RESEARCH UPDATE

2022

california almonds®

Almond Board of California

ALMOND BOARD OF CALIFORNIA

RESEARCH UPDATE 2022

Advancing California Almonds Through Innovation

Funded by grower assessments, Almond Board supported research adds value to the industry by:

- Improving grower profitability and tools to meet increasingly complex farming regulatory requirements
- Supporting almond market development through:
    - Expanding the global health halo for almonds
    - Demonstrating grower stewardship in how we grow
    - Increasing the value derived from almond co-products

This report summarizes current research on almond production, environmental aspects of production, human nutrition, co-product biomass, almond quality, and food safety.

- ABC research is directed by over 60 industry stakeholders who share their expertise through service on:
    - Strategic Agricultural Innovation Committee
        - Biomass Work Group
        - Pollination Work Group
        - Production Stewardship Work Group
    - Nutrition Research Committee
    - Almond Quality and Food Safety Committee

These volunteers ensure research targets industry priorities and deliver practical and relevant information. We are grateful for committee members sharing their time and experience and invite others in the industry to consider service on Almond Board committees.

Almond Board of California Research Staff

Josette Lewis
Chief Scientific Officer,
Research and Innovation
jlewis@almondboard.com

Sebastian Saa
Associate Director, Agriculture
Research and Innovation
ssaa@almondboard.com

Guangwei Huang
Associate Director, Food Science
Research and Innovation
ghuang@almondboard.com

Lauren Fann
Senior Specialist, Pest Management
Research and Innovation
lfann@almondboard.com

Tim Birmingham
Director, Quality Assurance and
Industry Services
tbirmingham@almondboard.com

Elena Hemler
Associate Director, Nutrition
Research and Innovation
ehemler@almondboard.com

Gabriele Ludwig
Director, Environment & Sustainability
Government, Technical & Regulatory Affairs
gludwig@almondboard.com

Jesse Roseman
Principal Analyst
Government, Technical & Regulatory Affairs
jroseman@almondboard.com

Research Projects

Strategic Agriculture and Innovation Committee

Biomass

Harvest

Irrigation, Nutrient, & Soil Health

Pollination

Orchard, Tree, Rootstock

Almond Quality Food Safety Committee

Nutrition Research Committee

Cognitive/Mental Health

Diabetes & Metabolic Syndrome

Heart Health

Immune Health

Carbon Sequestration and Soil Health Improvement in Almond Orchards Using Dairy Manure and Woody Biomass Compost

PROJECT NO: 19-ZhangR-BIO-01

Principal Investigator:
Name: Ruihong Zhang
Institution: UC Davis
Email Address: rhzhang@ucdavis.edu

Summary
The application of organic amendments (i.e., manure and almond woody biomass) in almond orchards could improve soil properties such as water holding capacity. It can also reduce greenhouse gas (GHG) emissions, resulted from the uncontrolled degradation of the woody biomass. Reducing the GHG emissions could increase the sustainability of almond production. The objectives of this research were to (1) produce compost from dairy manure solids and almond woody biomass and apply the the compost to an almond orchard in Hilmar, California; (2) study the effect of loose and pelletized compost products on almond yield, soil properties and health, greenhouse gas emissions, and almond safety; and (3) disseminate project findings to almond growers and other stakeholders. Dairy manure solids has high moisture content and low carbon to nitrogen ratio (C/N) while almond woody biomass has low moisture content and high C/N. Mixing the two materials in appropriate portions will create a mixture with desirable moisture, C/N, and material properties required for effective composting and producing high quality compost. Pelletized compost product would allow slow release of nutrients and could reduce air and water pollution after compost application. Pelletizing the compost could also reduce rates of physical or biological degradation of the products. Applying the compost products to sandy soils orchards reduces the reliance on synthetic fertilizer that could deteriorate groundwater quality due to nitrate leaching even under best management practices employed by our grower collaborator.

Compost was produced, for the second year, from manure solids and their mixture with almond biomass sticks. Two piles of each material were studied. The bulk density and temperature of the compost at different locations were measured. The temperature increased gradually after turning the piles. During the first four week of composting, a maximum temperature of about 78C could be measured directly before turning the windrows. The average losses of dry matter during the composting was 29.9% and 33.4% for manure alone, manure and almond biomass, respectively. The losses of volatile solids were 34.5% and 51.3%, respectively. Compost samples were collected for pathogen analysis. The compost was pelletized using a pilot scale system. The produced pellets had a moisture content ranging from 20.2% to 28.1%. The bulk density of the pellets produced from manure alone , manure and stick was 53.5 and 47.7 lb/cubic feet, which were higher than the bulk density of the loose manure compost and loose manure and stick compost, 27.3 and 28.6 lb/cubic feet , respectively. The produced products were applied to the almond orchard for the second year. The yield of almond kernels in the second year was determined to be 3,188; 3,435; 3,282; 3,071; and 3,492 dry lb/ Acre, respectively for the control, manure compost, manure-stick compost, pelletized manure compost, and pelletized manure stick compost. The emissions of GHG were measured in May and October. Soils were collected for the analysis of elements. Two virtual filed days were successfully conducted. Project results were presented during the field days, at ASABE meeting, and at the 2021 California Bioresources Alliance Symposium.

Long-term effects of almond hulls on meat production and quality in broilers and egg production and quality in laying hens

PROJECT NO: BIO-21-02

Principal Investigator:
Name: Woo Kyun Kim
Institution: University of Georgia
Email Address: wkkim@uga.edu

Summary

Background & Objectives

Our previous battery cage broiler studies suggested that almond hulls as a feed ingredient can be used up to 7.5% on top of normal corn-soybean meal broiler diets maintained efficient growth performance compared to the control group and enhanced antioxidant capacity for broilers. Furthermore, almond hulls supplementation on top of the corn-soybean meal diets reduced feed cost while maintaining the same performance level. However, effect of almond hulls on broilers during the whole grow out period yet remained unknown. Additionally, another major issue in the poultry industry currently facing is breast muscle abnormality (woody breast and white striping), negatively influencing consumer preference and profits for the industry. Thus, identifying strategies to reduce woody breast incidence. One of the main causes for woody breast is limited blood supplies to the muscles creates oxidative stress in the breast muscle, causing muscle abnormality. Because almond hulls contain high levels of antioxidants, supplementing almond hulls into broiler diets is a potential strategy to enrich antioxidants in the muscle to reduce the incidence of woody breast in broilers during a full grow out period (42days).

The objective of the present project is to evaluate the effects of almond hulls on growth performance, meat production and meat quality in broilers during a whole grow out period (42days). It is hypothesized that almond hulls containing high antioxidants and dietary fiber will promote growth performance, feed efficiency, meat production and meat quality in broilers raised in floor pens.

Results & Discussion

During d 0-14 period, broilers fed a diet contained almond hulls at 2.5% showed a higher (P=0.025) body weight gain compared to the control group. Broilers fed diets containing almond hull from 2.5 to 7.5% had a higher (P=0.020) feed intake compared to the control group. Supplementation of almond hulls quadratically increased ($P \leq 0.01$) broiler body weight gain and feed intake during d0-14 period with the peak dosage at 2.5%. Similarly, during the whole 42 d grow out period, supplementation of almond hulls quadratically (P=0.013) increased broiler body weight gain. Broilers fed the diet contained 2.5% of almond hull had a higher body weight gain compared to those fed the diet contained 7.5% of almond hull. Supplementation of almond hulls linearly (P<0.01) increased the FCR during d 0-14, d 0-28 and d 0-42 period. Broilers fed diet with 7.5% of almond hull had the highest (P<0.05) FCR compared to other treatments.Likewise, broilers fed 2.5% of almond hull had the highest hot carcass, chilled carcass, wings and whole legs weight among all the treatments. All the treatments showed a similar white striping and woody breast scores. Supplementation of almond hulls at 5 and 7.5% showed a higher (P<0.01) lightness value on breast fillet compared to control group. Meanwhile, increasing the almond hull level in the diet linearly decreased (P<0.01) pH values of breast fillet. However, the effect of pH and color lightness change on cooked fillet texture is limited. Zhuang and Savage (2010) reported that dark (L: 52.6, pH: 5.8) and medium (L: 57.2, pH: 5.8) breast fillet showed a similar texture and the sensory descriptive flavor profiles. There is no difference in the drip loss between treatments suggested all the breast fillet has the similar water holding capacity. In conclusion, including almond hull at 2.5% and 5% showed a positive effect on growth performance. The carcass yield and breast fillet meat quality was not affected by almond hull inclusion.

Effect of Almond Hulls on Reduction of Enteric Methane Emissions from Cattle

PROJECT NO: BIO-21-04

Principal Investigator:
Name: Ruihong Zhang
Institution: UC Davis
Email Address: rhzhang@ucdavis.edu

Summary
At present, the hulls are used as a feed supplement for dairy cattle. Significant opportunity exists to increase the feeding ration of almond hulls to livestock in California. With over 600,000 beef cattle in California, the Almond Board has identified the incorporation of almond hulls into their diets as an important strategy to make use of the hulls. However, additional measures must be taken to realize the hull's full potential and provide additional benefits. This project increases the attractiveness of almond hulls to beef cattle farmers by coupling the proven benefits of almond hulls as feed with an additional function of reducing enteric methane emissions from cattle. The main goal of this project is to increase the market share of hulls as cattle feed by creating stable, high quality and nutritious feed from almond hulls that can potentially reduce enteric methane emissions. The fermented feeds center on the mutual benefit of the almond and beef cattle industries.

We have collected and characterized three varieties of almond hulls: Monterey, Independence, and Nonpareil. We also conducted experiments to produce a fermented feed from the hulls. The fermented animal feed was created using anaerobic conditions. Yeast, bacteria, and a mixture of yeast and bacteria were used as inoculums for the fermentation. Volatile fatty acids and ethanol composition was analyzed pre- and post-fermentation to determine the optimal fermentation conditions to reduce rumen methane production. The gas produced during fermentation was analyzed for composition. The fermented hulls were tested using in-vitro digestion experiment to simulate their digestion by cattle, and the gas produced was analyzed to see if methane reduction was achieved. The fermented hulls were found to have a very good potential for reducing methane emission from enteric fermentation as compared with the un-fermented hulls. More research is underway with the results to help us determine the optimal conditions for fermentation of almond hulls to create a feed that is nutritious for the cattle and cows while reducing ruminant methane generation.

Production Analysis for Automotive Headliner Made from Almond Shells and Recycled PP Plastics

PROJECT NO: BIO-21-07

Principal Investigator:
Name: Joseph Greene
Institution: CSU Chico
Email Address: jpgreene@csuchico.edu

Summary
The objective of this project was to measure the mechanical properties of automotive plastics made with recycled polypropylene and almond shells. The project attempted to make an automotive prototype part from recycled polypropylene (PP) twine, rice straw, and almond shells. Almond shells were obtained from Northern State Hulling Company while the polypropylene twine and recycled rice straw powder were obtained from the CALPLANT 1 in Willows . The prototype part was designed for a 2020 Ford Escape center console mat. An aluminum mold was designed and built and the recycled PP were compounded with almond shells and rice straw. Then injection mold parts were made with the new mold. The almond shell fiber material was ground down to a powder ranging from 60 - 100 mesh, approximately: 149 - 250 microns. The ideal powder needs to be at 150 microns before it can be used in the extruder and injection molding machines. The PP twine strand was cut with a chopper shown to approximately ½ inch or 15mm in length. The fibers and almond shells were fed into the twin screw extruder and blended with almond shells and rice straws to make a plastic pellet. Tensile and impact bars were produced with injection molding process, then tested for mechanical properties.

The tested samples had between 15 and 40% almond shells, the rest was polypropylene plastic. The tensile strength increased slightly with the increase in almond shells from 700 MPa to 850 MPa. The tensile modulus decreased slightly from 32 MPa to 26 MPa. The impact strength decreased from 1.82 kJ/m2 to 1.4 kJ/m2. Scan Electron Microscopic images showed that there are some notable differences between the almond shell and polypropylene material particles. The almond shells have a visibly more circular shape whereas the rice straw dust is characterized by longer strands. One of the biggest findings from the breakage points of the test subjects was the presence of voids in the center of the pieces. These voids could characterize how the plastic and natural fibers were ripped apart when they reached their yield points for both tests as the materials might not have mixed well together. Fourier Transform Infrared Spectroscopy was a measurement tool used to determine changes in chemical composition and bond strength as the different types of natural filler were added to polypropylene. It is not certain whether the source of polymer being virgin or recycled has an effect on the properties of natural fiber composites.

When looking at the almond shell spectra the changes in the prominent peaks may be observed visually. As expected, when the amount of filler content increases, the intensity of the peaks decrease. This is especially true for the fingerprint region from 500 to 1400 wave numbers. Future work can improve the properties of polypropylene and almond shells with the use of adhesion prompters.

An evaluation of the dietary functionality of almond hull inclusion in growing beef cattle diets

PROJECT NO: BIO-21-01

Principal Investigator:
Name: Dale Blasi
Institution: Kansas State University
Email Address: dblasi@k-state.edu

Co-PIs: Zachary Duncan, Z.L. DeBord, M.G. Pflughoeft, K.J. Suhr, W.R. Hollenbeck, F.K. Brazle, H.K. Wecker, C.B. Paulk, E.C. Titgemeyer, K.C. Olson

Summary

Almond hulls could potentially be incorporated as a feed ingredient in beef cattle diets; however, limited research evaluating the effects of almond hull inclusion in beef cattle diets is available. In addition, the current bulk density of almond hulls makes transporting them long distances to cattle feeding-areas difficult. The objective of this experiment was to evaluate the effects of almond hull inclusion in limit-fed growing beef cattle diets. An additional objective was to determine the effects of grinding almond hulls with a hammermill on almond hull particle size and bulk density. Almond hulls were obtained from the California Central Valley and contained 18.6 % crude fiber (as fed basis). In experiment 1, twenty pounds of almond hulls were ground with a laboratory-scale 1.5 HP Bliss Hammermill (Model 6K630B) using a 7/16-inch screen, a 3/4-inch screen, a 1-inch screen or no screen. Geometric mean particle size was greatest ($P < 0.01$) when no screen was used, intermediate ($P < 0.01$) when a 3/4-inch and 1-inch screen was used, and least ($P < 0.01$) when a 7/16-inch screen was used to grind almond hulls. Bulk density of non-processed hulls was 14.1 lbs/ft3. Grinding almond hulls with no screen, a 1-inch screen, a 3/4-inch screen, and a 7/16-inch screen increased bulk density by 111, 114, 115, and 140%, respectively. In experiment two, 364 crossbreed steers (initial body weight 567 ±45.7 lb) were assigned to one of four diets to evaluate the effects of almond hull inclusion on growth performance of growing beef cattle. The control diet (CON) contained (dry matter basis) 39.5% dry-rolled corn, 7.5% supplement, 40% wet-corn gluten feed, and 13% prairie hay. Non-processed almond hulls replaced prairie hay and were fed at 13%of dietary dry matter (13AH) or replaced prairie hay and a proportion of dry-rolled corn and were fed at 26% of dietary dry matter (26AH). In addition, a subset of almond hulls was processed using a grinder mixer with no screen. Processed almond hulls replaced prairie hay and were fed at 13% of dietary dry matter (13PAH). Steers were limit-fed experimental diets at 2.2% body weight (dry matter basis) for a 56-d period. Final body weights were greater ($P < 0.01$) for 13AH and 13PAH compared with 26AH and tended to be greater ($P = 0.09$) for CON compared with 26AH. In addition, overall average daily gains were greater (P 0.05) for 13AH, 13PAH, and CON compared with 26AH. In experiment three, eight ruminally cannulated heifers were arranged in a 4×4 Latin rectangle to evaluate the effects of almond hull inclusion on ruminal fermentation and diet digestibility. Diets were identical to those used in experiment 2. Apparent total tract dry matter digestibility did not differ ($P = 0.21$) among treatments. Total VFA concentrations were greater ($P < 0.01$) in 13PAH and 13AH compared with 26AH and tended to be greater ($P = 0.06$) in 13PAH compared with CON. In addition, propionate concentrations were greater ($P < 0.01$) in 13PAH, intermediate (P 0.01) in 13AH, and least (P 0.05) in 26AH and CON. Ruminal pH was greater (P 0.05) in 26AH and CON compared with 13PAH. Replacing proportions of dry-rolled corn with almond hulls reduced growth performance; however, growth performance was similar between steers fed prairie hay or processed and non-processed almond hulls at 13% of dietary dry matter. Processing almond hulls increased their bulk density and increased proportions of propionate compared with prairie hay. We interpreted these data to suggest almonds can be considered as an alternative to prairie hay in limit-fed growing diets without reducing growth performance or feed efficiency.

Almond Hull Composition: Search for the Missing 20%

PROJECT NO: BIO-21-05

Principal Investigator:
Name: Edward DePeters
Institution: UC Davis
Email Address: ejdepeters@ucdavis.edu

Co-PIs: Katherine Swanson, Hernan Rodriguez, Maia Zack

Summary
Background: Almond hulls (AH) are a common feedstuff in the diet of lactating dairy cows. Almond hulls can be used as a concentrate ingredient to replace flaked corn and as a forage to replace silage. In the past decade feeding amounts have increased from 3.5 to over 5.0 pounds AH daily. Research supported by the ABC, Biomass Workgroup, found that AH could be fed up to 12 pounds per cow daily.

Rations fed to dairy cows are formulated with computer software that is based on the chemical composition of each feed ingredient to predict the nutrients and energy available to support milk yield – often called Precision Feeding. The amount of a feedstuff used in a ration is restricted when there is a "missing" information on chemical composition. All feeds have "missing" information on chemical composition. However, the "missing" information for AH is large. The nonfiber carbohydrate composition of AH is 65% while the nonstructural carbohydrate composition is 35%. These two estimates will not be identical, but they should be similar and they are not. That large amount of "missing" chemical composition for AH restricts their use in the diet of lactating dairy cows.

Approach: Twenty-one samples of AH were analyzed. Varieties included Nonpareil (6), Independence (2), and 13 categorized as Other. Samples were hand-sorted to remove debris creating two samples. Whole contained AH + debris. Pure contained only AH.

Lignin: Lignin is a polyphenolic compound. Lignin is indigestible and provides no energy to the animal. Lignin interacts with fiber (cellulose and hemicellulose) to reduce digestibility. As the lignin content of AH increases, fiber digestibility decreases. Nutritionists measure lignin as acid-detergent lignin (ADL). However, biofuels scientists measure lignin as Klason lignin (KL) because ADL does not measure all of the lignin in plant material. Difference between KL and ADL is referred to as soluble lignin. Question: does soluble lignin account for a portion of the "missing" 20%?

Development of New Almond Hull Products in Combination with Alfalfa for emerging Domestic and International Markets

PROJECT NO: BIO-21-06

Principal Investigator:
Name: Daniel Putnam
Institution: UC Davis
Email Address: dhputnam@ucdavis.edu

Co-PIs: Katherine Swanson, Ed DePeters, Hernan Rodriguez

Summary
Almond hulls (AH) are a byproduct of almond production and are in excess in California. These AH can be fed to cattle as an economical feedstuff, rich in highly fermentable carbohydrates. Unlike alfalfa, AH are low in protein and digestible fiber. It could be possible that by combining alfalfa hay with AH that we could utilize the strengths of each of these feeds. This combination could potentially produce a 'synergy', which could lead to the development of new products that open new markets for alfalfa and AH. The aim of this project was to evaluate the apparent digestibility, palatability, and effect on production in dairy cattle of alfalfa- almond hull cubed mixes compared with pure alfalfa cubes. This project built on previous research conducted using in vitro fermentation and a sheep digestibility study.

The previous in vitro work aimed to determine dry matter (DM) and neutral detergent fiber (NDF) digestibility of four different qualities of alfalfa hays mixed with 0, 25, 50, or 75% AH. In vitro results showed that the Low/Medium quality alfalfa mixed with 25 or 75% AH had improved dry matter and NDF digestibility and had calculated metabolizable energy similar to that of High-quality alfalfa hay. In sheep, a diet consisting of Low/Medium quality alfalfa cubed with 10% AH was found to have the highest DM, organic matter, and crude protein (CP) digestibilities (62.9, 64.1, and 72.1% respectively) with only small decreases in acid detergent fiber (ADF) and NDF digestibilities compared with the 0% AH diet. Overall, we found that mixing low amounts of AH with Low to Medium (e.g. 38-48% NDF) quality alfalfa hay could be beneficial by increasing the overall DM and CP digestibility with only slight decreases in fiber digestibility.

From this work it was determined that we would use medium quality alfalfa cubed with 0, 20, or 30% AH in the dairy cattle feeding study. In this study, six lactating multiparous and three lactating primiparous Holstein cows were fed three diets in a replicated 3x3 Latin square design study. There were three 21-day periods. In a Latin square design, each cow received each diet. The diets were a total-mixed ration (TMR) with added cubed feed. The treatment effect was the feeding of 0, 20, or 30% AH mixed with medium quality alfalfa in cube form per cow daily. Cows were milked and fed twice daily with milk yield and feed intake recorded daily for each cow. During the sampling period (the last seven days of each 21-day period), refusals from each cow were sampled daily. Fecal, blood, milk, and rumen fluid samples were also collected along with weekly body weights. Feed and refusal samples were sent to a commercial laboratory for analysis to determine intake for DM, CP, ADF, NDF, calcium, and phosphorus. Fecal samples were analyzed for DM, ADF, NDF, and CP to determine apparent digestibility. Milk samples were analyzed for fat, protein, lactose, total solids, somatic cell count, and milk urea nitrogen. Blood samples will be analyzed for two metabolic parameters: free fatty acids and beta-hydroxy-butyrate. Rumen fluid will be analyzed for changes in volatile fatty acids. Rumination data were also collected using rumination collars to determine the average minutes each cow spent ruminating daily. Overall, production measurements included DM intake, milk yield, milk composition, body weight change, time spent ruminating, and two metabolic parameters. We have completed the dairy cattle feeding study but are still in the process analyzing samples in preparation for statistically analyzing the data.

Drying Fresh Harvest Almonds

PROJECT NO: HARV01

Principal Investigator:
Name: Michael Coates
Institution: Plant and Food Research Australia
Email Address: Michael.Coates@plantandfood.com.au

Co-PIs: Dr. Irwin R. Donis-Gonzalez, Ismael Mayanja, Carlos Orozco, Lucia Felix, Mark Montgomery, Franz Niederholzer, Brendan Sidhu, Scott McKenzie, Peter Cavalaro, Mark and Luke Stoeckel

Summary

Drying fresh harvest almonds was a two and a half year project that ran both in Australia and California. This made use of the offset seasons to gather drying data on five harvests. The purpose of the project was to determine if it is possible to mechanically dry the fruit outside of the orchard, if the industry moved to a catch frame style harvest, where the fruit is immediately removed from the trees. This would involve either a batch dryer or a modified version of the traditional stockpile with added aeration, which would need to dry almond fruit that ranged from 10%-35% moisture content dry basis (Md) kernel, down to ~5.5% equilibrium moisture content (EMC) (kernel).

It has been shown in commercial applications that a stockpile with a large aeration duct running down its center can adjust the fruit's Md a couple of percentage points up or down to EMC in approximately 24 h (conditioning) or in the case of batch dryers, dry fruit down from 10% Md (kernel) to EMC in approximately 24 h. It was unknown how these systems would respond to almonds at a higher Md. Initially, it was expected that the heat of the ambient air alone would be enough to encourage dehydration. It was also expected that the mechanical airflow would combine with the natural wind to accelerate the drying process, but as the project progressed, most of these assumptions were proved false, specifically under commercial-scale applications. This changed the focus of the project from 'how' stockpiles could be used to dry fruit to 'if' stockpiles could be used to dry fruit. It was expected that the almonds in bulk would provide enough density to evenly distribute the air that passes through them.

In the first experiment, it was apparent that evaporative cooling was going to play a greater role than anticipated, with low velocity ambient airflow reducing the core temperature within the fruit from 104°F (40°C) to 68°F (20°C) as the saturated air (100% relative humidity (RH)) was forced through the bulk fruit. The second trial used a 2 hp (1.5 kW) fan heated to 122°F (50°C) to dry three tonne of 'Monterey' down from 12.6 Md. This took 11 days and showed pockets of mold from inconsistent airflow. The third trial was focused on ambient heat and airflow and used three 20 tonne stockpiles of 'Nonpareil', one with a 3 hp (2.2 kW) centrifugal fan, one with an electric fan at the center of the stockpile and one open to the natural air flow on a windy plain. After 8 days the stockpiles were torn down as mold was present throughout the bases of each pile. The fourth trial used an air distributor connected to the 2 hp (1.5 kW) fan heated to 122°F (50°C) to direct the air out along the base of the stockpile. Three stockpiles of 'Nonpareil', 'Winters' and 'Monterey' were evaluated. The stockpiles of 4.7 tonne @ 12% Md, 2.5 tonne @ 12% Md and 6.8 tonne @ 21% Md, respectively, resulted in successful drying after 6-7 days. The stockpiles in this fourth trial were covered with a tarpaulin and held down by tied around its parameter, which allowed much better control and distribution of the air. Using an 15 hp (11 kW) fan heated to 104°F (40°C), 200 tonne stockpiles of 'Nonpareil' and 'Carmel' at 16% and 10% Md (kernel) were dried to EMC within three and one day respectively. While ultimately successful, there was still some non-uniform drying observed furthest from the fan, which would need further modification to address.

Handling Fresh Harvest Almonds

PROJECT NO: HARV03

Principal Investigator:
Name: Michael Coates
Institution: Plant and Food Research Australia
Email Address: Michael.Coates@plantandfood.com.au

Co-PIs: Reza Ehsani, Reza Serajian, Arash Toudeshki, David Pohl, Brendan Sidhu, Scott Mckenzie, Michael Ward, Peter Cavallaro, Anthony Wachtel

Summary

Harvesting fresh harvest almonds was a 2.5 year project that ran both in Australia and California. This made use of the offset seasons to gather data on five harvests. The purpose of the project was to look at alternative methods of harvesting and collecting the fruit off the ground. The aim was to reduce the dust that is produced by the current harvesting combination of blowing and sweeping to produce a narrow windrow (3 ft, 0.8 m) that is then collected by a 'pick-up' machine. The research looked to see if the addition of a deflection shield placed above the shaker arm might deflect more fruit away from the tree line and out into the row, followed by a 'finger wheel' pick-up system (used by the macadamia industry) that collects a wide windrow of fruit ~8 ft (~2.4 m). The finger wheel pick-up system is supported by an offset, slow sweeping arm that sweeps fruit close to the tree line out into the path of the finger wheels. This essentially combines the sweeping and pick-up in one dustless harvesting process.

The addition of the deflectors provided some benefit to reducing the fruit falling on the tree line. Trees shaken without the deflector accumulated ~17% of the fruit along the tree line, whereas this was reduced to 10% of the total fruit when the deflector was used. However, the architecture of the tree made it difficult to accurately position the deflector and the minimal crotch height and low branches were a continuous impediment for the driver of the shaker.

The harvester went through multiple iterations of development, starting with a number of finger wheel designs, then moving away from the finger wheel to a slow horizontal paddle and finally a horizontal brush, each with different variations of an offset sweeper arm. The finger wheel struggled to pick up more than a single layer of fruit and though the first pass accuracy of the finger wheel increased with each iteration (32% to 77%), each trial took at least three passes to collect all of the fruit. The horizontal paddle was 100% successful on flat surfaces, but only 80% where the contour of the ground changed from flat, while the sweeper is proving to be a potential alternative with a 100% collection rate and minimal dust creation.

Optimization of Drying Conditions for Off-ground Harvested Almonds Using Drying Trailers

PROJECT NO: HARV6

Principal Investigator:
Name: Zhongli Pan
Institution: UC Davis
Email Address: zlpan@ucdavis.edu

Summary
The main objective of this research was to optimize the drying conditions of trailer dryers for drying off-ground harvested almonds. This research was conducted using commercial trailer dryers at West Valley Hulling Company, Firebaugh, CA. The off-ground harvested almonds of three varieties of Nonpareil (NP), Wood colony (WC), and Monterey (MT) were used for conducting the drying tests. Nonpareil almonds were dried by using six trailers under three different drying conditions, including ambient air drying, hot air drying at 61°C and 72°C. Wood Colony almonds were dried by using four trailers with hot air drying at temperatures of 56°C and 65°C. Monterey almonds were dried by using four trailers with hot air drying at temperatures of 50°C and 59°C. The drying air velocity was 1.2 m/s. The initial almond characteristics, insect damage, drying performance, dried product qualities, and energy consumption for the off-ground harvested almonds were determined and compared with those of conventionally harvested almonds.

The key findings and recommendations from this research project are summarized as below: 1. Off-ground harvested almonds were much cleaner and had less insect damage (0 to 5.0%), compared to the conventional harvested almonds (2.0 to 6.0%); 2. Among the three fractions (in-hull almond, in-shell, and loose hull) of freshly harvested almonds, in-hull almonds were the largest proportion (88.1 to 98.2%) of the total mass; 3. Depending on the initial moisture content and almond varieties, the capacity of trailer dryers ranged from 16 to 23 tons per trailer of freshly harvested almonds; 4. The initial moisture had significant effect on drying time. The drying time to dry almonds from their initial whole almond moistures of 34.4 to 57.4% to kernel moistures of 5.2 to 2.9% took 6.8 and 40.9 hours, respectively; 5. The drying temperature had significant effect on the drying time and cost. For Nonpareil almonds, the drying at 72°C reduced the drying time by 28% and had higher energy cost by 57%, compared to the drying at 61°C; 6. All dried products had no cavity, concealed damage and significant change of kernel color and oil quality under all tested drying conditions; 7. The energy use and cost increased with the increase in drying air temperature. The specific energy consumption and cost ranged from 0.67 to 5.37 MJ/kg water removal and 0.31 to 3.2 ¢/lb of dried whole almonds, respectively; 8. Thetrailer dryers can be used for drying the off-ground harvested almonds under high temperature without quality concerns. This could be an effective method to achieve high drying throughput and also may simultaneously kill insects in almonds. Consequently, a further study needs to be conducted to demonstrate the high throughput and disinfestation effectiveness of high temperature drying with trailer dryers.

Demonstration of high temperature drying for off-ground harvested almonds to achieve high throughput and disinfestation

PROJECT NO: HARV7

Principal Investigator:
Name: Zhongli Pan
Institution: UC Davis
Email Address: zlpan@ucdavis.edu

Summary

The main goal of this research was to demonstrate high temperature drying for off-ground harvested almonds to achieve high throughput and effective disinfestation. This project was also to validate the significance in reduction of insect damage by adopting off-ground harvest and determine the critical/minimum drying temperature for achieving insect disinfestation.

Ten different orchards (5 from north region and 5 from south region) were selected for evaluating the initial insect damage and insect development rate of the conventional on-ground dried almonds. They were six different almond varieties (Nonpareil, Kochi, Fritz, Monterey, Aldrich, and Sonora) and came from 3 harvesting times throughout the harvest season of 2021. In addition, the insect damage data from past seasons of 2019 and 2020 are also included. The Monterey variety harvested from off-ground was used for conducting the column and commercial trailer drying tests. For column drying, the samples were dried with hot air under two different approaches, including constant temperature drying (50°C, 60°C, 70°C) and stepwise temperature drying (pre-drying with 90°C for 1 hours or 80°C for 2 hours, and then finishing drying at 60ºC) expressed as 90°C (1h)-60°C and 80°C (2h)-60°C, respectively. For commercial trailer drying, the samples were dried with hot air temperatures in a range of 59 to 67°C since the temperatures could not reach the planned stepwise temperatures. The drying air speeds were 1 m/s and 1.2 m/s for column drying and trailer drying, respectively. The drying time, drying rate, energy use and cost, dried product quality, insect disinfestation, and the critical temperature for achieving disinfestation were determined.

The key findings and recommendation from this research project are summarized as follow:

1)The orchards in north region had higher insect damage ratio (5.0±4.6%) than those (0.4±0.6%) in south region in 2021.

2)Based on the data from three almond harvesting seasons of 2019, 2020, and 2021, the off-ground harvesting had significantly lower average insect damage ratio (2.0±1.7%) than the conventional harvesting (4.2±3.7%). Some damage occurred during on-ground drying.

3)The stepwise temperature drying with the 90°C (1h)-60°C reduced the drying time by 42% and specific energy consumption by 9% compared to the constant temperature drying at 50ºC based on the results from the column drying.

4)The capacity of trailer dryers ranged from 17 to 20 metric tons per trailer of freshly harvested almonds, depending on the initial moisture content.

5)The initial moisture content of almonds had significant effect on drying time. It took 5.4 to 14.1 h to dry almonds from their initial moisture contents of 15.8 - 26% to the final moisture contents of 8.8% -- 12% of whole fruit for trailer drying.

6)The trailer dryers had specific energy consumption and cost ranging from 2.37 to 3.74 MJ/kg water removal and 0.22 to 0.65 cent/lb of dried whole almonds depending on hot air temperatures (59ºC to 67ºC).

7)The 35% relative humidity (RH) at the top layer of the trailer dryer can generally be used as an indicator for finishing drying to achieve the average final moisture content of almonds being less than 12%.

8)There were no significant differences in insect damage ratios between before/after drying and after incubation for both column and trailer drying. The drying with temperature of 59ºC or above achieved complete disinfestation of almonds and did not affect product quality.

9)The recommended drying condition is to use stepwise drying with minimum temperature of 60ºC to simultaneously achieve high drying throughput and disinfestation with reduced energy cost.

Demonstration of wireless technology for monitoring insect activity and moisture of almonds

PROJECT NO: HORT65

Principal Investigator:
Name: Zhongli Pan
Institution: UC Davis
Email Address: zlpan@ucdavis.edu

Summary

The objective of this project was to demonstrate a wireless technology for detecting and controlling insects in almonds when they emerge during processing, handling, and stockpile storage with the ultimate goal of avoiding insect damage to the product and reducing fumigation chemical use. The wireless system has two major components: smart catching device/trap and software for cloud computing and data storage along with user interface and alerting function. The new detection technology remotely monitors the activities of insects trapped in the smart catching devices and alerts the managers of storage and processing facilities to take proper steps to control the insects.

The systems were installed at two processing facilities in Firebaugh CA. The tests were conducted as (1) Four traps were installed in four wood bins of rejected almond kernels at West Valley Hulling Co.(WVHC);(2) Six traps were installed in two wood bins of rejected almond kernels, two fiber bins, and two carton boxes (one with and one without plastic liner) of finished products (kernels) at Silver Creek Almond Co.(SCAC); and (3) Twenty-eight traps were installed in four different stockpiles of in-hull almonds at (WVHC). The insect activities were monitored over the test periods. The insect damage rates were evaluated.

The key findings and recommendations from this research project are summarized as below:

1) The new wireless technology quickly detected insect activities in most of tested almonds when insects existed, but no insects in those products were expected and detected by human visual inspection.

2) The insects were detected in some of rejected kernels bins in less than 30 min after the trap installation. Insects were also detected in the carton box without a plastic liner and fiber bin of the final products after three and five days of the trap installation, respectively.

3) The new technology was able to detect insects when they emerged in in-hull almonds during the stockpiling.

4) The technology is effective to catch all types of insects, including the larva of navel orangeworm, redflour beetles, bugs, and moths

5) The insect damage in stockpiled in-hull almonds was up to 7.3±2.4%.

6) The temperature and relative humidity of almonds were recorded by the device during the test periods, which can be used for monitoring the storage conditions.

7) The new technology determined the effectiveness of the fumigation treatment.

8) The new detection and alerting technology was fully demonstrated as a needed effective tool for early detecting insect activity in almonds to maintain the product quality, reduce chemical fumigation and associated costs, and mitigate food safety, health, and environmental concerns. This technology made the insect early detection and monitoring possible for almonds during storage, handling and transportation. More demonstration will encourage the processors to adopt the technology in the industry.

Influence of Whole Orchard Recycling on GHG Emissions and Soil Health in Newly Established Almond Orchard

PROJECT NO: AIR10

Principal Investigator:
Name: Mae Culumber
Institution: University of California, Davis
Email Address: cmculumber@ucanr.edu

Summary
Whole orchard recycling (WOR) incorporates orchard waste on-site, without burning or moving the debris to another location, preventing the release of air pollutants into the atmosphere. When mulched into the soil, high carbon (C) containing amendments like woodchips increase soil organic matter (SOM). Agricultural research has found both decreases and increases in carbon dioxide (CO2) and nitrous oxide (N2O) greenhouse gas (GHG) emissions in response to amendment applications of varying quality and quantity, different fertilization rates and types, and varying soil characteristics. A study was initiated after a 13-year-old stone-fruit orchard was recycled in late 2017, then replanted to almond in early 2018 in a commercial orchard in Parlier, CA. The objective was to characterize the impact of incorporating a high rate of recycled woodchips (approximately 40 t/ac or 99 t/ha) on N2O and CO2 emissions, soil factors, and tree establishment after planting. Woodchip treatments had higher CO2 and N2O emissions than controls during the first year after orchard recycling. The majority of emissions occurred in the first year when an estimated 11 tons/ha (4.5 tons/ac) C in CO2 was lost, representing the easily degradable portion of the wood material. Estimates based on CO2 flux found 68% of initial wood biomass C remained after 3 years. Like CO2 emissions, the greatest N2O losses were observed in the wood chip plots in the first year. Compared to the control, higher N2O fluxes in the woodchip treatment were observed during the first four days after fertigation; other times they were consistently similar. Total seasonal N2O emission factor (EF) was 0.6% in control plots and 1.0% in wood chip treatments the first year after recycling. The EF%declined each year and by the fourth growing season control plots EF was 0.3% and recycled plots 0.4%. The resulting emission factors for both treatments at this site were comparable to levels found in other studies by the third growing season. These findings highlight the importance of identifying the optimal rate and application timing of N to limit N losses via N2O during the first two seasons of establishment in orchards planted after recycling. Applying the right type of N inputs at the right rate, time, and placement in the rootzone can help mitigate N2O emissions and other pathways for N losses. Our findings highlight the importance of identifying the optimal rate and application timing of N to limit losses via N2O during the first two seasons of establishment in orchards planted after recycling. Soil organic matter (SOM) andtotal nitrogen (N) levels declined in the first year after replanting, but the wood chips treatments returned to baseline SOM levels (~2.4%) by year 3. Orchard N fertility applications were 2.4 times larger than the standard recommendation for newly planted orchards in the 1st year but were consistent with best management recommendations for the following 3 years. Tree nutrition and growth was not different between conventionally managed and woodchipped trees by the end of 2019. Whole orchard recycled treatment Nonpareil and Monterey yields were not different from the control treatment in 2020 or 2021. These findings suggest additional fertilization may not be needed after orchard recycling, but early applications at planting that target the small tree rootzone may be beneficial to overcoming the high C to N ratio created by the wood biomass. Further research is needed to pinpoint the optimal timing and necessary season-long fertility rates in the first growing season after recycling.

Nickels Soil Lab Projects

PROJECT NO: HORT6

Principal Investigator:
Name: Franz Niederholzer
Institution: UC Cooperative Extension - Colusa County
Email Address: fjniederholzer@ucanr.edu

Summary
The Nickels Soil Lab (NSL) is a privately owned, commercial orchard SW of Arbuckle in Colusa County. It was established with a bequest from Mr. Leslie Nickels to conduct applied research in support of local agriculture. While the property is owned by the Nickels Trust, UC ANR coordinates research at the site under an MOU with the Trust. A total of 160 acres on 2 properties constitute the NSL; 110 acres of almonds, 30 acres of open ground, 17 acres of walunts, and 2 acres of olives. There are 11 on-going projects at NSL conducted by UC and USDA personel. The operating budget for the Nickels Soil Lab comes primarily from crop sales. The Almond Board of CA provides regular support for two projects, providing extra funds for non-commercial projects. The Almond Board also provides critical support for large ticket items (irrigation infrastructure) when market conditions make it impossible for NSL to pay for the project.

This report covers two projects at NSL; 1) organic practices demonstration and 2) in-row spacing trial on two different rootstocks.

In 2021, overall almond yield at Nickels Soil Lab was off from the excellent crop in 2020, due to alternate bearing (off year) in the older blocks. Organic yield was 70-80% of conventional. Yield reduction appears to be due to conditions other than differences in organic and conventional practices. Deficient N levels are a continuing challenge in the organic block as organic N sources are extremely expensive.

In the spacing trial, the Titan peach/almond (P/A) hybrid rooted block (5rd leaf) was harvested for the third time in 2021 and the plum/almond hybrid (Pl/A) rootstock planting (4th leaf) was harvested for the second time. All plantings are 50% Nonpareil, 25% Aldrich and 25% Kester. No significant yield differences were measured between Nonpareil or Aldrich varieties on Titan or Rootpac-R rootstock at alltree spacings (12’, 14’, 16’, or 18’, all at 21’ row spacing). Kester variety on Rootpac-R rootstock also had statistically identical yield across all spacings. For both rootstocks, Nonpareil trees at 12’ spacing were significantly smaller than those at 18’ at the start of the season indicating that the closer planted trees yielded less per tree than the wider spaced trees. To date, there are no differences in tree health at the different spacings.

Updating information on evapotranspiration (ET) and crop coefficients (Kc) of micro-irrigated almond production orchards grown in California for use in water resource management and irrigation scheduling decisions

PROJECT NO: HORT52

Principal Investigator:
Name: Richard Snyder
Institution: UC Davis
Email Address: rlsnyder@ucdavis.edu

Summary
During this period, we continued collecting datasets from earlier almond orchard ET measurements. For data collected with logger programs developed after 2007, we developed a quality control (QC) application program to standardize the analysis and make comparisons between results throughout the Central Valley. For data collected prior to 2008, the collection methods were quite different from the more recent methods, and it is difficult to apply the same quality control techniques. Therefore, the quality control of the new data is more robust than the earlier data. Consequently, in our evaluation of Ka values, we will have more confidence in the post 2007 data. We improved the actual Ka determination by identifying end points for various growth stages, iterating the Ka values, calculating the predicted Ka = ETo x Ka values and comparing the predicted with observed ETa rather than curve fitting through daily calculated Ka data. This methodology provides the most accurate prediction of Ka by eliminating erroneous spikes in the Ka values, especially when ETo is small and small errors in either ETo or ETa can lead to big errors in Ka = ETa/ETo. In some locations during the harvest period ETa dropped considerably below what was observed at other locations, and we attribute the differences to a combination of factors including grower management, suspension of irrigation water application, soil differences, and irrigation system differences. Our current efforts are directed to determining what exactly causes the differences, and how we can estimate the Ka values without having to measure ETa. We hope to determine what is causing the differences by adding ETa estimates from the fairly large set of ETa observations conducted by Land IQ.

Data-driven Smart Irrigation for Almond Orchards

PROJECT NO: HORT69

Principal Investigator:
Name: Isaya Kisekka
Institution: UC Davis
Email Address: ikisekka@ucdavis.edu

Summary

Almond cultivation has expanded into places with more marginal soils as deep, well-drained soils have become scarce and expensive. These marginal soils exhibit greater heterogeneity in the soil profile's depth, texture, structure, available water capacity, fertility, sodicity, and salinity. This results in increased orchard variability in canopy growth and productivity. Growers are interested in management strategies and technologies that can transform this variability from a liability to an opportunity by either increasing production in low-producing areas or reducing inputs e.g., water, energy, and fertilizer. There is a critical need to develop data-driven smart irrigation management strategies and technologies that can assist growers to be profitable while also being environmentally sustainable. In this project, we are evaluating data-driven smart irrigation technologies which combine variable rate irrigation concepts with integrated sensing of water status in the soil-plant-atmosphere system to refine irrigation scheduling decisions in almond orchards.

We have developed a framework that combines monitoring of the soil-, plant, and ET using ground-based sensors, proximal sensors, and remote sensing. We tested this framework at 6 almond orchards in the Sacramento and San Joaquin valleys. Our preliminary results show that it is now possible to use recent advancements in soil water sensing technology (i.e., Cosmic ray neutron probe) to monitor soil water at the orchard scale (~11-acre blocks), overcoming the limitations of point measurements. New SWP sensors (e.g., Saturas and FloraPulse) for direct measurement of stem water potential (SWP) were also investigated at several sites as a potential replacement for the pressure chamber in this project. We observed acceptable accuracy between SWP sensors and pressure chamber although proper installation is critical. We developed a model to upscale individual tree SWP measurements to the entire orchard. Remote sensing and aerial imagery were also used to estimate high-resolution spatial evapotranspiration (ET) maps at scales ranging from individual tree to orchard scale. A comparison was made between commercially available remote sensing ET services to ground-based Eddy Covariance flux tower measurements to determine the accuracy of these products. Preliminary results show that remotesensing of ET is a promising technology for the estimation of orchard-specific ET.

We evaluated the effect of zone-based variable rate irrigation on yield at the CAPEX site near Corning California. Yield varied substantially between low and high-producing areas within the orchards. In 2019, 2020, and 2021 growing seasons, the average nut yield were 1,721, 2,843, and 2,304 lbs/ac, respectively. Although there was significant variability between the low and high producing areas within the orchards In 2019, the yield ranged from 1,143 to 2,764 lbs/ac, in 2020 the range was 2,252 to 3,365 lbs/ac, and in 2021 it ranged from 1,419 to 3,498 lbs/ac. Results indicate that soil heterogeneity was a significant factor driving root water uptake and yield. Yields from the low-producing areas increased over the three-year period. The results indicate the potential of variable rate irrigation to increase overall almond yield. However, for variable rate irrigation to be successful in almond production automation of the irrigation systems is required in order to seamlessly implement irrigation prescriptions.

Based on results to date, we recommend that almond growers use a combination of stem water potential (to determine when to initiate an irrigation set), soil water (to monitor irrigation adequacy and leaching during an irrigation set), and ET (to determine how long to run an irrigation system based on irrigation system application rate). Variable-rate irrigation improved production in low-yielding areas of the orchard.

Almond Orchard Recycling

PROJECT NO: PREC3

Principal Investigator:
Name: Brent Holtz
Institution: UC Cooperative Extension - San Joaquin County
Email Address: baholtz@ucanr.edu

Summary
Whole orchard recycling (WOR), as an alternative to open field or co-generation burning, could reduce net orchard greenhouse gas emissions by sequestering carbon from almond orchard biomass. The woody residue generated by WOR, estimated to be 30-70 tons per acre depending on tree size, spacing, and varieties, increases soil carbon, soil organic matter, soil fertility, soil water infiltration rates, and soil water retention. The barrel trial shows carbon is still sequestered 20 years after recycling. The first orchard grinding trial at Kearney, established in 2008, compared WOR of stone fruit trees ground with the Iron Wolf (a rock crusher), estimated at 30 tons per acre, to burning and incorporating the ash. The orchard was replanted to almond in 2009. Ultimately, significantly greater tree circumference, yields, soil nutrients, organic matter, and soil carbon were observed in the grind treatment when compared to the burn. Leaf petiole analysis also revealed higher nutrients levels in trees growing in the grind treatment, thus proving that the organic matter did not stunt replanted trees. A deficit irrigation trial also showed less water stress from trees growing where the previous orchard was ground, suggesting increased water holding capacity with additional organic matter. Preliminary data from several of the newly established trials have suggested that our nitrogen recommendation for first year almond trees will increase from 3 ounces of actual nitrogen per tree per year to 4-5 ounces after implementing WOR, because of the additional carbon added to the soil. Early nitrogen applications appear to be more critical than late season applications. WOR did not interfere with fumigation trials conducted at two locations in Kern County. Based on positive results from this trial and the closure of half of California's co-generation plants, we estimate almond growers have chipped and incorporated over 50,000 acres since 2015. WOR is a regenerative agricultural practice that has increased soil health and fertility while providing growers with an alternative to co-generation and open field burning. The adoption of WOR has improved land management by increasing soil quality, organic matter, fertility, water holding capacity, and yield. WOR has improved air quality by diverting woody biomass from being burned while increasing our soil's resilience to climate change by sequestering carbon. WOR has made the growing of California's largest commodity, almonds, more sustainable! In November 2018, the San Joaquin Valley Air Pollution Control District began rewarding growers who implemented WOR $600 per acre (up to $60,000 per grower / year). Since then, "539 growers received awards totaling $18.1 million, recycling 25,934 acres and diverting 727,980 tons of woody biomass from being burned!" (SJVUAPCD report). In 2020, WOR was added to the Healthy Soils Program and 14 growers received $680,342 (CDFA Report).

Effect of Partial Substitution of Fertilizer with Organic Matter Amendments on Nutrient Cycling

PROJECT NO: PREC7

Principal Investigator:
Name: Sat Darshan Khalsa
Institution: UC Davis
Email Address: sdskhalsa@ucdavis.edu

Co-PIs: Vivian Wauters, Amelie Gaudin, Patrick Brown, Michelle Perez

Summary
The impact on environmental quality and profitability of synthetic fertilizers in California almond orchards may be lessened by the use of organic matter amendments (OMA). In the short term, OMA can act as partial substitute to synthetic nitrogen (N) fertilizer while over the long-term increase soil organic matter and other essential nutrients like phosphorus (P) and potassium (K). This project builds off of ABC, FFAR and WSARE-funded work using OMA plots located in an almond orchard near Escalon in San Joaquin County. Furthermore, we expanded our trials with ABC matching funds to include almond hulls and shells as an OMA. The OMA compost trial was split into two N fertilizer rates starting in 2019 where plots were previously amended with the same OMA sources since 2015. We measured leaf nutrient status, soil moisture, N availability and almond yield. A separate OMA hull and shell trial started in 2020 where plots were amended with almond hulls and shells compared to an amended control, and we measured leaf nutrient status, soil exchangeable K and tree water stress over time.

In 2021, soil moisture sensors measured higher volumetric water content at 15 cm depth in the composted manure plots compared to the control. In 2021, we continued to measure cumulative N availability across all plots. There were no significant differences between amended and unamended plots at both N rates. In 2019, 2020 and 2021, we collected almond yield across all plots. There were no significant differences between amended and unamended plots at both N rates. Yields under composted manure and green waste compost were the same at both N rates. Challenges from this project include a high irrigation nitrate inputs. This additional N may be reducing the differences in the N rates leading to a range that is too narrow to accurately quantify potentials differences in cumulative N availability and almond yields. This three-year data set shows that OMA use has had no negative impact on overall orchard performance.

Funding from this project also matched our proposal entitled, “Advanced harvest techniques facilitate soil health practices in almond” where we examined almond hulls and shells as a soil amendment, K availability from hulls and shells, and the role of off-ground harvest in facilitating soil health practices. There were no statistically significant differences in leaf N, P, Ca, S, B, Zn, Mn, Fe, or Cu. In the amended trees, leaf K was significantly higher. Soil exchangeable K in hull and shell plots were significantly greater compared to the control from fall 2020 through spring 2021. Stem water potential was significantly less negative in the hull and shell treatments than the unamended control in 2021. These results show that OMA sources including composted manure, green waste compost and hulls and shells did not contribute directly to increased almond yields, but do effect soil moisture and fertility, as well as tree nutrient and water status.

Boron Management and Remediation in Almond

PROJECT NO: WATER12

Principal Investigator:
Name: Patrick Brown
Institution:UC Davis
Email Address: phbrown@ucdavis.edu

Co-PIs: Katherine Jarvis-Shean, Loasheng WU, Sabine Goldberg, Konrad Mathesius, Keith M. Backman, Sat Darshan S. Khalsa, Daniela Reineke

Summary

Too much boron (B) in the soil or irrigation water in almond orchards can cause ongoing issues with sticktights, dead tissue and sugary wounds at branching points that can provide entry points for fungal diseases. Boron toxicity ultimately results in tree decline, yield decline and death. A novel system was developed in 2019 to remove B from irrigation water, however it failed, and thus a new system was re-engineered and re-built over 2020 and 2021. The B removal system enables the implementation of rate and season treatments in order to determine how irrigation water boron (B) concentration, time of exposure and life-stage of the orchard interact to cause B toxicity, productivity loss and orchard decline. 2021-2022 efforts went to developing B extraction curves for the new system that will allow the control of the average B value delivered to the trees by flow rates and time. In addition, baseline tree tissue was collected from all established plots and processed for tree response to existing B levels to be contrasted to treatments. New external funding received for this project (2022-2025) will be used to conduct all stated objectives and will be reported to ABC on a regular basis. In the meantime, growers can mitigate high B groundwater irrigation by planting B resistant rootstocks, using surface water to leach B in soils, and by using gypsum and organic matter to ameliorate soils.

Determining Almond Tree Water Use and Stress using Surface Energy Balance Models with Unmanned Aircraft Systems

PROJECT NO: WATER16-ATR

Principal Investigator:
Name: Alfonso Torres-Rua
Institution: Utah State University
Email Address: Alfonso.Torres@usu.edu

Co-PIs: Andrew McElrone, Bill Kustas, Kyle Knipper, Nicolas Bambach

Summary
This project focuses on the estimation of water status and stress at the almond tree scale using unmanned aerial vehicles, ground measurements, and validation sources (Eddy Covariance, leaf water potential, others). The followed methodology uses optical, infrared, and thermal imagery to spatially estimate biomass distribution (LAI) and surface energy components, towards the estimation of consumptive water use (evapotranspiration) and stress (by separating the almond tree transpiration component from ET). The project methodology is based on the Two-Source Energy Balance Model (TSEB) model and previous multiyear experience in commercial vineyards across California. This ABC project complements the USDA Agricultural Research Service T-REX (Tree-crop Remote sensing of Evapotranspiration eXperiment); a project that aims to integrate ground, sensors, UAV, and satellite data to provide a comprehensive integration of information on consumptive water use and stress for commercial almond sites across California Central Valley.
2021 was the initial year of the project, with significant activity and efforts by the T-REX lead (Andrew McElrone and Nicolas Bambach at USDA Agricultural Research Service and University of California –Davis Campus) towards the site selection and coordination with growers and research collaborators for the installation of scientific instrumentation and ground sensors (Eddy Covariance Flux Towers). Later in the growing season (last week of July / first week of August) a field data collection campaign called
"Intensive Observation Period (IOP)" over a span of 8 days at one of the experimental sites (Olam KG Ranch in Madera, CA) was conducted.
Several UAV flights, using the Utah State University AggieAir drone technology, at different times in the day, encompassing 0.7 sq miles and 10 individual orchards, each at a different development stage (leaf age and almond varieties like Nonpareil, Shasta, others) were surveyed. The diversity of almond conditions in the Olam KG ranch provides a unique opportunity to extend this water use and stress research under multiple crop growth stages and conditions. The UAV information collected included optical-infrared and thermal imagery at 0.10 and 0.60m/pixel resolution respectively.
Initial analysis of the collected UAV information indicated that optical and infrared information can identify occurring irrigation management on the pollinating almond variety within an orchard. This was observed for the instrumented orchard under the application of chlorophyll-related vegetation indexes (e.g., Chlorophyll Green Index, Simple Ratio, SAVI, NDVI).
An initial second finding was a preliminary estimation of distributed evapotranspiration using the TSEB model. The ET estimate results show great variability among the different orchards and almond ages, although ET variability within each individual orchard was lower. For mature almond orchards, ET estimates were close to the daily reference ET while young orchards (first leaf) were close to 1mm/day or 15% of daily reference ET. This ET variability can be explained by the differences in canopy size and interrow conditions, which in turn impacted estimation of energy and water processes at tree scale by the TSEB algorithm.
Throughout the growing season, plant biophysical and physiological observations were collected on 5 different days at each experimental site; resulting in a total of 15 days of observations coinciding with the Landsat satellite overpasses. Preliminary analyses have provided some insights regarding field heterogeneity and plant variety physiological response to heat and water stress dependence. Similar activities will be carried out throughout the 2022 growing season aiming to further understand the link between almond water use and physiological stress responses.
Field activities planning for 2022 year is under way, with Intense Observation Periods preliminary scheduled for May, June, and August, across Central Valley on three major study sites.

How to irrigate almond orchards - for the current year's expected yield or for maximum yield potential?

PROJECT NO: WATER17

Principal Investigator:
Name: Maciej Zwieniecki
Institution: UC Davis
Email Address: mzwienie@ucdavis.edu

Summary
Main Goal: Determine the impact of matching irrigation to the spring estimates of current year's yield on final yield and the following year's yield potential:

Objective (1) Develop a sequential yield prediction model that allows for near-real-time estimation of orchard yield potential using carbohydrate content, winter weather conditions, and satellite spectral images. In 2021, we have analyzed over 5000 samples for content of soluble sugars and starch from 80 orchards, and collected data on local orchard climatic conditions. We have developed first version of the yield association with NSC content and determine crucial periods when high or low content of NSC are best predictor of yield. An in-depth analysis and the whole information is available at a recent publication: Zwieniecki, M.A., Davidson, A.M., Orozco, J. et al. The impact of non-structural carbohydrates (NSC) concentration on yield in Prunus dulcis, Pistacia vera, and Juglans regia. Sci Rep 12, 4360 (2022). https://doi.org/10.1038/s41598-022-08289-8

Objective (2) Analyze the impact of management practices (irrigation) on changes in yield potential and actual yield of both current and the following year by utilizing large-scale, multi orchard analysis of all participating growers in the Carbohydrate Observatory. In 2021, we have initiated collection of data related to irrigation practices, irrigation volume, and associated yield. We have improved and We also developed and streamline the access to large scale geographic data through the Google Earth Engine. We have developed the bloom model for California that allow analysis of long term shifts in bloom time in response to climate change.

Milestones:
Increasing availability of NSC data and yields from this proposal, main carbohydrate observatory activity, and collaboration with BARD would provide increasingly accurate inputs for development of yield prediction model – each year an iteration of the model will be tested and progress reported.
Evaluation of irrigation on yield potential will be tested every year to account for climatic variability and increasing accuracy of the predictive model. Each fall will provide new information to adjust next year'spractice to best reflect progress being made.

Remote-controlled evaluation of distribution uniformity and stem water potential: Extending imagery to integrated decision support

PROJECT NO: WATER18

Principal Investigator:
Name: Mallika Nocco
Institution: UC Davis
Email Address: manocco@ucdavis.edu

Summary

The Almond Board of California (ABC) has established an industry goal to reduce the water used to grow a pound of almonds by 20% by 2025. The simplest path for achieving this goal on time is by optimizing irrigation application and scheduling through (1) increasing Distribution Uniformity (DU) via improved system testing, maintenance, and application flow metering; and (2) energy-efficient irrigation scheduling using stem water potential (SWP) at key stages ("when to start", hull-split, "when to end"). This project addresses obstacles and knowledge gaps through outreach campaigns, new integrated irrigation decision support, and remote sensing tools to transform imagery to actionable information. Additionally, as a part of the larger Tree Crop Remote Sensing of Evapotranspiration Experiment (T-REX), this team is also collecting high resolution multispectral & thermal imagery on a frequent basis at eddy covariance tower locations. These data will be used by the T-REX team to develop complete seasonal records of high-resolution evapotranspiration as well as compare/refine drone-based ET and energy balance mapping algorithms for California almonds.

Our overarching goal is to remove obstacles, provide training, and develop integrated decision support tools to CA growers. Key milestones for year 1 include establishment and data collection from three collaborative field sites across the Central Valley in Chico, Woodland, and Ripperdan. The field sites were chosen based on collaborator activities including comprehensive ground measurements of stem water potential, latent heat flux (actual evapotranspiration), as well as delayed irrigation scheduling and almond variety testing. We conducted 22 aerial missions collecting multispectral and thermal data throughout the growing season at these sites in coordination with collaborators who collected synchronous measurements of stem water potential, photosynthesis, stomatal conductance, and other key physiological measurements. Missions were conducted at a 90-meter (400 feet) altitude over 15-50 minutes depending on the acreage of the site. Preliminary results show promising relationships between the spatial variability of thermal imaging and stem water potential as well as scaling potential of satellite imagery to tree-level insights despite flux and pixel matching challenges between satellite, flux tower, custom aerial, and commercial aerial imagery.

Another look at pheromonal or related attractants for leaffooted bugs (*Leptoglossus spp.*) infesting California nut crops

PROJECT NO: ENTO18

Principal Investigator:
Name: Jocelyn Millar
Institution: University of California Riverside
Email Address: millar@ucr.edu
Co-PIs: Houston Wilson, Kent Daane

Summary

The longterm goal of our project is to develop pheromone-based tools for monitoring and managing leaffooted bug species (LFB) which can cause serious losses in California nut crops. There was some evidence that sexually mature male bugs produced an aggregation pheromone that is attractive to both sexes. Thus, the major goals of our project were to identify these pheromones and develop protocols for the private sector to develop commercial products to use in bug management.

In a multiyear effort, we isolated, identified, and synthesized nine compounds from sexually mature males of Leptoglossus zonatus, the most important species for California nut crops. These compounds included aldehydes, esters, and several sesquiterpene hydrocarbons, including two bergamotene isomers, sesquiphellandrene, and a compound new to science. This compound, although a relatively minor component of the overall blend, elicited the strongest responses from live bug antennae in electroantennogram assays. After 2 years of collecting volatiles from cohorts of male bugs, we were finally able to get enough of the material to conclusively identify it, and we have developed a short synthesis from readily available starting materials. In preliminary field bioassays carried out in late summer of 2021, the new compound, dubbed leptotriene, proved to be the key component in the attractive blend produced by males. The compound is also produced by sexually mature Leptoglossus clypealis, or other target species, so it is likely a pheromone component of that species as well. To date, we have not been able to test it with L. clypealis because this species has become uncommon in central California, for reasons unknown. In parallel studies, in anticipation of having a pheromone lure available, we have tested different trap designs and colors. Hanging cross-vane panel traps coated with fluon proved to be the best among the trap designs tested, with yellow or blue being the optimal colors.

Finally, to begin unravelling the signals that mediate the formation and maintenance of overwintering aggregations of LFB, we have tested the responses of summer- and winter-form bugs of both sexes to each other, in all possible combinations. These studies showed that males of both forms will mate with summer-form females, but winterform females will not mate with males of either form. These behavioral preferences may correlate with seasonal differences in the cuticular hydrocarbons on the surface of the insects, which are used for recognition of species and sex. If so, it may be possible to develop semiochemically based tactics to disrupt the ovewintering aggregations, resulting in greater overwintering mortality.

These results could lead to development of commercial traps and mating disruption technologies.

Influence of different cover crop systems on navel orangeworm (NOW) and its natural enemies

PROJECT NO: ENTO22

Principal Investigator:
Name: Houston Wilson
Institution: UC Riverside
Email Address: houston.wilson@ucr.edu

Summary
Habitat diversification has been shown to positively influence a variety of ecosystem services to agriculture, including biological control of arthropod pests. The impact of increased biodiversity tends to be species specific though, and practices therefore need to be developed on a case-by-case basis for each cropping systems. In perennial systems, numerous studies have demonstrated that cover crops can have positive impacts on soil quality and other ecosystem services, such as pollination and pest management. That said, few studies have focused on the use of cover crops to enhance pest control in almond orchards, especially winter cover crops. The primary pest of almonds in North America is navel orangeworm (Pyralidae: Amyelois transitella) (NOW), which overwinter as larva or pupa on remnant nuts, many of which are on the orchard floor. Later in the spring, first flight adults subsequently use these remnant nuts as reproductive substrate. Here, a 2-year experiment was conducted to evaluate the influence of winter cover crops on overwintering mortality and spring egg deposition of A. transitella. Remnant nuts placed into cover crop plots produced fewer adult A. transitella in the spring, suggesting increased overwintering mortality. Additionally, spring egg deposition was reduced in the cover crop plots, possibly due to the ground cover interfering with host location and access. In this way, winter cover crops appear to contribute to the reduction of A. transitella populations in the orchard by possibly altering abiotic and physical conditions, although studies to document specific mechanisms are still needed.

This project was catalyzed by Dr. Amelie Gaudin (UC Davis), who has built a collaborative cross-disciplinary team to explore the multiple ecosystem and economic benefits/tradeoffs of winter cover crops in almond orchards. Funding from the Almond Board of California provided support to develop these initial experiments, most of which have produced promising results. Dr. Gaudin has subsequently led the development of a new 5-year proposal which was recently funded by USDA NIFA AFRI to further explore ecological mechanisms and new blends of cover crops. This new project includes a focus on overwintering navel orangeworm, so we plan to continue our efforts in this area in the years ahead.

Biology, monitoring, and management of native and invasive stink bugs in almond orchards

PROJECT NO: ENTO23

Principal Investigator:
Name: Jhalendra Rijal
Institution: UC Cooperative Extension - Stanislaus County
Email Address: jrijal@ucanr.edu

Co-PIs: Raman Bansal, Andrea Joyce, Sudan Gyawaly

Summary
Hemipteran “true bugs” are important pests of almonds. These include native stink bugs, leaffooted bugs, and invasive brown marmorated stink bugs (BMSB). Leaffooted bug and BMSB feeding in the spring (March – April) can result in high levels of almond drop. Other native stink bugs and smaller hemipterans are not known to be present or cause damage in the spring. The mid-to-late season (May – July) infestation by major hemipterans can result in necrotic kernels - broadly referred to as “brown spots.” In addition, these hemipterans can cause shriveled or completely defective kernels – “gummy kernels.” In the last 4-5 years, the incidence of brown spots and gummy kernels in almonds has been increased steadily. According to the Blue Diamond record, the incidence of brown spots in almonds reached (~37%) almost the same level as the navel orangeworm (~39%) out of the total reject kernels statewide in 2021. Besides large hemipterans, several smaller hemipterans such as Lygus, Calocoris, Phytocoris, box elder, and false chinch bugs can be present and may cause occasional damage to almonds.

In the 2021 season, we surveyed 21 almond orchards in northern and southern San Joaquin Valleys using various sampling methods. We found that brown marmorated stink bug, green stink bug, and leaffooted bug were the most common hemipteran pests in these almond orchards. The invasive hemipteran pest, brown marmorated stink bug, was found in six of the 11 orchards in the northern and two of 10 orchards in the southern San Joaquin Valley, suggesting their infestation is increasing in the area. Infestation of hemipterans in almond orchards can result in significant crop damage. For example, we found as high as 5.5% damage of almond kernels. Scouting hemipterans may be necessary for determining potential damage. For monitoring BMSB, a clear panel trap with a BMSB lure is effective. However, for monitoring of leaffooted bug and green stink bug, other sampling methods, such as beating tray or visual sampling methods, are more effective.

Improving and Verifying Quality of Mass-Reared Navel Orangeworm for Sterile Insect Technique

PROJECT NO: ENTO24A-HW

Principal Investigator:
Name: Houston Wilson
Institution: UC Riverside
Email Address: houston.wilson@ucr.edu

Co-PIs: Charles Burks

Summary
Recently, the pistachio and almond industries made a significant investment in the development of sterile insect technique (SIT) for navel orangeworm (Pyralidae: Amyelois transitella) (NOW) that leverages the availability of a preexisting mass-rearing and irradiation facility operated by USDA-APHIS in Phoenix, AZ that was originally developed for a sterile pink bollworm (Gelechiidae: Pectinophora gossypiella) (PBW) program. The goal of this program is to develop SIT as a complementary strategy to augment existing integrated pest management (IPM) tools for NOW. Over the past four years (2018-2021), co-PIs Wilson and Burks have led various scientific efforts to evaluate the quality and performance of sterile NOW produced by this USDA-APHIS facility in Phoenix. In doing so, the goal has been identify and rectify key bottlenecks in the production, transportation and/or release process.

Initial field tests in 2018 revealed little to no recovery of sterile males produced by this facility. In contrast, sterile females were shown to call, attract and successfully mate with wild NOW males, albeit after some photoperiod adjustment following their release into field plots. Since then, efforts have focused on isolating key aspects of the production, transport and release process that are driving these negative impacts on performance. In 2019 and 2020, modifications to the release process led to increased recovery of sterile males in pheromone traps, and in 2021 sterile males were recovered in mating tables for the first time, demonstrating that they can indeed successfully locate and mate with a wild-type sentinel female. That said, their performance is still not on par with locally-reared NOW that are not subjected to the negative impacts of mass-rearing and transport.

Laboratory assays in 2019-2020 demonstrated that sterile males from this facility indeed respond to female NOW pheromone, but their flight ability seems to be reduced by the mass-rearing and transportation process. A modified transportation process was developed by M3 Agriculture, a private industry partner, which led to some further improvement in moth performance in 2020. Adult NOW are currently held at low temperatures during the collection, irradiation and transportation process that were optimized for PBW, not NOW, and this appears to be a primary source of negative impacts on their performance.

Field trials in 2021 focused on (1) comparing the interaction of rearing (mass-reared vs locally-reared) and release device (paper bags vs drone) on NOW recovery in small almond and pistachio plots (2-5 acres) at the Kearney Ag. Center, (2) measuring sterile NOW dispersal in replicated large pistachio plots (640 acres each) when released using the modified APHIS airplane and (3) evaluating wild NOW activity and crop damage in replicated paired almond plots (40 acre blocks) with and without sterile NOW release, also using the modified APHIS airplane.

Results from 2021 continue to suggest that the current mass-rearing process is leading to negative impacts on NOW performance, even when the improved transportation methods are utilized. Recovery of sterile moths released by drone were on par with those released using the paper bag systems, suggesting drones can be a viable strategy for release of sterile NOW.

In parallel, additional efforts are underway in collaboration with M3 Agriculture to develop automated trapping that can differentiate wild and sterile NOW, as well as explore the use of x-ray irradiation as an alternative approach to the sterilization of NOW (x-ray effort is funded separately by US Dept. of Energy).

Sustainable management tools for leaffooted bugs in almond orchards

PROJECT NO: ENTO27

Principal Investigator:
Name: Andrea Joyce
Institution: UC Merced
Email Address: ajoyce2@ucmerced.edu

Co-PIs: Jhalendra Rijal, Sudan Gyawaly

Summary
The leaffooted bugs (LFPBs) are among the larger Hemiptera insects found in almond orchards, and they occasionally cause substantial crop damage to almonds. These insects have long stylet mouthparts which probe into developing almonds resulting in almond drop and kernel damage. There is currently no well adopted monitoring tool for these insects to assess their numbers in the orchard, and this makes IPM challenging. Leaffooted bug control previously counted on Chlorpyrifos, but this option has been eliminated in California. Another chemical control option is pyrethroid insecticides. Pyrethoids are available for use, but insects can develop resistance when one insecticide class is relied upon for management, and there are environmental regulations and concerns for their overuse. Most importantly, the application of pyrethroids can lead to mite flare up due to its impact on mite predators. Finding products to control LFPB for organic production systems is another challenge. Therefore, there is a need for alternative chemical and biological controls for leaffooted bugs, and pest management would benefit from a more thorough understanding of the leaffooted bug ecology in the field.

Other potential control options for LFPBs in the IPM toolbox include biological control through the use of predators and parasitoids, management through application of biopesticides (bacteria, fungi, and novel chemistries), monitoring or mating disruption using pheromones or attractants, among others; any of these tools could be used in the almond orchard and might be compatible with other pest management products used for key orchard pests, while preserving biodiversity in the orchard and providing sustainable pest control. This project investigates which predators and parasitoids are attacking leaffooted bug in the field. In 2021, sentinel eggs of L. zonatus were placed at 6 sites late in the growing season to look for evidence of parasitization and predation. Little evidence of biological control of eggs of L. zonatus was found. Additional sampling dates and additional trapping methods are being including in sampling methods for 2022. In 2021, we increased the size of our leaffooted bug colonies, so that we have higher numbers of adult leaffooted bugs, and we can run insecticide trials in 2022. Insecticide trials in the field will begin in 2022, and we will also examine the impact on predators and parasitoids. In 2021, the cross mating and biology of two strains of Leptoglossus zonatus was examined. We produced colonies of two strains of L. zonatus. Cross mating of the two strains was observed, which suggests that the two strains could be attracted to the same pheromone, and the same pheromone might be used to manage the both strains.

Spatiotemporal Models to Evaluate the Potential Value of Sterile Insect Technique for Control of Navel Orangeworm

PROJECT NO: ENTO28

Principal Investigator:
Name: Houston Wilson
Institution: UC Riverside
Email Address: houston.wilson@ucr.edu

Co-PIs: Ran Wei, Brittney Goodrich, Charles Burks

Summary

The goal of this project is to evaluate the potential efficacy and costs of sterile insect technique (SIT) for control of navel orangeworm (NOW) in California tree nuts. This is an effort that is agnostic to any specific technology used to produce, sterilize, transport or release sterile NOW. Rather, the project is focused on accurately modeling the various crop, insect and management parameters that will create a simulated environment in which the introduction of sterile NOW can then be evaluated, regardless of where they come from or how they are produced. The economic analysis component will then provide an estimate of the maximum allowable cost per acre for use of this technology, given current tree nut production costs and profit margins. When paired together with the ecological models, it will then be possible to derive estimates of the required overflooding ratio, frequency and extent of sterile moth releases, and ultimately the cost per sterile moth required for an ecologically and economically viable program.

The research team has so far been focused on the development and parameterization of an agent-based model (ABM) for NOW. The current model incorporates data or estimates for multiple parameters of NOW life-history, including development and dispersal. This information was then overlaid into an environmental model that includes spatially-explicit information on the arrangement, extent and phenology of tree nut crops in California. The current model was then run over ten distinct areas throughout the Central Valley, each of them 20 x 20 km in dimension, using climate data over the period 2010-2020. The ten regions were selected to reflect the diversity of tree nut production scenarios found across the state.

Currently, we are preparing to integrate data on pesticide use for the period 2010-2020, developing a method to model the impacts of mating disruption, and acquiring long-term NOW datasets that will be used to verify model accuracy. Once these components are in place, we should then be ready to begin introducing sterile moths into the model. Once these different ecological scenarios have been modeled,we can then move into development of the economic analyses.

Arthropod Pest Management in the Lower San Joaquin Valley

PROJECT NO: ENTO6

Principal Investigator:
Name: David Haviland
Institution: UC Cooperative Extension - Kern County
Email Address: dhaviland@ucanr.edu

Summary
Mating disruption and biological control represent key integrated pest management strategies for the management of navel orangeworm and spider mites, respectively, in the lower San Joaquin Valley. Between 2019 and 2021 we used replicated 40-acre plots to evaluated mating disruption systems that disseminate pheromone using aerosol cans, meso emitters, and foliar application of sprayable products. Aerosol-based products caused significant pheromone trap shutdown of >95%, reduced egg trap captures by
69-72% across the four navel orangeworm flights, and reduced damage to Nonpareil and Monterey by 58.4% and 51.8%, respectively. Meso emitters likewise reduced pheromone trap captures by a season-long avererage of 88%, reduced egg captures by 34% to 58%across the four flights, and reduced damage by 22.0% in Nonpareil and 31.8% in Monterey. Applications of sprayable formulations of pheromone, regardless of whether they were applied four or two times during the season, failed to reduce pheromone trap captures by more than 60% and had no impact on the number of eggs or damage levels at harvest.

Research on sixspotted thrips confirmed the presence of two periods of thrips activity: one in April and May followed by a second in response to increases in mite density after hull split. We developed threshold models showing that growers need to apply miticides whern there are 1.4 mites per leaf, which is approximately 38% of leaves infested, which is consistent with previous work done in the 1980s. Correlations showed that mite density remains unchanged over 7 days if there are 0.42 thrips per yellow sticky trap per week for every 1.0 mite per leaf. During April and May these predictions suggest that no miticide applications are needed if thrips are present in the orchard. After hull split, an alternative threshold model was proposed whereby capture rates of 3 thrips per trap per week suggest that miticides treatments can be avoided because mite densities will not reach treatable levels during harvest.

Improving non-fumigant-based approaches for management of almond replant problem

PROJECT NO: PATH1

Principal Investigator:
Name: Gregory Browne
Institution: USDA ARS, Davis
Email Address: gtbrowne@ucdavis.edu

Summary
The overall goal of this project is to develop sustainable management strategies for costly soilborne disease complexes affecting young replanted almond orchards, especially Prunus replant disease (PRD; Prunus-specific growth suppression induced by an ill-defined soil complex) and Phytophthora crown and root rots (PCRR; caused by multiple Phytophthora spp.). Preplant soil fumigation can provide an effective foundation for management of these problems, but it faces increasing regulatory constraints and an uncertain future in California. This project aims to assemble practices, knowledge, and tools that will sustain economic management of almond replant problems without dependence on fumigation.

The first project objective is optimized soil remediation protocols based on agricultural byproducts of rice bran (RB) and ground almond hull and shell (Ahs) for control of PRD. In support of this objective, amendment-based approaches, including variations of anaerobic soil disinfestation (ASD) and whole orchard recycling (WOR), each augmented with standard and experimental N and P fertilization treatments, are being tested for management of PRD at the Kearney Agricultural Research and Extension Center (KARE). In 2021 KARE trials, tree growth data were collected to document responses of replanted almond trees to all soil treatments, and soil and root samples were collected to examine impacts of the treatments on soil chemical properties and soil and root microbial communities. Overall, the first-year growth responses to the preplant soil and fertilizer treatments at KARE suggested it is possible to develop economical approaches to manage PRD without soil fumigation. Affordable amendment-based treatments were identified that were as effective as fumigation for prevention of PRD. Also, there was a robust, positive response to fertilization with phosphorus across all preplant amendment, WOR, and fumigation treatments, indicating that continued examination of phosphorus fertilization treatments for young orchards is justified. First and second-year tree growth responses in replanted orchards typically carry through to result in significant cumulative yield benefits, but solid conclusions on long-term treatment benefit of our amendment- and fertilizer-based alternatives to fumigation will require collection of yield data .

The second project objective is up-to-date knowledge of species and manageable factors associated with Phytophthora on almond in California. In support of this objective, Central-Valley-wide Phytophthora diagnostics support was continued with UCCE Farm Advisors. Our observations and diagnostics suggested the following: (1) multiple species of Phytophthora, some relatively “new” to CA almond production, are contributing almond tree death in young orchards including, especially, P. mediterranea and P. niederhauserii; (2) stock from multiple nurseries has sometimes been infested with Phytophthora species; (3) several of the hybrid almond rootstocks are relatively susceptible to Phytophthora crown rot; and (4) suboptimal soil water management (e.g., retention of dual drip irrigation lines near root crowns as root systems reach beyond the lines) is contributing to infection by Phytophthora species in young orchards.

Epidemiology and Management of Phytophthora Root and Crown Rot of Almond

PROJECT NO: PATH15

Principal Investigator:
Name: Jim Adaskaveg
Institution: UC Riverside
Email Address: jim.adaskaveg@ucr.edu

Summary
Between 2018 and 2021, 64 isolates of Phytophthora spp. were obtained in surveys of 53 almond orchards with declining trees throughout the main growing areas in California. P. mediterranea (formerly P. sp. ax) and P. niederhauseri were most commonly isolated, but P. syringae, P. citricola, and P. cactorum were also detected. The former two species have a high temperature optimum for growth of approximately 30C. In greenhouse trunk inoculation studies, they were found to be the most virulent, and plants were killed 2-3 weeks after inoculation. This supports field observations where disease caused by these species progresses very rapidly and often results in tree death. Highly efficacious, non-phytotoxic alternative fungicides with different modes of action that can be applied as soil chemigation treatments are being developed for managing Phytophthora root and crown rot of almond. Alternatives to mefenoxam and phosphites are needed because resistance has been reported to both fungicides in Phytophthora species on other tree crops. And soil fumigations face continuing regulatory restrictions. The new fungicides oxathiapiprolin (Orondis), mandipropamid (Revus), fluopicolide (Presidio), and ethaboxam (Elumin) have different modes of action (FRAC codes 49, 40, 43, and U5, respectively) and were highly toxic in vitro against 11 Phytophthora species from almond in California. Oxathiapiprolin had the highest activity with EC50 values for mycelial growth inhibition of <0.001 mg/liter. In a second field study at UC Davis that was established in 2017, almond trees on Hansen or Nemaguard rootstocks were inoculated with Phytophthora spp. soon after planting and in 2018 and 2019. After annual treatments, Orondis (at the 4.8- and 9.6-fl-oz rates), Revus, and Presidio were highly effective in managing Phytophthora crown rot, and no diseased trees were observed. In comparison, approximately 45% of control trees either died or showed gumming trunk cankers. In studies in commercial orchards, P. mediterranea was the main pathogen involved. Three rotation/mixture soil treatment programs were done that included the new fungicides as well as Ridomil Gold (mefenoxam) and ProPhyt (phosphite). None of the programs was highly effective when applied to dry soil. This was not expected when compared to the UC Davis trial, and studies were done to determine the reason. In a comparative field trial, soil treatments were done to almond trees to dry or wet soil. Tree trunks were then wound-inoculated 10-14 cm above the soil line with P. cactorum to evaluate if the chemical was taken up by the root system and translocated. Only when Orondis was applied to wet soil, was canker formation on was almost completely inhibited. This indicates that Orondis is bound to dry soil. To obtain high efficacy and systemic movement, it has to be applied to pre-wetted soil to allow for root uptake. The systemic uptake explains the long-lasting efficacy of Orondis and its potential use in mixtures to manage Phytophthora crown and trunk cankers using soil applications will prevent the selection of resistant sub-populations of Phytophthora spp. Orondis received the California registration for almond in the fall of 2021. California registrations of Elumin and Presidio (both nominated into the IR-4 program are ongoing. Studies for Elumin will be done in 2022, and those for fluopicolide will be initiated in 2023. Revus is planned for nursery registration.

Epidemiology and Management of Almond Band Canker Disease in Young Orchards

PROJECT NO: PATH16

Principal Investigator:
Name: Themis Michailides
Institution: UC Kearney Agricultural Research and Extension Center
Email Address: tjmichailides@ucanr.edu

Summary
Almond band canker is becoming more severe, particularly in very young orchards in California. In this study, we focused on two objectives. We selected two commercial nurseries where we collected budwood materials. Our previously developed quantitative real-time PCR assay (qPCR) was used to quantify the latent infection levels for 6 canker-causing pathogens. Various levels of latent infection by several canker-causing fungal species were found in different varieties in both nurseries. Infections by Cytospora spp. and Neofusicuccom spp. were detected in most varieties from both shoots and buds. The second objective of our study involved trials of fungicide spray treatments in two young almond orchards. In Orchard Y, both sprays of Topsin M on trunks in either fall or spring reduced significantly the incidence of canker disease compared with the untreated control. In Orchard W where we sprayed a fungicide (Topsin M solo or Topsin M+Rally) in spring of 2019, before the appearance of any canker symptoms, both spray treatments reduced the incidence of cankers significantly even 16 months after the treatment. Surprisingly, 2 and ¾ years after the initial treatment in the spring of 2019, one could still find trees with very severe band canker in the untreated trees but none in the treated trees.

Investigation of *Aspergillus niger* causing Hull Rot and Conditions Conductive to Disease Development in Kern County

PROJECT NO: PATH18

Principal Investigator:
Name: Mohammad Yaghmour
Institution: University of California, Davis
Email Address: mayaghmour@ucanr.edu

Summary
Hull rot is primarily caused by Rhizopus stolonifer and Monilinia fructicola. Infections by these fungi result in killing leaves, spurs, and parts of the shoot bearing the infected fruits. In Kern County, and the Southern San Joaquin Valley, R. stolonifer is more prevalent, and this fungus produces a toxin (fumaric acid) which moves from the infected fruit into the surrounding tissues killing the vascular tissues. Thus, hull rot affects future yields by killing fruiting spurs and wood. In the past years, orchards affected with hull rot in Kern County and other counties in the central valley showed the presence of Aspergillus niger growing among the hulls and shell in fruit with hull rot.

Many samples were processed at Kearney Agricultural Research and Extension Center in Dr. Michailides' lab showed that hull rot samples from the San Joaquin and Sacramento Valleys were also infected with A. niger alone and/or R. stolonifer.

In 2021, we repeated and completed our pathogenicity tests and successfully reproduced the symptoms using two different isolates of A. niger. Furthermore, we assessed the natural incidence of hull rot infections in a commercial orchard. The incidence of A. niger causing hull rot was significantly higher than the incidence caused by R. stolonifer.

In a small-scale fungicide trial, almond fruit protected with a fungicide spray at hull split stage c showed that fungicides in FRAC groups 7/11, and 3 having the most disease protection against hull rot caused by A. niger. However, all protective fungicides did not significantly reduce hull rot when used to protect the nuts at stage b2 (deep V).

Assessing nematode control soil health and tree vigor in a commercial almond orchard four years after soil biosolarization

PROJECT NO: PATH19

Principal Investigator:
Name: Christopher Simmons
Institution: UC Davis
Email Address: cwsimmons@ucdavis.edu

Summary
This project aims to understand the long-term effects of biosolarization (aka anaerobic soil disinfestation) fumigation alternative that relies on thermal and organic amendment-driven microbiological processes to inactivate soil pests) on orchard soils and trees. In 2017, the researchers worked with an industry partner to biosolarize an orchard during pre-plant preparations. Almond hulls and shells from the Nonpareil variety or from a mixture of pollinator varieties were used as biosolarization soil amendments. Nonpareil, Monterey, and Bennett-Hickman varieties were subsequently planted in treated and control soils in early 2018. Prior project cycles have highlighted the multi-year benefits of biosolarization to soil nutrient content and phytoparasitic nematode suppression. In the current monitoring period, differences in soil nutrients among treatment subsided but significant differences in tree growth emerged. Specifically, Nonpareil and Monterey trees grown in soils biosolarized with Nonpareil hull and shell showed significantly greater trunk diameters than the untreated controls. Multispectral imaging of the orchard canopy was performed to measure several absorbance indices associated with tree vigor or stress. At 4 years following biosolarization, Bennett-Hickman trees grown in biosolarized soils containing pollinator variety hulls and shells possessed enhanced canopy reflectance and color properties associated with elevated chlorophyll and photosynthesis compared to control trees. Based on significant CIgreen and GNDVI values, Bennett-Hickman trees grown in biosolarized soils amended with hull-rich Nonpareil residue exhibited elevated chlorophyll content compared to control trees. TCARI and red metrics for Monterey trees grown in soils biosolarized with hull-rich Nonpareil amendments exhibited elevated chlorophyll production over control trees. These results indicate that benefits to almond trees may depend on interaction effects between biosolarization conditions and tree variety.

Improve the detection and risk prediction of Pseudomonas syringae causing bacterial blast and bacterial canker of almond in California

PROJECT NO: PATH20

Principal Investigator:
Name: Florent Trouillas
Institution: UC Davis
Email Address: flotrouillas@ucanr.edu

Summary

Bacterial canker and bacterial blast of almond are two phases of a disease that can affect most parts of the almond tree, including flowers, leaves, trunk and scaffold branches. In California, the disease has been mainly attributed to Pseudomonas syringae pv. syringae, although few studies have attempted to characterized Pseudomonas species affecting almond. Recently, different species of Pseudomonas and several distinct pathovars of P. syringae have been shown to be responsible for bacterial canker and blast in various Prunus hosts worldwide. The present study aimed to investigate the diversity of Pseudomonas species associated with almond and gain knowledge of the epidemiology of bacterial blast and canker to improve disease diagnosis and management. The intraspecific diversity of Pseudomonas species associated with almonds and other Prunus species in California was investigated using phylogenetic analyses and phylogenomics. At least 7 groups (clades) representing putative 7 species of Pseudomonas were recognized from almond. These included Pseudomonas syringae, P. fluorescens, P. koreensis, P. viridiflava, P. baetica and P. rhodesiae. The study indicated also that P. syringae isolates from almond likely constitute a species complex comprising at least 3 variants. Pathogenicity studies in almond and cherry orchards indicated that isolates from groups 5 (P. viridiflava) and 6 (P. syringae) can cause disease in almond. The study revealed also that isolates from group 5 could only cause canker, whereas isolates from group 6 produced both the blast and canker diseases in almond trees. Several primers for use in conventional and real time PCR were evaluated for accurate and reliable detection of the almond-adapted pathogenic strains of Pseudomonas. This work identified primers Psy F/Psy R as being highly specific for the detection of P. syringae. Therefore, Psy F/Psy R primers were used for routine detection of P. syringae isolates in this study.

Finally, we examined the overwintering strategies and seasonal population dynamics of Pseudomonas bacteria in almond throughout the fall 2021, winter 2021-2022 and early spring 2022. This study indicated that leaves, old nut peduncles, shoot surface as well as dormant flower and vegetative buds all serve as inoculum sources for pseudomonads bacteria in almond orchards. Bacterial populations were particularlyabundant on leaves following early rainfalls in November in most locations under study. The abundance of bacteria on leaves generally was correlated with heavy fog and high moisture levels in orchards occurring throughout December 2021 and early January 2022, and following important precipitations in November and December 2021. Bacterial populations in dormant flower and vegetative buds generally were low after December in most orchards sampled. The occurrence of a few blast events in almond orchards during the bloom season of 2022 confirmed the abundance of P. syringae pv. syringae on symptomatic flowers. Several declining orchards of self-pollinating cultivars were also sampled during this study. Tree sampling from these orchards showed high levels of P. syringae in the bark of diseased trees, thus confirming bacterial canker as a leading cause of tree decline. Overall, the high population levels of Pseudomonas bacteria on leaves suggests that leaves play an important role as inoculum reservoir in the disease cycle of bacterial blast and canker, particularly in orchards where leaves remain on trees during fall until nearly mid-January. During winter rains, inoculum from leaves potentially can spread throughout the tree to other plant parts thus allowing infection of newly developed tissues in the spring. These findings suggest that an application of zinc sulfate in late October to early November to hasten leaf fall, could prevent the buildup of high inoculum levels in almond orchards during the dormant season, and thus limiting the spread of bacteria to susceptible tissue during winter and spring.

Implementing a Nematode Management System for Almond Using Chemical and Biological Treatments

PROJECT NO: PATH22

Principal Investigator:
Name: Andreas Westphal
Institution: University of California Riverside
Email Address: andreas.westphal@ucr.edu

Summary
Almonds are frequently planted following crops that leave behind assemblies of different species of plant-parasitic nematodes. Such may be the case when almond is replanted or when it follows another perennial crop. For example, walnut and grape may harbor nematode species that can also be damaging to almond. Some production issues can be averted by rootstock choice but currently there is no commercial rootstock available that resists all possible nematode infestations. Different combinations of Root-knot nematodes (Meloidogyne spp.), root lesion nematodes (Pratylenchus vulnus), ring nematodes (Mesocriconema xenoplax) and other species are common in such fields. Preplant soil fumigation with 1,3-D containing materials formulated as Telone is frequently used to reduce soil infestations of plant-parasitic nematodes. Environmental and human health concerns have led to restrictions of use of this method leading to buffer zones, tarp or other off-gassing reduction methods being required, etc.. Currently proposed changes to the application patterns of Telone potentially make treatments more expensive and some of the protocols may reduce efficacy. Alternative, cost-effective soil preplant treatments are urgently needed. In the current project, new materials and nematode management strategies are developed and tested for efficacy. Preplant treatments available for possible introduction may not be at the high efficacy level as a properly administered Telone fumigation. It seems likely that future nematode management strategies will comprise a management system of preplant soil treatments coupled with post-plant strategies. The current projects examines such strategies. In addition, strategies for suppression of ring nematode – a species that is notoriously difficult to control - complement these nematode management studies.

Evaluation of potential pest pressure reduction for early off-ground harvest

PROJECT NO: HORT58

Principal Investigator:
Name: Patrick Brown
Institution: UC Davis
Email Address: phbrown@ucdavis.edu

Co-PIs: Sat Darshan S. Khalsa, David R. Haviland, Brent A Holtz , Ricardo Camargo

Summary
Almonds (Prunus dulcis (Mill.) D. A. Webb) are one of the most economically important agricultural commodities in California. As production in the state continues to increase, growers seek sustainable methods to manage agricultural water use and pests that are affordable and environmentally sustainable. The Almond Board of California (ABC) has identified the need to transition the industry to early harvest to (1) reduce the severity of harvest water stress, enhance plant vigor and return bloom, which will improve long term yields and hence economic water use efficiency, and (2) reduce navel orange worm (NOW) and Hull Rot (HR) damage and therefore reduce dependence on pesticides. This final report details our research findings from two field sites in the Sacramento and San Joaquin Valleys during the 2020 growing season comparing harvest timing. The aim of this research is to evaluate harvest timing on irrigation scheduling yield, pest and disease pressure. Specifically, the objectives of this research were to test the efficacy of hull split regulated deficit irrigation in combination with early harvest of almonds for improved irrigation efficiency and control of pests (NOW) and disease (HR).

Hull split occurs in the two months leading up to almond harvest, during July and August in most California almond orchards. In early July, almond hulls begin to open along their suture (Figure 1). Fruits lose moisture throughout July and August, with the hull split widening and the hull pulling away from the almond shell. Different stages of hull split in almond production correspond with the extent of fruit development and are used by growers to time harvest. These stages are critical management periods because as hull split progresses there is an increased risk of pest pressure that can compromise almond yield and quality. Early harvest (EH), where almond fruits are removed from the tree 3-4 weeks earlier than standard harvest (SH), is one such strategy that can be successfully deployed with careful consideration for irrigation management.

Standard Harvest (SH) timing was compared to Early Harvest (EH) timing at approximately three to four weeks earlier in two California almond orchards using a randomized complete block design at each orchard. Stem water potential (SWP) measurements were used to monitor tree water status and manipulate irrigation to prepare trees for EH treatments. Trees were maintained at -1400 to -1800 kPa SWP for two to three weeks leading up to both EH and SH. Our results show there were significantly lower HR strikes in EH treatment trees than in SH treatment trees, and significant reductions in the percentage of kernels infested with NOW when EH was employed. There were no significant kernel yield, marketable yield, or shaker efficacy differences between the two treatments. Although 83.3 and 40.9 mm less water was applied to EH trees than SH trees at the Denair and Woodland sites respectively, the trees from both treatment regimes at both sites returned to the same water status after SH and recovered from the induced moderate water stress by the same date after harvest. With further development of complementary harvest and processing strategies, early harvest of almonds shows promise as a strategy for improved water use efficiency and pest and disease control in almond orchards.

Spray Drift Study in Orchard/Vineyard to Support Orchard Airblast Drift Modeling Effort

PROJECT NO: WATER14

Principal Investigator:
Name: Peter Ako Larbi
Institution: University of California, Davis
Email Address: palarbi@ucanr.edu

Summary

The U.S. Environmental Protection Agency (EPA) has been using a 20-year-old AgDRIFT® model to assess human and environmental exposure from spray drift from all crops. However, the agency uses a default condition of the worst-case scenario (young, dormant apple trees), a much different structure from foliated almond canopies. The dormant tree scenario can significantly overestimate drift that occurs in almond orchard airblast spray applications, leading to regulations that are potentially stricter than needed. It is therefore crucial to develop a new mechanistic model that considers actual application parameters used in real almond orchard situations.
The development of such a model is underway, an effort which started in Washington State in 2016. With the intent to validate the model using a subset of the same series of tree crops used by AgDRIFT® to develop the three composite groups, aggregated by orchard characteristics into Normal [grapes, apples], Dense [almonds, oranges], and Sparse [dormant apples], validation data was generated for Washington apples. Washington-California collaboration in 2019 led to a plan to generate validation data for almond, citrus, and grape in California, with all the commodity groups agreeing to jointly fund shared
equipment/instruments for efforts in all three commodities to minimize cost.

This report covers two projects that jointly supported efforts in almond (Water14 and ABC/ANR Spray Technology Grant Project 19-6065) with a single objective to conduct field trials to generate spray drift data for developing/validating a mechanistic airblast spray drift risk assessment model. In the composite project period covering October 15, 2019, to December 31, 2021, we pursued and obtained all funding required for the three crops, built sampling structures needed for the field experiments, purchased shared resources, configured/tested instruments, and conducted field data collection in all three California crops following the same EPA-approved protocol used for similar efforts in Washington apple.

Prior to field testing, we conducted a lab test to identify two tracer dyes from different sources for potential use in the field experiments, establishing that, depending on limitations of cost or availability, either dye can be used to generate similar data. We also evaluated the nature of air speed of a small airblast sprayer and found that the behavior of air on each side of the sprayer was somewhat different, which can be attributed to direction of rotation of the fan. Also, air speed reduced gradually with distance from the sprayer outlet and with decreasing opening of sprayer fan inlet. These differences influence target canopy spray penetration, coverage, and deposition on each side and needs to be managed for effective spray application.

The almond field study was conducted between May 26 and June 30, 2021, in a 10-year-old commercial orchard (Independence variety) having about 18-ft tall trees with 21.5 ft row spacing and 15 ft tree spacing within rows. The field setup involved: artificial spray sampling structures distributed along four equally spaced transects from within the orchard up to 600 ft from the edge of orchard; and two weather stations. Pyranine fluorescent dye solution spray was applied in 22 trials at a target application rate of 100 gallons per acre with the sprayer making four passes along the third drive lane upwind from the edge of the orchard. A complete set of samplers was installed before and collected after each trial, and each sample was analyzed by fluorometry in the lab to generate dye drift deposition data.

The data show drift deposit decline with downwind distance, indicating the extent of drift under different prevailing weather conditions. This new dataset provides opportunities for objective pesticide risk assessment decision-making that will directly impact the severity of regulations affecting the California almond industry.

Field Evaluation of Almond Varieties

PROJECT NO: HORT2

Principal Investigator:
Name: Phoebe Gordon
Institution: University of California, Davis
Email Address: pegordon@ucanr.edu

Co-PIs: Luke Milliron, Roger Duncan, Phoebe Gordon

Summary
The current generation Regional Almond Variety Trials were planted in the winter of 2014 in Butte, Stanislaus, and Madera counties. Rows of Nonpareil were alternated with 29 varieties and/or experimental selections at all three sites. Trees at the Butte, Stanislaus, and Madera trials were planted on Krymsk 86, Nemaguard, and Hansen 536 rootstocks, respectively, (with the exceptions listed at the bottom of Table 5). Unlike the previous generations of Regional Almond Variety Trials, there are four replications of each variety and selection at each of the three sites. Bloom overlap of pollenizers with Nonpareil has been generally good at all the sites, with the exception of UCD 3-40, which blooms an average of ten days before Nonpareil. Yields in 2021 were higher than in past years, primarily due to excellent weather during bloom and the young orchards nearly reaching full canopy cover. Main kernel defects observed in 2021 were doubles, twins, naval orange worm damage, blanks, and severe shrivel. Four of the varieties were not monitored in the Madera and Butte County sites in 2021 due to unacceptable field performance, and more will likely be dropped in the upcoming year.

Results & Discussion
In 2021, bloom and hullsplit data were collected at all 3 replicated trials. Light interception data was collected at the trials as well using the mobile platform lightbar. In addition, the trials were harvested for the sixth time in 2021. Yields at the Butte trial averaged from 1564 to 3579 kernel pounds per acre in the sixth leaf. At the Stanislaus trial yield ranged from 885 to 4293 kernel pounds per acre. The yields at the Madera trial ranged from 1394 to 3175 kernel pounds per acre.

Since the point of the variety trial is to identify varieties with issues that make them unsuitable for commercial production due to problems, in this early stage we are focusing on determining these factors that might make a variety or selection unsuitable for commercial production. So far we have only eliminated selections that have been discarded by the nursery that developed it. There are, however, new varieties that show promising yields across all three sites: Y117-91-03, which is being cleaned of viruses by Foundation Plant Services before release; UCD18-20, which is unfortunately afflicted with a high rate of doubles; Kester on the Hansen rootstock; and Booth. Nonpareil still has the best average cumulative yield across all three sites.
We are also working to evaluate yield and production efficiency by using data from the mobile platform lightbar that measures light intercepted by the tree canopies. We are also working with Ali Pourreza in Bio and Ag Engineering at UC Davis to further refine these relationships.

Field Evaluation of Almond Rootstocks

PROJECT NO: HORT4

Principal Investigator:
Name: Roger Duncan
Institution: UC Cooperative Extension - Stanislaus County
Email Address: raduncan@ucanr.edu

Co-PIs: Joe Connell, Katherine Jarvis-Shean, Gurreet Brar, Mohammad Yaghmour

Summary
This project is a compilation of long-term field assessments of over 25 rootstocks for the culture of almonds in California under various irrigation, weather, disease, and soil chemistry & physical conditions. This project encompasses trials conducted in five counties by UC Cooperative Extension Farm Advisors and a CSU Fresno faculty member.

Field Evaluation of Almond Rootstocks for the West Side of the North San Joaquin Valley

- Rootstock has had no substantial effect on bloom start or end dates.
- Initiation of hull split in the most vigorous rootstocks has been delayed by up to two weeks, and harvest maturity by more than three weeks compared to Nemaguard, Lovell, and Krymsk 86.
- The largest trees were on Empyrean 1, Flordaguard x Alnem, BB 106, Hansen, and Hansen x Monegro. Lovell and Krymsk 86 are the smallest trees in this trial. Paramount and Brights 5 are significantly smaller than the other PxA hybrid rootstocks and are similar in size to trees on Viking, Atlas, and Nemaguard.
- Krymsk 86 and PAC9908-02 have significantly higher leaf chloride than other rootstocks. Nemaguard and Lovell have more than three times the critical level of 0.3%. Rootpac R and the peach x almond hybrid rootstocks have the lowest chloride.
- Lovell, Atlas, Cadaman, HBOK 50, and Nemaguard had the highest hull boron while all peach x almond hybrids, Viking, Rootpac R, and Empyrean 1 had low hull boron.
- Many of the largest rootstocks were the highest yielding and had higher yield efficiencies (crop per unit of canopy or trunk circumference). Lovell, HBOK 50, Nemaguard, and Krymsk 86 have the lowest cumulative yields in this trial, producing only 40-60% of the highest yielding rootstocks. Trees on Lovell had the lowest yields and the lowest yield efficiency.

Effects of Eight Almond Rootstocks on Nonpareil Tree Growth Grown on Marginal Soil High in Boron

Trees on Nickels, FxA, and Brights 5 continue to produce the highest yields in these high boron conditions. This year yields of trees on Viking and Hansen 536 were similar to these peach-almond hybrids. Trees on Rootpac-R, Krymsk 86, and Lovell produced the lowest yields. These results are consistent with previous years. Notably, this is the third year that Rootpac-R yields have grouped with Krymsk-86 and Lovell.

Evaluation of conventional as well as growth controlling rootstocks for growth, yield, water use efficiency and photosynthetic parameters

Rootstocks included are: Nemaguard, Lovell, Cornerstone, Empyrean 1, Guardian, Rootpac R, and Rootpac 20 on Nonpareil and Monterey cultivars, planted in 2017. The effect of rootstock on gross yield per acre was significant ($P < 0.05$) with the highest yield on Empyrean1 and the lowest on Rootpac 20. The effect of scion cultivars on the yield was not significant ($P > 0.05$).

Performance of Almond Rootstocks in the Southern San Joaquin Valley

Trees were planted October 22, 2019, in a fumigated, replanted orchard on sandy loam soil where orchard recycling was performed. Titan SG1 has the largest trunk circumference and Krymsk 86 the smallest among all rootstocks. Growth of Flordaguard, resistant to a new population of peach root-knot nematode, was not statistically different from peach-almond hybrids, nor from Krymsk 86. Four rootstocks (Hansen 536, FXA, Empyrean-1, and Titan SG1) showed leaf nitrogen status slightly below the adequate range value of 2.2%. However, these rootstocks are among the most vigorous rootstocks as expressed by trunk circumference and no nitrogen deficiency symptoms were observed. Leaf tissue analyses revealed the beginning of chloride accumulation in almond trees on Krymsk 86 and Flordaguard. Sodium was not detected in samples any rootstock. There were no significant differences in midday stem water potential among rootstocks.

Integration of Tree Spacing Pruning and Rootstock Selection for Efficient Almond Production

PROJECT NO: HORT5

Principal Investigator:
Name: Roger Duncan
Institution: UC Cooperative Extension - Stanislaus County
Email Address: raduncan@ucanr.edu

Summary
2021 marked the 22nd season for this very long-term pruning & spacing trial. The pruning treatment portion of this trial was terminated at the end of 2018 (19th leaf) but data collection continued for the spacing portion through 2021. Throughout the duration of this trial, the data have consistently shown that annual pruning to improve light penetration and preserve the lower canopy has not maintained yield better than trees that have been essentially unpruned except for equipment access and safety. In general, the more that trees have been pruned, the lower the cumulative yields have been, although differences were often insignificant within a given year. Based on results of this trial, annual pruning would have cost the grower between $7,500 and $14,000 per acre in cumulative pruning costs and loss of production, depending on variety and rootstock. In general, trees on Nemaguard rootstock have the highest cumulative yields at the more closely planted spacings (10 – 14 feet apart down the row), especially for the smaller Carmel variety. For the most vigorous trees (Nonpareil on Hansen rootstock) yields have tended to be highest in the more moderate spacings (14' – 18'). Closely planted trees are smaller, shake more easily, have less cumulative shaker injury on their trunks, have fewer mummies per acre and have lost far fewer trees than widely spaced trees, regardless of rootstock. It appears that orchards with trees planted closely down the row may be easier to maintain and have a longer productive lifespan than more widely, conventionally spaced orchards.

Rootstock Breeding

PROJECT NO: HORT10

Principal Investigator:
Name: Thomas Gradziel
Institution: UC Davis
Email Address: tmgradziel@ucdavis.edu

Summary
The California almond industry's transition to more efficient water and nutrient utilization while, at the same time, adapting to less optimal soils and orchard environments, requires the introduction of new genetic solutions while maintaining the larger complex requirements for commercially effective rootstocks. Over the last 3 decades, the UCD breeding program has developed an unprecedented range in interspecies hybrids possessing both the required traits of nematode, disease and salinity tolerance within a diverse genetic background that promotes greater orchard resilience under changing production and regulatory climates. Concurrently we have developed with regional collaborators, replicated trials targeting both effective field resistance as well as a more precise knowledge of the genetic control including identification of physiological and molecular marker candidates for more efficient future identification and selection. Twelve ongoing trials currently evaluate resistance/tolerance to regionally important orchard afflictions including nematodes, soil salinity, reduced quantity and quality of irrigation water and oak root fungus. Building upon our success in identifying both promising species sources as well as individual crossing parents within species for delivering the required resistance, ongoing efforts focus on breedingthe large segregating populations of these elite germplasms to both facilitate marker development and to increase the probabilities of capturing that rare individual combining the newly targeted resistance with the wider range of traits required for commercial success. Populations developed include over 300 additional hybrids between selected species, and the propagation over 160 new clones for replicated field testing and marker development. Over the next 4 years, these advanced rootstock candidates will be further tested to identify the most promising individuals for more extensive regional validation as well as to provide elite breeding parents for future public and private rootstock breeding efforts. The identification of the most promising resistance sources and, when available, selectable markers for the specific resistance/tolerance expression, will allow continued progress in ongoing public and private breeding efforts to sustain almond orchard productivity under the challenging future climate and regulatory scenarios currently anticipated.

Utilizing Canopy Light Interception-Yield Potential Data to Improve Management of Almond

PROJECT NO: HORT13

Principal Investigator:
Name: Bruce Lampinen
Institution: UC Davis
Email Address: bdlampinen@ucdavis.edu

Summary
A mobile platform for measuring midday canopy light interception has been developed and has now been in operation for about 10 years. The mobile platform was used extensively for mapping midday canopy light interception in almond orchards again in the 2021 season. Data collected with the mobile platform suggests that there are a number of potential uses for this technology. The first is for providing a baseline for assessing how an orchard is performing relative performance to other orchards of similar age and variety. Another is for separating out the effects of rate of canopy growth from productivity per unit canopy light intercepted in different selections or varieties. A third potential use is for assessing the efficacy of different fumigants by again separating out the effects of canopy size from productivity per unit light intercepted. A fourth use is for evaluating the impacts of different pruning regimes on canopy growth, light interception and productivity per unit light intercepted. This technology also allows the elimination of canopy size differences from any type of trial.

Integrated Conventional and Genomic Approaches to Almond Rootstock Development

PROJECT NO: HORT16

Principal Investigator:
Name: Daniel Kluepfel
Institution: USDA ARS, Davis
Email Address: daniel.kluepfel@usda.gov

Co-PIs: Greg Browne, Andreas Westphal

Summary

The overall goal of this research is to identify horticulturally desirable rootstocks with improved durable resistance to key soilborne pathogens. The project is an interdisciplinary team effort involving D. Kluepfel (overall project coordination, resistance to Agrobacterium/crown gall), G. Browne (resistance to Phytophthora/crown and root rot) and A. Westphal (resistance to root lesion and root knot nematodes). In the 2020-21 research cycle our key activities included the following, listed by objective: Obj 1: Experimental rootstocks were propagated via hardwood cuttings collected from our Prunus germplasm collection located at Armstrong Field, Department of Plant Pathology at UC Davis. Rooting of these and additional standard rootstocks (e.g., Nemaguard, Hansen 536, and Krymsk 86) was conducted by Sierra Gold Nursery. In an orchard planting of fall 2020, 23 experimental and three comparative rootstocks were inoculated with root-knot and root lesion nematodes. Most of the experimental rootstocks were on track to outperform the nematode-susceptible Krymsk 86 comparative. In the 1-year nematode screening evaluation, 43 of 90 test lines including commercial comparatives had root gall rating <1 (on a scale 0-10). Objs. 2 and 3: We established multiple 2021 plantings of standard and experimental rootstocks, including trees with and without scions, at UC Davis and at Kearney Agricultural Research and Extension Center (KARE) for 2022 screens of pathogen resistance. We collected and summarized rootstock response and growth data from trials including inoculations with Agrobacterium, Phytophthora and nematode species in previous years. Additional experimental rootstock plantings were conducted at the Nickels Soils Lab and KARE to evaluate horticultural performance of the selected rootstocks in the absence of pathogen inoculations.

Physiology and Management of Salinity Stress and Nitrate Leaching in Almond: Influence of Rootstock Scion and Supplemental Nutrition

PROJECT NO: HORT20

Principal Investigator:
Name: Patrick Brown
Institution: UC Davis
Email Address: phbrown@ucdavis.edu

Co-PIs: Daniela Reineke, Francisco Valenzuela Acevedo

Summary
Heterogeneous ion distribution is a characteristic of micro-irrigation systems and yet our understanding of the biology and management of these systems is inadequate. When NaCl and nutrients are spatially partitioned, plants may avoid NaCl uptake by selectively utilizing the ideal root sub-zone, but colocalization of nutrients and NaCl causes roots to be active in saline regions resulting in increased NaCl accumulation and decreased nitrogen use efficiency. Hydroponic experiments demonstrated that even when nutrients are present in the saline root sub-zone, this effect may be ameliorated with the omission of N and K. However, the relative importance and dose response to specific ions in modulating root activity under nonuniform salinity remain unclear. Controlling the distribution of nutrients in the sub-zones of the whole root system by choosing the optimal irrigation and fertigation management may therefore be a useful tool to reduce root activity in saline zones, thereby minimizing salt uptake.

A lysimeter experiment was conducted to investigate the implications of the conclusions drawn from the hydroponic experiments for irrigation and fertigation management in a drip-irrigated almond orchard under saline conditions. Experiments were conducted using four-year-old almond trees grown outdoors in large (8 m long, 2.2 m wide, 1.2 m high) fiberglass bins that were exposed to three different irrigation/fertigation treatments (low frequency saline (LFS), high frequency saline (HFS), high frequency non-saline (HFNS)). It was shown that application of saline water (LFS) significantly increased leaf Cl concentration, but increasing the irrigation/fertigation frequency in presence of salinity (HFS) did not significantly decrease leaf Cl concentrations. HFS and LFS did however alter leaf Cu, Zn, Fe, and Mg concentrations, indicating that irrigation/fertigation frequency may still have an impact on plant growth. The absence of an effect of irrigation/fertigation frequency on Cl may be explained by insufficient nutrient concentrations within the non-saline zone created by the drip emitters or due to a smaller than expected difference in salinity and nutrient distributions between the HFS and LFS treatments. The difference with respect to other elements between the two treatments could either be an effect of the salinity dynamics caused by the different systems or by the different irrigation frequency and therefore moisture dynamics itself. As expected, a lower salinity zone under the area wetted by the drip-emitters was observed and root abundance was higher in these areas, confirming the concept of salinity-heterogeneity under drip irrigation and illustrating the preferential exploration of non-saline zones by roots.

Three-dimensional model-based analysis of the impact of variability in almond Tree structure and configuration

PROJECT NO: HORT45

Principal Investigator:
Name: Brian Bailey
Institution: UC Davis
Email Address: bnbailey@ucdavis.edu

Summary
This project proposes to develop and use state-of-the-art modeling tools to quantify and predict interactions between traits (phenotypes) and environmental conditions in the context of almond production. The scope of this project focuses more specifically on tree growth, structural development, and yield dynamics as it pertains to canopy configuration and architecture. The modeling framework will represent tree development in three-dimensions, explicitly representing every leaf and branch as it evolves in time. This approach allows for direct representation of the effects of inter- and intra-crown competition for resources such as light, and how it drives shoot growth and spur dynamics.

The overall goal of this project is to develop a detailed, three-dimensional modeling framework that can inform breeding and selection practices by predicting how tree structure and growth/yield dynamics vary in response to variability in genotypes, management, and orchard configuration. The model will then be used to determine optimal tree structures that maximize yield over the lifespan of an orchard. This project fits within a wider vision of incorporating next-generation models within the modern breeding pipeline to accelerate the rate of new cultivar development and assessment.

Specific objectives of the project are as follows:

1. Collect phenotypic data for model parameterization
2. Develop and validate improved models to predict the 3D development of canopy structure, spur dynamics, and yield
3. Determine optimal tree architectures for various orchard configurations, and quantify the associated potential yield and efficiency gain

Field measurements of structure and leaf physiology were collected on four different varieties with varying tree architectures to aid in model testing and calibration. A framework for modeling the 3D structure of shoots during growth has been implemented and is being extended to full tree structural development. Preliminary simulations on idealized canopies suggest sprawling tree architectures may be advantageous in terms of productivity and water use efficiency prior to canopy closure. Whether this productivity and efficiency can be maintained throughout the lifespan of the orchard is a focus of ongoing research within this project.

The application of molecular tools and quantitative phenotyping for genomics-assisted breeding in almond

PROJECT NO: HORT46

Principal Investigator:
Name: Gina Sideli
Institution: UC Davis
Email Address: gsideli@ucdavis.edu

Summary
This project aims to integrate genomics-assisted breeding tools in the UC Davis breeding program and extend the availability of these tools to commercial breeders. Molecular markers have been used extensively in modern breeding programs to increase precision and speed selections, as well as to identify genetic relationships between diverse varieties. Marker-assisted breeding can reduce the time it takes to select for advantageous traits, thereby enhancing genetic gain. Exome sequencing is one molecular breeding tool that to identify variants in a population, particularly traits that are significant but less common. These tools can be combined to make genomic predictions, forecasting phenotypes from breeding crosses based on marker effects, genetic relationship and performance for a trait. Each of these tools can assist breeding schemes by increasing precision and expediency. This project uses these technologies to understand genetics of traits for almond quality, phenology (timing of tree development such as budding, harvest, etc) and pest resistance to better inform breeding selection decisions.

Applied epigenomics towards measuring the risk of noninfectious bud failure in almond

PROJECT NO: HORT47

Principal Investigator:
Name: Jonathan Fresnedo Ramirez
Institution: The Ohio State University
Email Address: fresnedoramirez.1@osu.edu

Summary
Noninfectious bud failure (NBF) has been recognized as a threat to the almond industry since the beginning of the 20th century, claiming cultivars such as 'Jordanolo' and 'Carmel.' Even with the development of new cultivars and breeding germplasm, the disorder is still present, threatening new varieties as well as the continued propagation of old varieties. Despite the threat posed by NBF, little is known about its origin, prevention, or measurements to decrease the risk of incidence. One theory is that epigenetic mechanisms (i.e., mechanisms that modify gene expression without modifications to the actual DNA sequence) which are influenced by environmental conditions that trigger the onset and exhibition of NBF. In 2017, Fresnedo-Ramirez and collaborators found that scions exhibiting NBF showed a distinct pattern of DNA-methylation (the best-studied epigenetic mark in genomes). This project aimed to test the association of DNA-methylation and the exhibition of NBF in current almond germplasm. We have produced methylation profiles for distinct almond cultivars and breeding selections from distinct growing regions in California and Murcia, Spain. Through our analysis, we have shown the variability of the methylomes of distinct almond genotypes grown in distinct environments, indicating that DNA-methylation is a promising indicator of the potential for breeding and nursery clones to exhibit NBF. This promising result may lead to development of a commercial assay to allow nurseries and breeders to reduce the likelihood of NBF in the future.

Are Californian almond cultivars and rootstocks susceptible to PPV and can almonds be a host for the spread of Sharka in California?

PROJECT NO: HORT48

Principal Investigator:
Name: Manuel Rubio
Institution: Centro de Edafología y Biología Aplicada del Segura (CEBAS) Consejo
Email Address: mrubio@cebas.csic.es

Summary
Plum pox virus (PPV) is responsible for Sharka disease, which is one of the most important limiting factors for Prunus production (apricot, plum, prune and peach) in affected areas.
PPV was detected in the USA in 1999, and it was declared eradicated by the USDA in October 2019, after 20 years of fighting. Despite the official declaration of eradication, Sharka is still of great importance, mainly because of the huge quarantine efforts and millions of dollars spent on it, even though it has never been described in California.
Studies about Sharka on Californian almond cultivars and rootstocks are scarce, and the behavior of these cultivars and rootstocks against Sharka remains unknown. Several years ago, our own results showed a limited potential role for almond as a virus source in Sharka epidemics. However, Sharka is still a global threat for areas of stone fruit production including almond.
Based on the little information available, it is important to know the level of susceptibility/resistance presented by almond varieties as well as the rootstocks used by the almond industry in California, clarifying the possible role almond trees could play in the permanent threat that Sharka represents.
The preliminary results obtained in the eleven almond cultivars studied, are confirming the resistance showed by almond species against PPV. However, ten out twelve rootstocks included in our assays, have displayed important sharka symptoms and ELISA and RT-PCR positives, showing resistance only two rootstocks the interspecific hybrid ‘GF677’ and the almond seedlings ‘DryStock One’. This results, point the importance that rootstocks could play in a potential outbreak of sharka disease in California.

Discovery of genetic variation in related self-fertile species of almond

PROJECT NO: HORT49

Principal Investigator:
Name: Pedro Jose Martinez-Garcia
Institution: Centro de Edafología y Biología Aplicada del Segura (CEBAS) Consejo
Email Address: pjmartinez@cebas.csic.es

Summary
The almond breeding program at the University of California at Davis is developing traits for new California varieties, including new sources of self-fruitfulness (i.e. self-compatibility), improved disease and pest resistance, improved water efficiency and adaptation to a changing climate. Globally, most self-fruitful almond varieties use a single genetic source of the trait and thus limit the range of genetic traits that can be combined easily into new varieties. UC Davis has developed advanced introgression lines transferring self-fruitfulness from multiple independent sources including P. webbii, cv. 'Tuono', P. mira, and P. persica (peach). Several factors affect the breeding efficiency for self-fruitfulness as the degree and stability of the trait and the tedious and time-consuming backcrossing required for successful trait introgression. Although, molecular markers exist for the Tuono source of self-compatibility, this project will develop markers to allow breeders and nurseries to use novel sources of improved self-fruitfulness cultivars from UC Davis.

Advances in high-throughput sequencing technologies provide a great opportunity to bring molecular breeding to full application in California almond breeding. Molecular breeding allows more efficient selection by using genomic variation that is known or demonstrated to be tightly linked to alleles with superior phenotypes. A robust breeding program requires knowledge of the many alleles at each genetic locus in the Prunus gene pool. This project will identify allelic variants for self-fruitfulness cased by or tightly linked to single nucleotide polymorphisms (SNPs). Once identified, these will be made available to breeders and nurseries to accelerate development of new sources of self-fruitful almond varieties for California.

Field Screening of Size Controlling Rootstocks for Off-Ground Harvested Almond Orchards

PROJECT NO: HORT50

Principal Investigator:
Name: Roger Duncan
Institution: UC Cooperative Extension - Stanislaus County
Email Address: raduncan@ucanr.edu

Summary
Many stonefruit industries have turned to size controlling (dwarfing) rootstocks to maintain smaller tree size to accommodate cultural activities. Higher density almond orchard systems using dwarfing rootstocks for off-ground harvesting systems has not been adequately explored. Rootstock compatibility with Nonpareil and Monterey Scions. After planting in the fall of 2020 and during spring of 2021, growth on all rootstocks appeared to be good, normal, and healthy. However, by May 2021, scattered trees of both varieties on Citation and Controller 9 rootstocks began to show signs of distress, including stunted growth and pale, rolled leaves with necrotic edges. Symptomatic trees on Controller 9 often displayed a brown line at the bud union when the bark was scraped with a knife. Brown lines were not obvious on randomly selected symptomatic trees on Citation. By July, many affected trees of Monterey on Citation rootstock collapsed and died suddenly. By the end of the first season, 17.9% and 78.6% of Nonpareil and Monterey trees, respectively, on Citation rootstock, showed obvious signs of distress and 53.6% of the Monterey trees on Citation died. No trees of Nonpareil on Citation died and no trees of either variety on Controller 9 died during the first season. Samples of both scions on Citation and Controller 9 were submitted to Foundation Plant Services for virus testing. Both scions on Controller 9 were infected with plum bark necrosis stem pitting-associated virus. No pathogenic viruses were detected in Citation. Diagnostic field symptoms and the lack of obvious fungal cankers or signs of other biotic or abiotic problems suggested the problem was caused by incompatibility between the rootstocks and scions.

Phytophthora: By midsummer 2021, several trees on TRIO 2507 rootstock also exhibited signs of distress (stunted growth and rolled, burned leaves). Further inspection revealed that symptomatic trees of TRIO 2507 showed the presence of amber gummosis extending below ground and several inches up the trunk. In September, 2021, all trees were inspected for obvious signs of crown gummosis. Half of all Monterey trees and 35.7% of Nonpareil trees on TRIO 2507 rootstock exhibited crown lesions and associated gumming. In addition, 7.1% of Nonpareil trees on Controller 6 showed similar crown lesions. Subsequent tests by Dr. Greg Browne, USDA ARS, confirmed affected trees were infected by Phytopthora spp. It isunknown whether the Phytopthora originated from field infections or were present in nursery trees when planted.

Rootstock dwarfing: Trees on most rootstocks grew well during the first season,. End-of-season trunk circumference measurements indicated growth of tested rootstocks ranged from 65% to 109% of trees on Nemaguard. Trees on Brights 5 peach x almond hybrid were the largest (106-109% of Nemaguard with Monterey and Nonpareil scions, respectively). Nonpareil trees on Controller 6, MP-29, and D63.182 rootstocks were smaller than Nemaguard trees but not with Monterey scions ($P<0.05$). Trees on 3776, TRIO 2507, Citation, Controller 9, DA 6, and Rootpac 20 were significantly smaller than Nemaguard for both varieties. Rootpac 20 was the most dwarfing of the tested rootstocks, with trunk circumference of both varieties an average of 65% of those on Nemaguard. Trees on Citation and Controller 9 were smaller than those on Nemaguard, but some of the average reduction in growth was surely increased because of the incompatibility and Phytopthora problems associated with these rootstocks.

Accelerated Assessment of Almond Variety Candidates

PROJECT NO: HORT51

Principal Investigator:
Name: Thomas Gradziel
Institution: UC Davis
Email Address: tmgradziel@ucdavis.edu

Summary
California almond production has a long history of exploiting a rich genetic diversity in cultivars introduced from around the world during and just after the gold rush with a "can-do" orchard management perspective that has transformed production from its traditional status as a low-input/low-return crop planted on marginal land to a major global commodity. As it enters a similar transformative era, those resources will again be called upon to maintain its role as a world leader not only in almond production but also in ag innovation. Because of long-term efforts to incorporate diverse germplasm from European and Asian almonds as well as related wild almond and peach species, the UC Davis Variety Development Program currently contains more promising almond genetic diversity than any other collection in the world, including at the otherwise very impressive nearby USDA/ARS Germplasm Repository. The UCD breeding program has incorporated much of this new and diverse germplasm into California adapted selections meeting commercial requirements for nut quality and tree productivity while possessing novel characteristics such as self-fruitfulness, improved resistance to diseases, pests and environmental stresses such as frost, drought and salinity, as well as novel tree architectures and bearing habits. The incorporation of novel traits inherently runs the risk of also incorporating undesirable traits, some of which may not be readily detectable. To rogue-out selections with undesirable traits, a series of regional trials have been developed to allow accelerated assessment of promising breeding candidates prior to larger scale Regional Variety Trial (RVT) testing. In 2020/21, five new regional accelerated assessment trials were added for evaluating over 50 new UCD and international selections, totaling over 3000 trees. These trials and novel genetics also offer opportunities to develop and test innovative crop management strategies such as exploiting modified tree and nut architectures for more efficient catch-frame harvesting and/or orchards designed to maintain consistent production with reduced water quality and quantity. Likewise, previously unavailable traits such as self-fruitfulness and very early (mid-June) harvests permits the opportunity to decouple current season crop production from flower initiation (which determines next season's potential crop) thus allowing even more transformative cropping systems where current season production and flower production for next year's crop are no longer competitive processes can be independently optimized.

Evaluating new breeding material for salinity tolerance in almond rootstocks and exploring novel sources of salinity tolerance in Prunus germplasm

PROJECT NO: HORT55

Principal Investigator:
Name: Devinder Sandhu
Institution: USDA ARS, Riverside
Email Address: devinder.sandhu@usda.gov

Summary
The principal goal of the proposed study is to develop new vigorous rootstocks resistant to diseases, insects, and nematodes, as well as tolerant to salinity. Breeders (Drs. Tom Gradziel, UC Davis, Malli Aradhya (USDA-ARS Davis), and Daniel Kluepfel, USDA-ARS Davis) have evaluated various rootstocks for traits, including performance, vigor, biotic stresses, and abiotic stresses, and selected some elite hybrids. We have evaluated this elite set of rootstocks, including 26 from the Gradziel group and 19 from the Aradhya-Kluepfel group, for salinity tolerance in the 2020-21 season. Different hybrids were classified based on the survival rate and the relative change in trunk diameter. The survival rates of the genotypes varied from 0% to 100%, and the relative change in trunk diameter varied from 0.79 to 1.11. Seven rootstocks had survival rates of 100% and the relative change in the trunk diameter more than 1. Leaf Na and Cl concentrations were negatively associated with survival rates suggesting that exclusion of Na and Cl is an important component trait of salt tolerance mechanisms in Prunus. Proline ratio (salt/control), an indicator of salinity stress, also displayed an inverse relationship with the survival rate, suggesting that it can be used as an important biochemical marker for screening salinity tolerance of Prunus rootstocks. Sixteen selected rootstocks from the current study are being evaluated for their salinity tolerance in the second year.

Comparing root traits and depth distributions for mature almond rootstocks; is there a link between root architecture and propagation method?

PROJECT NO: HORT67

Principal Investigator:
Name: Astrid Volder
Institution: UC Davis
Email Address: avolder@ucdavis.edu

Summary

Propagation methods that do not use seeds (e.g., cuttings, tissue culture) have many advantages, such as uniformity of traits and a high rate of production. However, one possible disadvantage is the change in root architecture that can be expected when roots are generated artificially or develop as adventitious roots. In a germinating seed a main root that grows straight down is developed first after which lateral roots develop at regular distances along the axis of the main root. In young trees originating from cuttings or tissue culture the goal generally is to produce as many roots as possible. All these roots originate close to the base of the sapling, potentially crowding each other out as the tree matures. This process can lead to cracks developing at the base of the tree, allowing for increased disease vulnerability and structural instability. In addition, as these roots extend laterally from the base (instead of vertically as would happen in a seedling), it is likely that these framework roots do not develop as deep into the soil profile. More shallow root systems will need more frequent irrigation when evaporative demand is high (i.e., during the summer season). We propose to do a more in depth survey as to how root architectural traits and framework rooting depth vary across almond rootstocks developed with different propagation methods and planted in different locations across the state. We will air excavate root systems and quantify rooting depth and quantify architectural design using a LiDar scanner. In addition, we will run a targeted field experiment to study the initial (1-2 year) development of seedling versus cutting versus tissue culture produced root systems on a few select rootstocks.

Effective use of water by deeper rooting can make a large difference in the overall water budget, where deeper rooted trees will be more resistant to short term drought conditions in the upper soil layers. This reduces the need for frequent irrigation in the summer months. In addition, by testing the idea that propagating more roots is “always” better we will get a better handle on long term impacts of propagation methods aimed at increased rooting. Many studies have shown that more roots increases transplanting success, however, few (none?) have followed up by tracking root architecture once the tree matured. Field observations we made on 5 year old tissue culture produced trees that we air excavated appear to suggest that more structural cracks occurred at the base of trees that had more roots radiating from them.

Answering these questions can have long term beneficial impacts on the production and use of rootstocks in California almond orchards. The ideas we propose to test will provide data that will inform future water use and carbon sequestration models, as well as a field evaluation of root traits of mature rootstocks as affected by propagation method. The questions arising from this work are of great interest to the orchard industry as a whole as it is aimed to quantify how tree propagation method affects rooting depth (access to deep water), root defects (potential for disease development), and soil exploration
(branching of the root system).

We will do an in-depth survey as to how root architectural traits vary across almond rootstocks with different production methods and planted in different locations across the state. For that we will air excavate root systems and quantify rooting depth and architectural design using a LiDar scanner (Bailey lab). In addition, we will do a targeted field experiment to study the initial (1-2 year) development of seedling versus cutting versus tissue culture produced root systems on a few select rootstocks.

Resilient Prunus rootstocks for a changing climate

PROJECT NO: HORT57

Principal Investigator:
Name: Harley Smith
Institution: Commonwealth Scientific and Industrial Research Organization (CSIRO)
Email Address: Harley.Smith@csiro.au

Summary
This project will investigate methodologies for establishing a genetic transformation system for Prunus rootstock that could be used for gene editing to develop improved rootstocks in the future. Genetic transformation systems provide a pathway to introduce key traits into existing rootstocks without having to go through lengthy breeding cycles, as a means to improve rootstock performance to meet challenges associated with a changing climate. In this project, methods in plant regeneration will be explored, as this is a necessary step in the development of a transformation system. If successful, the project will evaluate agrobacterium mediated transformation of genes used to select for transformed plants. Future project(s) could utilize the transformation and plant regeneration system to introduce or edit genes that increase rootstock performance in a changing climate.

Yield prediction for resource management and yield optimization in almond

PROJECT NO: HORT66

Principal Investigator:
Name: Patrick Brown
Institution: UC Davis
Email Address: phbrown@ucdavis.edu

Co-PIs: Sat Darshan S. Khalsa, Yufang Jin, Mason Earles, Brian Bailey, Stavros Vougioukas, Douglas Amaral

Summary

Optimization of a resource management using remote sensing tools is limited without biological insights into yield drivers in tree crops. In turn, precision water and N use is constrained by a limited understanding of predicting yield and adjusting water and N fertilizer to match tree demand. Uncovering the biological mechanisms that determine yield in tree crops together with the development of remote sensing tools for scalable allows this proposal to develop scalable solutions grounded in tree biology and agronomy. Predicting yield will require a more in depth assessment of the drivers of yield in tree crops including spur dynamics and monitoring fruit set. These parameters in combination with remote sensing technologies will underscore the biological basis for the development of scalable tools and solutions for precision management.

In 2021, we made substantive progress toward our work objectives. We selected more than 360 data trees across grower sites near Woodland, Vacaville and Madera, California including cultivars of 'Nonpareil', 'Monterey', 'Independence' and 'Wood Colony'. We identified and tagged branches for all data trees. During three monitoring periods including bloom, mid-April and late July, we collected a complete dataset of 128 trees for total two cultivars and four NDVI classes at the Woodland site. Furthermore, measured trunk circumferences and collected July leaf samples for all data trees at all study site locations. At harvest in Woodland, we collected individual tree yields at all data trees and measured crackout, kernel size, fruit yield and kernel yield for 'Nonpareil' and 'Monterey' across four NDVI classes. All tree data was openly shared with all project collaborators in order to facilitate data workup and delivery of project goals.

Jin Lab has been leading the task of developing scalable machine learning models to predict almond yield from cultivar to block level early in the season and adjust the prediction in the mid-season (Obj. 3: Develop cultivar level yield prediction and improve block level prediction early in the season). In 2021, we made substantive progress for each one of the proposed tasks toward improving yield prediction.
Dr. Earles Lab has been leading the task of developing AI-enabled ground-level tractor mounted yield and phenology sensors (Obj. 2). In 2021, we made progress on these objectives, with some learnings, and are continuing to work toward them in 2022.

Dr. Vougioukas Lab has developed an instrumented bin which attaches to the receiver unit of a shake & catch system. A conveyor on the receiver drops the almonds into the bin which weighs the load and records the precise location of the tree. This data is processed to produce a yield map for the orchard. After weighing, the almonds are dropped from the bin into a windrow for drying. This research tool focused on obtaining high accuracy rather than matching the speed of commercial harvesters.

In 2021 the UC Davis bin was used to collect and weigh the fruit load from 128 individual data trees at the Westwind orchard in Woodland and 1,937 trees at the Sharma orchard in Vacaville. A detailed tree-level color-coded yield map was produced for the trees harvested at the Sharma orchard.

Cross-project approach to accelerate multidisciplinary research on the interaction of nonstructural carbohydrates (NSC) with biotic and abiotic stresses management practices and varieties in assessing NSC's dynamics impact on yield

PROJECT NO: PREC8

Principal Investigator:
Name: Maciej Zwieniecki
Institution: UC Davis
Email Address: mzwienie@ucdavis.edu

Summary
Main Goal: To use the Carbohydrate Observatory analytical capacity to develop, coordinate, and implement a cross-project analysis of NSC seasonal dynamics for ABC funded projects to accelerate our understanding of the NSC role in almond production and to provide support to individual projects' principal investigators.

Objectives:

(1) Analysis of NSC within each experiment funded by ABC or independently funded research benefiting almond growers by addressing the issue of intensive sample collection, in-depth analysis of results and bi-directional communication of knowledge.

(2) Acceleration of NSC research by utilizing all projects simultaneously in a cross-disciplinary approach to better understand NSC dynamics as affected by cultivar and abiotic and biotic stressors to provide guidance in the management of almond orchards and increased yield.

Milestone 1: Develop and implement procedures for effective cross-project collaboration that meets each specific project specifications. Develop and streamline analysis to meet the objectives of each project. Provide timely data interpretation. In 2021 we have conducted extensive discussion with researchers supported by ABC to find projects that would benefit from information about non-structural carbohydrates. Selected project for collaboration include:

- Yield prediction for resource management and yield optimization in almond - Sat Darshan Khalsa
- Three-dimensional model-based analysis of the impact of variability in almond tree structure and configuration – Brian Bailey
- Whole Orchard Recycling - Mae Culumber, Brent Holtz
- Determining almond tree water use and stress using surface energy balance models with unmanned aircraft systems -Andrew McElrone, Nicolas Bambach, Kosana Suvocarev
- Navel orangeworm modeling – Houston Wilson
- Improving water productivity of almond orchards by deficit irrigation and biostimulant application – Giulia Marino

Milestone 2: NSC analysis would be tied to each project specific timeline.

In 2021 we have developed the timeline for the sampling and started analysis - we have analyzed over 2000 samples for NSC content. Data from analysis are also used in long term project run by Zwieniecki lab to developed use of NSC as a tool in optimization of management practices.

Implementation of gaseous chlorine dioxide fumigation to improve post-harvest stockpile management of almonds

Principal Investigator:
Name: Vivian C.H. Wu
Institution: USDA ARS, Albany CA

Co-PIs: Alison Lacombe, Bhargavi Rane, and Paul Pratt

Project Summary
Stockpile management of in-hull almonds directly after harvest and before processing almonds is critical because of its potential to harbor myotoxic molds such as Aspergillus and insect pests like the navel orange worm. We have developed a nonthermal gaseous chlorine dioxide (ClO2) fumigation system to target moisture-induced mold growth, augment insect control, and reduce the risk of aflatoxin contamination during almond stockpiling. We utilized a phased approach to progress the ClO2 fumigation technology from laboratory study with pathogens to onsite pilot studies with environmental challenges. Laboratory scale experiments determine that 0.02 mg/L ClO2 can reduce 87.1% of A. flavus molds, 96.7% reduction of aerobic bacteria, 83% reduction of coliforms, and 88.3% reduction of yeasts & molds present on in-hull almonds. A gas concentration of 0.1 mg/L of ClO2 demonstrated a 100% mortality rate on premature (24 h old) and mature (48 h old) NOW eggs post-treatment. When the treatment was increased to 2.9 mg/L, a 99.7% reduction of A. flavus molds and 80% degradation of aflatoxins was achieved. Analysis of the genomic expression of A. flavus following gaseous ClO2 exposure suggested that cellular aflatoxin is impaired due to the lower relative abundance of the critical toxin-producing genes laeA and lipA. In addition, the quality of almond kernels, lipid peroxidation, and color was not affected at the antimicrobial treatment concentrations. This data was carried forward to a pilot scale trial of almond stockpile on the Harris Wolfe premises. A 1 metric ton challenge study was conducted on third-shake in-hull almonds following the Almond Board of California stockpile guidelines. The stockpile was placed directly on the ground and covered with an industrial grade 'white on black' tarp. Gaseous ClO2 was generated using equal amounts of two dry precursors (NaClO2, FeCl3, and zeolite crystals) placed in a vibratory mixer inserted into a 30-gallon plastic drum (ICA TriNova, LLC). The drum was connected to a centrifugal blower to actively diffuse the gas into the pile through aeration ducting placed at the far end of the pile for 24 h. The relative humidity (RH) was monitored using a hygrometer logger, and the gas concentration was detected using a detector probe during treatment. After 24 h of active diffusion, the gas injection was stopped, the holes in the tarp were duct-taped, and the stockpile was left undisturbed for one month of storage. The gaseous ClO2 concentration was observed to be evenly distributed under the tarp within minutes and dropped to 0 mg/L in less than 2 hours. No visual mold was observed on the control and the treated pile directly. However, a ring of mold growth was observed on the untreated in-hull almonds in contact with the ground, where condensation was collected. Our study suggests that a batch treatment of ClO2 would help prolong the storage of in-hull almonds and their kernels in situations of moisture challenge. In addition, efficiency would be higher in known condensation pockets, such as the tarp based, with direct application of mixed precursor. Currently, gaseous ClO2 can be used as an antimicrobial agent for fumigating raw agricultural commodities in the process of preparing, packaging, or holding food for commercial purposes consistent with the Food Drug and Cosmetic Act section 201(q)(1)(B)(i). Furthermore, the EPA has received an expanded pesticide product registration to label gaseous ClO2 as an antimicrobial pesticide for an additional 14 crop groups, including tree nuts. The findings of this study, along with the removal of regulatory hurdles, can be used as a foundation to conduct more extensive pilot-scale studies allowing gaseous ClO2 to be commercially validated.

Randomized controlled trial of almond supplementation vs. isocaloric diet on cognitive functions in middle-aged (40-60 years) Asian Indians with Prediabetes

Principal Investigator:
Name: Anoop Misra
Institution: National Diabetes, Obesity, and Cholesterol Foundation (NDOC)
Email: anoopmisra@gmail.com

Objectives
This 24-week, randomized, controlled, parallel-arm, clinical trial hypothesizes that almonds (20% of energy intake per day) will improve cognitive function in middle-aged Asian Indian with prediabetes. This free-living randomized control parallel arm study of 24 weeks of almond intervention, will recruit apparently healthy middle aged (age range 40-60 years) prediabetic Asian Indians having fasting blood glucose ≥100mg/dl and <126 mg/dl and /or 2-h plasma glucose ≥140mg/dl and <200mg/dl (after ingestion of 75-gram anhydrous oral glucose). The primary objective of the study is to evaluate the effect of almond supplementation on cognitive functions using computerized neuropsychological assessment systems (CANTAB). The study will also evaluate changes in neuroimaging (blood flow, and the expression of functional brain networks during cognitive demands) using functional MRI.

Current Status
The study has obtained IRB approval and has screened 30 subjects and enrolled 10 to date. S. Kalgaonkar visited the study site and the site for MRI assessment in May 2022.

Almonds and the gut-brain axis: a randomized controlled trial to improve mental health, psychological distress, and quality of life

Principal Investigator:
Name: Eirini Dimidi
Institution: King's College London, London, UK
Email: eirini.dimidi@kcl.ac.uk

Objectives
The aim of this project is to explore the effects of whole almonds on mental wellbeing, compared to a commonly consumed snack. A single-blinded, two-arm, parallel-group RCT will be undertaken over 12 weeks in 84 healthy adults with symptoms of psychological distress. Participants will receive either 56g of almonds (28g twice daily) or an isocaloric commonly consumed snack (lab made muffins) for the intervention duration. Major outcomes will be assessed at weeks 0, 6, and 12. A range of validated tools and techniques will be used to assess mental wellbeing, sleep, and quality of life. Gut microbiological outcomes will also be assessed to provide the role of microbiota in mental wellbeing.

Understanding the mechanism of long-term almond consumption on chronic glucose regulation and its translation into improved vascular function and cognitive performance: The AL-INCLUSIVE trial

Principal Investigator
Name: Jogchum Plat
Institution: Maastricht University Medical Center (MUMC), Maastricht, Netherlands
Email Address: j.plat@maastrichtuniversity.nl

Objectives
To examine and understand the impact of long-term almond consumption on chronic glucose regulation in subjects with impaired glucose tolerance. The primary hypothesis is that almond consumption over five months improves chronic glucose metabolism in subjects with impaired glucose tolerance (IGT). Whole body insulin sensitivity will be measured by a hyper-insulinemic-euglycemic clamp. The study is a 12-month long-term randomized controlled intervention trial with a cross-over design, including 34 overweight and obese (BMI<35 kg/m2) men and women with IGTT. During the intervention period of 5 months, subjects will receive daily 50g almonds, but not in the 2 months wash out and 5 months control periods. Both groups will receive instructions about health dietary guidelines. Therefore, effects of almonds will be evaluated against a healthy background diet. A secondary research question is whether improved chronic glucose metabolism after long-term almond consumption can translate into improved peripheral & brain vascular function, and enhanced cognitive performance.

Current Status
All subjects have completed the intervention. The research team was able to draft an abstract for submission to the 22nd International Congress of Nutrition (IUNS-ICN 2022) by the extended deadline. The abstract was submitted; however, a post-submission error was identified in one of the glucose metabolism measures and the abstract submission has since been withdrawn. The team submitted a manuscript with results from the study to the American Journal of Clinical Nutrition but the manuscript was not accepted. The team is working to re-submit the manuscript to another journal.

Effects of almonds on glycemia in adults with elevated HbA1c concentrations

Principal Investigator
Name: Richard Mattes
Institution: Purdue University, W. Lafayette, IN
Email Address: mattes@purdue.edu

Objectives
This 16-week, randomized, controlled, parallel-arm, clinical trial will assess the effects of almond consumption on longer-term blood sugar control. Eighty-four adults with prediabetes will be recruited through public advertisements. Eligibility will be determined at a screening session and those meeting specified criteria will be randomly assigned to receive 56g/d of almonds or a control snack (pretzels or cereal mix). Participants will be requested to consume their almonds in two 28g (1 ounce) portions: one serving with breakfast and one serving as a replacement of a mid-morning snack. Compliance with the dietary prescription will be assessed by measurement of plasma alpha tocopherol and circulating fatty acid profile at baseline and week 1. The primary outcome will be a reduction of HbA1c.

Current Status
The study initiated subject recruitment but ran into recruitment issues and requested a change in scope to broaden inclusion criteria. These changes included changing the BMI criterion to >20kg/m2 and changing HbA1c level requirement to > 5.7% without diabetes complications. The researcher assured that neither change would have an impact on the study outcomes. This request was reviewed and approved by the Nutrition Research Committee in April 2022.

Effect of almond supplementation on gut health and glycemic control in adults with prediabetes in rural settings of Karnataka, India: impact assessment in a cluster parallel randomized trial

Principal Investigator
Name: Ruchi Vaidya
Institution: Ramiah International Centre for Public Health Innovations, Bangalore, India Email Address: ruchi.vaidya@ramaiahgroup.org

Objectives
A total of 178 prediabetic Indian adults (89/study arm) of the age group 20-50y of both genders will be recruited from the rural settings of 3 taluks (Chikbalapur, Kolar, and Rural Bangalore). The intervention arm will be provided with 56g/d of whole almonds for a duration of 16 weeks. The control group will be provided with an isocaloric local snack for the same duration. Primary endpoint will assess the effect of almonds on HbA1c and gut microbiota and the secondary endpoint will assess their effect on fecal SCFAs.

Current Status
The study agreement has been signed. IRB application has been submitted. Almond order has been placed. S. Kalgaonkar visited the study site in May 2022.

Diet and lifestyle intervention strategies to treat β-cell dysfunction and insulin resistance in Asian Indians

Principal Investigator
Name: Jeannie Tay
Institution: Singapore Institute for Clinical Sciences, A*STAR, Singapore
Email Address: Jeannie_Tay@sics.a-star.edu.sg

Objectives
This 24-week, parallel arm, randomized controlled trial aims to determine the differences in glycemic outcomes in 60 Subjects (30/group); Asian Indian men and women; body mass index (BMI): 23-40; 21-50y on a low glycemic diet vs. a control diet. Primary outcomes include ß-cell response and insulin sensitivity evaluated using 3h-75g oral glucose tolerance test (OGTT). Secondary outcomes include body fat distribution using MRI (abdominal, pancreatic, and gluteofemoral fat), body composition (DXA), genotyping analyses to assess a 53-SNP genetic risk score comprising 53 genetic variants representative of an insulin resistance phenotype, and biochemical measures such as glucose, insulin, C-peptide, total cholesterol, HDL-C, TAG, markers of inflammation (CRP, IL6, and TNF-alpha) and satiety hormones (leptin, ghrelin, peptide YY, gastric inhibitory polypeptide, and glucagon-like peptide 1).

Current Status
The study has been planned for 60 participants and is being conducted over 3 separate randomized cohorts to manage participant flow and engagement. Recruitment for cohort 1 was initiated in Sept/Oct 2020 and completed in April-June 2021 (14 participants completed the study). Second cohort commenced the study in Jun/Jul 2021 with 15 participants and completed the study in December 2021 (12 participants completed the study). Cohort 3 commenced in August-September 2021 and many participants dropped out due to a rise in COVID again. The research team commenced a fourth cohort in March 2022 to make up for the dropouts. The new projected timelines show manuscript preparation and submission by June 2023.

Evaluation of pre-meal and bedtime load of raw almonds on postprandial hyperglycemia and other metabolic responses in Asian Indians with prediabetes

Principal Investigator
Name: Anoop Misra
Institution: Diabetes Foundation (India), New Delhi, India
Email Address: anoopmisra@gmail.com

Objectives
This study hypothesizes that dietary intervention with almonds (60g per day, 20 g before breakfast, lunch, and dinner) may decrease the glucose and insulin excursions after meals, and thus reduce overall hyperglycemia. The primary objective of the study is to evaluate the effect of preload of 20g of raw almonds to major meals on postprandial glucose levels in Asian Indians with prediabetes. Secondary objectives include measuring overall glycemia (HbA1c), 3-day continuous glucose monitoring system (CGMS), serum insulin, GLP-1, free fatty acids, triglycerides, HOMA-IR, tumor necrosis factor alpha, glucagon, pro-insulin, and satiety. Effect of a single preload of almonds is being evaluated with oral glucose tolerance test as part of an acute study. A three-day almond preload, monitored with CGMS, is being evaluated as part of a sub-acute study, and a 90-day almond intervention with self-monitoring of blood glucose and glycosylated hemoglobin will be evaluated as part of a chronic study. Acute and sub-acute studies will follow a cross-over study design.

Current Status
This study has three phases (acute, sub-acute, and chronic) and each phase needed 60 completers. The research team reports that all three phases have been completed with 60 subjects each. Additionally, data analysis is complete on acute and chronic studies. A manuscript featuring the results of the acute and sub-acute was submitted to AJCN, but was not accepted. The research team submitted a revised manuscript to the Journal of Nutrition and Diabetes in mid-April. A manuscript with the results from the chronic analysis was submitted in July 2022 to the Journal of Clinical Endocrinology & Metabolism.

Effect of almond supplementation in overweight Indian adults on insulin resistance, glycemic markers, inflammation, and satiety

Principal Investigator
Name: Sudha Vasudevan
Institution: Madras Diabetes Research Foundation, Chennai, India
Email Address: s2r_7@mdrf.in

Objectives
This randomized, controlled, two-arm study aims to determine the effects of almond supplementation on 1) insulin resistance (HOMA IR) and beta cell dysfunction, 2) biomarkers of glucose metabolism (i.e., fasting glucose and HbA1c), lipid profile (triglycerides, total cholesterol, LDL-C, and HDL-C), plasma fatty acid profile, satiety related gut hormones and selected inflammatory markers (hs-CRP, TNF alpha, MCP-1). A 1-week run-in period will be conducted to evaluate participant motivation and compliance and to obtain baseline data. Diet and physical activity pattern will be assessed at regular intervals. Blood samples will be collected at the baseline, mid and end of the study.

Current Status
The study poster was presented at ASN 2022. A manuscript with primary outcomes of the study was submitted to Frontiers in Nutrition on September 28th, 2022. A paper with the methodology of the trial ""Research design for a randomized crossover trial to assess the effects of almond supplementation on insulin resistance, glycemic markers, inflammation among overweight Asian Indians" was published in the Journal of Diabetology. The team is working on 2 additional manuscripts and are planning to submit an abstract to the Indian Research Society for the Study of Diabetes in India (RSSDI).

Updated Literature Search for submission of a Health Claim to Health Canada Related to the Effects of Almonds on Blood Lipids

Principal Investigator:
Name: Kathy Musa-Veloso
Institution: Intertek, Canada
Email Address: kathy.musa-veloso@intertek.com

Objectives
The last literature search to identify studies on the lipid-lowering effects of almonds was conducted on 17 February 2015. As more than 4 years have elapsed since this search, Intertek was tasked to conduct an updated literature search to identify additional relevant studies that have since been published and that must be considered in the "totality of evidence". Using the same keywords and literature databases as were used previously and limiting the search to studies published in or after 2014, Intertek conducted a mock literature search and identified 588 titles that needed to be filtered through. The relevance of these 588 publications was determined at 3 stages using the titles, abstracts, and the full texts of publications.

Current Status
Based on the literature search conducted, 11 additional studies were identified for inclusion in the health claim application, taking the total number of applicable studies to 30. The next step requires running a meta-analysis of the total number of identified studies and updating the integrative discussions within the health claim application.

A randomized, comparator-controlled parallel study to investigate the dose response of an almond-enriched diet on lipid levels in a population with hypercholesterolemia.

Principal Investigator:
Name: David Crowley
Institution: KGK Science Inc, Ontario, Canada
Email Address: dcrowley@kgkscience.com

Objectives
This study will determine the optimal quantity of almonds consumed as a snack that will provide the most relevant increase of HDL-C levels. This study will evaluate HDL-C levels in multiple ways: absolute increases, clinically relevant changes based on cardiovascular disease risk (CVD) and National Cholesterol Education Program (NCEP) guidelines, change in directionality, and relation to CVD risk score. Further, it will investigate the dose-response effects of almonds on other lipid profile markers, blood pressure, weight and markers of abdominal obesity. Compliance will be assessed with study diaries, food records, and serum α-tocopherol concentrations as a biomarker of compliance.

Current Status
The study is tracking on time for completion. The research team has screened 244 subjects to date, with 22 completers and 18 currently randomized. The study has achieved 58% of the enrollment target and nearly 30% of the completion target.

Effects of almond consumption on innate myeloid and lymphoid cell composition and activity

Principal Investigator:
Name: Mònica Bulló Bonet
Institution: Institute of Health Pere Virgili University, Spain
Email: monica.bullo@urv.cat

Objectives
This is an 8-week, parallel-group, randomized-controlled dietary intervention trial that will be conducted in 110 adult participants with overweight BMI (27-29.9kg/m2) who report routinely eating a Western-style diet and regularly consuming unhealthy snacks. The study aims to examine the effect of regular consumption of almonds on changes in innate and adaptive immune systems. The primary objective is to evaluate the effect of almond consumption on the maturation of innate lymphoid cells which are crucial effectors of innate immunity as they are the primary line of defense. Secondarily, the study aims to examine the effect of regular consumption of almonds on: a) other innate immune system cells related to infection disease progression and severity; b) adaptive immune system assessed by the ability to produce inflammatory markers; c) circulating immune-related miRNAs. It will additionally investigate whether changes in miRNAs mediate the effect of almonds on innate lymphoid cells activity and the other innate and adaptive immune system indicators analyzed.

Current Status
The project is actively recruiting but has expressed difficulties with subject recruitment. The current study design is focused on overweight subjects only (27-29.9kg/m2), thereby limiting the BMI range from recruitment perspective. The PI has expressed the need to increase the BMI range to enable more recruitment, providing supporting evidence that obesity impairs immune system too and not very differently from overweight. Several people in the BMI of 30-32kg/m2 range have expressed interest in participating and extending the BMI to accommodate them will nearly triple the number of participants available for recruitment at this time. Similarly, suggestion has also been made to broaden the age range from 40-65y to 30-65y. The committee approved the change to the BMI range. The amendment signing the change into effect was used for Ethical Committee approval, which in turn was received on May 19th. There has been a significant delay in shipping almonds to the study site due to customs issues, which was finally resolved by asking the researcher to purchase almonds locally for the interim. Local distributors are being sought to provide a continuous supply for the study.

Almonds and their impact on immune optimization to viral infection: a randomized controlled trial of vaccination model of immune response

Principal Investigator:
Name: Eirini Dimidi
Institution: King's College London, London, UK
Email: eirini.dimidi@kcl.ac.uk

Objectives
The aim of this study is to assess the effects of whole almonds compared to an isocaloric snack in enhancing immune responses in a vaccination model of virus infection. This will be a single-blinded, 2-arm, parallel-group randomized controlled trial comparing the effect of 8-week consumption of whole almonds vs an isocaloric, commercially available snack on markers of immune response to the seasonal influenza vaccination in a healthy population. This will include the consumption of intervention products for 8 weeks, with influenza vaccination at 4-week midpoint. Participants will also be followed up 3 months post-vaccination to assess the incidence of self-reported upper respiratory symptoms. The study will recruit 88 healthy adults and randomize them to receive 56g/d almonds or 6 crackers/day with a spread. The primary outcome is seroconversion four weeks after the administration of the vaccine.

Current Status: Project contract is finalized, the project has received IRB approval and recruitment has been initiated.

Effects of whole almonds on immune health and responsiveness in adults with obesity

Principal Investigator:
Name: Jaapna Dhillon
Institution: The Curators of the University of Missouri, Columbia, MO
Email: jdhillon@missouri.edu

Objectives
The proposed study is a 6-wk randomized, controlled, parallel arm clinical trial. Participants will be block randomized to consumer either whole almonds (57g/d, n=30) or an isocaloric commonly consumed snack (cookie, n=30) for a 6-week intervention duration. The study subjects will consist of 60 adults with obesity (males and females, 30-45 years of age). Primary outcomes will assess circulating and tissue immune and inflammatory markers, immune function gene expression, and immune response to influenza. Secondary outcomes will include anthropometric measures, cardiometabolic outcomes, dietary intake, appetite ratings, and hedonic ratings.

Current Status
The study agreement has been signed. Almond order for the study is currently being processed.

Exploring the role of almonds in enhancing immune strength

Principal Investigator:
Name: Mark Kern
Institution: San Diego State University, San Diego, CA
Email: kern@sdsu.edu

Objectives
The COVID-19 pandemic highlights the importance of good nutritional status for immune strength and for reducing comorbidities that increase morbidity and mortality of infections. Almonds likely confer numerous immune strength advantages over common snacks; however, little empirical research is available.
The study aims to determine the impacts of almonds on immune health through an 8-week parallel arm trial of 48 overweight/non-obese (BMI=24-30) adult (aged 40-65 years) men (n=24) and women (n=24) tested to be free of almond allergy/sensitivity who will be randomly assigned to consume daily isoenergetic portions of almonds (15-20% of energy intake) or a common snack (pretzels). Outcomes to be tested prior to initiating the study and after eight weeks include measures of cell-mediated and systemic immunity. The study will also monitor outcomes related to incidence, severity and duration of any unanticipated acute infections (from SARS-CoV-2 and other pathogens). Physical activity, food cravings and dietary intake will be monitored via questionnaires. Data will be analyzed using a mixed-design repeated measures ANOVA followed by paired T-tests for within group effects and independent T-tests for between group comparisons within timepoints.

Current Status
The project has received full IRB approval and is running smoothly. The study team is actively recruiting participants by posting study flyers in the neighborhood around campus (coffee shops, gyms, cafes, residential areas, campus itself, etc.), on online sites (craigslist, school boards, Nextdoor Neighbor, etc.), and on social media (Facebook, Instagram). So far, 18 volunteers have been assessed for eligibility in the study and from those, 14 were enrolled to participate. Six participants have completed the study, four females and two males. There are seven ongoing participants and another two are in process of being scheduled to start the study. Of the ongoing participants, two are in the trial group and four are in the control group.

Effect of daily consumption of almonds on immune strength and response to flu vaccination in overweight middle-aged men: a randomized controlled study

Principal Investigator:
Name: Joan Sabate
Institution: Loma Linda University, Loma Linda, CA
Email: jsabate@llu.edu

Objectives
The proposed study is a parallel-group, free-living, observer-blind, randomized controlled dietary intervention trial on 54 overweight middle-aged men. This study will be carried out in two phases: Phase 1 will examine the effect of almonds on clinically relevant markers of immune function, and Phase 2 will assess the antibody response to influenza vaccination following almond consumption. Participants will be randomized to one of two groups: the almond group, which will receive 15% of their daily energy intake in the form of almonds as a snack and the control group, which will receive an isocaloric commercial snack (pretzels). The intervention duration is 12 weeks.

Current Status
The study was well underway when the PI reached out with changes to the study design for inclusion of post-menopausal women, incorporation of a western style diet as a control, and increasing the total subject number by 12 to help reduce variability. A corresponding increase in budget was also shared. An amendment was signed to incorporate these changes. Since then, the study team has actively recruited subjects for the study. Approximately 150 people have applied through the dedicated web page and 83 have come to the face-to-face information meeting. 42 have been selected for enrollment. The first randomized group of 6 subjects has been initiated and another 21 are awaiting randomization.

Roles of Almonds in Physical Performance

Principal Investigator:
Name: Mark Kern
Co-PI: Oliver Witard
Institution: San Diego State University, San Diego, CA
Email: kern@sdsu.edu

Objectives
Sixty men (n=30) and women (n=30) aged 30-50 years with BMIs of 23-30 will be recruited. A cross-over design performed in random order will be utilized in which participants will complete 2 trials separated by at least 4 weeks at two testing sites, one in the United States (San Diego, CA) and one in Europe (London, UK). At each site, 30 moderately active (1-3 hours of structured exercise per week) men (n=15/site) and women (n=15/site) will be assessed. Participants will consume 2.0 oz of raw, shelled, unsalted almonds or an isocaloric amount of unsalted pretzels daily for 8 weeks during separate trials performed in random order. Prior to and following each 8-week period, fasted blood samples will be collected and fitness/performance (VO2max and strength), height, body weight, and body composition will be assessed. Blood will be analyzed for total antioxidant capacity, TNF-á, blood lipid concentrations, glucose, and insulin. For each trial, vigor will be assessed by POMS-2, food cravings, dietary intake, and physical activity will be determined by questionnaire, and activity will be measured during 4 random days using Actigraph meters. At the end of each trial, the impacts of the test foods on muscle soreness, quadricep and hamstring strength and vertical jump performance will be assessed prior to and every 24 hours for 3 days following a 40-min downhill run at -10% grade. At each timepoint, blood-borne markers of muscle damage will be tested.

Current Status
All subjects for the SDSU research site have been recruited and are either in progress or have completed the study. An no-cost extension to December 31, 2022 was requested and granted to make up for lost time due to COVID delays.

The Effects of Almond Consumption on Functional Performance, Aerobic Capacity, and Physical Activity in Overweight and Obese Active Older Adults

Principal Investigator:
Name: Bahram Arjmandi
Institution: Florida State University, Tallahassee, FL
Email: barjmandi@fsu.edu

Objectives
This study is a 12-week randomized-controlled crossover study design, with a 4-week washout period. Fifty men and post-menopausal women will be recruited and assessed for their physical activity, sleep patterns, and dietary intake. The study aims to determine the extent to which consumption of roasted almonds affects functional performance and aerobic capacity in active, overweight, and obese older adults compared to an isocaloric commercially available snack.

Current Status
The study team experienced delays due to COVID and the research facility closure due to mold detection and requested a one year no cost extension to the project.

Influence of almond supplementation on energy, performance, and inflammation resolution from exercise-induced muscle damage.

Principal Investigator:
Name: David Nieman
Institution: Appalachian State University, Kannapolis, NC
Email: niemandc@appstate.edu

Objectives
Using a randomized, parallel group design, almond supplementation (42.5 g/d) for a 4-week period prior to the eccentric exercise challenge will be investigated as a countermeasure strategy to exercise-induced muscle damage and inflammation. An acute 90-minute bout of eccentric exercise will be used to induce muscle damage and inflammation in a group of 60 relatively untrained male and female adults (ages 18-50 years). The control group will ingest a calorie-matched common snack (cookies and potato chips). The study will measure changes in 70 different oxylipins and lipid mediators that are involved in regulating inflammation. The Profile of Mood States (POMS) will be used to measure mood state and specific domains including vigor or activity, and fatigue or inertia. Exercise performance will be measured each time a blood sample is collected using a comprehensive battery that includes vertical jump, leg/back muscle strength, bench press muscle endurance, and anaerobic power (30-second Wingate test). Primary Objectives: To determine the effect of almond consumption on feelings of energy, exercise performance, and muscle soreness and damage during a 5-day period after engaging in an acute, 90-minute bout of eccentric exercise. Secondary Objectives: To determine the effect of almond consumption on inflammation (inflammatory cytokines and oxylipins) and metabolic recovery during a 5-day period after engaging in an acute, 90-minute bout of eccentric exercise.

Current Status
The study is complete, and the research team presented the study results at the American Society for Nutrition annual meeting in 2022 in the form of a poster presentation. A manuscript with study results was submitted to Frontiers in Nutrition in September 2022.

The effect of topical almond oil on facial wrinkles

Principal Investigator:
Name: Raja Sivamani
Institution: UC Davis, USA
Email Address: rksivamani@ucdavis.edu

Objectives
This study is a randomized, controlled, parallel-group, rater-blinded study to evaluate the impact of topical application of almond oil on appearance of wrinkles. The study will have two treatment arms with topical almond oil and topical retinol (standard treatment for fine lines and wrinkles). The study aims to enroll and evaluate a total of 50 post-menopausal women (25/arm) of Fitzpatrick skin types 1 and 2. Primary endpoint is appearance of wrinkles, whereas secondary endpoints include appearance of facial color tone and evenness, appearance of facial redness, and subjective tolerability. The study will be conducted at two sites.

Current Status
This study is fully recruited and is expected to complete on time.

The Effect of Almonds on Facial Aesthetics and Modulation of the Microbiome and Lipidome

Principal Investigator: Raja Sivamani
Institution: UC Davis & Integrative Skin Science and Research (ISSR)
Email Address: rksivamani@ucdavis.edu

Objectives
Almonds have long been studied as a rich source of fatty acids, phytochemical polyphenols and antioxidants such as vitamin E. Recent studies compared almond supplementations to a calorie matched intervention for 16 weeks, yielding statistically significant improvement in wrinkle severity in postmenopausal women with Fitzpatrick skin type I & II that received almonds. This study furthers that assessment with a larger population and duration of 24 weeks to assess the influence of almond consumption on wrinkle severity, skin pigmentation and other skin biophysical profiles. The goal of this study is to investigate the effects of almond consumption on photoaging such as wrinkles and pigment intensity as well as facial biophysical parameters such as sebum production, skin hydration and water loss.

Current Status
A manuscript “Prospective Randomized Controlled Trial on the Effects of Almonds on Facial Wrinkles and Pigmentation” was published in the journal Nutrients in Feb 2021. This manuscript reported results of the study that average wrinkle severity was significantly decreased in the almond intervention group at week 16 and week 24 compared to baseline by 15% and 16% respectfully. Facial pigment intensity was decreased 20% in the almond group at week 16 and this was maintained by week 24. There were no significant differences in skin hydration, or transepidermal water Loss (TEWL) in the almond group compared to the control although sebum excretion was increased in the control group. The team is working on developing additional manuscripts from this project looking at modulation of these effects by the microbiome and lipidome.

Almond supplementation in mild to moderate Acne Vulgaris

Principal Investigator: Raja Sivamani
Institution: UC Davis & Integrative Skin Science and Research (ISSR)
Email Address: rksivamani@ucdavis.edu

Objectives
This study hypothesizes that daily supplementation with 60 grams of almonds will improve mild to moderate acne vulgaris compared to those that receive control supplementation. Aim 1: To measure the change in acne in those with mild to moderate acne. The facial grading will be assessed through the use of total, inflammatory, and noninflammatory lesion counts along with the assessment of the acne facial and trunk investigator global assessment (IGA). The final data will be subanalyzed among those that are younger than 25 years of age and those that are 25 years old and older. Aim 2: To assess the shift in the plasma short chain fatty acids. Venipuncture blood samples will be collected from participants on a monthly basis. Aim 3: To assess the shift in gut microbiome diversity and in the short-chain fatty acid producing microorganisms in the gut.

Current Status
The study was approved by Nutrition Research Committee at the beginning of FY 2021-22. IRB approval has been obtained. Study recruitment is underway.

The effect of topical almond oil on facial pigmentation

Principal Investigator: Raja Sivamani
Institution: UC Davis, USA
Email Address: rksivamani@ucdavis.edu

Objectives
This study hypothesizes that daily topical application of almonds oil will 1) improve the evenness and intensity of facial skin pigmentation (primary objective) and 2) improve the facial wrinkle severity in premenopausal women (secondary objective). Participants will be asked to exclude all current topical cosmetic related products for 2 weeks as a washout prior to commencing in the study. The almond oil and the hydroquinone will be randomized between the subjects in the two groups, and they will be instructed to apply daily at night. There will be five visits that will involve assessment of the face with and with facial photography at baseline, 4 weeks, 8 weeks, 12 weeks, and 16 weeks. Facial brightness and hyperpigmentation will be assessed with use of a validated high-resolution facial modeling system. Clinical grading will be performed by two board-certified dermatologists through the assessment of photographs in a blinded fashion to assess the appearance of facial pigment evenness and intensity.

Current Status
The study is ongoing and nearing completion of recruitment.

Does inclusion of almonds in an energy restricted diet enhance weight loss and protect against weight regain?

Principal Investigator:
Alison Coates
Institution: University of South Australia, Adelaide, South Australia
Email Address: alison.coates@unisa.edu.au

Objective:
Whilst many studies have demonstrated efficacy for achieving weight loss through dietary energy restriction, most individuals are unable to maintain weight-loss, with 80% regaining weight within the first year and less than 5% being able to sustain weight loss over the longer term. This might be in part due to the removal of professional support after initial weight loss. In the absence of such support, the inclusion of foods that promote satiety may assist in preventing weight regain. The profile of almonds, which are rich in monounsaturated fats, protein and fiber, may assist with weight maintenance through increased satiety. Currently, data are lacking on the role of almonds in weight control diets to limit weight regain. This 3-year study will provide evidence of whether regular snacking on almonds can help sustain satiety and limit consumption of excess calories.

Current Status:
The article **"**Acute feeding with almonds compared to a carbohydrate-based snack improves appetite-regulating hormones with no effect on self-reported appetite sensations: a randomized controlled trial" was published in the European Journal of Nutrition. Significant improvements in appetite-regulating hormones including postprandial C-peptide scores, GLP-1, glucagon, and pancreatic polypeptide were observed compared to control. Gut hormones were found to be the same between groups as were self-reported appetite ratings and energy intake following an acute test. As a tangential outcome, the team has also drafted an abstract focused on changes in pain observed after weight loss from the study, which has was submitted to the International Congress of Obesity. The team is also working on drafting of a manuscript that will compare all three timepoints (baseline, 3 months, and 9 months) with respect to appetite data.

Effects of almond consumption on the gastrointestinal microbiota and postprandial glucose handling in adults with overweight and obesity

Principal Investigator: Hannah Holscher
Institution: University of Illinois at Urbana-Champaign, Urbana, IL
Email Address: hholsche@illinois.edu

Objectives
This study is a randomized, controlled, investigator-blinded, parallel arm design with two treatment conditions. The study has a 1-week lead-in period that is devoid of all nuts prior to participant randomization. Recruited subjects are randomized to a 12-week intervention of either 2oz/d of roasted almonds or 3oz/d of pretzels. Study participants (n=84; 42/arm) include adults with overweight and obesity (BMI 25-34.9) between 30-60 years of age, without physician diagnosed metabolic or gastrointestinal diseases. Primary aim of the study is to determine the impact of almond consumption on GI microbiota, assessed by sequencing the V4 region of the 16S rRNA gene. Secondary aim is to determine the impact on oral glucose tolerance, hepatic steatosis, microbial fermentation end product, microbial-derived bile acids, and alpha- and beta-diversity. Tertiary aims include assessing fasting glycemic and insulinemic indices, circulating non-esterified fatty acids and body composition. Other study assessments include gut health measures, including self-reported bloating, flatulence, regularity, and stool consistency using the Bristol Stool Scale. Compliance is being assessed using plasma alpha-tocopherol concentrations as a biochemical fidelity measure.

Current Status
The research team reported a significant reduction in trial participation due to the pandemic and proposed revisions to the inclusion/exclusion criteria to facilitate study completion. Rather than excluding individuals for use of several medications, the revised I/E criteria could be modified to recruit such subjects and the study procedures could be modified to record the medication information in detail and utilize it as a statistical covariate if necessary. This proposed change was presented to the committee during the last NRC meeting. Also, with the age range of 30–60-year-old adults, the team feels that post-menopausal females are being excluded and that it would be best to include this group to better represent the US population. The committee approved the age range change request.

Almonds and their impact on gastrointestinal physiology, microbiology and function: Phase 1

Principal Investigator: Kevin Whelan
Institution: King's College London, London, UK
Email Address: kevin.whelan@kcl.ac.uk

Objectives
To understand the effect of different forms of almonds on markers of gastrointestinal health. The primary focus of Study 1 is to gain insight into the optimization of almonds' benefits on gut physiology and microbiology in health. This will be used to a build a scientifically robust rationale regarding how almonds may improve gut health in people with sub-optimal gut function (i.e., to correct gut microbiota dysbiosis through prebiotic effects, low short-chain fatty acid (SFCA), and slow gut transit seen in functional constipation) for a possible Study 2. Study 1 will utilize a comprehensive range of state-of-the-art technologies to assess a broad range of outcome measures including the wireless gastrointestinal motility capsule
(SmartPill) to inform mechanisms of action; 16S sequencing using Illumina Miseq platform to investigate microbiology-based hypotheses; and patented statistical pipelines for VOCs analysis applied as a novel mechanistic tool. The primary objective of both studies is to investigate the effects of different almond components on gut health.

Current Status
The research team submitted a manuscript in the American Journal of Clinical Nutrition titled "Almonds and the impact of almond processing on gastrointestinal physiology, luminal microbiology and gastrointestinal symptoms: a randomized controlled trial and mastication study." This manuscript received media coverage for the results reporting that almonds may have positive impacts on gut microbiota functionality. The study found that consuming almonds leads to significant increases in butyrate, a type of beneficial short-chain fatty acid (SFCA), as well as significant increases in stool output. Butyrate, which is produced by microbes in the gut when they digest fiber, is the primary fuel source for colonocytes, the cells that line the colon, and may play a role in multiple processes related to human health, including improving sleep quality, fighting inflammation, and has an association with lower risk of colon cancer.

Effects of consuming almonds on body weight management and satiety

Principal Investigator: Rachel Brown
Institution: University of Otago, Dunedin, New Zealand
Email Address: rachel.brown@otago.ac.nz

Objectives
Cross-sectional studies have found that nut consumers are leaner than non-nut consumers and no evidence of weight gain has been demonstrated in the short-term following the addition of nuts to the diet. However, there is a lack of longer-term studies assessing body weight as the primary outcome. For a study assessing body weight, it is crucial to have an intervention period of at least 1 year. A long term, well-controlled, adequately powered study would provide important insight into the role of almonds in weight management and satiety.

Current Status
The research team submitted a manuscript to European Journal of Nutrition in October 2022 with the study outcomes including body weight and composition, satiety, blood lipids and lipoproteins, Apo A1 and B100, HbA1c, Vitamin E, RMR, and dietary intakes. The team also presented the primary findings to American Society for Nutrition (ASN) 2022 conference as a poster presentation.

Almonds to improve gut health and decrease inflammation in metabolic syndrome

Principal Investigator: Laura Beaver
Institution: Oregon State University, Corvallis, OR
Email Address: Laura.Beaver@oregonstate.edu

Objectives
An almond snack intervention trial will be carried out in participants with metabolic syndrome (MetS) between 35-60 years of age and a BMI of 25-35kg/m^2. A total of 80 subjects will be recruited (40/arm) for a 12-week intervention duration. The almond intervention will provide 2oz/d of whole, dry-roasted, unsalted almonds and the control intervention will provide non-whole grain crackers of equal caloric content. The study hypothesizes that almond consumption will improve gut barrier health and help mitigate cause and consequences of increased inflammation in MetS.

Current Status
The study agreement has been signed and IRB approval has been obtained.

Effects of almond snacking on gastrointestinal health in adults with overweight or obesity

Principal Investigator: Ravinder Nagpal
Institution: Florida State University, Tallahassee, FL
Email Address: rnagpal@fsu.edu

Objectives
This study will utilize study samples stored from the study conducted by Penny Kris-Etherton at Penn State University, published in the Journal of American Heart Association in 2015. This is a secondary analysis using the stored samples from the original study. Forty-eight participants were randomized and 31 completed the study. Of these, 21 provided fecal samples. The study will extend the extent to which almond consumption (42.5g/d) modulates gut permeability and intestinal/systemic inflammation in those with overweight or obesity. Gut bacterial, fungal, and viral microbiomes, microbial metabolites, and gut-derived hormones and bile acids will be assessed as part of secondary outcomes.

Current Status
The study agreement has been signed and IRB approval has been obtained.

Biology and Management of Almond Brown Rot, Jacket Rot, Shot Hole, and Hull Rot

PROJECT NO: PATH4

Principal Investigator:
Name: Jim Adaskaveg
Institution: UC Riverside
Email Address: jim.adaskaveg@ucr.edu

Summary
In 2021, we continued to evaluate new fungicides and biological treatments for the management of brown rot (caused by Monilinia spp.), jacket rot (caused by Botrytis and Sclerotinia spp.), shot hole (caused by Wilsonomyces carpophilus), and hull rot (caused by Monilinia, Rhizopus, and sometimes by Aspergillus spp.). Due to little rainfall in the spring, diseases did not develop at high levels naturally. Therefore, incidence of brown rot was low, no shot hole was observed at our trial sites, but gray mold data were obtained from natural infections of flower petals that were incubated in the lab. Based on 2021 and previous years' data, new fungicides with high efficacy against brown rot blossom blight are the single-site Cevya (FRAC 2), Pyraziflumid (FRAC 7), and the experimental GF-4536, as well as the pre-mixtures Miravis Duo (FRAC 3/7), Miravis Prime (FRAC 7/12), Mibelya (FRAC 3/7), and Regev (FRAC 3/BM-01 – natural product). Among biological treatments, the biocontrols Botector and CR-7, as well as the natural products EcoSwing and Dart resulted in moderate to very good disease control.

The efficacy of full bloom treatments against petal infections by Botrytis cinerea was used to evaluate activity against gray mold, the cause of green fruit rot. Among treatments applied in 2021, the new Regev, Miravis Prime, Miravis Duo, and Mibelya reduced disease incidence to the lowest levels. In studies on hull rot management, several fungicides (e.g., Aproach, Cevya, Mibelya, Regev, Miravis Prime, Merivon), natural products (EcoSwing, Vacciplant, Guarda, Regalia), and foliar fertilizers (Banx, diKaP) performed statistically equally well, reducing the disease by 50 to 75% as compared with the control. The mode of action of diKaP against hull rot caused by R. stolonifer was found to be a reduction of fumaric acid that is produced by the pathogen and is involved in causing hull rot symptoms. When the fungus was grown in a minimal medium with the addition of diKaP, the production of fumaric acid was almost completely inhibited, while growth was increased.

No diseases developed in 2021 in our almond block at UC Davis with new genotypes and cultivars in comparison with some older cultivars. Based on previous years' data, some new cultivars such as Capitola, Folsom, Sterling, Supareil, Jenette, and several numbered genotypes showed consistent low susceptibility, similar to Nonpareil. For shot hole on fruit, cvs. Capitola, Supareil, and Sterling and genotypes UCD 8-160 and 2-19e Total (Kester) were identified to have reduced susceptibility.

Technical Transfer Teams Servicing Commercial Beekeepers in Almonds

PROJECT NO: POLL5

Principal Investigator:
Name: Annette Meredith
Institution: Bee Informed Partnership
Email Address: annette.meredith@beeinformed.org

Co-PIs: Dennis vanEngelsdorp, Marla Spivak, Ramesh Sagili, Elina L. Nino, Meghan Milbrath, Juliana Rangel

Summary
The Bee Informed Partnership's (BIP's) goal is to improve the health and long-term sustainability of US honey bee colonies, thus ensuring a sufficient supply of healthy colonies able to meet California's annual almond pollination needs. Since 2011 the Almond Board of California has provided support to BIP's Technical Transfer Team (TTT) to help accomplish that aim.

The TTT is now comprised of six full-time and four part-time highly trained field specialists who visit commercial beekeeping operations across the U.S., providing colony health assessments, sampling for pests and diseases, performing hygienic testing for breeders, and rapidly returning these results to beekeepers so that they may make timely, informed management decisions. Field specialists also provide field support and project development assistance for several field trials, case studies, and research grants. They also perform education and outreach to the beekeeping community through webinars and presentations at conferences, bee clubs and other invited speaking engagements. In 2021 the TTT program provided services for 56 commercial beekeeper participants, conducted field work for 8 funded grant research projects and gave 40 oral presentations.

Long term TTT monitoring has provided several important insights into trends in the major drivers of colony losses experienced by beekeeping operations that provide California almond pollination services. These results have identified key measures that help accurately predict colony survival, allowing for the development of seasonally- and regionally specific pest and disease threshold levels to help guide beekeeper management actions. The past decade of the Almond Board of California's support to BIP has helped facilitate the continued growth and adaptation of the TTT program, and the IT and research support that undergirds it, to improve the services we offer our program participants and the broader community of beekeepers, researchers and other stakeholders who benefit from the TTT program.

Effects of field-relevant pesticide-adjuvant combinations applied to almonds during bloom on honeybees

PROJECT NO: POLL17

Principal Investigator:
Name: Reed Johnson
Institution: The Ohio State University

Summary
Beekeepers providing honeybees for almond pollination continue to experience losses of adult and developing bees, sometimes resulting in colony failure after removal from almonds. The role of adjuvants included in pesticide applications may play a role in causing bee problems. To establish the toxicity of formulated adjuvants to bees we tested commonly used products on adult bees applied using a Potter Tower laboratory sprayer at multiples of the maximum labeled field application rate. Of the 12 tested, 9 showed a significant dose-response relationship, and 7 showed an LC_{50} estimate within 30-times the maximum application rate, validating beekeepers' concerns about adjuvant toxicity. Adjuvants contain a range of "principal functioning agents", the equivalent of "active ingredients" for traditional pesticide products. "Principal functioning agents" were tested for adult bee toxicity using a laboratory sprayer (Figure). These findings will help pesticide applicators choose adjuvant products with lower potential for bee toxicity.

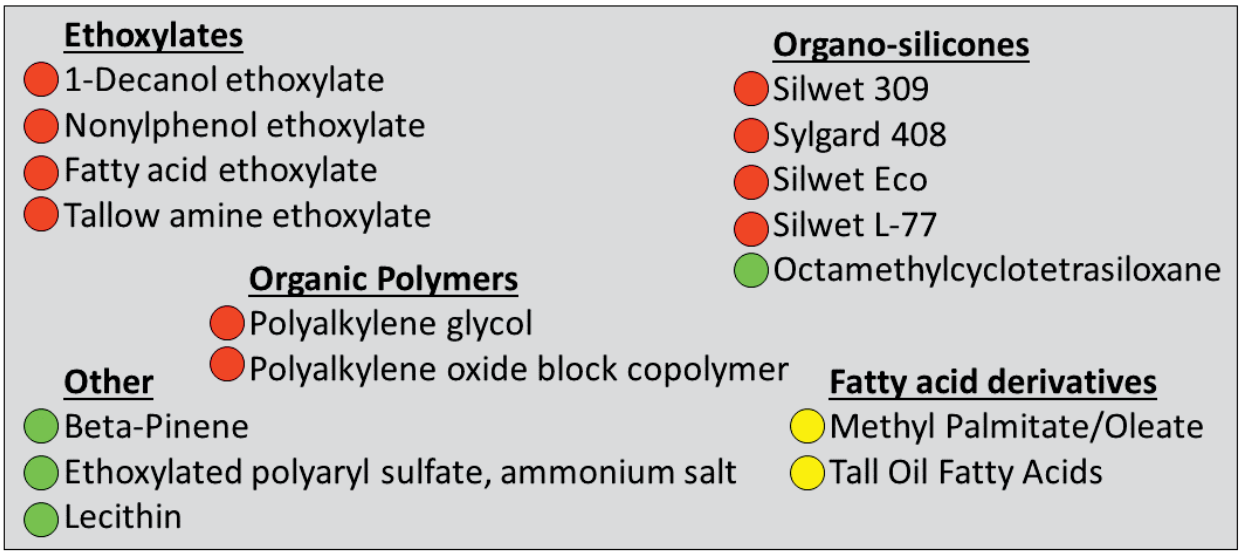

Figure. Dose-response relationships for each adjuvant "principal functioning agent" tested, sorted by chemical class. Green indicates there was no significant dose-response relationship at the concentrations tested, yellow indicates there was a significant dose-response relationship outside of near field application rates ($LC_{50} \geq 10\%$ concentration), and red indicates a significant dose-response relationship at near field application rates ($LC_{50} \leq 10\%$ concentration).

Almond Variety Development

PROJECT NO: HORT1

Principal Investigator:
Name: Thomas Gradziel
Institution: UC Davis
Email Address: tmgradziel@ucdavis.edu

Summary
As California almond growers, nurseries, and processors adapt to current and emerging challenges, new genetic options will be needed to enable the required changes in production, processing and marketing. An analysis of breeding germplasm worldwide, however, continues to document a reduction in genetic opportunities, due largely to the historic use of a single genotype, the Italian variety Tuono, as the source for self-fruitful varieties. The resultant inbreeding not only limits future genetic opportunities, but directly leads to reduced productivity and environmental resilience. Because of efforts at UC Davis over the past three decades to expand available breeding germplasm, including the incorporation of multiple sources for self-compatibility and self-pollination (self-fruitfulness), UCD has been identified in multinational studies as the only exception to this inbreeding trend. Multi-year and multi-region testing continues to demonstrate potential for high production as well as high production consistency (environmental resilience) in advance UCD breeding selections. In ongoing ABC sponsored multi-region Variety Trials
(RVT), the recently released self-incompatible variety Kester as well as the self-fruitful selection UCD18-20 continue to show very strong performances in both kernel quality and yields, including year-to-year production consistency, despite serious regional challenges in the form of disease, variable water quality and quantity, variable air quality (smoke, dust, etc.) and freezing temperatures during bloom. These and other advanced UCD breeding selections also continue to demonstrate opportunities for improved disease, pest and environmental stress resistance, improved kernel quality -including both oil and protein content as well as longer post-harvest storage, earlier and later bloom times and earlier and later harvest times. These traits are also available within a range of tree sizes and architectures and so have the required genetics to support next generation orchard management and processing strategies. For example, a very early harvest timing allows a decoupling of current-year crop development from next-year crop development (i.e. current-year flower induction). We have combined this trait with a more compact pillar-type tree architecture and a semi-hard-shelled and easily hulled nut to develop a Hedge with Harvest strategy that overcomes many of the challenges of catch frame mechanical harvest.

Almond Board of California
1150 Ninth Street, Suite 1500
Modesto, CA 95354

T: 209.549.8262 | F: 209.549.8267

Almonds.com