

Multistate Research Project S-294
Quality and Safety in Fresh-cut Vegetables and Fruits

2014 Compiled Annual Report

Activities

Objective 1. Evaluate methods of sampling and measuring flavor and nutrition of fresh-cut products to facilitate comparison to traditional shelf life factors.

- Barrett and Negre and other colleagues completed work on aroma volatiles and flavor quality in melons. See Vallone et al., 2013 publication.
- Cantwell and associates are studying the relationship between ammonia concentrations and quality of intact and fresh-cut leafy and green vegetables.
- The hedonic 9-point scale was compared with the hedonic general Labeled Magnitude Scale (gLMS). (Kalva et al., 2014).
- Continued studies using trained descriptive panels and chemical analysis (volatiles, sugars, acids) to evaluate citrus, strawberry, and tomato germplasm from University of Florida and ARS Ft. Pierce. 10-years of tomato data are being analyzed to establish a model for tomato quality. (USDA ARS US Hort. Research Lab)
- Continued flavor research on strawberries: inheritability of the aroma volatile methylanthranilate (MA). MA imparts fruity flavor to strawberries and is only produced in European lines. (USDA ARS US Hort. Research Lab)
- Conducted studies on effect of greening disease (Huanglongbing, HLB) on citrus fruit with emphasis on effect of pre-harvest nutritional sprays. Evaluation of GC-MS sampling technology for volatile flavor analysis of fresh and processed fruits and vegetables, especially binding site competition in a SPME sampling system. (USDA ARS US Hort. Research Lab)
- Initiated study to evaluate flavor of Citrus x Poncirus hybrids that might impart partial resistance to citrus greening disease (HLB) due to *Candidatus Liberibacter asiaticus*. (USDA ARS US Hort. Research Lab)
- Initiated study to evaluate physical quality of citrus peel and flesh influenced by citrus greening disease (Huanglongbing). (USDA ARS US Hort. Research Lab)

Objective 2. Develop new strategies to improve and better maintain inherent fresh-cut product quality and nutrition.

- Cantwell and visiting scientist Marina Buccheri demonstrated that physical damage to breaker tomatoes increased translucency and reduced lycopene in slices from ripe fruit (U of California-Davis)
- Cantwell and visiting scientist Marina Buccheri demonstrated that higher ripening temperatures increased juice loss upon slicing tomatoes. (U of California-Davis)
- Barrett and colleague Elizabeth Mitcham and graduate student Panita Ngamchuchitare are working on fresh-cut mango: treatments before and after fresh-cut processing of different varieties that affect quality and shelf-life of the cut product. 4 papers to be published in 2014. (U of California-Davis)
- Cantwell and associates worked on the tuber sunchoke as a fresh-cut product to be used raw or cooked. The basic physiology, and browning and control were studies. 3 papers to be published from this research. (U of California-Davis)

- Quality Of Packaged Fresh-Cut Celery As Affected By Different Sanitizers And Atmospheres- Overall, the high oxygen packages, independently of the sanitizer, showed the best balance of quality of celery sticks during storage at 7 °C, while traditional snap-fit containers did not help to maintain quality. In conclusion, the gas composition has an impact on the quality of celery sticks, and specific sanitizers can interact with specific atmospheres having a negative effect on the quality of fresh-cut celery. (Michigan State University)
- Isolating and identifying heat- resistant fungi from blueberries and blueberry products. Conducting challenge tests to determine heat treatment conditions for control fungal spores (and tissues) (Lihua Fan).
- Investigation of impact of heat shock on protein profiles on heat-resistant fungal spores (Lihua Fan and Jun Song).
- Inhibitory effect of bacteriocinogenic lactic acid bacteria (LAB) on *Listeria innocua* inoculated in simulated medium of vegetable or fruit juice (Lihua Fan).
- Antimicrobial effect of cranberry juice on *E. coli* and *L. innocua* in water and culture broth systems (Lihua Fan).
- Investigation of antimicrobial effect of small fruit extracts on food pathogens using Bioscreen (Lihua Fan).
- Development of packaging and postharvest handling systems for novel hydroponic leafy green products (Charles Forney).
- Enhancement of apple aroma through volatile precursor treatments (Charles Forney and Jun Song).
- Determination of factors that impact the flavor chemistry (volatiles, sugars, acids) of blueberry and apple juice (Charles Forney).
- Screening of raspberry and strawberry cultivars and breeding lines for fruit quality and storage-life (Charles Forney and Andrew Jamieson).
- Evaluation of the impact of vapor heat treatment on storage and retail quality properties of whole cantaloupe melons (Greg Bezanson, Lihua Fan, Charles Forney and Denyse LeBlanc).
- Quality Of Packaged Fresh-Cut Celery As Affected By Different Sanitizers And Atmospheres (Jaime González-Buesa, Natalie Page, Chelsea Kaminski, Elliot T. Ryser, Randolph Beaudry, Eva Almenar)
- Examined the performance of microencapsulated hexanal release into the headspace above apple slices for the inhibition of *Penicillium expansum* (Susan Bach and Pascal Delaquis)
- The optimal ripeness stage for processing and marketing fresh-cut 'Kent' mangos with best quality and maximum shelf life was determined. (Dea et al., 2013).
- Treatment of 'Beta' avocado, a Guatemalan-West Indian hybrid, with aqueous 1-MCP at 2.77 $\mu\text{mol/L}$ (150 $\mu\text{g/L}$) for 1 minute effectively delayed ripening by 6 days (to 14 days at 20C), delaying the onset of climacteric and lowering respiration rates, without compromising sensory acceptability. This technology has the potential to permit shipment of these fruit to more distant markets than currently possible (Pereira et al., 2013).
- Fruit volatiles were assessed during ripening of Florida 'Simmonds', 'Booth 7', and 'Monroe' avocados with or without 1-MCP treatment. (Canto Pereira et al., 2013).
- Mechanically harvested (MH) southern highbush blueberry was compared to hand-harvested (HH) in two years. (Sargent et al., 2013).

- The effects of ultrasound amplitude on the surface appearance and quality of a porous colloidal product (apple) sensitive to browning reaction during storage were investigated. (U of Illinois Urbana Campaign)
- The effects of a thiamine dilauryl sulfate (TDS) and MA combined wash on the quality of romaine lettuce under modified atmospheric conditions. (U of Illinois Urbana Campaign)
- Radish microgreens constitute a good source of bioactive compounds; however, they are very delicate and have a short shelf life. The main goal of this study was to optimize postharvest handling conditions to reduce the quality loss, extend the shelf life and maintain nutrient profile of daikon radish (*Raphanus sativus* L. var. *longipinnatus*) microgreens during storage. (U of Maryland).
- Evaluated effect of edible coatings to preserve physico-chemical and sensory quality for fresh-cut and fresh-cut stored then cooked zucchini. (USDA ARS US Hort. Research Lab)
- ClO₂ experiments were conducted using various types of clamshell packaging for blueberries and strawberries in collaboration with an industrial partner under a CRADA. (USDA ARS US Hort. Research Lab)
- Investigated humidity efficient clamshells, with time release anti-microbial agents, for effect on microbial growth, flavor and nutritional quality of strawberries, blueberries and lychees. (USDA ARS US Hort. Research Lab)

Objective 3. Improve understanding of physiological mechanisms that affect fresh-cut product quality.

- Saltveit and colleagues are evaluating MRI to diagnose chilling injury in tomato. (U of California-Davis)
- Suppressing wound-induced phenolic metabolism results in increased microbial growth. See Barros and Saltveit publication. (U of California-Davis)
- Identification and characterization of volatile compounds responsible for fruit flavor using gas chromatography-mass spectroscopy-olfactory detection (GC-MS-OD) of apples and highbush blueberries (Charles Forney).
- Impact of vapor heat treatment on ripening physiology of whole cantaloupe melons (Charles Forney, Greg Bezanson, Lihua Fan, and Denyse LeBlanc).
- Identifying metabolic changes associated with and preceding the development of storage disorders in apples (Charles Forney and Jun Song).
- The response of Romaine lettuce to cutting temperature was evaluated by processing heads at 5 or 15C. (Deltsidis et al., 2012).
- Spinach and bok choy leaves, disks from tomato epidermis, stem-scar and avocado-exocarp tissues, and whole tomato fruit were used to examine ingress of gaseous 1-MCP. (Dong et al., 2013).
- The early dynamics of ethylene responses in immature cucumber fruit were investigated in order to provide insight into the water soaking triggering mechanism. (Hurr et al., 2013). (USDA ARS US Hort. Research Lab)
- Continued studies on C₆ volatiles and jasmonic acid signaling studies in tomatoes subjected to chilling and heating stresses. (USDA ARS US Hort. Research Lab)
- Conducted study to understand the mechanism of water-induced senescence in strawberry and lychee fruits. (USDA ARS US Hort. Research Lab)

Objective 4. Determine critical factors in controlled inoculation studies with human pathogens and surrogates that influence the outcome of quantitative microbial risk assessments.

- Assessment of impact of stress-induced behaviors on non-O157 verotoxin-producing *E. coli* (VTEC) on leafy greens (Greg Bezanson and Susan Bach).
- Phenotypic diversity in *E. coli* O157:H7 and its influence on pathogen survival on leafy vegetables (Greg Bezanson and Pascal Delaquis).
- Effects of chemical treatments to destroy *Listeria monocytogenes*, *E. coli* O157:H7 and non-O157 and *Salmonella enterica* on the outer rind surface of cantaloupe and watermelon. (Angela Shaw)
- Survival and control of *E. coli* O157:H7 and non-O157 STEC on spinach. Dr. Shaw's lab completed a survivability study with spinach in the summer of 2013. (Angela Shaw)
- Inactivation of pathogens on whole cucumbers. Dr. Mendonca's lab led a multi stage project to determine appropriate methods to inactivate *Listeria monocytogenes* and *Salmonella* from the surface of cucumbers. (Aubrey Mendonca)
- Inactivation of pathogens with grape seed oils on fresh produce. (Dr. Brehm—Stecher)
- Inactivation of peanut skin extracts on *Zygosaccharomyces bailii*, and spoilage yeast. (Dr. Brehm-Stecher)
- Evaluation of the effects of cold stress on the survival of non-O157 Verotoxin-producing *Escherichia coli* (VTEC) on intact and fresh-cut lettuce. (Susan Bach and Pascal Delaquis)
- Studies are continuing to evaluate the effects of starvation, cold, UV and oxidative stress on non-O157 VTEC on leafy greens using phenotypic and genotypic characterisation. (Susan Bach and Pascal Delaquis)
- Irrigation regime did not affect susceptibility of tomato fruit to postharvest proliferation of *Salmonella*. However, *Salmonella* grew significantly better in water-congested tissues of green tomatoes.
- Red ripe tomatoes were significantly and consistently more conducive to proliferation of *Salmonella* than mature-green tomatoes. (Marvasi et al., 2013).
- The Ratkowsky (or square-root) model was shown to be generally suitable for predicting the growth of both *Salmonella* and *E. coli* O157:H7 on cantaloupe, honeydew, and watermelon over a range of storage temperatures (4 to 25C). (Li et al., 2013).

Objective 5. Evaluate and control unintentional and intentional microbial contamination of intact and fresh-cut produce.

- *Salmonella* can grow in pesticide solutions. Research from Suslow group clearly shows that pesticide solutions do not retard pathogen growth. See publication by Lopez-Velasco et al. (U of California Davis)
- Common bacteria on plants can protect survival of *Salmonella enterica*. See publication by Posa-Carrion et al., 2013. (U of California-Davis)
- Since human pathogens occur at low frequency, concentration of water is required and Suslow and group report of a sampling technique. See publication by Sbodio et al., 2013. (U of California-Davis)
- Interactions Between Sanitizing Treatments and Packaging Gas Compositions and their Effects on the Growth of Spoilage Microorganisms and *Salmonella* on Fresh-cut Onions- While these interactions between sanitizer and gas composition affected both safety and

quality, overall, the best results were obtained using sodium hypochlorite in combination with an elevated level of CO₂ in the package. (Michigan State University)

- Development Of A Bio-Based Antimicrobial Film Based On Gliadins Containing Cinnamaldehyde And Natamycin- The greatest effectiveness was obtained for films containing natamycin and treated with 5% of cinnamaldehyde. The level of cinnamaldehyde reached in the headspace of the test assay showed a diminishing trend as a function of time, which was in agreement with fungal growth and cinnamaldehyde metabolism.
- Evaluation of hydrogen peroxide as an agent for controlling *E. coli* O157:H7 on fresh cut spinach (Greg Bezanson and Megan Fisher).
- The impact of nutrient deprivation (starvation-associated stress) on “big six” VTEC colonization of and survival on intact Romaine lettuce plants is being measured at both phenotype and gene expression levels under chamber and field growth conditions (Greg Bezanson and Susan Bach).
- *E. coli* serotype O157:H7 cells that remain viable on intact field-grown Romaine lettuce plants and in growth soil after rapid post-inoculation declines in their culturable numbers are being characterized at phenotype and genetic levels in order to establish factors/behaviors that contribute to the “persistor” state (Greg Bezanson and Pascal Delaquis).
- Hydrogen peroxide control studies have been extended to include an additional spinach cultivar and three strain mixtures of test serotype O157:H7 surrogates (Greg Bezanson and Megan Fisher).
- Emerging Technologies for Detection and Characterization of Foodborne Pathogens. Dr. Brehm-Stecher continued his work in the development of new rapid detection technology to detect the presence of unintentional and intentional microbial contamination on fresh cut produce Wheatgrass juice and *Listeria monocytogenes*. Drs. Shaw and Mendonca
- Interactions Between Sanitizing Treatments and Packaging Gas Compositions and their Effects on the Growth of Spoilage Microorganisms and Salmonella on Fresh-cut Onions (Natalie Page, Emily Huston, Shelby Curlew, Elliot Ryser, and Eva Almenar)
- Development Of A Bio-Based Antimicrobial Film Based On Gliadins Containing Cinnamaldehyde And Natamycin (Mari Pau Balaguer, Paula Fajardo, Hunter Gartner, Jose Gomez-Estaca, Rafael Gavara, Eva Almenar, Pilar Hernandez-Munoz)
- Listeria Detection Technology and Validation. We developed the one-tube Listeria test kit for in-house testing to satisfy detection limit, rapid detection time, sensitivity/specificity, cost-effective and easy-to-use operation. (Taejo Kim and Ramakrishna Nannapaneni)
- Pathogen Intervention Technology. The presence of non-biocidal concentrations of thyme, oregano and carvacrol at 0.006-0.012% suppressed the Salmonella spp. biofilm formation by 2-4 folds but could not completely eliminate biofilm formation by these three Salmonella strains.(Taejo Kim and Ramakrishna Nannapaneni)
- Continued research on the behaviour of STEC during the production, processing and distribution of leaf lettuce, with emphasis on the development of predictive models. (Susan Bach and Pascal Delaquis). To this end: Completed development of a model to predict the fate of *E. coli* O157:H7 in field lettuce. Completed simulations of *E. coli* O157 behaviour in packaged lettuce distributed in Canadian cold chains. Performed studies on the behaviour of non-O157 STEC in field lettuce. Results showed that kinetics of decay were similar for serotypes O157, O111, O44, O145, O26 and O103. The cross-

contamination rates between fresh-cut lettuce, celery, carrot, and watermelon and common kitchen surfaces (ceramic, stainless steel, glass, and plastic) were quantified using scenarios that differ by cross-contamination direction, surface type, produce type, and drying time/moisture level.

- Surface moisture and direction of transfer were shown to have the greatest influence on microbial transfer rates (Jensen et al., 2013).
- Salmonella transfer to-from contaminated gloves and mature-green tomatoes upon up to 25 touches was evaluated. (Brar et al., 2013).
- Freshly cut or outer uncut surfaces of celery were inoculated at ca. 3 log CFU/g and stored for 0, 1, 3, 5, and 7 days at 4 or 12C, or 0, 8, and 17 24, and 48 h at 22C. (Vandamm et al., 2013).
- The efficacy of two leafy produce wash methods, the traditional cutting-before-washing process and a new washing-before-cutting method, on reduction of *Escherichia coli* O157:H7 inoculated on Iceberg lettuce was compared. (U of Illinois Urbana Campaign)
- The survival characteristics of *E. coli* O157:H7 on microgreen surfaces stored in a refrigerator and to examine the surface morphology of microgreens and mature greens. (U of Illinois Urbana Campaign)

Impacts

- The 3 studies (and resulting publications) by Suslow and colleagues cited in Objective 5 dealt with important gaps in information of direct relevance to fresh produce growers and processors. (U of California-Davis)
- The 18th Annual Fresh-cut workshop was held at UC Davis Sept 24-26, 2013. This is a unique workshop in the U.S. and is recognized as providing an excellent overview of fresh-cut preparation and handling. In 2013 there were 79 attendees including speakers, and they represented fresh-cut processors, as well as some suppliers (packaging, sanitizers), researchers, and quality control personnel. Speakers are from academia (UC Davis, Univ. Florida), USDA, and the private sector (equipment manufacturers, water sanitation systems).
- Fresh-cut mango is increasingly important fresh-cut fruit product and contributions by Barrett and colleagues provide information on quality management of direct use to the fresh-cut industry. (U of California-Davis)
- The 2013 book edited by L.J. Harris about safety and quality of nuts provides the most current authoritative summary of the latest research on microbial food safety control of the most important nuts. Chapters on almonds, pistachios, walnuts, pecans, peanuts. Also chapters on pests and allergens as well as preparation, processing, rancidity and other quality aspects. (U of California-Davis)
- Frozen blueberries from different harvest sources were screened for heat-resistant fungi. Nine heat-resistant fungal isolates have been identified. The D- and Z-values of *Neosartorya pseudofischeri* at 80, 85, 90, 93, 95, 96 and 99 °C were determined. These results provide useful information on preventing losses due to spoilage caused by the heat-resistant fungi (Lihua Fan).
- Developed methodology to extract proteins from fungal spores and determined protein profiles of *N. pseudofischeri* using LC/MS (Lihua Fan and Jun Song).
- LAB applied at 10⁶ or 10⁷ CFU/mL to fruit and vegetable juice significantly inhibited the growth of *L. innocua* by 3 or 4.5 logs, respectively, at 25 °C for 3 days (Lihua Fan).
- Antimicrobial effects of cranberry juice were dependent upon the concentrations of juice, culture conditions (temperature and matrix) and bacteria tested. *L. innocua* was more

sensitive to cranberry juice compared with *E. coli*, and both bacteria were killed more effectively in the distilled water system than in culture broths (Lihua Fan).

- The antimicrobial effect of various small fruit extracts on food pathogens was determined and minimum inhibitory concentrations (MICs) of the extracts measured using the Bioscreen method (Lihua Fan).
- Provided scientific advice to the local fresh-cut fruit and vegetables industry to ensure the safety and quality of fresh-cut vegetables and fruits (Lihua Fan and Charles Forney).
- Vapor heat treatments that effectively reduced *Listeria* sp. inoculated on whole cantaloupe melons by 4 log altered volatile metabolism of the fruit. The heat treatment increased concentrations of methyl, ethyl and acetate esters and decreased concentrations of butyl, hexyl and non-acetate esters in the fruit (Charles Forney, Lihua Fan and Greg Bezanson).
- Aroma impact compounds in ‘Honeycrisp’ and ‘Ambrosia’ apples were identified in intact and macerated fruit. The most intense aroma compounds included butyl acetate, ethyl 2-methylbutanoate and hexyl acetate in ‘Honeycrisp’ and hexyl acetate, 2-methylbutyl acetate and butyl acetate in ‘Ambrosia’, which all contributed “fruity” aromas. Maceration of the fruit induced the production of substantial quantities of hexanal, which imparts a “green” aroma (Charles Forney).
- The postharvest behavior of 9 raspberry cultivars and selections were evaluated at 1 °C in air and controlled atmosphere storage. Initial fruit firmness strongly correlated with fruit storage-life. Atmospheres of 12.5% CO₂ were effective in minimizing postharvest decay (Charles Forney and Andrew Jamieson).
- Nutrient-deprived VTEC (held in sterile water for 96 h prior to inoculation) display more rapid declines in culturable cell numbers on chamber-grown Romaine lettuce than do those “starved” in tryptose soya broth. However, at 5 days post-introduction, greater percentages of water-exposed cells are strongly associated with plant leaf tissue. Decay and leaf attachment rates vary between *E. coli* serotypes, with O103 strains displaying both greater stability and attachment proficiency. Correlations between this behavior and starvation-associated changes in verotoxin production, biofilm formation, curlei presence, and acid and antibiotic resistance are being determined for both pre- and post-inoculation starved cells (Greg Bezanson).
- Procedures for recovery of low numbers of persister cells present on *E. coli* O157-exposed lettuce plants 14-21 days post inoculation are being developed (Greg Bezanson).
- Spinach cultivar (Menorca vs Unipak 12) does not significantly influence the efficacy of 1% hydrogen peroxide-mediated removal (sanitization) or subsequent survivor outgrowth behavior of the *E. coli* O157:H7 strain ATCC 700728. The peroxide treatment was as effective against a cocktail of ATCC strains 700728, 43888 and 43895 as it was with 700728 alone (Greg Bezanson and Megan Fisher).
- Drs. Shaw and Wilson were active with extension and outreach to provide guidance to growers on Good Agricultural Best Practices (GAP). Dr. Shaw and colleagues provided eight full-day GAP training courses to growers throughout the state which impacted 125 different farms as part of a 3- level USDA funded Statewide On Farm Food Safety Program
- Dr. Shaw lead train the trainer sessions for extension staff and faculty along with local foods community stakeholders. These workshops ranged from 2 hours to 4 hours in length and reached 350 different individuals.

- The one-tube *Listeria* detection kit was developed/validated to satisfy the following requirements.(Taejo Kim and Ramakrishna Nannapaneni)
- The role of sublethal acid, alkali and oxidative stress on the attachment, induction, internalization and spread of biofilms of *Salmonella* and *L. monocytogenes* on fresh/fresh-cut produce/food contact surfaces .(Taejo Kim and Ramakrishna Nannapaneni)
- Increased fundamental knowledge pertaining to the behavior of non-O157 VTEC when exposed to stresses encountered during the ‘farm to fork ‘continuum. (Bach and Delaquis)
- Models were developed to predict the behavior of *E. coli* O157:H7 on field lettuce destined for processing, in packaged fresh-cut lettuce and in Canadian distribution systems. (Bach and Delaquis)
- The (gLMS) is being used for evaluation of quality traits in blueberry, peach, strawberry and tomato breeding programs, especially for identification of flavor quality impact compounds.
- Guidelines for optimal ripeness stage for processing and marketing fresh-cut mangos are being used by companies producing fresh-cut mango. (U of Florida)
- Suitability of blueberry selections for mechanical harvesting is being evaluated in the Florida breeding program based on guidelines developed in this project. (U of Florida)
- Understanding how patterns of 1-MCP distribution differ has lead to the ability to explain previously obscure differences in response to 1-MCP by different crops and varieties of the same crop. (U of Florida)
- Understanding how ethylene and ROS interact to induce tissue watersoaking now allows development of treatments to overcome the disorder in fresh-cut products. (U of Florida)
- Knowledge of tomato production risk factors for Salmonella proliferation provides guidelines for development of GAP procedures. (U of Florida)
- The Ratkowsky model is available as a fast and cost-effective method to estimate the effects of storage temperature on fresh-cut melon safety and could also be used in subsequent quantitative microbial risk assessments. (U of Florida)
- Determination of the risk of Salmonella transfer to and from tomatoes handled by single-use or reusable gloves provides guidelines for development of GAP procedures for tomato handling. (U of Florida)
- Information on the temperature effect on survival and proliferation of *E. coli* O157:H7, *Salmonella*, and *L. monocytogenes* on cut or uncut celery provides guidelines for development of GMP procedures for fresh-cut celery processing. (U of Florida)
- Apples cut with ultrasound showed a better quality during storage compared to the control. (U of Illinois Urbana Campaign)
- The TDS + MA wash may provide an effective means to reduce the microbial risk of fresh produce while maintaining acceptable quality attributes. (U of Illinois Urbana Campaign)
- With sanitizer, washing-before-cutting is better than cutting-before-washing.
- The ability of *E. coli* O157:H7 to survive on microgreens compared to mature produce highlighted the importance of developing effective sanitation strategies for reducing the microbial safety risk associated with this produce product. (U of Illinois Urbana Campaign)
- Identified the optimal storage conditions and post-harvest technologies for extending shelf-life and enhancing nutritional and microbial quality of radish microgreens, which

might be interested to the produce industry. Knowledge gained through this study could be used to assist fruit growers and processors to achieve enhanced product quality and microbial safety. Contributed to better understanding of sensory property of microgreens. (U of Maryland)

- BARD to establish optimum storage and harvest condition of mandarin cultivars
- Florida Specialty Crops Block Grant to determine effect of preharvest nutritional sprays on orange flavor.(USDA ARS US Hort. Research Lab)
- Cooperative Research and Development Agreement (CRADA) with company to explore use of volatiles in induce sweet and/or suppress bitterness in orange juice
- Grant from company to identify flavor compounds responsible for off-odor and taste of orange pulp. (USDA ARS US Hort. Research Lab)
- CRADA with company to develop rapid instrumental methods and predict quality of orange juice. (USDA ARS US Hort. Research Lab)