.00	171.00	243.00	316.00	388.00
5	1.25 mil tarp mulch	-88.00	-15.00	57.00	130.00	202.00	274.00	347.00
6	1.25 mil tarp mulch	-111.00	-39.00	34.00	106.00	178.00	251.00	323.00
7	1.25 mil tarp mulch	-134.00	-62.00	10.00	83.00	155.00	227.00	300.00
5	polymer emulsion	-160.00	-88.00	-15.00	57.00	129.00	202.00	274.00
6	polymer emulsion	-198.00	-126.00	-53.00	19.00	91.00	164.00	236.00
7	polymer emulsion	-236.00	-164.00	-91.00	-19.00	53.00	126.00	198.00

LOT SIZE AND DUST CONTROL TREATMENTS MUST BE FINELY TUNED TO QUANTITY OF ALMONDS

Mechanical drying scenarios



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

Almond Board of California

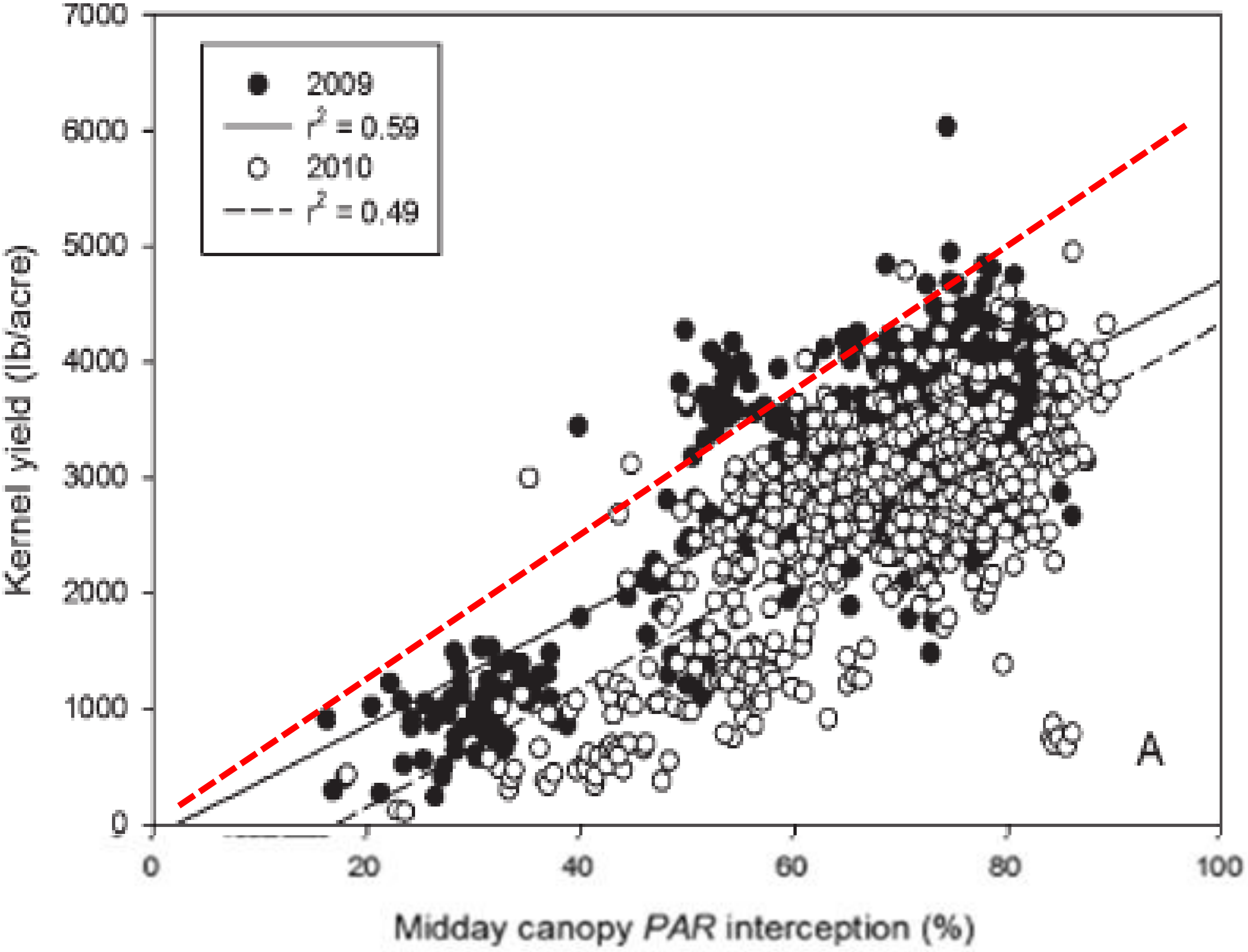
Plants, nature's original solar energy collectors

- 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.

Almonds



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.

almonds Almond Board of California

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 Teneus 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




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

californiaalmonds®
Almond Board of California

QUANTITATIVE OUTCOMES

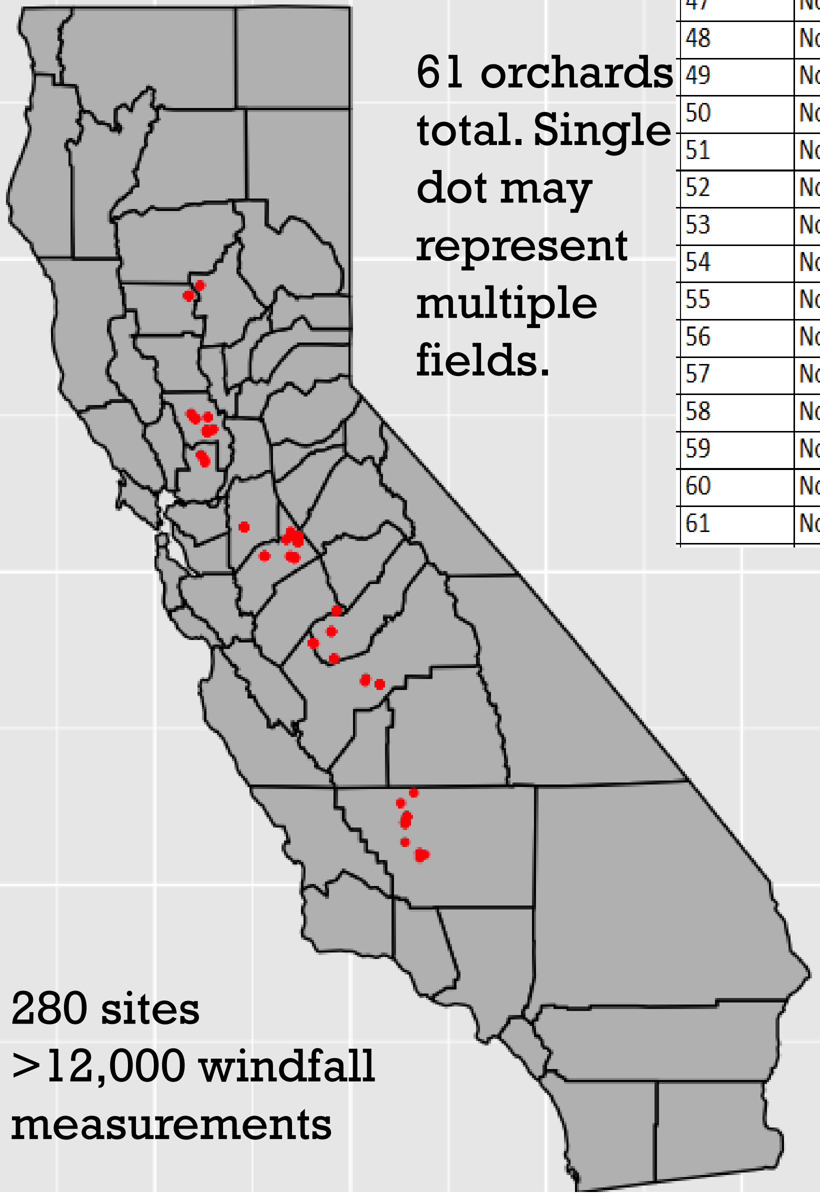
- How Much Windfall Occurs
- When Does Windfall Occur
- Effect of location, cultivar and date

QUALITATIVE OUTCOMES

- Determine effect of windfall date on quality of final harvest.
- Determine effect of harvest date on nut quality

MORE ABOUT THE ORCHARDS

Orchard #	Varieties				Age	CA Location
1	NonPareil		Monterey		7	South
2	NonPareil				9	South
3	NonPareil	Sonora	Monterey		6	South
4	NonPareil	Sonora	Monterey		7	South
5	NonPareil	Sonora	Monterey		6	South
6	NonPareil		Monterey		12	South
7	NonPareil		Monterey		9	South
8	NonPareil		Monterey		12	South
9	NonPareil	Avalon	Wood Colony		16	South
10	NonPareil		Monterey		11	South
11	NonPareil		Monterey		16	South
12	NonPareil	Fritz	Monterey		12	South
13	NonPareil	Aldrich	Monterey		15	South
14	NonPareil	Aldrich	Monterey		12	South
15	NonPareil	Sonora	Monterey		16	South
16	NonPareil	Supareil			4	South
17	Independence				6	South
18	Independence				6	South
19	NonPareil		Monterey		19	South
20	NonPareil	Carmel			19	South
21	NonPareil	Fritz	Butte	Padre	11	South
22	NonPareil		Monterey		15	South
23	NonPareil	Fritz	Monterey		6	South
24	NonPareil	Carmel	Monterey		15	South
25	NonPareil	Monterey	Fritz		10	Central
26	NonPareil	Supareil	WoodColony		6	Central
27	NonPareil	Avalon	Wood Colony		12	Central
28	NonPareil	Aldrich	Sonora	Monterey	11	Central
29	NonPareil	Monterey	Carmel		9	Central
30	NonPareil	Monterey	Carmel		9	Central
31	NonPareil	Monterey	Carmel		9	Central
32	Independence				7	Central
33	NonPareil	Aldrich	Carmel	Butte	13/5	Central
34	Independence				10--5	Central
35	NonPareil	Butte	Padre		22	Central
36	NonPareil	Fritz	Aldrich	Carmel	22	Central
37	NonPareil	Fritz	Aldrich	Carmel	13	Central
38	Independence				4	Central
39	NonPareil	Carmel			38	Central
40	NonPareil		Monterey		7	Central
41	NonPareil		Monterey		7	Central
42	Independence				4	North
43	Independence				4	North
44	Independence				4	North
45	Independence				4	North
46	NonPareil	Woodcolony	Carmel		8	North
47	NonPareil	Monterey	Fritz		10	North
48	NonPareil	Monterey	Fritz		9	North
49	NonPareil	Monterey	Fritz		11	North
50	NonPareil	Woodcolony	Carmel		7	North
51	NonPareil	Woodcolony	Carmel		7	North
52	NonPareil	Woodcolony	Carmel		6	North
53	NonPareil	Woodcolony	Carmel		6	North
54	NonPareil	Woodcolony	Carmel		6	North
55	NonPareil	Woodcolony	Monterey		7	North
56	NonPareil	Woodcolony	Monterey		9	North
57	NonPareil	Monterey	Fritz		6	North
58	NonPareil	Carmel	Butte		15	North
59	NonPareil	Carmel	Butte		12	North
60	NonPareil	Carmel	Butte		17	North
61	Nonpareil	Fritz	Monterey		15	North



61 orchards total. Single dot may represent multiple fields.

280 sites
>12,000 windfall measurements

THE ORCHARDS

Barcode 4
Barcode 3
Barcode 2
Barcode 1

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

DRIP LINE DRIP LINE DRIP LINE

TREE TRUNK
Barcode 1
Barcode 2
Barcode 3
Barcode 4
TREE TRUNK

DRIP LINE DRIP LINE DRIP LINE

- Orchards sampled **in transect**
- Three reps per variety present
- Eight photo frames per rep
  - 4 Along row (0°)
  - 4 Across rows (90°)

DRIP LINE DRIP LINE DRIP LINE

TREE TRUNK
TREE TRUNK

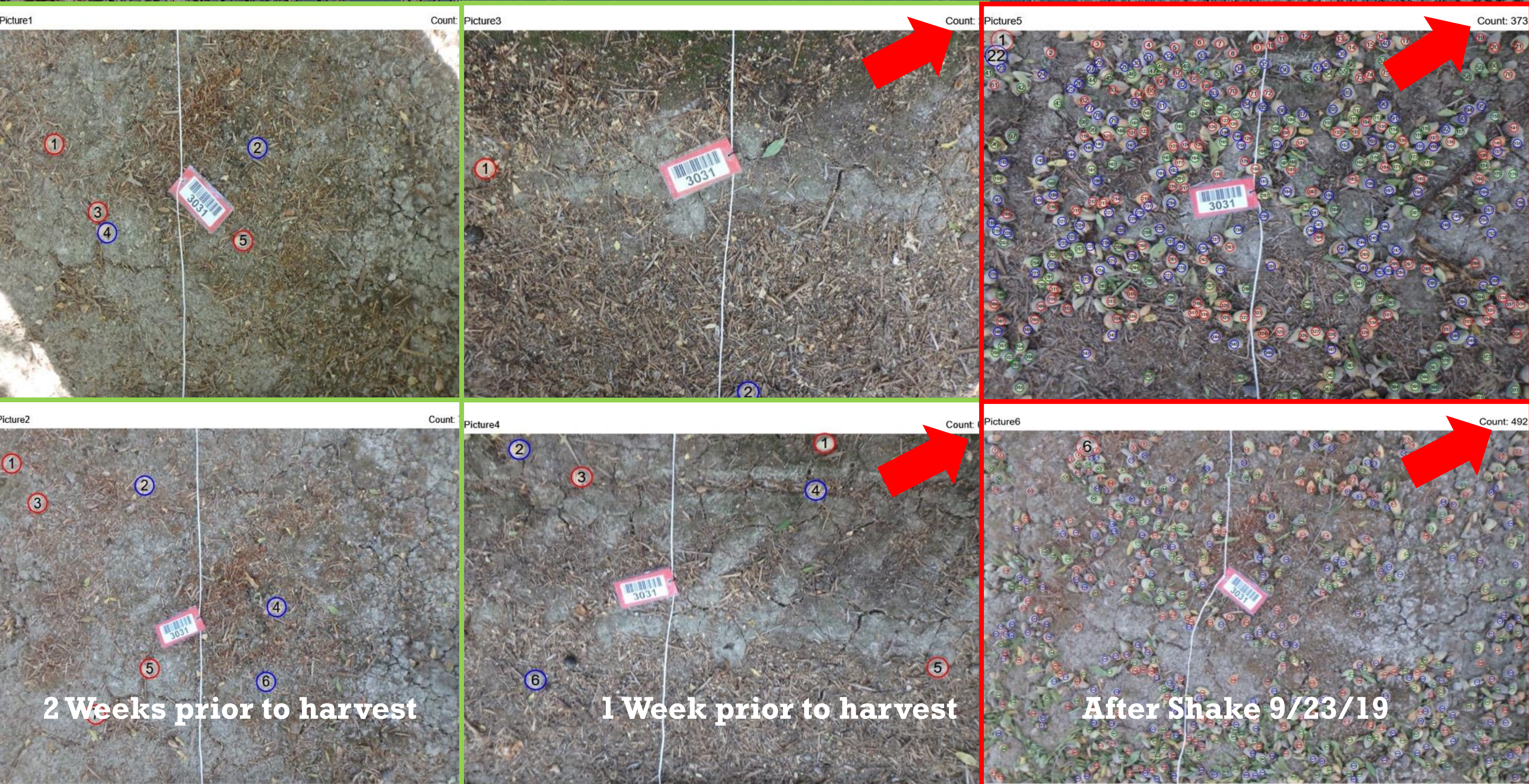
EXAMPLE QUANTITATIVE OBSERVATIONS (LOW WINDFALL 0-0.1% 2-3 LBS)

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

COUNTING NUTS USING ARTIFICIAL INTELLIGENCE

A WORK IN PROGRESS!

MACHINE LEARNING SOFTWARE USING HUMANS



QUALITATIVE PROJECT

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

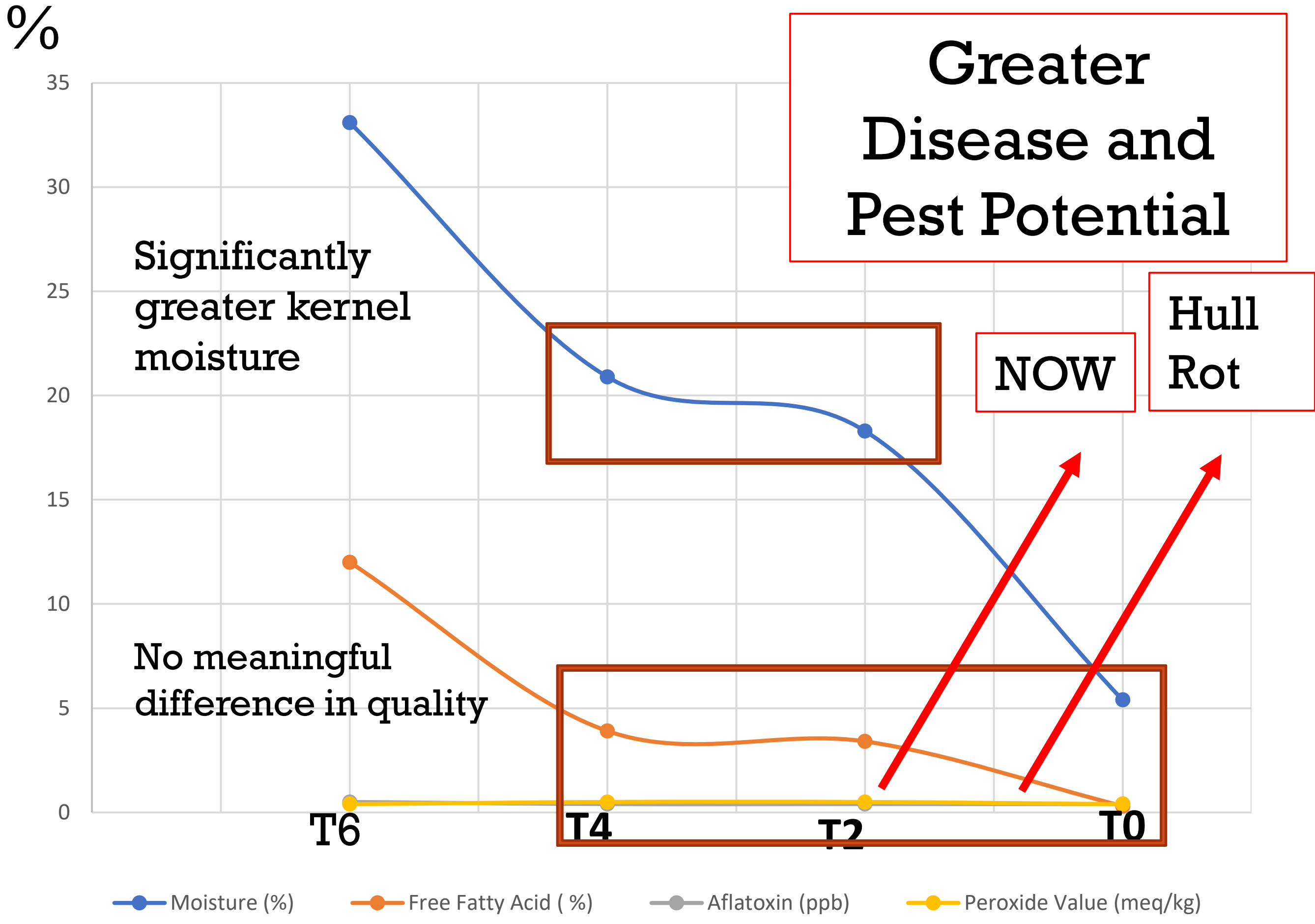
- Goal : Determine the effect of pre-harvest incubation times of nuts on orchard floor on quality
- Locations : Kern county (Bakersfield) and Butte County (Chico)
- Replications : 6 replications with 6 pseudo-replications made of 6 trees each (20 nuts/tree)
- Measurements : continuously monitored soil 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

I			II			III			IV			V			VI		
T6	T4	T2	T2	T6	T4	T2	T4	T6	T2	T6	T4	T6	T2	T4	T4	T6	T2
T6	T4	T2	T2	T6	T4	T2	T4	T6	T2	T6	T4	T6	T2	T4	T4	T6	T2
T6	T4	T2	T2	T6	T4	T2	T4	T6	T2	T6	T4	T6	T2	T4	T4	T6	T2
T6	T4	T2	T2	T6	T4	T2	T4	T6	T2	T6	T4	T6	T2	T4	T4	T6	T2
T6	T4	T2	T2	T6	T4	T2	T4	T6	T2	T6	T4	T6	T2	T4	T4	T6	T2
T6	T4	T2	T2	T6	T4	T2	T4	T6	T2	T6	T4	T6	T2	T4	T4	T6	T2

Treatments	Dates	
	Bakersfield	Chico
T6=6weeks pre-harvest	July 3rd	July 4rd
T4=4weeks pre-harvest	July 17TH	July 18th
T2=2weeks pre-harvest	August 2nd	August 4th
T0= Control at	August 17th	August 18th

QUALITATIVE RESULTS AND OUTCOMES

Kern-Bakersfield	T6	T4	T2	T0
Moisture (%)	33.1	20.9	18.3	5.4
Free Fatty Acid (%)	12.0	3.9	3.4	0.3
Aflatoxin (ppb)	0.5	0.4	0.4	0.4
Peroxide Value (meq/kg)	0.4	0.5	0.5	0.4



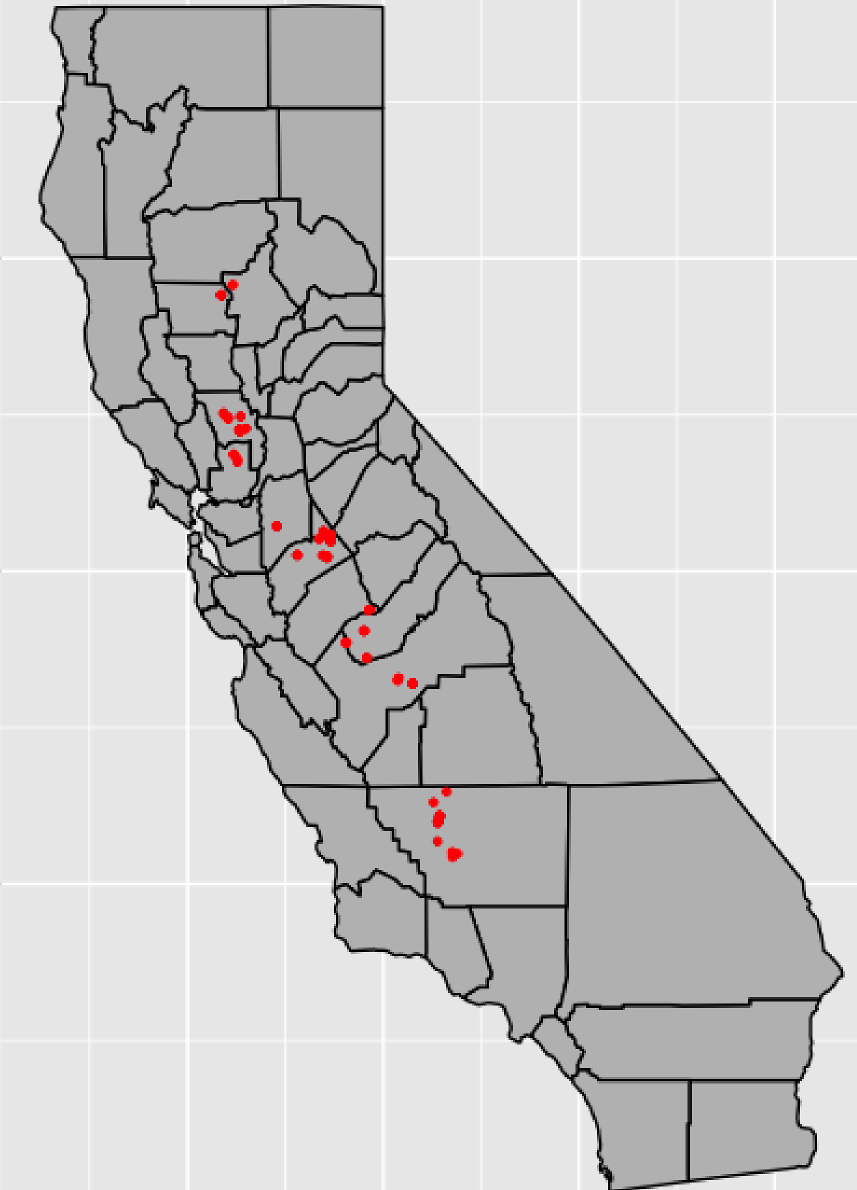
Preliminary analysis of composite samples from Bakersfield shows Moisture and FFA percentages **gradually decreasing** from T-6 (6 weeks before harvest) to T-0 (nuts at harvest) while aflatoxin concentration and peroxide value remained constant.

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.



NOW
infested nut
Mid July /
Bakersfield

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.

Drying Fresh Almonds

Dr. Michael Coates

Dr. Michael Coates

Michael.Coates@plantandfood.com.au
Plant & Food Research Australia

Dr. Irwin R. Donis-González

irdonisgon@ucdavis.edu
UC Davis

Ismael Mayanja
ikmayanja@ucdavis.edu
UC Davis, MSc. student

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.

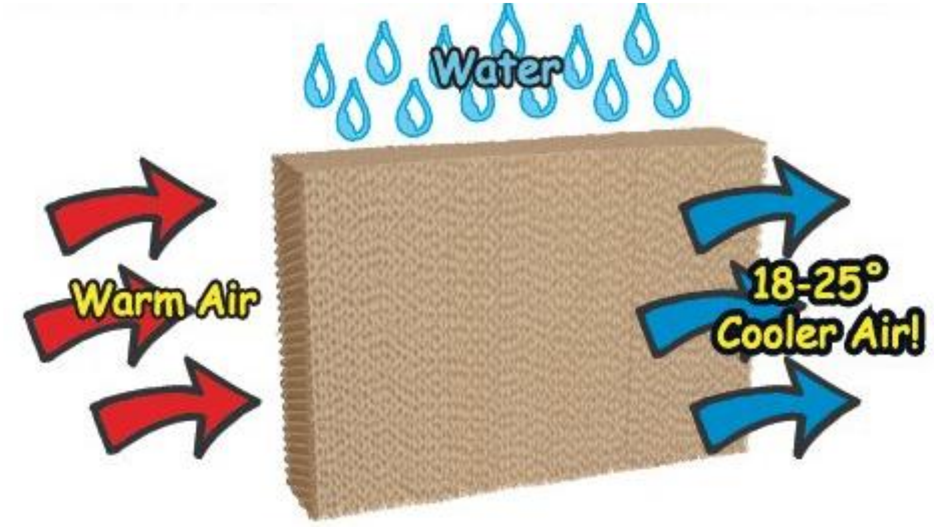
Drying

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.

Manage

evaporative cooling

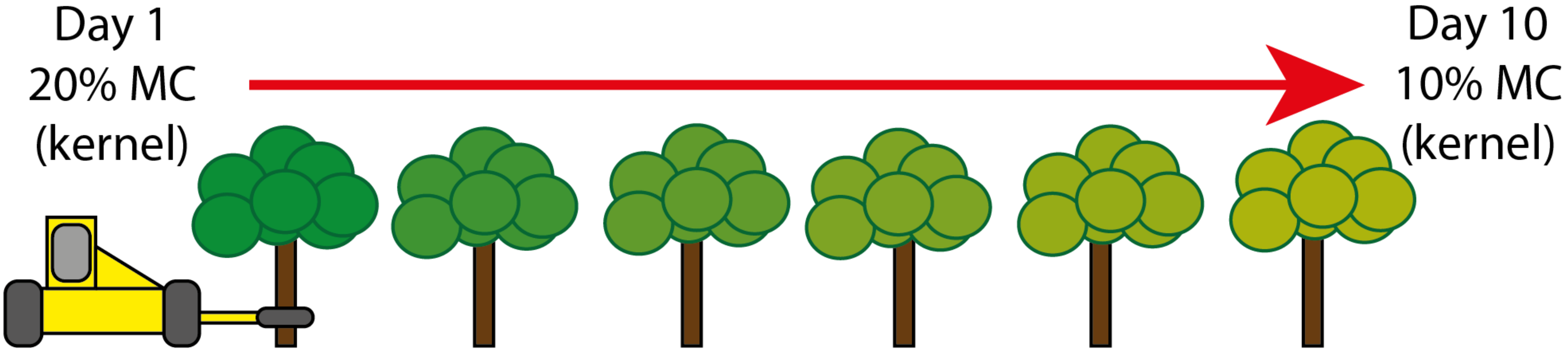


Fruit that takes 3-10 days to dry in a tree row, can take 2-3 weeks to dry in a stockpile or batch dryer with evaporative cooling caused by insufficient air flow.

https://portablecoolers.com/evap/

Drying

Harvest time variability for each cultivar



Additional resources:
- Forced Air
- Heat

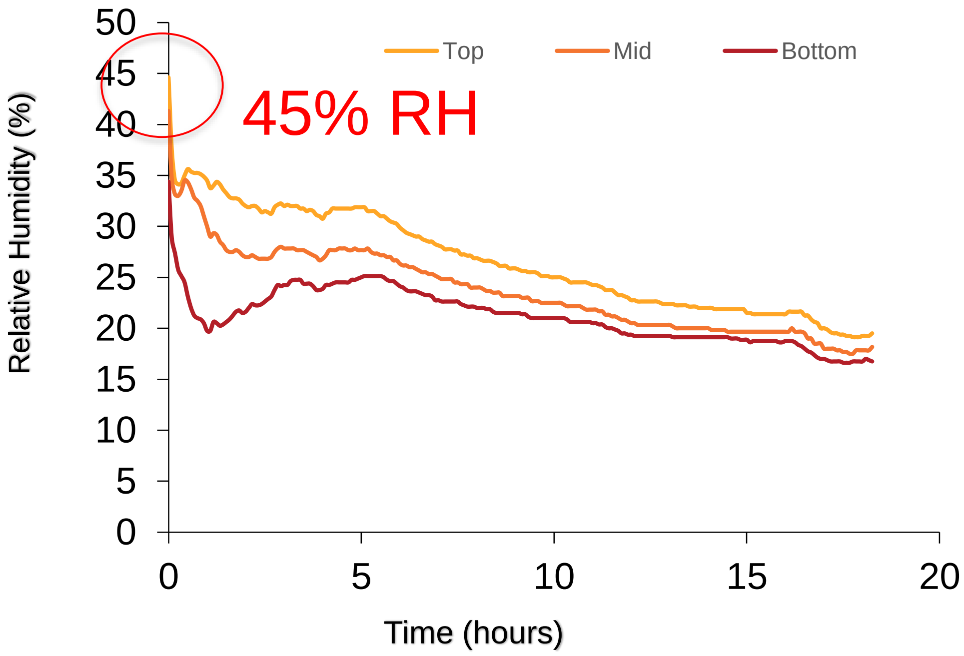
Additional resources:
- Ambient air

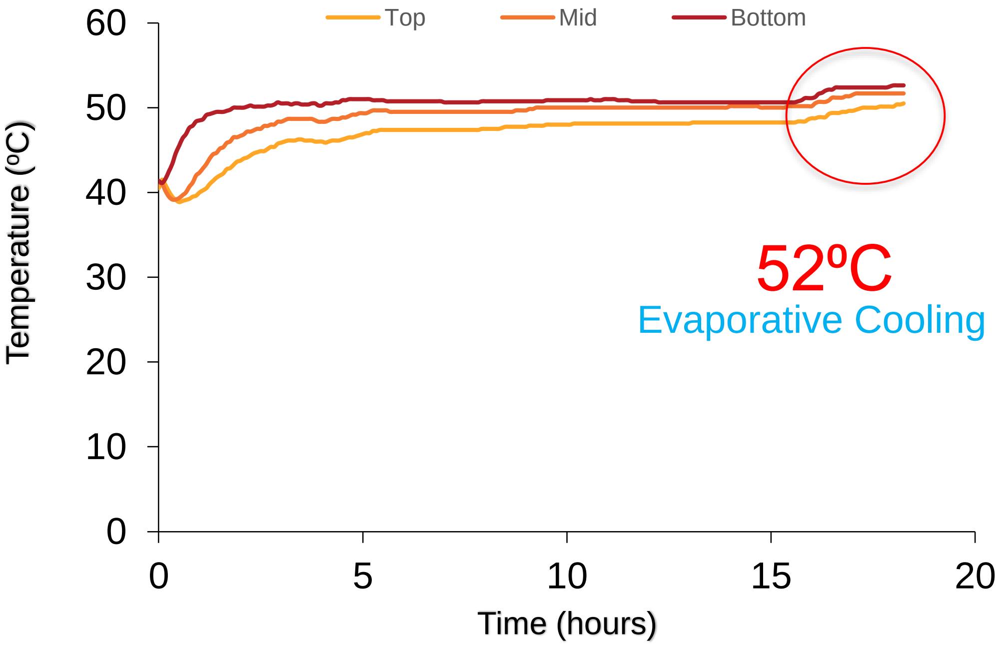
Batch Drying

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. 52ºC (80ºF)
~5200 ft^3 of almond fruit
15 kW fan

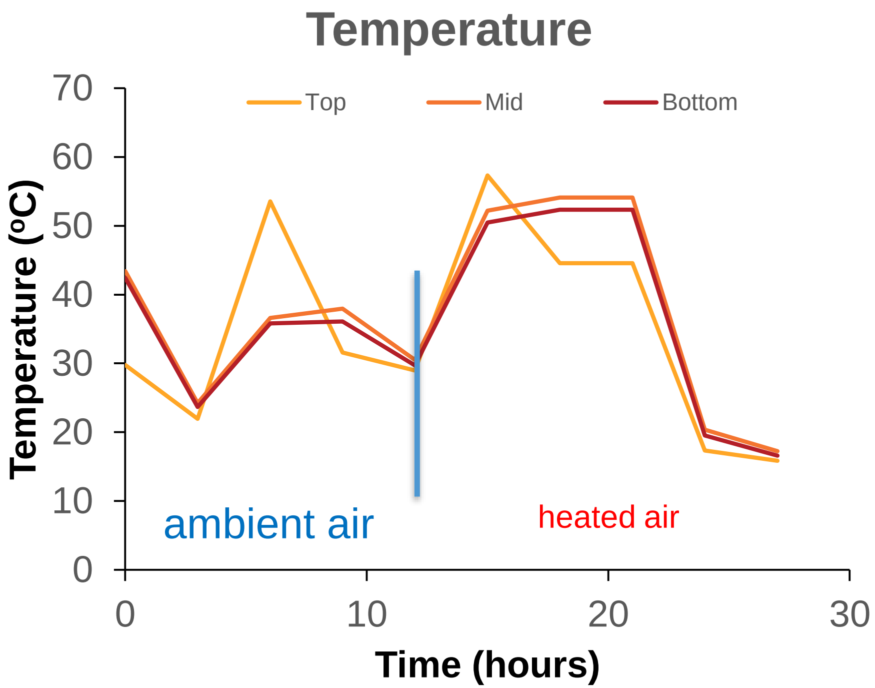


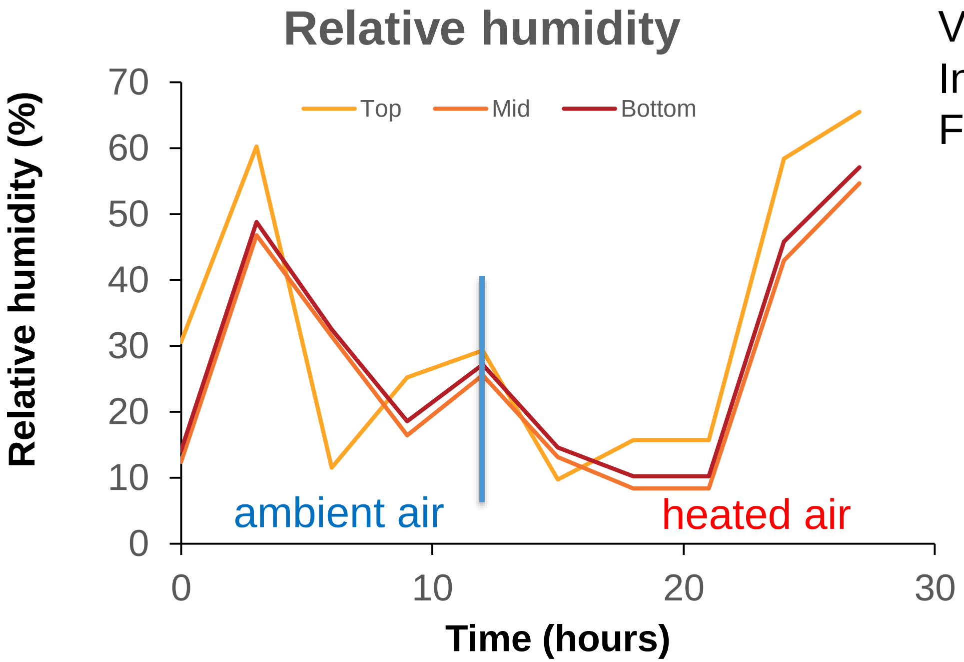


Batch Drying

UC Davis batch dryer

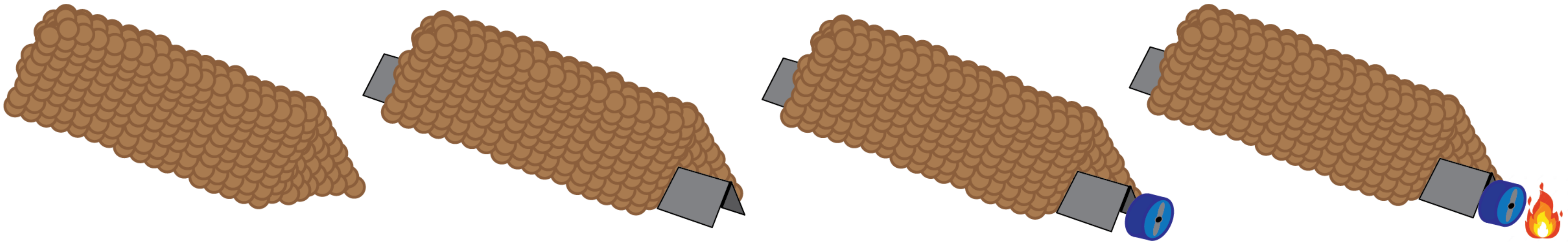
- ~750 lbs. of fruit per bin (340 kg dry)
- Air flow of 23-25 cfm/ft^3 (~1 m^3/s/m^3)
- Heat capacity of 50ºC (122ºF)





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)

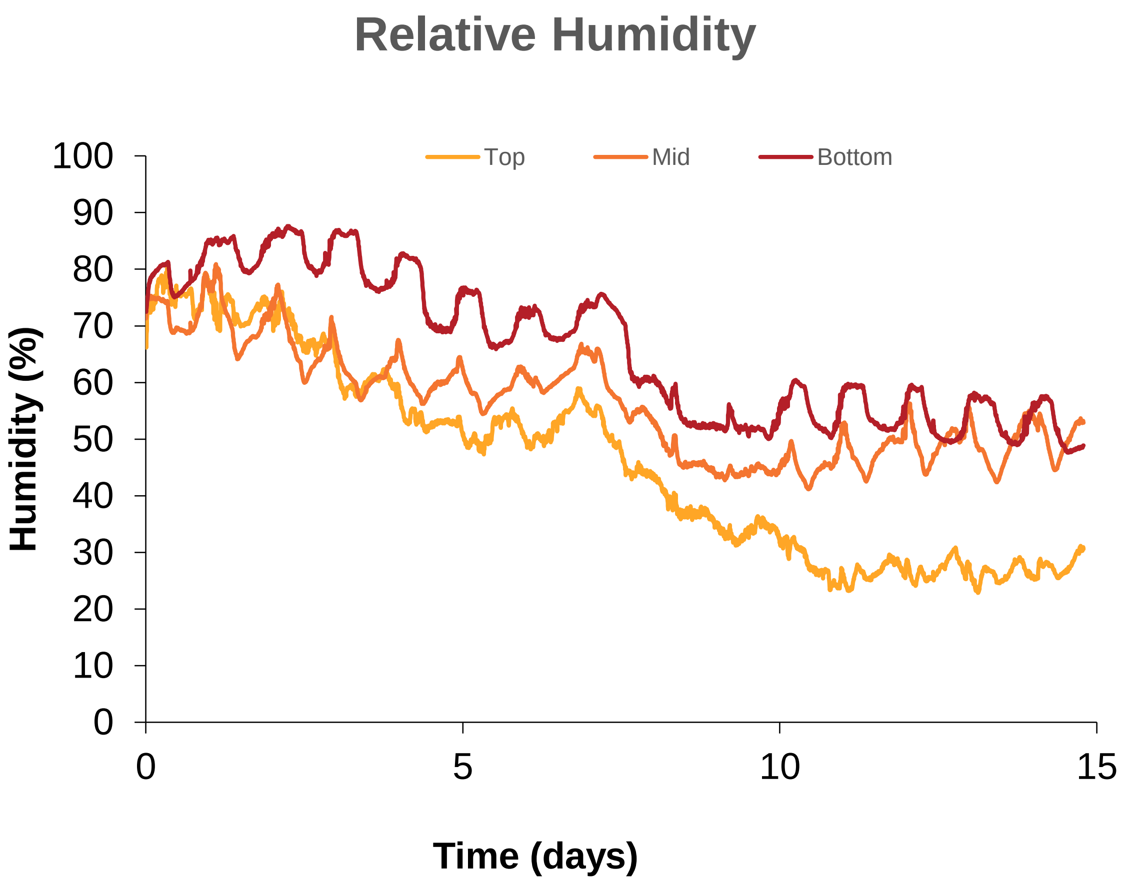
This is currently the direction the research is going, but it is still preliminary.

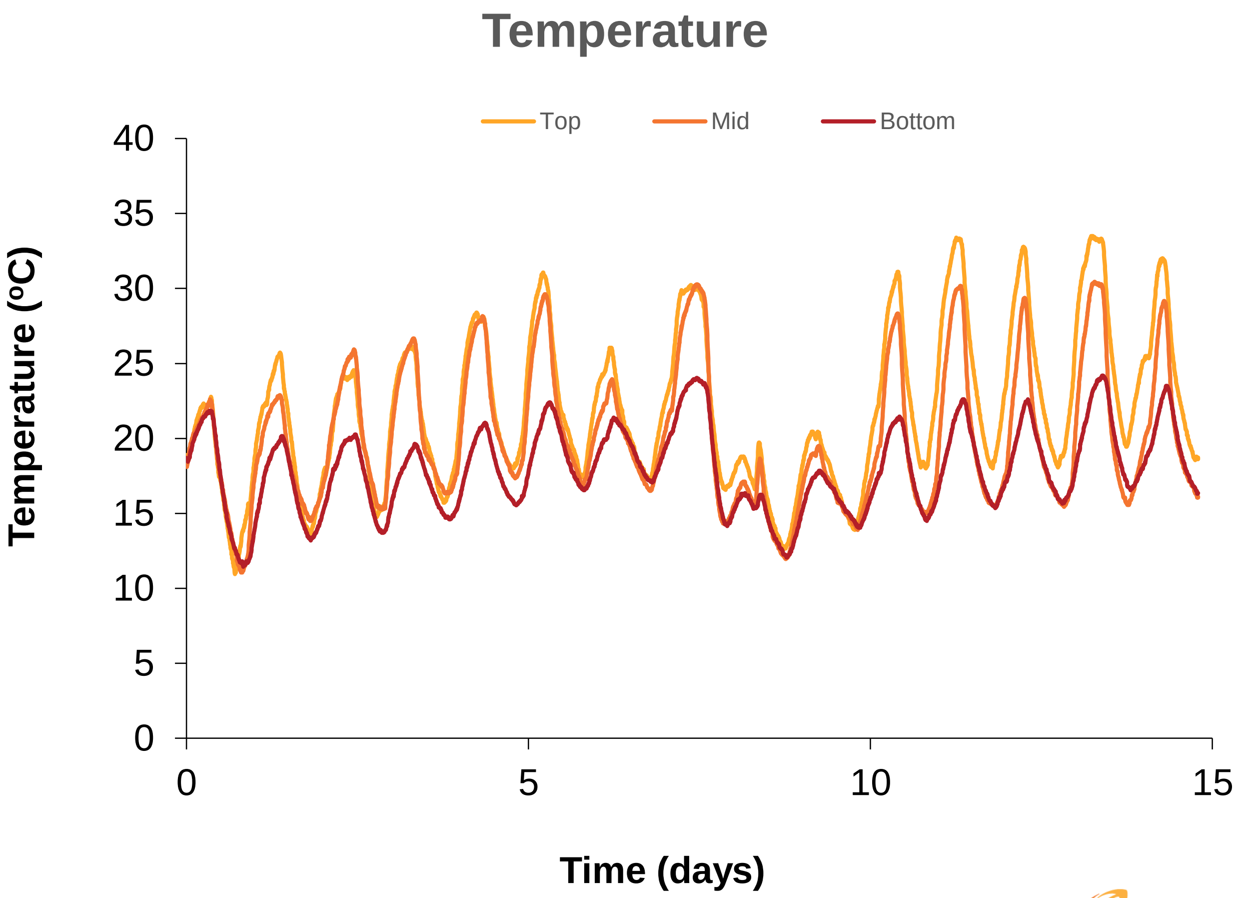
Stockpile Drying

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)





California almonds
Almond Board of California

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)

Michael.coates@plantandfood.com.au

THE SCIENCE OF PREMIUM™

Efficient Drying of Off-ground Harvested Almonds without Quality Concerns

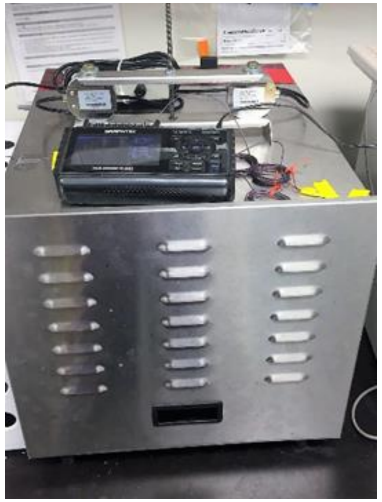
Zhongli Pan Ph.D.
Food Processing Research Group
Department of Biological and Agricultural Engineering
University of California, Davis
zlpan@ucdavis.edu

california almonds
Almond Board of California

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?

Trailer Drying at West Valley Co.



• Benchtop Dryer

Column dryer

Tunnel Drying at Campos Brothers

Stadium Drying at Emerald Farm

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

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

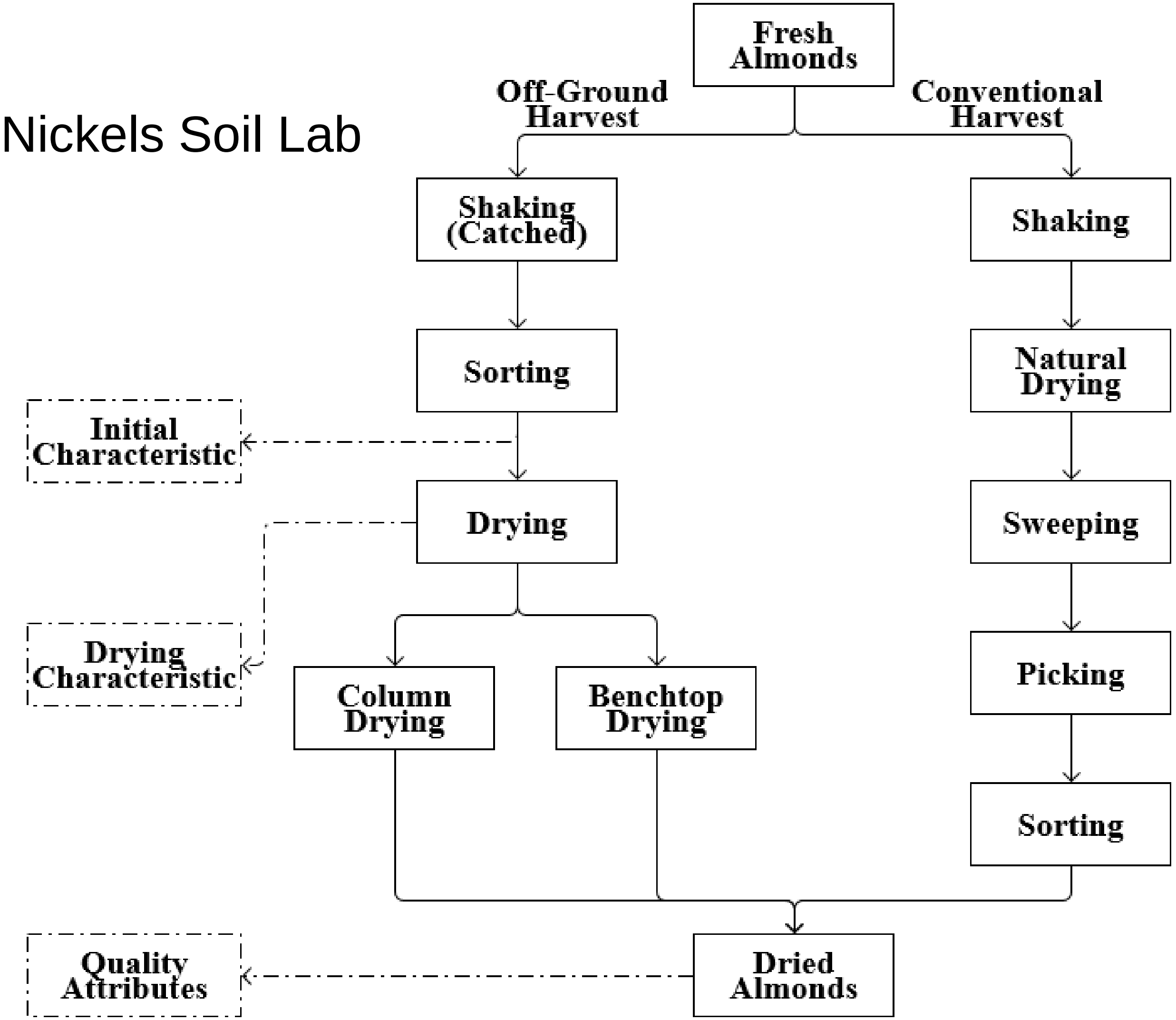
california almonds
Almond Board of California

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

Benchtop Dryer

Column dryer



Experimental approach

Characteristics of Almonds from Off-Ground and Conventional Harvest

- Less insect damage and cleaner from off-ground harvest

Percentage of insect infestation for different varieties

Variety	Days on ground	Insect infestation (%)	
		Conventional	Off-ground
Nonpareil	11	6.3	3.3
Monterey	14	11.4	6.3
Fritz	9	4.5	2.5

Appearance

Off-ground harvest almonds **Conventional harvest almonds**

- Dimensions

Variety	Category	Axial dimension (mm)		
		length	width	thickness
Nonpareil	In-hull	37.53±2.71	28.00±2.52	23.63±4.41
	In-shell	33.63±2.43	21.80±1.85	13.80±1.21
	kernel	24.47±1.60	13.93±1.22	7.00±0.53
	hull	38.13±2.57	27.33±4.23	23.70±7.11
Monterey	In-hull	38.27±3.22	24.80±2.28	23.20±1.99
	In-shell	37.97±3.00	22.23±1.50	17.37±1.40
	kernel	24.93±3.26	13.73±1.83	8.33±0.72
	hull	40.20±2.99	24.77±4.43	24.30±3.78
Fritz	In-hull	35.93±2.70	24.10±2.45	24.47±2.47
	In-shell	32.47±2.69	20.33±1.63	17.17±1.26
	kernel	21.93±1.71	12.47±1.06	8.60±1.18
	hull	36.27±2.98	22.70±6.08	28.27±7.86

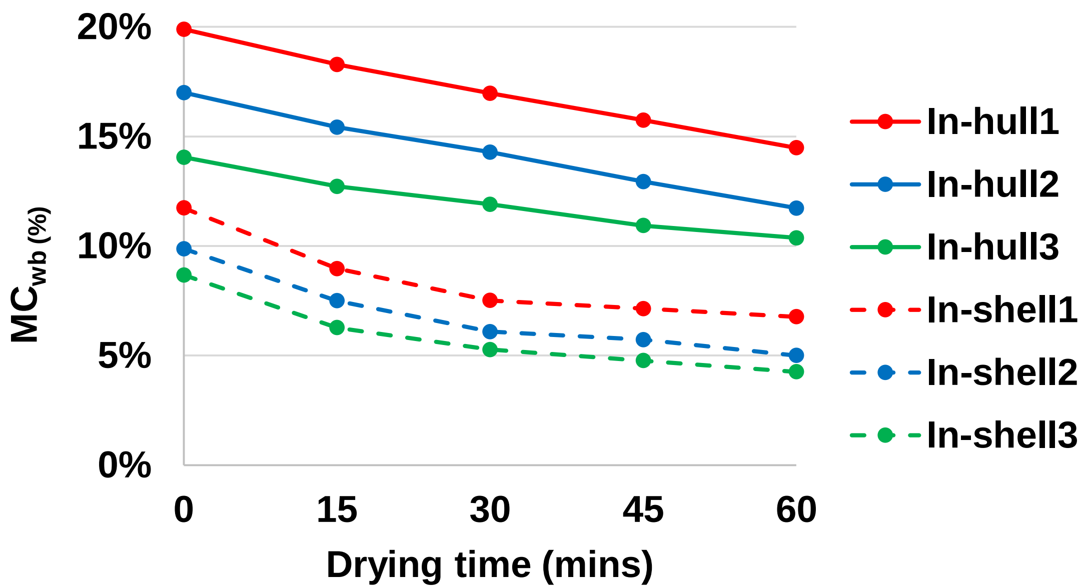
- Monterey - largest length and width
- Fritz – smallest in length and width
- Nonpareil - smallest thickness

Initial Moisture Content of Almonds

Variety	Overall	In hull			In shell	
	Average, min and max initial moisture contents (%wb)					
		Hull	Shell	Kernel	Shell	Kernel
Nonpareil	20.9	23.7 (13.3-46.9)	9.2 (5.4-16.5)	7.8 (3.2-20.2)	8.7 (5.9-11.1)	6.1 (3.0-10.7)
Monterey	17.7	19.8 (12.2-51.9)	10.0 (6.7-25.5)	8.4 (3.6-23.3)	8.4 (5.9-15.1)	6.5 (3.5-19.3)
Fritz	20.8	27.1 (12.4-55.7)	15.3 (8.5-26.6)	13 (3.6-32.5)	9.9 (6.4-13.2)	6.5 (3.4-15.8)

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



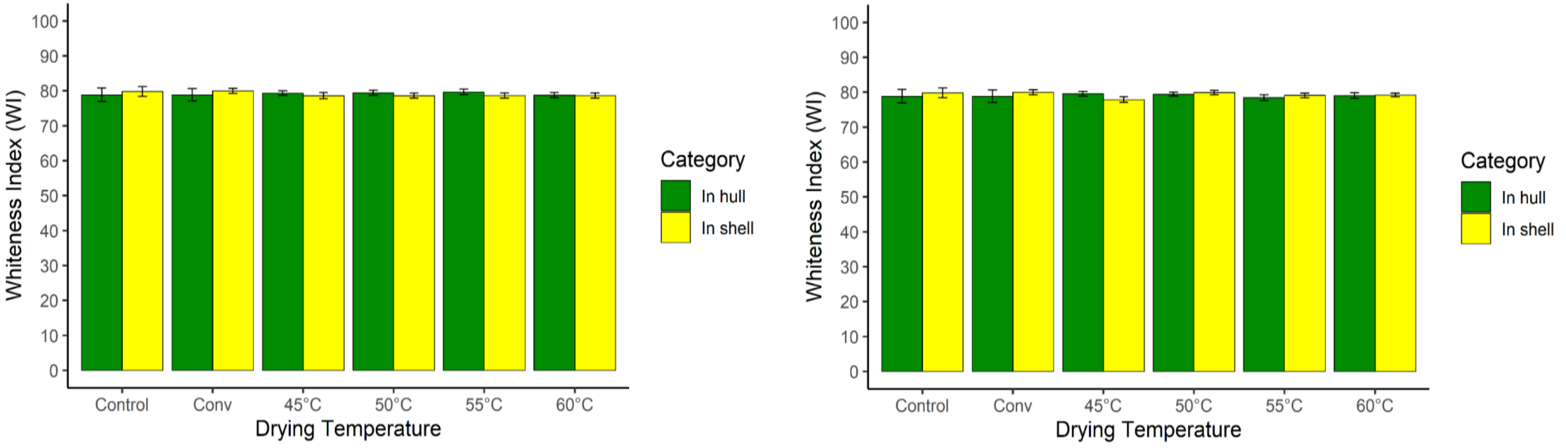
Drying curves of in-shell and in-hull almonds with different initial moisture contents at 60°C and 2 m/s (Nonpareil)

Drying performance of benchtop drying at different conditions (Nonpareil)

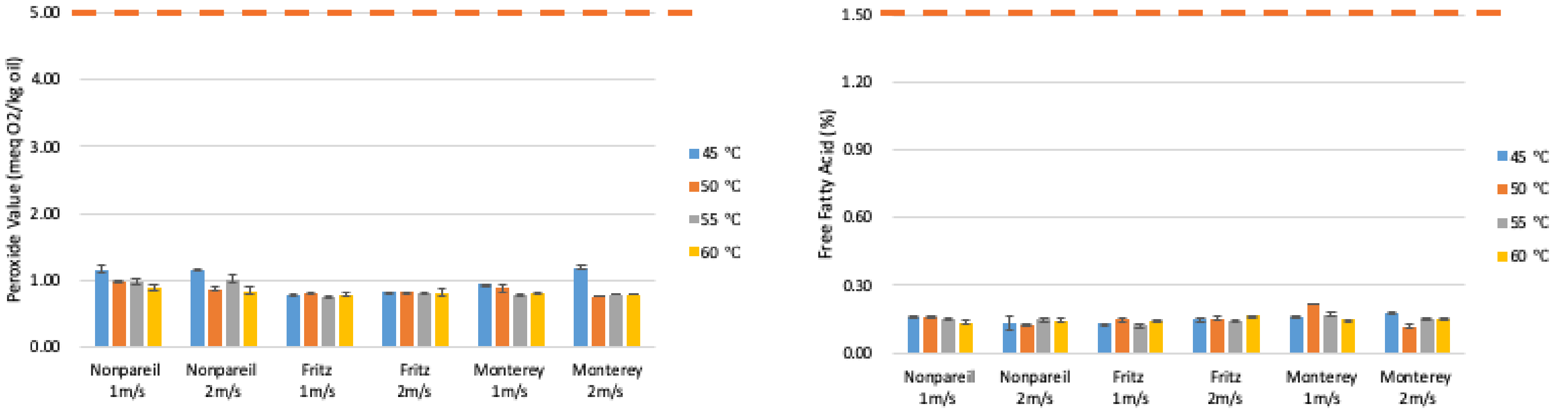
Air velocity (m/s)	Temp (°C)	Initial MC (%)		Final MC (%)		Drying time (h)	Overall drying rate (kg/h-kg)	
		Ave	Std	Ave	Std		Ave	Std
1	45	21.25	0.64	16.70	0.71	2	3.5E-02	3.0E-04
	50	17.50	0.99	13.15	0.92	1.25	4.9E-02	2.1E-03
	55	17.75	0.64	13.05	0.49	1	6.5E-02	2.8E-03
	60	20.15	0.49	14.55	0.49	1	8.1E-02	1.4E-03
2	45	19.15	1.06	15.20	1.84	1.25	3.9E-02	3.5E-03
	50	15.05	0.64	11.55	0.64	1.25	3.7E-02	3.1E-04
	55	15.90	0.71	11.75	0.64	1	5.6E-02	1.4E-03
	60	15.85	0.35	11.60	0.71	0.75	7.5E-02	4.2E-03

Almond Quality from Benchtop Drying

- No significant changes
  - Color
  - Cavity
- PV and FFA
  - Much lower than the industry standards: (5 meq O_2/kg oil and 1.5%)



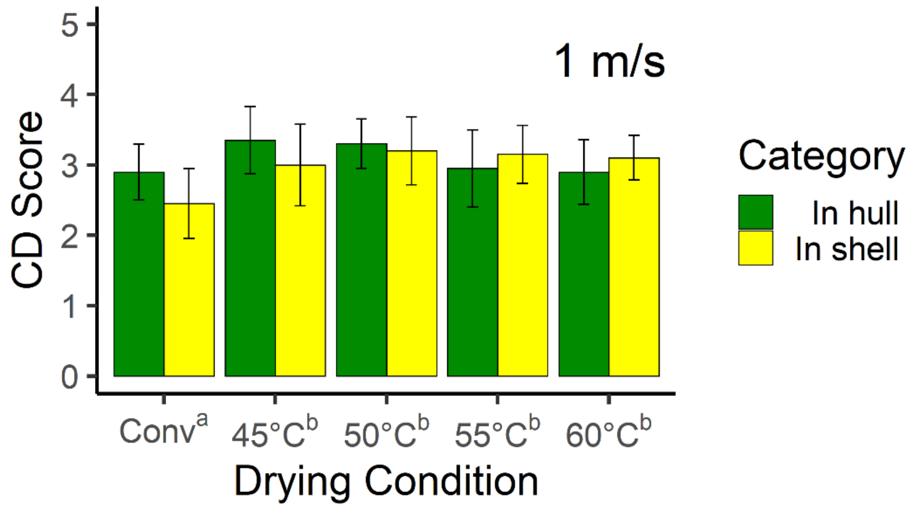
Final product kernel whiteness index at different temperature levels at 1m/s (left) and 2m/s (right) (Nonpareil)



Peroxide value (left) and free fatty acids (right) of almonds after benchtop drying (Nonpareil)

Concealed Damage from Benchtop Drying

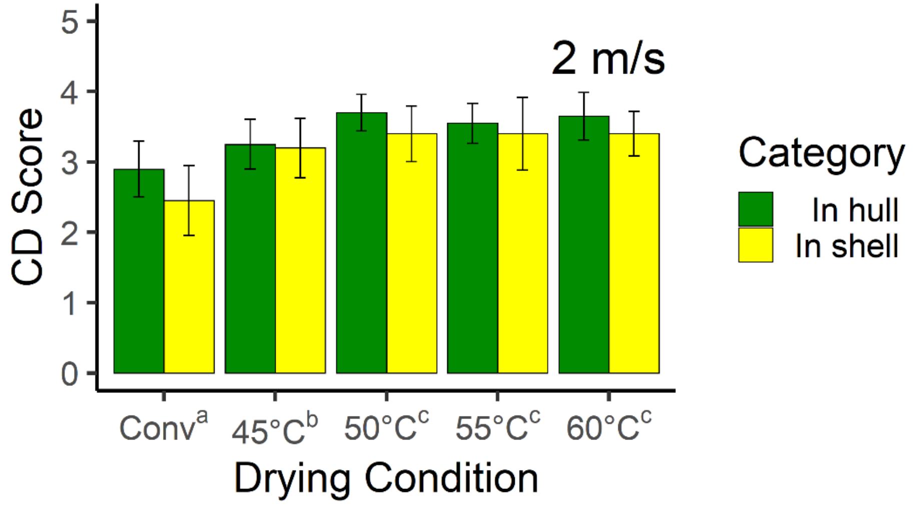
- Color development
  - Slightly higher color development scores than conventional and column drying
- Air velocity had some effect on the color scores of some samples



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

Score	1	2	3	4	5
Example					

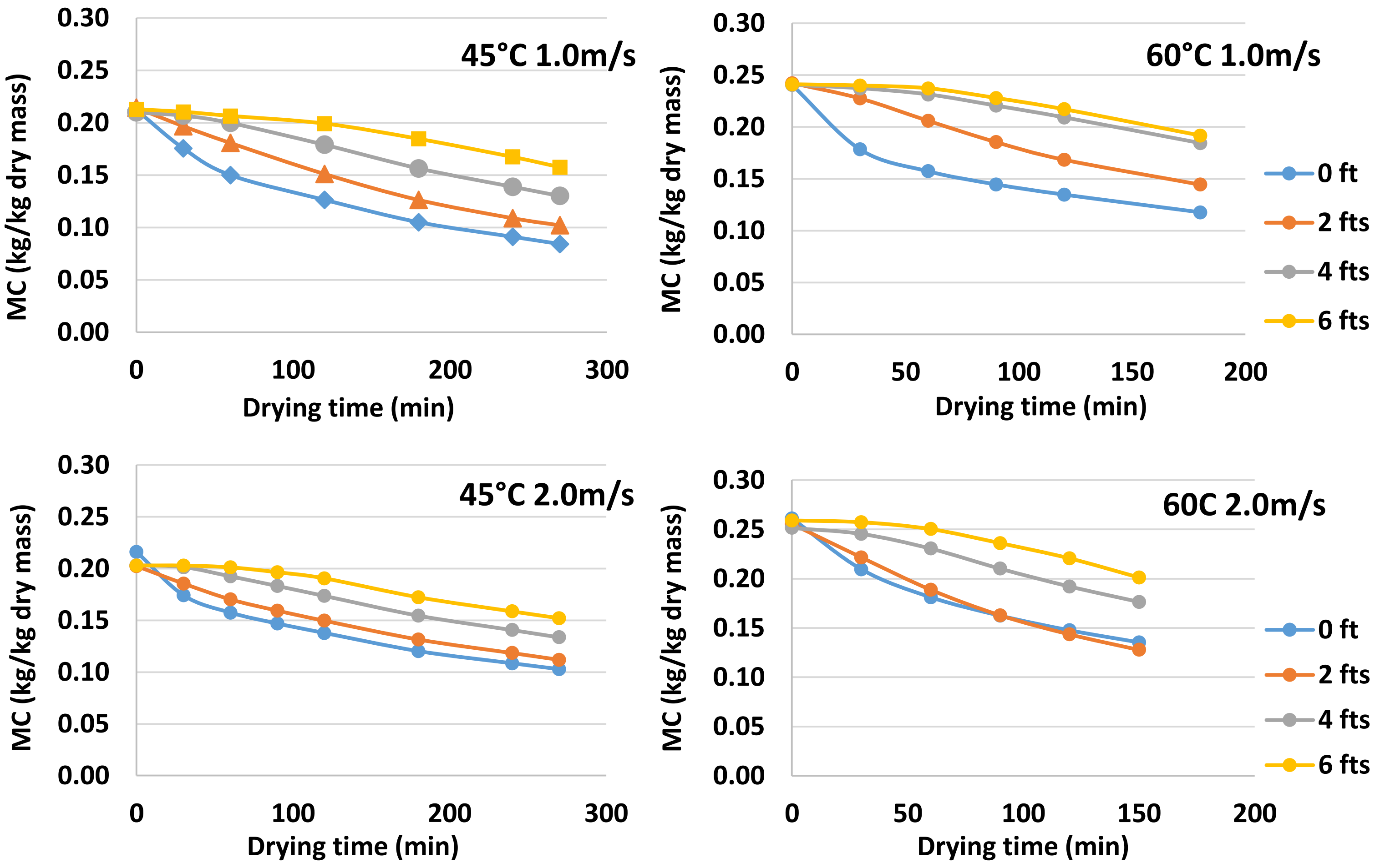
Concealed damage grading reference



Concealed damage of benchtop drying at 2m/s (Nonpareil)

Drying Performance and Product Quality of Column Drying

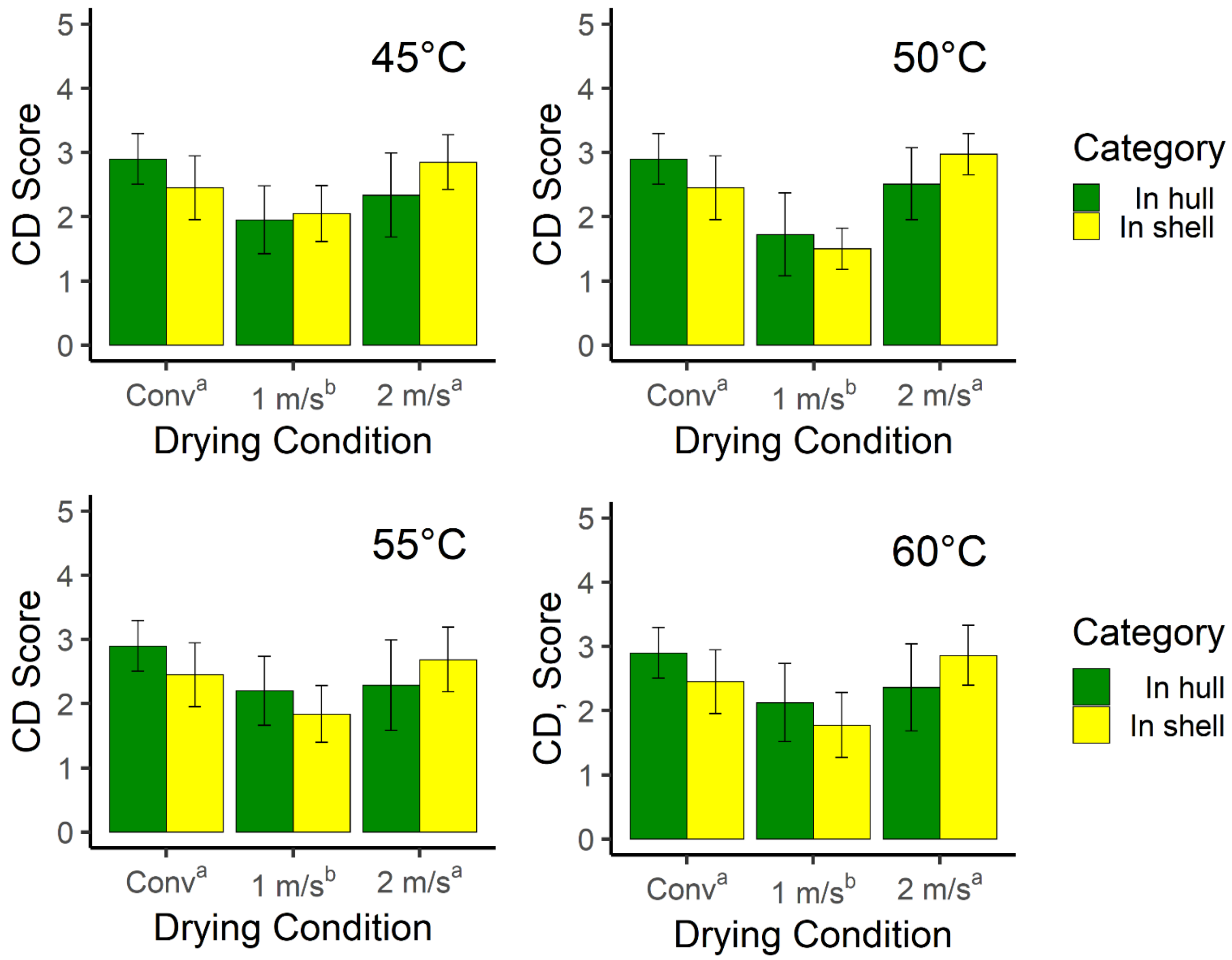
- Drying time↓ as the temperature and air velocity↑
  - 4.5 h (45°C, 1 m/s) vs 2.5 h (60°C, 2 m/s)
- Overall drying rate and final moisture content uniformity varied at different heights
  - Slower drying and more uniform MC at the column top than at the bottom
- No color change (kernel whiteness) or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



Drying curves under different temperatures and air velocities of of column drying for Nonpareil

Concealed Damage from Column Drying

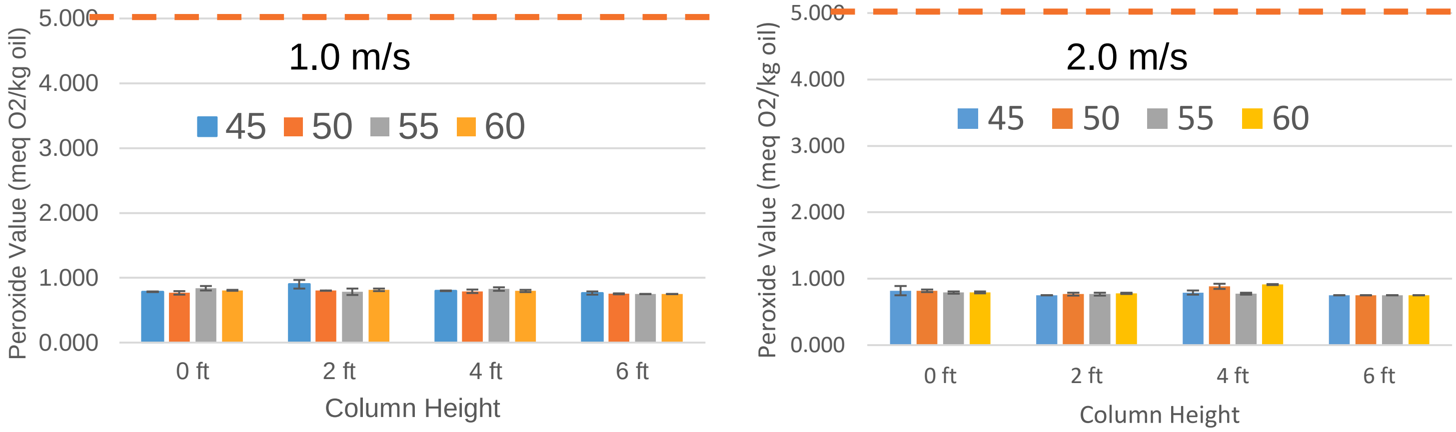
- No concealed damage for both conventional and column drying
- Color development scores of column drying were similar or lower than conventional drying
- Air velocity had significant impact
  - Air velocity of 1 m/s had significantly lower scores (vs. conventional drying)



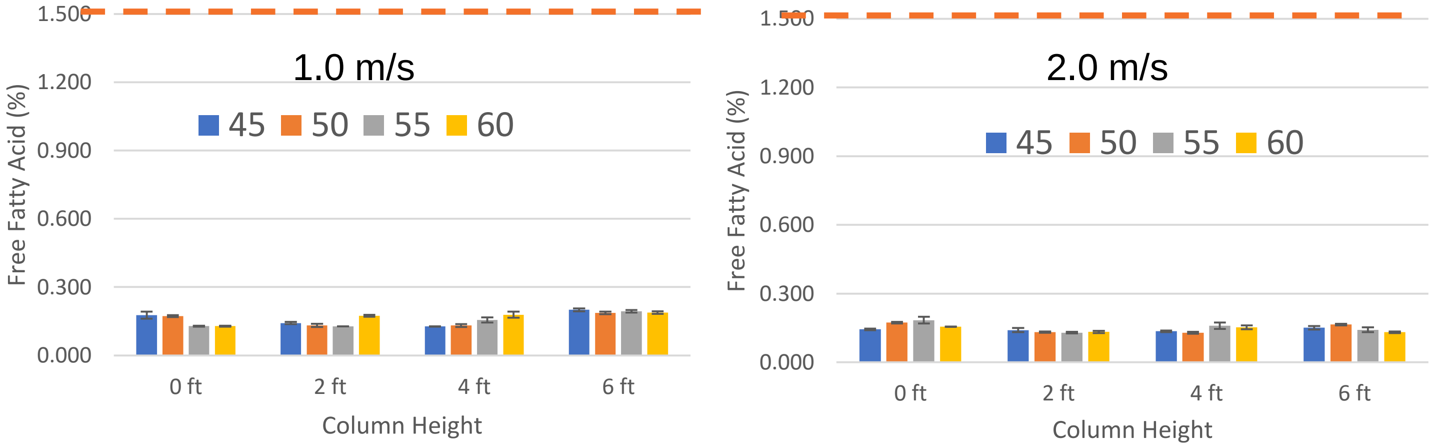
Color development (CD) scores of column drying (Nonpareil)

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.



Peroxide value (PV) of almonds after column drying (Nonpareil)



Free fatty acid (FFA) amount of almonds after column drying (Nonpareil)

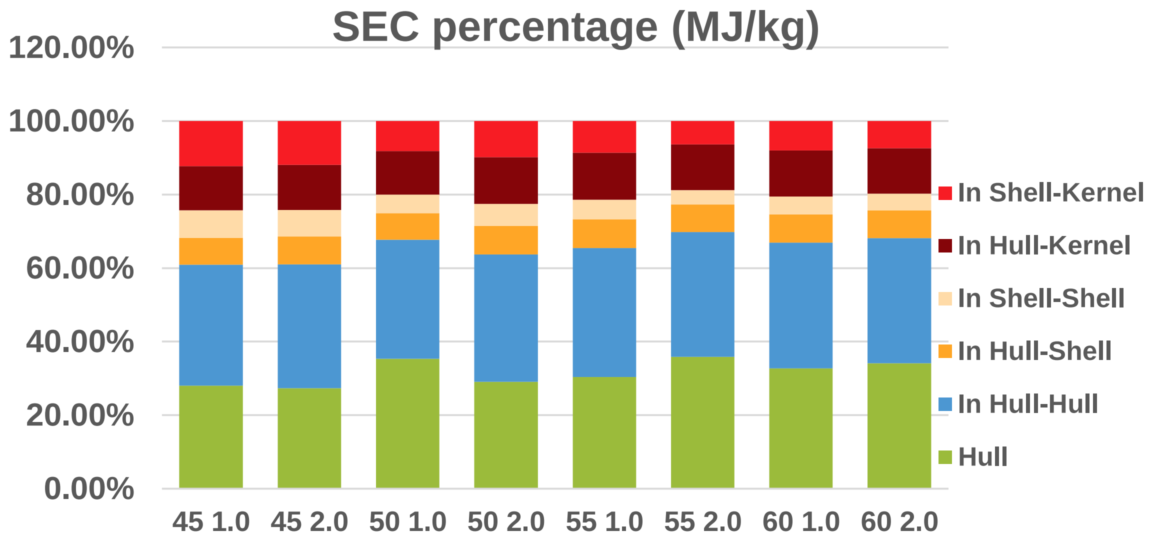
california almonds
Almond Board of California

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 ($R^2 > 0.99$)

$$MR = \exp(-kt^n)$$

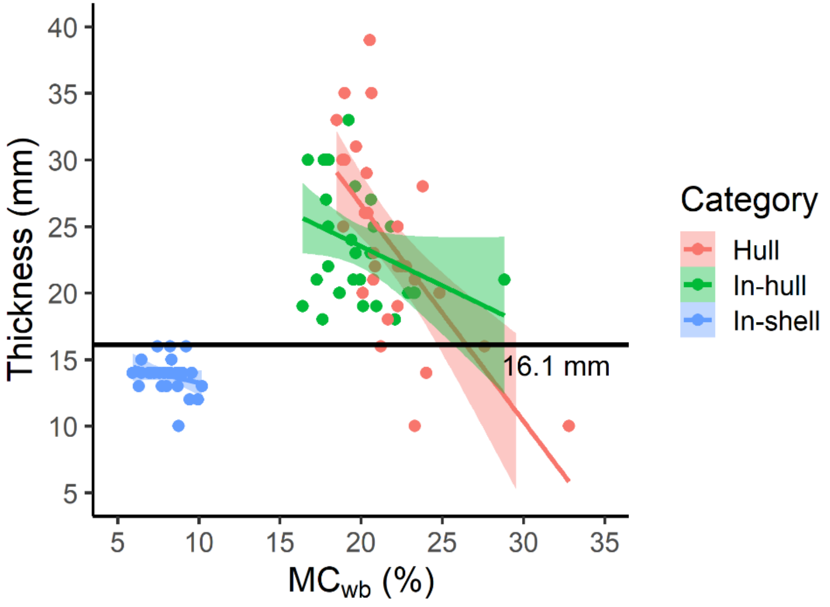
- The drying time decreased with the increase of drying air temperature and air speed
- Specific energy consumption of almond drying increased with temperature and air speed
- Drying at 55°C led to relatively short drying time and low energy cost
- Optimum drying conditions varied with the almond variety



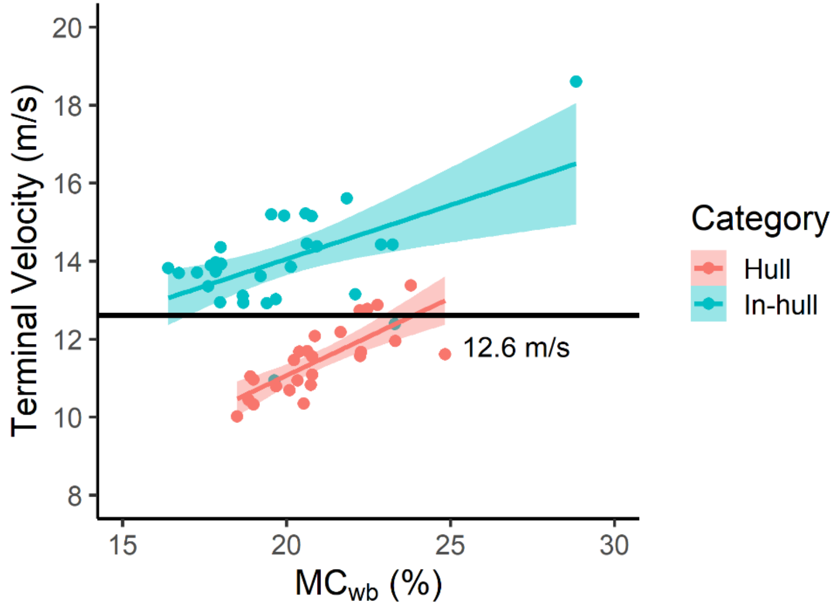
Air velocity (m/s)	Temp (°C)	Initial MC_{wb} (%)	Final MC_{wb} (%)	Drying time (h)	Specific energy consumption (MJ/kg)	Energy cost (¢/lb)
1	45	20.77	11.98	5.32	9.26	1.8
	50	20.77	11.98	5	10.91	3.4
	55	20.77	11.98	4.55	11.95	2.1
	60	20.77	11.98	4.2	12.86	3.6
2	45	20.77	11.99	5.25	17.22	2.3
	50	20.77	11.97	4.4	18.32	3.8
	55	20.77	11.97	3.78	19.05	2.5
	60	20.77	11.93	3.2	18.88	3.7

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.



Classification of major fractions with thickness (Nonpareil)



Classification of major fractions with terminal velocity (Nonpareil)

Terminal velocity measurement

2. Performance Evaluation of Commercial Dryers for Drying Off-Ground Harvest Almonds

california almonds
Almond Board of California

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

Variety	Orchard	Weight ratio		
		Hull	In shell	In hull
Independence	J.Y.	0.32	0.17	0.51
Monterey	Emerald	0.16	0.28	0.56
Fritz	Emerald	0.12	0.16	0.72
Monterey	Baker	0.14	0.12	0.74

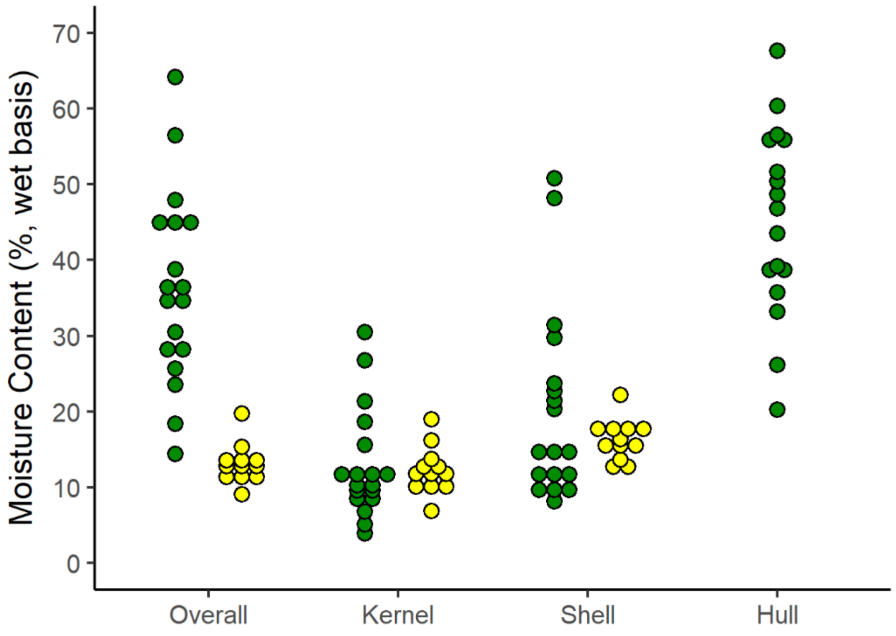
Insect damage comparison

Variety	Orchard	Insect Infestation (%)	
		Conventional	Commercial
Independence	J.Y.	10.0	3.3
Monterey	Emerald	9.1	2.8
Fritz	Emerald	7.7	3.3
Monterey	Baker	2.0	0.8

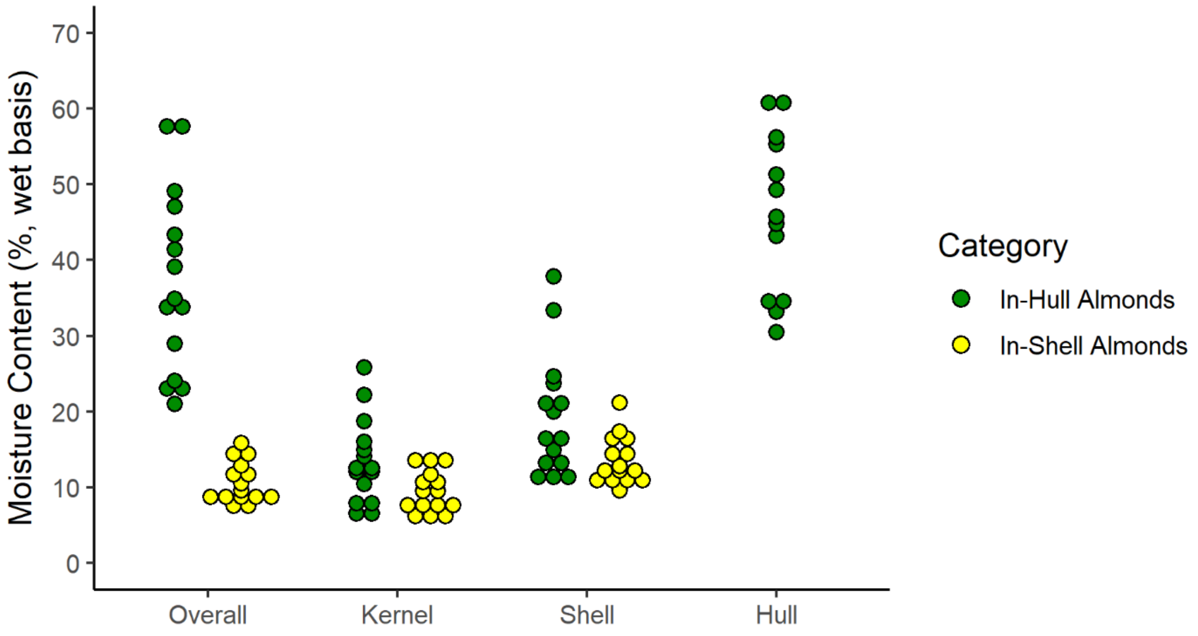
Off-ground harvested almonds

Conventional harvested almonds (natural dried)

Moisture Content Characteristics before Drying



Moisture content distribution before ambient air drying (tunnel drying)

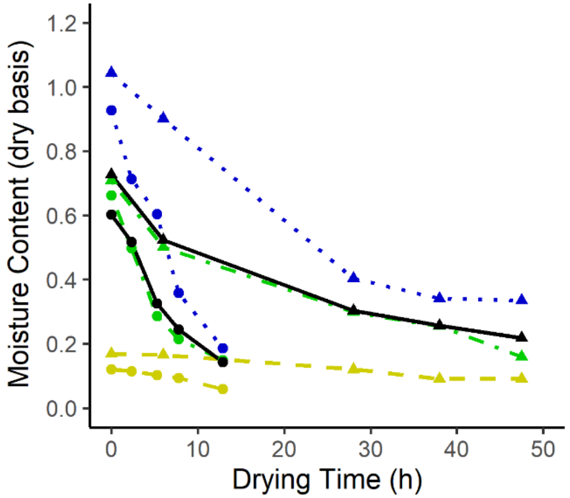


Moisture content distribution before hot air drying (tunnel drying)

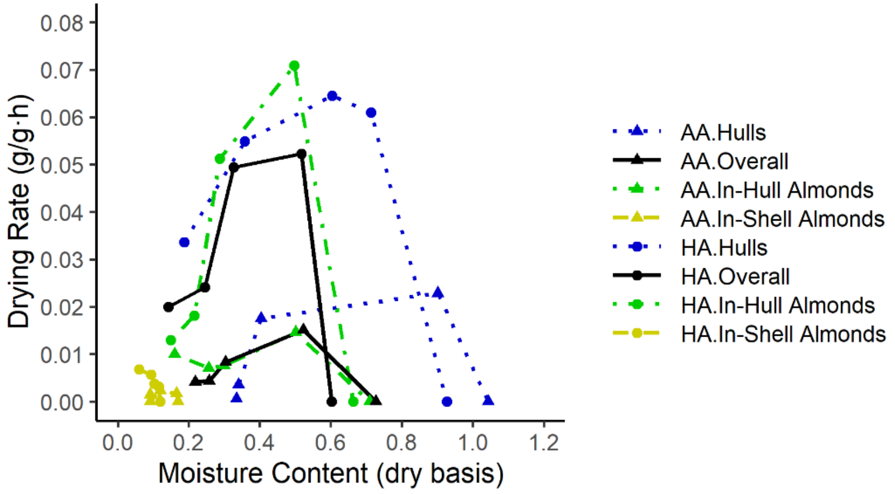
Average moisture content (tunnel drying)

MC_{wb} (%)	Ambient Air		Hot Air	
	In hull	In shell	In hull	In shell
Whole Almond	**36.3**	**13.2**	**37.2**	**10.6**
Kernel	**12.9**	**12.2**	**13.3**	**9.5**

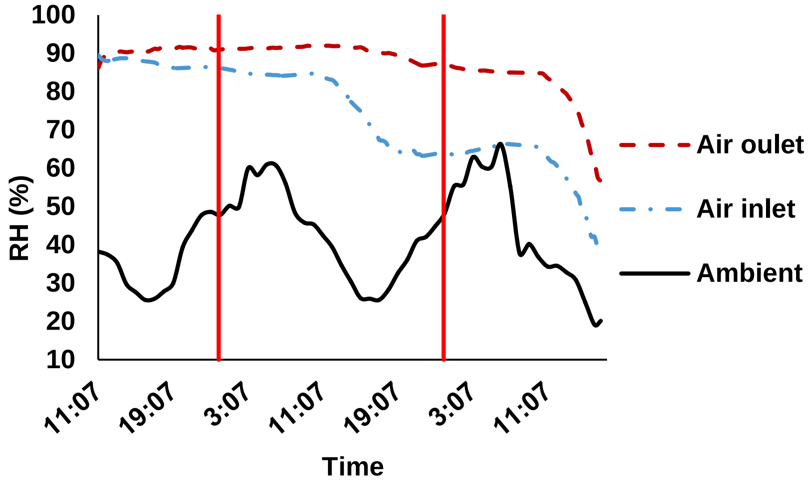
Drying Characteristics of Commerical Drying



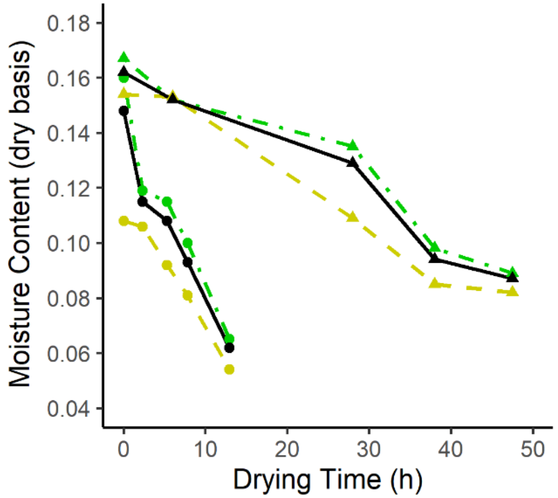
Whole almond MC profile (tunnel drying)



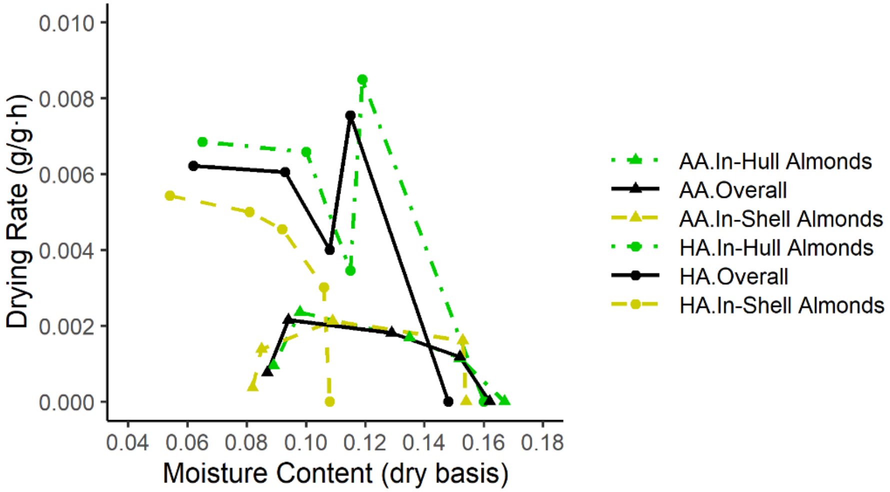
Whole almond drying rate (tunnel drying)



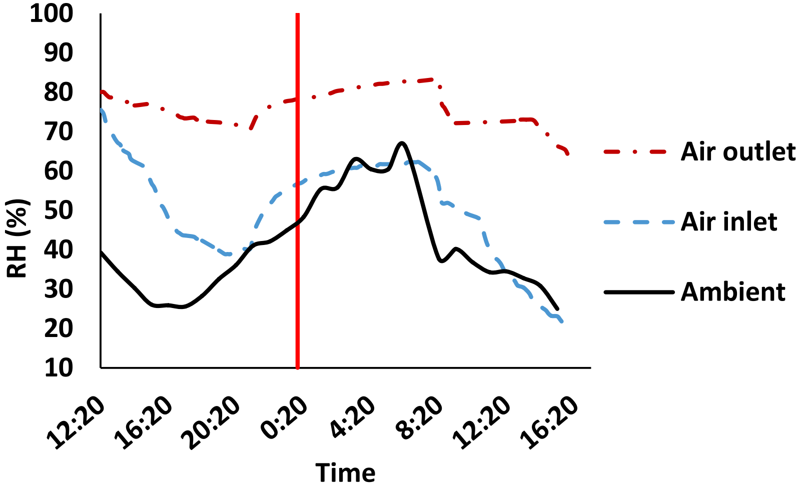
RH during ambient air drying (tunnel drying)



Kernel MC profile (tunnel drying)



Kernel drying rate (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)

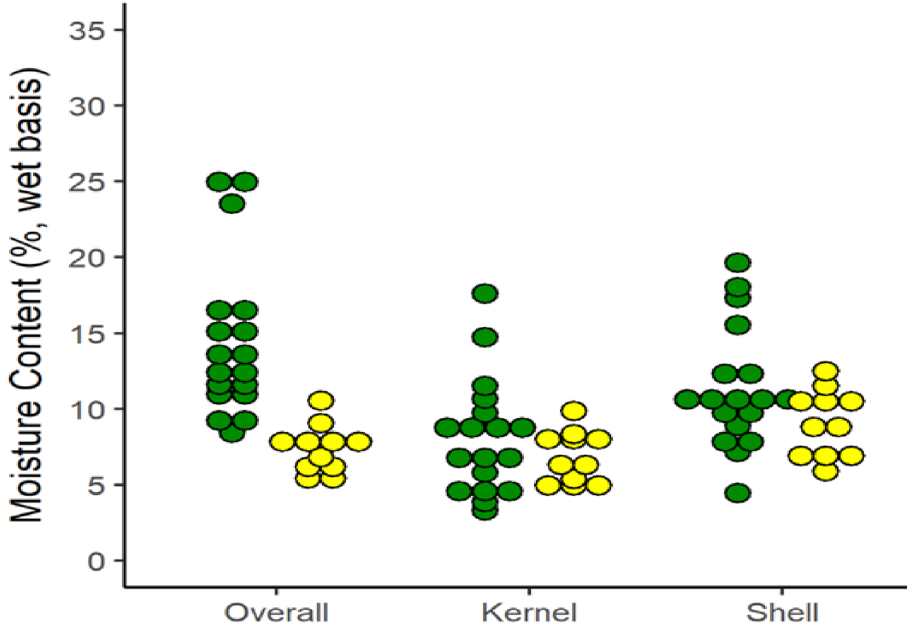
Performance of commercial dryers

Drying condition	Variety	Initial MC (%)		Final MC (%)		Drying time (h)	Energy Cost (cents/lb)[1]
		Whole	Kernel	Whole	Kernel		
Tunnel (ambient)	ID	42.3	14.4	16.8	7.8	51.8	2.5-4.9
Tunnel (115°F)	ID	37.6	12.9	12.5	5.8	12.9	3.7-4.1
Stadium (95°F)	MT	24.4	12.7	7.8	3.9	16.9	1.5-2.0
Stadium (95°F)	FR	44.3	17.7	6.5	3.8	48.0	2.5-3.4
Trailer (110°F)	MT	21.1	7.8	8.3	4.8	6.5	0.23-0.28
Trailer (130°F)	MT	21.1	7.8	7.8	4.1	5.8	0.51-0.55

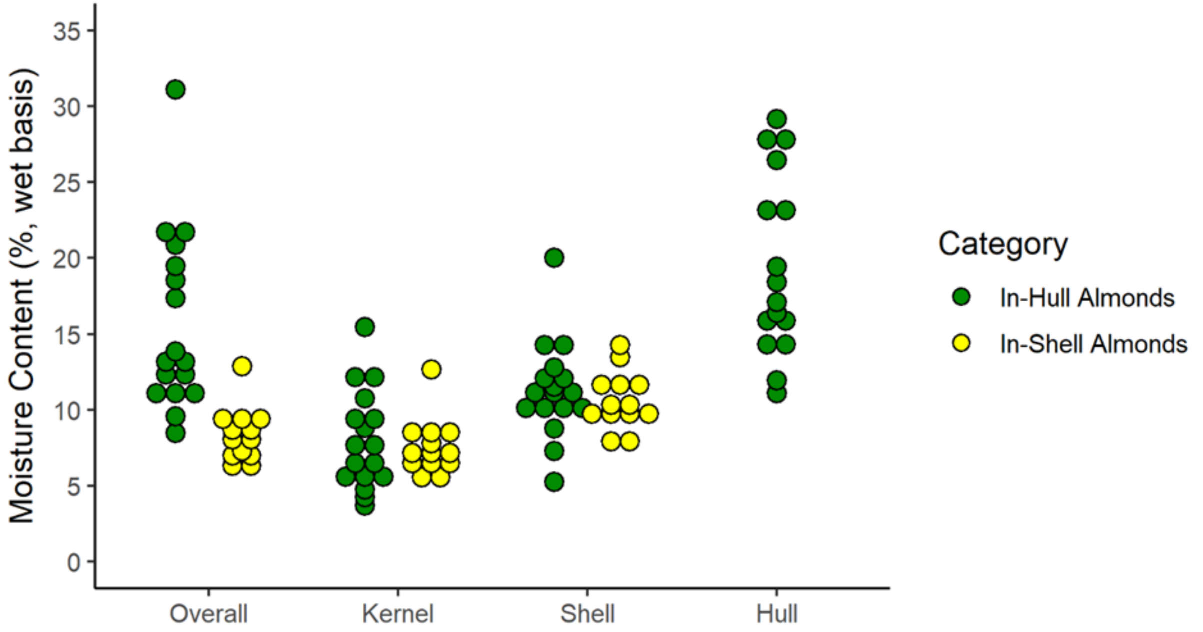
[1] cent/lb of dried almond kernels, energy cost only

california almonds
Almond Board of California

Moisture Content Characteristics after Commerical Drying



Moisture content distribution after ambient air drying (tunnel drying)



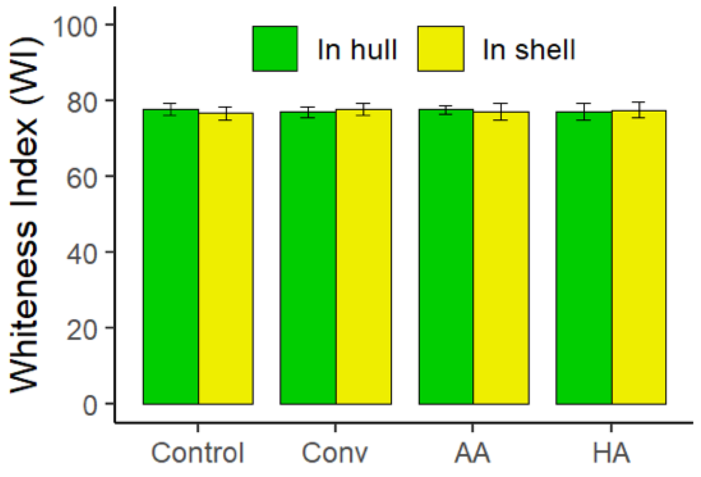
Moisture content distribution after hot air drying (tunnel drying)

Average moisture content after drying (tunnel drying)

MC_{wb} (%)	Ambient Air		Hot Air	
	In Hull	In Shell	In Hull	In Shell
Whole Almond	14.5	7.4	12.8	5.6
Kernel	8.1	6.8	6.1	5.1

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)

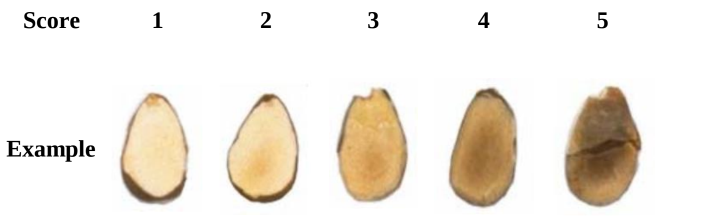


Kernel whiteness index (tunnel drying)

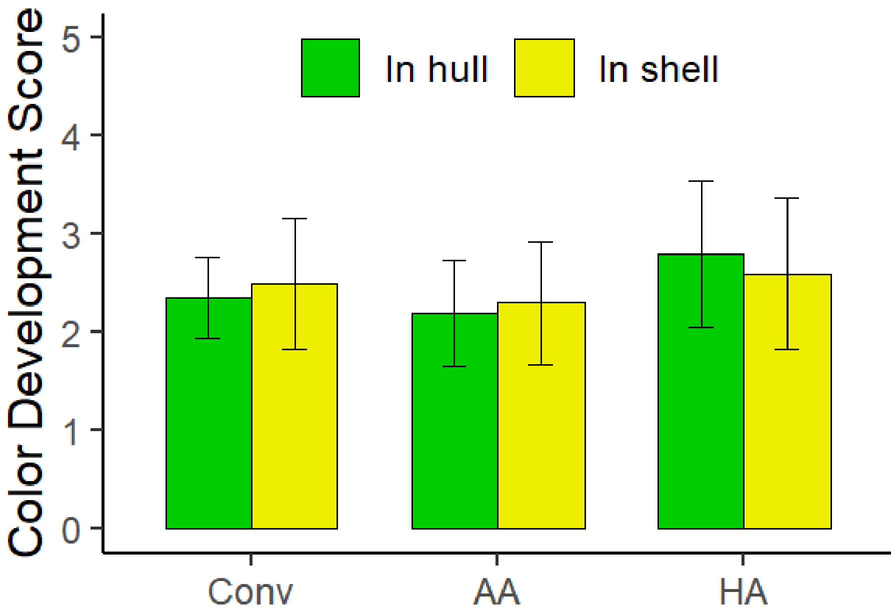
Kernel color after commercial drying

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)



Color development score grading reference



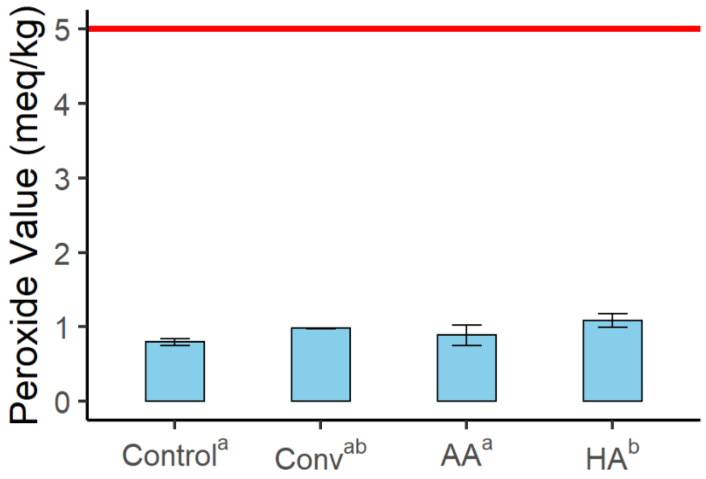
Color development score (tunnel drying)

Suture of almonds after commercial drying

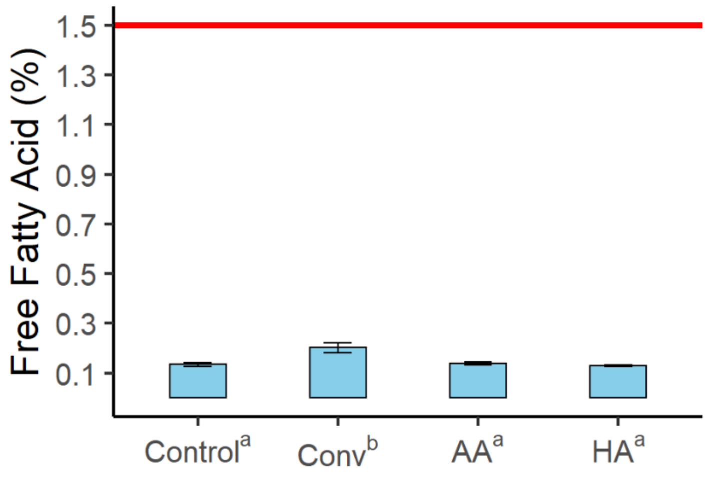
Concealed damage of almonds after commercial drying

Quality of Almonds from Commercial Drying (Continued)

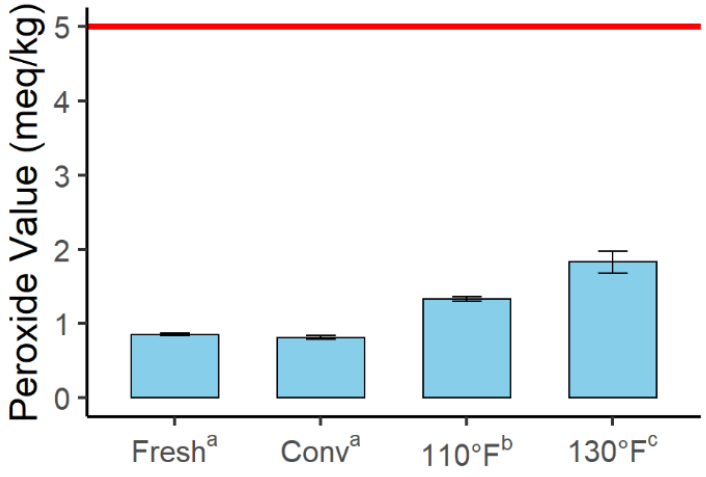
- Peroxide value
  - Slightly increased but much less than industrial standard (5 meq/kg)
- Free fatty acid
  - Slightly increased but much less than industrial standard (1.5%)



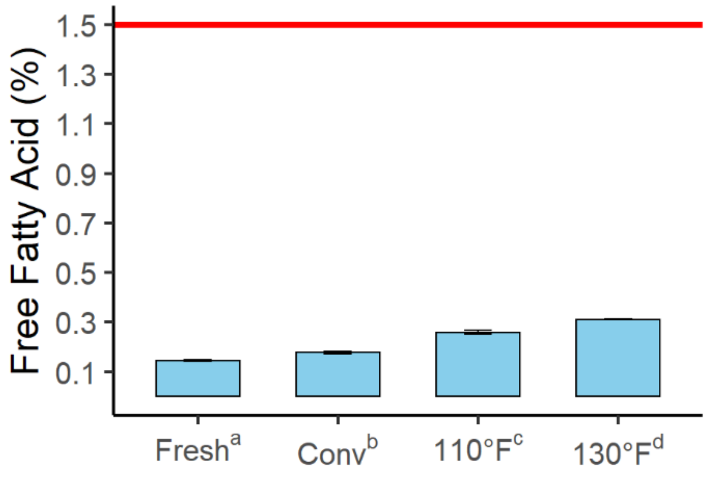
Peroxide value of extracted oil (tunnel drying)



Free fatty acid of extracted oil (tunnel drying)



Peroxide value of extracted oil (trailer drying)



Free fatty acid of extracted oil (trailer drying)

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 60ºC and 2m/s
- Energy cost: 0.23 to 5 cents per pound almond
- Sorting for reducing energy cost

california almonds
Almond Board of California

Acknowledgement

- Food Processing Research Group
  - Ragab Khir, Yi Shen, Chang Chen, Zhaokun Ning, Xingzhu Wu, Irving Rabasa, Lizhen Deng, Xiangyu Cao, Rentang Zhang, Tianxin Wang, and Haruka Tomishima.
- Almond Board of California
  - Guangwei Huang and Sebastian Saa
- Collaborators
  - Campos Brothers Farm
  - Emerald Farm
  - West Valley Hulling Company
  - Wizard Manufacturing Inc.
  - Nickels Soil Lab
- Dr. Franz Niederholzer

Thank you!