CEUs – New Process

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Sign in sheets and verification sheets are located at the back of each session room.
AGENDA

• Guangwei Huang, Almond Board of California, and Kelly Covello, Almond Alliance of California, moderator

• Jean VanderGheynst, UC Davis

• Chris Simmons, UC Davis

• Bor-sen Chiou, UniverUSDA Albany
Production of black soldier fly larvae on almond by-products

Jean VanderGheynst, PhD
Biological & Agricultural Engineering
UC Davis

December 5, 2017
• World population is expected to grow to 9 billion by 2050
• Demand for animal protein is projected to increase by 76% by 2050
• Livestock production currently uses more than 2/3 of agricultural land

Addressing food insecurity will require innovative approaches to food production that are more sustainable than current practices while still yielding nutritious food.
Insect production offers one potential solution to food insecurity

- Insects have high conversion efficiency
  - Cattle require 8 kg of feed to produce 1 kg of edible weight
  - Insects require 1.5 kg of feed to produce 1 kg of edible weight
- Insects are a natural component of diet for fish and poultry
- Insect farming requires less land and water and results in less greenhouse gas emissions compared to livestock farming

Greenhouse gas production per kg protein produced (Oonincx and de Boer, 2012)
The Rise Of The Incredible Edible Insect

Start-ups are marketing an unlikely new protein. It’s nutrient-rich, all natural, and six-legged.

By Brooke Borel  May 12, 2015

The future of animal feed? Fly farming

French company Ynsect keen to replace fish and pet foods with crushed insects

By Tara Duggan  May 3, 2017  Updated: May 3, 2017 2:12pm

AgriProtein to build 20 fly farms in US and Canada

By Clint Jasper  January 22, 2017 3:55 pm
Updated 22 January 2017 at 3:55 pm
First posted 22 January 2017 at 2:57 pm

New proteins
News  29 Mar 2017  6990 views  3 comments

abc.net.eu
popsci.com
sfchronicle.com
allaboutfeed.net
Insects at Commercial or Near Commercial Production

• Crickets
• Grasshoppers
• Mealworms
• House fly
• Silkworm
• Black soldier fly larvae (BSFL)
Characteristics of BSF that Make Them Ideal for Production

• Non-pest insect
• Do not carry harmful pathogens
• Enhance organic matter decomposition process
• Grow on many types of organic matter
• Nutritional value for feed
BSFL Nutritional Value

Percentage of dry weight depending on production feedstock
• Crude protein: 39 – 43%
• Methionine: 0.5 – 0.9%
• Calcium: 0.12 – 6.6%

Challenges
• Composition varies with production environment
• A consistently sourced feedstock is needed to achieve consistent larvae composition

In 2016, the CA almond industry produced 3.37 billion pounds of almond hulls and 1.35 billion pounds of almond shells (CA Almond Board, 2017)

By-products from the almond industry are a potential resource for insect production
Preliminary Studies

• Preliminary studies done in May, 2017 indicated larvae will grow on almond hulls and shells
• Requested funds from ABC for additional research
Management steps and variables in larvae production

1. Growth feedstock
2. Grinding
3. BSFL rearing & inoculation
4. Cultivation (time, temperature)
5. Nitrogen
6. Water
7. Aeration
8. Spent feedstock
9. Larvae
Processing steps

• Pollinator variety hulls obtained from processor in Chico, CA in June 2017. Material had been stored outdoors under roof

• Material was ground
  – Used hammer mill (1/4 inch screen). Additional small batch grinding with coffee grinder

• Water and nitrogen added and equilibrated overnight at 4°C prior to each experiment
Processing steps

• BSF eggs purchased from commercial supplier
• Larvae reared from eggs and separated from feed prior to inoculation onto moistened hulls
Processing steps

• Larvae inoculation onto hulls
• Incubation and larvae cultivation
BSFL Cultivation Reactors

- Exhaust fitting
- Filter to prevent BSFL escape
- Inlet fitting for aeration
- Solid tubing
- Perforated hose
- End plug
- Inoculated hulls
Larvae Cultivation Reactors
BSF Life Cycle

https://taxo4254.wikispaces.com/Hermetia+Illucens
Larvae harvest

• Developed baiting system for harvest
• Larvae also collected manually
Measurements

• Larvae specific growth:
  – change in larvae mass per mass inoculated onto hulls

• Yield:
  – change in larvae mass per change in hull mass

• Calcium and amino acids in harvested larvae

• Hull consumption

• Change in hull composition
Experimental Variables

- Aeration (oxygen supply)
- Moisture
- Particle size
- Nitrogen supplementation
- Feeding rate
Aeration

• Metabolism of hulls is expected to increase with increasing air supply

• Experiments were completed with varying aeration levels
Aeration increases larvae growth

![Graph showing the relationship between aeration rate and specific larvae growth (dry basis). The x-axis represents the aeration rate (mL/min/g dry wt) ranging from 0 to 1, and the y-axis represents specific larvae growth (dry basis) ranging from 0 to 9.]
Aeration increases larvae yield from hulls

![Graph showing the relationship between aeration rate and larvae yield. The x-axis represents the aeration rate (mL/min/g dry wt), and the y-axis represents the change in larvae weight divided by the change in hull weight (dry basis). The graph indicates a positive correlation between aeration rate and larvae yield.]
Aeration increases hull consumption
Microorganism synergy or competition with larvae?

- Microorganisms are growing simultaneously with larvae
- Do certain conditions support microorganism growth over larvae growth?
Low aeration supports microbial consumption of hulls over larvae consumption.
Moisture

- Water is essential for growth and breakdown of hulls by microorganisms and larvae
- As received moisture content of hulls was <20% wet basis
- Experiments were completed to test larvae growth at varying moisture levels
  - Incubations were completed with and without larvae
There is an optimum moisture for larvae growth on hulls.

![Graph showing the relationship between specific larvae growth (dry basis) and moisture content (% wet basis). The graph indicates an optimum moisture content for maximum specific larvae growth.]

- Specific larvae growth (dry basis)
- Moisture content (% wet basis)
Larvae yield increases with moisture

![Graph showing the relationship between Larvae wt/Δ Hull wt (dry basis) and Moisture content (% wet basis). The graph indicates a positive correlation as moisture content increases, larva yield increases.](image-url)
Larvae enhance the decomposition of hulls

![Graph showing the relationship between moisture content and hull consumption with and without larvae.]
Potential mechanisms for enhanced decomposition

• Synergy with microorganisms
• Microorganisms in the gut of larvae contribute to decomposition
• Increased mixing associated with larvae results in improved distribution of nutrients required for all organisms to grow
Nitrogen supplementation

• Nitrogen is important for the synthesis of enzymes necessary to breakdown hulls

• The carbon to nitrogen ratio (C/N) of as-received hulls was 60

• Experiments were completed to test larvae growth on hulls amended with urea to achieve different C/N levels
  – Two particle sizes of hulls were also tested
There is an optimum C/N for larvae growth on hulls

Specific larvae growth (wet basis)

Coarse hulls
Coarse hulls support greater larvae growth than fine hulls

![Graph showing specific larvae growth (wet basis) vs Carbon to Nitrogen Ratio. The graph indicates that coarse hulls support greater growth than fine hulls.]
Hull consumption increases with C/N

![Hull Consumption Graph](image)

- Coarse hulls
- Fine hulls

Hull Consumption (% dry)

Carbon to Nitrogen Ratio
Increasing C/N supports microbial growth on hulls over larvae growth.
Summary

• Black soldier fly larvae can be cultivated on almond by-products
• Cultivation variables (aeration, moisture and C/N) impact growth and yield from hulls
• Cultivation conditions play a role in consumption of hulls by microorganisms versus larvae
Future Research

• Additional variables to examine for impact on larvae growth and hull consumption
  – Almond by-product sources
  – Alternative nitrogen sources
  – Cultivation time and temperature
Acknowledgements

• BSFL production team
  – Deb Niemeier
  – Maurice Pitesky
  – Lydia Palma
  – Shannon Ceballos
  – Paulina Johnson
  – Sara Pace
  – Matt Paddock
  – Suzy Karagosian

• Financial support
  – CA Almond Board
  – Methionine project
Thank you!
Biosolarization - a method to recycle almond waste biomass and disinfest orchards during replant

Christopher Simmons
Department of Food Science and Technology, UC Davis
Christopher Simmons (PI)
Department of Food Science and Technology

Amanda Hodson (Co-PI)
Department of Entomology and Nematology

Jim Stapleton (Co-PI)
Division of Agricultural and Natural Resources

Jean VanderGheynst (Co-PI)
Department of Biological and Agricultural Engineering

In collaboration with
& with support from
Western Center for Agricultural Health & Safety
California Almonds
Almond Board of California
Biosolarization

Uses solar and microbial processes to control soil pests.

Replaces fumigants and herbicides.

Adds organic matter to soil.
Biosolarization uses soil amendments to induce microbial activity.

Field soil + Compost inoculum (optional) + Agricultural or food processing organic residues
APPLY CLEAR FILM AND IRRIGATE TO FIELD CAPACITY
BACTERIA PRODUCE BIOPESTICIDES VIA ANAEROBIC FERMENTATION

FOR EXAMPLE, ORGANIC ACIDS:

- ACETIC ACID
- PROPIONIC ACID
- BUTYRIC ACID
How can we maximize biosolarization performance when using almond processing residues?
### Initial screening of almond processing residues

<table>
<thead>
<tr>
<th>Material</th>
<th>N (% dw)</th>
<th>C (% dw)</th>
<th>C/N</th>
<th>Moisture content (g water/g fresh weight)</th>
<th>VS content (% dw)</th>
<th>Water holding capacity (g water/g dw soil)</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil</td>
<td>0.13</td>
<td>1.52</td>
<td>12.07</td>
<td>0.12</td>
<td>9.57</td>
<td>0.44</td>
<td>7.01</td>
</tr>
<tr>
<td>Pollinator shells</td>
<td>0.58</td>
<td>48.73</td>
<td>84.51</td>
<td>0.12</td>
<td>96.46</td>
<td>1.44</td>
<td>4.70</td>
</tr>
<tr>
<td>Pollinator shells and hulls</td>
<td>0.60</td>
<td>46.00</td>
<td>76.67</td>
<td>0.12</td>
<td>94.26</td>
<td>1.51</td>
<td>4.71</td>
</tr>
<tr>
<td>Nonpareil hulls</td>
<td>0.65</td>
<td>43.07</td>
<td>65.92</td>
<td>0.14</td>
<td>90.60</td>
<td>2.02</td>
<td>4.81</td>
</tr>
</tbody>
</table>
Initial screening of almond processing residues

- Anaerobic soil bioreactors simulate soil conditions during biosolarization.
- Examined soil amended with 5% hulls, shells, or hull/shell mix.
Hulls and hull/shell mix are sufficiently biodegradable to drive soil fermentation during biosolarization

Acidification after 8 days simulated biosolarization is a predictor of pest inactivation in the field.
Hull- and hull/shell mix-amendments lead to accumulation of organic acids in the soil

Endogenous organic acids on almond residues provide immediate acidification of the soil, which may improve pest inactivation kinetics.
Root lesion nematode (Pratylenchus spp.) inactivation
Extracts from amended soils exhibit robust nematocidal activity

- Soil amended with nonpareil hulls (5% dw).
- Aqueous extracts taken immediately after amendment and after 8 days of anaerobic incubation.
Biosolarization field work

Current field work in collaboration with Nicolaus Nut Co.
Biosolarization field work

- Kittyhawk Ranch
- 50 acre orchard
- Recently removed walnut orchard
- Slated for replanting with Nonpareil, Bennett-Hickman, and Monterey varieties
- Grower offered 8.9 acres for biosolarization trial
Biosolarization field work – soil responses

Pest levels:
- Total and phytoparasitic nematodes
- Pathogenic microbes
- Weed coverage

Pest stresses:
- Soil heating
- Soil acidification

Pending
Microbiome:
- Diversity
- Pathogenic taxa
- Enrichment of microbes involved in mineralization

Phytonutrients:
- Total and mineral N
- Extractable P and K
Weed inactivation
Field plots were initially infested with plant parasitic nematodes.
Significant nematode reduction in treated plots by 10 days of treatment
Solar heating elevated peak and average soil temperatures

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biosolarized with hull (1 inch)</td>
<td>63°C 51°C</td>
</tr>
<tr>
<td>Biosolarized with hull+shell (1 inch)</td>
<td>64°C 51°C</td>
</tr>
<tr>
<td>Untreated control (8 inch)</td>
<td>56°C 38°C</td>
</tr>
<tr>
<td>Solarized without amendment (8 inch)</td>
<td>68°C 51°C</td>
</tr>
</tbody>
</table>

Temperature (°C) vs. Time (days)
Organic acids accumulated in biosolarized soils

Biosolarized with amendment down to 7 inches (1.25% by dry mass)

- Hull amendment, 0-6 inches
- Hull amendment, 6-12 inches
- Hull/shell amendment, 0-6 inches
- Hull/shell amendment, 6-12 inches

*No acids were detected in non-amended soils
Soil column bioreactors are used to study biosolarization effects as a function of soil depth.

- Columns allow aqueous sampling every 6 inches down to 5 ft depth.
- Irrigation can be controlled and tracked throughout the column.
Irrigation during biosolarization can leach biopesticidal organic acids deeper into the soil.
Biosolarization field work - responses

Direct and drone-based measures of tree vigor:
- Trunk diameter
- Canopy area
- Chlorophyll index
- Indicators of disease
  - Stunting
  - Thinning
  - Yellowing/dieback
- Yield (eventually)
• **Benefits**
  - True translational study with all farm operations and materials that would be used at commercial scale.
  - Measure interactions between biosolarization treatments and almond varieties.
Acknowledgements

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Ygal Achmon
Jesus Fernandez Bayo
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Amy Parr
Emily Shea
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Kelley Hestmark
Tara Randall
Jean VanderGheynst (Co-PI)

Jim Stapleton (Co-PI)
Deborah Bennett (Co-PI)
Amanda Hodson (Co-PI on Almond Board project)
Janina Milkereit

Nicolaus Nut Co.
Rory Crowley
George Nicolaus
Almond Board of California
Guangwei Huang
Karen Lapsley
Gabriele Ludwig

Western Center for Agricultural Health and Safety

National Institute for Occupational Safety and Health
Thank you
Contact: cwsimmons@ucdavis.edu
Torrefaction of Almond Shells: Properties and Applications

Adding Value to Almond Co-Products

Bor-Sen Chiou¹, Zach McCaffrey¹, Trung Cao¹, Diana Valenzuela-Medina¹, Mark Wechsler², Cristina Bilbao-Sainz¹, Tina Williams¹, Delilah Wood¹, Greg Glenn¹, William Orts¹

¹Bioproducts Research, USDA, Albany, CA
²Renewable Fuel Technologies, San Mateo, CA
Acknowledgements

- Almond Board of California
- California Walnuts
- California Department of Food and Agriculture
- CRADA with Renewable Fuel Technologies
Outline

– The Issue

– Torrefied biomass-polymer composites
  • Improving heat stability of plastics using shells
  • Improving their mechanical properties too

– Scale up to Pilot-scale

– Potential commercial production
  • Current and future work

– Conclusions
The Issue: Almond Biomass is Increasing ⇔ Good News!

Almond Biomass Projection (MT, DM)

G. Huang, Associate Director, Food Research and Technology

August, 2017
The Relative Value of Co-Products is Decreasing

2017 Almond Biomass (2.5 mil. MT DM)
- Hulls 59%
- Shells 25%
- Pruning (30%) 9%
- Skins 0%
- Inedible 0%
- Tree Removals 5%
- Twigs 2%

Hulls once fetched ~$125/ton

Our Goal: Add value to shells >$25/ton

The industry is losing millions in potential revenue……
Torrefaction:

- Torrefaction: 200°C to 300°C under inert atmosphere
- Removes moisture and volatiles → stable to microbial attack
- Densify torrefied biomass → cheaper to transport
- Energy value ~ low rank coal
Torrefied Almond Shells

230°C

260°C

290°C

60 min  80 min  100 min
Torrefied Biomass-Polymer Composites

- Alternative to wood-polymer composites
- Wood-polymer composites: > 1 million tons annually for non-structural applications
- Torrefied biomass: process composites over 200°C, more hydrophobic, lower moisture
Making plastic parts with almond shell additives

Torrefied biomass:  
Almond shells at 280°C  
Walnut shells 260-280°C

Polymer:  
Polypropylene

Bor-Sen Chiou
The Softening Point of Recycled Plastic

a.k.a. \( \Leftrightarrow \) the heat distortion temperature

Temperature at which material deforms under specific load

![Heat Distortion Temperature Graph]

- **Polypropylene**
- **15% Torrefied almond shells**
- **15% Torrefied pine**

---

Filler size 700-1000 microns
The Softening Point of Recycled Plastic

a.k.a. ⇔ the heat distortion temperature

Temperature at which material deforms under specific load

![Bar graph showing the effect of fillers on HDT of polypropylene](image)

<table>
<thead>
<tr>
<th>Material</th>
<th>HDT (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PP</td>
<td>140</td>
</tr>
<tr>
<td>Talc</td>
<td>145</td>
</tr>
<tr>
<td>CaCO3</td>
<td>145</td>
</tr>
<tr>
<td>Fiber</td>
<td>145</td>
</tr>
<tr>
<td>Torrefied almond shells</td>
<td>160</td>
</tr>
<tr>
<td>Torrefied pine</td>
<td>165</td>
</tr>
</tbody>
</table>
Early Research – Lab Scale

• Different torrefied biomass sources improved the properties of plastics at lab scale

• Problems with brittleness were identified
Tensile Properties

12.5% (w/w) torrefied almond shells

Polypropylene:
Modulus: 909 MPa
Strength: 36 MPa
Elongation: 715%
Scanning Electron Micrographs of Composites

- Space between filler + polymer → weak interfacial adhesion
- Consistent with tensile properties

- Polymer strands in filler space → some adhesion between filler + polymer
Pilot-scale Torrefaction Reactor

- Three heating zones to control temperature
- Produce 10-20 lbs of torrefied shells/hour
- Provide consistent samples for optimization studies
How? Next Step – Scaled R&D

- Produce tons of Material
  - Torrefied material was provided under contract from Earth Care Products using a DOE-funded torrefaction ‘truck
  - The USDA has been offered a “Free” lease on this
Recent Research – Pilot Scale

• We challenged the industry to create “buckets” of material, which have been processed

• We produced sheet capable of making high quality parts at pilot scale.
Converting plastic sheets into products
Commercial Application

- Grow Plastics and FDS Manufacturing are purchasing a compounding extrusion sheet line capable of 1,000 lbs/hour.
- This will likely justify a sheet production facility in Northern California that adds torrefied almond shells into plastic sheets.
Current and Future Work

– Optimize properties of torrefied shell-polymer composites
  • Polyethylene terephthalate (PET)

– Optimize scale-up in the pilot plant
  • Test pilot-scale prototype materials from varied biomass sources

– Create commercial prototypes and work with companies toward commercialization scale
Conclusions

– Produced composites with high levels of torrefied shells
  • Composites had higher modulus and $T_d$, but lower strength and elongation
  • Some interactions between filler + polymer matrix

– Pilot-scale torrefaction reactor is to be used to provide consistent samples
Thank you!
What’s Next

Tuesday, December 5 at 1:45 p.m.

• Common Errors in Orchard Set Up– Room 308-309
• Repositioning Plant-Based Protein – Room 306-307
• The Science and Practice of Intentional Recharge in Almond Orchards – Room 312-313
• Produce Safety Rule for Farms: How to Comply and What About the Grower Exemption? – Room 314
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