Almond Shelf Life and Quality Preservation

December 8, 2015

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The Almond Conference

Speakers

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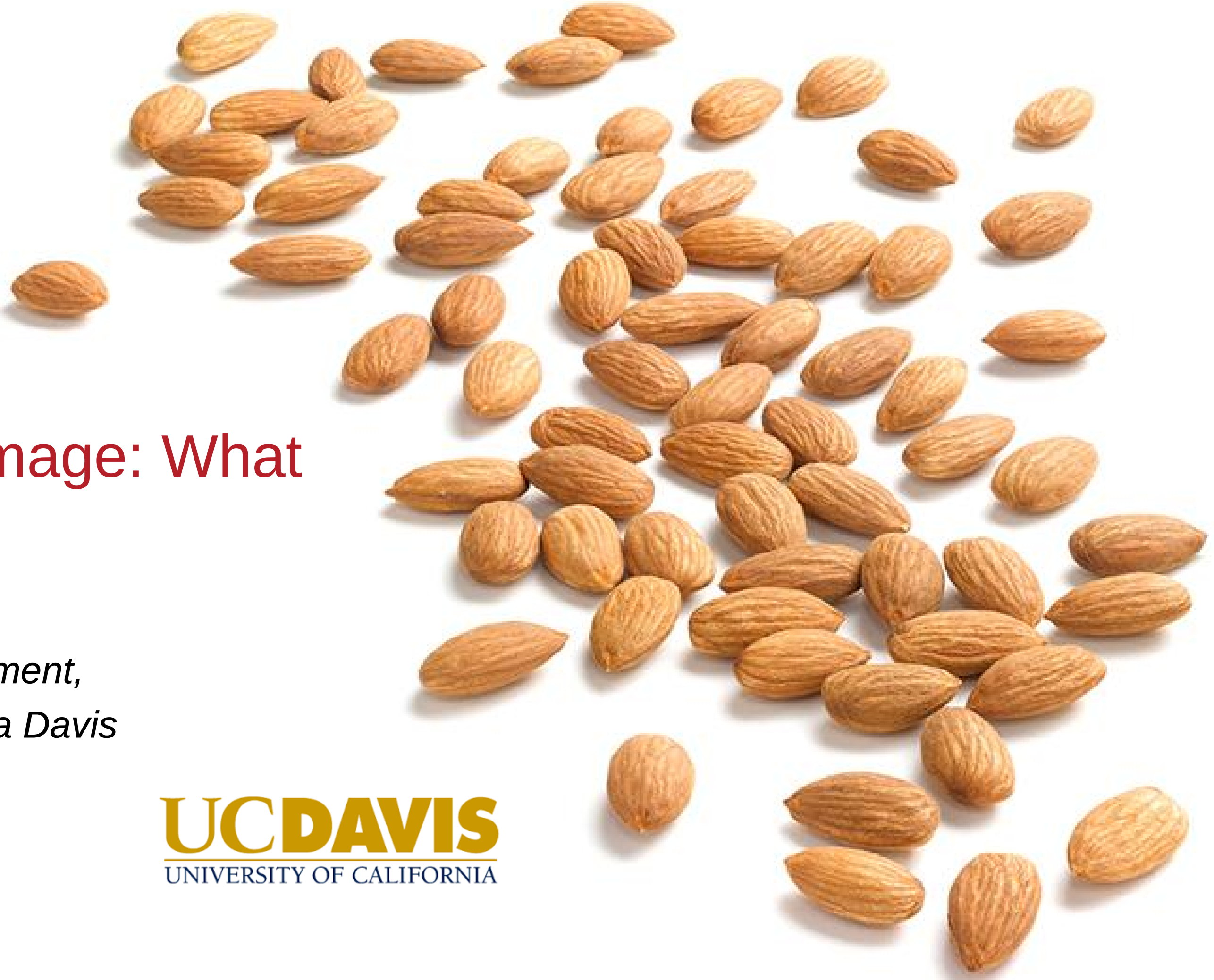

Concealed Damage: What We Know

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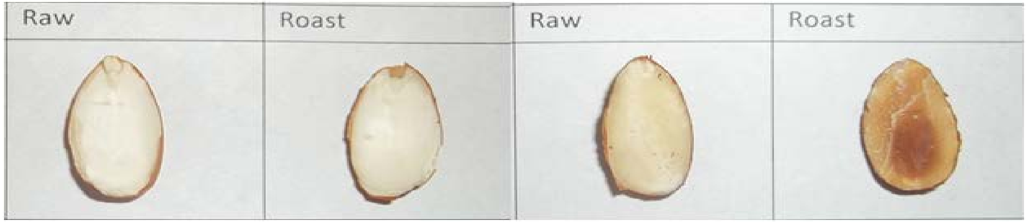
Concealed Damage

- Concealed damage (CD) is a “hidden defect” that can only be seen in almond kernels after they are exposed to moderate heat (e.g. blanching, roasting, etc.)
  - Results in a light to dark brown discoloration in the kernel interior
- Seems to occur more frequently with wet harvest seasons and may be associated with early germination events
- To date, CD can’t be detected by screening methods and the mechanism by which the color forms is unknown
- Extreme cases of CD can result in a very bitter off-flavor
  - Lower consumer acceptance
  - Nuts may be more susceptible to lipid oxidation and rancidity development which may influence shelf-life

CD is a Challenge as it is a *Hidden Defect*

- Industry Challenge:
  - How do you identify/sort raw almonds for this defect if you can not see it?
- Analytical Challenge:
  - How do identify raw almonds with CD so that you can identify what the chemical changes are that result in CD?



(a) raw and roasted almonds exposed to 5% moisture (control)

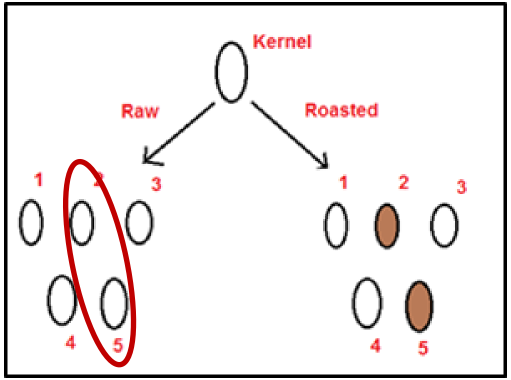
(b) raw and roasted almonds exposed to 11% moisture (CD).

Experimental Goals

1. Identified a colorimetric value that correlates with “CD” in roasted almonds
   – Use this value to identify raw almonds with CD
2. Established a time course for CD development in raw almonds exposed to 8% and 11% moisture at 35°C and 45°C
3. Evaluate the composition of volatile compounds in almonds with CD
4. Evaluate Near Infrared Spectroscopy (NIRS) for identifying CD in raw almonds
5. Evaluate the effect of drying treatments on the development of CD (on-going)

Identifying Almonds with CD

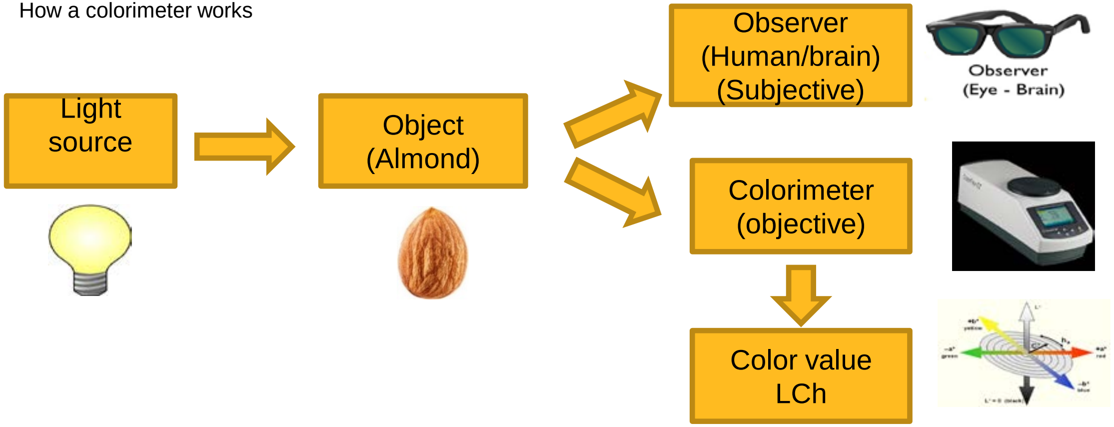
- Our first objective was to sort almonds into two groups:
  - No Concealed Damage (NCD)
  - Concealed Damage (CD)
- Raw kernels were cut in half, numbered and placed into 2 identical racks
- One rack was roasted [120°C for 90 min]; while, the other was not
- The roasted almonds kernels halves that develop color (i.e. those with CD) were matched with the raw almond halves to identify raw almonds with the CD defect



Establish a Colorimetric Value to Define CD

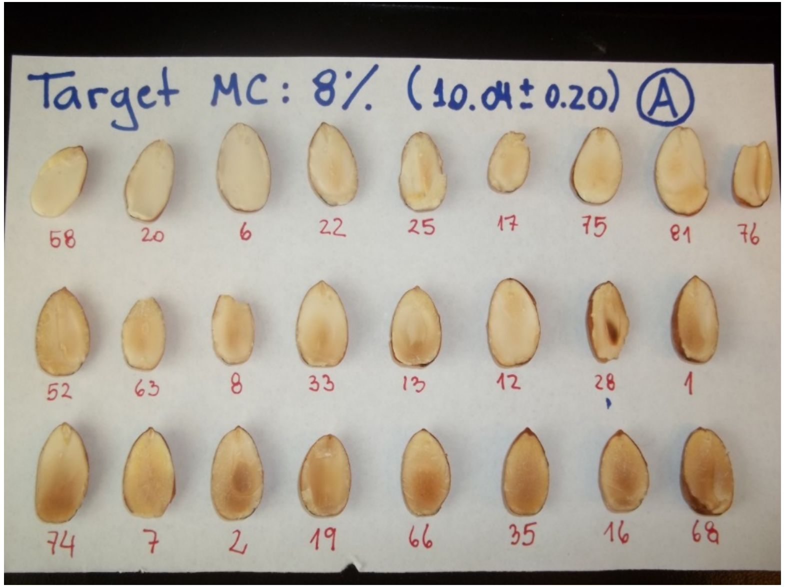
- The surface of ~ 800 almond kernels were evaluated using colorimetry
  - L (lightness), C (Chroma), and h (hue) were measured

How a colorimeter works



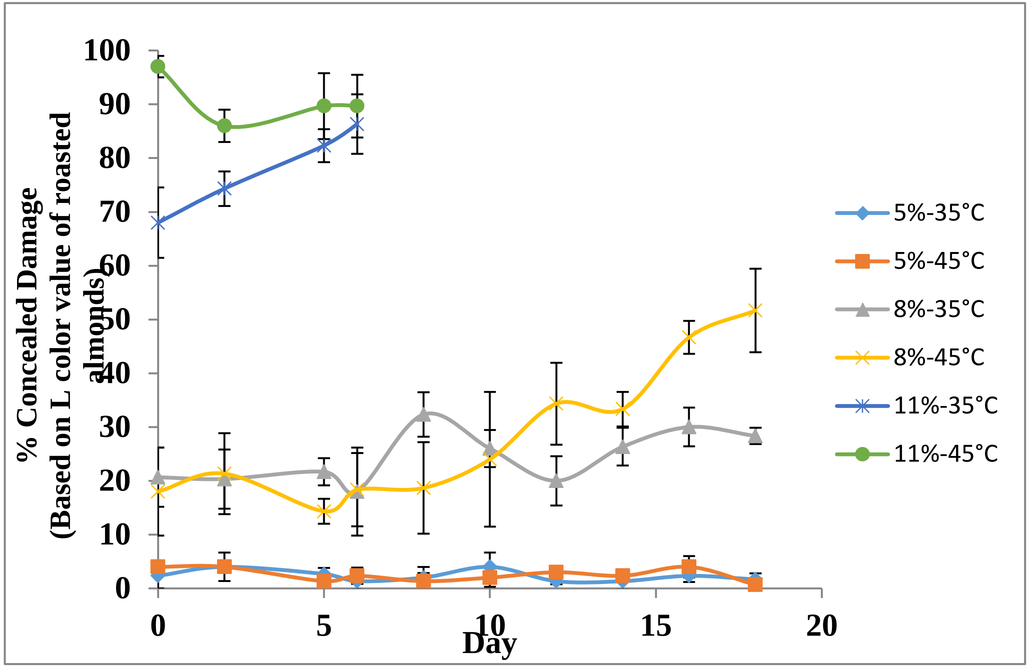
Colorimetric Value Defining CD in Almonds

- We found that discoloration correlates best with the L colorimetric value
- A L color value of ~71 distinguishes almonds with obvious brown discoloration from those without it
- Colorimetric Value
  - L ≥ 71 → No Concealed Damage (NCD)
  - L < 71 → Concealed Damage (CD)

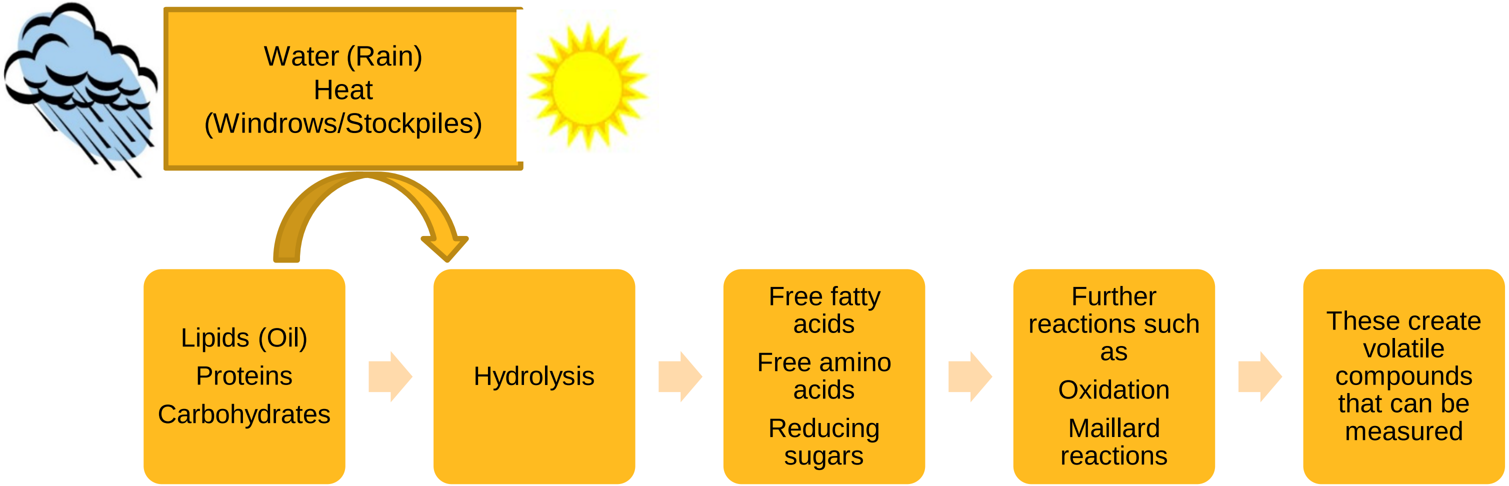


Influence of Moisture & Temperature on CD Development

- Almonds were exposed to 6, 8 and 11% moisture and stored at either 35°C, or 45°C for 19 days
- L color values were measured
  - Almonds exposed to < 6% moisture did not develop CD
    - Control
  - Almonds exposed to 8 and 11% moisture developed CD
    - The higher temperature accelerated development of CD



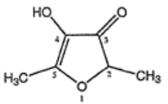
How Moisture and Temperature Could Accelerate CD

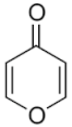


Types of Volatiles Formed

Carbohydrates

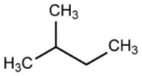
Furanones
Pyrones

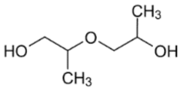




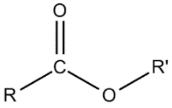
Lipids

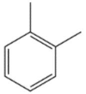
Aliphatic:
Alcohols
Aldehydes
Methyl keytones
Acids
Lactones
Esters





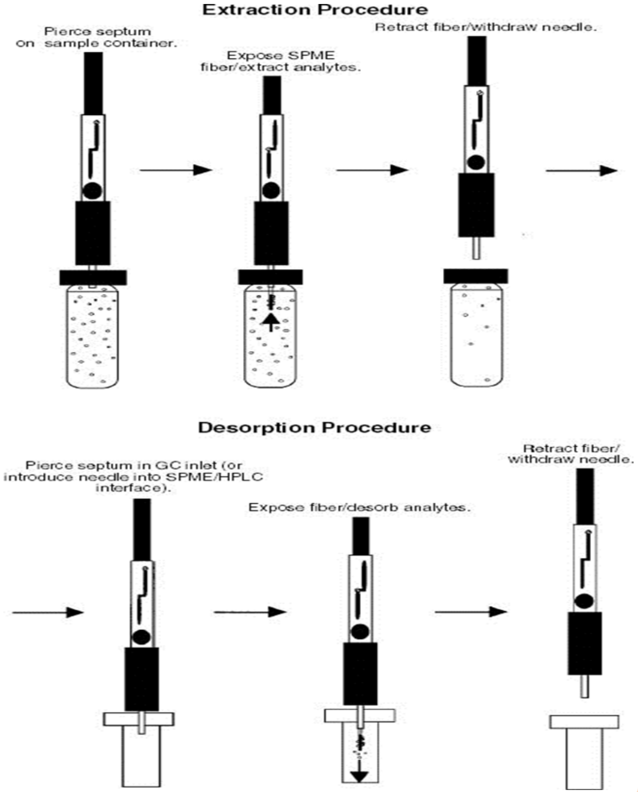
Amino Acids





Methyl branched:
Alcohols
Aldehydes
Acids
Esters

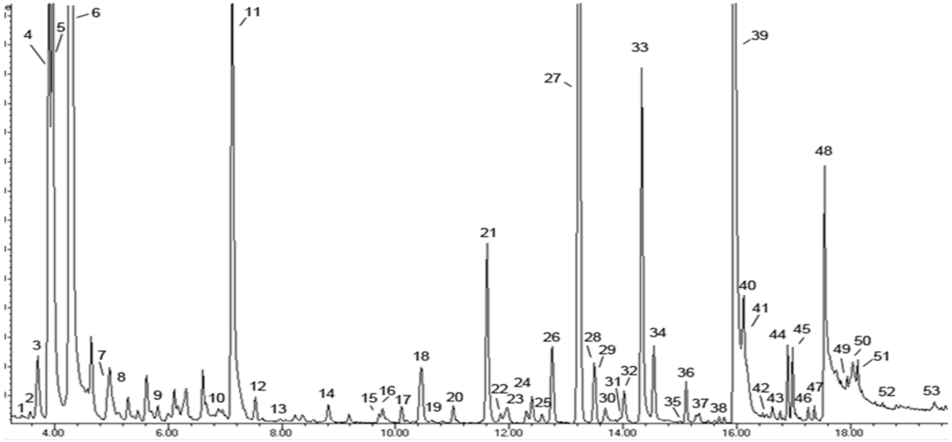
Volatiles are measured using headspace solid-phase microextraction (HS-SPME) and gas chromatography (GC)



- Sample is equilibrated for 30 minutes in a special HS vial
- Exposed to a 1 cm 50/30 μm coated fiber for 30 min at room temp
- Desorption (230°C): 10 min in GC injection port

GC Chromatogram of Almond Volatiles

- GC chromatogram of peaks that correspond to the different volatile compounds
- Using MS we can identify the compounds
- Measure the amount by summing the area under the peak and comparing this with standards



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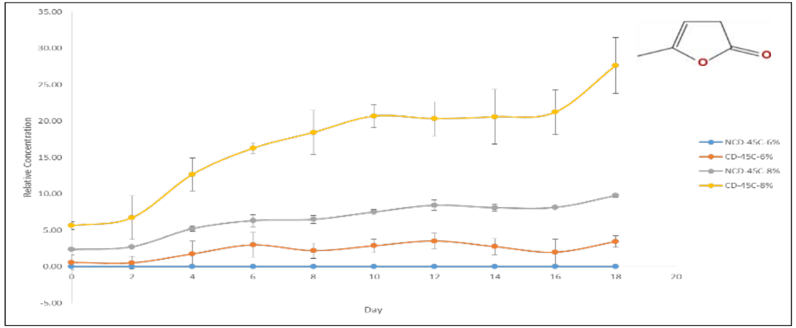
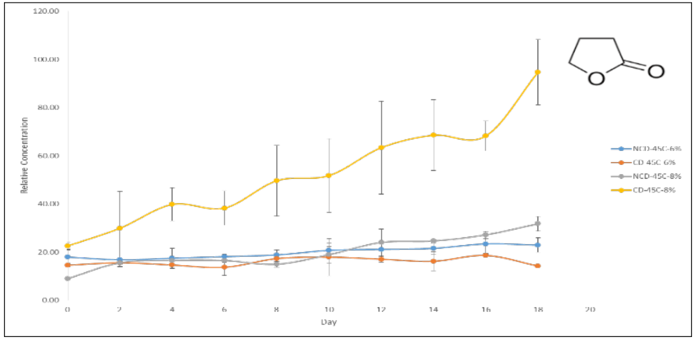
Increases in Select Lactones (lipids)

45*C and 8% Moisture

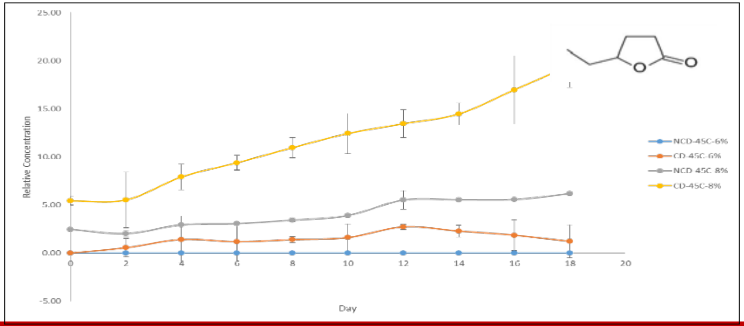
γ-Pentalactone



Butyrolactone



γ-Hexalactone



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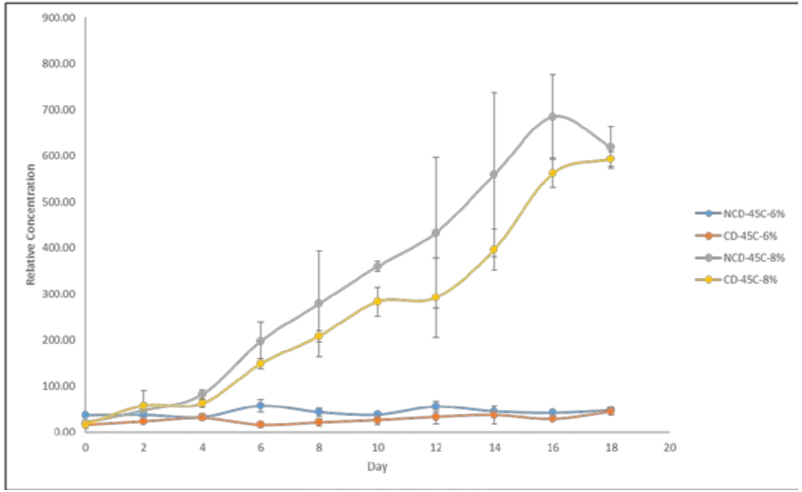
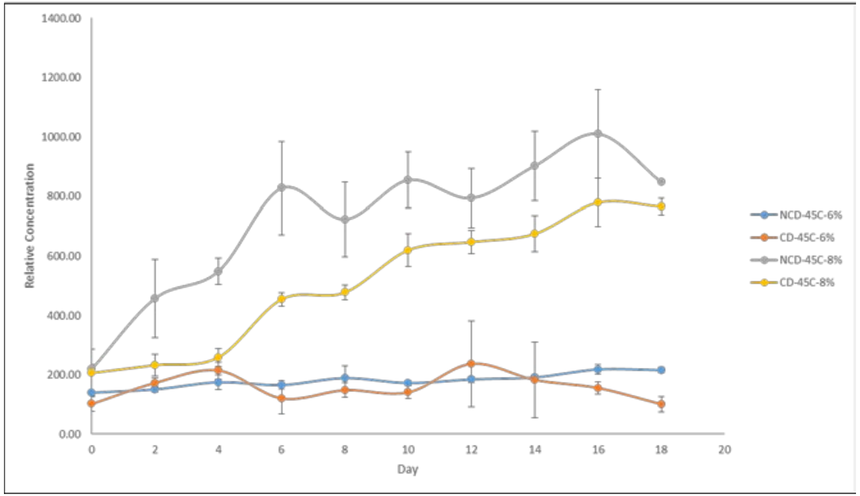
Increases in Acetic Acid & 3-Methyl Butanol

Acetic Acid



Lipid degradation

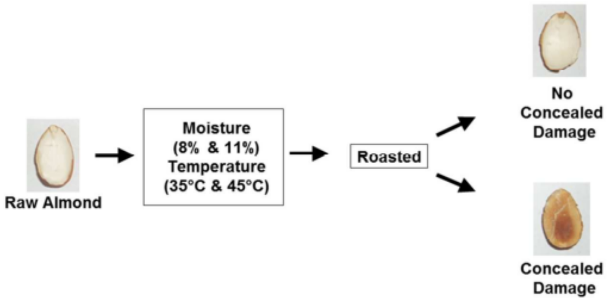
3-Methyl-1-Butanol



Amino acid degradation

Rogel-Castillo et al. Journal of Agricultural and Food Chemistry **2015** *63* (37), 8234-8240

Summary: Volatile Compounds in Almonds with CD



- CD increase volatiles related to:

1) Lipid oxidation
   - Acetic acid
   - Lactones

2) Amino acid degradation
   - 3-methyl-1-butanol

- Results suggest that post-harvest moisture exposure resulting in an internal kernel moisture > 8% is a key factor in the development of CD in raw almonds and that CD is accelerated by temperature

Rogel-Castillo et al. Journal of Agricultural and Food Chemistry **2015** *63* (37), 8234-8240

Developed model for identifying raw almonds with CD before roasting

- No available screening method for CD in raw almonds
- Color value (LCh) is not sensitive enough to predict almonds with CD
  - The error rate is to high
- Near Infrared Spectroscopy (NIRS) was evaluated
  - More sensitive
  - Shown some value for this in previous research

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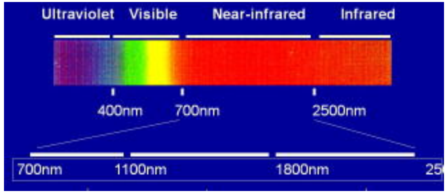
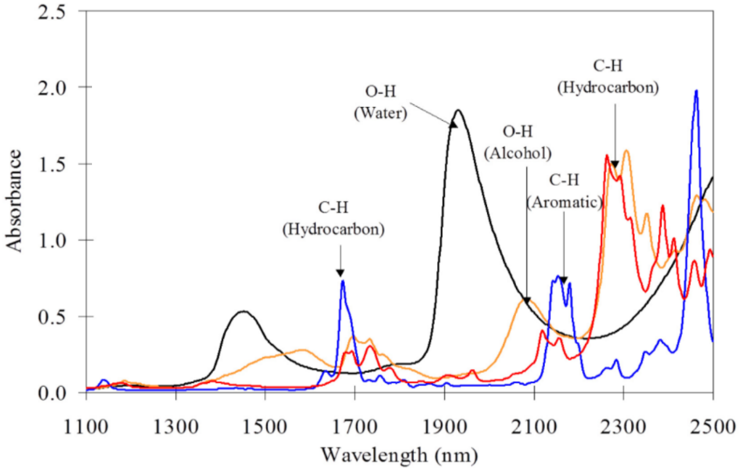
Near-Infrared Spectroscopy (NIRS)

- Utilizes the light spectral range from 780 to 2500 nm



- Shine a light over the sample and measure the amount of IR absorbed
  - Refine the approach by using only select wavelengths of light to monitor
- Noninvasive
- Fast
- Robust

Common Chemical Groups Easily Measured
O-H, C-H and Others



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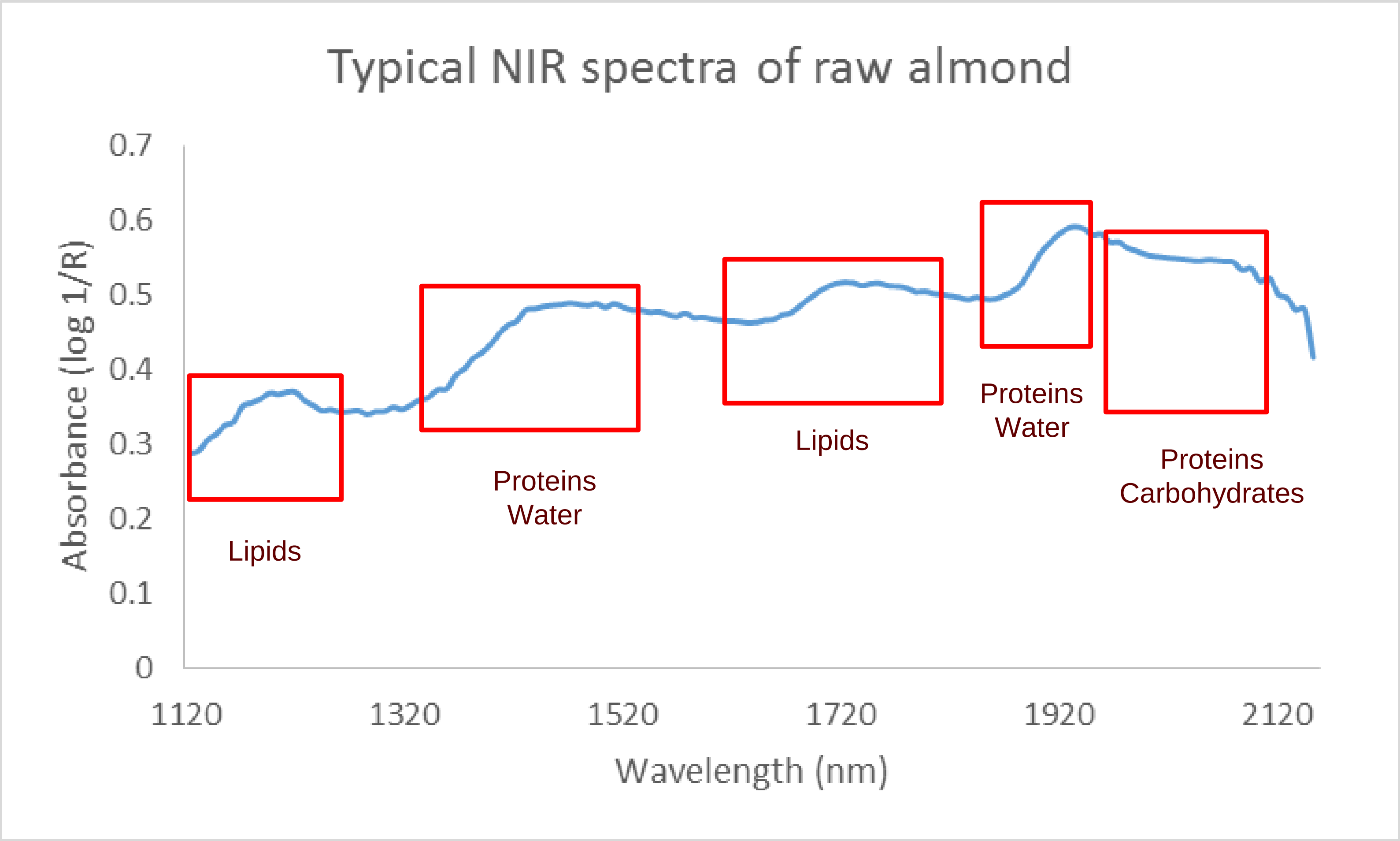
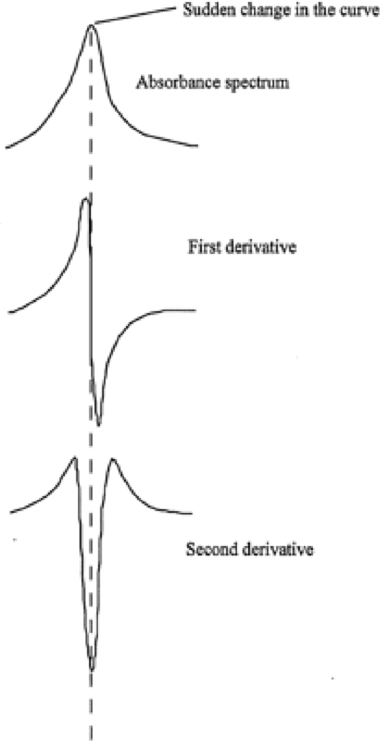


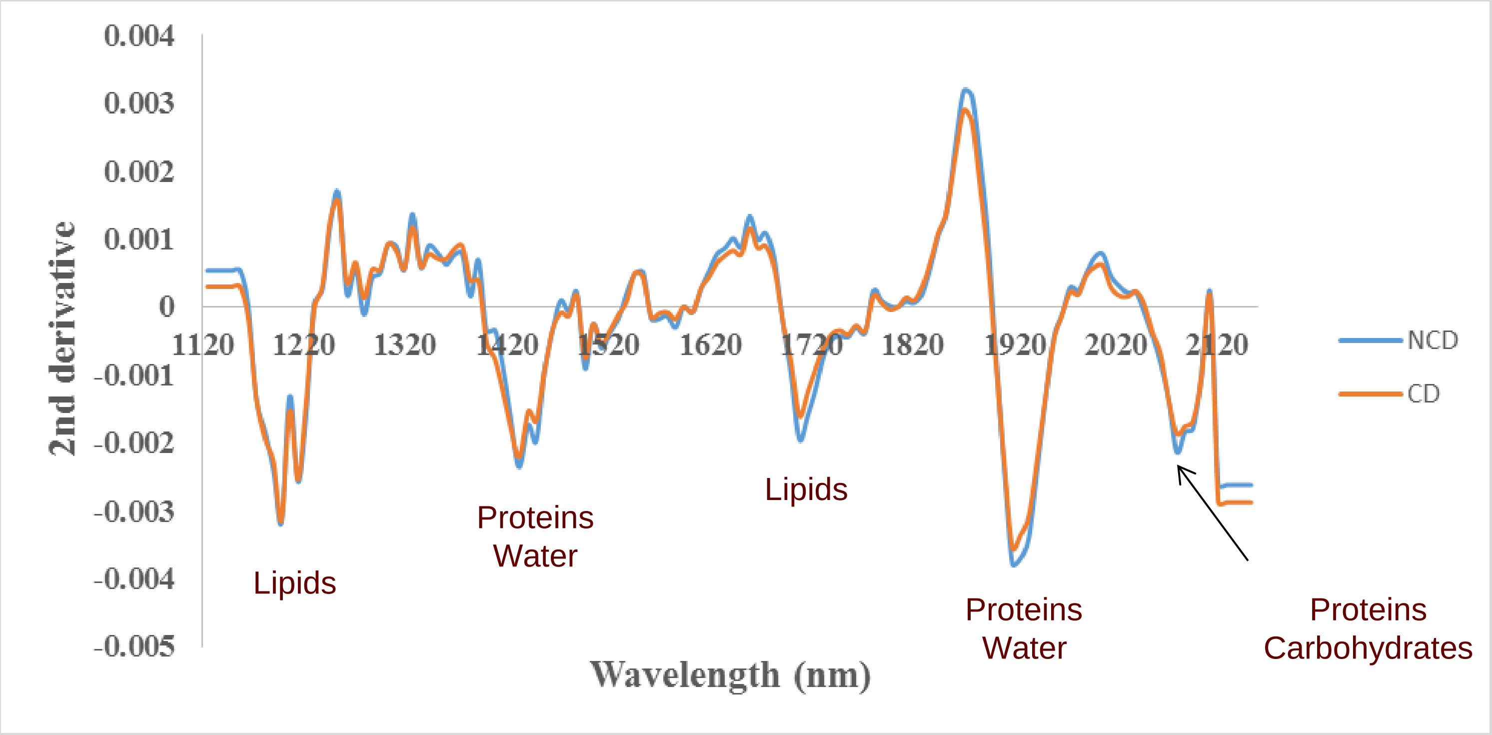
Typical NIR spectra of raw almond
Absorbance (log 1/R)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1120
1320
1520
1720
1920
2120
Wavelength (nm)
Lipids
Proteins
Water
Lipids
Proteins
Water
Proteins
Carbohydrates

NIRS Data Treatment: Second Derivative

- Application of Math!
- Derivatives are common signal pre-treatments applied to spectral data
- Taking a derivative can enhance resolution and baseline drift between samples
- A maximum in the original spectrum becomes a minimum in the second derivative
- Program the instrument to do this as part of the data collection process



Second Derivative of the NIRS Almond Spectra



Building a Predictive Model using NIR Spectrum

Raw almonds (855) exposed to conditions to develop CD

Roast half at 248°F (120°C) for 90 min

Measured L color value

Identification of almonds with CD

Analyze the raw almond halves

NIRS

Data analysis (PLS-DA)

Create the model (training data set) 655 almonds

Validation of the model (validation data set) 200 almonds

Application of the model in new raw almond samples exposed to conditions to develop CD

NIRS Model Results

- Error Rate Percent (% ER):
  - The percentage of almonds in the validation set incorrectly classified
  - 6%
- False Positive Percent (% FP):
  - Almonds with no CD classified as having CD
  - 9%
- False Negative Percent (% FN):
  - Almonds with CD misclassified as having no CD
  - 5%
- These results indicate that it may be possible to use NIRS as an inline sorting method for CD detection

Sneak Peak: The Effect of Drying on CD

- Almonds were exposed to 8% and 11% moisture and incubated at 25°C and 55°C (~12 hours)
  - Future experiments will include a range of incubation times

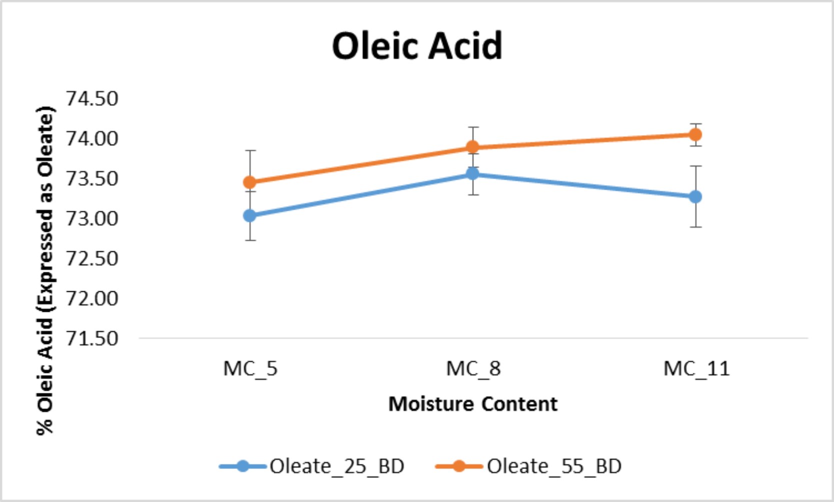
- Almonds were dried to < 5% moisture at 45°C
  - Future experiments will include different drying temperatures

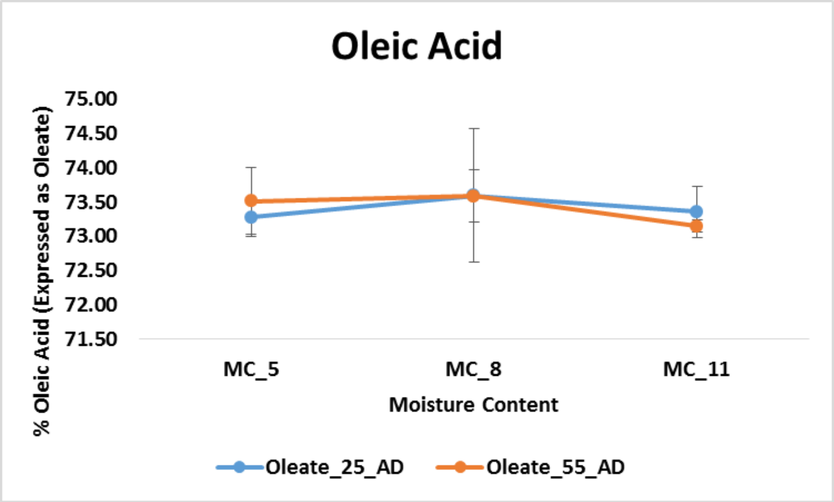
- Monitoring
- Free Fatty Acids (lipid hydrolysis)
  - Fatty Acid Methyl Esters (FAMEs)

- Volatiles (HS-SPME-GC/MS)

Free Fatty Acids:

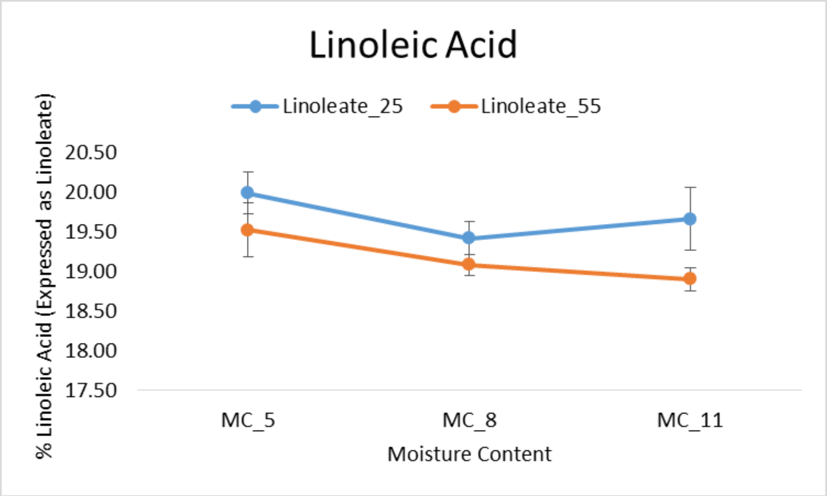
Incubation at 25°C and 55°C and dried at 45°C

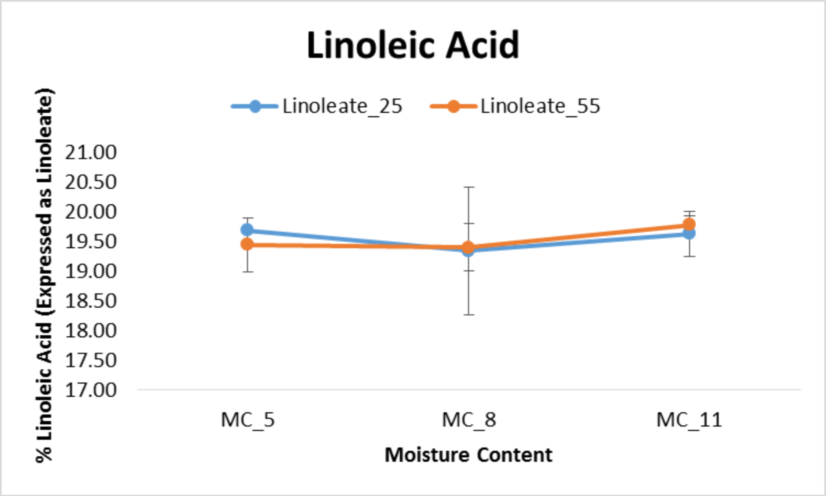




- *Oleic acid levels increase slightly at 11% moisture (not significant)*
- *Before drying vs after drying: No significant difference ($p > 0.05$)*

Free Fatty Acids: Incubation at 25°C and 55°C and dried at 45°C





- *Before drying vs after drying: No significant difference ($p > 0.05$)*

Conclusions:

- Colorimetry can be used to identify roasted almonds with CD using a L color value of 71
  - Not sensitive enough to be used for in-line applications – just research
    - Almonds exposed to < 6% moisture do not develop CD
    - Almonds exposed to 8 and 11% moisture developed CD
      - The higher temperature accelerated development of CD
- Volatile analysis indicates increased levels of acetic acid and lactones (lipid oxidation) and 3-methyl-1-butanol (amino acids degradation) in CD
- NIRS may have application as an in-line sorting tool for detecting CD in raw almonds
  - ER 6%
  - FP 9%
  - FN 5%
- NIR spectra indicate hydrolysis of lipids and amino acids are associated with CD

Acknowledgements
Advancing Knowledge a Team Effort

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University of Minnesota

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SHELF LIFE STUDY OF RAW AND ROASTED ALMONDS FOR CHINESE MARKET

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Fuzhou University

University of Minnesota

Almond Board of California

Background

- ABC founded two phases of the project. Phase I was started in early 2009 and Phase II in late 2012.
- In Phase I, the effects of temperature and relative humidity on the water and oil migration and texture were investigated.
- In Phase II, we focused on the effects of almond form and packaging on the shelf life especially in Chinese market place.

Outline

- Background
- Phase I results
- Phase II results
- Recommendations

Rationale for the research

- Water and oil migration in almonds during transportation and storage affect shelf life, quality, and quantity (weight), and result in loss of sale and/or profit
- There is a need to have a systematic understanding of changes in shelf life and quality of almond during storage as a function of storage environment, form of almond, and packaging methods.

Experiment design

Samples

- Three forms of almond samples with or without PE packaging
- Three different temperatures and three relative humidity (RH) levels.
- A vs. B is expected to indicate the role of PE packaging.
- A vs. C would show the protective role of skin.
- C vs. D may tell us whether the increased surface area of almond slices present additional vulnerability to external factors, i.e., temperature and RH.

Storage conditions

Codegram	ID	Temperature	RH%
0	Room temperature (RT)		
1	40/45	40 F	45
2	40/75	40 F	75
3	40/95	40 F	95
4	70/45	70 F	45
5	70/70	70 F	70
6	70/95	70 F	95
7	100/35	100 F	35
8	100/65	100 F	65
9	100/85	100F	95

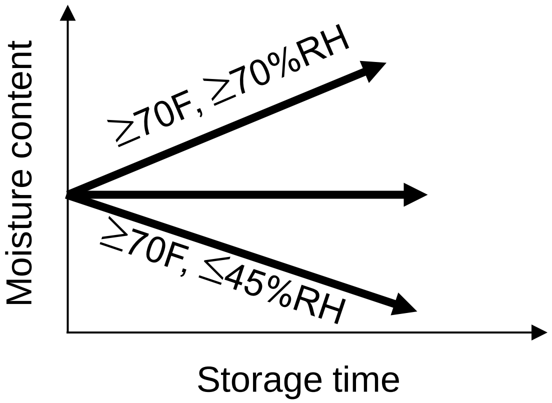
Equipment

Analysis

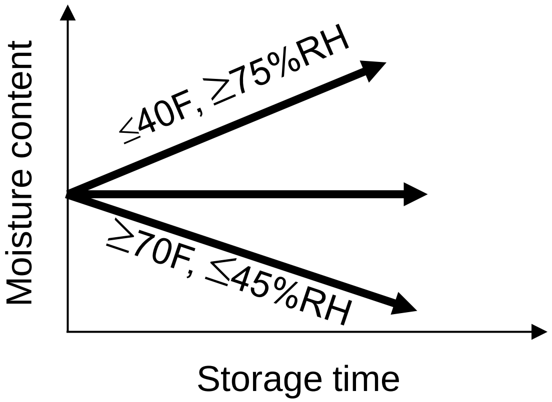
- Moisture
- Texture
- Mold
- Color
- Lipid
  - Iodine/PV
  - FFA

Change in moisture content during storage

With PE



Without PE



Change in PV during storage

- Blanched samples show much higher PVs and greater change over time than raw samples, suggesting that outer brown skin plays an important role in anti-oxidation in almond nutmeats.
- Blanched slices have lower PVs than blanched whole nuts over time, which may be attributed to low initial PV for the slices. However, the change (%) in PV appears to be slightly higher for blanched slices than blanched whole nuts.
- Raw samples without PE packaging exhibited greater change in PV than PE packaged raw samples over time. Raw samples with or without PE packaging reached the peak PVs after 60 days while the PVs for the blanched samples appear to continue to rise.
- At lower temperature, samples are more sensitive to humidity change. The unpackaged samples are also more sensitive to temperature and humidity changes than the packaged samples. The sensitivity is lowered after the PVs have peaked.

Change in FFA during storage

- FFA increased with increasing temperature and humidity. The effect of humidity was enhanced at higher temperature, especially for the blanched samples that exhibited significant changes only at 100F.
- Raw samples have higher FFA values than blanched samples, attributable to some degree of inactivation of lipases during blanching.
- Unpackaged raw samples did not exhibit a consistent pattern, and sometimes have lower FFA values than the packaged samples. The uncertainty may arise from FFA generation via enzymatic hydrolysis of lipids and non-enzymatic oxidative degradation of FFA taking place simultaneously but unpredictably during storage.

Change in colors during storage

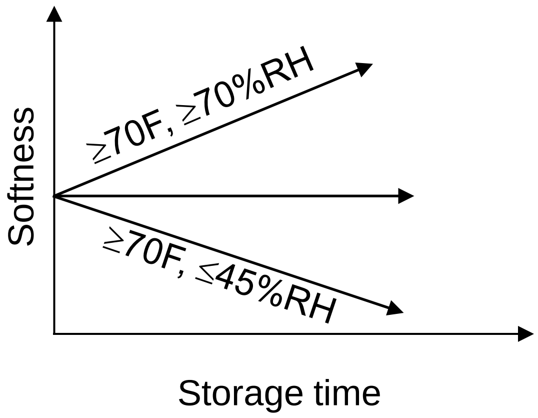
High temperature and high humidity (37.6℃， 85%)

Low temperature and medium humidity (4.6 ℃， 75%)

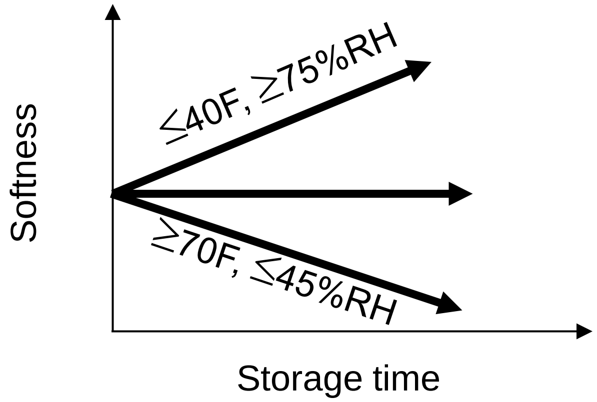
Change in texture during storage

Highly correlated with change in moisture content

With PE



Without PE



Mold growth


B-70/95 (20 days)


B-70/95 (30 days)

B-40/95 (210 days)


B-100/85 (20 days)


B-100/85 (30 days)

B-100/65 (210 days)

Summary of shelf-life under different conditions

Storage conditions	A	B	C	D
RT	360 days	180 days	150 days	330 days
40/45	660 days or longer			
40/75	660 days or longer	30 days	270 days	330 days
40/95	240 days	Inappropriate	240 days	240 days
70/45	660 days or longer		120 days	270 days
70/70	180 days	30 days	240 days	240 days
70/95	120 days	Inappropriate	90 days	90 days
100/35	210 days	150 days	60 days	90 days
100/65	180 days	180 days	90 days	120 days
100/85	90 days	Inappropriate	90 days	30 days

Phase II work and results

- Additional storage conditions
- More packaging options
- More in-depth look at lipid deterioration
- More rigorous sensory evaluation

Hypothesis

- High respiration rate due to inappropriate control of storage conditions and packaging can cause serious damages to almonds
- High oil content and high level of unsaturated fatty acids, prone to lipid oxidation
- Lipid oxidation can reduce almonds' sensory quality, and result in loss of flavor (rancidity), color, nutrient value, functionality, and accumulation of unhealthy compounds

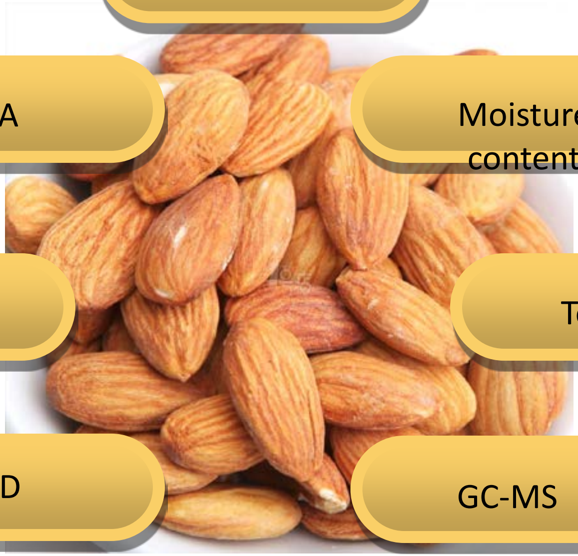
Objectives of Phase II

To determine the effects of almond forms (raw and salty light roast), package materials (carton box and PE, vacuum or atmospheric pressure PE packaging), storage conditions (temperature and humidity) on moisture, texture, lipid changes (lipid oxidation parameters, volatile flavor compounds), and sensory quality of almond during two years of storage.

SAMPLE LABELING

Sample ID	Sample Codes	Almond form	Package	Temperature (C)	RH (%)
1	RAW-APE-AT-ARH	Raw	Atm. pressure + PE	ambient tempt	Ambient RH
2	RAW-CAR-AT-ARH	Raw	Carton unlined	ambient tempt	Ambient RH
3	SLR-APE-AT-ARH	Salty light roasted	Atm. pressure + PE	ambient tempt	Ambient RH
4	SLR-VPE-AT-ARH	Salty light roasted	Vacuum + PE	ambient tempt	Ambient RH
5	RAW-APE-4T-UCH	Raw	Atm. pressure + PE	4	Uncontrolled RH
6	RAW-CAR-4T-UCH	Raw	Carton unlined	4	Uncontrolled RH
7	SLR-APE-4T-UCH	Salty light roasted	Atm. pressure + PE	4	Uncontrolled RH
8	SLR-VPE-4T-UCH	Salty light roasted	Vacuum + PE	4	Uncontrolled RH
9	RAW-APE-15T-50H	Raw	Atm. pressure + PE	15	50
10	RAW-CAR-15T-50H	Raw	Carton unlined	15	50
11	SLR-APE-15T-50H	Salty light roasted	Atm. pressure + PE	15	50
12	SLR-VPE-15T-50H	Salty light roasted	Vacuum + PE	15	50
13	RAW-APE-15T-65H	Raw	Atm. pressure + PE	15	65
14	RAW-CAR-15T-65H	Raw	Carton unlined	15	65
15	SLR-APE-15T-65H	Salty light roasted	Atm. pressure + PE	15	65
16	SLR-VPE-15T-65H	Salty light roasted	Vacuum + PE	15	65
17	RAW-APE-25T-50H	Raw	Atm. pressure + PE	25	50
18	RAW-CAR-25T-50H	Raw	Carton unlined	25	50
19	SLR-APE-25T-50H	Salty light roasted	Atm. pressure + PE	25	50
20	SLR-VPE-25T-50H	Salty light roasted	Vacuum + PE	25	50
21	RAW-APE-25T-65H	Raw	Atm. pressure + PE	25	65
22	RAW-CAR-25T-65H	Raw	Carton unlined	25	65
23	SLR-APE-25T-65H	Salty light roasted	Atm. pressure + PE	25	65
24	SLR-VPE-25T-65H	Salty light roasted	Vacuum + PE	25	65
25	RAW-APE-35T-50H	Raw	Atm. pressure + PE	35	50
26	RAW-CAR-35T-50H	Raw	Carton unlined	35	50
27	SLR-APE-35T-50H	Salty light roasted	Atm. pressure + PE	35	50
28	SLR-VPE-35T-50H	Salty light roasted	Vacuum + PE	35	50
29	RAW-APE-35T-65H	Raw	Atm. pressure + PE	35	65
30	RAW-CAR-35T-65H	Raw	Carton unlined	35	65
31	SLR-APE-35T-65H	Salty light roasted	Atm. pressure + PE	35	65
32	SLR-VPE-35T-65H	Salty light roasted	Vacuum + PE	35	65

Analysis and Evaluation



LIPIDS

Sensory evaluation

FFA

PV

CD

Moisture content

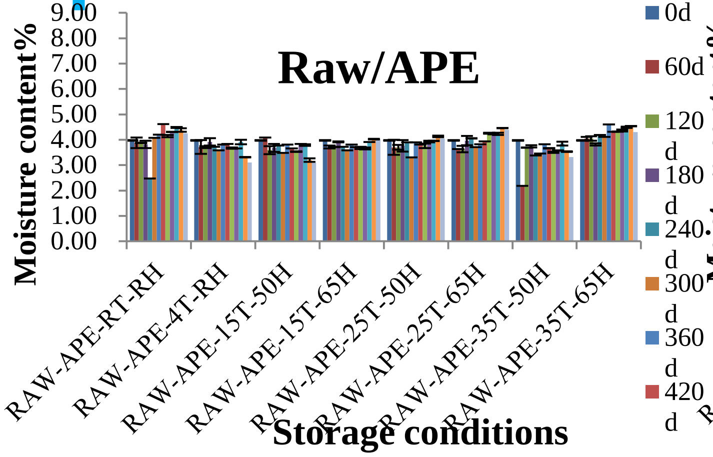
Texture

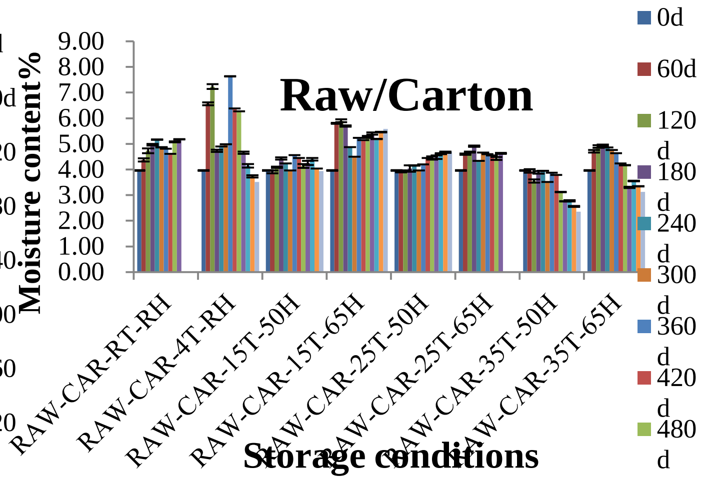
GC-MS

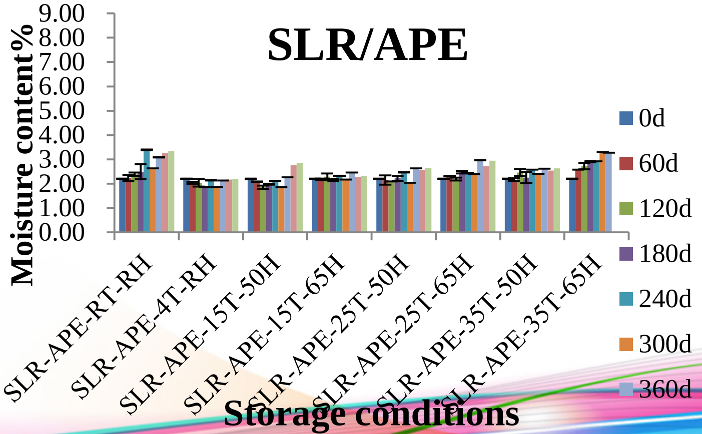
Sampling and testing schedule

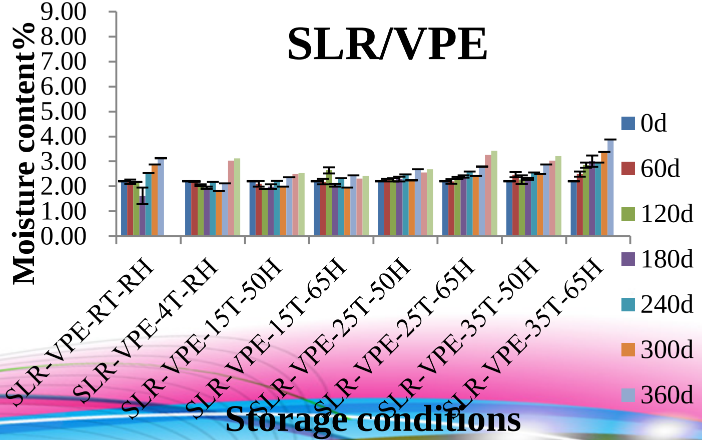
<table>
<tr><th rowspan="2">Storage time</th><th colspan="2">Sample type</th></tr>
<tr><th>NP 23/25 (raw)</th><th>Salty light roasted NP 23/25</th></tr>
<tr><td>Month 0</td><td colspan="2">Analytical, trained panel, and consumer panel</td></tr>
<tr><td>Month 2</td><td rowspan="11">Analytical and trained panel</td><td rowspan="5">Analytical and trained panel</td></tr>
<tr><td>Month 4</td></tr>
<tr><td>Month 6</td></tr>
<tr><td>Month 8</td></tr>
<tr><td>Month 10</td></tr>
<tr><td>Month 12</td><td>Analytical, trained panel, and consumer panel</td></tr>
<tr><td>Month 14</td><td></td></tr>
<tr><td>Month 16</td><td></td></tr>
<tr><td>Month 18</td><td></td></tr>
<tr><td>Month 20</td><td></td></tr>
<tr><td>Month 22</td><td></td></tr>
<tr><td>Month 24</td><td>Analytical, trained panel, and consumer panel</td><td></td></tr>
</table>

Change in moisture content









Summary on moisture content

- The moisture content in roasted almond was more stable than the raw almond.
- Moisture content of almond packed in the cartons changed more than those packed in PE bags；
- The change in moisture content of the roasted almond increased with increasing temperature and RH. However the raw almond exhibited irregular changes in moisture content.

Summary on firmness

- The raw almond experienced greater change in firmness than the roasted ones. At high temperature and RH, raw almond softened significantly. At 40F (4C) without RH control, raw almond did not exhibit significant hardening.
- Most textural profiles did not exhibit a first initial peak and therefore we were unable to evaluate the fracturability.

Summary on lipid oxidation

- The changes in FFA, CD and PV showed that roasted almond was more stable than raw almond in terms of lipid oxidation
- FFA and CD increased with increasing temperature and RH
- Lipid changed the most when almond was stored at 35C (95F) and RH65%.
- AT 4C (40F) and uncontrolled RH, almond was very stable.
- Almond packed in carton experienced greater changes compared with samples packaged in other materials.

Summary on aromatic compounds

- High temperature and high RH speed up lipid oxidation and hence resulted in aroma deterioration
- Carton box is not suitable for long term storage because almond will develop carboardy odor.
- 40F and uncontrolled RH is suitable for APE packaging of raw almond. Both APE and VPE SLR samples showed minimal changes in aroma when stored at 40F(4C)/uncontrolled RH, or 50F (15C)/RH50-60%.
- N-hexyl alcohol and toluene are the main aromatic compounds in raw almond. 2,4-dimethyl-1-heptene may be used as the main indicator of oxidation in raw almond.
- N-hexanol, 2,5, - dimethyl pyrazine, n-heptanol, n-butanol, 2-methylbutyraldehyde, furfural, phenylacetaldehyde, and 3-methyl butanal are the main aromatic compounds in roasted almond. N-hexanal and 2,4-dimethyl-1-heptane can be used as the main indicators of oxidative deterioration.

Summary on sensory evaluation

- In general, sensory attributes of the raw almond samples deteriorated gradually over time except aroma which suffered dramatic decrease after 60 days storage. There was insignificant difference in sensory quality among the storage conditions
- Raw almond packaged in carton boxes showed poor textural properties when stored at high temperature RH and their rancidity was high too. Therefore, CAR-35T-65H is unsuitable for raw almond storage.
- Changes in sensory quality of both raw and roasted almond generally agreed with the analytical parameters.

Summary of findings from both studies

- **The moisture content in roasted almond was more stable than the raw almond. Moisture content of almond packed in the cartons changed more than those packed in PE bags. The changes in moisture content of the roasted almond increased with increasing temperature and RH. However the raw almond exhibited irregular changes in moisture content.**
- **The raw almond experienced greater change in firmness than the roasted ones. At high temperature and RH, raw almond softened significantly. At 40F (4C) without RH control, raw almond did not exhibit significant hardening. Most textural profiles did not exhibit a first initial peak and therefore we were unable to evaluate the fracturability. Firmness is closely correlated with moisture content**

Summary of findings from both studies (cont'd)

- The changes in FFA, CD and PV showed that roasted almond was more stable than raw almond in terms of lipid oxidation. Skin protects almond and extends shelf life. FFA and CD increased with increasing temperature and RH. Lipid changed the most when almond was stored at 35C (95F) and RH65%. Almond packed in carton experienced greater changes in lipids compared with samples packaged in other materials. Carton box is not suitable for long term storage because almond will develop carboardy odor. There are interaction effects of temperature and humidity on lipid oxidation during storage. High temperature and high RH speed up lipid oxidation and hence resulted in aroma deterioration.
- All above analytical parameters were found to be highly correlated with sensory attributes

Summary of findings from both studies (cont’d)

- **Sensory attributes of the raw almond samples deteriorated gradually over time except aroma which suffered dramatic decrease after 60 days storage. There was insignificant difference in sensory quality among the storage conditions.**
- **High temperature and high RH conditions and carton box packaging are highly unsuitable for almond storage.**

General recommendations from Phase I study

- Whole almond can be stored at low temperature-low humidity or high temperature-medium humidity conditions without packaging.
- Blanched almond nuts or slices should be stored at low temperature and medium humidity (e.g. 75% RH).
- Since humidity control is cheaper than temperature control, we recommend low humidity and moderate temperature with PE packaging for almond storage.

General Recommendations from Phase II study

- Raw and salty light roasted almond are best kept at 40F (4C) without the need to control RH. However, 60F (15C)/RH 50-65% is recommended if energy consumption is a concern. Carton boxes are not suitable for long term storage of almond products. We recommend PE at atmospheric pressure or vacuum sealed.

- These outcomes should help ABC to provide better guidelines for end processors on packaging and long-term storage in challenging regions such as China that have high and fluctuating temperatures and relative humidity.

Questions?

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EVALUATION OF STORAGE PRACTICES TO PREDICT CONSUMER ACCEPTABILITY OF RAW AND DRY-MEDIUM ROASTED ALMONDS

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December 8, 2015

The University of Georgia

Factors that Affect Shelf Life

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

Major Factors Influencing Almond Quality and Shelf Life (ABC 2014)

Product characteristics	Environment	Package
Composition; Water activity; Form.	Temperature; Humidity; Oxygen; Processing conditions; Insects, pests, microorganisms.	Physical protection; Moisture barrier; Gas barrier.

ABC Recommendations – Storage Conditions and Handling Practices

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

High Quality → Moisture <6%, a_w 0.25-0.35, Free fatty acids <1.5%, PV <5 meq/kg

Objectives for this Study

To evaluate/validate current storage practices employed by the almond industry at maintaining quality, specifically consumer acceptability, of the crop as a means to maximize its value.

1. To characterize the relationships between chemical and instrumental (i.e., notably physical measurements) indices as well as consumer sensory evaluation of almond quality subjected to different storage conditions;

2. To assess changes in chemical, textural, and sensory properties of roasted and raw nonpareil almonds as a function of packaging type, storage temperature, and RH conditions over a 16-mo and 24-mo period, respectively;

3. To determine a comprehensive trigger point that is associated with consumer rejection of almond acceptability based on chemical and textural attributes;

4. To determine how different packaging strategies (*i.e.*, choice of bags with different moisture and O_2 transmission rates, N_2 flushing, environmental control currently employed by the industry) impact the shelf-life of roasted and raw nonpareil almonds.

Experimental Design

Packaging of nonpareil raw and roasted almonds

	Raw	Roasted
Unlined carton (UCs) (600 ± 5 g)	X	
Polypropylene bag (PPBs) (300 ± 5 g)[a]	X	X
High barrier bag (HBBs) (300 ± 5 g)		X

[a] Bags were flushed with food-grade N_2 and sealed, providing a “pillow-pack” design. The headspace was analyzed in multiple samples, and the initial O_2 level was < 0.5%.

UC: No WV or O_2 barrier

PPB: WVTR = 8 g/m^2/day; OTR = 860 cm^3/m^2/day

HBB: WVTR <0.5 g/m^2/day; OTR < 1 cm^3/m^2/day

Study Design

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

Raw Only
UCs
T and %RH

- Ambient RH
  - 4 ^{o}C
- 50% RH
  - 15 ^{o}C
  - 25 ^{o}C
  - 35 ^{o}C
- 65% RH
  - 15 ^{o}C
  - 25 ^{o}C
  - 35 ^{o}C

Raw and Roasted
PPBs
T and %RH

- Ambient RH
  - 4 ^{o}C
- 50% RH
  - 15 ^{o}C
  - 25 ^{o}C
  - 35 ^{o}C
- 65% RH
  - 15 ^{o}C
  - 25 ^{o}C
  - 35 ^{o}C

Roasted only
HBBs
T (No %RH)

- 4 ^{o}C
- 15 ^{o}C
- 25 ^{o}C
- 35 ^{o}C

Samples were analyzed at 2-mo intervals until consumer rejection or conclusion of the study, and compared to baseline values.

Sampling Plan

Samples stored under each T/RH condition were removed at 2-mo intervals from the environmental chambers for assessment.

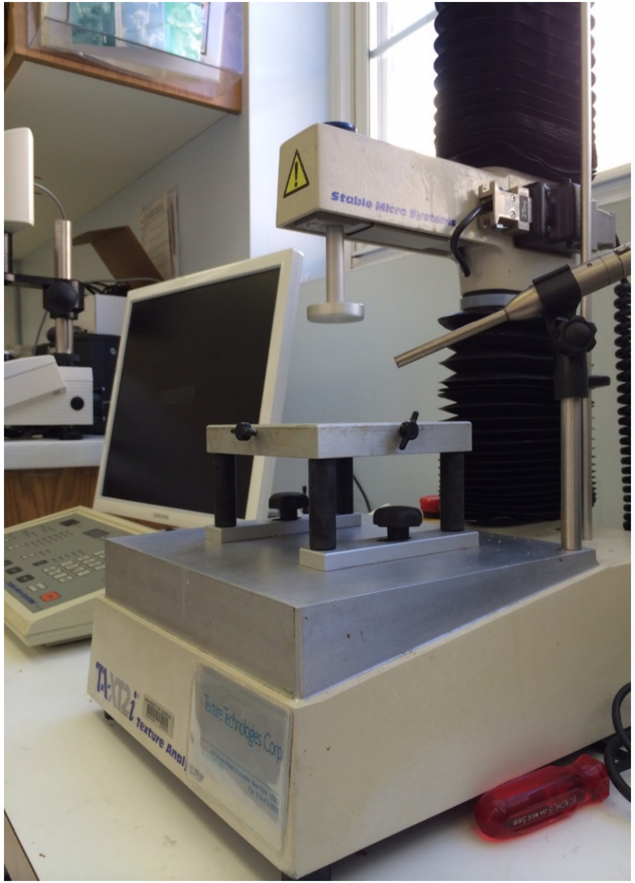
Breakdown of Sampling Plan

Day 1	Day 2	Day 3 (if sample "triggers" sensory)	Day 4	Day 5
Expeller-pressed Oil	Peroxide Value[a,d]	Roasted Trained Panel (*n* = 6 x 2)[e]	Roasted Screening Panel (*n* = 35)[f]	Roasted Confirmatory Panel (*n* = ~120)[g]
Particle Size Reduction	Free Fatty Acids[a]	Raw Consumer Screening Panel (*n* = 34-40)[g]	Raw Confirmatory Panel (*n* = ~120)[g]	
Headspace Analysis[b]	Conjugated Dienes[a]			
Moisture Analysis[b]	TBARS[a]			
Water Activity[b]				
Texture Analysis[c]				

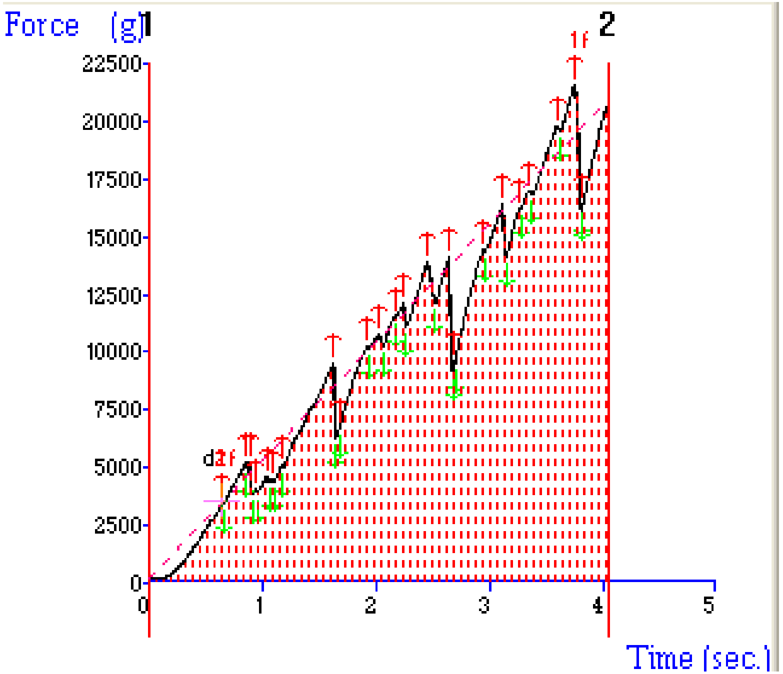
[a]Evaluated with oil; [b]Evaluated with ground sample; [C]Evaluated with whole almonds; [d]Peroxide value 2 meq active O_2/kg oil; [e]Trained panel only for Roasted Samples, [f]Screening panel only necessary if roasted samples are deemed unacceptable to the trained panel, but not conclusively [g]Confirmatory panel for "triggered" raw samples and roasted samples that are deemed unacceptable to the screening panel.

Method for Texture & Sound Analysis

- Texture analysis was performed using a Texture Technologies TA-XT2i texture analyzer.
- The fracturability of whole almonds was evaluated using the texture analyzer with a compression disk.
- The audio was recorded during texture analysis and will be analyzed to provide a more complete fracturability profile.



Description of textural factors extracted from the force/displacement curves



Parameter	Textural association
Number of force peaks (FP)	Crispness Brittleness
Average gradient (AG)	Chewiness
Average drop-off (AD)	Crispness Brittleness

Sensory evaluation

Sensory evaluation (If sample "triggers")	
Day 3-9	
Roasted Samples	
Roasted Screening Panel (*n* = ~35)	Roasted Confirmatory Panel (*n* = ~120)
Raw Samples	
Raw Screening Panel (*n* = ~35)	Raw Confirmatory Panel (*n* = ~120)

9-Point hedonic scale

- Odor
- Flavor
- Texture
- Overall acceptability

Rejection Question

If you had purchased this product, would you eat it?

≥25% - **No**; sample is deemed "unacceptable"

Product Code Number: ______ Panelist Number: ______

Almond Sensory Scorecard

You will evaluate XX samples today, each presented in a closed container. Please check the box (□) that best reflects your opinion of this sample

Before tasting, evaluate the odor of the product. Hold the cup close to your nose and gently lift the lid as you take three short sniffs.

Odor

□ □ □ □ □ □ □ □ □

Extremely Dislike ... Extremely Like

Eat the almonds and evaluate texture, flavor and overall acceptability by marking the box (□) that best reflects how much you like this product

Texture

□ □ □ □ □ □ □ □ □

Extremely Dislike ... Extremely Like

Flavor

□ □ □ □ □ □ □ □ □

Extremely Dislike ... Extremely Like

Overall Acceptability

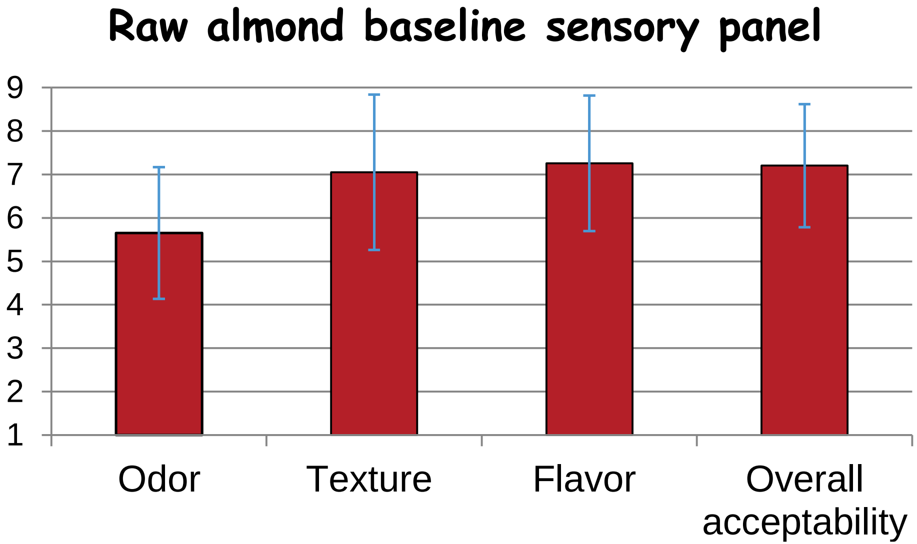
□ □ □ □ □ □ □ □ □

Extremely Dislike ... Extremely Like

Please drink water and eat some crackers and/or carrot to cleanse you mouth

Turn-over and complete the back

Baseline Consumer Data: Sensory Raw Almonds (n = 118)



Rejection Question:
If you had purchased this product, would you eat it?

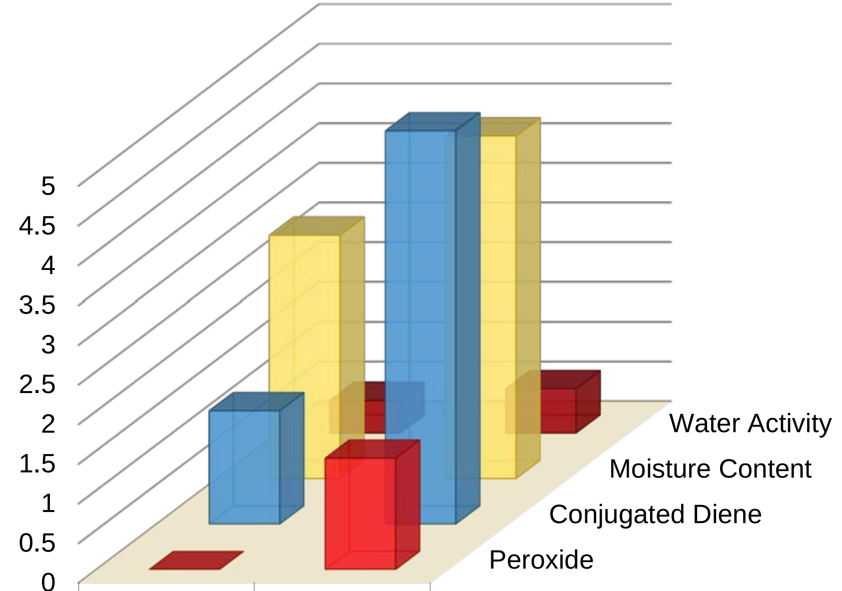
5.98% - No

Panel profile for raw baseline (n = 118) of 118 participants:
78.4% were female and 75.9% were aged between 18 to 27 years.

	Daily	Several times a week	Several times a month	Once a month	Several times a year	Never
Consumption	Frequency (%)					
Nuts	19.0	35.3	28.4	10.3	6.0	0.9
Almonds	6.9	25.0	32.8	12.1	19.8	3.4

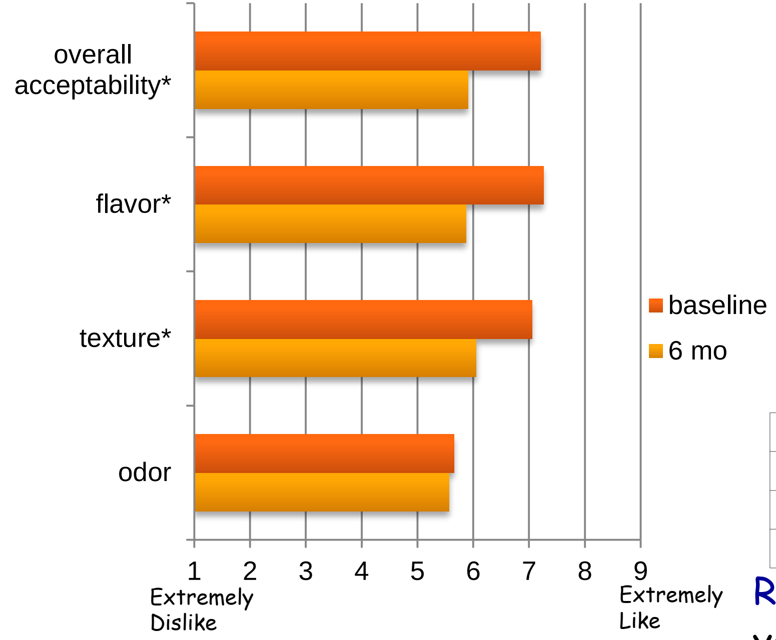
6 mo - Results for Rejected Raw Almond Sample in a PP Bag @ 35 °C/65% RH

Chemical analyses: baseline vs. rejected sample



	Baseline Raw	35 65% 6 months
Peroxide	0	1.405
Conjugated Diene	1.43	4.95
Moisture Content	3.06	4.31
Water Activity	0.414	0.561

Consumer sensory evaluation: Baseline vs. rejected sample

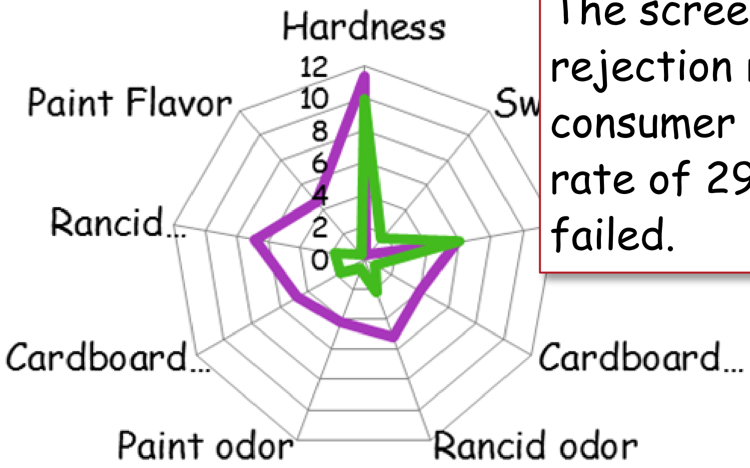


Rejection Question: If you had purchased this product, would you eat it?

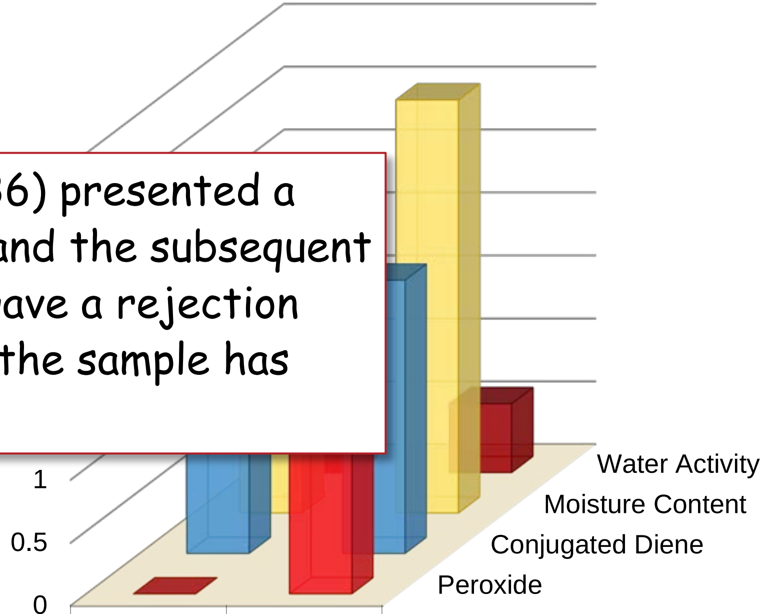
5.98% 'No' at baseline; 27.2% 'No' at 6 months.

12 mo - Results for Roasted Almond Sample in a PP Bag @ 35 °C/65% RH

Descriptive sensory evaluation: Baseline vs. 12 mo



The screening panel (n = 36) presented a rejection rate of 25.0%, and the subsequent consumer panel (n = 101) gave a rejection rate of 29.7%, indicating the sample has failed.



	Baseline Roasted	35 65% 12 mo
Peroxide	0	1.89
Conjugated Diene	1.85	2.17
Moisture Content	0.893	3.28
Water Activity	0.141	0.548

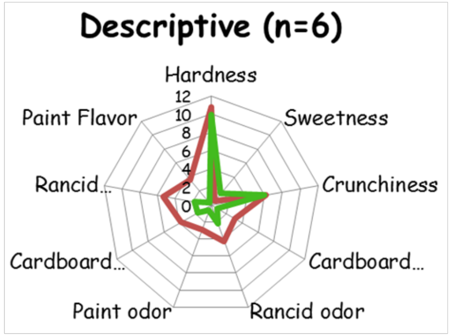
Attribute means on truncated 15-point lines (* = $p < 0.05$)

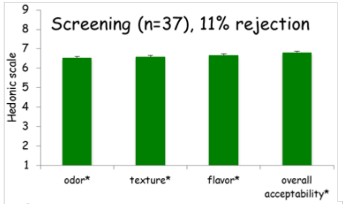
Analysis type	Effect on Consumer Acceptability
↑ PV	↑ Rancid odor/flavor
↑ Moisture	Δ Texture Characteristics
↑ a_w	Δ Texture Characteristics
↓ # of Fractures	Δ Texture Characteristics

Roasted Almonds
PE bag 35°C/65% RH

Non-sensory data	
PV (meq. O_2/kg oil)	1.49±0.18
Moisture (%)	2.87±0.07
a_w	0.46±0.003
# of Fractures	10.2±4.78

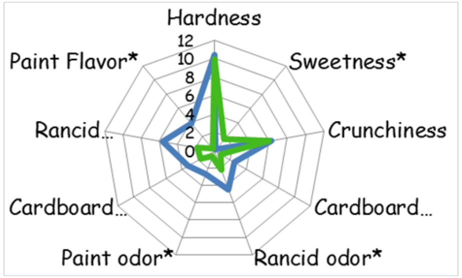
8 mo

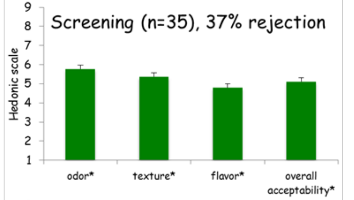


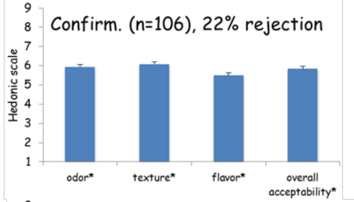


Non-sensory data	
PV (meq. O_2/kg oil)	1.84±0.022
Moisture (%)	3.80±0.31
a_w	0.53±0.006
# of Fractures	5.3±3.53

10 mo

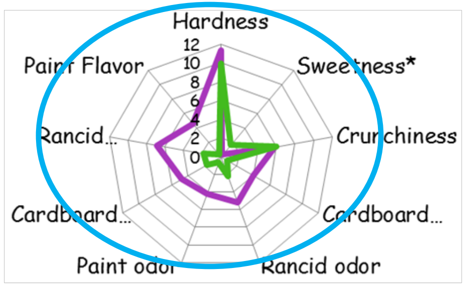


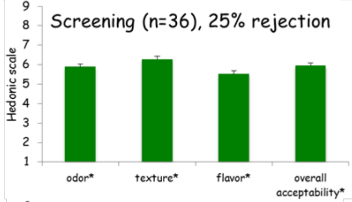


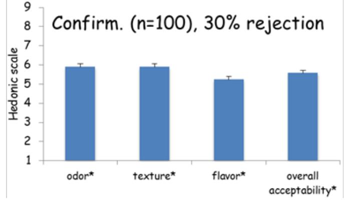


Non-sensory data	
PV (meq. O_2/kg oil)	1.89±0.048
Moisture (%)	3.28±0.09
a_w	0.55±0.004
# of Fractures	4.1±1.45

12 mo







Rejection timeline for raw and roasted almond samples

Rejection timeline (mo) for all samples

A (Raw PPB)				35/65			35/50		25/65	15/65
B (Raw UC)		35/65		35/50 4/90			25/65 15/65		25/50 15/50	
Mo	**0**	**2**	**4**	**6**	**8**	**10**	**12**	**14**	**16**	**>> 24**
C (Roast PPB)							35/65	35/50	25/65	
D (Roast HBB)									35	

Samples that were not rejected

Sample	Rejection Rate
A 25/50	22.5%
A 15/50	10.0%
A 4/90+	12.7%
C 25/50	18.6%
C 15/65	20.6%
C 15/50	8.9%
C 4/90	9.8%
D 25	2.9%
D 15	7.9%
D 4	5.9%

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

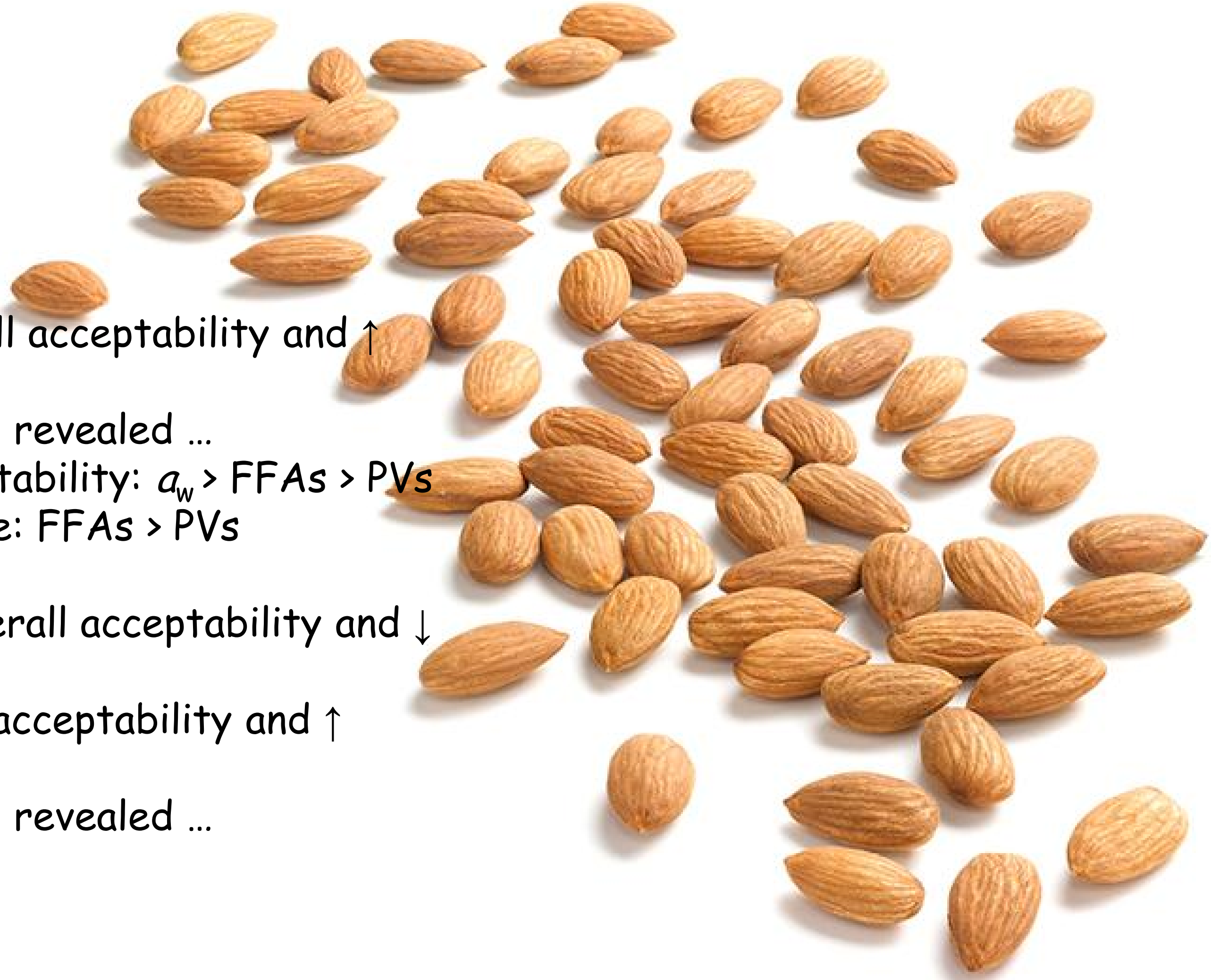
Results

Explaining consumer rejection: positive vs. negative intent to consume responses

- All rejected samples differed significantly for all attributes from those of the control
- Of the three raw samples in PPB not rejected …
  - Almonds stored at 25°C/50% RH differed significantly for all attributes
  - Samples stored in polypropylene bags at 4°C and at 15°C/50% RH differed significantly in all attributes, except for odor
- Weak points commonly stated by individuals who rejected the samples …
  - Texture – gummy, mushy/soggy, stale
  - Flavor/taste – lingering flavor/aftertaste, sour/tangy, oxidized, rancid, cardboard, no/weak almond/nutty flavor, stale
  - Odor – no/weak almond/nutty odor

Objective 1:

To characterize the relationships between chemical and instrumental (*i.e.*, notably physical measurements) indices as well as consumer sensory evaluation of almond quality subjected to different storage conditions.



Summary

<u>Chemical</u>

- ↑ values → ↓ overall acceptability and ↑ rejection rate
- Univariate analysis revealed …
  - Overall acceptability: a_w > FFAs > PVs
  - Rejection rate: FFAs > PVs

<u>Textural</u>

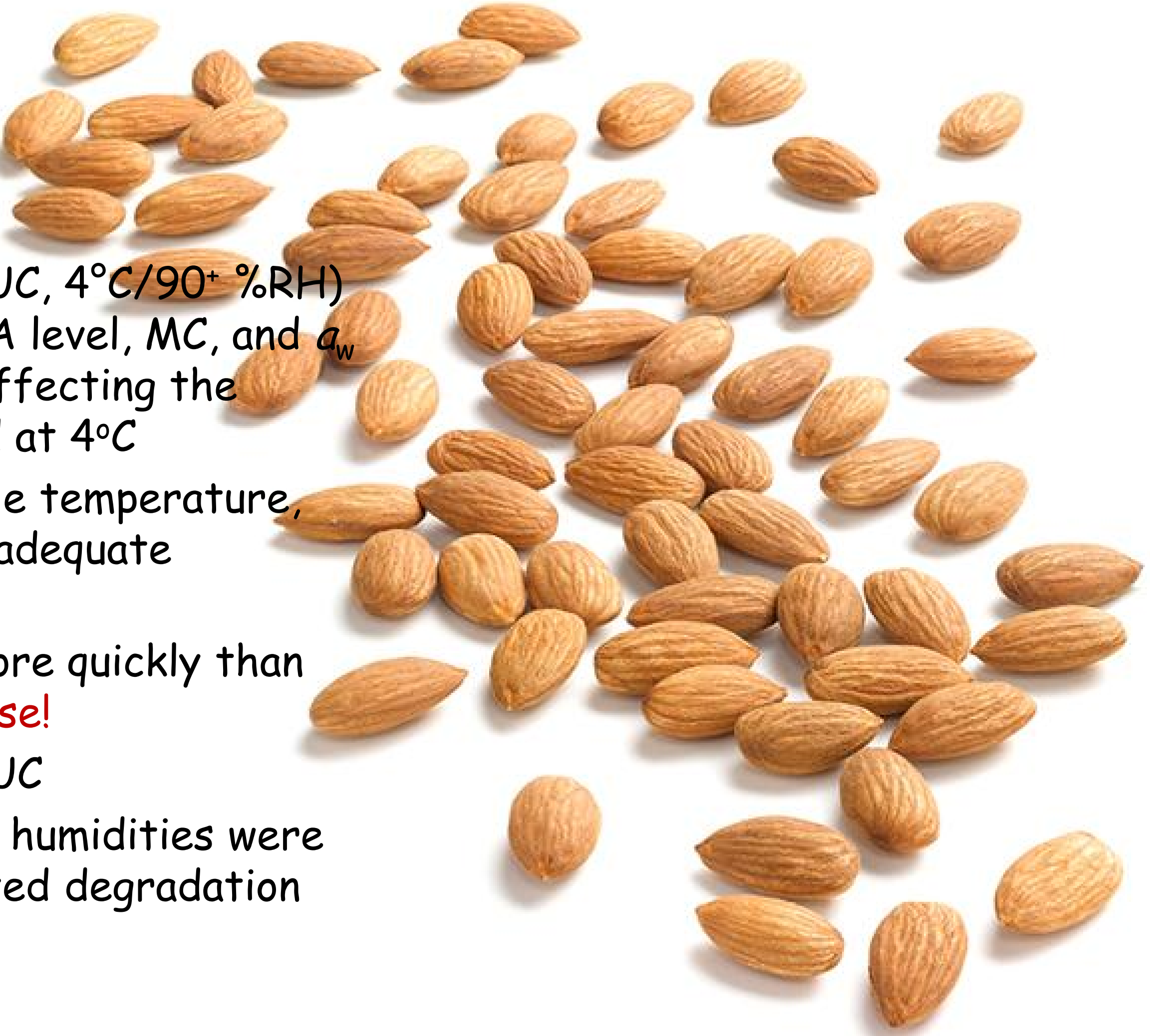
- ↑ FPs, ADs → ↑ overall acceptability and ↓ rejection rate
- ↑ AGs → ↓ overall acceptability and ↑ rejection rate
- Univariate analysis revealed …
  - FPs > ADs

Objective 2:

To assess changes in chemical, textural, and sensory properties of roasted and raw nonpareil almonds as a function of packaging type, storage temperature, and RH conditions over a 16-mo and 24-mo period, respectively.

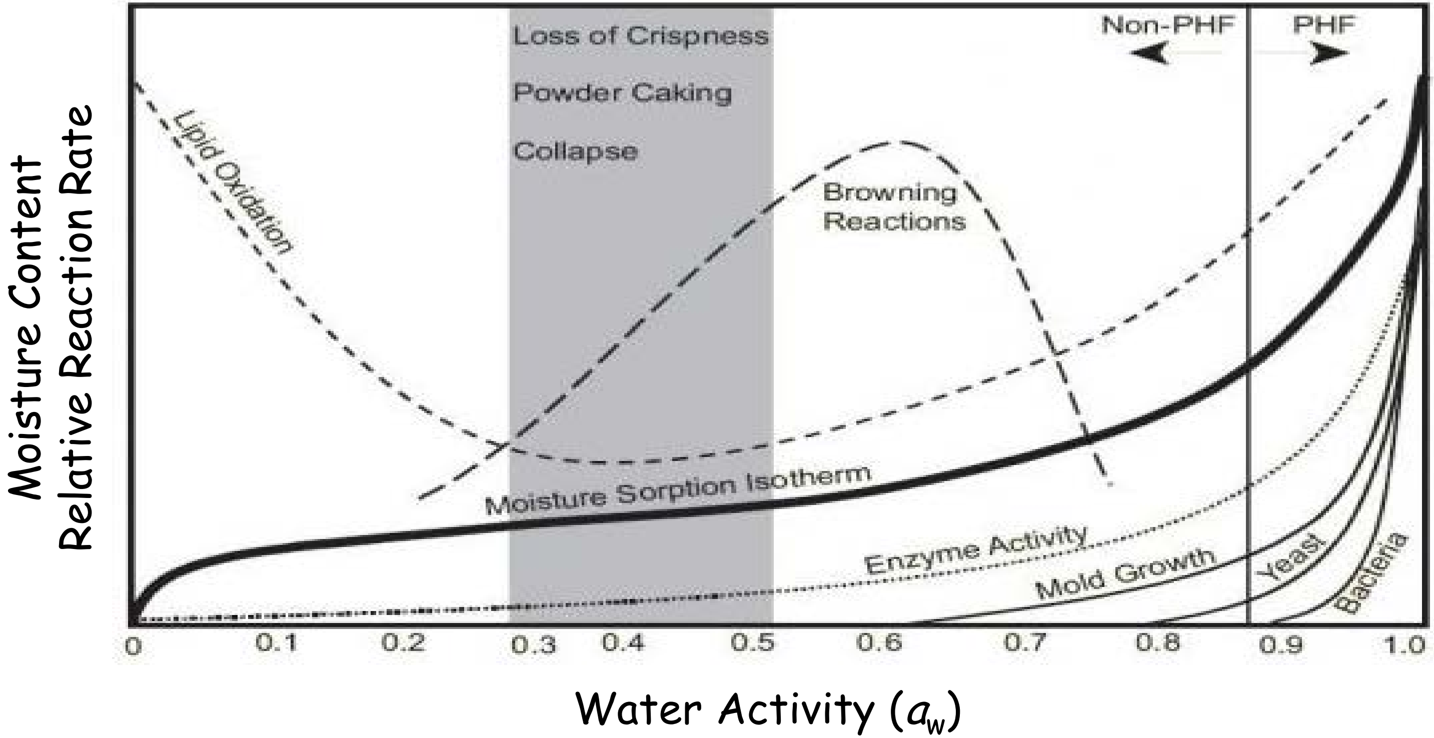
Summary

- One raw almond sample (UC, 4°C/90^{+} %RH) displayed the highest FFA level, MC, and a_w by a significant margin, affecting the results of samples stored at 4°C
    - Despite the favorable temperature, UCs did not provide adequate protection
- Raw almonds degraded more quickly than roasted almonds; a surprise!
- Packaging: HBB >> PPB >> UC
- Higher temperatures and humidities were associated with accelerated degradation



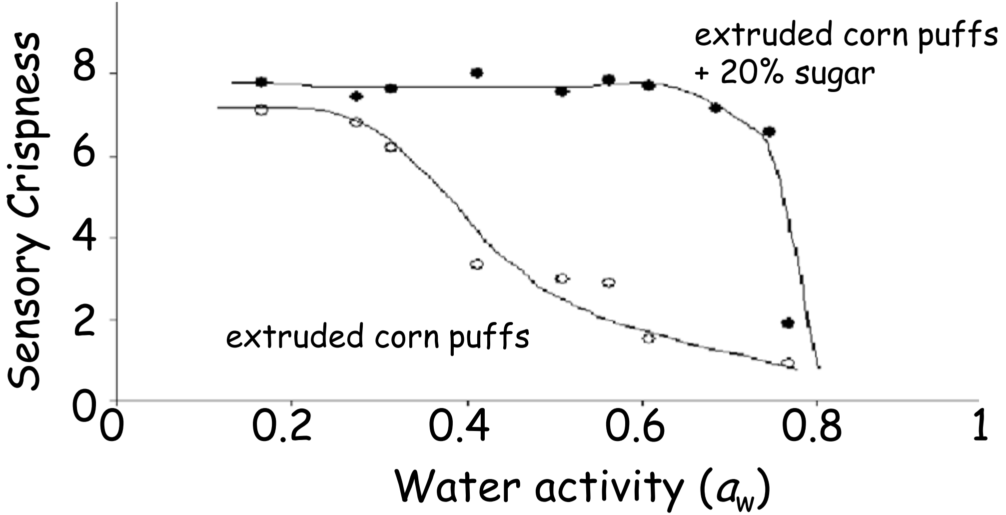
Lipid oxidation is lowest at a_ws of ~0.2 to 0.4

Water Activity (a_w) – Stability Diagram



source: www.aqualab.com

Crispness scores drop when a critical moisture (a_w) is reached



Source: G. Roudaut. (2007). Ch 8 in *Water Activity in Foods*. Blackwell Publishing.

Objective 3:

To determine a comprehensive trigger point that is associated with consumer rejection of almond acceptability based on chemical and textural attributes.

Rejection profile of raw almond samples

	PVs	FFAs	MC	a_w	FPs	ADs	AGs	Average rejection rate
Raw 0 mo.	<0.01	0.29±0.03	3.06± 0.03	0.41±0.001	5.91±1.88	6.89±3.11	57.7±17.3	5.98
Failed raw samples (*n*=11)	2.58±1.63*	0.79±0.56	4.98±0.94*	**0.58±0.09*[1]**	**5.37±0.97*[1]**	6.11±2.19[1]	57.4±5.88[1]	30.84
Acceptable raw samples (*n*=3)	2.20±0.23*	0.47±0.20	4.59±0.44*	0.43±0.02[1]	6.70±1.40[1]	**11.00±0.88*[1]**	**83.41±7.57*[1]**	13.87

Raw almond samples rejected during the study exhibited significantly different (α = 0.05) values compared to baseline and acceptable almond samples for a_w and FPs.

Samples displaying a_ws above 0.580 and significantly lower FPs compared to baseline will likely fail consumer panels.

Rejection profile of roasted almond samples

	PVs	FFAs	MC	a_w	FPs	ADs	AGs	Average rejection rate
Roast 0-mo	<0.01	0.44±0.03	0.89±0.06	0.14±0.001	20.40±5.82	12.45±3.15	143±22.4	4.16
Failed Roast samples (n=4)	2.30±0.90*	0.31±0.11[1]	**2.62±1.00*[1]**	**0.43±0.13*[1]**	**9.63±4.98*[1]**	**9.69±3.32*[1]**	**112± 30.3*[1]**	28.86
Acceptable roasted samples (n=7)	1.62±1.10*	0.20±0.04*[1]	1.70±0.86[1]	0.31±0.09*[1]	15.49±2.67*[1]	12.03± 1.46[1]	130±11.8[1]	10.67

Roasted almond samples rejected during the study exhibited significantly different (α = 0.05) MC, a_w, FPs ADs, AGs compared to baseline and acceptable.

Samples displaying a_ws above 0.430, MCs above 2.62%, and a significant decrease in FPs, ADs, and AGs compared to baseline will most likely fail consumer panels.

Overall Study Conclusions

- For both raw and roasted almonds, an interaction of chemical and textural parameters predicted shelf life.
- Both temperature and humidity are important to regulate during storage …
  - Almonds stored at higher Ts degraded more rapidly than counterparts at lower Ts.
  - Almonds stored at higher %RH degraded more rapidly than counterparts at lower %RH
- Using univariate analysis, a_w and MC were determined to be the better predictors of overall acceptability and rejection rate.

Overall Study Conclusions

- MAP HBB can substantially offset the effects of environmental conditions on product quality.
- Raw samples stored in MAP PPB exhibited anywhere from 4 mo. (35/65) to 18^{+} mo. ($4/90^{+}$) shelf-life extension compared to UCs.
  - It is not recommended to store almonds in UCs, as samples stored in this manner displayed shortened shelf life compared to samples stored in PPBs.
- At 35°C, roasted samples stored in MAP HBB exhibited 4 mo. shelf life extension compared to MAP PPB.

MAP PPB are adequate storage materials for roasted and raw nonpareil almonds for up to 16-mo and 24-mo, respectively, at 25°C/ 50% RH and below.

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Questions?