ALMOND BOARD OF CALIFORNIA

RESEARCH UPDATE 2025

ADVANCING CALIFORNIA ALMONDS THROUGH INNOVATION

Funded by grower assessments, Almond Board-funded research adds value by

- Providing growers and processors with information and resources to maximize their efficiency and profitability and navigate increasingly stringent regulations;
- Stimulating higher value and more diversified markets for almond co-products (shells, hulls and woody biomass); and by
- Contributing to global demand for California almonds through
    - Strengthening the health halo for almonds
    - Amplifying California almonds environmental stewardship story
    - Marshalling research to stimulate almond ingredient use

Long-term analyses of the impact of past research investments demonstrate these benefits:

- Research and outreach on nitrogen management resulted in an average decrease of 12 lbs/acre, a savings of more than $10 million per year across bearing acres. Recent published research on crops across California shows that almond growers are the most nitrogen efficient crop and the second highest in adopting multiple fertilizer best management practices.
- Almonds pioneered the technique of Whole Orchard Recycling (WOR), positing growers with an alternative for orchard removal in the face of the ag burning ban in the San Joaquin. With over 50% of orchard removed now undergoing WOR, research shows that the practice results in a 19% gain in yield, returning $1,400/acre over the life of the next orchard.
- Over the past two decades, research on orchard spacing and pruning has contributed to yield gains of over 400 lbs/acre, valued at $15,000/acre over the life of an orchard.
- Similarly, the development and regional trials of new rootstocks resulted in a shift toward hybrid rootstocks, significantly increasing yields, up to $30,000 per acre over the life of the orchard.
- More recently, research and outreach has demonstrated the value of cover crops for improving soil water infiltration and soil quality and improving honey bee health. 20% of almond orchards now plant cover crops. Further aiding biodiversity, over half of orchards provide hedgerows for habitat.
- As California policy makers and food brands set environmental goals, scientific research provides credible fact-based communication on the environmental stewardship of almond growers. See all you get with a handful of almonds: https://www.almonds.org/sites/default/files/2024-06/ES_Infographic_Digital.pdf

- In the area of nutrition, almonds are one of the most-researched foods globally, with over 200 peer-reviewed publications resulting from the Almond Board's nutrition research program.
- Research showing that almonds improve exercise recovery inspired the Deion Sanders Own your Prime campaign, which elevated CA almonds' visibility with consumers.
- Due to the Almond Board's research and global marketing efforts, almonds are considered the healthiest nut globally and health is the #1 reason consumers choose almonds. Consumers rank almonds highly for managing weight, providing energy, and improving digestive and heart health.
- Almond nutrition research has significantly contributed to shifting dietary recommendations and food policy. Dietary guidelines used to advise consuming nuts sparingly. Today, over 40 countries now recommend nuts as a core component of healthy diets.
- The Almond Board and the Almond Alliance leveraged almond health research to inform revisions to the U.S. Women, Infants and Children's (WIC) program which provides resources to women and children at nutritional risk to purchase specific healthy foods. Almond butter and almond-based milks, yogurts and cheeses that meet specific nutrient criteria can now qualify.
- World-leading scientific experts endorsed CA almonds as an essential part of diets to improve cardiometabolic health, which has achieved significant interest from consumers, food professionals and health professionals globally.
- Research showing that eating almonds improves skin health served as the basis for marketing campaigns in Asia to increase consumer perceptions of almonds as a key food to promote beauty.
- Research to identify and synthesize leaffooted bug pheromones was primarily funded by the Almond Board. Additional research focused on developing traps for these pheromones. As a result, commercially available lures and traps are now on the market.

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Nutrition Research

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

PROJECT NO: 19-ArjmandiB-NR-01

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Summary
This randomized controlled crossover trial evaluated the effects of almond consumption compared to a calorie-matched control snack on multiple physiological outcomes in physically active, overweight or obese middle-aged and older adults. A total of 38 physically active adults aged 50–64 years with overweight or obesity (BMI 25.0–34.9 kg/m^2) were enrolled in this 12-week randomized crossover study. Participants included both males and females and were free of cardiovascular disease, diabetes, and other chronic conditions. Compliance to the intervention was high, with participants reporting ~90%adherence to both the almond and control snack regimens. The most notable improvements were observed in vascular health and objective sleep measures. Almond consumption significantly increased brachial artery flow-mediated dilation (FMD), indicating enhanced endothelial function. This finding is consistent with previous evidence that almonds support vascular health, likely through their content of vitamin E, polyphenols, and unsaturated fats. There were no significant changes in pulse wave velocity
(PWV) or pulse wave analysis (PWA), suggesting that almond intake did not affect arterial stiffness within the duration of this intervention. The absence of change in PWV may reflect the relatively short intervention period or the preserved vascular compliance in this active cohort. Despite almonds being energy-dense, their inclusion in the diet did not lead to weight gain, which supports prior findings suggesting a potential food displacement or satiety effect. In summary, almond consumption for 12 weeks enhanced endothelial function and sleep efficiency without adversely affecting body weight, metabolism, or physical performance. These results support almonds as a beneficial snack for promoting cardiovascular and sleep health in a physically active, at-risk population. Future studies may consider longer durations, higher-risk populations, or combining dietary changes with other lifestyle interventions to expand the range of observed benefits.

Effects of Almond Consumption on the Gastrointestinal Microbiota and Postprandial Glucose Handling in Adults with Overweight and Obesity

PROJECT NO: 19-HolscherH-NR-01

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Summary
This study assessed the effects of daily almond consumption (56g) for 12 weeks on the intestinal microbiome and metabolic health of overweight adults. Almond consumption significantly increased the relative abundance of Roseburia hominis and Lachnospira eligens, and increased the relative production of a beneficial short-chain fatty acid linked to health effects, butyrate (+27.8%). It also led to significant decreases in pro-inflammatory secondary bile acids and modified the postprandial bile acid response, with correlations observed between bile acid profiles and improved glycemic response. These findings suggest that almond consumption can beneficially influence gut microbiota-derived metabolites that are linked to metabolic regulation. Results support further exploration into almonds' role in personalized nutrition and metabolic health.

Effects of Almond Consumption on Innate Myeloid and Lymphoid Cell Composition and Activity

PROJECT NO: 21-Bullo-NR-01

Principal Investigator:
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Summary
The final report for this project was submitted to ABC in September 2024, following its completion in May 2024. The study was designed as an 8-week, parallel-group, randomized controlled dietary intervention involving 110 overweight adults (BMI 27–29.9 kg/m^2) who regularly consume a Western-style diet and unhealthy snacks. The primary objective was to examine the effect of regular almond consumption on the innate and adaptive immune system, with a specific focus on the maturation and activity of innate lymphoid cells (ILCs). ILCs, including Natural Killer (NK) cells and helper ILC subsets, are critical first responders in immune defense, producing cytokines that not only combat pathogens but also regulate other immune cells. Secondary objectives included assessing the impact of almonds on other immune cell populations such as monocytes, T-cells, and B-cells. Monocytes serve as key antigen-presenting cells and precursors to macrophages, which are implicated in the severity of infectious diseases like COVID-19. T- and B-cell dynamics are crucial for effective cell-mediated and humoral immune responses, respectively, and their dysregulation has been linked to disease progression. The study also aimed to evaluate adaptive immunity through the measurement of circulating inflammatory markers (including hs-CRP, various interleukins, TNF-α, IFN-γ, TGF-ß, TLR4, and NOD1) and the ex vivo cytokine production capacity of peripheral blood mononuclear cells (PBMCs). Additionally, we examined changes in circulating immune-related microRNAs (miRNAs), investigating their potential role as mediators of almond-induced effects on ILCs and other immune parameters. This research was justified by the need to better understand how targeted nutritional strategies, such as almond consumption, can modulate immune function and contribute to restoring immune homeostasis in individuals exposed to unhealthy dietary patterns, thereby offering potential avenues for disease prevention and health promotion. Briefly, our findings showed a significant reduction in effector memory T lymphocytes and NK Cells CD56 in the intervention group compared to the control group, alongside a non-significant trend toward decreased CD14+CD16+ monocytes and increased total NK cells. Plasma IL-6 levels were significantly reduced following almond consumption, although cytokine production by stimulated PBMCs did not differ significantly between groups. Notably, miR-17-5p expression was significantly altered (P-value = 0.045) in the intervention group and associated with pathways involved in immune cell regulation and inflammation. We have submitted the main manuscript to AJCN for its review.

Can Almond Nut Consumption Improve Nocturnal Glycemic Control in Women with Gestational Diabetes Mellitus?

PROJECT NO: BGR-22-Flynn-NR-01

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Summary
Fasting hyperglycemia is a common challenge in managing gestational diabetes mellitus (GDM) and is thought to be linked to elevated nighttime blood sugar levels. Women with GDM are more likely to snack at night compared to those with normal glucose tolerance, and bedtime snacking has been associated with higher fasting blood sugar levels. However, the impact of snack type on nighttime blood sugar regulation remains unclear. The primary aim of this study is to conduct a randomised controlled trial to assess the impact of consuming whole dry roasted almonds as an evening snack, compared to a nut-free snack, on nighttime blood sugar levels in women with GDM. The secondary aim is to evaluate how almond intake influences various metabolic markers, including fatty acids, amino acids, glycolysis-related metabolites, ketone bodies, and inflammatory markers in this population. As of May 2025, all study setup activities are complete, and recruitment is underway.

Proposal to Develop a Strategy and Direction in Cardiometabolic Health Research and Produce a Consensus Paper on the Benefits of Almonds on Cardiometabolic Health

PROJECT NO: CARDIO01

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Summary
This project was a strategic initiative to advance research and public understanding of the role of almonds in cardiometabolic health. This project brought together eleven independent expert scientists and physicians through pre-meetings and a face-to-face roundtable to critically analyze the body of research on almonds and cardiometabolic health. These world-leading health and nutrition experts came to a scientific consensus on almond benefits in key health areas and published their conclusions in a peer-reviewed journal. They concluded that eating almonds daily is a proven dietary strategy to support overall heart health, weight management and the gut microbiome. The paper also concluded that higher daily consumption of almonds (at least 50g/1.8oz or nearly 2 servings) may help with modest weight loss. Achieving scientific consensus is extremely challenging. This expert consensus paper summarizes and validates over 30 years of research and is a testament to the strength of the almond science. Having these world-leading expert's endorsement of almond benefits elevates the credibility of the almond research. The experts also provided their insights to develop a strategy to further elevate the benefits of almonds on cardiometabolic health leveraging past research findings and new research technologies and designs. This project has successfully advanced almonds' role in cardiometabolic health research and public discourse. The outcomes—expert consensus, strategic recommendations, and a robust research framework—confirm almonds' position as a scientifically validated food for promoting heart and metabolic health. Key findings will be presented at several meetings and conferences. Continued investment in research and education will further elevate almonds' impact on public health.

Randomized Controlled Trial of Almond Supplementation vs Isocaloric Diet on Cognitive Functions in Middle-aged (40-60 years) Asian Indians with Prediabetes

PROJECT NO: CFP-21-MISRA-NR-01

Principal Investigator:
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Summary
Cognitive performance includes attention, memory, language, problem-solving, and decision-making. Cognitive impairment is well established in type 2 diabetes (T2D) patients but its relationship with prediabetes is less understood. This has public health significance in India, where nearly half of adults over 60 may have undiagnosed prediabetes. Insulin resistance, a hallmark of prediabetes, can disrupt neurobiological processes such as axonal growth and synaptic function, potentially impairing cognition even before the onset of T2D. Almonds, rich in vitamin E, monounsaturated fats, and antioxidants, are being studied for their neuroprotective effects. Some evidence suggests nuts may reduce inflammation, oxidative stress, and vascular dysfunction, factors contributing to cognitive decline. This 24-week randomized controlled trial assessed the effects of an almond-enriched vs. nut-free diet on cognitive function and brain structure in middle-aged Asian Indians with prediabetes, using the CANTAB battery and functional MRI. Based on preliminary findings from anthropometric, biochemical, cognitive, fMRI, and self-monitored glycemic data, this study shows that daily almond consumption over 6 months in individuals with prediabetes led to significant improvements in body composition, metabolic health, and lipid profile. Cognitive performance, assessed through CANTAB, improved significantly in domains of executive function, attention, and processing speed. Brain imaging further revealed increases in absolute white matter and myelin volumes in the almond group, suggesting neuroprotective effects. These findings provide evidence that almond supplementation can beneficially influence adiposity, glycemic control, inflammation, oxidative stress, cognitive function, and brain structure in Asian Indian individuals with prediabetes.

Effects of Almonds in Glucose-intolerant Adults- a Randomized Controlled Study on Muscle Mass and Obesity, Energy Metabolism and Lipidome, Non-alcoholic Fatty Liver and Inflammation

PROJECT NO: DMS-21-Kabisch-NR-01

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Summary
Tree nuts, like almonds, contribute to beneficial effects of the Mediterranean diet on risk for cardiovascular events, type 2 diabetes, dyslipidemia, hypertension, inflammation and non-alcoholic fatty liver disease. Almonds provide few carbohydrates, but lots of unsaturated fat and dietary fiber and may therefore have a significant impact on metabolic health. But questions remain about how almonds influence components of metabolic syndrome, in particular glucose tolerance, liver fat and subclinical inflammation. Previous clinical trials showed weaker effects in humans compared to rodent studies, most possibly due to low statistical power and metabolically insusceptible patients.

The 3-year AGAMEMNON project aims to investigate whether 16 weeks of supplementation with almonds (vs. no treatment) in 150 patients with prediabetes and NAFLD leads to significant improvements in glycemia and liver fat, lipid metabolism, body composition and inflammation. The study is an open-label two-arm single-blinded parallel randomized intervention study. Participants are selected to represent a responsive population with minimal medication use. The isocaloric design will control for weight loss and allow the analysis of metabolic pathways between fat depots, inflammation, insulin resistance and gut function. Oral glucose tolerance tests are used to monitor glycemic conditions. MR assessment will be used to measure body fat distribution and a psychometric battery will assess behavioral influences on initial metabolic state and responsiveness. Lipidomics serve as novel predictors of progression and metabolic response. Data collection is ongoing and results will be available after conclusion of the study (estimated summer 2026).

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

PROJECT NO: ECP-CHAUDHURY-NR-001

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Summary
This study examines the effect of almond consumption for 16 weeks on blood glucose levels and gut health in rural Indian adults with prediabetes, compared to traditional snacks like cereal and pulses. Conducted in six villages in Karnataka, it involved 129 overweight adults with prediabetes who weren't taking any diabetes medication.

Blood samples were taken at baseline, after 8 weeks, and after 16 weeks to see how almond consumption impacts health. Stool samples from 63 participants were also collected to understand the impact of almonds on gut health and beneficial bacteria.

Findings showed that consuming 56 grams of almonds for 16 weeks resulted in significant improvements in fasting insulin and HbA1c levels ($p<0.03$), as well as HOMA-IR and FBS ($p<0.05$) compared to baseline values. The almond group exhibited notably higher mean HDL levels ($p<0.01$) and a lower triglyceride (TG) and total cholesterol to HDL ratio (TC/HDL) than the control group ($p<0.05$). Sequence analysis revealed that almond consumption led to a higher percentage concentration of phyla with probiotic potential, such as Firmicutes, Proteobacteria, and Bacteroidetes and increased short-chain fatty acid (SCFA) levels, particularly propionic acid and butyric acid, in contrast to those consuming traditional cereal-based snacks. Furthermore, the waist-height ratio and BMI significantly decreased in the group consuming almonds for the 16-week duration.

Effects of Whole Almonds on Immune Health and Responsiveness in Adults with Obesity

PROJECT NO: ECP-Dhillon-NR-001

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Summary
This study evaluated the health effects of whole almond consumption compared to a calorie-matched cookie snack over a six-week period, with a focus on immune health markers in adults with obesity. Participants in the almond group received 57 g (320 kcal) of whole almonds daily, while those in the control group received a calorie-matched cookie snack. The study assessed the effects of almonds versus the control on immune and inflammatory biomarkers, the gene expression of metabolites involved in immune function, and cell-mediated immune responses in adults with obesity.

Data collection is complete and preliminary results were presented at the American Society for Nutrition Conferences in 2024 and 2025. A manuscript focused on the immune and inflammatory outcomes is expected in 2025. Key findings include: after six weeks of intervention, the almond group showed significantly lower concentrations of pro-inflammatory markers and higher concentration of the anti-inflammatory marker IL-10 compared to the cookie group. Almonds were generally more acceptable to participants than cookies, although palatability ratings were similar between groups. For appetite-related outcomes, the fullness over 12 hours decreased significantly in the cookie group after six weeks, while no significant changes were observed in the almond group. Additionally, participants consuming almonds demonstrated greater improvements in overall diet quality compared to those in the cookie group.

Manuscripts examining the effects of almond consumption on adipose tissue and blood gene expression, as well as microbiome profiles, are currently in preparation. Peripheral blood mononuclear cell (PBMC) immunophenotyping and stimulation assays are ongoing. Both remaining manuscripts are expected to be submitted by the end of the year.

Almonds and the Gut-brain Axis: a Randomized Controlled Trial to Improve Mental Health, Psychological Distress and Quality of Life

PROJECT NO: ECP-DIMIDI-NR-002

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Summary
Symptoms of depression and anxiety have seen a recent marked global increase. Growing evidence supports the role of healthy dietary patterns in managing symptoms of depression and anxiety, but further research is required. Almonds are a healthy snack option and are readily consumed worldwide. They are high in a range of nutrients and other bioactive compounds, some of which are known to elicit physiological responses that can affect brain function. For example, our meta-analysis has shown that almonds may affect gut microbiota composition, and our recent study has shown they can also modulate metabolite production, both of which are involved in the regulation of the gut-brain axis. However, there is little evidence of the effect of almonds on other aspects of mental health such as symptoms of depression and anxiety.

The NutriMood study aims to investigate the effects of whole almonds on mental health and the gut-brain axis compared to a commonly consumed snack, in adults with mild to moderate symptoms of depression and anxiety. 84 participants aged 18-45 enrolled in a 12-week parallel randomized controlled trial. Participants either consumed 56g of Whole Almonds per day or 2 iso-caloric muffins per day as a control snack. Mental health, including symptoms of depression, anxiety, mental well-being, quality of life, sleep quality, functional impairment and psychological distress, were assessed at weeks 0, 6 and 12 of the intervention. Stool and blood samples were collected at two time points weeks 0 and 12 for the analysis of the gut microbiome and serum vitamin E levels. Data collection was completed in May 2025 and results are being analyzed.

This study will provide unique and valuable data to the rapidly expanding field of nutritional psychology. There is a potential rationale and gap for almonds as a singular food to operate as an adjuvant treatment for mental health alongside traditional talking therapies or medication. The use of singular foods as an intervention for mental health may provide a highly accessible, low-cost intervention without the need for specialist dietary counselling which is integral to the success of whole-diet interventions.

Almonds as a Source of Healthy Fats: In Vivo Synthesis of Gut Microbiota-produced Cyclopropane Fatty Acids following Almond Feeding

PROJECT NO: GH-22-DebedatJ-NR-01

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Co-PIs: Dr Sean H Adams

Summary
This study explored how fats from almonds are processed in the human gut and whether they are transformed into unique molecules that could explain some of almonds' health benefits. Research focused on a special type of fat called cyclopropane fatty acids (CpFAs), which are hypothesized to be produced by gut bacteria using almond-derived fats. Participants consumed a single meal containing either almonds or coconut (used as fat-type control), along with a food-grade dye capsule to precisely match stool samples and gut metabolites to the timing of the meal.

Before the intervention, gut microbiome compositions were similar between groups, with about 17.5% of the gut bacteria having the potential to produce CpFAs. Using a new lipidomics analysis panel put together for this project, the fats in blood and stool samples were analyzed. Findings showed stool samples had far more lipid diversity than blood, highlighting the potential importance of gut microbes in shaping fat metabolism in the body. Notably, while CpFAs were not detected in blood and did not increase with almond intake, several other unique lipids appeared in stool that were specific to almond consumption. These included both known and previously unidentified novel fatty acids, suggesting a distinct gut metabolic response to almonds not previously discovered.

These findings are important as they point to specific gut-derived lipid signatures linked to almond intake. While CpFAs may not change acutely, other almond-associated lipids could serve as biomarkers of intake or play a role in delivering health benefits. This work introduces a powerful method to study gut lipid metabolism and sets the stage for identifying new bioactive compounds derived from almond consumption. In the future, this may help growers and industry partners better understand how almond components influence health and support science-based marketing or product development.

Almonds to Improve Metabolic Syndrome Health Outcomes through Improved Microbiome, Oxylipin and Immune Health Profiles

PROJECT NO: GUT01

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Summary
Metabolic syndrome affects ~35% of Americans and over a billion people world-wide. The conditions associated with metabolic syndrome are high blood sugar, high blood pressure, high blood triglycerides, low levels of good cholesterol, and excess body fat around the waist, all of which increase the risk of type 2 diabetes, heart disease, stroke, and fatty liver disease. Gut health and chronic inflammation are key factors that contribute to the development of metabolic syndrome. Almonds may help improve gut health and decrease inflammation by improving the gut microbiome and oxylipin profiles of almond consumers. Oxylipins are bioactive lipids produced from polyunsaturated fatty acids (PUFAs), which are abundant in almonds, and play a role in regulating inflammation and other biological processes. This controlled clinical intervention examines the impact of almonds on gut health and inflammation in adults with metabolic syndrome. 82 participants were recruited and consumed almonds (2 oz, whole, dry roasted) or crackers, as a daily snack for 12 weeks. In the previous funding cycle, almond consumption decreased total cholesterol, “bad” cholesterol (LDL cholesterol), and was associated with a modest but significant improvement in waist circumference. It also improved vitamin E status and dietary intakes of α-tocopherol, soluble fiber, copper, biotin, magnesium, and PUFAs, as compared to cracker consumers. Almond consumption improved biomarkers of gut barrier function and intestinal inflammation in participants with elevated inflammation at baseline. In this current funding cycle, analysis of the gut microbiome showed no change in α-diversity with almond consumption, but a small, significant treatment effect was observed for ß-diversity. Almond consumption was correlated with increased levels of beneficial bacterial genera (Bacteroides, Butyricicoccus and Monoglobus) and decreased levels of Streptococcus which can be an opportunistic pathogen. Work is currently underway to determine the effect of almond consumption on plasma oxylipin concentrations and associate changes in bacterial taxa with health outcomes. The beneficial dietary and gut inflammation changes observed with almond consumption may contribute to the improvements in cardiovascular health. Overall, the study provides evidence for the benefits of almond snacking in people with metabolic syndrome and supports changing dietary recommendations to incorporate almonds into daily diets.

Investigation into Associations between Almond Consumption and Metabolic Health, Mental Health, Gut Microbiome, Menopausal Symptoms, Skin Health and Sleep: the PREDICT Studies

PROJECT NO: GUT02

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Co-PIs: Sarah Berry, Nicola Segata

Summary
The Personalised Responses to Dietary Composition Trials (PREDICT) project is the world's largest nutrition study, with data from over 300,000 participants across the UK and US. It explores how individuals respond to different foods, including the effects of diet on gut health, mental wellbeing, and a range of physical health outcomes. This project uses PREDICT data to examine how almond consumption relates to health, microbiome composition, and demographic factors.

Data analyses are ongoing to address four key questions:

1. Who consumes almonds, and how does this vary across demographic and risk groups?
2. What is the relationship between almond intake and health, and what factors (e.g., age, BMI, socioeconomic status) mediate this relationship?
3. How does almond consumption affect the gut microbiota, and how might this explain individual differences in health outcomes?
4. How do these associations evolve over time?

This research aims to support the development of more personalized dietary guidelines that consider how different forms of almond consumption, such as whole almonds, almond milk, or almond butter, may benefit diverse population groups, with the goal of improving both physical and mental wellbeing across varied demographics. Importantly, this study is hypothesis-generating and will provide valuable direction for future intervention studies, particularly those exploring currently under-researched health outcomes related to almond consumption.

Comprehensive Fiber Characterization of Almonds by Variety, Plant Part and Processing

PROJECT NO: GUT03

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Co-PIs: Jonathan DeVries

Summary
This project aims to 1) synthesize a vast amount of scientific literature on almond gut health benefits and 2) conduct a comprehensive examination of almond dietary fiber composition and explore how almond variety, composition of different fractions, and processing methods (such as blanching, roasting, and grinding) impact fiber composition. By characterizing almond dietary fibers, the project will help to clarify their role in gut microbiota modulation and gastrointestinal health and provide additional mechanisms of action behind almonds established cardiometabolic benefits. As part of this project, the research team conducted two literature reviews one on the prebiotic effects of almonds and one on existing knowledge of almond fiber composition. The literature review summarizing the body of research on almonds and gut health has been published and makes the case that almonds have a prebiotic effect (they are used as a beneficial food source for gut bacteria which is associated with a health effect). The review on existing fiber composition of almond fractions—kernels, skins, shells, and hulls—highlighted compositional characteristics and pinpointed where analytical or functional evidence is lacking to guide future research avenues. The team has now finalized the sampling collection and safe storage of all almond samples to be sent for characterization analysis and are now in the final stages of vetting and selecting the appropriate laboratory for the studies and deciding what methodologies are to be used for the analysis work in collaboration with academic and commercial partners. Once results are obtained and interpreted with expert input, the second article will be drafted and reviewed by the co-authors and submitted to a peer-reviewed journal for dissemination into the scientific community, industry stakeholders, and consumers. This project represents a proactive effort to investigate almond dietary fiber in a comprehensive manner which is a significant and limiting gap in the research on almonds. It is also aiming to bridge research and application in a way that would inform future industry innovation on almond-based products for health and wellness.

Proposal for the Preparation, Submission, and Stewardship of a Systematic Review and Meta-analysis on the Effects of Almonds on Blood Lipid Levels

PROJECT NO: HEART01

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Summary
While the benefits of almond consumption in reducing levels of total cholesterol and LDL-Cholesterol (the "bad" cholesterol related to increased heart disease risk) are well established, the effects on additional lipids that have emerged as important predictors of cardiovascular disease, such as a protein named ApoB and the ratio of ApoB:ApoA, are not well characterized. In this systematic review and meta-analysis, the effects of almond consumption on blood lipids were comprehensively assessed. A systematic search of ten literature databases was conducted. Randomized controlled trials at least 4 weeks in duration were included if the investigational product was almonds; the control was void of nuts/tree nuts; the subjects were adults without cardiovascular disease; and blood lipid levels were assessed. 36 publications (48 almond–control datasets) representing 2485 participants were included. Eating almonds significantly reduced harmful LDL-cholesterol, total cholesterol (TC), non-HDL-cholesterol, ratios of TC:HDL and TC:LDL, and achieved a borderline significant reduction in triglycerides, while preserving beneficial HDL-cholesterol. Eating almonds daily reduced ApoB, a type of harmful protein that promotes plaque formation and improved the balance of ApoB to a beneficial protein ApoA (which is a novel discovery reported here for the first time). ApoB is an indicator of increased risk of cardiovascular diseases while ApoA is related to decreased risk. A high ApoB/ApoA ratio is a powerful warning sign of cardiovascular disease.

In conclusion, almond consumption significantly reduces levels of multiple blood lipids, especially in people with elevated levels, and can improve cardiovascular health.

Almonds and their Impact on Immune Optimization to Viral Infection: a Randomized Controlled Trial of Vaccination Model of Immune Response

PROJECT NO: IH-21-DIMIDIE-NR-01

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Co-PIs: Sarah Berry, Wendy Hall, Esperanza Perucha, Victor Turcanu, Kevin Whelan

Summary
Background: Almonds may positively impact immune function as they are high in immunoregulatory nutrients (e.g. vitamin E and zinc), they may influence the gut microbiota and their metabolites (known to interact with the immune system), and they are high in fiber and micronutrients. The impacts of dietary interventions on the immune response are commonly studied using a vaccination model of viral infection; however, there have been no published studies in this area administering a whole food that has the potential to impact immune function, such as almonds.

Objective: This project is a parallel group, randomized controlled trial (RCT) that aims to investigate the impact of 8-week consumption of almonds (56 g/d) or a control of pretzels (86 g/d; isocaloric) on the immune response using a vaccination model of viral infection in healthy, middle-aged adults aged 40-64 years old. After 4 weeks of the intervention, participants received the seasonal influenza vaccine. Immune response is assessed by measuring rates of seroconversion and geometric mean antigen-specific antibody titres at 4 weeks post-vaccination. Participants are also followed-up at 2- and 3-months post-vaccination to assess the incidence of self-reported upper respiratory symptoms to provide valuable clinical data to support the biomarkers of immune responses.

Key results so far: 90 participants were randomized (almonds: n = 45; control: n = 45). Results for study outcomes are currently being analyzed and a full report of the findings will be available soon.

Discussion: The trial concluded in April 2024. Sample analysis is now complete, and data analysis is currently being finalized. The project will provide valuable data, with the potential to inform public health messages regarding almonds on the immune response following influenza vaccination.

Effect of Daily Consumption of Almonds on Immune strength and Response to Flu Vaccination in Overweight Middle-aged Men: a Randomized Controlled Study

PROJECT NO: IH-21-SabateJ-NR-01

Principal Investigator:
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Summary
This study will determine if almond consumption in overweight men and post-menopausal women enhances immunity by assessing changes in lymphocyte populations, inflammatory serum biomarkers, antibody and immune response to influenza vaccination and the incidence, duration and severity of symptoms associated with upper respiratory tract infections (URTI) before and after vaccination. A well-functioning immune system is essential for resistance to infections and survival and older adults are at a higher risk of URTIs like the seasonal flu, with higher rates of hospitalization and mortality. Although vaccination could be an efficacious strategy for preventing URTIs, age-related and/or diet-influenced decline in immuno-competence often interferes with efforts to induce herd immunity. Nutrition and diet play an enormous role on the immune system. Recent evidence suggests that plant foods that are also minimally processed may provide a wide range of immune enhancing nutrients and can be a useful strategy for individuals that seek to improve their immunity and body's defense mechanism against pathogens but the scientific support for this is sparse. Given that plant foods such as almonds have a plethora of nutrients that individually and in synergy provide several health benefits, they may have a role to play in enhancing immune functions.

Almonds are a good source of several immune-enhancing micronutrients like fiber, zinc, copper, vitamin E, magnesium, selenium, folate, and antioxidant polyphenols, and when regularly consumed as a snack, are likely to enhance immunity and reduce the risk of URTIs and symptoms such as those associated with the seasonal flu. A promising study outcome will significantly enhance almond's reputation as an immune-boosting superfood and encourage individuals around the world to consume more almonds.

Association and Mechanisms of Almond Consumption and Mental Health in The Hispanic Community Health Study/Study of Latinos (HCHS/SOL)

PROJECT NO: MH&C02

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Co-PIs: Kenny Mendoza

Summary
Depression is rising globally and scientific evidence shows that certain foods and nutrients can influence mood and mental well-being. Almonds are rich in fiber, healthy fats, vitamins, minerals, and plant compounds and including almonds in our regular diet could help prevent or manage depression. However, little is known about whether almond intake benefits the bacteria in the gut or metabolites in ways that might protect against depression. Metabolites are small molecules that reflect what we eat and how our bodies process it. This study explores whether eating almonds is linked to fewer depression symptoms, how much almonds are typically consumed, and who is more likely to consume them. It also investigates how almonds may influence gut bacteria and metabolites to understand how the nutrients and chemicals in almonds influence mental health, using data from the Hispanic Community Health Study/Study of Latinos (HCHS/SOL). Among 8,783 Hispanic/Latino adults, average almond intake was under 1 gram per day. Dominicans, older adults, women, Bronx residents, and people with more education or a partner consumed more. U.S.-born individuals and smokers consumed less. Higher almond intake was linked to healthier diets - more fiber, vitamins, and healthy fats, and less sugar and processed meats. Almond consumption was also associated with lower depression symptoms six years later among Mexican heritage participants (15% less likely), San Diego residents (24% less likely), and women. Almond intake appears to align with healthier eating patterns and may reflect specific social and lifestyle factors and higher almond consumption is linked to lower experiences of depression symptoms among individuals of Mexican heritage, San Diego residents, and women. Consuming the recommended 30 g/day of almonds may support a high nutritional quality and mental health in Hispanics/Latinos. Analyses are ongoing to include almond by-products, like almond butter and will also test whether substituting less healthy foods (like sugary snacks or processed meats) with almonds influences depression symptoms. Finally, we will explore how the gut bacteria and metabolites differ by the amount of almonds people consume, and if these differences connect to risk of depression.

Characterization and Validation of a Plasma Metabolomic Signature of Almonds in Randomized Controlled Trials of the Portfolio Diet

PROJECT NO: ONTHN02

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Co-PIs: David Jenkins, Cyril Kendall, Frank Hu, Jordi Salas-Salvadó, Andrea Glenn

Summary
Nutrition remains the cornerstone for the prevention and management of cardiovascular disease (CVD), yet the evidence to support the implementation of specific dietary strategies is limited. Current dietary advice relies largely on evidence from small randomized controlled trials (RCTs) of risk factors and prospective cohort studies that are based on self-reported diet, both of which have limitations. An innovative research paradigm in nutrition is needed that can complement the evidence from traditional large clinical outcomes trials at a much lower cost, restoring public trust in nutrition research while strengthening the evidence for clinical and public health policy.

Metabolomics is an emerging field in nutrition and CVD epidemiology and uses the products of overall metabolism to develop an objective metabolomic signature for a dietary pattern or specific foods. These can be used to monitor adherence in dietary interventions, assess mechanisms underlying diet-disease relationships, and open avenues for precision nutrition approaches in the future by identifying individuals whose health may benefit the most from specific foods, such as almonds.

Almond intake is poorly measured by existing dietary instruments (food frequency questionnaires) in prospective cohort studies and these measures have failed to show robust signals with important clinical outcomes such as type 2 diabetes. A metabolomic signature of almonds would help overcome this measurement issue by providing an objective, reliable assessment of almond exposure which could be leveraged for analyses of important exposure-outcome relationships.

This research aims to identify a metabolomic signature of almonds in our metabolically controlled feeding trials of the portfolio diet (N=453 samples, where almonds were the only nut source) and validate it in another portfolio diet trial (PortfolioEX) where key foods (including almonds) were provided (N=282 samples). Metabolomics data related to almond consumption in the clinical trials is currently being analyzed.

Almond Consumption and the Risk of Cancer Incidence and Mortality in a Population with a Wide Range of Intake

PROJECT NO: OTHN01

Principal Investigator:
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Summary
Cancer is the second leading cause of death in the U.S., accounting for one in five deaths between 2016 and 2022. While increased consumption of nuts has been linked to cardiovascular health many of the nutrients present in almonds have also been identified as protective against cancer. However, research into the potential protective effect of almonds on cancer is limited.

The Adventist Health Study-2 (AHS-2) prospective cohort launched in 2002 with an initial food frequency questionnaire which contained comprehensive information on over 200 food items, including almond consumption, completed by more than 96,000 study participants upon enrollment. There have been linkages with the National Death Index for nationwide vital statistics, and state-level cancer registries for data on cancer incidence and the cohort has both a low presence of notable confounders like alcohol and tobacco use, and a wide range of almond consumption. Analyses are currently being performed in this cohort to investigate the effects that almonds have on the risk of cancer incidence and mortality.

Both the American Institute for Cancer Research (AICR) and the World Cancer Research Fund (WCRF) have recognized the potential benefit of nuts and thus included nuts in their shared 2018 dietary recommendations. While almonds contain nutrients that have been individually related to cancer prevention, research into the effect of almonds as a whole food on cancer is much less abundant, leaving a gap in the literature to investigate the possible synergistic effects which all of these beneficial nutrients could have when combined in the almond as a whole.

Modeling Replacing Snacks or Incorporating Almonds into Meals and Impact on Key Nutrient Consumption among US Children and Adults

PROJECT NO: OTHN03

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Co-PIs: Matthieu Maillot, Romane Poinsot, Adam Drewnowski, Maha Tahiri

Summary
Replacing typical American snacks with almonds may improve diet quality and help align intake with the 2020–2025 Dietary Guidelines for Americans (DGAs). This proof-of-concept modeling study assessed the nutritional impact of replacing between-meal snacks with almonds on a per-calorie basis.

Analyses used data from the National Health and Nutrition Examination Survey from 2017–2020 and 2021–2023 (n=15,258). Three models were developed. Model 1 replaced all between-meal solid snacks with almonds on a calorie-per-calorie basis. Model 2 exempted “healthy” between-meal snacks consisting of whole fruit, non-starchy vegetables, or whole grain products. Model 2 (100%) replaced 100% of non-healthy snacks, while Model 2 (50%) replaced 50% of non-healthy snacks. Model 3 added one serving (30 g) or almost two servings (50 g) of almonds, without any replacement. A composite almond nutrient profile, weighted by the relative frequency of consumption, was developed. Outcomes of interest will be Healthy Eating Index-2020 (HEI-2020) scores and sub-scores, with a focus on added sugars, saturated fats and sodium. We will also explore the modeled diets content of saturated and mono- and polyunsaturated fatty acids, fiber, protein, sodium, potassium and magnesium.

Snacks accounted for roughly 20% of daily calories, with the highest intake seen in children, adolescents, and young adults. Older adults consumed fewer total snacks but a higher proportion of healthier ones.

Replacing snacks with almonds led to significant increases in HEI-2020 scores, which was primarily attributed to the reduction in nutrients to limit. This was particularly notable in Models 1 and 2. Replacing 100% of unhealthy snacks (Model 2) increased HEI from 52.4 to 60.6. Even a 50% replacement improved scores. Model 3, which added almonds without substitution, also raised HEI and nutrient density per 1000 kcal. Analyses still to be conducted will explore the impact of incorporating almonds into meals on other diet quality metrics.

Effects of Almond Consumption on Quality of Sleep in Adults: A Randomised Controlled Trial

PROJECT NO: OTR-22-Desai

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Co-PIs: Dr. Shobha Udipi, Research Director and Head. Hon Director, Integrative Nutrition and Ayurceuticals Kasturba Health Society-Medical Research Centre , Dr. Rama Vaidya; MD PhD Reproductive Endocrinologist Director, Division of Endocrine and Metabolic Disorders Medical and Research Centre - Kasturba Health Society

Summary
The goal of this research is to study the impact of almond consumption on sleep patterns in adults in India. A randomized trial was conducted to assess the impact of daily almond consumption on sleep quality measured using Polysomnography, the Pittsburgh Sleep Quality Index (PSQI) and the Epworth Sleep Scale (ESS). The results will help determine the effect of almond consumption on associated biochemical measurements like serum melatonin, serotonin, brain derived neutropic factor (BDNF), cardiometabolic risk factors (blood glucose, insulin levels, inflammatory cytokines and lipid profile) and serum alpha-tocopherol in adults aged 21-55 years in India. Data collection is complete and data analysis and manuscript writing is in progress.

Evaluating Almond Protein for Human Health Benefits

PROJECT NO: PHYS01

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Co-PIs: Angelos Sikalidis, Aleksandra Kristos, Elisabet Borsheim, Scott Reaves

Summary
Protein is a key component for supporting optimal health and wellbeing as well as development. The importance of protein supplements is emerging especially in the context of meal replacements and/or shakes. With consumers choosing not to use animal products for a variety of reasons, improvement of the quality and anabolic capacity of plant-based proteins is key. This study aims to provide a high-quality environmentally- and vegetarian-friendly plant-based protein as a good alternative to whey.

40 healthy female college students will be recruited to the intervention. Each will be provided with either a basic almond protein powder shake, an enhanced almond protein shake, or a whey protein shake (the control).

The study addresses the following Objectives/Hypotheses:

1. Compare the effectiveness of almond protein supplement on participants' nitrogen balance with whey as a control, with the hypothesis that almond protein will be effective in increasing nitrogen balance and that 30 g doses will elicit more significant changes than 15 g.

2. Examine the levels of postprandial amino acids and other anabolic signaling molecules in the blood, shortly after the consumption of each different protein supplement to assess bioavailability, with the hypothesis that almond protein will exhibit increased postprandial amino acids and anabolic signaling molecules in the blood, thereby indicating amino acids available to support muscle protein synthesis.

IRB approvals, amendments, and extensions have been received and recruitment was successfully completed. The intervention and data collection are now underway.

The Acute and Accumulative Effects of Almonds on Exercise Recovery

PROJECT NO: PHYS02

Principal Investigator:
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Co-PIs: Shirin Hooshmand

Summary
The goals of this study are two-fold. First, to determine if post-exercise almond consumption can promote gains in lean mass as well as muscular strength throughout an eight-week weight training program. Second, to assess the acute effects of almonds on recovery that may explain the overall long-term adaptations. Almonds are a protein-rich nut and provide an array of healthful nutrients; therefore, we anticipate that compared to a more refined snack food (cereal bars), almonds will promote the acute recovery from a single, rigorous resistance exercise session and will enhance overall recovery from an 8-week progressive weight training program as measured by improvements in body composition and strength.

56 men (n=28) and women (n=28) will complete the two-phase project. Phase I will assess daily recovery over a 3-day period as measured by delayed onset of muscle soreness, strength, vertical jump performance, and biochemical indicators of muscle damage after an initial 1-hour strength training work-out that is followed by consumption of almonds or cereal bars. Phase II will assess how the long-term effects of consuming the recovery test foods following each workout of an 8-week progressive resistance training program influences muscular strength and gain of lean mass. Data collection is currently ongoing.

ALMOND ProFIT-PM – Almond Protein Powder to Enhance Fitness Training Adaptations in Postmenopausal Women

PROJECT NO: PHYS03

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Co-PIs: Leanne Fitzpatrick,

Summary
The overarching goal of the ALMOND ProFIT-PM study is to evaluate whether daily supplementation with defatted almond protein powder (APP) enhances the physiological benefits of structured fitness training in overweight, postmenopausal women, when compared to a calorie-matched placebo.

Study 1 focuses on whether APP supplementation leads to significantly greater gains in lean body mass over a 10-week concurrent (strength + cardio) training program, compared to an energy-matched placebo.

Recruitment is ongoing and the protocol development and testing phase has been highly productive. Early findings confirm the feasibility of daily supplement delivery, training session scheduling, and data collection procedures. Feedback on the supplement has been positive, with no major barriers reported regarding adherence or tolerability.

Secondary objectives of study 1 include assessing whether APP supplementation combined with training improves fat mass reduction, aerobic fitness, muscular strength, blood lipid profiles, glycemic control, appetite regulation, dietary intake, and supplement acceptability.

Preparation has begun for study 2, which will examine some of the mechanisms of action of APP by addressing the acute postprandial metabolic and amino acid response to APP. It will also include an assessment of acute acceptability and appetite effects of the supplement.

This project will provide clinically relevant and mechanistic insights into how almond protein supplementation may support healthy aging by enhancing exercise-induced adaptations in muscle, metabolic, and cardiovascular function. Outcomes will inform nutritional strategies for active aging and contribute new evidence on the functional health benefits of almond-based proteins.

The Effect of Almond Consumption on Skin Collagen and Elastin in Women

PROJECT NO: SH-01

Principal Investigator:
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Summary
The purpose of this randomized controlled trial is to evaluate whether daily almond consumption can improve overall skin health by enhancing collagen production, increasing elastin levels, reducing wrinkle severity, and impacting facial pigmentation in premenopausal and postmenopausal women of all Fitzpatrick skin types. Skin aging is influenced by multiple factors, including collagen breakdown, elastin reduction, and pigmentation changes, which collectively contribute to wrinkle formation and decreased skin elasticity. Almonds are nutrient-dense, containing antioxidants, healthy fats, and dietary fibers that may beneficially impact skin health through various biological mechanisms. The primary outcomes of this study include quantification of skin collagen and elastin levels and assessment of facial wrinkle severity. Secondary outcomes encompass changes in facial pigmentation intensity, changes in the expression of enzymes involved in collagen breakdown and preservation. To investigate potential underlying mechanisms, this study will analyze biochemical markers of collagen metabolism and evaluate enzyme expression involved in skin collagen matrix remodeling. Additionally, patient-reported outcomes, including subjective evaluations of skin improvements and assessments of mood and gastrointestinal comfort related to almond consumption, will be analyzed through standardized questionnaires. Results from this study aim to clarify the effects of almond supplementation on skin aging parameters, explain the biochemical pathways involved in collagen and elastin changes, and assess patient-reported outcomes related to dietary interventions targeting skin health.

Prospective Clinical Trial on the Effects of Topical Almond Oil vs Retinol on Facial Wrinkles and Pigmentation

PROJECT NO: SH02

Principal Investigator:
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Summary
The objective of this study was to determine whether almond oil can serve as an effective and well-tolerated alternative to tretinoin for reducing the appearance of wrinkles and enhancing various skin parameters. Almond oil is naturally rich in unsaturated fatty acids (approximately 70% oleic acid and 20% linoleic acid) and contains beneficial minor compounds including α -tocopherol (vitamin E), squalene, and phytosterols. We aimed to assess the effects of daily topical almond oil, almond oil with 0.5% vitamin E added, and 0.0025% tretinoin in a castor oil base on the appearance of facial fine lines and wrinkles over a 16-week treatment period. Participant-reported tolerability and skin irritation symptoms within each group were monitored. A total of 90 participants were enrolled in the study and 79 successfully completed all visits. Subjects were randomized to receive one of three treatments for the study duration. Preliminary findings suggest that daily topical application of almond oil can visibly improve the signs of photoaging to a similar level compared to either almond oil that is augmented with additional vitamin E or to tretinoin 0.025%. Each treatment arm achieved a similar degree of wrinkle reduction at week 16 when compared to baseline, and there were no significant differences in wrinkle outcomes between both almond groups and the tretinoin group. Notably, the vitamin E augmented almond oil group did not outperform almond oil alone, suggesting that the addition of 0.5% α-tocopherol provided no clear incremental benefit for reducing wrinkles and almond oil alone is effective at reducing wrinkles.

Almond Supplementation in Mild to Moderate Acne Vulgaris

PROJECT NO: SH-21-Sivamani-NR-03

Principal Investigator:
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Summary
The purpose of this randomized controlled trial is to evaluate whether daily almond consumption can reduce acne severity compared to a control diet in individuals with mild-to-moderate acne vulgaris. The primary outcome of this study is the change in total acne lesion count. To explore potential underlying mechanisms, this study will also examine plasma short-chain fatty acid (SCFA) concentrations and microbiome composition shifts in both gut and skin microbiota. Lastly, genetic analyses will be conducted to identify possible associations between specific polymorphisms and acne severity or response to dietary interventions. Sixty participants (aged 15–45) were randomized to either an almond group or control group, with 36 completing the 20-week study. Forehead sebum levels increased in both groups early in the study, but there were no significant differences between them. Cheek sebum levels remained stable throughout. Daily almond intake was associated with a gradual, significant reduction in acne lesions. No significant within-group improvements were observed in the control group at any timepoint. By the end of the study, only the almond-supplemented group demonstrated a significant reduction in acne lesions, suggesting a benefit of almonds in reducing acne severity.

Effect of Almond Supplementation on Mild to Moderate Acne Vulgaris in a community living population in India

PROJECT NO: SH-22-Udippi-NR-01

Principal Investigator:
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Summary
The primary objective of this study is to measure the impact of almond consumption on facial acne in those with mild to moderate acne in India. The secondary objectives are to assess both the shift in the plasma short chain fatty acids and the shift in the gut microbiome diversity and in the short-chain fatty acid producing microorganisms in the gut after almond consumption. This study will examine the impact of daily almond consumption on metabolic health parameters, 3D Imaging for acne, skin hydration and skin microflora, acne quality of life index assessment and anthropometry measurements. Data cleaning and analysis is in progress; manuscript preparation will commence following a final quality check and remaining analysis.

Effect of Water Activity, Temperature and Incubation period on Fungal Growth and Aflatoxin Production on Almond Nuts

PROJECT NO: 22-GizachewD-AQFSS-01

Principal Investigator:
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Summary
We investigated the growth of the two main toxigenic fungal species, Aspergillus flavus and Aspergillus parasiticus, and their aflatoxin production on different California almond kernels at different water activities, temperature and incubation periods. A. parasiticus produced high levels of aflatoxin (>300 µg/kg) on split kernels over a wide range of conditions (0.80 to 0.95 aw and 20 to 35 ºC). Contour plots revealed that the optimum conditions for aflatoxin production on split kernels were at 0.90-0.95 aw and 20-27 ºC. Aflatoxin production also depended on incubation time. By day 30, aflatoxin production on split kernels exceeded 300 µg/kg at 0.80 aw at all temperatures. There was no fungal growth and aflatoxin production at 0.65 and 0.75 aw. However, A. flavus didn't grow and produce aflatoxin at 0.85 aw on any of the kernel types. At 0.92 aw, only the split kernels supported growth and aflatoxin synthesis. The fungus was able to grow and produce aflatoxins on in-shell, shelled and split kernels at 0.95- 0.98 aw and 20-35 ºC. Both A. flavus and A. parasiticus were able to grow at 0.95-0.98 aw and 20-35 °C on almond hulls. While Aspergillus flavus grew well on the in-hull almonds at 0.95-0.98 aw and 27-35 °C, it did not produce any aflatoxins under any of the study conditions. In contrast, A. parasiticus produced aflatoxins B1, G1, B2 and G2. On the in-hull kernels, A. parasiticus synthesized the highest levels of total aflatoxins (>100 µg/kg) at 27 °C and 0.95-0.98 aw. On the hull fragments, 20 °C and 0.95 aw was the ideal condition for aflatoxin production, where the average total aflatoxin production was of 35 µg/kg. The predominant aflatoxin synthesized by A. parasiticus was AFG, accounting for up to 100%of the total aflatoxin produced on the hulls, which highlights the need to measure and report total aflatoxins (rather than AFB only) for almond hulls. Further studies are needed to determine the factors that limit AFB synthesis by A. flavus and A. parasiticus on almond hulls. Also, the types of phenolic acids present in California almond hulls need to be identified.

In conclusion, exposing the nutrient rich inner almond kernel allows rapid fungal growth and aflatoxin contamination at a wide range of water activities and temperatures. The risk of aflatoxin contamination during storage and transportation can be reduced by sorting damaged kernels and maintaining low water activity (<0.75 aw). California almond hull may prevent the synthesis of AFB. The hull might be used to minimize aflatoxin contamination of almonds and other crops.

Effect of Water Activity, Temperature and Incubation Period on Fungal Growth and Aflatoxin Production on Almond Nuts

PROJECT NO: 2024-AQ-Gizachew-01

Principal Investigator:
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Summary
The aims of this study were to: 1), identify the presence and contamination levels of mold species and 2), determine the aflatoxigenic potential of isolated Aspergillus section Flavi strains in California almonds.

In all, 80 almond samples from 10 lots and six different processing streams (Input, Electronic #1 (E1), Electronic #2 (E2), Electronic #3 (E3), Hand Sort, and Output) were analyzed. Two samples per lot were collected for both Input and Output streams. Only one sample per lot was collected for each of the processing streams E1, E2, E3 and Hand Sort. Thus, a total of eight samples were analyzed in each lot.

For total mold counts, 62 samples (77.5%) had a total mold count less than 1.0 x 104 CFU/g, while 14 samples (17.5%) contained 1.0 - 2.4 x 104 CFU/g. The four highest total mold counts were 4.3, 7.0, 9.6 and 12.5 x 104 CFU/g. The average and median total mold counts for all 80 samples were 1.0 x 104 and 5.5 X 103 CFU/g, respectively. There was no statistically significant difference in total mold counts among the 10 lots.

The prevalence and concentrations of mold species and the aflatoxigenic potential of Aspergillus section Flavi isolates were studied using aflatoxin producing medium FU/g, respectively. The most common mold contaminants were Aspergillus section Nigri (100% of samples), followed by Penicillium (57.5%) and Cladosporium (52.5%) species. Rhizopus, Fusarium and Alternaria spp were less frequently encountered. Aspergillus flavus was detected in nearly one third of all samples (31%); however, A. parasiticus was not observed.

Safety Assessment of Almond Hull as a Novel Food and Food Ingredient

PROJECT NO: BIO-22-01

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Summary
The study aimed to evaluate the safety and potential health benefits of almond hulls, a byproduct typically discarded during the almond processing cycle. With growing interest in sustainability and functional foods, this research was designed to determine whether almond hulls could be utilized as a safe, valuable ingredient in the food industry while offering potential health benefits to consumers.

The safety of almond hulls as a food ingredient was a primary focus. Safety assessments followed by OECD guidelines, including acute oral toxicity, genotoxicity and sub-chronic toxicity studies, provided reassuring evidence of their safety for human consumption. Genotoxicity testing, which assesses whether a substance could cause genetic damage, demonstrated that almond hulls do not induce mutations or chromosomal abnormalities in laboratory conditions. These findings indicate that almond hulls are not harmful at the genetic level. In addition, a 90-day sub-chronic toxicity study was conducted on rats, where almond hull powder was incorporated into their diet at varying concentrations. The study concluded that even at the highest doses tested, no adverse effects were observed on the rats' health. There were no significant changes in blood chemistry, organ function, or general well-being. These safety profiles suggest that almond hulls can be safely incorporated into food products without posing risks to human health.

In addition to safety, the research explored the potential health benefits of almond hulls, particularly in the context of blood sugar regulation. Given the increasing prevalence of diabetes and the growing demand for functional foods, understanding the effects of almond hulls on blood glucose management was a key objective. Our studies revealed that almond hull extract significantly inhibited the activity of enzymes (α-amylase and α-glucosidase) responsible for breaking down carbohydrates. This mechanism could slow the digestion and absorption of sugars, helping to moderate blood sugar spikes after meals. Animal studies further supported this finding, showing that almond hull extract delayed the rise in blood sugar levels after consumption, similar to the action of certain diabetes medications. These results suggest that almond hulls could potentially be developed into an ingredient that supports blood sugar regulation, offering a natural option for individuals managing diabetes or those at risk. Beyond their health benefits,

almond hulls also represent an opportunity for sustainability in food production. As a byproduct of almond processing, almond hulls are typically discarded, leading to waste. By developing uses for almond hulls in food products, this research aligns with growing interest in upcycling and sustainable ingredient sourcing. The utilization of almond hulls could help reduce food waste while providing a valuable functional ingredient for consumers.

Based on these findings, it is recommended that almond hull-derived ingredients be considered for regulatory approval, including the pursuit of GRAS (Generally Recognized as Safe) status. The promising safety data provide a strong foundation for regulatory consideration. Furthermore, while the initial studies show potential for blood sugar regulation, further clinical research involving human participants is essential to fully establish the efficacy and health benefits of almond hulls in managing blood glucose levels. Additionally, the development of food products that incorporate almond hulls as a functional ingredient should be explored, particularly in areas such as diabetic-friendly snacks and beverages. Overall, the research provides compelling evidence that almond hulls are not only safe for human consumption but also offer promising health benefits. Their potential as a sustainable, functional ingredient offers significant opportunities for the food industry. With continued research and regulatory approvals, almond hulls could emerge as an important ingredient in the food and nutraceutical sectors, benefiting consumers, the almond industry, and the environment.

Allergenicity and Risk Assessment of Novel Almond Hull Food Ingredients

PROJECT NO: BIOM02

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Summary
Background
Almond hulls, a byproduct of almond processing, contain proteins that may pose allergenic risks to consumers. The primary focus of this study was to determine whether allergenic proteins are present in almond hulls and assess their potential cross-reactivity with proteins from other fruits, particularly those within the Prunus genus, such as cherries, peaches, and apricots. Given the absence of standardized regulations for assessing allergenic proteins in novel food ingredients, the study followed the Codex Alimentarius (CODEX) guidelines. These guidelines emphasize a weight-of-evidence approach, integrating multiple analytical techniques to ensure accurate allergen detection.

Project Objectives
The research aimed to achieve two primary objectives:

1. Extraction and identification of potential allergenic proteins in almond hulls – Various protein extraction techniques were tested to optimize allergen recovery.
2. Allergenicity risk assessment of almond hulls as a novel food ingredient – This involved analyzing almond protein residues, assessing in vitro antigenicity, and investigating potential cross-reactivity with other Prunus species.

Discussion and Key Findings
A combination of biochemical techniques, including protein extraction, SDS-PAGE, Western blotting, and LC-MS/MS, was used to evaluate the presence of allergenic proteins. The primary allergen of interest, amandin (Pru du 6), was assessed using an anti-almond IgG antibody (2B4).

1. Protein Detection and Extraction Efficiency
   - Immunoreactivity for amandin was observed in three of the four almond hull samples tested: Butte (BT), Nonpareil (NP), and NP-S (Nonpareil South). The fourth sample, NP-N (Nonpareil North), did not show positive results, nor did the manually hulled dried Nonpareil hull sample (NP-H).
   - Various protein extraction methods were employed to minimize allergen loss, including borate-buffered saline (BBS) and precipitation techniques (20% trichloroacetic acid/acetone and ammonium sulfate).
   - While some extraction methods revealed unknown proteins, SDS-PAGE and Western blotting showed limited immunoreactivity, likely due to low protein concentrations in almond hull samples.
   - Notably, NP-H extraction using a native buffer showed a positive response in dot blot analysis, suggesting the successful detection of proteins.

2. Cross-Contamination and Cross-Reactivity with Prunus Species
   - LC-MS/MS analysis indicated the presence of proteins from related fruits, including cherries, peaches, and apricots, raising concerns about potential cross-contamination during processing.
   - Dot blot analysis demonstrated a strong immunoreactive response between almond hull extracts and apricot proteins, suggesting possible cross-reactivity. Further, IgE-based serum analysis confirmed that apricot extracts reacted strongly to anti-almond antibodies, reinforcing the possibility of shared allergenic determinants.

3. Potential Health Risks and Industry Implications
   - The findings suggest that while almond hulls may contain allergenic proteins, the extent of their presence varies across different samples, potentially due to processing conditions or extraction inefficiencies.
   - The observed cross-reactivity with apricot proteins necessitates further investigation to determine whether individuals allergic to almonds or related Prunus fruits could experience adverse reactions from consuming products derived from almond hulls.

Conclusion and Future Directions

This study highlights the complexities of allergen detection in almond hulls and emphasizes the need for refining protein extraction techniques to improve allergen recovery. The presence of potential cross-reactivity between almond hull proteins and apricots suggests that individuals with Prunus-related allergies could be at risk. Future research will focus on:

- Optimizing extraction methods to enhance allergen detection.
- Conducting sequence-based allergenicity prediction for proteins identified in almond hulls.
- Expanding studies to include additional almond varieties to gain a comprehensive understanding of their allergenic potential.
- Presenting findings at scientific and industry conferences to refine methodologies and enhance food safety guidelines.
- This research provides critical insights into the potential allergenicity of almond hulls and underscores the importance of thorough risk assessment before their inclusion in food products.

Comprehensive Shelf Life and Contamination Analysis of Almond Hull Powder

PROJECT NO: BIOM03

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Summary
Almond hulls, which make up more than half of the almond fruit by weight, have long been used as low-value animal feed. Yet they are naturally rich in fiber, phenolics, and bioactive compounds, making them strong candidates for novel food ingredients. This project is designed to generate the shelf-life and safety data required for a GRAS (Generally Recognized as Safe) dossier on almond hull powder, enabling its use in human food applications.

Over the past year, we conducted accelerated storage studies at 95 °F (35 °C) under two humidity levels (60% and 75%), using two types of packaging: simple polyethylene zip bags and sealed aluminum-laminated polyethylene (ALPE) bags. Quality indicators such as moisture content, water activity, microbial stability, particle size, functional properties, and polyphenol retention were monitored.

The results clearly show the importance of packaging. Under high humidity, powders stored in polyethylene bags absorbed moisture, experienced increased water activity, and supported higher microbial counts, though all remained within food safety limits. Physical changes such as particle agglomeration reduced flowability and led to declines in water- and oil-holding capacity, emulsifying ability, and antioxidant retention. In contrast, sealed ALPE packaging maintained low water activity, minimized microbial growth, and preserved both physical integrity and functional properties throughout 180 days of storage.

These findings demonstrate that almond hull powder can be safely stored and retains its functional value if proper packaging is used. Real-time shelf-life testing and comprehensive contamination analyses are underway and will provide the final data needed for regulatory submission. Together, this work highlights the potential to elevate almond hulls from a byproduct to a high-value, safe, and functional food ingredient that benefits the entire almond supply chain

Another Look at Pheromonal or Related Attractants for Leaffooted bugs (Leptoglossus spp.) Infesting California Nut Crops

PROJECT NO: ENTO18, ENTO39

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Co-PIs: Jocelyn Millar and Kent Daane

Summary
Epicarp lesion, nut abortion, and kernel necrosis or brown spot caused by the feeding of a suite of true bug species are a major source of yield losses in California nut crops. Leaffooted bugs (LFB, Leptoglossus spp.) cause some of the worst damage, in part because their mouthparts are robust enough to penetrate maturing endocarp tissues (Daane et al. 2005). Damage is unpredictable because bugs can rapidly migrate into nut crops from surrounding crops or native vegetation. For the congener L. australis, field bioassays suggested that males move into a crop first and begin producing an attractant pheromone that accelerates the aggregation of adults of both sexes (Yasuda and Tsurumachi 1994). Because of these rapid buildups, and since bug damage may only become apparent after the bugs have moved on, continuous monitoring of LFB populations is crucial for timing treatments. Current monitoring relies on beat sampling and/or visual assessment of nuts for damage, both of which are time and labor intensive, and many times fail to detect LFB populations early enough to take action. As such, attractant-baited trapping systems would be of great value for monitoring and potentially control purposes.

Several recent pieces of evidence strongly support our working hypothesis that male LFB produce powerful pheromones that attract both sexes. First, Inoue et al. (2019) demonstrated in olfactometer bioassays that adults were attracted to odors released by sexually mature males. Even more important, in 2021, our European collaborators studying the invasive Leptoglossus occidentalis trapped >10,000 bugs in trials with synthetic pheromone blends. In 2021, we successfully synthesized all components of the L. zonatus pheromone and were able to demonstrate its ability to attract LFB adults in the field. Since then, work in 2022 and 2023 has focused on efforts to (1) improve the efficiency of the synthesis process and (2) compare different blends and ratios of possible pheromone compounds – all aimed towards development of an operational pheromone lure for LFB. We have also started to work with a private company (Sterling International, Spokane, WA) to explore production of a pheromone lure at scale.

In 2024, we continued to evaluate commercial lures, and are happy to report that a new commercial lure from Alpha Scents was highly attracting to LFB adults. Furthermore, using the new lures in a revised trap study, we confirmed that yellow sticky-traps could be as or more effective of a trap relative to the black and yellow hanging panel-traps used to date.

Improving Integrated Pest Management Practices of Major Hemipteran Pests in Almond Orchards

PROJECT NO: ENTO32

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Summary
Several hemipteran pests attack almonds in California. These pests include several native stink bug species (e.g., green stink bug), leaffooted bugs (Leptoglossus spp.), and invasive brown marmorated stink bug (Halyomorpha halys) (BMSB). These pests have piercing-sucking mouthparts, which they use to penetrate plant tissues, release salary enzymes, and uptake liquefied plant tissue content. The feeding impact of hemipteran pests results in nut abortion or necrotic kernels, generally called “brown spots.” In recent years, the hemipteran damage has increased, causing widespread economic loss to almond growers.

The current practice of controlling stink bugs and leaffooted bugs, is applying pyrethroid insecticides on a “first sight” in spring/early summer. The leaffooted bug is the only economically important pest during the early season. However, the recent establishment of the invasive brown marmorated stink bug (BMSB) in the almond-growing regions of the San Joaquin Valley has further complicated the pest management decision-making process, as this pest can attack almonds throughout the growing season. Since its detection in crops in 2016, we have conducted a BMSB survey in San Joaquin Valley, but little is known about its status in the Sacramento Valley region. So, with this project, we conducted surveys of almond orchards in Sacramento Valley and detected the BMSB population in traps and crop damage in an almond orchard in the Chico area. This shows that BMSB has been spreading to other regions of California and causing some damage. In many instances, growers and pest control advisers are unaware of the BMSB problem due to the lack of awareness about this insect.

In addition, the green stink bug population and seasonal occurrence have been increasing, likely due to warm winter and hot summer conditions. Although threshold-based decision-making is one of the prerequisites of IPM, no thresholds for these hemipteran pests in almonds exist, and it is critical to develop some decision-support criteria to guide their management in California. The increased activities of these “large” hemipterans in the almonds and plenty of feeding injury (i.e., localized gumming) in

developing fruit might have contributed to secondary issues such as hull rot or other mold types and aflatoxin contamination. In our studies, almond fruits collected at harvest from almond orchards with a high stink bug population and nut damage also showed a high incidence of hull rot disease (Unpublished data, Rijal, and Michailides). A study is underway to determine the association between aflatoxin and Hemiptera feeding damage.

Effective use of insecticides against hemipteran pests is essential to almond IPM. Studies were conducted to evaluate the efficacy of reduced-risk insecticides and explore long-term solutions for using biological control for sustainable almond production. Multiple insecticides were evaluated, and a few selected ones can be used as rotational products.

UC Shafter Almond Research Orchard Maintenance

PROJECT NO: ENTO34

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Summary
Since 2009 the University of California has maintained an almond research orchard in Shafter, Kern Co., CA. This 7-acre orchard was planted in 2009 with alternating rows of Nonpareil and Monterey. It features an irrigation system that was set up in groups of 15 trees (half of each row) that can each be turned on or off independently to facilitate irrigation studies. Orchard maintenance costs are covered through donations from private companies combined with a grant from the Almond Board that covers the costs associated with water and power. Over its fourteen-year lifespan, this orchard has hosted more than 80 research trials related to the management of insects, mites, diseases, weeds, and irrigation. Many of these trials benefited greatly from being located on a University farm where experimental pesticides can be tested without the concerns of doing crop destruct, where true untreated checks can be maintained, where nuts treated with experimental pesticides are not at risk of accidentally entering the food chain, and where pest density can be manipulated to levels that are higher than are typical for commercial orchards. Of greatest significance during the past season was usage of the orchard for studies funded by the Almond Board to identify and test microbial and biological pesticides for potential use against navel orangeworm. This study, along with the more than 80 other studies conducted in this orchard over the past 14 years, represent the type of work that will continue to be facilitated by long-term maintenance of the orchard through UC’s partnership with the Almond Board.

Region-Wide, Disease Risk Forecasting System

PROJECT NO: ENTO35

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Summary
This project developed an area-wide disease risk prediction system for seven of the main almond-producing counties representing 13 regions in the California Central Valley. Counties included Butte, Colusa, Fresno, Kern, Madera, Merced, and Stanislaus. The forecasting system was based on in-canopy environmental data supplied by the Semios network of data loggers. By using the epidemiological models developed for anthracnose, Alternaria leaf spot, bacterial blast, bacterial spot, brown rot, and scab, we successfully scaled the use of the models to regional forecasts via aggregated site-level, in-canopy data. In 2024, the model for anthracnose was adjusted to higher rainfall amounts before reaching a critical value or action level. A new model for scab lesion sporulation on 1-year-old twigs was included on-line for 2024 forecasts. Weekly forecasts started on Feb. 26, 2024, and continued through June 24, 2024. The Almond Board website where forecasts were posted had a high number of visits for most of the spring and early summer seasons. Thus, this project effectively provided growers regional forecasts of the relative risk of these diseases for at-site-level management decisions. A farm advisor, an extension specialist, and the PI confirmed forecasts in selected regions by observing disease outbreaks for brown rot, scab, bacterial spot, and Alternaria leaf spot. Documentation in the field was also done for diseases forecasted but not posing a risk in any county or in specific regions of the state such as anthracnose and blast. This project was developed to ultimately contribute to the Almond Orchard 2025 goal of increasing adoption of environmental stewardship and successful disease management by reducing fungicide use by 25% to 50% based disease risk forecasts.

Ecology, Monitoring and Management of Carpophilus Beetle

PROJECT NO: ENTO37

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Summary
Carpophilus beetle (Nitidulidae: Carpophilus truncatus) is a new invasive pest of almonds and pistachios in California. Damage occurs when adults and larvae feed directly on the developing kernel, causing reductions in both yield and quality. Survey efforts conducted during the past year following detection have shown that this pest has already spread to almond and pistachio orchards throughout the San Joaquin Valley.

The carpophilus beetle is recognized as one of the top two pests of almond production in Australia, where growers typically experience 2-5% of kernels infested, and can sometimes experience damage exceeding 30%. Australian farmers primarily utilize overwintering sanitation as a way to reduce damage. Other management options, such as biological and chemical controls, have very limited or unknown efficacy.

This project was designed to (i) improve our understanding of the phenology and temperature requirements of this pest, (ii) determine the timing of its activity in orchards, (iii) confirm crop infestation patterns within the tree canopy and within the field (i.e. edge effects), (iv) evaluate chemical controls and (v) evaluate an experimental pheromone lure (developed in Australia) under California conditions, as well as (vi) educate growers and pest control advisors about this pest.

Over the past year, new information was generated on the timing of spring emergence of carpophilus beetles from remnant mummy nuts, as well as the initiation of activity on new crop nuts. At hull split, chemical controls were evaluated in almonds. At harvest, stratified samples will be collected to determine if infestation varies between the lower and upper areas of the tree canopy, as well as between the orchard edge and interior, which will contribute to the development of better monitoring strategies. Additionally, improved rearing methods have been developed, which allows to produce large numbers of carpophilus beetles to support laboratory assays. Using these methods, a study to determine the lower and upper temperature thresholds of this pest, as well as its development rate, has been initiated and is currently underway. A new pest identification guide for carpophilus beetle in almonds was also developed, and this

was complimented by dozens of extension and outreach events across the Central Valley to educate growers and pest control advisors about the ecology, monitoring and management of carpophilus beetle. This included an online webinar featuring research and industry personnel from Australia, who shared their experiences managing this pest in almonds over the past decade. Finally, the research team secured the necessary administrative and importation protocols to acquire an experimental pheromone lure for carpophilus beetle that was developed in Australia. Research and extension on this new invasive pest of tree nuts will continue in 2025, with continued focus on the development of pest ID and monitoring strategies, as well as cultural and chemical controls.

Evaluating the Influence of Landscape Composition on Almond Orchard Susceptibility to Leaffooted Bug (Coreidae: Leptoglossus zonatus) Colonization in the Spring

PROJECT NO: ENTO38

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Summary
Leaffooted plant bug (Hemitpera: Coreidae: Leptoglossus zonatus) (LFB) is a key pest of almonds early in the season. The adults feed on immature nuts, which can damage the developing embryo and/or lead to nut drop. Tools for monitoring LFB are currently very limited, and those that do exist (e.g. beat sampling the canopy, looking for signs of feeding on nuts) are very time and labor intensive.

Over the past seven years, co-PIs Wilson, Millar and Daane have been able to develop a new pheromone-based lure that is attractive to LFB adults (project co-funded by the Almond Board of California and California Pistachio Research Board). Here, we proposed to use this new lure and trap system to monitor a series of twenty almond orchards to gather data on LFB spring colonization activity, and then see if it was possible to relate those data to key features in the landscape surrounding the orchards. If successful, this information could be used to develop a risk assessment tool that would allow growers to prioritize LFB monitoring and management efforts in almond orchards located in areas with high risk of LFB colonization.

Key findings from this project identified that almond orchards with higher proportions of citrus, and/or developed land within a 2 km radius tended to have higher abundance of LFB adults in the spring. This suggests that these habitat types may serve as critical overwintering habitat for LFB adults, and as such lead to greater risk of colonization of nearby almond orchards by this pest in the spring.

Almond Variety Development

PROJECT NO: HORT1

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Summary
The UC Davis almond development and germplasm improvement program has amassed an enriched breeding germplasm demonstrating a range of traits with promise for addressing current and anticipated almond production and marketing challenges including self-fruitfulness, improved disease and pest resistance, improved water-use-efficiency and continued productivity under changing climates. At a time when European, Australian and Chinese almond breeding programs are experiencing inbreeding and associated reduced productivity because of dependence on a single source of self-fruitfulness in the variety Tuono (citation 15), the UCD program has developed 5 independent sources for self-fruitfulness. The genetic diversity of these sources, ranging from cultivated almond and peach, to the wild peach species Prunus mira and the wild almond species Prunus webbii, also allow the genetic complementation of complex traits for achieving greater environmental stability and resilience. This expanded germplasm, bred over the last three decades for adaptability to California growing conditions, also offers a rich source of new genetics for sustaining profitability for this economically important crop. With my anticipated retirement in the next 3-5 years, the final breeding challenge is to consolidate this advanced germplasm collection, currently numbering over 30,000 genotypes to a core collection of 1000 genotypes or less, yet which still retains the most promising genetics as a foundation for continued improvement in future public and private almond breeding programs. Because the development of self-fruitful Nonpareil-type varieties continues to be a main objective of this program, there is an immediate need to identify the required genetics needed to ensure future breeding progress. Even a relatively straightforward trait such as self-fruitfulness has been found to have multiple and independent components such as self-compatibility and capacity for high levels of self-pollination. Consequently, concurrent multi-trait selection is required and no single genetic manipulation can guarantee the desired outcome. The genetic as well as environmental interactions will also require multi-year to multi-decade regional testing to assure dependable profitability prior to large-scale commercial plantings.

Regional Field Evaluation of New Almond Varieties & Selections - 3rd Generation

PROJECT NO: HORT2-3rd

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Summary
The 3rd generation of the regional almond variety trial examine the performance of advanced selections and recently released almond varieties. Of the original 30, only 13 are still under evaluation; the rest have been eliminated due to low yields or other kinds of poor in-field performance. Nonpareil is still the top-performing cultivar, however there are several soon to be or newly released cultivars that have also yielded very well, such as Booth, UCD 18-20, and Y117-91-03. Of these, Booth and UCD 18-20 have extremely high rates of doubles, which may limit their commercial potential. Y117-91-03 and the newly released Yorizane are self-fertile and have had few issues in this trial.

Regional Field Evaluation of New Almond Varieties & Selections – 4th Generation

PROJECT NO: HORT2-4th

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Summary
This project is the fourth generation of almond variety trials conducted by the University of California and sponsored by the Almond Board of California. The overall goal of this project is to enhance supply diversification by identifying better almond varieties that fulfill distinct market demands and provide enhanced traits such as self-compatibility, pest resistance, and high yield efficiency. The specific purpose of this project is to evaluate the most promising new and experimental almond varieties from public and private breeding programs throughout the world and compare them to standard California commercial varieties in side-by-side field trials in three California almond growing regions.

In 2021, a request was distributed to all public and private California breeders and nurseries and several international breeding programs to obtain promising new almond varieties and experimental selections for comparative testing under commercial California growing conditions. Candidate varieties and experimental selections were received from California, Australia, Spain, and Israel. A committee of UC farm advisors, commercial almond handlers, and consultants participated in a blind evaluation of 50 shelled and in-shell almond samples provided by participating breeders and nurseries. From these, we identified 24 top-tier contenders for field testing (Table 6). All but two are purportedly self-fertile. Replicated field trials were established in the North (Butte County), Central (Stanislaus County), and South (Kern County) regions of the California Central Valley to document the performance of the experimental varieties and compare them against six industry standards. Important phenological and horticultural characteristics, kernel quality, and yield will be monitored for several years.

The Stanislaus County trial was harvested after the second growing season due to an unusually heavy crop in the vigorous, higher density, minimally pruned orchard. Yorizane had the highest calculated yield (1013 lb / acre) of all varieties ($P<0.05$). Shasta (745 lb/a), Pyrenees (713 lb/a), Carina (668 lb/a), and Constanti (640 lb/a) also had outstanding 2nd leaf yields (Table 2). Because of the cool, wet spring in 2024 and a minimal pesticide spray program in the young orchard, brown rot (Monilinia spp.) and bacterial blast (Pseudomonas syringae) were abundant in the trial. Varieties exhibiting serious levels of blossom brown rot and shoot death included UCD B14, Yorizane, Florida, and Shasta. Varieties with less severe brown rot infestations included Vela, UCD B9, UCD B2, UCD B12, UCD B6, Y117-106-03, and UCD B4. Varieties with up to moderate levels of hull rot (R. stolonifer) at harvest included Conway, UCD B2, UCD B8, UCD B12, and UCD B15.

Field Evaluation of Almond Rootstocks in the Southern San Joaquin Valley

PROJECT NO: HORT4

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Summary
Trees were planted on October 22, 2019, in fumigated soil. The experiment is part of a replanted orchard on a sandy loam soil where orchard recycling was performed. Also, high winds in this part of the valley are one of the biggest challenges. Trees continued to grow well, and a significant difference in tree circumference was observed among the different rootstocks. While differences in tree trunk circumference between a few rootstocks are no longer statistically different compared to the early period of orchard development, the previous trend is still the same as the orchard is moving into the production phase. Rootstocks Flordaguard x Alnem and peach-almond hybrids except for Cornerstone expressed the biggest growth. Krymsk 86 and Rootpac R had the smallest trunk circumference among all rootstocks. Growth of Flordaguard, resistant to a population of peach root-knot nematode, was not statistically different from other peach-almond hybrids such as Hansen 536 and Bright's hybrid 5. Furthermore, the yield trend followed the tree size as expressed by tree circumference with trees grafted on Cornerstone, Viking, Krymsk 86, and Rootpac R producing the least yields. Furthermore, Krymsk 86 had the highest number of kernels per ounce, which will correspond to smaller kernels.

Mid-July leaf analysis of Nonpareil shows that most of the trees in the orchard had nitrogen level at the adequate range value of 2.2-2.5%, and there was no statistical effect of rootstocks on leaf nitrogen content in 2024 compared to 2023. Significant differences in leaf potassium levels were detected, however, phosphorus levels were not statistically different between trees grafted on the different rootstocks. We have not noticed any deficiency symptoms on the trees or any other negative effect on tree yield and general health. Similar to the results from 2023, chloride and sodium leaf content in 2024 shows chloride accumulation in leaves of trees grafted on Krymsk 86 or Flordaguard. The levels were less than the levels detected in earlier years, however, sodium was not detected in leaf samples on average except in very low amounts in a few peach-almond hybrids, FxA, Viking, and Rootpac R rootstocks. Both elements are below the critical values to cause leaf symptoms and affect tree health. Furthermore, significant differences in hull boron content between the different rootstocks were detected with all values within the critical value. Unlike 2022, and similar to 2023, we did not detect any significant differences in midday stem water potential among the different rootstocks before harvest in 2024.

In 2022, trees grafted on rootstocks showing the biggest tree growth as measured by tree trunk circumference had the biggest stress compared to trees with the least growth. The same trend was observed in 2024 despite the fact that the results were not statistically different. We have also evaluated the progression of hull split for Nonpareil on the different rootstocks during the 2024 season. In general, peach-almond hybrids, and FxA had slower hull split progression compared to Rootpac R, Krymsk 86 and Viking. In this part of the valley and in commercial orchard using Krymsk 86as a rootstock, hull split always starts before trees planted on peach-almond hybrids allowing for early shaking and harvesting. Furthermore, we measured tree anchorage, and trees grafted on Krymsk 86, Rootpac R, Hansen 536, and Viking, are the most straight trees, while rootstocks Empyrean-1, BB106, Flordaguard, and Cornerstone were leaning the most in the orchard.

Nickels Soil Lab Projects

PROJECT NO: HORT6

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Summary
Objectives:
Provide support for long-term research and demonstration projects at Nickels Soil Lab in Arbuckle, CA (Colusa Co); 1) organic demonstration plot, Independence vs Nonpareil+pollinizers, and 3) new spacing trial on two different rootstocks. The objectives of those projects are:
1. To demonstrate certified organic almond production practices and materials in the Sacramento Valley and compare with conventionally managed trees.
2. Assess the nut yield potential and economic productivity of self-fertile (Independence variety) compared to a high value, self-incompatible planting (25% Aldrich, 25% Sonora, 50% Nonpareil).
3. Evaluate production and orchard health (tree loss, shaker damage, etc.) over time for orchard plots at 12', 14', 16', or 18' tree spacing (at 21' row spacing) using Titan peach x almond (vigorous) or Rootpac-R plum x almond (less vigorous) rootstocks.

Background:
Organic demo block.
A 7-acre demonstration orchard comparing organic vs conventional almond orchard management practices was planted in 2006. Three production systems; conventional, transitional and organic were initially compared, but now only conventional and organic practices are compared. Three quarters of the demonstration is managed with organic practices (24 rows) and one quarter (8 rows) with conventional practices.

All trees are planted 16'x 22' and irrigated with subsurface drip irrigation (SDI). The planting is 3:1 Nonpareil:Fritz in every row. All trees are on Lovell peach seedling rootstock. The conventional trees are managed using practices typical for almond production in the area. The organic trees are grown using practices approved for organic production by the USDA and CCOF using certified organic pesticides and fertilizers. This trial is not replicated due to the limited space available. However, this side-by-side comparison is intended as a careful case study of comparing differing almond management systems.

Self-fertile (Independence) vs Self-infertile planting (Nonpareil/Sonora/Aldrich)
In January, 2013, a replicated experiment was planted to assess nut yield potential and gross income per acre for self-fertile (100% Independence variety) and high value traditional, self-incompatible almonds

(25% Aldrich, 25% Sonora, 50% Nonpareil varieties). Spacing and rootstock was the same for all trees – 15' x 20' (145 trees per acre) on Viking rootstock. Irrigation is by double-lined drip hose. Each replicate is 5 rows wide and 21 trees long.

Spacing Trial:
In 2017, a 16 acre trial was planted to compare the economic sustainability of four row spacings (12', 14', 16', or 18') on two almond rootstocks of differing vigor. Row spacing is 21' across the entire planting. Irrigation is by double-lined drip hose.

Two rootstocks of differing vigor – Titan peach/almond hybrid and Rootpac-R® almond/plum hybrid – are used in this planting. These two rootstocks were selected for 1) good tolerance of elevated boron and/or chloride in irrigation water and 2) expected relatively higher (Rootpac-R) or lower (Titan) tolerance of saturated soils.

Bareroot Titan trees and potted Rootpac-R trees were planted in late April and late October, 2017, respectively. All plantings are 50% Nonpareil, 25% Aldrich and 25% Kester. There are 5 replicates of each rootstock x row spacing and each replicate is roughly 200' of tree row (0.1 acre). Direct comparison of rootstock performance is not possible due to the planting layout.

2024 results
Organic yield was 50% that of conventional yield, down from 70% ratio measured the previous year and the lowest since 2012. Tree sizes are similar between the two plantings. Deficient N levels are a continuing challenge in the organic block as organic N sources are extremely expensive.
Independence vs Nonpareil+pollinators results continued the pattern of irregular production for the self-infertile planting (Nonpareil/Sonora/Aldrich) and consistent production for the self-fertile (Independence) planting. Yield and crop value was significantly greater in 2024 for the Nonpareil+ pollinators planting compared to Independence with good bloom weather and bee activity. Independence variety continued to produce consistently, but yield was less than all the varieties in the Nonpareil +pollinizer planting. Independence trees are 30% smaller than Nonpareil. Gross crop value for the Nonpareil+pollinizer planting was significantly greater than that for the Independence planting. This comparison excluded production cost differences and insect damage.

In the spacing trial, the Titan peach/almond (P/A) hybrid rooted block (8th leaf) and the plum/almond hybrid (Pl/A) rootstock planting (7th leaf) showed no difference in Nonpareil or Aldrich yields based on tree spacing.

Irrigation Management: Evaluating Current Sensor-based Products and Remotely Sensed Information and Testing Thresholds for Delaying the Start of Irrigation in the Spring

PROJECT NO: HORT22

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Summary
Building on previous lysimeter-based findings that tree water use (ET) declined by about 4% for each bar that stem water potential (SWP) was below baseline, the focus of this research was 1) to evaluate the reliability of automated and remote water stress sensors in almonds, and 2) to determining whether the start of irrigation in almond can be delayed in the spring to save water without causing significant tree water stress, as has been found in walnuts. Commercial plant-based methods for directly measuring Stem Water Potential (SWP, FloraPulse and Saturas) or indirectly measuring plant water status (Phytech dendrometer) were compared to the most reliable measure of SWP (manual pressure bomb measurements). In some years other measurements were also evaluated, such as plant-based sap flow devices for measuring whole tree transpiration, and remote image (satellite) sensing of canopy temperature as a measure of water stress. All plant-based water stress sensors showed a similar overall seasonal pattern with generally low levels of stress in the spring and high levels of stress as a result of deficit irrigation at hull split and harvest. In most cases the FloraPulse sensor showed a very high level of agreement to the pressure bomb SWP with an average deviation of 1.5 to 1.8 bars. The Saturas sensor agreed with pressure bomb SWP during some but not all of the season, and also had a much higher variability (4.6 bar), even after adjusting for a 1 day delay in sensor response to tree water status. To the authors knowledge, the Saturas company is no longer active. The Phytech sensor showed the lowest agreement with the pressure bomb and a wide range of variability (3.8 to 8.8 bar, depending on the year). This sensor appears to be very sensitive during the early stages of stress, but less sensitive as stress increases. A new commercial sap flow sensor for measuring absolute water use (in gallons per day per tree) was compared to tree water use measured directly with a lysimeter. For some short periods of time (weeks), the daily gallons of water use measured by one of two sensors on the lysimeter tree was a very close match to the water use measured lysimetyrically. However, over longer periods (5 months) there were examples of substantial (25-30%) disagreement, with all sensors consistently measuring less daily water use than measured lysimetrically. Hence, at this time it is premature to regard this technology as a reliable stand-alone guide for irrigation management. Satellite images provided a value of Crop Water Stress Index (CWSI) for each tree in the lysimeter block on April 28, May 26, and July 28, 2023.

For many trees CWSI indicated moderate and serious water stress on April 28, when SWP spot checks indicated baseline (non-stressed) vales. SWP showed a statistically significant difference between control and stressed trees on May 26 whereas CWSI did not. After May 26, SWP showed an increasing separation among irrigation treatments and by July 28, which was close to harvest, both SWP and CWSI showed a statistically significant difference among all stress levels and were statistically correlated. Based on these data CWSI values did not reliably reflect tree stress until very late in the season. Unlike walnuts, delaying the start of irrigation in the spring has not shown promise for significant water savings and/or improved tree health in almonds. The data indicated that both cop load and final kernel weight may be sensitive to early season SWP levels in a much lower range of stress than is tolerated later in the season, for instance during hull split and harvest. Although yields were only statistically different in 2021, the cumulative yield over 3 years showed a trend for lower yield with longer (more stressed) delays. An important difference between almond and walnut has been that almond shows a relatively rapid drop in SWP from the baseline value in the spring, compared to a much slower drop in walnut. Given the evidence of almond sensitivity to relatively small differences in early season SWP found in this research, further research on early season irrigation management strategies in almonds may be warranted.

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

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Summary
Plum pox virus (PPV) is responsible for Sharka disease, one of the most important limiting factors for Prunus production (apricot, plum, prune and peach) in affected areas.
PPV was first detected in the USA in 1999 and was declared eradicated by the USDA in October 2019. Despite this official declaration, Sharka remains highly significant, even though it has never been reported in California. PPV was identified in Mexico, which is much closer to California than the areas where it was found in the USA.

The surface of almond culture in California is over 0.65 million Ha (1.63 million acres); in 2023, it reached over a million tons (2.34 billion pounds). That means even a scarce presence of symptoms of Sharka in infected almond cultivars could result in the multiplication of PPV in almond orchards, and the infected trees could act as a source of virus for other fruits cultivated close to these orchards. This could be a liability for the almond culture industry 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 results showed a limited potential role for almonds as a virus source in Sharka epidemics. However, Sharka is still a global threat to areas of stone fruit production, including almond trees. Based on the little information available, it is important to know the level of susceptibility/resistance of almond varieties and the rootstocks used by the almond industry in California, clarifying the possible role almond trees could play in the permanent threat that Sharka represents.

In our study, we included a group of 23 almond cultivars and 19 rootstocks to determine their behavior against PPV. After four years of work and over 1100 tests performed, we have infected 11 almond cultivars and 17 rootstocks. None of the almonds that tested positive (21) displayed Sharka symptoms. However, most of the 19 rootstocks in our assays have displayed significant Sharka symptoms and tested positive (327).

The results obtained show very high infection rates in some rootstocks—mainly those with a plum-type genetic background, like Adesoto, Marianna 2624, Rootpac® R, Tetra (Empyream 3), and Penta (Empyrean 2), as well as peaches Nemaguard and GF305 (positive infection host). This suggests that these rootstocks should be avoided. Nurseries should handle them with great care, and their use in new plantations should be limited. After completing three phenotyping cycles, we detected 4.2% of positives in the almond cultivars. Although Sharka disease has rarely been reported in almond trees, our ability to detect the virus by diagnostic methods confirms recent findings, where Tuono and Mission almond cultivars were infected with PPV-D (Isolate Penn4) and an efficient host for aphid transmission. Our findings force us to be very alert against a possible outbreak of PPV in California, indicating the role that rootstocks could play in a potential Sharka disease outbreak. Meanwhile, almond tree infection was possible for the first time with our PPV-D isolate, but in a very low ratio. Further studies are required to establish the potential risk linked directly to almond tree cultivation in California.

Discovery of Genetic Variation in Related Self-Fertile Species of Almond

PROJECT NO: HORT49

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Summary
The almond breeding program at the University of California at Davis is pursuing the development of new California adapted varieties solving current and emerging needs. These include mainly self-fruitfulness, improved disease and pest resistance, improved water efficiency and adaptation to a changing climate. In the long term the program has developed advanced introgression lines transferring self-fruitfulness from multiple independent sources including P. webbii, cv. 'Tuono', P. mira, and P. persica (peach). Other relatives (species) such as P. fenzliana or P. argentea have been used as a source for improved tree architecture or other traits (e.g. amaretto flavor market.) rather than self-fruitfulness. 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, a few low-density markers methods for marker assisted breeding have been used and a large number of promising new germplasm is being developed, the number of improved self-fruitfulness cultivars belonging to the almond breeding programs in California is low. Advances in high-throughput sequencing technologies provide a great opportunity to bring molecular breeding to full application in the almond breeding program at the UC Davis. Molecular breeding is based on the efficient selection of genomic variants known or hypothesized to be associated (tightly linked) with alleles with superior phenotypic effects. A robust breeding program requires knowledge of the many alleles at each genetic locus in the Prunus gene pool. Many allelic variants will have a different effect depending upon the desired phenotype, such self-fruitfulness. These allelic variants are largely caused by or tightly linked to single nucleotide polymorphisms (SNPs), the most abundant genetic variations within the genome.

New advances have been achieved in the genetic characterization of S alleles in the founders, resolving inconsistencies, and confirming the self-compatibility introgressed from related species. The SFB genotyping results show allelic polymorphisms, supporting the self-compatibility observed in the breeding results. Additionally, the genome assembly of 27 founders has been completed, providing insights into genetic relationships and clades. Further analyses are recommended to ensure current and future breeding progress toward obtaining a self-compatible Nonpareil using the current self-compatibility sources in the program.

Accelerated Assessment of Almond Variety Candidates

PROJECT NO: HORT51

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Summary
Regional accelerated evaluation plots have been established at the Nickels Soil Lab, Colusa County, RVT plantings in Butte, Solano, Stanislaus, Madera and Kern counties, High-density trial in Kern County and Salinity trial in Riverside County. The accelerated testing of promising almond selections continues to provide rapid detection, identification and early elimination of candidates that show unacceptable levels of regional vulnerability to important pests and diseases as well as historically important kernel and tree disorders such as double-kernels, Bud-Failure and rootstock-incompatibility. Because most advanced selections have incorporated self-fruitfulness from related almond and peach germplasm, this enriched, California-adapted germplasm also possesses a wealth of new kernel and tree types with value for improved production efficiency and market expansion. These include improved water-use-efficiency and salinity tolerance, disease and pest resistance, and improved kernel flavor, roasting quality, and postharvest storability. The introduction and regional evaluation of new nut and tree traits is also facilitating the development of more economical and water-efficient orchard systems such as more compact and productive tree architectures for single variety orchards, catch frame harvesting and in-field hulling.

Evaluating New Breeding Material for Salinity Tolerance in Almond Rootstocks and Exploring Novel Sources of Salinity Tolerance in Prunus Germplasm

PROJECT NO: HORT55

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Summary
This project focuses on identifying and developing new almond rootstocks and varieties that can thrive in salty soils or when irrigated with saline water, a growing challenge in agriculture caused by water scarcity and soil degradation. High salt levels in the soil or water can severely impact almond tree health, reducing growth and overall productivity. To address this issue, we are working in collaboration with renowned almond breeder Dr. Tom Gradziel. His breeding program at UC Davis has a long-standing history of developing and rigorously testing almond lines for resilience against various stresses, including pests, diseases, and environmental factors. Together, our efforts aim to create salt-tolerant almond varieties and rootstocks that can sustain productivity and support the future of almond cultivation in saline-affected regions.

In year 2023-24, we evaluated eight rootstocks, 15 newly developed almond varieties, and four existing varieties to determine which ones are better suited for salty environments. To measure their performance, we looked at how well the trees grew by assessing trunk thickness, as this is an indicator of overall tree health and vigor. Among the new almond varieties, UCD-B9 and USDA-Y117 showed outstanding growth under saline conditions, proving to be among the best performers. For rootstocks, UCD-516 stood out as the top performer, supporting healthy tree growth while also maintaining lower levels of harmful salts, like sodium and chloride, in the tree's leaves. Interestingly, we also found that some almond varieties that stored higher amounts of sodium and chloride in their leaves still managed to grow well. This suggests that these varieties have unique traits that allow them to tolerate and manage the salt in their tissues without being negatively affected. These varieties may have a natural ability to deal with salt stress, making them valuable for cultivation in areas with salinity challenges.

Looking ahead to the 2024-25 growing season, we are expanding our research with two new experiments. The first experiment will study how drought and salinity affect almond trees when combined, as both are common problems in agriculture and often occur together. The second experiment will test the performance of Nonpareil almonds, one of the most widely grown and commercially important almond varieties, when grafted onto two rootstocks from UC Davis that have already shown promise in earlier trials. By testing these combinations, we hope to identify solutions that not only improve salinity tolerance but also ensure stable and productive almond yields.

Yield Prediction for Resource Management and Yield Optimization in Almond

PROJECT NO: HORT66

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Summary
In 2024, the Brown/Khalsa Lab investigated almond yield variations, focusing on bloom overlap, pollination efficacy, growth, and nutrient dynamics. Results revealed that bloom synchronization with adjacent pollinizer cultivars significantly impacts 'Nonpareil' productivity, emphasizing the importance of effective pollination. Yield disparities highlighted that flower abundance, rather than fruit-set, is a primary yield driver, though bloom overlap and pollination are equally critical. Trunk growth dynamics showed a trade-off between growth and yield, influenced by resource allocation and potassium (K) levels. While K supported growth and fall carbohydrate recharge, it negatively impacted bee rewards, fruit-set, and yield. In contrast, phosphorus (P) levels strongly influenced starch mobilization and utilization, supporting yield. The results emphasis that high plant K levels were not simply yield-driven but rather a key factor influencing growth-yield relationship, likely due to spatial K variability.

In 2024, the Vougioukas Lab focused on advancing tree-level yield mapping for almonds by deploying a monitoring system on commercial off-ground harvesters. This system, designed and built by UC Davis, was rigorously tested in three California almond orchards. Results showed a relative error as low as 5.06% when estimating yield at the individual tree level. Improvements from the previous year included an increase in the harvester conveyor belt speed, which reduced uncertainty during yield assignment. By combining GPS data with vibration sensors on the shaker, we pinpointed the location and harvest time of each tree. As a result, we produced accurate tree-level yield maps that help growers understand yield variability in their orchards.

In 2024, Jin Lab wrapped up the yield forecasting with time series of PlanetScope, based on 1800+ tree yield in 2021 in Vacaville Independence orchard, and a manuscript is almost ready for submission. We moved on to build more robust tree-level yield forecasting models to capture both spatial and year-to-year variability of almond yield, by pooling 4 years of manually harvested yield data over three orchards and using monthly aerial imagery from Ceres. Separate models were built with various forecasting cadence. A suite of features were extracted at the tree level across various growth stages as predictors. Further analysis was done to understand the drivers for tree-level spatial and temporal yield variability. We have assembled more data and is in the process of building an improved orchard level yield forecasting models.

Comparing Root Traits and Depth Distributions for Mature Almond Rootstocks; is there a Link Between Root Architecture and Propagation Method?

PROJECT NO: HORT67

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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 root production. However, one disadvantage of this method is the change in root architecture that can be expected when roots are generated artificially or develop as adventitious roots. Young trees that originate from cuttings or tissue culture tend to produce many roots, which helps increase transplanting success. All these roots originate at the base of the sapling, which can potentially crowd out adjacent roots and cause cracking between roots as the tree matures. In addition to potential for increased cracking, clonally propagated root systems extend more laterally from the base instead of vertically. It is likely that shallower root frameworks do not develop as deep into the soil profile and will need more frequent irrigation when evaporative demand is high (i.e., during summer months). We have excavated mature root systems (6-20 years of age) in two commercial orchards (at Brentwood and Durham) and one experimental orchard at UC Davis. These root systems have been scanned 3D models of mature root architecture are being developed. Root systems at these sites include clonally propagated Krymsk 86, Brights 5, and Marianna 2684, and seed propagated Nemaguard and Lovell. In addition, young trees of both clonally propagated and seed generated rootstocks of Lovell, Nemaguard, Hansen 536 and Titan, and clonally propagated Krymsk 86 and Marianna 2624 were planted in the field at UC Davis in May 2024. Preliminary excavations 7 months later, in October 2024, showed that roots from seed generated Titan and Nemaguard seedlings reached well below 1 m soil depth, while Krymsk seedlings displayed less steep root angles and spread more horizontally.

Data-driven Smart Irrigation for Almond Orchards

PROJECT NO: HORT69

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Summary
Efficient water management is vital for sustaining almond production in California, particularly amid droughts and water regulations. This project explored innovative irrigation tools and strategies to enhance water use efficiency (WUE), reduce consumption, and maintain or improve yields. The research focused on precision agriculture technologies, WUE analysis, and providing growers with actionable insights for site-specific irrigation management.

A key outcome was evaluating stem water potential (SWP) sensors, such as microtensiometers (MT) and osmotic sensors, for continuous tree water status monitoring. These sensors provided reliable data for optimizing irrigation schedules, reducing labor compared to traditional pressure chambers, and improving WUE. MT sensors demonstrated high accuracy in near real-time SWP measurement, allowing early water stress detection and timely irrigation adjustments.

Remote sensing technologies, particularly satellite-derived evapotranspiration (ET) estimates using the SEBAL model, were also assessed. While daily SEBAL ET estimates showed some variability, cumulative seasonal ET values were within 10–12% of eddy covariance flux tower measurements. This suggests satellite-based ET is valuable for seasonal water use assessments and irrigation planning but is currently more suited for long-term allocation rather than daily decisions.

The study found that ET and the crop water stress index (CWSI) were more effective than the normalized difference vegetation index (NDVI) for delineating irrigation management zones in almond orchards. ET and CWSI-based zones were more responsive to transient orchard water use and stress changes, while NDVI zones were more stable over time. Both ET and CWSI better captured spatial variability in water status and yield. CWSI, being cost-effective and easy to compute, presents a practical option for precision irrigation management in almonds.

An exciting development was the AI-enabled UC Davis iPAR mobile app, designed to estimate canopy light interception, yield, nitrogen requirements, and water use. Using artificial intelligence, the app predicts canopy intercepted photosynthetic active radiation (iPAR) and correlates it with yield, water, and nitrogen requirements. This tool is particularly beneficial for growers seeking precision irrigation but hesitant about satellite-derived estimates. By providing ground-based insights, the iPAR app can significantly enhance orchard management at a zone-specific level.

The research demonstrated that optimized irrigation management can sustain high yields despite water limitations. For instance, in one study site, average applied irrigation across 14 orchard blocks decreased from 37.15 inches in 2019 to 30.83 inches in 2021, while yields increased from 1,721 lbs/acre in 2019 to 2,843 lbs/acre in 2020. These findings highlight the potential for almond growers to balance water conservation with productivity using precision agriculture technologies.

Recommendations for Growers:
1. Adopt Precision Irrigation Tools: Use SWP sensors like microtensiometers for real-time tree water stress monitoring and integrate soil moisture or ET-based monitoring to refine irrigation scheduling.
2. Leverage Remote Sensing for Water Management: Utilize satellite-derived ET estimates for seasonal water planning and to ensure compliance with the Sustainable Groundwater Management Act (SGMA).
3. Delineate Irrigation Management Zones: Use ET or CWSI maps for existing orchards and digital soil mapping for new orchards to group areas with similar water-holding capacities for optimized irrigation scheduling.
4. Explore AI-Enabled iPAR Mobile App: Test the AI-powered iPAR app to estimate block-specific canopy light interception, yield, nitrogen, and water needs for improved decision-making.
This research underscores the value of integrating advanced technologies and data-driven approaches into almond orchard water management. By adopting these strategies, growers can enhance WUE, support sustainable production, and navigate challenges posed by water scarcity. These findings provide a roadmap for the almond industry to optimize productivity while addressing water limitations.

Immobilizing Soil Nitrate Using Almond Shells in Winter-Fallow Vegetable Fields to Reduce Nitrate Leaching

PROJECT NO: INSH02

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Summary
In the fall, incorporating nitrogen-rich cool-season vegetable crop residues (e.g., broccoli, cauliflower) allows rapid tissue decomposition under mild winter temperatures in Coastal California. The resulting pool of residual soil nitrate is vulnerable to leaching by rains during the winter fallow. When cover cropping is impractical, immobilizing nitrate by high-carbon amendment applications can help reduce nitrate leaching. Our previous studies found <1/4" sieved almond shells applied at 5 -10 T/Ac as one of the most effective immobilizers. The present non-replicated demonstration field study in Salinas Valley comparing ground almond shells' application rates of 0, 5, and 10 T/A indicated ground almond shells 5 T/Ac and 10 T/Ac reduced nitrate leaching in the top 3' soil profile by 81 lb-N/Ac and 166 lb-N/Ac, respectively, during November 2023 and April 2024. The soil organic matter content distribution pattern of the trial site also appears to have affected the soil nitrate and water dynamics in the trial. Spring lettuce head yields at 5 T/Ac and 10 T/Ac plots were comparable to or greater than Control's. Unfortunately, bringing almond shells from Central Valley to Central Coast increases the cost beyond the current Salinas Valley vegetable growers' compost budget, and this practice is not economically feasible for them unless a sufficient incentive is given in the water quality regulations. The potential of using this approach to reduce nitrate leaching in Central Valley, where the transportation cost would be lower, will be explored in 2025.

Optimizing Potassium Management in Almond

PROJECT NO: INSH03

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Summary
Potassium (K) is the most important nutrient for almond trees after nitrogen (N). Almonds have in fact an extremely high K demand, with a total of 248-388 kg K/ha allocated to fruits in high-yielding crops. Potassium is an abundant element in the topsoil, however only 0.02-2% of the total K is available to plants. The availability to plants of soil K is affected by a multitude of different factors, such as soil type, soil texture, clay mineralogy, organic matter, pH, and plant uptake. For this reason, variability in the spatial distribution of soil available K has been often detected, despite being not entirely explained. The combination and the interactions between these factors create variability in the spatial and temporal distribution of soil plant-available K, and ultimately complicate K management in agricultural settings. Even in relatively small areas with the same fertilization history, non-uniform patterns of K have often been observed. Moreover, in the context of micro-irrigated tree crops, in which wetted zones are concentrated in limited portions of the soil, the dynamics between soil and plant processes that affect K availability can be particularly non-homogeneous within the orchard.

Despite the significance of the issue, our understanding of the dynamics that regulate potassium availability in soil, its uptake by plants and the soil response to fertilization remains limited. Consequently, we are still unable to effectively address the undesired heterogeneous spatial distribution of soil potassium. Incomplete understanding of K dynamics compromises sampling technologies and limits our ability to manage orchard K effectively. In light of this, given our lack of understanding of soil and plant K dynamics, growers rely on old-fashioned diagnostic tools, such as traditional leaf and soil testing, despite their limited accuracy, and apply uniformly high rates of K applications to avoid deficiency of K. However, with the recent dramatic increases in K fertilizer prices, excessive applications are not economically viable, and do not provide an actual benefit for the yield.

This research aims to improve our understanding of the complex dynamics of K in the soil and in the plant with the ultimate objective of improving K management and K use efficiency. While most research on K has focused on one single factor and studied how that factor affects the K distribution and availability, very little work has been done to understand the effect of the combination of all the factors involved in K dynamics.

Our research is conducted in two productive almond orchards located in Woodland, CA and Madera, CA, where we are conducting extensive soil and plant sampling.

The results of our research, so far, show that the drivers of K variability are different based on different soil properties and therefore one unique solution to guide fertilization plan cannot be offered. However, our data suggest that the use of sensors increases the quality of the distribution maps, that then can be used to formulate guidelines for growers. Given the within-field plant-available soil K variability, approaches alternative to the one-rate application can be a strategy to optimize the K management. Our results also show that a reconsideration of our standard leaf sampling protocols is essential to guarantee accuracy and precision, as evidence of the effect of sampling time and sampling was gathered.

Evaluating HFLC Nitrogen Management Strategies to Minimize Reactive Nitrogen Mobilization from California Almond Orchards

PROJECT NO: INSH04

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Summary
This project provides a comprehensive assessment of groundwater nitrate impact from a promising best management practice, High Frequency Low Concentration fertigation (HFLC). The project evaluates HFLC and compares three monitoring approaches to assess nitrate impact to groundwater: (1) Groundwater monitoring, the regulatory gold standard to assess pollution sources. Groundwater sampling is performed at 20 monitoring wells (screened at 7-14 m below ground surface). (2) Vadose zone monitoring provides early feedback on potential groundwater nitrate discharge but can be labor-intensive. Vadose zone monitoring is performed at 7 multi-level sites (0-3m depth) where soil moisture, nitrate, and ammonium fluxes are measured. (3) The NUE or nitrogen balance is a tool familiar to growers under the ILRP but its relationship to actual groundwater nitrate discharge is not well understood. Field monitoring data are collected to calculate water and nitrate (N) mass balance, as employed by the ILRP and enhanced with on-site measurement equipment (flow-meter, ET-station). The study makes important findings for growers, for consultants, and for regulatory agencies and the public:

Key Results for Growers: HFLC has shown promising results during the seven-year span of this project (2018-2024). On average, reported NUE has increased by 18% and kernel yields have increased by 15% when compared to the previous five years of pre-HFLC orchard management. Residual N mass in the first 60 cm of the orchard soils and pore-water nitrate concentrations in the vadose zone (measured to a depth of 280 cm) have both shown decreases following the switch to more efficient nutrient management.

Key Results to Environmental Consultants: Numerical models suggest that although nitrate concentrations quickly decrease in the shallow vadose zone, there will be an up to 30-year delay between the start of HFLC and an observable decrease in groundwater nitrate concentrations at this site. This delay is caused by the long transport time that nitrogen experiences between surface application and recharge at the water table, as well as slow movement of groundwater flow. Our unsaturated zone models suggest that this transport time

can be between 5 and 15 years, depending on soil types (i.e. water and nitrate-N move slower in clayey soils than in sandy ones). Computer simulations of the orchard's vadose zone and groundwater, calibrated to our extensive data set, suggest that lower irrigation- and nitrogen-efficient young orchard management may be the largest contributor to the highly spatially distributed groundwater N concentrations measured in the monitoring wells and throughout the vadose zone soils. Other causes of the large variability in groundwater nitrate may stem from block-scale non-uniformity of fertilizer and irrigation application, but less so from the highly heterogenous local geology. Calibration of the computer simulation models was most aided by vadose zone water content measurements to 10 ft, which was key to properly determine the amount of recharge and, hence, the proper dilution of residual nitrate mass in the leachate to measured concentrations in the vadose zone and in groundwater (legacy leaching). Properly determining recharge rates also reduces the uncertainty about travel time in the deep vadose zone and affects groundwater flow.

Key Results to Regulatory Agencies and the Public: Importantly, with respect to groundwater quality control, monitoring and assessment, this study makes the following key findings: First, nitrate concentrations in first-encountered groundwater across an orchard farm are highly variable, ranging over an order of magnitude, which has implications for the design and proper application of groundwater monitoring networks. Second, spatially averaged nitrate concentration across the farm (orchard), at first encountered groundwater, are consistent with the NUE, i.e., with field/orchard/farm scale nitrate losses estimated from N mass balance, with proper recharge estimates. And, third, nitrate transport in the unsaturated zone, under efficient irrigation management, in California climates and/or in drought years with regularly less than about 300 mm of annual precipitation may be subject to exceedingly long (years to decades) travel time due to the small amount of recharge.

Multi-Scale Evaluation of Stacked Regenerative Practices in Almond Systems

PROJECT NO: INSH05

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Summary
Regenerative agriculture as a production model is gaining momentum and aims to shift the emphasis away from just yield to also include management of a functioning ecosystem that actively restore soil health, biodiversity, ecosystem health and water quality while producing sufficient food of high nutritional quality (Grant 2017, Rhodes 2017). Almond orchards have potential to become flagship models for regenerative agriculture due to their perennial and low disturbance nature and the possibility to stack multiple practices in space and time with potentially low yield lags, if well managed. Practices such as compost and other organic amendments, whole orchard recycling, cover cropping and hedgerow plantings could form the backbone of regenerative almond systems (Figure 1). To date, these practices have been studied in isolation, with ABC funding and support, showing context-specific benefits to sustainability by allowing a decrease or substitution of inputs and/or increasing soil health and groundwater and biodiversity conservation with often no yield lags. However, the combination or stacking, of multiple of these practices remains understudied, especially when considering multiple socio-ecological functions of relevance to growers and environmental integrity.

There is also considerable landscape-level variation that results in more granular constraints and opportunities to implement regenerative models across the vast almond growing regions. Landscape-level factors include soil-related conditions that affect the outcome of soil-focused practices, precipitation differences that impact non-irrigated plant growth potential, habitat connectivity for airborne insects, and land ownership that affects practice adoption and the level of individual and community impacts. Knowledge of the context specific feasibility and outcomes of these systems is therefore needed to better pinpoint opportunities, constraints and expected benefits for orchard multifunctionality. Our project is integrated with other research initiatives to explore both the within-field and landscape-level impacts of stacked regenerative practices in almond orchards across the CA Central Valley.

During this second year of the project, we implemented two complementary approaches:

1) Maintained an on-farm demonstration site in collaboration with the East Stanislaus RCD with a controlled, replicated, multifactorial trial implementing three-way comparisons of establishment practices (conventional, Whole Orchard Recycling (WOR), and WOR+almond shell biochar), and soil management practice combinations (control (no-till + mineral N fertilizer) and soil health (control + cover crops + compost)) Figures 2 and 3. Practices have been maintained and tree growth has been monitored.

2) Measurements of multiple outcomes across a gradient of commercial orchards. We have connected with growers and identified 18 commercial orchards to compare outcomes across two gradients: a landscape potential gradient (defined by soil type, landscape heterogeneity and quality) and a within-orchard practice gradient (none, low, or high adoption of regenerative practices) (Figure 4). Regenerative practices include compost and other OM additions, cover crops or resident alley vegetation and grazing. We have streamlined the team and methods to quantify orchard response to practice adoption with a focus on ecosystem functions, both as it affects the multifunctionality of the orchard systems, and the production-relevant aspects of the ecosystem that are of highest importance to growers (Table 1).

Improving Fruit Removal and Harvest Efficiency of Independence Almond Cultivar

PROJECT NO: OTR01

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Summary
Incorporating an abscission agent into an almond early harvest strategy may improve the harvest efficiency and greatly benefit the almond industry by reducing pest pressure from navel orangeworm and hull rot. Improving harvestability may be particularly beneficial for the self-fertile cultivar Independence, which has shown fruit release problems. In this experiment, the ethylene precursor 1-amino cyclopropane-1-carboxylic acid (ACC), commercially called ACCEDE®, was sprayed at two different doses (300 and 500 ppm) when about 20% of the nuts were at the hull split stage of deep V. The effects of ACC on nut ripening (detachment force, hull split, fresh weight) and its toxic effect (leaf drop, leaf chlorophyll content, return to bloom) were evaluated weekly. We have found that the application of ACC significantly accelerated ripening. The effect was very quick, with an increase in hull split and a reduction in nut detachment force observed in treated trees versus control one week after the ACC application. The higher ACC dose produced a stronger effect on ripening than the lower dose and did not cause phytotoxicity. This is promising as, in older experiments, ethephon produced strong gummosis and leaf drop, preventing its adoption. The effect of ACC on harvestability could not be reliably evaluated as commercial harvest occurred when nuts from all treatments were already fully ripened. Next season we will investigate the effect of higher ACC concentrations, different spray times, and harvestability improvement with early harvests.

Improving Non-Fumigant-Based Approaches for Management of Almond Replant Problems

PROJECT NO: PATH1

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Summary
In 2024, we continued two replant trials at the Kearney Agricultural Research and Extension Center (KARE) focused on management of Prunus replant disease (PRD), which is a growth and yield suppressing soilborne complex that affects successive plantings of almond and other stone fruits.

KARE trial 1 tested non-fumigant preplant soil treatments based on rice bran (Rb) and ground almond hull and shell mixture (Ahs). The treatments were applied in September 2020 on land cleared from old peach trees. Rb and Ahs were tested as: (i) alternative carbon sources for anaerobic soil disinfestation (ASD) and (ii) alternative soil amendments, without ASD. Non-treated controls and a standard preplant shank fumigation treatment (Fum) were included. All treatments were administered to row strips comprising ~50% of the land area. The Rb and Ahs treatments were soil incorporated at 9 tons/treated acre, whereas (Fum), which included 1,3-dichloropropene plus chloropicrin at 332 plus 200 lb/treated acre, respectively, was shank injected.

KARE trial 2, which was situated beside trial 1 on the land cleared from peach, tested factorial preplant soil treatment combinations based on whole orchard recycling (WOR) and Fum. The goal was to determine whether WOR influenced PRD severity and its management with Fum. The treatments were: (i) no WOR plus no fumigation (-WOR -FUM); (ii) no WOR plus fumigation (-WOR +FUM); (iii) WOR plus no fumigation (+WOR -FUM); and (iv) WOR plus fumigation (+WOR +FUM). WOR chips from almond were incorporated in row strips at 61 tons/ treated acre. The Fum treatment for trial 2 was the same as that for trial 1.

Tree growth and yield data from trial 1 suggested economic feasibility for some of the non-fumigant treatments. Two-year (2023 + 2024) cumulative ‘Monterey’ yields were increased by Rb+ASD, Ahs+ASD, Rb, and fumigation by factors of 4.2X, 2.9X, 2.0X, and 3.2X, respectively, compared to the non-treated control, whereas Ahs alone was less effective (1.2X). Similarly, 2-year cumulative ‘Nonpareil’ yields were increased by Rb+ASD, Ahs+ASD, Rb, and fumigation by factors of 2.8X, 2.2X, 2.1X, and 2.0X, respectively, compared to the control, whereas Ahs was less effective (1.2X). Net ‘Monterey’ revenues, estimated as total 2023 + 2024 crop income minus preplant treatment costs (see treatment cost estimates in 2024 report of Browne et al. to the Almond Board of California), were increased by Rb9+WT and Fum by 415 and 358 $/acre, respectively, compared to the control. The net ‘Nonpareil’ crop revenues were increased by Rb9, Rb9+WT, Ahs+WT, and Fum treatments by 441, 773, 61, and 250 $/acre, respectively, compared to the control. No other preplant soil treatments resulted in net revenue gains, compared to the control.

Data from trial 2 indicated relatively small but generally positive impacts of WOR on PRD management. In ‘Monterey’, interaction of fumigation X WOR treatments occurred, and WOR only benefited yield in non-fumigated plots. Two-year cumulative ‘Monterey’ yields were increased by 4.3X, 3.8X, and 1.6X in the preplant treatment combinations of -WOR +FUM, +WOR +FUM, and +WOR -FUM, respectively, compared to -WOR -FUM. In ‘Nonpareil’, only main effects of fumigation and WOR were significant for the cumulative yields; fumigation increased the yields by 2.0X, whereas WOR increased the yields by 1.2X, compared to the non-fumigated and no-WOR controls, respectively.

KARE trials 1 and 2 will continue through 2025 yield evaluations. The continuation will provide for more complete economic assessments of the fumigation alternative and WOR treatments.

Phytophthora sampling was concluded in 2024. Almond on Krymsk 86 rootstock samples were received from Butte County but did not exhibit symptoms of disease caused by Phytophthora. Previous years’ isolates of Phytophthora mediterranea were shared with Jim Adaskaveg for fungicide sensitivity testing.

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

PROJECT NO: PATH4

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Summary
In 2024, we continued to evaluate new fungicides and biological treatments for the management of brown rot, jacket rot, shot hole, hull rot, scab, and Alternaria leaf spot. Environmental conditions in the spring of 2024 were favorable for disease development. Rainfall occurred at our trial sites, and temperatures were conducive for foliar diseases. The incidence of brown rot and gray mold was high, whereas shot hole occurred at low severity. Fungicides that resulted in statistically similar high efficacy in 2024 were the single-site Cevya, Fontelis and Tesaris, Approach, Axios, the pre-mixtures Elysis and Miravis Duo, Merivon, and Miravis Prime, rotations of Luna Experience and Luna Sensation with Adament, or Indar, Approach, and Fontelis, as well as the experimentals CX-10490 and V6M-5-14. The plant extract treatments BTS 300 and ProBlad Verde, and the biocontrol Serenade ASO showed intermediate efficacy in one study where trees were inoculated. In general, biologicals such as Botector, Serenade, and YSY were inconsistent between trials and years evaluated. For gray mold, all conventional treatments significantly reduced the incidence and severity of the disease with Miravis Prime and the rotation of Luna Experience and Adament providing the highest efficacy. In general, biologicals were much less effective than conventional fungicides, and some increased disease, whereas others significantly reduced the disease compared to the untreated control but were not commercially acceptable. The biologicals BM-01 and BM-02 were ineffective as pre- and post-infection treatments in laboratory assays against brown rot blossom blight. In contrast, Axios and V6M-5-14 both significantly reduced infection from the control. The in vitro toxicity of the new fungicide ipflufenoquin was previously found to be very high against M. laxa (EC50 range 0.005 to 0.022 ppm) and B. cinerea (EC50 range 0.002 to 0.091 ppm). In field studies for managing scab, Cevya, Regev, Elysis, Adament, Miravis Prime, and V6M-5-14 were highly effective, significantly reducing the disease to <20% as compared to 88.3% incidence in the control. Axios, Velum One (soil treatments), Fontelis+Aproach, SA-130, and SA-120, and CX-10490 were not significantly different from the control. Lack of efficacy of Fontelis+Aproach and Velum One could be explained by the presence of resistance to FC 7 and 11 compounds in the pathogen at the trial location. For Alternaria leaf spot (ALS), most treatments resulted in a high incidence and severity of disease after 3 applications and evaluation on 8-1-24. The most effective against ALS were Cevya, Regev, Miravis Duo, and Miravis Prime. Soil and combined soil and foliar applications with Velum One reduced the severity of ALS but not the incidence.

In a separate study, SA-120 and Quash significantly reduced the incidence and severity of ALS as compared SA-130 and the control. In previous studies, we found that the mode of action of the foliar fertilizer diKaP against hull rot was associated with reduction of fumaric acid by R. stolonifer that is a pathogenicity factor involved in the disease. 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 increased. All treatments significantly reduced hull rot from the control with 12.3 strikes/tree. The lowest number of hull rot strikes (<3 strikes/tree) was found on trees treated with Elysis, Miravis Duo, Miravis Prime, or V6M-5-14. In a second trial at KARE, all treatments reduced hull rot strikes to less than 2.8 as compared to 6.1 strikes/tree in the control. In our evaluations of natural host resistance to fungal diseases in our almond variety block at UC Davis, brown rot was not observed in 2023 and 2024. Based on 2017-2020 evaluations, some new cultivars such as Capitola, Folsom, Sterling, Supareil, Jenette, and several numbered genotypes (e.g., y121-42-99, p13.019, and UCD 8-27) showed consistent low susceptibility to brown rot blossom blight similar to Nonpareil. For evaluations of shot hole from 2017-2020 and 2022-2023 (no data in 2024), cvs. Aldrich, Capitola, Jenette, Kester, Nonpareil, and Sterling, as well as genotypes 7-159 ucd, p13.019, p16.013, and UCD 8-160 had low disease on fruit and leaves for years as compared to the other accessions.

Epidemiology and Management of Phytophthora Root and Crown Rot of Almond

PROJECT NO: PATH15

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Summary
In 2024, an additional 26 isolates of Phytophthora spp. were collected from four orchards with declining trees in the main almond growing areas of California and from a nursery, now totaling 326 isolates from 93 almond locations in our collection. P. niederhauseri and P. mediterranea were most commonly isolated, followed by species that are considered endemic in California for many years such as P. syringae, P. cactorum, and members of the P. citricola complex (P. acerina, Clade 2c). Isolates of P. niederhauseri and P. mediterranea have an optimum temperature for growth of approximately 30C; therefore, they are most active in late spring and summer, whereas the other species are found during cooler conditions of late winter and spring. The occurrence of the new high-temperature species may be due to shifts from well to surface water usage by growers and nurseries that provided new sources of inoculum, often originating from distant areas and habitats. With lower rainfall and warmer temperatures in the spring of 2024, P. syringae was not found causing 'aerial Phytophthora' infections of scaffold branches as in 2023. P. syringae died out in cankers of scaffold and trunks during the summer heat of 2023. Unlike the typical symptoms of infected pruning wounds, the infections caused by P. syringae were associated with young shoots. In baseline sensitivity studies, we continued to demonstrate the high in vitro toxicity of the new fungicides oxathiapiprolin (Orondis), mandipropamid (Revus), fluopicolide (Presidio), and ethaboxam (Elumin) (FRAC codes 49, 40, 43, and 22, respectively) against all Phytophthora species from almond in California. P. mediterranea, however, was insensitive to phosphites. We also continued to evaluate the efficacy and persistence of Orondis, Presidio, and Prophyt using grafted trees in greenhouse and field studies. Soil applications were followed by wound inoculations of Nonpareil or Monterey scions (16 cm above the graft union) or Krymsk or Brights hybrid 5 rootstocks (8 cm above the soil line) with P. cactorum. Orondis, Presidio, and ProPhyt were systemic and significantly reduced canker formation on the scions for at least 9 weeks after treatment. The systemic uptake explains the long-lasting efficacy of Orondis and Presidio in roots and trunks after soil applications. Binding of Orondis to dry soil (previously reported by us) was supported by laboratory studies where elution of Orondis was significantly reduced from dry soil in comparison to wet soil. Thus, to allow root uptake and obtain high efficacy and systemic movement, Orondis has to be applied to pre-wetted soil. Crotch rot studies were

repeated in 2024 with scaffold branch inoculations with P. citricola on 5th-leaf trees after soil application of Orondis, Presidio, or ProPhyt. Only the ProPhyt treatment significantly reduced scaffold cankers even 16 weeks after treatment. Fungistatic and fungicidal assays were conducted with the four new fungicides. Fluopicolide, oxathiapiprolin, and ethaboxam reduced cyst germination and accumulated the least amount of vital stain demonstrating fungicidal activity whereas PO3 and mefenoxam had significantly higher levels of viability indicating mostly fungistatic properties. Registrations of Elumin and Presidio (both nominated into the IR-4 program) are ongoing with field GLP studies completed in 2022-23. Syngenta is seeking registration of Revus for nurseries, and our data are used to support this usage. Thus, highly efficacious, non-phytotoxic alternative fungicides with different modes of action that can be applied in soil chemigation are being developed for managing Phytophthora root, crown, and lower trunk rots of almond. Alternatives to mefenoxam and phosphites are needed because metalaxyl/mefenoxam can be phytotoxic to young trees, resistance has been reported to phenylamide and phosphonate fungicides in Phytophthora species on other tree crops, P. mediterranea isolates are insensitive to phosphites, and soil fumigants are being greatly restricted by regulatory agencies.

Epidemiology and Management of Almond Band Canker Disease in Young Orchards

PROJECT NO: PATH16

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Summary
Almond band canker has become more severe in California, especially in young orchards in recent years. Three objectives were involved in this project. In Objective #1, various materials were tested in an almond nursery by using culturing isolation in synthetic media and real-time quantitative PCR (qPCR). Based on the two years of study, we found that Botryosphaeria dothidea and Neofusicoccum spp. were the predominant pathogens, mostly as latent phase, in the nursery both with incidence of >90%. Various fungal species were isolated from canker-symptomatic trunk tissues of a mother tree and a 2nd –leaf orchard. In Objective #2, fungicide treatments on trunks and crotches of young trees were conducted in two young orchards. Topsin and BioMend+ significantly slowed the canker development compared to the untreated control in 2023. Two years (2022 – 2024) of experimental results demonstrated that the incidence of trees changing from healthy to diseased (H→D) ones with untreated control was significantly higher than those of other two Topsin treatments in one orchard. The incidence of trees changing from diseased to healthy (recovered) ones (D→H) with Topsin treatment was significantly higher than that of the untreated control trees in the same orchard. Thus, Topsin application showed an effect on tree recovery from canker disease. However, no difference in any fungicide effect among different treatments was found in the other orchard. Such efficacy was found in 2023 but not in 2024, implying the less stability of BioMend+ treatments in canker control. In Objective #3, distribution of trees showing various levels of canker disease was investigated in an almond orchard, and various almond varieties were evaluated for their susceptibility to canker disease. Varieties ‘Peerless’ and ’Butte’ are most susceptible, ‘Nonpareil’ is less susceptible, and ‘Aldrich’ is most resistant among the four varieties. The observations also showed strong evidence of recovery of trees from canker disease in nature during the two years. Although different varieties showed significantly different levels of resistance to canker disease, this recovery effect was found in all the tested varieties.

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

PROJECT NO: PATH22

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Summary
Almond production expands on ~1.5 million in different micro-climate regions, on diverse soil types, and with differing water sources across California. Almond often follows its own species or may be planted after other (specialty) crops that leave behind soil-borne plant pathogens. Plant-parasitic nematodes, e.g., Meloidogyne spp. (root-knot nematodes, RKN), and Pratylenchus vulnus (root lesion nematode, RLN) are often found in soils scheduled for almond planting. Preplant soil fumigation, with methyl bromide until 2005 and then with 1,3-dichloropropene (1,3-D) often in mixes with chloropicrin has been used to mitigate the risk for damage by these soil-dwelling parasites. Preplant soil treatments were used to protect rootstocks with incomplete resistance against some of the nematodes. Since January 1, 2024, regulations on the application pattern of 1,3-D based on environmental and human health concerns have changed. Increased moisture requirements and the possibility of using TIF tarp reduce the treatment efficacy, or increase the expense, respectively. The sustainable pest management road map (SMP) envisions further reductions of chemical input of 90% by 2050. Alternative cost-effective nematode management strategies are urgently needed. In this project, materials and methods known to be suppressive against RLN were implemented in field plots as part of nematode management systems. It was tested if principally efficacious chemistries were sufficient compared to soil fumigation to protect almond plantings. Post plant remedies were included in the current experiments. While the AITC-containing Dominus was highly efficacious, agro-political developments have made its registration for use in California unlikely. After optimization of the irrigation scheduling, anaerobic soil disinfestation (ASD) was included in the testing program. In this method, easily decomposable substrate is spread on the soil surface, incorporated in the upper 5-6 inches of soil, and the profile kept soil water saturated for about one month after installing drip irrigation lines and covering the soil with tarp. In a simplification, the substrate was incorporated with a moldboard plow, and the recompacted soil layer above the substrate horizon used as sealant from atmospheric oxygen. These various preplant soil treatments were coupled with postplant applications to comprehensively and reproducibly determine benefits and limitations of management strategies.

Examination of Hull Metabolites in Hull Rot Sensitive and Resistant Almond Cultivars

PROJECT NO: PEST03

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Summary
This trial seeks to determine whether any nutrients or simple metabolites are correlated with hull rot severity by examining cultivars with a range in hull rot sensitivity in several orchards in the San Joaquin Valley of California. Hull rot ratings were collected prior to harvest, and fruit were harvested at the 2a and 3 stages. Hulls were analyzed for nutritional analysis, and submitted for a simple metabolite analysis. There are as of yet no findings from the trial, as the intention is to analyze two years' worth of data, and the metabolomic analyses have not yet been completed. The metabolite analysis should be completed in 2025 and the results will be shared in early 2026.

Evaluation of Microbial and Biological Pesticides for Navel Orangeworm

PROJECT NO: PEST05

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Summary
This project was conducted in conjunction with the Almond Board of California to satisfy its internal goals to identify and test microbial and biological pesticides for use against navel orangeworm in almonds. This included a two-step process whereby the Almond Board made a public solicitation for products to consider for inclusion, after which it provided guidance to the project leader on which it would like tested. Also included in the trial were industry standard conventional products along with experimental conventional pesticides with potential benefit to the almond industry.

When compared to Intrepid, microbial and biological products had mixed results. The currently registered peptide-based product Spear-Lep, when applied with Leprotec, a Bacillus thuringiensis (Bt) product used to facilitate penetration of the peptide into the insect midgut, was not effective. This is similar to the results obtained for this product in trials conducted by the same researcher over the past three years. A newer, experimental peptide product, Basin Flex, when combined with the Bt product Javelin, caused a slight reduction in damage compared to the untreated check to levels statistically equivalent to Intrepid. However, the same results were achieved when the Bt product was applied by itself, suggesting that the peptide product failed to make any contribution to the efficacy.

Javelin, which was entered into the trial as a representative of the several Bt products available on the market, resulted in damage that was reduced to levels comparable to the industry standard Intrepid. However, Bt products have been tested against navel orangeworm in many trials over the past decade and this result is extremely atypical. We are uncertain if the Bt results in this trial are an anomaly, or if there have been some sort of formulation or other changes resulting the efficacy. Future work on Bt-based products is justified and we advise inclusion of Javelin, alongside other Bt products currently available, in future studies to test their efficacy and consistency across trials, years and products. The final microbial product tested was Onira, which for the past few years has been known as MBI-306. It was not effective in this trial, which is consistent with the results of other trials conducted over the past two years.

Also included in this trial were two experimental pesticides that have potential for use in conventional orchards. The first, LX1601 is an early-development product whose active ingredient and mode of action have not been made public. The other product, Plinazolin, was one of the top performers in this trial.

This is consistent with multiple trials conducted over the past two years where the high rate of Plinazolin has consistently provided reductions in damage that are statistically equivalent to, and sometimes numerically better than, industry standard products. Plinazolin represents a new mode of action, and has broad spectrum activity, meaning that it could also be highly valuable as a pyrethroid alternative for growers who are simultaneously attempting to control navel orangeworm as well as stink bugs in an effort to prevent brown spot damage at harvest. At present, the manufacturer of Plinazolin has submitted registration packets for its use in a variety of crops and states, but has not made a decision on if, or when, it will pursue a registration for almonds in California.

Navel orangeworm is a particularly difficult pest to control with insecticides. Adults are not all present at the same time, eggs are often laid within cracks in the hull where pesticide residues are difficult to obtain, especially as the hull continues to split after applications are made, and because larvae spend most of their life protected within the kernel. Historically, the most effective pesticides are products that have good efficacy when they come in direct contact with adults, the egg, or hatching larvae, and that have long residual when applied in the field. These factors make it difficult to identify microbial and biological products that are effective due to the speed with which they break down in the environment, and because many need to be ingested to be effective.

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 - Amendment to an Ongoing Carbohydrate Observatory Project

PROJECT NO: PREC8

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Summary
The goal of the project is to use the Carbohydrate Observatory's analytical capacity to develop, coordinate, and implement a cross-project analysis of NSC for ABC-funded projects to accelerate our understanding of NSC's role in almond production and to provide support to individual projects' principal investigators. Specifically, we developed a chemometric technique to reduce the cost of NSC analysis to a fraction of the enzymatic digestion technique. We are following and developing a better understanding of the environmental impact (loss of chill hours, wildfire smoke, rainfall) on NSC content in almond trees and analyzing the physiological long-term repercussions on yield potential. In addition, we provide no-cost analysis to multiple projects supported by ABC.

Last year, we analyzed the impact of smoke exposure on almonds in the years following the 2020 and 2021 fire seasons and found a significant loss of carbohydrate reserves in the months leading to senescence as well as during winter months. This loss was associated with a significant reduction in yields, which correlated with the length and intensity of smoke exposure.

Avian Biodiversity in Almond Orchards of Central California

PROJECT NO: SUS01

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Summary
This is a three-year study to assess the biodiversity of bird fauna utilizing almond orchards during different seasons in the California Central Valley. Our study seeks to fill a gap in baseline knowledge of bird species utilizing almond orchards annually. While studies on bird diversity in almond orchards have been conducted in other places, like Australia, there is a lack of data on the California Central Valley. The California Central Valley is an important stopover along the Pacific Flyway and serves as home to hundreds of bird species. We anticipate that this assessment of bird biodiversity in almond orchards will serve to quantify the value of these habitats to avian fauna, as well as seasonal differences in habitat use. We hypothesize that migratory songbirds will use almond orchards as a stopover point in the early spring and fall during migration periods, and there will be a population of non-migratory birds that reside in orchards year-round.

The study approach is to collect baseline data utilizing the emerging technology of autonomous recording units (ARUs) to gather acoustic data of bird vocalizations. ARUs, when used appropriately, can provide an efficient, standardized, and unbiased data-collection procedure at a lower cost than traditional site visits by skilled observers (Priyadarshani et al. 2018, Darras et al. 2019). ARUs are devices that record audio at user-defined times, sensitivity, and frequencies. The audio recordings are then digitized and processed with computer-aided signal recognition systems to identify recorded birdsong to species. Isolating and identifying bird vocalizations can be a challenge because they are usually produced within a busy sonic environment. Background noise can include traffic, farm equipment, irrigation, wind, rain, and running water. Bird songs are extremely varied and complex, and when multiple species and individuals vocalize simultaneously, such as during the dawn chorus, elements of songs overlap in time, frequency, and amplitude. With ARUs, samples can be collected daily and year-round to provide a much more robust dataset than can be achieved by intermittent traditional field surveys.

During this past year of study, three ARUs were deployed in Stanislaus and San Joaquin Counties, along with traditional in-person point count surveys, to collect data during the spring, summer, and fall sample periods. Winter 2025 sampling is currently underway. Preliminary results confirm that a much greater representation of avian biodiversity is achieved through passive acoustic monitoring than through traditional in-person point count surveys. Preliminary results from the spring 2024 sampling period resulted in 165 bird species recorded by ARUs, as opposed to only 27 species recorded by in-person point counts. Acoustic recordings from the summer and fall sampling sessions are currently being processed. Once the winter 2025 sampling period is complete and data is processed, we will be able to make the first seasonal comparisons of almond orchard utilization by bird species. In the third year of the study, we intend to expand the geographical range of the study and add additional ARUs to sites in the Northern Central Valley and Southern Central Valley.

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

PROJECT NO: WATER16

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Summary
An increasing demand for healthy food options like tree nuts has tripled over the last 50 years. In response, California's almond acreage has increased by 145% in the past two decades, with almonds becoming the state's most prevalent crop. However, California faces recurrent droughts and a severe groundwater crisis. To address some of these issues, we introduced the Tree-Crop Remote Sensing of Evapotranspiration Experiment (T-REX), an interdisciplinary project focused on developing fundamental and applied science on crop sensing. T-REX aims to support agricultural management, particularly in irrigation and sustainable practices, support local and regional water management decisions, and inform state policies on water usage and agricultural-environmental sustainability. We combine different data sources across various temporal and spatial scales, including leaf physiological measurements, micrometeorological monitoring (surface energy, water vapor, and CO2 fluxes), uncrewed aerial systems for near-ground thermal and spectral remote sensing, and satellite thermal and spectral imagery. Using state-of-the-art modeling techniques, we have developed a framework that provides near-real-time crop water use estimates with reasonable accuracy.

The T-REX project team has collaborated closely with the OpenET team to advance a cloud computer-based near-real-time evapotranspiration (ET) platform. A comprehensive evaluation of the OpenET platform can be found in Volk et al. (2024). As part of our research efforts, a more focused study led by Knipper et al. (2024) evaluated the performance of OpenET at six commercial almond sites equipped with state-of-the-art micrometeorological instrumentation. In addition, further analysis were performed to compare OpenET's ensemble ET data against applied irrigation and rainfall records for an additional 148 almond orchards throughout California's Central Valley. The findings indicate that OpenET's models, including the ensemble ET values, deliver practical and reliable ET estimates. However, the study identifies limitations in capturing short-term ET fluctuations due to the 8-day revisit cycle of Landsat satellites and the interpolation techniques used. Our findings underscore the potential of remote sensing ET models as valuable tools for enhancing water management and agriculture sustainability in California.

Nonetheless, the study emphasizes the necessity for a detailed understanding and careful application of these models, considering the specific local conditions.

Most almond orchards in California have precision irrigation systems (microsprinklers, drip) to increase water application efficiencies. Most of these systems do not have the flexibility to irrigate at a tree-level precision. However, new technologies such as variable drip irrigation systems offer granularity that could lead to potential water savings, increased yields, and improved fruit quality. Moreover, UAS technologies have been growing their presence in agriculture and irrigation management, aiming to provide information to support irrigation decisions at the tree level. Within the T-REX project, UAS missions were designed 1) to test and further develop airborne remote sensing thermal and multispectral data collection, which are referred to as “basic missions,” and 2) to develop a workflow for timely production of ET maps for irrigation management and develop product types of interests for growers, which are referred as “applied missions.” Through this work, we have demonstrated the advances in drone technology (avionics, sensors, and data collection protocols) as a viable means to effectively collect reliable imagery for ET modeling. The project methodology is based on the extensively used Two-Source Energy Balance (TSEB) model.

Our current research efforts are focused on ET forecasting, advancing the accuracy of near-real satellite-based modeled actual ET estimates, collaborating on the development and testing of the OpenET-Farms tool, developing ground-UAV-satellite data fusion schemes for ET and crop stress modeling, and integrating on-farm management into watershed-scale hydrological modeling. These research efforts are being supported through several research initiatives aiming to leverage the work that was initially funded by the Almond Board of California through this WATER-16 research grant.

How to Irrigate Almond Orchards - for the Current Year's Expected Yield or for Maximum Yield Potential?

PROJECT NO: WATER17

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Summary
The main goal: Determine the impact of matching irrigation to the spring estimates of the current year's yield on final yield and the following year's yield potential. The study requires developing a yield prediction model (YPM) for early spring, i.e., prior to fruit set. To develop the model, we use specific characteristics of the orchards (age, variety, location), stochastic environmental conditions (precipitation, temperature, frost, persistent air pollution, etc.), and trees' non-structural carbohydrates (NSC; soluble sugars and starch) content. Model accuracy can be scaled with the size of the dataset, i.e., it requires a large-scale, multi-year time series dataset that captures most of the variability. We are collecting data from multiple orchards distributed across Central Valley, including hourly temperature and precipitation, spectral images from Google Earth Engine datasets, bloom time from a lab-developed satellite-based model, air pollution data from the MODIS satellite OD47, monthly observations of non-structural carbohydrates (NSC) from the Carbohydrate Observatory covering 54 orchards, orchard parameters such as variety, age, and location, irrigation data from 152 orchards, and true yield measurements. Data has been retrieved from 2018 to 2024 to capture different climatic scenarios.

Remote-Controlled Evaluation of Distribution Uniformity and Stem Water Potential: Extending Imagery to Integrated Decision Support

PROJECT NO: WATER18

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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 energy-efficient irrigation scheduling using stem water potential (SWP) at key stages ("when to start", hull-split, "when to end"), adjusting irrigation in response to actual evapotranspiration, and increasing distribution uniformity via improved system testing, maintenance, and application flow metering. This project addresses obstacles and knowledge gaps through new remote sensing tools, outreach, and integrated irrigation decision support to transform thermal, multispectral, and hyperspectral imagery to actionable information. As a part of the larger Tree Crop Remote Sensing of Evapotranspiration Experiment (T-REX), our team conducts applied remote sensing missions using off-the-shelf UAV platforms on a frequent basis at T-REX eddy covariance tower locations. Our team is using these data to develop and validate high-resolution actual evapotranspiration and energy balance maps at the tree scale. Our high-resolution models continue to demonstrate that off-the-shelf UAV platforms can provide maps of high-resolution actual evapotranspiration at acceptable and actionable levels of precision and accuracy to inform smart irrigation in California almonds.

Our overarching goal is to address research gaps, provide training, and develop decision support tools for CA growers and almond industry and water data service providers (e.g., CCAs). Key milestones for year 4 include: (1) We are heavily into analysis and model development for the water stress component of this project targeting easy to use, early indicators of water stress using hyperspectral and thermal imagery validated by comprehensive physiological data (stem water potential, Florapulse sensors, photosynthesis) from the almond variety and delayed irrigation trial in Butte County. We published two studies and a trade article related to the SWP work and are preparing a third study for submission comparing SIF, PRI, and other hyperspectral indices to stem water potential over two stress periods in 2022 and 2023. (2) For T-REX, we flew 36 UAV missions using our off-the-shelf platform in conjunction with Intensive Observation Periods measuring on the ground physiological data at Woodland, Ripperdan, and Westley sites.

In addition, we published our first TREX article and will continue to process/fuse data and over the remaining project period to prepare another publication in 2025. (3) We partnered with Resource Conservation Districts to perform comprehensive distribution uniformity tests at Woodland, Ripperdan, and Westley sites, while also conducting high-resolution UAV missions on satellite overpass days to identify anomalies or changes within a field scene. We are using these combined ground, UAV, and satellite data to develop new models easily assessing distribution uniformity. We will collect validation data for these models from additional orchard sites in partnership with Resource Conservation Districts during the growing season of 2025 to ensure that models can be applied across a variety of orchards. The last year of this project will be heavily focused on data analyses, model development and testing, publication, and final data collection.

Determining the Sensitivity of Fruit (Nut) Set and Crop Load to Early Season Water and Carbohydrate Status, Developing a Water/ Carbon Model for Fruit Set, and Evaluating whether Low Set and Resulting Low Crop Loads Require Less than Full In-Season Irrigation

PROJECT NO: WATER19

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Summary
One primary objective of this research is to determine if less than full irrigation water can be safely applied to almonds in years of low crop potential (e.g., poor pollination conditions and low set) without harming future yields. Since yield is primarily a function of fruit set and crop load however, another important objective is to determine whether irrigation influences fruit set, either through winter irrigation prior to the current crop year or in-season irrigation for the following crop year. An important difference between this and previous irrigation-related studies is that irrigation is managed to achieve 3 levels of stress (control, moderate, and severe) based on target levels of stem water potential (SWP). In this way, the response of the trees (flowering, set, stem non-structural carbohydrate [NSC] levels, and yield) will be directly related to the actual stress experienced by the tree. This will allow irrigation management recommendations based on ranges of SWP achieved, which should be reliable across soils and environmental conditions. In the first year of the study (2023), crop load and yield was very low (averaged 1,560 Kernel #/ac in the controls) due to poor pollination conditions, and the thinning treatments that were applied to generate different crop loads (only in the moderate and severe stress treatments) were not very effective. However, there was some range in crop load in the moderate and severe treatments over blocks, and one clear result was that there was no effect of crop load on the amount of irrigation associated with a particular level of tree stress. In the second year, yields were much higher (averaged 3,970 Kernel #/ac in the controls), and the thinning treatments reduced yield by 20-40% in the severe and moderate stress treatments, respectively, but the same result was obtained: no effect of crop load on the amount of irrigation associated with a particular level of tree stress. However, we did see a substantial

increase (about 60%) in water applied to the control treatments in 2024 compared to 2023, despite there being a similar calculated water demand (ET) in both years. Hence, natural and artificial thinning may not have the same effects, and based on the controls, more irrigation may be needed in a high crop year compared to a low crop year. These results must be repeated. Thus far, the measured levels of NSC have shown the anticipated seasonal patterns, with some effects of water stress, but increases in NSC have not been associated with increases in crop load, as suggested in the literature. We will continue to track NSC to obtain a large enough data set to test these hypotheses. Automated, high-resolution images were collected daily over the season by a fixed, tower-mounted camera. These images had sufficient magnification to identify individual flowers and fruits on selected branches from each tree in the study over time. Based on manually tracking over 2000 individual flowers on a selection of images from the 3 main treatments (control, moderate and severe stress), a clear progression of maximum bloom in early March followed by a gradual, linear flower/fruitlet drop to late March was observed. Surprisingly, this pattern was identical in each of the irrigation treatments. Also, from late march through late May there was little additional drop, with no clear 'third period' of drop (often referred to as 'June drop' in the literature). Based on these manually collected images, there was no statistical difference in final set across the three irrigation treatments, which ranged from 24.6% in the control to 29.3% in the severe stress treatment. These values are consistent with published field counts of about 30% set in almond, and we are currently developing an automated image analysis method to allow analysis of all the images collected. Based on these % set values and the observed yield and crop load values, we calculate that the initial number of flowers (millions of flowers per acre) was 6.56, 5.69, and 3.19 in the control, moderate and severe stress treatment, respectively. This is a preliminary analysis without statistics, but it appears that crop reduction under water stress may result from less flowers at bloom, and hence be a carry-over effect, rather than effect of stress on % set.