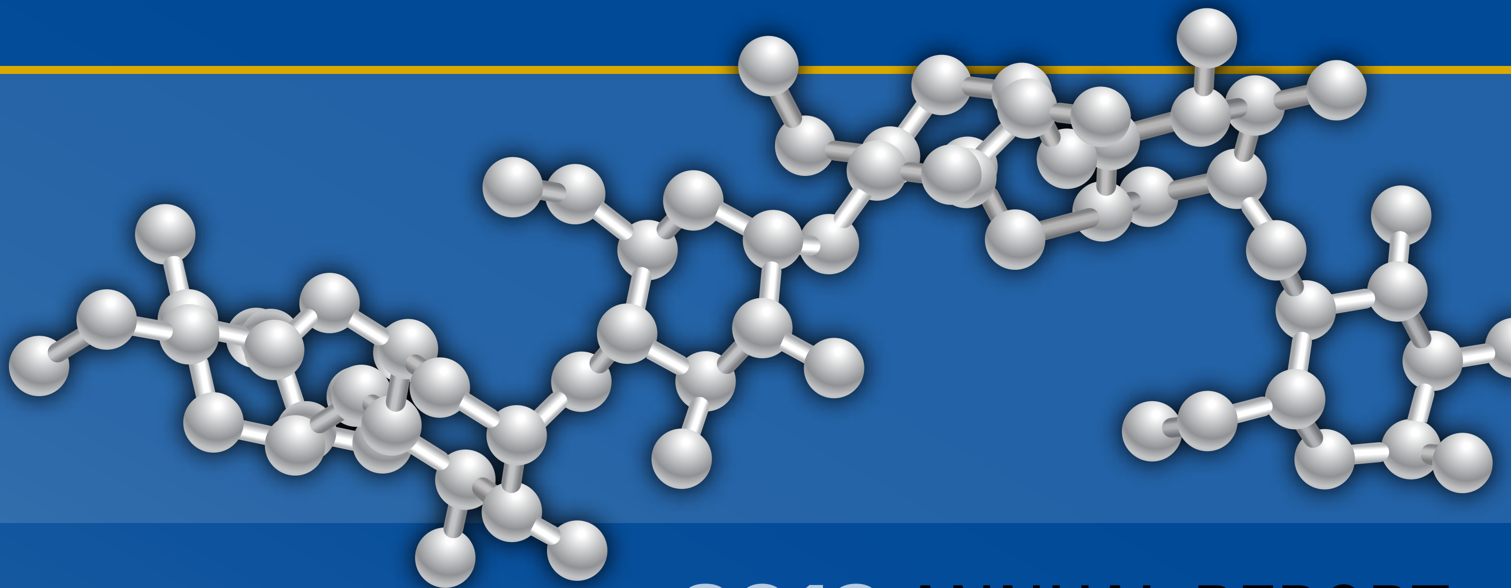
WHISTLER CENTER
for Carbohydrate Research



2019 ANNUAL REPORT

PURDUE UNIVERSITY

Industrial Members

(Members of 2019 Industrial Advisory Board)

Archer Daniels Midland

Cargill

Grain Processing Corporation

Hayashibara Co.

Ingredion

Kaleido Biosciences

Mars Wrigley

Mondelēz International

Nestlé

Novozymes

PepsiCo

Roquette

Tate & Lyle

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Purdue
Aseptic Workshop
2009

Director's Statement

As I write this last part of our Whistler Center Annual Report, we're into the COVID-19 pandemic, and I hope you and your loved ones are well and safe. Certainly, food companies are essential and busy at this time, and many running at near or full capacity. As always, we are available to answer your carbohydrate-related questions or plan needed research activities.

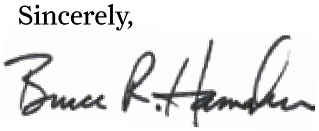
In 2019, a number of new things happened at the Whistler Center. In response to changes in the consumer world regarding dietary carbohydrates and impacts on the food industry, we 1) made a formal external faculty program in the Center, 2) brought in two new external faculty doing translational research – on fundamentals of carbohydrate science taken to application and a new Purdue faculty member, 3) expanded our popular Webinar series to 6 times per year, and 4) initiated a new educational package ($2500) where individuals can access our Webinars and attend our fall Short Course. Nowadays it makes sense to look externally to add top scientists to increase our research breadth, and use communication technologies to make them regular participating Center members. We want to be the go-to place to do carbohydrate research and facilitate strong collaborations for our industrial members. Our new faculty members are Mario Martinez, Assistant Professor at University of Guelph, and Senay Simsek, Professor at North Dakota State University. This adds to our other two external faculty members, who were previously at Purdue in the Whistler Center, Mario Ferruzzi, Distinguished Professor at North Carolina State University, and Osvaldo Campanella, Chair Professor at The Ohio State University. Purdue faculty, Lavanya Reddivari, also joined the Center, bringing her expertise in plant polyphenols and interest in their interaction with starch and dietary fibers. Take a look at their Project Summaries to understand what they do and can offer you.

Whistler Center faculty made progress in a number of research fronts. Our internally-funded Big Idea research projects on Sugar Replacement and Reduction advanced the understanding of sugars and small oligosaccharides on starch gelatinization and retrogradation and cookie quality. Prediction of swelling behavior of starch is being investigated with sucrose and other sugars. In other work in the carbohydrate and nutrition area, we are finding new dietary fiber and gut microbiota relationships for predicted responses for gut and whole-body health, and have a new understanding of how dietary carbohydrates can activate the gut-brain axis to affect food intake. Another Center project investigated micro-analysis of carbohydrate functionality using a molecular rotor.

In other highlights of the year, Angie Gutterman joined us in September as our new Whistler Center Coordinator. In May, at our half-day Technical Conference following our full-day Industrial Board meeting and poster session, we had Professor Robert Gilbert from University of Queensland and Yangzhou University give a great Belfort Lecture on the intricacies of starch and glycogen structures driving health and physical functions. Our popular every-year 3-day Short Course was held at Purdue on the first week of October, which is part of industrial membership benefits and is open to non-members for a registration fee.

Please take some time and peruse through our 2019 Whistler Center Annual Report. Feel free to contact us with any questions through Angie or myself.

Sincerely,



Bruce R. Hamaker
Distinguished Professor of Food Science
Roy L. Whistler Chair, Director

Summary of Major Research Accomplishments

Starches, Non-starch Polysaccharides and Cereals

J. BeMiller published more results on a multi-year project initiated about 10 years ago when the Industrial Advisory Board encouraged the Whistler Center faculty to undertake a study of the effects of hydrocolloids (HC) on starch properties. He accepted the challenge. He had done one study earlier with a post-doctoral associate on the effects of HC on gelatinization because it had been concluded by several investigators that HC lowered the gelatinization temperature. Shi & BeMiller [*Carbohydr. Polym.,* 50 (2002) 7] found that, as suspected, they did not do so, but rather the presence of HC apparently lowered the pasting temperature (the temperature of the beginning of the rapid viscosity increase determined in a Brabender or RVA instrument), probably as a result of complexation of HC molecules with leached starch (primarily amylose) molecules from somewhat swollen, gelatinized granules. The first project of the new study was to do a literature search, which resulted in a review article [BeMiller, *Carbohydr. Polym.,* 86 (2011) 386]. The article points out that the results obtained from more than 150 basic research papers on the subject seemed to be functions of (at least) the specific starch-HC combination, the ratio of the two components, and the method of/conditions used for preparation of the paste or gel, that different results had been obtained by different investigators using the same HC and different starches and the same starch and different HC, and that 14 different mechanisms for observed effects had been proposed. The first research paper in the new study (of research done with another post-doctoral associate) [Kim & BeMiller, *Carbohydr. Polym.,* 88 (2012) 1164] reported the effects of HC on the pasting and paste properties of commercial pea starch (an investigation requested by a supporting member company). The second research project [Kim, Patel & BeMiller, *Carbohydr. Polym.,* 98 (2013) 1438] used 4 rice starches with amylose contents ranging from 0% to 28%. In it we concluded that the amylose content of the starch was a greater determinant of the pasting, paste, and gel properties of starch-HC combinations than was the added HC and that there were more differences in the natures of the granules of the starches than the amylose content that affected the behaviors of the starch-HC pastes and gels. (Rice starches with different amylose contents all from the same genetic background could not be obtained.) The next paper (research done with a visiting scientist) [Fu & BeMiller, *Food Hydrocoll.,* 69 (2017) 36] described an investigation of the effects of HC on retrogradation of native and hydroxypropylated normal maize starch. Again, no clear-cut mechanism for the action of the various HC could be concluded. However, it was hypothesized that the apparent inhibition of retrogradation by xanthan and guar gum found in the study (and reported previously by us and others) might be due to an inhibition of granule swelling and disintegration and dissolution of starch polymer molecules. This insight into the possibility that the differences of the effects of different HC on different starches under different conditions may be due to differences in their effects on the early events (i.e., the pasting process) led to the paper published this year (of research done with two visiting scientists) on the effects of HC on normal maize starch [Zhuang, Feng & BeMiller, *Food Hydrocoll.,* 96 (2019) 231] in which we concluded that the various HC did indeed interact to different degrees with normal maize starch granules (controlling their swelling and disintegration, which in turn had an effect on subsequent processes, such as starch polymer leaching and associations between starch polymer molecules and between starch polymer molecules and HC molecules) and that their tendency to interact with granule surfaces may also have promoted associations between swollen granules and granule fragments. One additional paper on this subject is in press; one has been submitted, and one is in preparation.

O. Campanella and **B. Hamaker** continued work on a novel waxy potato starch that exhibits shear thickening as well as gelation at low pH, and published the first of a series of papers by former student and current post-doc F. Fang. Fang also had a paper in press in *Food Hydrocolloids* related to the topic of J. BeMiller titled "Neutral hydrocolloids promote shear-induced elasticity and gel strength of gelatinized waxy potato starch".

M. Martinez' group is a new part of the Whistler Center. They work on the characterization of carbohydrate polymers and their modification through process-intensifying technologies. They apply chromatography and mass spectrometry for the elucidation of the structure and hydrodynamics of polysaccharides (Project 24). In other research, they investigated shear-scission of biopolymers (Project 25), phenolic-carbohydrate interactions (Project 26), shear-banding of proteins (Project 27), and the valorization of food and agricultural waste through thermomechanical processing, such as high-shear extrusion. The long-term goal of his group's research is to bring agricultural waste biomass and bio-polymeric raw materials into food applications, to contribute to a more circular green chemistry, and to develop carbohydrate biopolymers for the prevention/intervention of nutrition-related chronic diseases.

L. Mauer's group has a focus on sugar reduction/replacement research and continues to take materials science approaches to manipulate and investigate food ingredient structures and functions, water-solid interactions, and amorphization and crystallization tendencies. Ongoing studies include investigations of the roles of sugars and oligosaccharides on the gelatinization and retrogradation of starch (Project 28), the roles of hydrocolloids in disrupting the crystallization tendencies of sugars and vitamins (Project 29), and the responses of complex ingredient blends to fluctuating storage environments (Project 30). Her scientific approaches build a framework of understanding around intermolecular non-covalent interactions and material properties.

G. Narsimhan's group continued work on fundamental aspects of starch gelatinization and swelling through a modeling approach and related to sugar reduction and replacement (Projects 31 and 32).

S. Simsek is a new member to the Whistler Center. Her group has developed a research program focused on the integration of cereal quality with the structure-function relationships of carbohydrates. They have a strong focus on expanding value-adding strategies for cereal and legume by-products (Projects 36 and 37), and utilization of grain derived and carbohydrate functional ingredients in the baking industry (Project 38). The ultimate goal of this group is to increase the utilization of cereal crops and their by-products while finding new and innovative applications for carbohydrates in the baking industry. In order to achieve this goal, her group has aimed to integrate partnerships between producers, scientists and food processors in order to optimize research potential and develop novel cereal carbohydrate derived functional ingredients.

Y. Yao's group continued to work on the characterization of carbohydrate polymers using a molecular rotor (MR) approach, as well as new biomaterials for food and pharmaceutical applications. His group made progress in exploring MR-related techniques to characterize the performance of biopolymers at oil-water interface, including emulsions. Individual projects included the use of a molecular rotor to characterize the properties of several biopolymers at oil-in-water interface and in emulsions (Project 39), continued study on using phytoglycogen and its derivatives to increase the solubility of poorly water-soluble active ingredients (Project 40), using a molecular rotor on rapid and milligram-level starch analysis with a focus on starch retrogradation and shear-resistance (Project 41), and continued work on pathogen biofilm reduction at the surface of fresh produce (Project 42).

Carbohydrates, Nutrition and Health

O. Campanella began investigation of the nature of gut microbial community interactions through a modelling approach (Project 3).

B. Hamaker's group continues to work mainly in the areas of dietary fibers and their potential for targeting changes in the gut microbiota related to health outcomes, and glycemic carbohydrates and slow digestion property-related activation of the gut-brain axis and ileal brake physiological mechanisms. His group studies in 2019 were: 1) continued research on fabricated fiber physical structures to understand how fermentable insoluble fibers support beneficial butyrate-producing Clostridia bacteria (Project 6), a large *in vitro* fecal fermentation screening of whole food-based fibers from cereals, legumes and pulses, and tuber, and the effect of different fibers on fermentation when proteins are present (Project 7), how more chemically and physically specific (and uncommon) dietary fibers are more targeted in function in the gut microbiota (Project 8), development of slowly digestible carbohydrates, and through an inhibitor approach, for low glycemic response and as activators of physiological systems to control appetite and food intake (Project 9), and enteroendocrine L-cell culture and animal studies on cellular and physiological response to slowly digestible carbohydrates (Project 10). His group also worked on projects related to cereals and grains for processing in Perú and Africa (Project 11).

M. Ferruzzi's group continues to pursue research on fundamental and applied aspects of both food and nutrition science disciplines. The long-term focus of his group is to identify food science strategies that will contribute to the prevention of chronic disease in humans. Related to carbohydrates, they continued to explore interactions between phytochemicals (phenolics and carotenoids) and carbohydrate and protein macromolecules, to define chemical interactions in altering phytochemical bioavailability and glycemic properties (Project 5).

S. Lindemann's research program further expanded in 2019 with investigations on 1) developing stable fiber-using gut microbial communities through passaging fecal microbiota by sequential transfers, and a systems biology approach toward generalizable fiber-microbiota research (Project 20), 2) continued work and publishing papers on the effect of cereal bran particle size on gut bacterial fermentation and mechanisms affecting community structure (Project 21), 3) how chemical structures of solubilized cereal bran arabinoxylans and inulin affect gut microbiota, related to chemical complexity of fiber structure and effect on microbiota communities (Project 22), and 4) understanding how different resistant maltodextrin structure select for different gut microbiota with different metabolic outcomes (Project 23). Steve is involved in various collaborations on fundamental aspects of the ecology of microbial communities, which is reflected in a number of his publications this year.

M. Martinez investigated starch structure-function-digestion relationships towards the development of slowly digestible carbohydrate-based functional structures (Project 25).

Dr. Reddivari's group is new to the Whistler Center and has a long-term focus on harnessing the polyphenols in foods to prevent or reverse low-grade inflammation, the underlying cause of many chronic diseases. Towards this goal, her group investigated the stability, bioavailability and anti-inflammatory properties of plant polyphenols in the whole food matrix in maintaining gut health (Project 34). Her group determined that anthocyanins in purple potatoes and blue maize and 3-deoxy flavonoids in red maize and sorghum reduce gut inflammation, gut permeability and gut bacterial dysbiosis in both chemical- and genetic-murine models of colitis. Her group is expanding research towards understanding the polyphenol structure and function relationships as well as the interaction between polyphenols, starch and dietary fiber and gut bacteria in maintaining gut barrier function in health and disease (Project 35).

Other Biomacromolecule Structures

O. Jones' research continues to determine the functional impacts of protein/polysaccharide assembly, whether in the construction and utilization of colloidal structures or in the solubility and rheological behaviors of those proteins or polysaccharides. Several projects on insect protein and nanometer-scale particulate protein structures were ended in 2018 and have been published in the past year. Dr. Jones continued a federally funded project on fibrous structures originating from maize and dairy proteins, which determines the capacity of elongated protein structures to simulate the large molecular weight glutenin protein structures found in traditional breads (Project 12). This work, performed in collaboration with O. Campanella and B. Hamaker, has also uncovered unique properties of electrospun and extruded proteins that could be of benefit to other starch-rich food materials. Another project continued in 2019 studies how conjugation of maize prolamin protein alters their solubility or interactivity with polysaccharides (Project 13). The goals of such projects are to increase the value of protein ingredients in polysaccharide-rich food systems, enhance contributions of structured ingredients at lower added contents, and improve the sensory properties of food products prepared with alternative protein or polysaccharide sources.

J. Kokini's group studies rheological and networking behavior of biopolymers, nanocomposites, their fabrication and properties, and new methods of detection of discrete components in complex food materials. In 2019, they were active in many research projects: 1) rheological properties of scallop protein hydrolyzates combined with chitosan (Project 14), making biosensor platforms from biopolymer nanofibers (Projects 15 and 17), investigation of the nonlinear rheological behavior of cream cheese and sour cream, and nonlinear behavior and network analysis of yogurt products (Projects 16 and 18), development of effective delivery systems for banana condensed tannins (Project 19).

Chemical Structures and Functions of Polysaccharides

B. Reuhs and **A. Terekhov** run the analytical core facility at the Whistler Center dedicated to complex carbohydrate structural analysis. With **O. Campanella**, **B. Hamaker**, and **S. Lindemann** the group provides expertise and studies non-starch polysaccharide structures and their physical functionality and gut microbiota fermentation.

The **O. Campanella**, **O. Jones**, and **B. Reuhs** group researches the structure and functionality of polysaccharides in processed foods, such as tomato products (Project 1).

Analysis typically involves monosaccharide profiling using the alditol acetate or TMS-methyl-glycoside analysis by GC, and linkage analysis by partial methylation using GC-MS, as well as 2D-NMR, MS, and FT-IR. Other chromatography methods are used to profile molecular size, and as preparative tools. All of these research efforts are related to understanding the role of polysaccharides in structure-function relations in various biological and food systems.

Emerging Food Processes

O. Campanella's group continued work on the processing of foods with the aim of optimizing conditions to achieve good quality and safe foods. Thermal and non-thermal processes are being studied. Thermal processing of foods involves the use of microwave, whereas non-thermal processes have involved research on cold plasma processing and pulsed electric field. They studied inactivation parameters of spore cells using cold plasma and other non-thermal processes (Project 2), and an innovative green clean-in-place technology for processing environments using microbubbles (Project 4).

Staff Directory

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Tao Feng	Campanella/Hamaker	September 2018-August 2019
Viridiana Tejada Ortigoza	Campanella/Hamaker	September 2018-May 2019
Secil Turksoy	Kokini	September 2018-August 2019
Genyi Zhang	Hamaker	June 2019- August 2019
Haining Zhuang	Hamaker	September 2018-August 2019

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Yulieth C. Reyes Roa	Kokini	July 2019-December 2019
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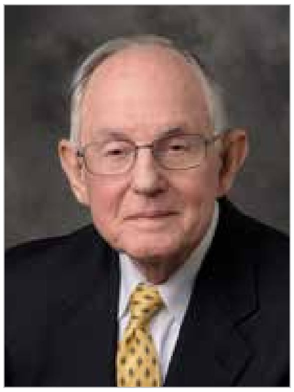


James N. BeMiller

General Research Areas

- Starch
- Carbohydrate chemistry

Specific Research Areas

- Starch granule structure, reactivity, and behavior
- Chemical and biological modifications of starch
- Structure-functional property relationships of polysaccharides

Osvaldo H. Campanella

General Research Areas

- Process modeling
- Rheology
- Material structure and texture
- Extrusion

Specific Research Areas

- Application of rheology to food science and food engineering
- Mathematical modeling of food process operations
- Online rheological techniques
- Rheology of biomaterials
- Dough rheology
- Rheology of dairy products
- Characterization of material structure and texture; relationship to rheological properties
- Effect of glass transition on product texture
- Bioplastics: Uses of food processing wastes
- Reactive Extrusion in the production of foods and bioplastics

Mario G. Ferruzzi

General Research Areas

- Phytochemical and botanical chemistry with focus on food pigments and flavonoids
- Development of methodologies for determination of phytochemicals in food and biological matrices
- Investigation of food processing effects on phytochemical profiles, bioavailability, and ultimate bioactivity
- Development of strategies for incorporation and stabilization of phytochemicals in food systems

Bruce R. Hamaker

General Research Area

- Carbohydrates and health
- Starch, chemistry and function
- Dietary fiber, chemistry and function

Specific Research Areas

- Glycemic carbohydrate digestion for slow digestion/low glycemic response, physiological response
- Dietary fiber, modifications in functionality and gut fermentability, gut microbiota and metabolites
- *In vitro, in vivo*, cell culture studies
- Cereal starch and protein functionality
- Textural properties influenced by carbohydrates
- Interactions between carbohydrates and other food components
- Appropriate methods of improving cereal utilization in developing countries

Owen G. Jones

General research areas

- Energy and stoichiometry of polysaccharide interactions with other materials
- Determination of size, morphology, and stability of colloidal suspensions
- Atomic force techniques to determine morphology and elasticity of sub-millimeter material

Specific Research Areas

- Role of chemical and physical structures in defining protein-polysaccharide interactions
- Controlled assembly of fibrous or particulate colloids from polysaccharides or proteins
- Emulsifying properties of colloidal materials
- Contributions of colloidal polysaccharide/protein assemblies to films, gels, or pastes

Jozef Kokini

General Research Areas

- Food materials science
- Linear and non-linear rheology
- Computational fluid dynamics
- Food nanotechnology and fabrication of nano-biosensors
- Phase behavior and compatibility of ingredients in food mixtures
- Food structure and texture during extrusion, mixing processes and computational fluid dynamics

Stephen Lindemann

General Research Areas

- Gut microbiome
- Genomics and metabolism
- Dietary fiber impacts on gut microbiome diversity
- Genomic mechanisms of polysaccharide fermentation
- Carbon, nitrogen and energy cycling by gut microbiota and host interfaces

Mario Martinez

General Research Areas

- Carbohydrate chemistry
- Edible plant tissues and health
- Thermomechanical processing

Specific Research Areas

- Application of multidimensional chromatography and mass spectrometry for the elucidation of the structure and hydrodynamics of polysaccharides
- Structure-function-digestion relationships toward the development of enhanced carbohydrate-based functional structures
- Shear-induced molecular fragmentation for improved biopolymer functionality in food systems
- Food and agricultural waste valorization through technology development
- Phenolic-carbohydrate interactions during food processing
- Wet extrusion and shear banding of food biopolymers in plant-based meat analogues

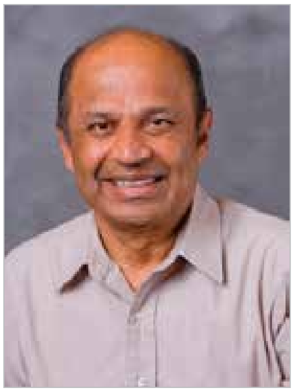
Lisa J. Mauer

General Research Areas

- Food chemistry
- Water-solid interactions
- Food materials science

Specific Research Areas

- Structure-function relationships of food ingredients
- Solid state characterization
- Glass transitions
- Moisture sorption
- Deliquescence
- Crystallization and amorphization



Ganesan Narsimhan

General Research Areas
- Emulsions and foams
- Biopolymer interactions

Specific Research Areas
- Pore formation by antimicrobial peptides in cell membranes and lipid bilayers
- Pasting behavior of starch
- Stability and texture of food emulsions and foams
- Adsorption of proteins and protein-polysaccharide complexes at interfaces
- Functional properties of proteins and protein-polysaccharide complexes
- Physical and chemical modification of proteins for use as food stabilizers
- Rheology of polysaccharide solutions and gels

Lavanya Reddivari

General Research Areas
- Plant bioactive compounds and health
- Flavonoids and carotenoids
- Gut microbial metabolism

Specific Research Areas
- Anti-inflammatory plant bioactives for improved gut health
- Reciprocal interaction of gut microbiome and plant bioactives in health and disease
- Interactions between plant bioactives and fiber/starch in the modulation of gut bacteria

Bradley L. Reuhs

General Research Areas
- Polysaccharide analysis
- Bacterial and plant cell wall compositions, structures and functions
- Sugars and polysaccharides in nutrition and food systems

Specific Research Areas
- Extractions and purification of acidic polysaccharides from cell walls of plants (including food products) and bacteria
- Pectin, hemicellulose, capsule, gum and lipopolysaccharides analysis
- Application of HPLC, MS, GC, GC-MS, FT-IR and NMR to structural studies of carbohydrates, including polysaccharides

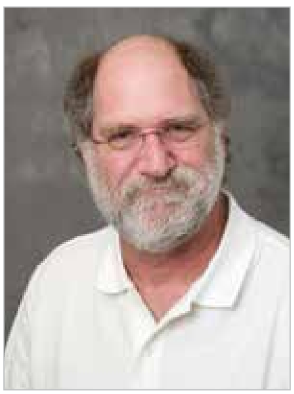
Senay Simsek

General Research Areas

- Structure-function relationships of carbohydrates
- Cereal and legume quality
- Utilization of cereal crops
- Application of carbohydrate ingredients in the baking industry

Specific Research Areas

- New carbohydrate functional ingredients
- Innovative uses for processing by-products and waste materials
- Biodegradable packaging films



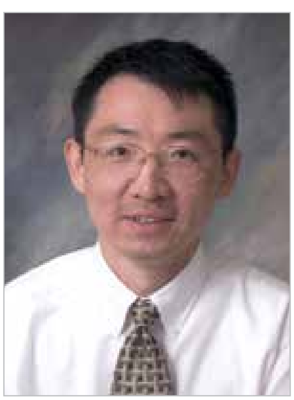
Clifford F. Weil

General Research Areas

- Plant classical and molecular genetics
- Protein structure and function
- Gene expression
- Large-scale forward and reverse genetics screening
- Genome maintenance and organization
- Genomics of starch digestion, composition and architecture

Specific Research Areas

- Rational redesign of corn starch composition
- Computer modeling of starch synthases
- Mutational analysis of starch biosynthesis in corn and *E. coli*
- Genetic modification of corn starch properties



Yuan Yao

General Research Areas

- Novel biomaterials for food and health
- Chemistry and genetics of carbohydrate polymers
- Nanotechnology for foods and drugs
- Coating of active ingredients

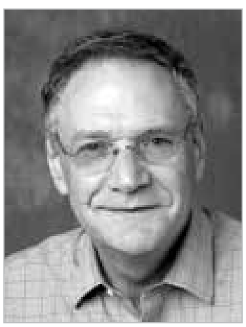
Specific Research Areas

- Construction and characterization of nano-biomaterials
- Stabilization, solubilization and delivery of active ingredients
- Genetic, enzymatic and chemical modifications of starch
- Functional food ingredients
- Carbohydrate microanalysis
- Evaluation and removal of pathogen biofilms
- Roll-to-roll coating of active ingredients

Adjunct Faculty

Yonas Gizaw, Ph.D., is Principal Scientist at The Procter and Gamble Co. Currently, he is technical leader for Advanced Cleaning Transformative Platform Technologies in Corporate R&D. Dr. Gizaw is a 20-year veteran of P&G with broad experience in biopolymers, nanotechnology, polymers physical chemistry, surfactants and colloids. He spent about eight years in Snack and Beverages, where he supported technology development for beverages (Sunny D) and Snacks (Pringles), then moved to the Fabric Care Strategic and Innovation division, where he was responsible for development of strategic technologies Downy/Lenor & Tide/Ariel, etc. In 2012, he joined Corporate Research – Transformative Platform Technologies. Prior to joining P&G, Dr. Gizaw received his doctoral degree from Purdue University in synthetic carbohydrate chemistry.

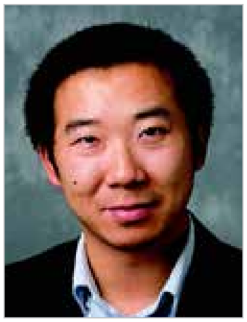
Sakharam K. Patil, Ph.D., is President of S.K. Patil and Associates. Dr. Patil was awarded a Ph.D. degree in Cereal Science from Kansas State University in 1973. He held several positions at American Maize Products Co., later Cerestar, from 1978 until his retirement in 2002. The positions included VP Marketing and Commercial Development (1994-1995), Vice President of Research and Development (1995-2000), Vice President of Research and Development and Director, Global, Technology Transfer (2000-2001), and VP Quality and Technology Transfer (2002). His expertise includes cereal chemistry, ingredient technology (food and industrial), technology transfer, marketing/commercial development, training/ coaching, cross-functional team development, global business development and strategic management.



Akiva Gross, Ph.D., is President of A.T. Gross Consulting, Ltd. Dr. Gross received his doctoral degree in Organic Chemistry from the Weizmann Institute of Science in Israel and then continued his scientific training in Applied Enzymology in the chemistry departments of Massachusetts Institute of Technology and Harvard University. Before starting his consulting business, Dr. Gross served as a Vice President of Global Product Development at Corn Products International. Prior to joining the company, Dr. Gross held several R&D leadership positions at CP Kelco and Monsanto. He was also a co-founder, Senior Vice President of R&D and a member of the Board of Directors of Opta Food Ingredients, Inc. Opta Food Ingredients was established as a spinoff of Enzytech, Inc., where Dr. Gross was a co-founder and Vice President of R&D.

Bernhard Van Lengerich, Ph.D., former CSO and VP Technology Strategy at General Mills, Inc. After more than 20 years of service, Bernhard retired from General Mills in March 2015. He is a strategic advisor and serves as a board member of several companies and nonprofit organizations. He is founder of the Seeding the Future Foundation, Past Chair of Feeding Tomorrow (IFT's nonprofit organization) as well as Vice Chair of Bountifield International (formerly Compatible Technology International), a nonprofit organization in Minnesota, focusing on post- harvest loss reduction in Sub Saharan Africa. Bernhard completed his Ph.D. in Food/Biotechnology at the Technical University of Berlin, Germany. His work experience includes Unilever Germany, RJR Nabisco, New Jersey; and Buehler AG in Switzerland. In 1994, Bernhard joined General Mills, Inc., in Minneapolis. He led the development of numerous technologies and capabilities resulting in major product innovations. Bernhard authored/co-authored more than 100 patents, established and led a Game Changer program, and created a novel "Cashless Venturing" initiative, enabling faster and more disruptive innovations.

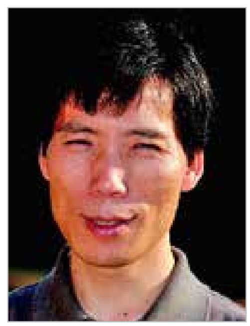
Visiting Professors



Tao Feng earned his Ph.D. in Food Science from Jiangnan University of China in June 2007. He is an associate professor at Shanghai Institute of Technology in China. He first came to Purdue University in May 2012 as a Visiting Professor in Food Science and was co-advised by Drs. Hamaker and Campanella. His research focuses on molecular dynamics simulation of triplex soluble nanoparticles self-assembled by amylose, beta-lactoglobulin(dimer) and free fatty acids. He and his wife, Haining Zhuang, came again as Visiting Professors from August 2018 to August 2019.

Viridiana (Viri) Tejada, Visiting Professor at the Whistler Center with Drs. Campanella and Hamaker, received her B.S. degree in Food Engineering (2010), M.S. degree (2013) and doctorate degree in Biotechnology from Monterrey Tech, Mexico. In summer 2007 and fall 2009, she attended internships at the University of British Columbia and Cornell University, respectively. Viri has worked as part-time lecturer at Tecnológico de Monterrey, teaching courses in the biotechnology department. Her recent work at the Whistler Center focused on dietary fiber obtained from agro-industrial residues, mainly fruit peels, and gut microbial mathematical modeling. Viri's expertise extends to non-thermal technologies, such as high hydrostatic pressure, and their use for enzyme inactivation and dietary fiber modifications. She returned to her faculty position at Monterrey Tech in Mexico City.

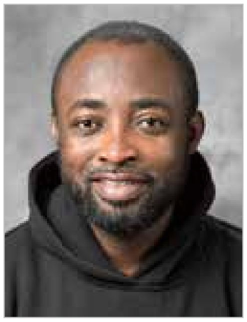
Secil Turksoy completed her B.S. degree in Food Engineering at Ankara University in 2001 in Turkey. She also completed her M.S. and Ph.D. degrees in the same department, in which she focused on functional properties of fruit- and vegetable-based dietary fibers. After receiving a TUBITAK Scholarship in 2018, she joined Dr. Kokini's group as visiting scholar. Her research focuses on rheological properties of viscoelastic food materials. Secil returned to her faculty position at Hitit University in August 2019.



Genyi Zhang is a Professor of Food Science at Jiangnan University, mainly focusing on the carbohydrate chemistry and nutritional properties of starch and, related to this, nutritional interference to prevent or delay the incidence of chronic diseases (diabetes) using functional food components. He also works on soft matter nanotechnology for functional component encapsulation and delivery. He was a Visiting Professor in summer 2019 with Dr. Hamaker.

Haining Zhuang earned her Ph.D. in Food Science from Jiangnan University of China in June 2011. She arrived at Purdue University in May 2012 as a postdoc research associate in Food Science and was advised by Dr. BeMiller. Her research focused on interactions between crosslinked starch and various hydrocolloids. She has worked in the Institute of Edible Fungi, Shanghai Academy of Agricultural and Sciences, since 2014. She rejoined Dr. Hamaker's group in August 2018 and returned to China in August 2019.

Visiting Scientists



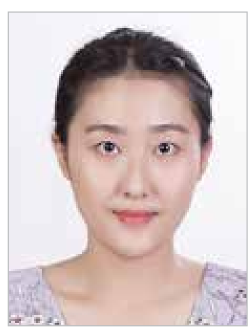
Isaac Kwabena Asare started his undergraduate education at the University of Cape Coast, Ghana, where he did a B.Sc. in Entomology and continued in a master's program at the University of Ghana in radiation processing. He is currently doing his Ph.D. at the University of Pretoria, South Africa. He came to Purdue University as a Visiting Scientist at the Whistler Center in Dr. Hamaker's lab on the topic of starch-lipid inclusions and their *in vitro* gut fermentation. He arrived in February 2019 for a year stay.

Neslihan Bozdogan earned her B.S. degree from the Department of Food Engineering of Hacettepe University in 2011 in Turkey. She completed her M.S. degree in the Department of Food Engineering at Ege University in 2015 in Turkey and began her Ph.D. degree in the same department. After receiving the TUBITAK Scholarship, she joined Dr. Kokini's group as a Visiting Scientist in June 2018. Her research focuses on the determination of extensional flows and maximum stable bubble size distribution inside a model batch mixer during the mixing of hard wheat flour dough using numerical simulation.

Nanci Castanha da Silva received her B.S. in Food Engineering from University of Campinas (Brazil). She earned her M.S. and Ph.D. in Food Science and Technology from University of São Paulo (Brazil). In 2018, she joined Dr. Campanella's lab as a Visiting Scientist for six months, working jointly with Dr. Jones and Dr. Reuhs on a collaborative research project. Her research focuses on the evaluation of the structure and properties of modified starches using different technologies. She returned to Brazil in May 2019.

Eponine Chambry received her H.N.D in Science and Food Techniques from the National School of Dairy Industry and Biotechnology in Poligny (France). She is also a registered dietician and received a Bachelor in Nutrition in September 2019. She joined Dr. Hamaker's lab group in March 2019 for a four-month internship as a Visiting Scientist. She worked with Thaisa Moro Cantu Jungles, post-doc on the dietary fiber fermentation by the gut microbiota. She now pursues her M.S. degree in Food Science at University of Burgundy in Dijon (France).

Fangting Gu came to Dr. Hamaker's lab in August 2018 as a Visiting Scientist from Yangzhou University with funding from both the Chinese government and Yangzhou University. Her Ph.D. research focused on the relationship between fiber and microbiota. She returned to China in February 2019.



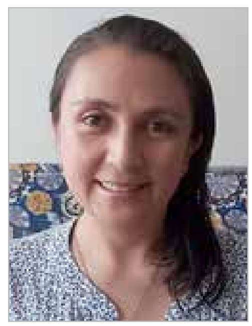
Wanying He is a visiting Food Science Ph.D. student from Huazhong Agricultural University in China. Her dissertation is on the structure and modification of corn protein, including zein. Wanying received funding from the China Scholarship Council to study at Purdue University in the laboratory of Dr. Jones for two years. She began her studies at Purdue in August 2019 and has been identifying techniques to improve zein functionality by chemical and enzymatic treatments, including interactions with polysaccharides.

Nida Kanwal is a native of Faisalabad, Pakistan, where she was born and raised. She graduated with a BS and MS in Food Technology from University of Agriculture, Faisalabad, Pakistan. She is earning her Ph.D. from University of Agriculture, Faisalabad. She joined Purdue University as Visiting Scientist for six months beginning October 2018. Her research focuses on characterization of Pakistani-grown barley varieties for their nutritional attributes and for preparation of value-added baked products using wheat barley composite flour.

Jingpeng Li received a M.S. in Food Engineering from Guizhou University in 2015, and she is now a Ph.D. candidate in Jiangnan University under Professor Zhengyu Jin. She studied the extrusion technique of coarse cereal particles for UHT milk as a master's student before working on her doctoral degree on instant cooking methods of enzymatic extruded noodles. Part of her work is on modeling and quantitatively determining cooking doneness and the rapid fermentation process of vegetables. Jingpeng is currently a Visiting Scientist in Dr. Campanella's lab to conduct research related to molecular dynamics simulation and rheology of carbohydrate. She returned to China in August 2019.

Laurine Macinot is a registered dietitian and received a bachelor's degree in Nutrition in France in September 2019. In March 2019, as part of her B.S., through the Whistler Center she joined Dr. Kee-Hong's laboratory for a four-month internship as a Visiting Scientist. She worked with Ph.D. students Miran Jang and Yuan Zhang on *Caenorhabditis elegans* used as an animal model of obesity and longevity research. She is now pursuing her M.S. degree in Food Science at University of Lorraine (France).

Laura Michelin is a registered dietitian and received a bachelor's degree in Applied Nutrition in France in September 2019. In March 2019, as part of her B.S., she joined the Whistler Center in Dr. Hamaker's laboratory for a four-month internship. She worked with Ph.D. student Pablo Torres-Aguilar on impacts of slowly digestible carbohydrates on gastric emptying rates. She is now pursuing her M.S. degree in Food Science at University of Lorraine (France).



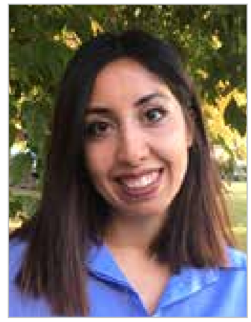
Yulieth Catherine Reyes Roa joined Dr. Kokini's lab as part of the Colombia-Purdue Exchange Program funded by the Colombian government. She was at Purdue from July to December 2019.

Shangyuan Sang received a B.S. (June 2012) and a M.S. (June 2015) in Food Science and Engineering from Jiangnan University under Dr. Bo Jiang. In September 2015, he started his Ph.D. study in Food Science and Engineering at Jiangnan University under Dr. Xueming Xu. The research topic of his Ph.D. is about the function of hen egg components during dough processing. He joined Dr. Narsimhan's group as a Visiting Scientist in August 2018 to conduct molecular dynamics simulation of complexation of egg yolk lipids with amylose.

Danli Wang was a Visiting Scientist from the Department of Food Science and Nutrition with the College of Biosystems Engineering and Food Science at Zhejiang University in China. She worked in Dr. Hamaker's lab on starch modification and the measurement of its structures, properties and applications. Danli returned to China in November 2019.

Binning Wu received her B.S. degree in Agronomy from China Agricultural University in 2016. She started her Ph.D. study in the Plant Biology Program at The Pennsylvania State University in August 2016. She joined Dr. Reddivari's group as a Visiting Scientist in January 2019 and focuses her study on the anti-inflammatory properties of maize 3-deoxyflavonoids and 3-hydroxyflavonoids against ulcerative colitis.

Haitao Wu completed her B.S. and M.S. degrees in Food Science from Dalian Polytechnic University in July 2002 and July 2005, respectively. She obtained her Ph.D. degree from the Graduate School of Natural Science and Technology of Okayama University in September 2008. Now she is a professor in the School of Food Science of Dalian Polytechnic University. She joined Dr. Kokini's group as a visiting scholar in September 2019. Her research focuses on the rheological and physiochemical properties of protein hydrolysates from scallop.



Gamze Yazar spent five months working with Dr. Kokini before returning to the University of Idaho. In collaboration with Professor Brennan Smith from Department of Food Science at University of Idaho, they developed a collaboration to study the interaction of polar lipids in wheat with gluten. Dr. Yazar is the scientific talent who bridges the collaboration. She was at the Whistler Center from July to November 2019.

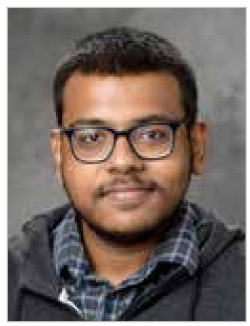
Xiangquan Zeng received his B.S. degree from the College of Biological Sciences and Technology in Beijing Forestry University in 2015. He then went to China Agricultural University to pursue his M.S. and Ph.D. study in Processing and Storage of Agriculture Products. His research topic is characterization and functional properties of condensed tannins from green-mature bananas. He joined Dr. Kokini's group as a Visiting Scientist in November 2019. His research focuses on the fabrication of effective delivery systems for banana condensed tannins.

Graduate Students

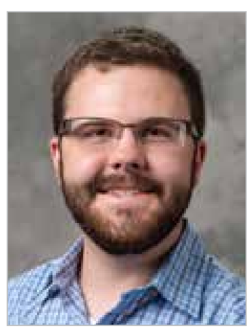
Miguel Alvarez Gonzales completed his B.S. in Food Science and Technology from the Department of Food Science and Technology at PanAmerican Agricultural School, Zamorano University. Previously, he worked on designing bioactive packaging materials for roll-to-roll manufacturing. In the Whistler Center, he worked under the advisement of Dr. Yao on a rapid screening test for breeding lines related to starch quality and the characterization of carbohydrate polymers, and graduated with his M.S. degree in the summer 2019. He will continue his studies towards his Ph.D. with Dr. Lindemann.

Emmanuel Ayua graduated from Moi University in December 2011 and earned a M.Sc. in Community Nutrition from the University of Eldoret. During his studies there, he worked with Prof. Stephen Weller (Purdue Horticulture) of the Horticulture Innovation Lab and his project focused on solar drying of fruits and vegetables and their nutrient retention. He has additional training on postharvest technology on fruits and vegetables from the Postharvest Foundation in Oregon. He joined Dr. Hamaker's lab in 2016 and is working on effect of extrusion on the fermentation of dietary fibers and extrusion processing of cereals in developing countries.

José Bonilla earned his B.S. in December 2014 from the Food Science Department at Zamorano University in Honduras. During the spring of 2014, he worked as a Visiting Scholar in Dr. Yao's lab using polysaccharides from starch to improve thymol solubility. In January 2015, he began studies for his doctorate degree in Dr. Kokini's lab. His Ph.D. research focuses on the use of inorganic fluorescent nano-probes (quantum dots) as an *in situ* labeling technique to study the distribution and rheological properties of cereal proteins.



Subhadeep Bose received his bachelor's degree in Food Technology and Biochemical Engineering from Jadavpur University, India in May of 2019 and joined Purdue in August for his M.S. in Food Science. He is currently co-advised by Dr. Jones and Dr. Narsimhan. His research primarily focuses on oligosaccharide impacts on starch swelling behavior and is part of the Whistler Center's project on sugar reduction/replacement.



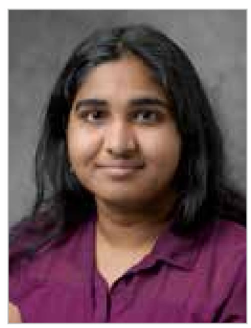
Nathaniel Brown received his B.S. in Biological and Agricultural Engineering with a minor in Food Science from Kansas State University in May 2018. He had various internships with companies like Bimbo Bakeries USA as a process engineer (2016) and McCormick & Company in Technical Innovation (summer, 2017 & 2018). He joined Dr. Campanella's lab in August 2018 in pursuit of a M.S. in ABE, conducting research on the interactions between rheology and interface science with microbubbles and applications in cleaning and sanitization.

Nuseybe Bulut completed her B.S. degree in July 2014 at the Food Engineering Department, Istanbul Technical University (ITU), Turkey. She joined Dr. Hamaker's lab group in January 2017. Her M.S. research focused on fabrication of plant cell wall-like materials and their impact on the human gut microbiota, and she finished and graduated in fall 2019. She will continue her Ph.D. studies with Dr. Hamaker in the area of dietary fiber and the gut microbiota.

Jingfan Chen received her B.S. in Food Science from Purdue University in 2015. She joined Dr. Yao's lab in 2016 to pursue her Ph.D. degree. Her main research focus has been on phytoglycogen and its derivatives for food and pharmaceutical uses. She has also studied the use of a molecular rotor for biopolymer characterization.

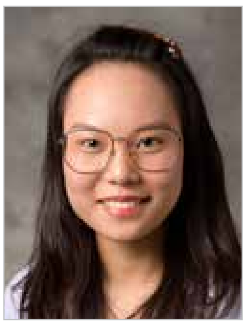
Dennis Cladis earned his B.A. in Chemistry and Mathematics from DePauw University in 2009. He earned his M.S. in synthetic inorganic chemistry at Purdue in 2012. From there, he discovered a passion for food science as a practical application of his chemistry and subsequently earned his M.S. in Food Science at Purdue in 2014, with his research focusing on fatty acid profiles and mercury content in fish. He completed his Ph.D. in Food Science at Purdue in December 2019 under the direction of Drs. Ferruzzi and Weaver investigating polyphenol toxicity and changes in metabolism that occur with increased doses of blueberry polyphenols.

Sarah Corwin received her B.S. in Nutrition from Case Western Reserve University in Cleveland, Ohio, in 2013. She worked in Dr. Nathan Berger's laboratory in the Genetics Department at Case Western Reserve University after graduation, examining the effect of dietary fats on prostate malignancy; and then for Jenny Craig as a Personal Consultant in 2014. Sarah then completed her dietetic internship through Indiana University-Purdue University, Indianapolis, with a capstone in Food Service Management. As a registered dietitian, she worked clinically for Hooverwood Home in Indianapolis. Sarah by-passed her M.S. degree and joined Purdue under Dr. Hamaker's advisement in 2016. Sarah completed a summer internship at PepsiCo Global R&D in 2019, working on the Discovery and Applications team. She is working towards her Ph.D. in the area of slowly digestible carbohydrates, with an anticipated graduation date of August 2020.

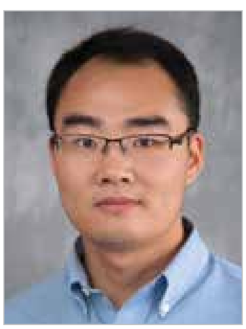


Gnana Prasuna Desam earned her B. Tech. degree in the Department of Agricultural and Food Engineering from Indian Institute of Technology, Kharagpur, in July 2014. She joined Dr. Narsimhan's group in June 2015 to pursue a Ph.D. degree in the Department of Agricultural and Biological Engineering and is working on prediction of swelling kinetics of waxy cornstarch and modified waxy cornstarch.

Enrico Federici earned his B.S. degree in Food Science and Technology in July 2014 from University of Parma. During work on his Master's at the University of Parma, he joined Dr. Campanella's lab as a visiting scholar for six months, working on a collaborative research project between Purdue University and the University of Parma. This contributed to the completion and defense of his M.S. thesis in October 2016. Enrico joined Drs. Jones and Campanella's lab in August 2017 as a Ph.D. student. His research focuses on improvement of gluten-free products with the use of novel protein preparations and assemblies.



Wenyi Fu received her B.S. degree from the Department of Food Science at Purdue University in 2019. She then joined Dr. Reddivari's lab group to pursue her M.S. degree. Her area of interest is food chemistry, and her current research focuses on how dietary fibers and polyphenols affect the human gut microbiota and gut health.

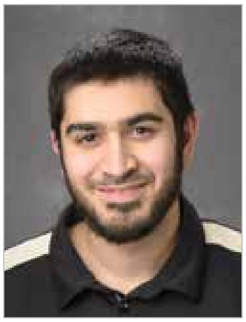


Yezhi Fu received his B.S. degree in Food Quality and Safety and M.S. degree in Food Engineering, both from China Agricultural University, Beijing. He started his research in Dr. Yao's group as a visiting student in 2014 and now is pursuing his Ph.D. degree. His research focuses on designing antimicrobial coating to improve the safety of fresh and fresh-cut produce, using cantaloupe as a model.

Anna Hayes received her B.S. in Food and Nutrition Science and her B.A. in Spanish from Saint Catherine University (Saint Paul, MN) in May 2014. Anna joined Dr. Hamaker's lab as a direct Bachelor's to Ph.D. student in the Purdue Food Science Department in August 2014. Her research focuses on investigating the slow digestion and satiety properties of pearl millet grown in sub-Saharan Africa as well as exploring the implications of starch fine structural features on digestibility and texture applications through collaborative projects. Ultimately, her work will help identify characteristics of glycemic carbohydrates that impart a slow digestion property and elucidate how they can be leveraged to design foods with targeted physiological outcomes.

Harrison Helmick is a master's student in the Department of Food Science at Purdue University under the guidance of Dr. Kokini. His research focuses on how yeast metabolites impact wheat dough rheology. Prior to Purdue University, Harrison studied at Kansas State University and obtained a degree in Bakery Science. This turned into a career at Bimbo Bakeries where he worked in production and process improvement. He hopes to continue to blend lean six sigma practices with the fundamentals of food science in order to advance the world of cereal science.

Rachel Jackson received a B.S. in Food Science from Purdue University in 2017. She then joined Dr. Hamaker's lab to continue her research and pursue her M.S, which she earned in December 2019. Her research focused on the influence of dietary fiber and protein interactions on the gut microbiome.

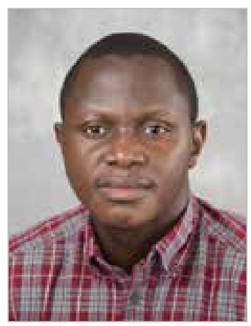


Enosh Kazem received his B.S. in Food Science from Purdue University in 2011. After graduation, he spent two years in medical school at Indiana University, and is now studying in Dr. Hamaker's group, where his research focuses on the role of fiber and microbiota in colon health.

Alyssa Kelley received her B.S. in Nutritional Sciences from the University of New Hampshire in 2016. Subsequently, she completed a two-year research fellowship at the U.S. Army Research Institute of Environmental Medicine in Natick, Massachusetts. She studied in Dr. Jones' laboratory from 2018 until the fall 2019 to identify new routes towards the glycosylation of maize proteins.

Cindy Mayorga completed her B.S. degree in Food Engineering at Universidad Tecnologica de Panama (UTP) in 2016. She worked as a research assistant during her bachelor's thesis at the same university before coming to Purdue University. In 2019 she received a Fulbright Scholarship to join Dr. Kokini's lab to pursue her M.S. degree and work on the development of biosensors.

Moustapha Moussa rejoined Dr. Hamaker's group in June 2016 to pursue his Ph.D. in Food Science. His research areas focused on grain chemistry and processing with the objective of use extrusion and nutrition-related technologies to better utilize and expand markets of local-based sorghum and millet grains. He received his M.S. in Food Science from Purdue University in 2007. Along with Dr. Hamaker, he successfully helped to implement the Hub-and-Spoke incubation system to backstop grain-based food technology development and with nutrition and market emphasis in urban and rural areas in Niger and West Africa. He was awarded his Ph.D. in December 2019 and returned home to Niger.



Smith G. Nkhata completed his B.S. in Nutrition and Food Science from Bunda College of Agriculture, University of Malawi, in 2007 in Malawi. He later joined the Government of Malawi through the Ministry of Agriculture and Food Security in 2009 as a Food and Nutrition Specialist, a post he holds to date. In 2011, he was admitted at Michigan State University, where he completed his M.S. degree in Food Science in 2013. He joined Drs. Ferruzzi and Hamaker's groups in August 2015 to pursue his Ph.D. in Food Science. His research area was in part on provitamin A stability during processing, in vitro bioaccessibility and bioavailability of provitamin A from maize-based products. He received his Ph.D. in summer 2019 and returned home to Malawi.

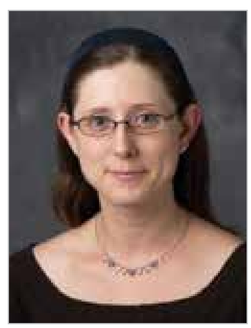
Gabriella Mendes Candido de Oliveira obtained her B.S. in Food Engineering from the University of São Paulo (USP) and joined Dr. Campanella's group for her Ph.D. in food process engineering. The objective of her dissertation was to develop a flexible modeling approach capable of incorporating process variables into the calculation of microbial inactivation in non-isothermal and non-thermal food processes. She concluded her Ph.D. in 2019 and accepted a postdoctoral position with the USDA-ARS. Gabriella was the recipient of the 2019 Outstanding Ph.D. Student Award in ABE.

Sarah Pitts received her B.S. in Biochemistry from Purdue University in 2019. She joined Dr. Mauer's lab group in 2019 to pursue a M.S. in Food Science. Sarah's current research focuses on sensory analysis of bakery products formulated with oligosaccharides.

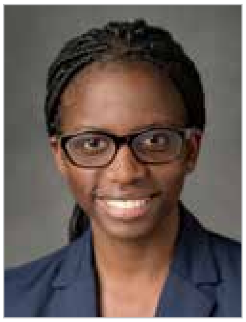
Arianna Romero Marcia received her B.S. degree in Food Science and Technology from Zamorano University, Honduras. She joined Dr. Lindemann's lab in 2018 to pursue her M.S. in Food Science. Her interests focus on dietary fiber and the interaction with the gut microbiota. She also had R&D industry experience connecting the microbiome sciences with product development. Her work relates to how glucans chemical structure modulates the human gut microbiome structure and function.

Tahrima Binte Rouf completed her B.S. in Chemical Engineering from Bangladesh University of Engineering and Technology in 2012 in Bangladesh. Before coming to Purdue, she was a lecturer in the Department of Chemical Technology at Ahsanullah Institute in Bangladesh. She joined Dr. Kokini's lab in Fall 2014 and completed her Ph.D. research in Fall 2019 on the functionalization of zein biopolymers using different nano-materials for application in biodegradable packaging and biosensors.

Felicia Aba Sackey has a B.Sc. in Biochemistry, Cell and Molecular Biology from the University of Ghana, Legon. She is currently a Pulse (Purdue Interdisciplinary Life Sciences) student working under the supervision of Dr. Steve Lindemann. Her graduate study is on the evolution and mechanism of the usage of multiple variably sized fructooligosaccharides in a wild human *Escherichia coli* strain.



Leigh Schmidt earned a B.S. in Food Science from Purdue in 2003 and an M.S. in Food Science from the University of California Davis in 2009, and also held quality and product development roles in the food industry. She joined Dr. Hamaker's lab group in 2013 to begin her doctoral work as a USDA National Needs Fellow in foods and health, with a research focus on designing food matrices as a method to slow starch digestion. She completed her Ph.D. in summer 2019.



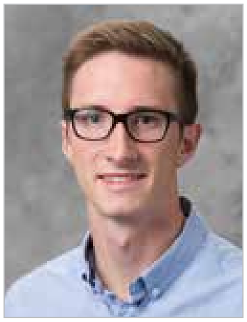
Geraldine M. Tembo completed her B.S. degree in Food Science and Technology at Botswana College of Agriculture (now Botswana University of Agriculture and Natural Resources) in 2015. In 2018 she received a Fulbright Scholarship to join Dr. Kokini's lab to pursue her Master's degree. She studies the use of biodegradable materials such as SERS platforms for detection of aflatoxins and other toxins in corn and peanuts.

Riya Thakkar completed her M.S. in Food Science in 2019. Her area of interest is Food Microbiology. She obtained her undergraduate degree, Bachelor of Technology in Biotechnology, in 2016 from D.Y. Patil University, India. She started her Master's degree under Dr. Lindemann's lab at Purdue University in January 2017. Her work focused on the effect of particle size of food on the colonic microbiota.

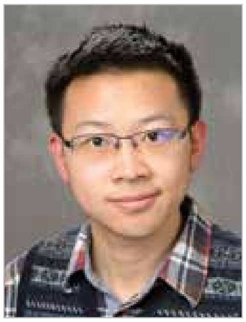
Pablo Torres-Aguilar received his M.S. in Nutritional Sciences from the University of Illinois at Urbana-Champaign, where his research focused on food insecurity and the impact of environmental factors on the diet of underserved groups, both in the U.S. and internationally. He joined Dr. Hamaker's group in the fall of 2014 and is working toward completing his Ph.D. degree in the area of food science and nutrition.

Hazal Turasan completed her B.S. degree in Food Engineering at Middle East Technical University in 2011 in Turkey. She completed her M.S. degree in the same department. After receiving a Fulbright Scholarship in 2014, she joined Dr. Kokini's group for her Ph.D. studies. She is currently working on fabricating biodegradable biosensor platforms from corn protein to detect food toxins and allergens.

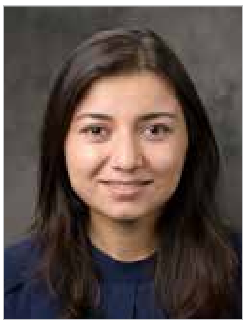
Adrienne Voelker graduated from the University of Notre Dame in 2016 with a B.S. in Chemistry. She joined Dr. Mauer's lab group in 2016 to pursue her M.S. in Food Science and has since received approval to bypass to the Ph.D. program. Adrienne's current research focuses on improving thiamine delivery in foods by studying its physical and chemical stability in its amorphous form in different formulations, and she has taken a leading role in a project exploring the use of sucrose crystallization inhibitors.



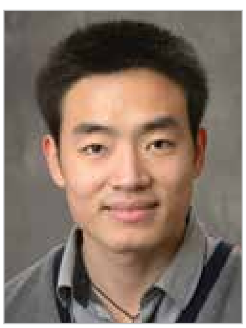
Travis Woodbury received a B.S. in Food Science from Brigham Young University-Idaho. He worked as a lab assistant for Dr. Kerry Huber, a starch expert and Ph.D. alumnus from Purdue and the Whistler Center. Travis has had multiple internships in production and QA within the dairy industry prior to coming to Purdue. He started his M.S. in August 2018 and bypassed to a Ph.D. in February 2020 in Dr. Mauer's lab. His research is focused on sugar reduction strategies from a food material science perspective; specifically to determine the physicochemical properties of prebiotic oligosaccharides and their effects on the thermal transition properties of wheat starch and various baked good systems (e.g., sugar snap cookies).



Tianming Yao obtained his B.S. in Food Science and Technology from Shanghai Jiao Tong University, China. His undergraduate research was on the OSA modification of small granule starches. He joined Dr. Janaswamy's group in August 2015 as a Master's student with support from China Scholarship Council (CSC). His research focused on the interaction between polyphenols and starches. Tianming is now a Ph.D. student with Drs. Lindemann and Hamaker and works on dietary fiber and the gut microbiome.

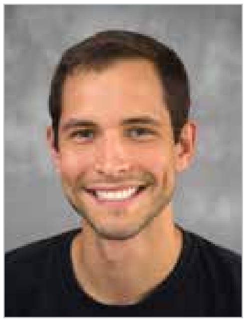


Merve Yildirim received her B.S. degree in Food Engineering from Middle East Technical University (METU) in 2013 in Turkey. She also completed her M.S. degree in the same department in which she focused on low-fat products with double emulsions. She joined Dr. Kokini's laboratory for her Ph.D. studies in 2017. Her Ph.D. research focuses on non-linear rheological properties of bio-polymers.



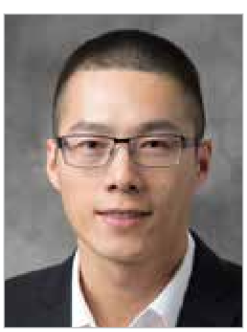
Xiaowei Zhang received B.S. and M.S. degrees from the Department of Food Science and Engineering at Shanghai Jiao Tong University, China. He joined Dr. Hamaker's group as a Ph.D. student in August 2014. Xiaowei's research project focuses on dietary fiber's structure-function relationships with the colon microbiota and relationship with health. Xiaowei received his Ph.D. degree in May 2019 and now works as a Postdoctoral Fellow at Shanghai Jiao Tong University, China.

Ph.D. Post-Doctoral Research Associates



Matthew Allan received a B.S. in Food Science from Washington State University in 2012 and received a M.S. (2014) and a Ph.D. (2018) in Food Science from Purdue University under Dr. Lisa Mauer. His graduate research focused on deliquescence, developing crystal hydrate phase diagrams, and investigating the effects of sugars on gelatinization. He was the recipient of the James and Pari BeMiller Graduate Scholarship. Matthew was a Postdoctoral Research Associate in 2019 in Dr. Mauer's lab, funded by a NIFA grant to research the effects of sugars and salts on starch retrogradation.

Thaisa Cantu-Jungles received her B.S. in Nutrition from the Pontificia Universidade Católica do Paraná (Brazil). She earned her M.S. and Ph.D. in Biochemistry at Federal University of Paraná (Brazil). In 2015 she joined Dr. Hamaker's group as a visiting scholar for a year to conduct part of her Ph.D. research. Her research has focused on the structural characterization of dietary fibers from fruits and its applications in the biological field. In 2018 she rejoined Dr. Hamaker's group as a postdoctoral researcher in the area of dietary fiber fermentation by the gut microbiota.



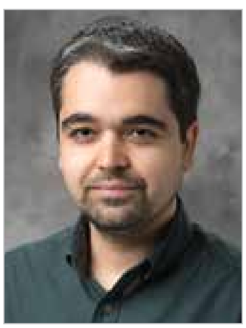
Da Chen joined Dr. Jones's lab in March 2019. He mainly worked on the nanofibrils fabricated from milk proteins. Those fibrils have been shown to increase the gel strength of starch without causing obvious phase separation. The work has been published on *Carbohydrate Polymers*. He also fabricated protein-contained electrospun fibers whose diameter and alignment can be tuned. The electrospun fibers show high mechanical strength comparable to those of silk and collagen. These fibers have great potential on tissue engineering, filtration and as drug carriers. The relevant results have been submitted to *Biomacromolecules*.

Ming-Hsu Chen received his Ph.D. degree in Agricultural and Biological Engineering from the University of Illinois in 2015. His research has focused on bioactive carbohydrates manufacturing as well as characterization and elucidation of structural-functional relationships. Before coming to the US, Ming-Hsu obtained his M.S. and B.S. degrees in Microbiology and Biochemistry from the National Taiwan University. Additionally, he had one year working experience at Academia Sinica, studying fungal secondary metabolites, carbohydrate recognition proteins, and lymphocyte maturation. He joined Dr. Lindemann's group in August 2017 and was interested in exploring the interactions among carbohydrates, gut microbiota, and human health. Currently, Dr. Chen is an assistant professor at the School of Chemical and Biomedical Engineering of Nanyang Technological University in Singapore.

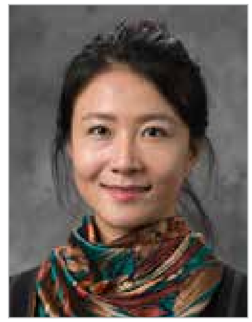
Hawi Debelo earned her B.A. degree in Biochemistry from Manhattanville College, New York, in 2012. Following her undergraduate career, Hawi worked at PepsiCo Global Research and Development Center as a Product Development Technician. She spent two years at PepsiCo conducting research with Product Developers in innovation, formulation, and commercialization of Pepsi products. Hawi joined Dr. Ferruzzi's lab in 2014 as a Ph.D. student, where she worked on a project to evaluate the stability, bioaccessibility and bioavailability of bioactive compounds from native African plant materials, and completed her degree in 2018 at Purdue University. Hawi is now a postdoctoral researcher for Dr. Ferruzzi at North Carolina State University.

Marwa El Hindawy is from Cairo, Egypt. She obtained her Ph.D. degree with Dr. Hamaker in December 2018, and worked on slowly digestible carbohydrates and their role in activating the gut-brain axis for satiety through the enteroendocrine L-cells. Her work showed the potential for ileal-digesting slowly digestible carbohydrates to be used in weight management. She is now a Post-doctoral Research Associate in his laboratory.

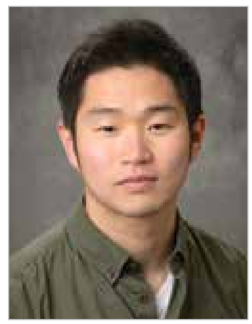
Fang Fang received her Ph.D. in 2017 with Drs. Campanella and Hamaker on starch amylopectin thickening and molecular aggregation properties with shear. She rejoined their groups in fall 2018 as a Post-doctoral Research Associate and works on industrial projects related to carbohydrate structure and function.



Oguz Kaan Ozturk completed his B.S. (2011) and M.S. (2014) degrees in Food Engineering at Middle East Technical University in Turkey. He also has an M.B.A. (2013) degree from the same university. He received his Ph.D. (2019) in Food Science and Human Nutrition Department from University of Illinois at Urbana-Champaign, where his research focused on modeling of water transport in food products during drying process. He joined Dr. Hamaker's lab in April 2019 as a Post-doctoral Research Associate and works on industrial projects related to structure and functionality of starches and proteins.



Shiyu Li received her Ph.D. (Preventive Veterinary Medicine) from the Academy of Military Medical Sciences in China. She received her B.S. and M.S. in Food Science. In 2017 she joined Dr. Reddivari's group as a visiting scholar for a year, and currently is working as a Post-doctoral Research Associate in the same lab. Her research focuses on the anti-inflammatory properties of food-based bioactive compounds and the role of gut bacteria.



Jongbin Lim earned his M.S. degree in Food Science and Technology from Sejong University in South Korea. He joined Dr. Hamaker's lab group in August 2014 to begin his doctoral work. His research was on the moderation of starch digestion rate by inhibition of digestion enzymes and the development of glycemic carbohydrates to digest in the ileal region of the small intestine for stimulation of physiological feedback systems. He graduated with his Ph.D. in 2019 and continues on as a Post-doctoral Researcher in Dr. Hamaker's lab.

Yony Román Ochoa received his BSc in Chemistry and a master's degree in Chemical Sciences at University of Antioquia-UdeA (Medellin, Colombia). In 2017, he finished his Ph.D. in Sciences-Biochemistry at University of Paraná-UFPR (Curitiba, Brazil), working on structural characterization, chemical modification and anticoagulant and antithrombotic activities of polysaccharides, derived of mushrooms and plants. In 2018, he continued his research as a post-doctoral researcher in Science-Biochemistry at UFPR. In 2019, he joined the Dr. Hamaker group as a Post-doctoral Research Associate, working on screening of heavy metals in local staple food-based processed products from Arequipa, Peru. He looked to identify or develop staple food sources/process to reduce heavy metal contamination to safe levels, and to evaluate the effects of the contamination food on the dietary fiber fermentation by the gut microbiota.

Whistler Center Staff

Aminata Diatta received a B.S. in Natural Sciences in 2002 and a pre-doctorate diploma in Chemistry and Biochemistry of Natural Products in 2006 from Cheikh Anta Diop University, Dakar, Senegal. She worked on the theme "Characterization of three varieties of sorghum (S. bicolor), composition and aptitude to form rolled flour products". She joined Dr. Hamaker's group in fall 2015 and successfully defended her M.S. in May 2018. Her work focused on "Using corn zein to improve the quality of gluten-free bread". Currently she works temporarily as a lab assistant in Dr. Hamaker's lab.

Angie Gutterman joined the Whistler Center as the Center's coordinator in September 2019. Before joining the Center, Angie worked at Krannert School of Management as an Administrative Assistant for the Department Heads, where she was responsible for managing the promotion and review files for more than 120 faculty members. She received her bachelor's degree in business administration from Butler University in 1985. Angie is enjoying working with graduate students and post-docs and is looking forward to meeting our members in 2020.

Bhavesh Patel received a B.S. degree in Dairy Technology from Gujarat Agricultural University, Anand, India, and an M.S. degree in Food Technology from Central Food Technological Research Institute (CFTRI), Mysore, India. His Ph.D. in Food Science is from Pennsylvania State University, where his research involved study of starch and polysaccharide structures and the effect of processing conditions on thermal and physical properties. Bhavesh joined Drs. Campanella and Hamaker's groups in 2008 and has worked on the development of processes for isolation of corn fiber polysaccharides and enhancing their functional properties, as well as fiber rheology and fiber incorporation into processed foods and gel formation kinetics. He recently conducted a project related to enzymatic conversion of complex polysaccharides into useful industrial and food products. Currently, he conducts short-term research projects for the Whistler Center member companies.

Anton Terekhov is proficient in analytical chemistry, molecular biology techniques and analytical instruments such as NMR, GCMS, LCMS and FTIR. Anton has more than 10 years of experience in an interdisciplinary laboratory environment, including the fields of analytical chemistry, microbiology, genetics, geology and chemical and civil engineering. His main research area is carbohydrate analysis using above-mentioned analytical instruments. He is Director of Analytical Services for the Whistler Center.

Our People, Our Projects

Campanella

1. Industrial Processing Properties of Tomato Products
2. Modeling Inactivation Parameters of Spore Cells Subjected to Cold Plasma and Other Non-Thermal Processes
3. Modeling the Microbial Community in the Gut: The Basics
4. Innovative Green Clean-in-Place Technology with Microbubbles

Ferruzzi

5. Starch-Phenolic Complexes: Implications for Phenolic Bioavailability and Glycemic Properties on Starch and Intestinal Glucose Transport

Hamaker

6. Fabrication and Modification of Dietary Fibers for Targeted Functions in the Gut
7. *In Vitro* Gut Fermentation Studies on Dietary Fibers
8. Specificity of Dietary Fiber Structures to Support of Gut Bacteria
9. Investigations on Slowly Digestible Glycemic Carbohydrates
10. Cellular and Physiological Response of Slowly Digestible Carbohydrates
11. Cereals and Grains

Jones

12. Protein Fibrous Structures as Physical Simulacrums of High-MW Glutenin
13. Effect of Protein Conjugation on Functionality and Polysaccharide Interactions

Kokini

14. Characteristic of Protein Hydrolysates from Male Gonad of Scallop (*Patinopecten yessoensis*): Nonlinear Rheological Behavior and Interaction with Chitosan
15. Soy Protein Isolate-Based Biosensors for Detection of Food Analytes
16. Investigating the Nonlinear Behavior of Cream Cheese and Sour-Cream
17. Fabrication of Biodegradable Zein Nanofiber-Based Surface Enhanced Raman Spectroscopy Platforms for the Detection of Food Allergens and Toxins
18. Relationship of Non-linear Rheological Properties and Network Analysis Parameters in Non-Fat, Low-Fat and High-Fat Yogurt Products
19. Fabrication of Effective Delivery Systems for Banana Condensed Tannins

Lindemann

20. Establishment of Model Dietary Fiber-Consuming Gut Microbial Communities for Generalizable Fiber-Microbiota Research
21. Particle Size Effects on Bran Fermentation by Gut Microbiota
22. Bran Arabinoxylan Chemical Structure Effects on Fermentation by Gut Microbiota
23. Differential Fermentation of Resistant Dextrins by Gut Microbiota

Martinez

24. Understanding Structure-Function Relationships of Pectic Polysaccharides from Fruits and Pulses
25. Investigations on Amylose and Amylopectin Fine Molecular Structure and Their Physical Modification to Develop Slowly Digestible Starch in Foods
26. Thermomechanical Processing and Phenolics for Regulation of Glucose Homeostasis
27. Whole Muscle Tissue Engineering Using Bio-Polymeric Materials from Plants

Mauer

28. Starch Properties in Different Environments
29. Amorphous Solid-State Dispersion (Amorphization) of Crystalline Ingredients
30. Water-Solid Interactions and Phase Diagrams

Narsimhan

31. Prediction of Swelling Behavior of Crosslinked Maize Starch Suspensions
32. Volume Fraction Dependence of the Elastic Behavior of Starch Suspensions
33. Synergistic Effect of Low Power Ultrasonication on Antimicrobial Peptide Action

Reddivari

34. Anti-Inflammatory Effects of Anthocyanins – Role of Gut Bacteria
35. Polyphenols and Fiber Interaction: Modulation of Gut Microbiota in Health and Disease

Simsek

36. Immunomodulatory Activity of Structurally Diverse Arabinoxylan Hydrolysates
37. Mechanical and Physical Properties of Biodegradable Wheat Bran, Maize Bran, and Dried Distillers Grain Arabinoxylan Films
38. Inclusion Complexes of β-Cyclodextrin with Selected Food Phenolic Compounds

Yao

39. Molecular Rotor-Based Characterization of Biopolymers at Oil-Water Interface and Emulsions
40. Phytoglycogen and its Derivatives to Improve the Solubility of Poorly Water-Soluble Active Ingredients
41. Milligram Analysis of Starch Materials on Retrogradation and Shear Resistance
42. Pathogen Biofilm Reduction at the Surface of Fresh Produce

Project Summaries

1 Industrial Processing Properties of Tomato Products

P.I.s: O. Campanella, B. Reuhs, O. Jones

Researcher: Xing Fei, Ph.D.

Objectives: Improving viscosity while enhancing sensory (color and flavor) and nutritional attributes of tomato products has long been scientifically challenging, and most of the research in this area has been completed during Dr Xing Fei's thesis, with several publications being submitted for publication. Our ongoing studies on the rheology suspensions identified tomato particles, rather than the traditionally held belief that enzymatically solubilized pectin was the dominant contributor to the viscosity of tomato suspensions. Ultrasound and extrusion showed promise as alternatives to "hot-break" for processing of tomato with less energy consumption. Our team has utilized high shear processing and extrusion to efficiently alter the morphology of tomato tissue particle and improve the viscosity, color and lycopene content of suspensions. New development has been initiated this year in which we are trying to pair our past research and new development with structural investigations to identify changes in tomato particle viscoelasticity, pectin distribution, and pectin interaction with other cell-wall polysaccharides. Sustainability will be enhanced by converting tomato peel, a by-product of the process, to reinforcing fillers of rubber and rubber-modified bioplastics.

Progress: This research project has identified and determined the effects that influence the rheology of tomato suspensions systems including (1) soluble pectin; (2) particle physical properties; and (3) processing conditions. The rheological behavior of industrially processed tomato suspensions was characterized. The main findings were the following:

1. The soluble pectin in the serum phase was identified as a limited contribution to the overall viscosity of the tomato suspension. However, it is playing an important role on the stabilization of the suspension by promoting the interaction between their particles. Both prepared pectin solutions and isolated sera exhibited Newtonian behavior with a low viscosity. Proton NMR of the dialyzed sera confirmed the presence of pectin in the serum phase. By using a cone-plate geometry for the suspension viscosity measurements, significant wall slip was observed due to phase separation in the suspension. The phenomenon was more noticeable when the pectin content in the sera was low. By using a vane geometry, a sound correlation between fundamental measurements of suspension viscosity and the empirical Bostwick consistometer method was established. Tests showed that the presence of higher concentration in the serum can stabilize the suspension and minimize liquid syneresis.
2. The particle volume fraction and particle properties displayed a predominant role in determining the rheological properties of tomato suspensions. Viscosity can be increased by increasing the concentration of tomato cell-wall-derived particle. Particles with intact cellular structures exhibited higher water retention and mechanical strength and formed suspensions with higher viscosity and viscoelastic properties such as the storage modulus (G'). Suppression of PME activity in some tomato cultivars resulted in a closely packed cellular structure and smaller pore size compared to the tissue of the original wild type tomato. Reduction in PME activity significantly strengthened the microstructures of cell wall particles, reduced serum separation and therefore improved the rheological properties of tomato suspensions.
3. The effects of thermal breaking, ultrasound, and high shear were studied in a laboratory processing scale, whereas the concentration process to produce tomato paste at an industrial scale was also investigated. Different processing conditions generated particles with various structures and strengths which altered the rheology of tomato suspensions.
4. During the industrial concentration process to produce pastes, the particle size and particle properties were modified due to the prolonged and intense heating, which resulted in a viscosity loss when pastes were diluted back to suspensions with the same soluble solid content. It was found that the concentration step in the production of pastes not only reduced the particle volume but also concentrated their mass into smaller volume and therefore negatively changed the particle properties that could explain the viscosity loss during concentration. Tomato particles from concentrates could not fully re-expand to the original shape, and the concentrated solute was only partially re-solubilized upon dilution, which explained the need to use more paste to achieve the same soluble solids measured as °Brix.

2 Modeling Inactivation Parameters of Spore Cells Subjected to Cold Plasma and Other Non-Thermal Processes

P.I.: O. Campanella

Researcher: Gabriella Mendes Candido de Oliveira, Ph.D.

Collaborators: F. San Martin, A. Deering (Food Science), Tony Jin (USDA)

Progress: The research developed in this project is associated with a wide range of applications that can assist the food industry to predict, control and improve the performance of their food processes. The food industry is constantly trying to adapt consumer expectations that foods are free from potentially harmful microbes, but that are considered fresher and more natural. Thus, this project met the growing interests of alternative technologies for food processing opening opportunities to explore technologies such as microwave heating, pulsed electric fields, and cold plasma, to meet those demands. This project developed both an experimental approach and mathematical modeling for the quantitative characterization of microbial survival for supporting food safety decisions considering these novel technologies.

Non-thermal plasma or cold plasma has emerged as an innovative technology for microbial inactivation in the last two decades. The abundant reactive species generated during cold plasma treatments have been considered the main process parameter affecting the inactivation of vegetative and spore-forming organisms. Because of the relatively mild conditions of cold plasma and the generation of highly oxidative gas species, the technology offers the opportunity to inactivate spore-forming organisms that present risks in foodborne diseases or food spoilage. For the quantitative evaluation of the cold plasma process, one of the major flaws is the assumption that the concentration of reactive species is constant, which is far from real conditions occurring during plasma processing. The other aspect that is not considered is the fact that, despite survival curves are visibly non-linear, first-order kinetics is used and, unfortunately, this shortcoming does not help in the design of plasma processes in practice. In this project a modeling approach that jointly considered the time-varying concentration of a major reactive specie and the kinetics of microbial inactivation was used. The model enabled the determination of a critical gas concentration of that specie, which would provide a threshold value to be employed in order to achieve significant microbial inactivation. Thus, from a practical standpoint, the modeling approach provided a useful and practical relationship between the inactivation characteristic of resistant spores with realistic plasma processing factors.

Microwave pasteurization was another technology studied in this project. Microwave pasteurization has similar processing variables as those used in traditional pasteurization protocols, but heating times are shorter and heat penetration is significantly higher. Furthermore, temperature profile in microwave processing is far from constant. Therefore, typical non-isothermal conditions of microwave heating are a major overcoming when modeling the process. The other issue in the modeling of microwave inactivation was the assumption of first order kinetics to describe inactivation, which realistically are far from that. Another flaw found in the literature is to ignore the temperature history of microwave processes and assume some arbitrary reference temperature to calculate processing parameters such as , and F values that are related to isothermal conditions. Results of this project related more realistic time varying temperature profile to the microbial inactivation kinetic by using a non-isothermal rate model. The major contribution of the project results was the finding of a critical temperature above which significant microbial effects were significant. Once the food industry tests this approach in its liquid products, a target temperature can be determined. This temperature should assist the food industry in the design of microwave process as well as in the decision-making process to define which variables should be evaluated to ensure that pasteurization is effective. Results would further assist in process validation to ensure that the 5-log reduction criteria requested by the FDA HACCP guidelines are met.

Pulsed Electric Fields (PEF) was also studied in this project. It was hypothesized that microbial inactivation is non-constant and depends on the energy density applied. From a calculated critical energy density, a critical electric field was calculated for processing conditions including pulse repetition rates. The electric field strength, the pulse repetition rate, the pulse width, the residence time, and the sample conductivity were incorporated in the microbial inactivation kinetics. Working with the energy density applied, the modeling approach proposed in this dissertation incorporated all these PEF processes to qualitatively describe inactivation of microorganisms for the pasteurization of apple juice. The proposed approach was validated in other samples and also in data published in the literature for other juices. For the first time, such a model has been developed and validated, which proves its usefulness and its rigorous framework for the design of PEF processes. Finally, in addition to its striking contribution to predictive models for PEF, the proposed approach will also assist the food industry by using the approach to support food safety decisions. For instance, in determining which parameters must be considered to ensure the safe production of foods, or in determining which factors need to be considered in the control of PEF pasteurization processes.

3 Modeling the Microbial Community in the Gut: The Basics

P.I.s: O. Campanella, J. Welti-Chanez (Tecnológico de Monterrey, Mexico)

Researcher: Viridiana Tejada Ortigoza, Post-doc (Tecnológico de Monterrey, Mexico)

Collaborator: Bruce Hamaker

Objectives: To understand the nature of microbial communities' interactions and how these might impact the host's health (or disease).

Progress: A book edited by Jorge Welti-Chanes, Sergio O. Serna Saldivar, Osvaldo H. Campanella and Viridiana Tejada-Ortigoza has been completed and will be published in 2020. The book, titled "Science and Technology of Fibers in Food Systems," will be published by Springer Nature. The book covers practical and scientific aspects related to the chemistry, analysis, technology, processing, functionality, and health implications of fiber components associated with different food matrices and is designed for scientists, students, food product developers, nutritionists, medical doctors, and health practitioners interested in the field of edible food fibers. The first part of the book introduces developments to include fiber components intended to reduce the caloric density of foods and the levels of cholesterol-containing lipoproteins and improve gastrointestinal function, glycemic index, blood pressure, and levels of antioxidants that protect mammalian systems against oxidative stress. Moreover, different dietary fiber components act as prebiotics that improve the microbiota or microbiome present in the hindgut. An article was presented in the ICEF 13 Conference in Australia, and a review article is written describing mathematical approaches to model microbiota dynamics that includes:

1. The microorganisms, including individual parameters (such as growth rate), species present in the community and the interactions between the microorganisms (mutualism, commensalism, neutral) are considered.
2. A molecular view on metabolic reactions, where the metabolite production (e.g., SCFA and vitamins) and consumption, as well as their physical parameters such as diffusion of nutrients through the microbial species or vice versa are considered, and
3. the host, by considering the environment provided to the microbial community (diet) and how this affects the presence or absence of specific species, and the nutrient production and diffusion through the host.

The use of several models involving computational analyses was reviewed. These models are based on parameters obtained experimentally through *in vitro* or *in vivo* studies. The use of very complex models also requires the input of many parameters which would complicate their application in a practical way. The main goal of the review is to identify general model(s) where general rules might be applied to gain practicality to model the microbial community in a pragmatic way by simplifying the use of this information not only for the scientific community but also for the industry.

4 Innovative Green Clean-in-Place Technology with Microbubbles

P.I.s: O.H Campanella, C. Corvalan

Researcher: Nathaniel H. Brown, M.S. student

Collaborator: J. Lu

Objectives: The general objective of this project is to use microbubbles to clean fouled surfaces of processing equipment. A model is being developed to further understand the mechanisms of fouling material detachment and separation by microbubbles. Work is being also done to study the coalescence and stability of the microbubbles. Specific objectives are the following:

1. Modeling
    - Validate model with experiments
    - Investigate bubble coalescence in a Non-Newtonian fluid
    - Investigate bubble coalescence involving surfactant
2. Experiments
    - Perform experiments to explore interactions and cleaning by microbubbles on a micro scale

Progress: Microbubbles present in liquids must move to the surfaces. These microbubbles can be totally or partially covered with active chemical species like surfactant or hydrophobic compounds that are separated from fouled surfaces. Marangoni phenomena describes the movement of active species in interphases, and the goal of this project was to progress the current understanding of self-induced movement of bubbles by Marangoni flows generated from surface-active species at an interface. The work was completed by performing direct numerical simulations solving the partial equations governing free surface flows and conservation of surfactant equations on an interface. These results allowed for a detailed investigation and understanding of the underlying physical mechanisms associated with the self-propulsion of active bubbles utilizing Marangoni flows. Simulation results showed that the initial area of surfactant coverage, surfactant strength, and the tube radius which the active bubble is propelled through, have a profound impact on the speed, displacement, and deformation that the microbubble experiences during the duration of the movement. The ability to predict how the behavior of Marangoni flows are associated with the transport of surface-active species is important in many natural and industrial processes, including the cleaning of oil spills, microfluidic device propulsion, and microbubble assisted cleaning of industrial equipment. The latter is of importance in this project

5 Starch-Phenolic Complexes: Implications for Phenolic Bioavailability and Glycemic Properties on Starch and Intestinal Glucose Transport

P.I.s: M. Ferruzzi, B. Hamaker

Researcher: Min Li, Post-doc (until August 2019); new Post-doc expected in 2020

Objectives: To define the chemical nature of interactions between phenolic constituents and starch in model food systems and their impacts on product quality, phenolic bioaccessibility and glycemic properties.

Progress: We continue to explore the nature of non-covalent interactions between starch and phenolic acids and the ability of these interactions to modify bioavailability of phenolics and glycemic properties of starch-based ingredients and foods. Expanding from our previous report defining conditions for formation of starch phenolic complexes and their impacts on pasting properties and resistant starch formation [Li et al., *Food Hydrocolloids*], we have recently reported on the chemical and nature of these complexes, their ability to survive thermal treatment and modify digestibility *in vitro* [Li et al. *Food Chemistry*]. In these experiments we complexed maize amylopectin and potato starch with caffeic acid, ferulic acid and gallic acid. Starch-phenolic complexes were found to not have measurable chemical modification (compared to native starch). Furthermore, complexes appear to survive hydrothermal treatment and resulted in modestly lower digestibility and significantly lower gelatinization temperatures. Complexes also had significantly lower levels of phenolic proton intensities and granule hydrodynamic radii relative to native starch and non-complexed phenolics providing evidence that phenolics may complex with starch through non-covalent CH-ϖ bonds along -(1 4) glycosidic chains.

As a next step in our examination we incorporated ferulic acid-potato starch complexes in wet cooked porridges to assess the impact on phenolic bioaccessibility, starch digestibility and glycemic response in an animal model. Complexation of ferulic acid reduced its relative bioaccessibility following in vitro digestion, suggesting that ferulic acid complexes may survive digestion. Starch digestion from complexes was modestly reduced as evidenced by lower glucose concentrations in aqueous digesta compared to native starch alone. However, glucose intestinal transport was not impacted by complexation, further suggesting that complexed phenolics are not highly bioaccessible and able to interact at the brush boarder. The decreased in starch digestibility and predicted glycemic response was confirmed in a Wistar rat model which found ~10-15% reduction in blood glucose Cmax and AUC from potato starch-ferulic acid complex compared to native potato starch. These reductions were attributed to complexation-induced resistant starch formation and phenolic encapsulation, suggesting a strong potential for such approaches to be translated to food for the purpose of modifying glycemic properties.

6 Fabrication and Modification of Dietary Fibers for Targeted Functions in the Gut

P.I.s: B. Hamaker, B. Reuhs

Researchers: Nusebye Bulut, M.S. student; Emmanuel Ayua, Ph.D. student; Xiaowei Zhang, Ph.D.; Isaac Asare, Visiting Scientist; Viridiana Tejada Ortigoza, Post-doc; Thaisa Cantu Jungles, Post-doc

Collaborators: A. Keshavarzian (Rush University Medical School, Chicago); S. Lindemann (Purdue University)

Objectives: Fermentable dietary fibers have the potential to produce positive short chain fatty acid (SCFA) changes in the colon, such as elevated levels of butyrate or propionate, and desired changes in microbiota composition by favoring certain bacteria or bacterial groups. Our interest in these studies is in finding ways to either improve fermentability and function of fibers through use of food technology methods or to fabricate new fiber materials with targeted function.

Progress: Our laboratory takes a food scientist's view on dietary fibers as materials that can be used directly, modified, or fabricated to achieve targeted function in the gut for improvement of localized and whole-body health. In 2019, the study of N. Bulut was completed showing that soluble fiber polymers fabricated into an insoluble cell wall matrix material promotes *in vitro* a group of beneficial gut bacteria called the commensal Clostridia. This is a recurring theme of recent studies in our laboratory and corroborates other work showing that fermentable matrix fibers support butyrate-producing Clostridia and increase butyrate amount. Butyrate is a fermentation fatty acid metabolite that is associated with reduced localized gut and systemic inflammation and improved barrier function. We published two papers in 2019 on fabricated fiber matrices showing this effect, a mouse study with starch-entrapped alginate microspheres by Kaur et al., in *Molecular Nutrition and Food Research* and an *in vitro* fecal fermentation study on re-crosslinked soluble arabinoxylan forming soluble matrices by Zhang et al., in *Food & Function*.

Nusebye Bulut competed her M.S. degree in this year with her thesis research on the gut microbiota response in vitro to soluble fiber polymers packaged back into a fabricated insoluble plant cell wall-like material. She solubilized corn bran arabinoxylan using a technique to keep a portion of ferulic acid residues on the polymer, and then re-crosslinked the arabinoxylan with laccase while casting it into a thin film with a thickness approximating a plant cell wall. She also included into the film nanosized pectin and/or nanofibrillated cellulose. These fabricated cell wall-like materials and their soluble counterparts were subjected to *in vitro* fecal fermentations. Two interesting findings were – 1) arabinoxylan promoted certain Clostridial bacteria when in the insoluble crosslinked form, and 2) pectin, when bound inside the crosslinked arabinoxylan film, promoted distinct butyrogenic Clostridia. Apparently, the more difficult fibers become to access for bacteria, their specificity toward certain bacteria increases. This has given us further insight into using dietary fibers to achieve targeted actions in the gut.

Other studies that occurred in modification of fibers and their effect on the gut microbiota and butyrate production included – 1) an ongoing study by Emmanuel Ayua on extrusion of cereal bran fibers to increase their fermentability and promotion of Clostridia, 2) a completed *in vitro* study by Viridiana Tejada Ortigoza from Monterrey Tech, Mexico, on processing of dietary fibers and their fatty acid and microbiota effects, and 3) a completed *in vitro* study by Isaac Asare from University of Pretoria, South Africa (student of Naushad Emmambux) on fatty acid starch inclusions and their fatty acid and microbiota effects. Final results of all three studies will be reported next year.

7 *In Vitro* Gut Fermentation Studies on Dietary Fibers

P.I.s: B. Hamaker, B. Reuhs, S. Lindemann

Researchers: Enosh Kazem, M.S. student; Rachel Jackson, M.S. student; Thaisa Jungles, Post-doc; Haining Zhuang, Visiting Scientist

Collaborator: A. Keshavarzian (Rush University Medical School, Chicago)

Objectives: Fermentable dietary fibers have the potential to produce positive short chain fatty acid (SCFA) changes in the colon, such as elevated levels of butyrate or propionate, and desired changes in microbiota composition by favoring certain bacteria or bacterial groups. Our interest in these studies is in understanding how dietary fibers act with the gut microbiota and how they interact with another macronutrient present.

Progress: It is well established that fiber prebiotics, which support and promote beneficial bacteria in the gut with coinciding production of short chain fatty acids, are important for localized gut and whole-body health. Prebiotics are now understood to include many types of fermentable fibers, not just oligosaccharides, that feed different important bacterial groups for good diversity of the overall community. Three different studies were completed in 2019.

The study of Enosh Kazem looked at over 30 different types of common and uncommon fiber-containing whole grain cereals, legumes and pulses, and tubers. All whole food samples were treated the same – dried, ground, cooked, and treated to an upper gastrointestinal tract digestion, prior to being subjected to *in vitro* fecal fermentation analysis. Compared to the completely fermentable control, fructooligosaccharides (FOS), the microbiota tested from three individuals generally showed a high level of fermentability often reaching the level of FOS. This was somewhat surprising given the thinking that many insoluble fibers are not well fermented. Perhaps not surprising was the finding that alpha-diversity of the microbiota community after 24-hour fermentation of the different fiber sources was mostly higher than for the FOS control. Whole foods have a collection of different types of fibers that feed a larger variety of different bacteria and bacterial groups.

The study of Rachel Jackson examined the effect of dietary fibers on gut microbiota response when protein is present. This project idea originated from the idea that dietary fiber intake is low in a standard Western diet, while protein consumption is above dietary recommendations, resulting in nearly equal amounts of dietary fiber and protein available potentially entering the gut for microbial fermentation. Furthermore, the popularity of high-protein diets for athletes, as well as that of high-protein low-carbohydrate diets for weight loss, may flip fiber and protein substrate proportions, resulting in more protein than fiber available. The objective was to elucidate how substrate ratios in protein-fiber mixtures affect protein fermentation and metabolites, as well as examine the degree to which fiber source may influence these outcomes. Overall, protein fermentation was shown to be relatively stable and not easily influenced by increasing the availability of dietary fiber, and no clear evidence of microbial preference for carbohydrates over protein was found. Microbiota samples will be sequenced and the full report given next year.

Haining Zhuang studied interesting gut microbiota fermentation responses to fibers from different mushrooms. Analysis of these and other mushrooms in our lab consistently show them to be butyrogenic. Microbiota sequencing was conducted and is being analyzed.

8 Specificity of Dietary Fiber Structures to Support of Gut Bacteria

P.I.s: B. Hamaker; S. Lindemann

Researcher: Thaisa Cantu Jungles, Post-doc; Xiaowei Zhang, Ph.D. student; Tianming Yao, Ph.D. student

Collaborators: A. Keshavarzian (Rush University Medical School, Chicago); E. Martens (University of Michigan Medical School); M. Tuinstra (Purdue University)

Objective: To understand the relationship between dietary fiber chemical and physical structures and their alignment to support specific gut bacteria and bacterial groups, and how gut bacteria community structure affects fiber response. This leads to the possibility of predictable outcomes of fibers in individuals with different microbial community structures.

Progress: In this year, a study by X. Zhang was completed on corn genotype differences in bran arabinoxylan chemical structure and microbiota changes; an ongoing study and concept paper by T. Cantu Jungles was on the idea that fiber structures with higher structural complexity (chemical and physical) are more robust in responding in the same way among individuals with different microbiota communities; and a study by T. Yao in collaboration with Eric Martens at University of Michigan was begun on understanding how polysaccharide structures are degraded by *Bacteroides spp*.

Xiaowei Zhang completed analysis of a genotype x environment study on corn bran arabinoxylan (CAX) showing that seemingly small differences in structure by genotype cause significant changes to preference and promotion of gut bacteria in an *in vitro* fecal fermentation. Monosaccharides and linkage analysis revealed that CAXs had different structures and the differences were genotype-specific, but not significantly due to environment. PCA analysis revealed that both short chain fatty acid production and the microbial community shifted also in a genotype-specific way. Thus, small structural changes, in terms of sugar and linkage compositions, caused significant changes in fermentation response showing very high specificity of structure to gut microbiota function.

Thaisa Cantu Jungles had a paper *in press* in the journal *mBio* (Cantu Jungles and Hamaker) at the end of 2019 presenting the idea that dietary fibers can be viewed in a hierarchical sense related to complexity of their chemical and physical structures. Simple and more non-specific fibers would have varying response in individuals dependent on their gut microbiota community differences, while complex and more specific fiber structures, that also may be more uncommon, would have more consistent response. This is borne out by a study she conducted in 2019 on 10 individuals and which will be reported next year.

9 Investigations on Slowly Digestible Glycemic Carbohydrates

P.I.s: B. Hamaker, M. Ferruzzi

Researchers: Leigh Schmidt, Ph.D. student; Anna Hayes, Ph.D. student; Sarah Corwin, Ph.D. student; Pablo-Torres Aguilar, Ph.D. student; Danli Wang, Visiting Scientist; Jongbin Lim, Ph.D. student and Post-doc

Collaborators: B.H. Lee (Gachon University, South Korea); S.H. Yoo (Sejong University, South Korea); G. Zhang (Jiangnan University); B. Nichols (Baylor College of Medicine, Houston); R. Quezada-Calvillo (University of San Luis Potosi, Mexico); D. Rose (University of Waterloo, Canada)

Objective: To design slowly digestible glycemic carbohydrates, and to investigate an inhibitor approach, for low glycemic response and with locational digestion into the small intestine ileum to activate the ileal brake and gut-brain axis physiological responses that promote satiety.

Progress: We continue to investigate carbohydrate foods and their digestion rates to moderate glycemic response and activate the satiety-related physiological responses. L. Schmidt finished her Ph.D. degree on the topic of forming protein matrices around starch granules to reduce starch digestion rate; A. Hayes published a paper (Hayes et al., *Food & Function*) on the fundamentals of pearl millet couscous slow digestion property, and prepared a manuscript for submission on a human study on millet; P. Torres-Aguilar began a human study on diet composition and physiological response of the body to slowly digestible carbohydrates; S. Corwin completed studies on slowly digestible a-glucans; and D. Wang completed her studies on highly branched maltodextrins and their slow digestion property. Additionally, J. Lim published articles in *Food Chemistry* and *Food & Function* on new methods to analyze phenolic inhibitors of digestive enzymes.

We reported many years ago that sorghum foods cooked with no or low shear (e.g., porridges) have expanded protein networks around the gelatinized starch granules that hold the granules into a dense packing. This was related to the slower starch digestion property of these foods. Leigh Schmidt reported in this year that the 3-deoxyanthocyanadins present in sorghum are mainly responsible for creation of these networks by mediating a sulfhydryl-disulfide exchange to build protein polymers. She was able to make the same effect in cooked corn flour by adding the polyphenol. This suggests the potential of creating a matrix effect for slower starch digestion.

Sarah Corwin completed studies on *in vitro* analysis of a range of soluble a-glucans of varying linkage patterns showing relative susceptibility of different linkages to rat intestinal a-glucosidases. Although these enzymes are known for their hydrolysis action on the a-1,4 and 1,6 linkages in starch, certain of them can also digest a-1,2 and 1,3 linkages. This is the first comprehensive look at how different a-linked glucans are digested.

We also examined the question of why pearl millet foods in Africa had very slow gastric emptying rate while in the US they did not, as shown by the study of Anna Hayes reported last year. Pablo Torres-Aguilar began a human study taking place in both the US and Africa looking at differences in diet affecting gastric emptying rates of slowly digestible carbohydrates. Anna did find reduced glycemic response to pearl millet foods, and a manuscript is in preparation.

10 Cellular and Physiological Response of Slowly Digestible Carbohydrates

P.I.: B. Hamaker

Researchers: Marwa El-Hindawy, Post-doc; Jongbin Lim, Ph.D. student and Post-doc

Collaborators: B. Nichols (Baylor College of Medicine, Houston); Roberto Quezada-Calvillo (University of San Luis Potosi, Mexico); David Rose (University of Waterloo, Canada)

Objectives: To understand the cellular and physiological responses to slowly digestible carbohydrates that might have value in the area of controlled glycemic response, satiety and the concept of sustained or extended energy release.

Progress: Marwa El-Hindawy did further research on tissues from mice studies we reported last year that showed slowly digestible carbohydrates fed to lean mice on obesogenic high-fat diets reduce rate of weight gain, and to obese mice on low-fat diets further increased weight loss. These were associated with stimulation of the gut-brain axis. Jongbin Lim completed his Ph.D. with a multi-faceted study on how partial inhibition of the starch digestion enzymes can be used to delay digestion and activate physiological responses.

11 Cereals and Grains

P.I.: B. Hamaker

Researchers: Oguz Ozturk, Post-doc; Yony Roman Ochoa, Post-doc; Moustapha Moussa, Ph.D. student

Collaborator: M. Ferruzzi (North Carolina State University)

Objectives: This collection of different projects includes: 1) understanding the physicochemical basis for retained starch in the corn wet-milling fiber fraction, 2) investigation of heavy metal accumulation in grains in the southern Perú mining areas, and 3) studies on pearl millet processing and nutrition in West Africa.

Progress: Oguz Ozturk researched different reasons for retained starch in the corn wet-milling fiber fraction using FTIR and Raman spectroscopy, confocal microscopy, and other methods to reveal ways to increase starch yield. Non-proprietary-related results will be published and presented next year. Yony Roman Ochoa and co-investigators in Arequipa, Perú, as part of the Purdue-UNSA NEXUS project, conducted heavy metal analysis on different cereal grains (maize, rice), pseudocereals (quinoa, amaranth), and legumes in different regions (mountains, irrigated lands, coastal areas). Results will be reported next year. Moustapha Moussa completed his Ph.D. degree in 2019 and returned to Niger in December. In his thesis work, he devised a new extrusion process for millet couscous using a high temperature/high-pressure technique followed by minor drying and grinding, and showed it to be equally preferred to traditionally prepared couscous. Throughput was about 10x what can be produced by a local processor manually, and using a low-cost extruded (~$20,000). He also showed that nutrient-enhanced millet blends using locally obtained nutrient-dense plant fortificants, made by rural processors that our project supports, were preferred to food-aid fortified blends and has resulted in large sales increases for rural women's associations of processors.

12 Protein Fibrous Structures as Physical Simulacrums of High-MW Glutenin

P.I.: O.G. Jones

Co-P.I.s: O.H. Campanella, Gordon Selling (USDA, Agriculture Research Station), B. Hamaker

Researchers: Enrico Federici, Ph.D. student; Da Chen, Post-doc

Objective: Determine the influence of physical and chemical attributes of fibrous protein assemblies on the mechanical behaviors of water/starch-based mixtures.

Progress: Mixtures of zein protein from maize with other globulin proteins or small molecule plasticizers were electrospun. Addition of globulin proteins add minor impact on the functional properties of the spun fibers, and imaging analysis indicated that the globulin proteins were poorly distributed in the fibers. Small molecules plasticizers were well incorporated in the fibers and led to significant differences in the mechanical properties. A manuscript was prepared and will soon be submitted. Extruded zein materials were prepared at different temperatures under the supervision of Dr. Campanella and Dr. Selling. Greater barrel temperatures during extrusion increased toughness and brittleness of the zein due to covalent protein interactions. After incorporating this material in doughs, the zein extruded at higher temperatures showed slight improvements in extensional behaviors that would be relevant to enhancing breadmaking performance within gluten-free breads. This work has been accepted for publication in the *Journal of Cereal Science* for 2020. Concurrent studies on the impact of extrusion conditions, high temperature oven treatments, and electrospinning conditions on zein's performance in doughs and breads have been underway throughout 2019 and will continue in 2020. An additional set of studies on the use of fibrous whey protein aggregates in starch-rich mixtures was initiated in February 2019. Fibrous whey protein was shown to synergistically enhance the viscoelasticity of potato starch gels, and this work has been submitted for publication. Ongoing studies are investigating the impact of whey protein fibrous structures in the behaviors of gluten-free doughs and breads.

13 Effect of Protein Conjugation on Functionality and Polysaccharide Interactions

P.I.: O.G. Jones

Researchers: Wanying He, Visiting Scientist; Alyssa Kelley, M.S. student

Objective: Determine the effect of protein glycosylation on the associative or segregative interactions with common polysaccharide materials.

Progress: A student and visiting scholar were tasked with preparing glycosylated proteins and determining the impact of glycosylation on the molecular characteristics and solubility. This project builds upon prior work in Dr. Jones' laboratory showing diminished interactions between proteins and polysaccharides conjugated with non-interactive fractions. Eventual goals of the project include identifying unique rheological attributes of the modified proteins and the impact of glycosylation on interactions with other food-relevant carbohydrates. Studies performed by Alyssa Kelley revealed flaws in a published technique to glycosylate zein by enzymatic treatments, and Wanying He has since been improving the solvent conditions, pre-treatments, and glycosylation procedures for facilitating practical yields of modified protein. Preliminary trials also revealed changes in the interactivity of whey protein and anionic polysaccharides in acidic condition after minor glycosylation of the whey protein. However, the project with whey protein has been discontinued until further funding is obtained.

14 Characteristic of Protein Hydrolysates from Male Gonad of Scallop (*Patinopecten Yessoensis*): Nonlinear Rheological Behavior and Interaction with Chitosan

P.I.: J. Kokini

Researcher: Haitao Wu, Visiting Scientist

Objective: The objective of this research is to gain the full understanding of protein hydrolysates from male gonad of scallop (*Patinopecten yessoensis*) (SMGHs) and SMGHs combined with chitosan.

Progress: In our previous studies, we have investigated the gel properties of SMGHs. However, we focused only on rheological properties of these samples in the linear viscoelastic region. In the present study, the LAOS behavior of SMGHs at different concentrations was investigated by rheometer. In addition, as SMGHs have negative surface charges. Therefore, the interaction between SMGHs and chitosan is also investigated. The polyelectrolyte solutions are prepared by approach of chitosan into SMGHs or SMGHs into chitosan. The zeta potential, particle size and polydispersity idex of polyelectrolyte solutions are determined. The microstructure of nanoparticle is investigated by SEM. Furthermore, the thermodynamic between SMGHs and chitosan is determined by ITC. Moreover, the effect of chitosan on LAOS behavior of SMGHs is also studied.

15 Soy Protein Isolate-Based Biosensors for Detection of Food Analytes

P.I.: J. Kokini

Researcher: Cindy Mayorga, M.S. student

Objective: the main goal of this research is to create a SERS biosensor platform based on electrospun nanofibers from soy protein isolate (SPI) that can be capable to detect analytes in foods. Future work: to fabricate and enhance the production of soy protein isolate nanofibers by using the electrospinning technique; as well, to functionalize the nanofibers of SPI with noble metals that will increase the detection of a food analyte in the biosensor.

16 Investigating the Nonlinear Behavior of Cream Cheese and Sour-Cream

P.I.: J. Kokini

Researchers: Louie (Anh) Le, Ruohan Xing, undergradate students; Merve Yildirim, Ph.D. student

Objective: This research aims to study the nonlinear rheological behavior of cream cheese and sour cream by analyzing the LAOS results on commercial brand.

Progress: Past studies have found that there are significant differences in the textural properties of cheese and sour cream made with different fat contents. In this study, two cream cheese and sour cream samples varying in fat content are taken from the same brand. The rest of the ingredients is almost exactly identical except for the protein content.

Specifically, the whole-fat version contains more fat and less protein than the low-fat versions. Hence, conducting LAOS measurements on these two samples will reveal the roles that fat and protein play in the rheological properties of cream cheese and sour cream. So far, it was found that both cream cheese and sour cream had a strain-stiffening and shear-thickening behavior when it enters the nonlinear viscoelasticity region. At small strain amplitude, the whole-fat cream cheese sample has a relatively stronger structure than the low-fat version but decays faster with increasing amplitude. Whether this result is caused by the reduction of the fat content or the increase of the protein content needs to be further studied by deeper data analysis and SEM network quantification.

17 Fabrication of Biodegradable Zein Nanofiber-Based Surface Enhanced Raman Spectroscopy Platforms for the Detection of Food Allergens and Toxins

P.I.: J. Kokini

Researcher: Hazal Turasan, Ph.D. student

Objective: This project is aiming to fabricate protein based electrospun fibers for the detection of food toxins and allergens using surface enhanced Raman spectroscopy (SERS).

Progress: Due to its unique properties, such as being more hydrophobic than other plant-based proteins, film and fiber forming capabilities, zein, the most abundant corn protein, is an excellent candidate for the production of biodegradable platforms for SERS biosensors. Using electrospun zein nanofibers additionally provide a very high surface-to-volume ratio which increases the sensitivity of the sensor platforms. In the first part of the project, fabrication of zein nanofibers using electrospinning has been optimized for the solvent type and zein concentration, use of a crosslinker and surface decoration of the nanofibers with gold nanoparticles. Surface properties of the nanofibers have been characterized using SEM and surface wettability measurements. Second part of the project focused on optimization of the type and concentration of nanoparticles used for the surface decoration. Highest sensitivity was obtained with silver-shelled-gold nanoparticles. The validation of the new optimized zein nanofiber-based SERS platform was done by detecting a model food carcinogen, acrylamide.

18 Relationship of Non-Linear Rheological Properties and Network Analysis Parameters in Non-Fat, Low-Fat and High-Fat Yogurt Products

P.I.: J. Kokini

Researcher: Merve Yildirim, Ph.D. student

Objective: This project is aiming to understand the relationship between the nonlinear behavior of yogurt products and network analysis of SEM-images.

Progress: Information on non-linear rheological properties of yogurt is very limited. With this research, rheological characteristics of non-fat, low-fat and high-fat yogurt products were studied by steady shear and large amplitude oscillatory shear measurements. The steady flow behaviors of yogurt samples were modelled by 3-region models; zero-shear viscosity region was followed by two power-law regions with different rates. For non-linear rheological properties, the distorted oscillatory stress response waves at large oscillatory shear deformations away from the linear region are fitted using Fourier transforms. Non-linear rheological parameters of large amplitude oscillatory shear measurements were calculated to characterize the nonlinear rheological properties of two commercial yogurt brands with three different fat contents. For both brands, LF yogurts had a weaker gel-like structure compared to HF and NF counterparts. In the nonlinear viscoelastic region, all of the yogurt samples exhibit strain stiffening (>0) and shear thinning (<0) behavior. Brand$_1$ had stronger gel-like structure compared to Brand$_2$ for all types of yogurts samples. Deformation due to applied strain amplitude was monitored by SEM imaging, it was found that network percentage area, junction density, average network length, and branching rate decreased, lacunarity decreased as applied deformation amplitude increased rheometer stage.

19 Fabrication of Effective Delivery Systems for Banana Condensed Tannins

P.I.: J. Kokini

Researcher: Xiangquan Zeng, Ph.D., Visiting Scientist

Objective: The objective of the present study is to develop effective delivery systems for banana condensed tannins (BCT) to improve their storage stability and bioavailability by using desolvation and coacervation techniques. Process: BCT isolated from green-mature bananas (Musa spp., AAA group, cv. 'Brazil') are a mixture of flavan-3-ol oligomers with DP in the range of 3-5 and with the trimers as the main component. Various biological activities of BCT have been demonstrated previously, including their high affinities with divalent transition metal ions, bile salts and proteins in vitro. However, it is shown that the stability and bioavailability of BCT can be relatively low. Nanoparticles are reported to be effective tools for the protection and targeted delivery of plant polyphenols. Particularly, desolvation is a one-step procedure for encapsulation of both hydrophilic and hydrophobic bioactives in nanoparticles, while the coacervation technique uses the principle of differences in the sign of ionic forces to cause the polymers to associate and form insoluble particles that drop out of solution.

Progress: In this project, we aim to make full use of these two methods to fabricate effective nanodelivery systems for banana condensed tannins to improve their storage stability and bioavailability. Prior to production of BCT nanoparticles, different biopolymers for the encapsulation of BCT are selected. The physico-chemical properties of BCT-loaded nanoparticles are characterized by morphology studies, FT-IR spectroscopy, X-ray diffraction, thermogravimetric analysis, particle size and zeta potential analyses. We also examine the total amount of BCT effectively incorporated within different nanoparticles, the release of BCT from the nanodelivery systems and the cytotoxicity effect of the nanoparticles on HeLa cells (ATCC® CCL-2). Finally, the stability and bioavailability of BCT-loaded nanoparticles can be measured by different assessments.

20 Establishment of Model Dietary Fiber-Consuming Gut Microbial Communities for Generalizable Fiber-Microbiota Research

P.I.: S. Lindemann

Researchers: Tianming Yao, Ph.D. student; Laura Libera, undergraduate student

Objectives: 1) To select for consortia that degrade specific dietary fibers of interest for use in fiber-microbiome studies, 2) Establishment of long-term cryopreservation methods for model communities, 3) Genome sequencing and reconstruction of model communities for use in systems biology analyses.

Progress: T. Yao continued work he and M.-H. Chen started to select for communities of 1) inulin-degrading and 2) sorghum arabinoxylan (SAX)-degrading microbes using fecal microbiota as an initial species pool. Consortia stable in membership resulted after approximately 5–7 sequential transfers in batch culture. These consortia resulted in stable growth rates, pH, and gas production over sequential batch transfers. SAX exerted much more selective effect on community membership than inulin did. Amino acid and vitamin amendment of inulin-fermenting consortia resulted in significant alteration of community structure, but influenced SAX-fermenting consortia much less substantially. These data suggest that 1) generation of model fiber-fermenting communities is possible and 2) that SAX much more strongly structures fermenting microbial communities than does inulin. In the second case, fortification of media revealed that interactions based upon auxotrophies are more likely to structure inulin-consuming consortia. 16S rRNA amplicon sequencing revealed that fortification of inulin-containing media resulted in an entirely different final community composition, where fortification of SAX-containing media made only minor impacts upon microbiome structure. Interestingly, communities from fecal samples from the same individual one month later grew remarkably similar consortia on SAX media. T. Yao has established methods for cryopreservation/resuscitation of consortia as well as for genomic reconstruction of consortium member organisms' genomes from metagenomes. L. Libera is working on long-term stability experiments to determine whether compositional stability can be maintained in ways that permit extended experiments.

21 Particle Size Effects on Bran Fermentation by Gut Microbiota

P.I.: S. Lindemann

Collaborator: B. Hamaker

Researchers: Yunus Tuncil, former Post-doc; Riya Thakkar, M.S. student

Objectives: 1) Determine the degree to which the fermentation of a bran particle depends upon its size, 2) Identify mechanisms by which particle size might influence the structure and function of gut microbiota.

Progress: Y. Tuncil and R. Thakkar discovered that the fermentation of hard red spring wheat bran particles, directly sieved from the miller sample into size ranges of 180–300, 300–500, 500–800, 850–1000, and > 1700m, result in very different successions of microbiota, with distinct metabolic function. Coarser particles favored members of family *Lachnospiraceae*, home to many butyrogenic taxa known to be associated with fermentation of wheat brans, and smaller particles favored most of the *Bacteroidaceae*. However, certain *Bacteriodes* species preferred larger particles, suggesting that the effect of selection by particle size can occur at the species or strain level. These differences in community structure produced distinct metabolic output — though small particles fermented more rapidly overall, coarser particles produced increased molar ratios of butyrate while finer particles produced increase molar ratios of propionate. Monosaccharide analysis revealed that smaller particles had increased glucose abundance, suggesting residual starches not removed by upper-GI in vitro digestion. However, milling of large particles suggested the difference was not starch content but availability, and that this may drive differences in microbial activity.

To separate the effect of chemical composition from particle size, Y. Tuncil and R. Thakkar milled down larger wheat bran particles and sieved them into a size range. No significant differences in monosaccharide composition were observed among sizes, but differences in microbial community composition and short-chain fatty acid production persisted. These data suggest that size, in its own right, governs metabolism of wheat brans. Further, we determined that there were significant differences between particle-associated and suspended microbial communities. Metagenome sequencing is underway to determine the functional differences associated with each community.

R. Thakkar extended this experiment into corn brans, by sieving out different size fractions and performing *in vitro* fecal fermentations. Our data suggest that corn bran particle size effects are more muted than for wheat, but particle size-dependent behavior was still observed. As for wheat brans, preference for particle size occurred at the level of individual species. Furthermore, to determine whether R. Thakkar addressed the question of whether particle size stably selected for microbiota over sequential batch cultivation, and discovered particle-size-dependent SCFA generation and microbial community structure. Interestingly, microbiota from three very different donors converged on very similar community structures when grown on particles of different size, suggesting a single consortium of organisms is most efficient in growing on wheat brans across individuals. New Ph.D. student Miguel Alvarez Gonzales is now attempting to determine whether milling methods influence microbiome function independently of particle size.

22 Bran Arabinoxylan and Inulin Chemical Structure Effects on Fermentation by Gut Microbiota

P.I.: S. Lindemann

Collaborators: B. Hamaker, B. Reuhs

Researchers: Ming-Hsu Chen, former Post-doc; Y. Tuncil, former Post-doc; Tianming Yao, Ph.D. student

Objectives: 1) To identify the structural properties of soluble fiber carbohydrates that exert significant impact upon the rate of metabolism by gut microbiota and their final metabolic fate, 2) To determine which structural features of soluble fibers influence gut microbial community structure and function, and 3) To generate a mathematical model that describes linkages between soluble fiber structure and gut microbiome structure and function that can be generalized across soluble fibers.

Progress: With respect to arabinoxylans, preliminary evidence suggests that fine structural differences can exert large impacts on community structure and function. Y. Tuncil discovered that wheat bran arabinoxylans from hard red (HR) varieties (grown either in winter or summer) select for gut microbial communities dominated by *Prevotella*, where soft red (SR) varieties (grown in winter) select for communities anchored by *Bacteroides*. Linkage analysis revealed that HR arabinoxylans possess a greater amount of 4-Xyl linkages, whereas SR varietals possess more

2,3,4-Xyl linkages – these data suggested that SR arabinoxylans were more highly branched than HR. Furthermore, SR arabinoxylans fermented more slowly than did HR arabinoxylans and different stoichiometries of short-chain fatty acid products.

M.-H. Chen and T. Yao have begun a project to identify the impact of degree of polymerization (DP) on the fermentation rate and metabolic fate of differently sized inulins. Inulin products across a size range were quantitated for DP and inoculated with inulin-consuming microbial consortia to determine the impact on growth rate and metabolic fate, finding preliminarily that increasing DP results in decreased growth rates and yields of inulin-consuming consortia selected on low- DP inulins. These data suggest that fermentation rates and metabolic fates may be strongly governed by DP. Sequential batch cultivation on different chain lengths (and one branched structure) of inulin revealed that longer chain inulins select for populations of organisms not present in shorter inulin fermentations, presumably because they are required for external hydrolysis and import of the molecules. Similarly, one organism was specific to branched agave inulin.

Finally, T. Yao has determined that structural differences in red and white sorghum arabinoxylan structure select for differing fermenting microbiota and result in distinct metabolic outcomes, with respect to SCFA production. Further, red SAX maintained significantly greater diversity than did white SAX over sequential batch cultures, reflected in both the 16S amplicons and genome reconstructions from metagenomes. Analysis is presently underway to determine the different gene content selected for by red SAX. T. Yao also found that *in vitro* debranching of white SAX greatly influences the ecological outcomes of SAX fermentation, both with respect to fermenting microbiome composition and metabolic outputs.

23 Differential Fermentation of Resistant Dextrins by Gut Microbiota

P.I.: S. Lindemann

Researchers: Arianna Romero, Ph.D. student; Renee Oles, undergraduate student

Objectives: To determine whether different glucans select for different microbiota and result in different metabolic outcomes.

Progress: A. Romero performed an experiment with three donors in which each donor's microbiota was exposed to 12 different resistant glucan structures in *in vitro* batch fermentations, measuring pH, gas production, SCFAs, and microbial community structure via 16S rRNA amplicon sequencing. She observed that 1) metabolic outcome from the same resistant glucan varied across donors (e.g., with respect to relative propiogenesis vs. butyrogenesis) and microbial responses. However, across donors some taxa were repeatedly selected by certain dextrin structures, suggesting that there are specificities in interactions among resistant glucans and the organisms which best consume them. Additionally, antagonism/competition among organisms could be observed, in which some organisms are seen to increase in relative abundance at the expense of others. Recently, A. Romero has determined that different polydextrose samples select for distinct microbial outcomes over sequential batch cultures and influence overall carbohydrate consumption/total microbial growth by the community.

24 Understanding Structure-Function Relationships of Pectic Polysaccharides from Fruits and Pulses

P.I.s: M. Martinez, B. Hamaker, B. Reuhs

Researchers: Laura Roman, Post-doc; Natalia Prieto, Post-doc

Collaborators: M. Guo (Shandong Agricultural University), K. Xu (Shandong Agricultural University)

Objectives: To understand the yield and molecular structure of pectic polysaccharides from novel sources and their functionality in food systems.

Progress: Two articles are being written that show successful purification and functionality of purified pectins from novel fruit sources. This work also shows the importance of considering endogenous pecin methylesterases (PME) and the removal of the starch fraction to attain higher purities. Results also suggest that the linearity of the polyuronide chain, as quantified by the relative molar ratio of rhamnogalacturonan I (RG-I) to homogalacturonan (HG) and the branching degree of RG-I (i.e., amount of galactan, arabinan and/or arabinogalactan side chains), is critical for successful application in emulsion and gel systems.

Two additional papers are in preparation showing also the importance of the fine structure of pectic polysaccharides on the mechanical properties of cell walls in pulses and on their cooking quality.

25 Investigations on Amylose and Amylopectin Fine Molecular Structure and Their Physical Modification to Develop Slowly Digestible Starch in Foods

P.I.s: M. Martinez, B. Hamaker, O. Campanella

Researchers: Laura Roman, Post-doc; Josephine Yee, M.Sc. student; Anna Hayes, Ph.D. student

Collaborators: E. Bertoft (Bertoft Solutions, Finland), L.A. Bello-Perez (Instituto Politécnico Nacional, Mexico), M. Gomez (University of Valladolid, Spain).

Objectives: To understand molecular structure-function-digestion relationships that result in baked goods with high degree of starch gelatinization and slow glycemic response. The second objective was to obtain mechanistic understanding on the fragmentation of starch subjected to different extrusion conditions in terms of shear and its effect on the creation of structurally driven slowly digestible starch (SSDS) and gel-like structures of fully gelatinized materials.

Progress: Processed starchy foods, owing to the amorphous stage of the starch molecules, are characterized for having high glycemic indexes and consequently considered of low nutritional value. A promising strategy to solve this problem is the selection and manipulation of the starch structure at the molecular level to result in targeted self-assemblies that are slowly digested. For the first-time, this work provided a mechanistic evidence about the feasibility of extrusion technology to create SSDS through retrogradation (Roman, Campanella & Martinez, 2019). Results showed that the nature of the formed SSDS was mostly consisting of molecular assemblies involving amylopectin and their fragments that do not necessarily bring deleterious effects on the food mechanical properties that may affect its texture quality. It was demonstrated that interactions promoting those molecular assemblies can be further increased by shear-induced reduction of the hydrodynamic radius (Rh) and molecular weight (Mw) of amylopectin molecules in a range between 54.3 and 58.9 nm and 9.9×10^6 and 17.1×10^6 g/mol, respectively. Interestingly, these concepts were successfully translated into a bread system. Results showed a SSDS increase from 1.09% (control) to 6.6 % in crumbs of breads made with only a 20% replacement and without affecting negatively their sensory acceptance (Roman, Gomez, Hamaker & Martinez, 2019; *Food Chemistry*).

26 Thermomechanical Processing and Phenolics for Regulation of Glucose Homeostasis

P.I.s: M. Martinez, M. Ferruzzi

Researchers: Joana Pico, Post-doc; Josephine Yee, M.Sc. student

Collaborators: M. Guo (Shandong Agricultural University, China), K. Xu (Shandong Agricultural University, China), M. Ladouze (Università di Corsica Pasquale Paoli, France), C. Candito (Lille Polytechnic University of Lille, France), B. Blanco (Cartiff Institute of Technology, Spain)

Objectives: The main aim was to aid in the development of manufacturing guidelines to produce flours with optimal nutritional properties, considering holistically the carbohydrate and phenolic fractions. The effect of the inclusion of developed flours on the phenolic profile of baked goods and their capacity to inhibit transepithelial glucose transport using a coupled in vitro digestion/Caco-2 human intestinal cell model was also investigated.

Progress: A review paper (Pico & Martinez, 2019; *Current Pharmaceutical Design*) was published highlighting previous works showing that the aglycones quercetin, myricetin, fisetin and apigenin strongly inhibit GLUT2, while quercetin-3-O-glycoside more effectively inhibits SGLT1. Meanwhile, epigallocatechin as well as epicatechin and epigallocatechin gallates were observed to inhibit both SGLT1 and GLUT2. Our experimental results showed the potential of native and extruded banana flours, even at a 10% flour replacement level, to inhibit the transepithelial glucose transport of wheat cakes using a coupled in vitro digestion/Caco-2 human intestinal cell model (Pico, Corbin, Ferruzzi & Martinez, 2019, *Food & Function*). This was attributed to the powerful action of the small quantities of quercetin and myricetin, although the high inhibitions achieved by the digesta of the cakes suggest that other compounds, presumably galactose, should be attenuating the glucose transport. The four banana flours used in this study increased the content of total phenolics in cakes, and only those that were freeze-dried, and extruder presented a significantly higher phenolic content in digesta (higher bioaccessibility). Thus, this work also showed how extrusion has the potential to improve the bioaccessibility of thermostable banana phenolics and how this results in an increase in the glucose transport inhibition. The results indicate the benefits of using fruit flours rich in targeted flavonols for regulation of glucose homeostasis, which could be critical in foods high in available carbohydrates.

27 Whole Muscle Tissue Engineering Using Bio-Polymeric Materials from Plants

P.I.: M. Martinez

Researchers: Vasanth Ragavan, Post-doc; Laura Roman, Post-doc; Farzaneh Nasrollahzade, Ph.D. student, Shiva Swaraj, M.Sc. student

Collaborators: I. Joye (University of Guelph, Canada), B. Bohrer (University of Guelph, Canada)

Objective: The purpose of this research project is to advance plant-based meat product and/or technology development in simultaneous protein sourcing/characterization, formulation and processing.

Progress: Promising fiber-forming and bulking plant components for continuous manufacture of high-quality High Moisture Meat Analogs (HMAA) were identified. Furthermore, high moisture extrusion and side co-extrusion were optimized for continuous manufacture of HMMA. Several papers are in preparation. Future results are expected to result in the development of the scalable production technology of textured plant proteins that are versatile for further conversion into consumer products. In addition, the development of extruded products from plants with sensory attributes that highly mimic conventional meat textures will accelerate consumer's acceptance of plant-based diet, reducing environment burden.

28 Starch Properties in Different Environments

P.I.: L. Mauer

Researchers: Matt Allan, Post-doc; Kathryn Johnson, M.S. student; Travis Woodbury, M.S. student; numerous undergraduate students

Objective: To investigate starch properties, including gelatinization and retrogradation, in the presence of a variety of sweeteners and oligosaccharides, and in environments containing different amounts of water.

Progress: We are investigating the thermal properties of starch in different environments and in the presence of a wide variety of sweeteners to establish relationships between sweetener and oligosaccharide type and structure, water activity, molecular weight, and intermolecular interactions with starch gelatinization, pasting, swelling, and retrogradation traits.

29 Amorphous Solid-State Dispersion (Amorphization) of Crystalline Ingredients

P.I.: L. Mauer

Researchers: Yahya Ismail, M.S. student; Adrienne Voelker, Ph.D. student

Objective: To manipulate the solid-state structure of inherently crystalline ingredients and document the resulting effects on physical and chemical stability.

Progress: We are investigating the differences in stability and delivery traits between crystalline and amorphous forms of both poorly water-soluble and highly water-soluble inherently crystalline ingredients. A variety of dispersion techniques and matrices are being explored to document crystallization inhibition properties of different polymers, as well as differences in solubility and stability traits between crystalline and amorphous forms of the same ingredient. In general, polymers that are capable of hydrogen bonding or ionic interactions with the target compound are better at maintaining amorphous structures during storage. Solubility enhancement was achieved when poorly water-soluble crystalline compounds were stabilized in amorphous dispersions, as well as between amorphous and crystalline forms of highly water- soluble ingredients. Physical and chemical stability differences between crystalline and amorphous states of a compound continue to be monitored. Interesting insights into molecular assembly and crystalline/ amorphous behaviors are being developed throughout the course of these studies.

30 Water-Solid Interactions and Phase Diagrams

P.I.: L. Mauer

Researchers: Matthew Allan, Post-doctoral Associate; Adrienne Voelker, Ph.D. student; numerous undergraduate students

Objective: To investigate the fundamentals and consequences of the five modes of water-solid interactions in terms of phase diagrams, kinetics, and their effects on the chemical and physical stability of single ingredients and multicomponent food systems.

Progress: We are investigating the fundamentals and consequences of deliquescence, absorption, and other water-solid interactions in food systems containing crystalline and/or amorphous components. In collaboration with a researcher in the Industrial and Physical Pharmacy Department, Dr. Lynne Taylor, we have demonstrated that deliquescence lowering occurs in mixtures of deliquescent crystalline ingredients (e.g., sugars, salts, organic acids, vitamins, etc.) and that reaction kinetics are influenced by this deliquescence lowering. We have also demonstrated that moisture sorption in blends of crystalline and amorphous solids deviates from a simple additive model, wherein the co-formulation of crystalline and amorphous ingredients has the potential to lower both the deliquescence RH and Tg of the blend, depending on the formulation, rendering the blend of ingredients more sensitive to environmental RH than the individual ingredients. Efforts are also focused on generating RH-temperature phase diagrams of different ingredient classes. This has importance for the formulation, sequencing, blending, storage, packaging and stability of dry ingredient mixtures and final food products.

31 Prediction of Swelling Behavior of Crosslinked Maize Starch Suspensions

P.I.: G. Narsimhan

Researchers: Prasuna Desam, Ph.D. student; Jinsha Lee, Ph.D. student

Objective: To characterize the pasting behavior of starch in terms of its structure.

Progress: Granule size distribution of 8% w/w suspension of normal rice starch (NRS), waxy rice starch (WRS), modified potato starch (MPS) and normal potato starch (NPS) in water when subjected to heating at 60, 65, 70, 75, 80 and 85 °C at different hold times (0 to 60 min) were characterized. The average starch granule diameter was larger at higher temperatures and hold times for NRS, WRS and MPS, indicating swelling, whereas for NPS it decreased, indicating breakage. Swelling varied in the order: MPS>NRS>WRS. Earlier proposed pseudo first and second order kinetic and Weibull models for swelling were evaluated. Swelling kinetics was also predicted using our previously developed mechanistic model (*Journal of Food Engineering* 222: 237-249) whose predictions agreed well with the experimental data of mean granule diameter and granule size distribution with time at different temperatures and therefore can be employed to describe swelling at different processing conditions.

32 Volume Fraction Dependence of the Elastic Behavior of Starch Suspensions

P.I.: G. Narsimhan

Researchers: Jinsha Lee, Ph.D. student; Prasuna Desam, Ph.D. student

Objective: To characterize the pasting behavior of starch in terms of its structure.

Progress: Starches are incorporated in food products for a variety of reasons, such as stabilizing, thickening, binding and gelling. Starch occurs as discrete granules. Upon exposure to water, starch granules swell when heated. This results in thickening of starch suspension (known as pasting) due to an increase in volume fraction of swollen granules. Starch pasting results in an increase in its viscosity. Therefore, the texture of a variety of food products, such as sauces, puddings, soups, batter mixes, etc., are influenced by pasting. The rheology and texture of starch paste obtained by cooking of starch granules are governed by its swelling. It is, therefore, necessary to quantify swelling in order to predict the rheology of starch paste as well as to develop new food formulations. A methodology is developed to predict the storage modulus (G') of starch paste due to granule swelling, given the physical properties of the starch granule and temperature history. This was tested on experimental measurements of granule size distribution and G' for 8% w/w suspensions of waxy maize, normal maize, waxy rice, normal rice, and cross linked normal maize – all heated to different temperatures (65 to 90 C) and holding times (2 to 60 min). Experimental data of storage modulus G^' vs volume fraction fall onto a master curve when G^' is normalized by its limiting value G_0^'. G_0^' is estimated from a foam rheology theory and measurements of granule interfacial energy. The master curve, coupled with previously developed theories to predict the granule size distribution over time, allows one to semi-empirically predict the storage modulus G' due to swelling with reasonable degree of accuracy.

33 Synergistic Effect of Low Power Ultrasonication on Antimicrobial Peptide Action

P.I.: G. Narsimhan

Researchers: M. Fitrityanti, Ph.D. student

Objective: To characterize the synergistic effect of low-power ultrasound and antimicrobial peptides on deactivation of microorganisms.

Progress: Ultrasound can be combined with other physical or chemical treatments such as heat, pressure, and antimicrobial solutions to increase its effectiveness. Ultrasound treatment could drastically improve decontamination action of antimicrobial peptides by increasing its diffusion in liquid system. The objective of this study is to investigate the synergistic effect of a cylindrical ultrasonic system on antimicrobial effect of a classic antimicrobial peptide Cecropin P1 on inactivation of a Shiga toxin-producing E. coli (STEC), Escherichia coli O157:H7. The inactivation of E. coli in PBS (pH 7.4) were performed using three different treatments: ultrasound (14 kHz, 22 kHz, and 47 kHz), Cecropin P1 (20 µg/ml), and combination of both. The results showed that the combined treatment at higher power level (22 kHz, 8 watts) for 15 minutes of exposure is more efficient, reducing the cell density to six orders of magnitude, compared to individual treatments. Our results on the effect of different frequencies (14, 22, and 47 kHz) also showed that combination of higher frequency (47 kHz, 7.5 W) and Cecropin P1 for one minute of exposure were able to deactivate more cells (up to six orders of magnitude) compared to combined treatment with 14 or 22 KHz ultrasound.

34 Anti-Inflammatory Effects of Anthocyanins – Role of Gut Bacteria

P.I.: L. Reddivari

Researchers: B. Wu, T. Wang, graduate students; S. Li, Post-doc

Collaborators: M. Vijay-Kumar and S. Chopra

Objectives: 1) Determine the extent to which white-, red- and purple-fleshed potatoes rich in bioactive polyphenols suppress intestinal chronic inflammation, 2) Determine the role of gut bacterial metabolism in the anti-inflammatory potential of color-fleshed potatoes using conventionally raised and germ-free mice, 3) Define the extent to which color-fleshed potato diets alter the inflammatory potential of the gut microbiota.

Progress: Mice supplemented with color-fleshed potatoes at 15, and 25% resisted the DSS-induced reduction in colon length. Purple-fleshed potato supplementation reduced splenomegaly and liver hypertrophy. Red-fleshed potato diets did not have any effect on DSS-induced splenomegaly. Mice on purple-fleshed potatoes at 25% supplementation alone resisted the DSS-induced increase in the intestinal permeability. Purple-fleshed potatoes at 25% alone reduced systemic MPO levels, a well-known pro-oxidative and pro-inflammatory enzyme, in mice exposed to DSS, but not red-fleshed potatoes, indicating that staple crop cultivar needs to be taken into consideration while evaluating the health benefits of plant foods.

We completed animal experiments using both conventional and microbiota ablated mice to understand the role of microbiota in the anti-inflammatory potential of color-fleshed potatoes. Administration of antibiotics resulted in a 95% reduction in gut bacterial load after eight weeks as measured by relative amplification of 16S using qPCR. Antibiotic-treated mice had five times greater cecum weight, a hallmark of germ-free mice, compared to no antibiotic mice irrespective of the treatment. Purple-fleshed potato supplementation suppressed ($p \leq 0.05$) DSS-induced reduction in colon length and gut barrier function and the increase in IL-6 and IL-1 ($p \leq 0.05$) compared to control diet in mice with intact microbiota. Potato diets did not suppress DSS-induced colitic like symptoms in antibiotic mice, indicating the critical role of gut bacteria in the anti-inflammatory potential of anthocyanin-containing potatoes.

35 Polyphenols and Fiber Interaction: Modulation of Gut Microbiota in Health and Disease

P.I.: L. Reddivari

Researchers: B. Wu, W. Fu, graduate students; S. Li, Post-doc

Collaborator: B. Hamaker

Objectives: 1) To determine the extent to which plant polyphenols alter fiber fermentation by gut microbiota, 2) To determine whether gut bacterial metabolism of different fibers differ in polyphenol-fiber complexes, 3) Identify the mechanisms by which polyphenol and fiber complexes influence gut bacterial metabolism and intestinal barrier function.

Progress: W. Fu is making anthocyanin and fiber complexes using different soluble and insoluble fibers and testing the bioavailability and anti-inflammatory activity in vitro after the upper GI digestion.

36 Immunomodulatory Activity of Structurally Diverse Arabinoxylan Hydrolysates

P.I.: S. Simsek

Researcher: Mihiri Mendis, Ph.D. student

Collaborator: B. Reuhs (Purdue University)

Objectives: Production and characterization of structurally different arabinoxylan hydrolyzates (AXH) using xylanases and arabinofuranosidases with different substrate specificity. Evaluate the immunomodulatory properties of enzymatically derived AXH using cell culture models derived from the immune system cells. Evaluate the immunomodulatory properties of enzymatically derived AXH using cell culture models derived from the intestinal cells. Understand the effect of enzymatically derived AXH on human gut bacteria.

Progress: AXs are ingested as part of cereal and non-cereal foods from our diet. AX is a complex plant polysaccharide that relays on many different enzymes for its hydrolysis into smaller oligosaccharides. Many gut microbes have evolved to contain enzymes, receptors and transporters that achieve efficient degradation and utilization of these complex AX molecules. The enrichment of different AX utilizing bacteria in the gut upon the consumption of AX rich diet could have beneficial health effects to the host. Furthermore, AXs and their hydrolyzates, as well as microbial fermentation by-products. could contribute toward the immune stimulation of the consumer. Due to their variation in degree of polymerization, degree of arabinose substitution, and ferulic acid substitution, AX hydrolyzates are considerably diverse and complex molecules compared to many other prebiotic compounds. Thus, AXs and their hydrolyzates should be closely evaluated for their structurally driven biological properties, especially related to their effect on gut bacteria and immunomodulatory aspects.

Ph.D. student Mihiri Mendis carried out research to generate 30 structurally different wheat arabinoxylan hydrolyzates (AXH) by means of different combinations of xylanases (*Cellvibrio japonicas* xylanase (CJX) and *Aspergillus niger* xylanase (ANX)) and arabinofuranosidases (*Bifidobacterium adolescentis* arabinofuranosidase (BAF) and *Clostridium thermocellum* arabinofuranosidase (CAF)). The AXH were grouped into four groups based on the initial enzymatic treatment (ANX, CJX, CAF and BAF series). The AXH were analyzed using GC-FID, GC-MS, 1H-NMR and SEC-MALS techniques to elucidate composition and structural details. In general, the AXH had high proportion of unsubstituted xylose and lesser amount of di or mono-substituted xylose. The average molecular weights of the AXH varied between 0.78-5.64 million Da. Between the two xylanases, ANX might be an enzyme of choice for the production of arabinoxylan hydrolyzates with simple structural details, while CJX might be selected for the production of arabinoxylan hydrolyzates with more complex structural features. The information derived about the capabilities of the two xylanases and two arabinofuranosidase could provide important information in choices made regarding enzymes used to generate arabinoxylan hydrolyzates with specific structural details. Also, these hydrolyzates could be useful as substrate for future research exploring the effect of fine structural details in arabinoxylan hydrolyzates on their biological and physical properties.

The next step was to investigate the inflammatory properties of the arabinoxylan hydrolysates and determine if there is any relationship between the inflammatory properties and fine structure. The LPS induced macrophage cell line is a model widely used to study inflammation. The AXH being tested exhibited both pro- and anti-inflammatory properties. Some of the hydrolyzates increased the production of NO compared to the control, while some AXH decreased the NO production. AXH with higher AX and substitution at O-3 position are favorable candidates to reduce the LPS induced inflammation. These results indicated that there might be a structure-function relationship for these AXH as immunomodulators.

37 Mechanical and Physical Properties of Biodegradable Wheat Bran, Maize Bran, and Dried Distillers Grain Arabinoxylan Films

P.I.: S. Simsek

Researcher: Cassie Anderson, Ph.D. student

Collaborator: L. Jiang (North Dakota State University)

Objective: To develop an extraction and purification method that produces AX of purity higher than that of previously published research for WB, MB, and DDG. To create films from WB AX, MB AX, or DDG AX in combination with a plasticizer (sorbitol or glycerol) at one of the following three levels: 100, 250, or 500 g kg-1, and analyze their mechanical, physical, and biodegradability properties. To determine if there are significant ($P \leq 0.05$) correlations between the chemical properties of the films and their mechanical, physical, and biodegradability properties.

Progress: A change in the food packaging industry must be made should we desire to provide our children and grandchildren with a healthy environment to live in. The change that is necessary is the switch from unsustainable food packaging made mainly from plastics, including polyoefins, polyamids, and polyesters, to food packaging made from the by-products of the cereal processing industry. When the AX is extracted from WB, MB, and DDG, it can be used as the basis of food packaging that is not only biodegradable but also edible (depending upon manufacturing processes used). This type of food packaging would improve the sustainability of both the food and packaging industries. In short, we need to recycle the AX from WB, MB, and DDG to utilize it in food packaging to create a sustainable tomorrow.

This research aimed to address the discrepancy of data for the materials properties of films made from MB AX and DDG AX. In addition this project will present an alternative method for extracting and purifying the AX from WB, MB, and DDG. Some of the materials properties that will be addressed in this research that have not been previously addressed include the surface topography, color, and biodegradability of all three types of AX films.

MSc Student Cassie Anderson began working on this project by conducting a large-scale extraction and purification of arabinoxylans from three byproducts of cereal processing. The arabinoxylan were extracted from wheat bran (WB), corn bran (CB) and dried distillers' grains (DDG). The effectiveness of the extraction and purification method developed in this experiment is clearly shown in the level purity of AX obtained in this experiment.

Cereal processing byproducts including WB, MB, and DDG obtained from commercial sources had varying chemical compositions. After extraction and purification, AX from these materials also had varying compositions. Overall, the utilization of these methods allowed for production of AX from WB, MB, and DDG that was of higher purity than previously established extraction methods.

After extraction, purification and characterization of the AX, the student prepared a series of biodegradable films from the AX. After which, the mechanical characteristics of films made from WB AX, MB AX, and DDG AX with the addition of either glycerol or sorbitol were determined. Water vapor permeability was highest for the MB AX films plasticized with 500 g kg-1 glycerol. Overall, this experiment utilized AX extracted from WB, MB, and DDG as the basis of films. The mechanical characteristics of all films were subsequently characterized to provide a comprehensive material profile for each type of AX film, which demonstrated unique materials properties for all films.

38 Inclusion Complexes of β-Cyclodextrin with Selected Food Phenolic Compounds

P.I.s: S. Simsek and C. Mayer (University of Duisburg-Essen)

Researcher: Tuba Simsek, M.S. student

Collaborators: B. Rasulev and A. Ugrinov (North Dakota State University)

Objectives: The objective of this project was to form inclusion complexes between β-cyclodextrin and phenolic compounds found in whole wheat. This project aimed to investigate the potential complex formation to improve the quality of whole wheat products by mitigating bitter flavors related to the presence of phenolic compounds.

Progress: Phenolic compounds, such as caffeic acid, trans-ferulic, acid and p-coumaric acid that are commonly found in food products, are beneficial for human health. Cyclodextrins can form inclusion complexes with various organic compounds in which the physiochemical properties of the included organic molecules are changed. In this study, inclusion complexes of three phenolic compounds with β-cyclodextrin were investigated.

Tuba Simsek, MSc student, worked on this project as part of her thesis work. The complexes were characterized by various analytical methods, including nuclear magnetic resonance (NMR) spectroscopy, Fourier IR (FT-IR) spectroscopy, mass spectrometry, differential scanning calorimetry, and scanning electron microscopy. Results showed that the phenolic compounds used in this study were able to form inclusion complexes in the hydrophobic cavity of β-cyclodextrin by non-covalent bonds.

The investigated chemical systems with experimental and computational studies showed that the flavors CA, CO, and FA are forming inclusion complexes with β-CD in a molar ratio 1:1. The chemical shift analysis indicated that the flavors are entrapped in the CD cavity. Analysis of MS spectra is also confirmed the complex formation. Computational analysis confirmed the potential of PM6 quantum-chemical method for robust prediction of flavor-cyclodextrin complex stability. The proven methodology will be used for further analysis of a large series of flavor compounds to form stable complexes with cyclodextrins.

39 Molecular Rotor-Based Characterization of Biopolymers at Oil-Water Interface and Emulsions

P.I.: Yuan Yao

Researcher: Jingfan Chen, Ph.D. Student

Objective: To establish an MR-based methodology for characterizing biopolymers associated with oil-water interface and emulsions

Progress: When biopolymers are used as emulsifiers to stabilize emulsions, the location and distribution of biopolymer molecules at the oil-water interface may affect the overall quality of emulsions. Through the fluorescence differences, molecular rotor (MR) has the capability to differentiate the performance of biopolymers at oil-water interface due to its interactions with both biopolymers and oil. In this project, the interactions between molecular rotor and modified starch, gum arabic, or sodium caseinate are detected in two different types of system: (1) oil-water layers in microplate wells, and (2) conventional oil-in-water emulsions.

40 Phytoglycogen and its Derivatives to Improve the Solubility of Poorly Water-Soluble Active Ingredients

P.I.: Y. Yao

Researcher: Jingfan Chen, Ph.D. Student

Objective: To improve water solubility and efficacies of poorly water-soluble active ingredients

Progress: Many pharmaceutical- and food-related active ingredients (AIs) are hydrophobic and thus poorly water-soluble, which adversely affects their bioaccessibility and bioavailability. In this project, curcumin, resveratrol, and quercetin are used as poorly water-soluble active food ingredient models to evaluate the capabilities of phytoglycogen and its derivatives (e.g., octenylsuccinate hydroxypropyl phytoglycogen) in solubilizing AIs and enhancing their biological efficacies, such as Caco-2 cell monolayer permeation and the reduction of biofilm formation of *Helicobacter pylori*.

41 Milligram Analysis of Starch Materials on Retrogradation and Shear Resistance

P.I.s: Y. Yao, C. Weil, B. Hamaker

Researcher: Miguel Alvarez Gonzales, M.S. student

Objective: To establish an analytical platform for high-throughput screening of cereal starches

Progress: This project is to support a high-throughput single-kernel starch screening program. The screening program requires starch property analyses at milligram level, which is usually difficult and cannot be conducted with high throughput. Currently, a molecular rotor (MR) based technique is being developed to characterize several important properties of starch, including retrogradation and shear resistance. The data obtained have shown very promising potential for further studies.

42 Pathogen Biofilm Reduction at the Surface of Fresh Produce

P.I.s: Y. Yao, A. Bhunia (Department of Food Science)

Researcher: Yezhi Fu, Ph.D. Student

Objective: To reduce or remove pathogen biofilm at the surface of fresh produce

Progress: Pathogen biofilm formation at food surface is a primary food safety concern. In this project, antimicrobial compounds are formulated and applied at the surface of fresh produce, including cantaloupes and alfalfa sprouts, and the efficacies to reduce the biofilm formation and bacterial growth of *Listeria monocytogenes* and *Salmonella* Typhimurium are evaluated. The goal is to design practical and effective treatments to realize 3-5 log reduction of bacterial load at the surface of fresh produce.

Publications and Other Scholarly Activities

A. Papers, Books, Chapters, and Patent Applications Published

BeMiller, J.N.

1. **Fu, Z.**, Zhang, L., Ren, M.-H., & **BeMiller, J.N.** (2019). Developments in hydroxypropylation of starch: a review. *Starch/Stärke, 71,* 1800167.

2. **BeMiller, J.N.** (2019). Corn starch modification. In *Corn Chemistry and Technology, 3rd Ed.*, S.O. Serna-Salvidar (ed.), Woodhead Publishing, Duxford, UK, pp. 537-539.

Campanella, O.H.

3. Castanha, N., Lima, D.C., Matta Junior, M.D., **Campanella, O.H.**, & Augusto, P.E.D. (2019). Combining ozone and ultrasound technologies to modify maize starch. *International Journal of Biological Macromolecules, 139*, 63-74. doi:10.1016/j.ijbiomac.2019.07.161

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93. Malalgoda, M., Ohm, J.B., **Simsek, S.** (2019). Celiac antigenicity of ancient wheat species. *Foods*, *8*, 675-680.

94. Malalgoda, M., Ohm, J.B., Manthey, F., Elias, E., **Simsek, S.** (2019). Quality characteristics and protein composition of durum wheat cultivars released in the last 50 years. *Cereal Chemistry*, *96*, 508-519.

95. Kumar, A., Mantovani, E.E., **Simsek, S.**, Jain, S., Elias, E., Mergoum, M. (2019). Genome wide genetic dissection of wheat quality and yield related traits and their relationship with grain shape and size traits in an elite × non-adapted bread wheat cross. *PlosOne*. https://doi.org/10.1371/journal.pone.0221826: 1-27.

96. Oh, M., Ma, Q., **Simsek, S.**, Bajwa, D., Jiang, L. (2019). Comparative study of zein- and gluten-based wood adhesives containing cellulose nanofibers and crosslinking agent for improved bond strength. *International Journal of Adhesion and Adhesives*, *92*, 44-57.

97. Magallanes-Lopez, A., Manthey, F., **Simsek, S.** (2019). Wet milling technique applied to deoxynivalenol contaminated wheat dry milled fractions. *Cereal Chemistry*, *96*, 487-496.

98. Naraghi, S., **Simsek, S.**, Kumar, A., Al Rabbi, H., Alamri, S.M., Elias, E., Mergoum, M. (2019). Deciphering the genetics of major end-use quality traits in wheat. *G3-Genes Genomes Genetics*, *9*, 1405-1427.

99. Anderson, C., **Simsek, S.** (2019). A novel combination of methods for the extraction and purification of arabinoxylan from byproducts of the cereal industry. *Journal of Food Measurement and Characterization*, *13*, 1049-1057.

100. Anderson, C., **Simsek, S.** (2019). How do arabinoxylan films interact with water and soil? *Foods*, *8*, 213.

101. Mendis, M., Leclerc, E., **Reuhs, B.L.**, **Simsek, S.** (2019). Structure driven immunomodulatory properties of xylo-/arabinoxylo-oligosaccharides and arabinoxylans in RAW264.7 macrophages. *Bioactive Carbohydrates and Dietary Fiber*, *17*, 100177.

102. Xu, M., Jin, Z., **Simsek, S.**, Hall, C., Rao, J., Chen, B. (2019). Effect of germination on the chemical composition, thermal, pasting, and moisture sorption properties of flours from chickpea, lentil, and yellow pea. *Food Chemistry*, *295*, 579-587.

103. Anderson, C.P., **Simsek, S.** (2019). Mechanical profiles and topographical properties of films made from alkaline extracted arabinoxylans from wheat bran, maize bran, or dried distillers grain. *Food Hydrocolloids*, *86*, 78-86.

Yao, Y.

104. **Rodriguez-Rosales, R.J.**, **Yao, Y.** (2019). Phytoglycogen, a natural dendrimer-like glucan, improves the soluble amount and Caco-2 monolayer permeation of curcumin and enhances its efficacy to reduce HeLa cell viability. *Food Hydrocolloids*, *100*, 105442

105. **Xie, Y.**, **Yao, Y.** (2019). Incorporation with dendrimer-like biopolymer leads to improved soluble amount and in vitro anticancer efficacy of paclitaxel. *Journal of Pharmaceutical Sciences*, *108*, 1984-1990

B. Papers Presented at Meetings, Conferences, and Invited Public Lectures

January

Ferruzzi, M.G. Maintaining bioactives through food processing, Harvest for Health Convening Meeting. Foundation Food and Agriculture Research, Washington, D.C.

Kokini, J.L. The basics of rheology without equations, Whistler Center for Carbohydrate Research Webinar, West Lafayette, IN.

Lindemann, S.R. Fiber is not just one thing: how fiber physical and chemical structure governs microbiome fermentation. Interdepartmental Nutrition Program Seminar Series.

February

Ferruzzi, M.G. Health benefits of phenolic rich beverages: Are we missing something without recommendations for tea and coffee? IFT/ASN Food Policy Impact Roundtable, Washington, D.C.

Hamaker, B. Dietary fiber chemical and physical structures for different functions related to the gut microbiome. Seminar Series Speaker, Food Science Department, Pennsylvania State University, State College, PA.

Magallanes-López, AM., Manthey, F.A., & **Simsek, S.** Does wet milling have an impact on starch and gluten fractions? North Dakota State University, 3 Minute Thesis Competition and Graduate Student Showcase, Poster presentation, Fargo, ND, **Showcase winner of People's Choice Award.*

Mauer, L.J. Update on CFSE approaches for developing novel pathogen detection technologies. ARS-FSIS National Meeting. Shepherdstown, WV.

Narsimhan, G. Swelling and Pasting Behavior of Starch, Whistler Center for Carbohydrate Research Webinar, West Lafayette, IN.

March

Bowen, K.J., Kris-Etherton, P.M., & **Reddivari, L.** Effects of diets that vary in fatty acid composition on fecal short-chain fatty acid levels and their relationship with circulating lipids and lipoproteins. American Heart Association Epi/Lifestyle meeting, Circulation, Phoenix, AZ.

Lindemann, S.R. Understanding the ecological principles governing the influence of carbohydrate structure on microbial diversity and metabolism. Office of Biological and Environmental Research, U.S. Department of Energy, Germantown, MD.

Maddakandage Dona, J., & **Simsek, S.** Dietary fiber variation and technological potential of ancient wheat species. NDSU 35th Annual Plant Sciences Graduate Student Symposium, Fargo, ND.

Magallanes-López, A.M., Manthey, F.A., & **Simsek, S.** Is wet milling an alternative for *Fusarium* infected grain? North Dakota State University, 35th Annual Plant Sciences Graduate Student Symposium, Oral presentation, Fargo, ND. **Second Place winner of Oral Presentation in Cereal and Food Science Award.*

Magallanes-López, A.M., Manthey, F.A., & **Simsek, S.** Starch fraction characterization obtained from deoxynivalenol infected wheat. ND EPSCoR 2019 State Conference, Poster presentation, Fargo, ND.

Snelling, J., Malekmohammadi, S., Bergholz, T., & **Simsek, S.** Vacuum steam pasteurization of hard red spring wheat. 35th Annual Plant Sciences Graduate Student Symposium, Fargo, ND, **First Place Presentation Winner in Cereal and Food Sciences Category.*

April

Hamaker, B. Collaborations to connect the dots. International Joint Food Safety Laboratory meeting (co-chair), Jiangnan University, Wuxi, China.

Hamaker, B. Fiber molecular structure and specificity of gut microbiota response (a strategy towards targeted functional fibers) (keynote). International Cereal Chemists Conference, Vienna, Austria.

Indukuri, V., Mason, M., **Reddivari, L.**, Lambert, J., & Vanamala, J. Anti-inflammatory effect of table grapes in Apc(Min/+) mouse model of intestinal tumorigenesis. Experimental Biology annual meeting, Orlando, FL.

Lim, J., Zhang, X., **Ferruzzi, M., & Hamaker, B.** Insight into flavonoid structure for mammalian α-amylase and αØ-glucosidase inhibition to control starch digestion rate. Experimental Biology annual meeting, Orlando, FL.

Maddakandage Dona, J., & **Simsek, S.** Do ancient wheat species differ from modern bread wheat? NDSU 3rd GSC Annual Research Symposium, Fargo, ND.

Magallanes-López, A.M., Manthey, F.A., & **Simsek, S.** Can we remove vomitoxin from wheat by wet milling? North Dakota State University Graduate Student Council 3rd Annual Research Symposium, Poster presentation, Fargo, ND. **First Place winner of Best Poster Award.*

Martinez, M.M. The importance of a bimodal starch granular size distribution in baking: optimizing dough viscosity and pickering stabilization. 70 Starch Convention of the Association of Cereal Research Association in cooperation with the Max Rubner Institute. Detmold, Germany.

Snelling, J., Malekmohammadi, S., Bergholz, T., & **Simsek, S.** Kill it before you mill it: Vacuum steam pasteurization of hard red spring wheat. North Dakota State University Graduate Student Council Research Symposium, Fargo, ND.

Snelling, J., Malekmohammadi, S., Bergholz, T., & **Simsek, S.** Vacuum steam pasteurization of hard red spring wheat. 2nd Annual Gamma Sigma Delta – NDSU Chapter Faculty and Student Symposium, Fargo, ND.

Yao, T., **Chen, M.-H.**, Tunçil, Y.E., Libera, L.A., & **Lindemann, S.R.** Fine carbohydrate structure sustains diversity in microbial consortia and governs competition at the strain level, American Chemical Society Annual Meeting, Orlando, FL.

May

Hamaker, B., Martinez, M., El-Hindawy, M., & Fang, F. Aspects of amylopectin fine structure that enhance retrogradation and slow digestion property. Whistler Center Technical Conference, West Lafayette, IN.

Lindemann, S.R. Bran fiber structure controls composition and metabolism of human gut microbiota. Purdue Microbiome Symposium, West Lafayette, IN.

Martinez, M.M. Sustainable engineering and chemistry of functional carbohydrates. Invited lectureship at the University of Valladolid, Palencia, Spain.

Rho, Y., Patterson, R., Joye, I., **Martinez, M.M.,** & Kiarie, E. Impact of steeping corn DDGS over 72 hours without or with fiber degrading enzymes and protease alone or in combination on concentration of sugars and organic acids and pH in the liquid medium. UoG Swine Research Day, Guelph, Canada.

June

Bonilla, J., Schaber, J., **Bhunia, A.,** & **Kokini, J.L.** Fluorescent visualization and image analysis of gliadins, low molecular weight glutenins, and high molecular weight glutenins at different stages of dough mixing in a farinograph. Institute of Food Technologists annual meeting, New Orleans, LA.

Burtch, H., **Ferruzzi, M.G.,** Kay, C., Lila, M., Iorrizo, M., & Mengist, M. Adaptation of an *in vitro* digestion model for high throughput phenolic bioaccessibility phenotyping within cultivated (highbush) blueberry varieties, ASN Nutrition 2019, Baltimore, MD.

Campanella, O.H. Course on food extrusion. University of Litoral, Department of Food Tecchnology and Chemical Engineering, Santa Fe, Argentina.

Campanella, O.H. Seminar: Methods to study the properties of foods and biomaterials: the role the process, Technological Institute for the Chemical Industry, University of Litoral, Santa Fe, Argentina.

Campanella, O.H. Course on food extrusion, College of Engineering, University of Buenos Aires, Buenos Aires, Argentina.

Cladis, D., Debelo, H., **Ferruzzi, M.G.,** & Weaver, C. Colonic metabolism of blueberry polyphenols in ovariectomized rats increases in a dose-response fashion. ASN Nutrition 2019, Baltimore, MD.

Debelo, H., Corbin, S., **Chegeni, M.**, Ferrara, F., Valacchi, G., & **Ferruzzi, M.G.** Repeated exposure of native African *Adansonia digitata* (baobab) and *Moringa oleifera* (moringa) modifies Caco-2 cell differentiation but not carotenoid absorption. ASN Nutrition 2019, Baltimore, MD.

Erturk, M.Y., Yazar, G., Duvarci, O.C., & **Kokini, J.L.** LAOS (Large Amplitude Oscillatory Shear) rheological characteristics of non-fat, low-fat, and high-fat yogurt samples. Institute of Food Technologists annual meeting, New Orleans, LA.

Ferruzzi, M.G. Carotenoids in human milk: bioavailability differences between human milk and infant formula, CARIG conference. ASN Nutrition 2019. Baltimore, MD.

Ferruzzi, M.G. From seeds to cells and back to seeds: Advancing nutritional impact with synergies between food, nutrition and agriculture. Leveille Award Lecture, Nutrition 2019, Baltimore, MD.

Hamaker, B., & Keshavarzian, A. Overview of gut microbiome, diet, and health. Institute of Food Technologists annual meeting, New Orleans, LA.

Hamaker, B. Dietary fiber structure controls on gut microbiome, composition and function. Institute of Food Technologists annual meeting, New Orleans, LA.

Hamaker, B., Martinez, M., El-Hindawy, M., & Fang, F. Carbohydrate structure, digestion and physiological effects. Institute of Food Technologists annual meeting, New Orleans, LA.

Hayes, M., Pottorff, M., Kay, C., Van Deynze, A., Osorio-Marin, J., Lila, M., Iorrizo, M., & **Ferruzzi, M.G.** Diversity in the bioaccessibility of carotenoid and chlorophyll compounds in 69 spinach genotypes. Nutrition 2019, Baltimore, MD.

Lindemann, S.R. Carbohydrate fine structure governs the composition and metabolism of gut microbiota. Army Research Office PI Meeting, Houston, TX.

Lindemann, S.R. Carbohydrate fine structure governs the composition and metabolism of gut microbiota, Tri-Service Microbiome Consortium Meeting, Framingham, MA.

Maiz, M., **Debelo, H.**, Lachcik, P., Lila, M., Bellido, T., McCabe, G., **Ferruzzi, M.G., &** Weaver, C. Consumption of Rabbiteye blueberry results in accumulation of hippuric acid in the bone marrow and increased bone deposition in ovariectomized rats but few other bone benefits, ASN Nutrition 2019, Baltimore, MD.

Malm, M., & **Kokini, J.L.** Fluorinating zein protein films for improved food packaging. Institute of Food Technologists annual meeting, New Orleans, LA.

Martinez, M. M. Sustainable engineering and food waste valorization. Invited presentation at Griffith Foods Limited Inc. Food Loss Commercialization Week, Toronto, Canada.

Rouf, T.B., & **Kokini, J.L.** Mechanistic understanding of the design and characterization of zein films reinforced with graphene oxide nanoparticles for biodegradable packaging application. Institute of Food Technologists annual meeting, New Orleans, LA.

Sorkin, B., Kuszak, A., Pauli, G., Bloss, G., Barrett, B., **Ferruzzi, M.G.,** Fukagawa, N., Kiely, M., Lakens, D., Meltzer, D., Paul, J., Sipes, N. Enhancing natural product clinical trials. ASN Nutrition 2019, Baltimore, MD.

Turasan H., Cakmak, M., & **Kokini, J.L.** A plant protein-based SERS biosensor platform for detection of food toxins and allergens. Institute of Food Technologists annual meeting, New Orleans, LA.

Wallace, T., Cassidy, A., Chung, M., **Ferruzzi, M.G.,** Jacques, P., Johnson, E., Wang, D.D., Zhao, N., Shams-White, M., & Karlsen, M. Tea flavonoids and risk of cardiovascular and all-cause mortality: A systematic review and meta-analysis. ASN Nutrition 2019, Baltimore, MD.

Whitney, K., & **Simsek, S.** FODMAPs in hard red spring wheat flours and breads. 2nd International Food Research Conference. Kuala Lumpur, Malaysia.

July

Hamaker, B. Ideas on making better carbohydrate foods for health. NEXUS UNSA Workshop, Purdue, West Lafayette, IN.

Hayes, A.M.R., Gozzi, F., & Hamaker, B. Slow gastric emptying rate for pearl millet-based foods in Mali is not observed in a U.S. population, though shows a slow digestion property. Society for the Study of Ingestive Behavior meeting, Utrecht, Netherlands.

August

Chen, J., & Yao, Y. Octenylsuccinate hydroxypropyl phytoglycogen to enhance the solubility and *in vitro* permeation of resveratrol. ACS National Meeting & Expo, San Diego, CA.

Chen, J, & Yao, Y. Octenylsuccinate hydroxypropyl phytoglycogen to enhance the inhibitory activity of curcumin against the biofilm of *Helicobacter pylori*. ACS National Meeting & Expo, San Diego, CA.

Kokini, J.L. Surface enhanced raman spectroscopy sensors for food applications. Ege University, Department of Food Science, Bornova, Izmir, Turkey.

Lindemann, S.R. Complex substrates and microbial diversity: how carbohydrate structure governs microbiome structure and function. Principles of Microbial Ecosystems Symposium, Tokyo, Japan.

Lindemann, S.R. Fiber structure impacts on maintenance of microbial diversity in the human gut microbiome. Department of Biological Sciences, Tokyo Metropolitan University, Tokyo, Japan.

Mauer, L.J. Deliquescence and sugar reduction strategies in starchy baked goods. Puratos. Brussels, Belgium.

Mauer, L.J. Fundamentals and consequences of water-solid interactions on physical state and molecular rearrangements. International Society on the Properties of Water (ISOPOW) 14th meeting, Dijon, France. [Keynote for session]

Mauer, L.J. Moisture induced vitamin destabilization in crystalline and amorphous systems, DSM, Reverse site visit in Dijon, France.

Mauer, L.J. Strategies for amorphization of sucrose. Nestle, Lausanne, Switzerland.

Mauer, L.J. Vitamin amorphization: opportunities and challenges. Nestle, Lausanne, Switzerland.

Mauer, L.J. Control of starch gelatinization and retrogradation. Nestle, Lausanne, Switzerland.

Yao Y. Characterization of carbohydrate polymers using molecular rotor as a structural probe. ACS National Meeting, San Diego, CA.

September

Ferruzzi, M.G. Food matrix and host factors influence bioavailability and metabolism of polyphenols from botanicals. 10th Annual Probiotics, Prebiotics and Botanicals Rome, Rome, Italy.

Hamaker, B. The Potential of Digestible Carbohydrates to Activate the Gut-Bran Axis for Weight Management, Whistler Center for Carbohydrate Research Webinar, West Lafayette, IN.

Lindemann, S.R. Tiny microbes with powerful impact, College of Agriculture Digital Agriculture Roundtable, Purdue University.

Mauer, L.J. Moisture-mediated phase transformations and challenges in powder ingredient blends. Givaudan, Naarden, Netherlands.

Pico, J., Pismag-Portilla, R., Laudouze, M., & **Martinez, M.M.** Suppressing interferences in the analysis of total phenolics: beyond the Folin-Ciocalteu reaction. Food Chemistry, Seville, Spain.

Roman, L., Joye, I., Bohrer, B., Marangoni, A., Lim, L., & **Martinez, M.M.** Whole muscle tissue engineering: innovative combination of microstructure engineering and high moisture extrusion. The Good Food Conference, San Francisco, CA.

October

Bozdogan, N., Tavman, S., Kumcuoglu, S., & **Kokini, J.L.** Comparison of the behavior and distribution of extension and shear rates in a model sigma blade mixer with a non-newtonian fluid and their impact on bubble size distribution. Society of Rheology 91th Annual Meeting, Raleigh, NC.

Bozdogan, N., Tavman, S., Kumcuoglu, S., & **Kokini, J.L.** Comparison of the behavior and distribution of shear and extension rates in a model sigma blade mixer for a non-newtonian fluid. American Institute of Chemical Engineers International Conference 2019, Orlando, FL.

Erturk, M.Y., **Turasan, H., & Kokini, J.L.** LAOS (Large Amplitude Oscillatory Shear) rheological characteristics of non-fat, low-fat, and high-fat yogurt samples. Society of Rheology 91th Annual Meeting, Raleigh, NC.

Ferruzzi, M.G. Influence of juice processing and natural variation in the bioaccessibility of phenolics from fruit. 13th International Congress on Polyphenol Applications, Malta.

Hamaker, B. A path towards designing carbohydrate-based foods for improved health. Seminar Series Speaker, Food Science and Nutrition Department, Florida State University.

Lindemann, S.R. Elucidating the ecological principles governing microbial competition (and cooperation) for complex substrates. Pacific Northwest National Laboratory Biological Sciences Division, Richland, WA.

Kokini, J.L. Rheology and viscoelasticity of foods, International Society of Food Engineering and Tecnológico de Monterrey Webinar, West Lafayette, IN.

Roman, L., Park, R., Widjaja, L., Falardeau, L., Joye, I., & **Martinez, M.M.** Compositional and structural factors of coat and cotyledon tissue of red kidney beans (*Phaseolus vulgaris*) from different varieties and growing locations. Cereals & Grains, Denver, CO.

Turksoy, S., Erturk, M.Y., & **Kokini, J.L.** Non-linear rheological behavior of doughs obtained from different wheat flours during dough aging. Society of Rheology 91th Annual Meeting, Raleigh, NC.

Woodbury, T., & Mauer, L.J. (distance given). Oligosaccharide structures, functions, and related opportunities for use in reduced sugar applications, American Association of Candy Technologists Annual Meeting, Oak Brook, IL.

Yazar, G., **Kokini, J.L.,** & Smith, B. The effect endogenous non-starch wheat lipids on gluten network nonlinearity. Society of Rheology 91th Annual Meeting, Raleigh, NC.

November

Alahmed, A., Ransom, J., & **Simsek, S.** Effect of pre-harvest desiccant application on properties of β-glucan from oat groats. Cereals & Grains 19 annual meeting, Denver, CO.

Allan, M., Chamberlain, M.C., & **Mauer, L.J.** The effects of sugars and sugar alcohols on the gelatinization temperature of different starches. Cereals & Grains 19 annual meeting, Denver, CO.

Allan, M., & **Mauer, L.J.** Effects of sugars and sugar alcohols on the retrogradation of wheat starch gels. Cereals & Grains 19 annual meeting, Denver, CO.

Bonilla, J., & Kokini, J.L. Mixing dynamics of gliadins, hmw-glutenins, and lmw-glutenins analyzed by fluorescent co-localization and protein network quantification. Cereals & Grains 19 annual meeting, Denver, CO.

Campanella, O.H. Forming functional shear-induced structures in starches and starch/non-starch polysaccharides mixtures by the application of controlled shear forces, Starch Round Table 2019, Denver, CO.

Campanella, O.H. Optimizing the functionality of carbohydrates for health enhancement through processing. Cereals & Grains 19 annual meeting, Denver, CO.

Campanella, O.H., & **Ferruzzi M.G.** Using polyphenol-protein and carbohydrate complexes to alter rheology/end-use properties. Alteration of grain protein properties with polyphenolic compounds Symposium. Cereals & Grains 19 annual meeting, Denver, CO.

Campanella, O.H., & Ferruzzi M.G. Using polyphenol-protein complexes to alter rheology/end-use properties. Cereals & Grains 19 annual meeting, Denver, CO.

Chen J., Yao Y. Phytoglycogen (PG) to enhance the solubility and in-vitro efficiency of resveratrol. Cereals & Grains 19 annual meeting, Denver, CO.

Desam, G. P., Li, J., Narsimhan, V., & **Narsimhan, G.** Prediction of swelling and linear viscoelasticity of starch suspensions. American Institute of Chemical Engineers annual meeting, Orlando, FL.

Erturk, M.Y., **Turasan, H., Kokini, J.L.** The effect of harmonic number on large amplitude oscillatory shear (laos) testing of starch suspensions. American Institute of Chemical Engineers annual meeting, Orlando, FL.

Fang, F., Diatta, A., Watanabe, H., **Campanella, O.H., Hamaker, B.** Effects of isomaltodextrin on rheological properties of model starch gels and its application in baked products as a promising source of fiber. Cereals & Grains 19 annual meeting, Denver, CO.

Ferruzzi, M.G. Research tools to assess the effect of phytonutrients on the microbiome. Council for Responsible Nutrition, Carlsbad, CA.

Ferruzzi, M.G. Phenolic interactions in whole grains: implications for starch functionality, digestion and glycemic properties. Cereals & Grains 19 annual meeting, Denver, CO.

Hamaker, B. Linking starch digestion to appetite control through activation of the gut-brain axis. Starch Round Table 2019, Denver, CO.

Hamaker, B. Concept of tailoring fiber-based prebiotics for personalized gut health (keynote). EFFOST meeting, Rotterdam, Netherlands.

Hamaker, B. Effect of dietary polyphenols on intestinal amylase/glucosidases and consequences on carbohydrate digestion. Cereals & Grains 19 annual meeting, Denver, CO.

Hamaker, B. Cereal starch structures that appear to be slowly digestible. Cereals & Grains 19 annual meeting, Denver, CO.

Hamaker, B. Structural aspects of corn arabinoxylans related to functionality (gut health and product incorporation). Cereals & Grains 19 annual meeting, Denver, CO.

Hamaker, B. Matrix cereal based dietary fibers support distinct gut bacteria, compared to soluble fibers. Cereals & Grains 19 annual meeting, Denver, CO.

Hamaker, B. Carbs – a journey to new ideas. Distinguished Professor 5-year Presentation, College of Agriculture, Purdue University.

Kokini, J.L. Extrusion of cereal materials – from starch, lipid, and protein molecular transformations to final extruded products. Whistler Center for Carbohydrate Research Webinar, West Lafayette, IN.

Lindemann, S.R. The influence of fiber physical and chemical structure on the structure and function of gut microbiota. Case Western Reserve University, School of Medicine, Department of Nutrition, Cleveland, OH.

Lindemann, S.R. Carbohydrate structure controls on the structure and function of gut microbiota. University of Michigan Center for Gastrointestinal Research, Ann Arbor, MI.

Lindemann, S.R. The influence of physical and chemical fiber structure on the composition and function of gut microbiota. Novozymes, Franklinton, NC.

Malalgoda, M., Howatt, K., & **Simsek, S. 2019.** Pre-harvest desiccant timing and effects on the fine chemistry of wheat starch. Cereals & Grains 19 annual meeting, Denver, CO.

Magallanes-López, AM., Osorno, J., & **Simsek, S. 2019.** Varietal and location effects on antioxidant potential of pinto and black beans. Cereals & Grains 19 annual meeting, Denver, CO.

Martinez, M.M. Structurally-driven slowly digestible starch of different banana and plantain cultivars is linked to its amylopectin unit and internal chain length distribution. Starch Round Table 2019, Denver, CO.

Martinez, M.M. The unexpected nutritional benefits of high shear extruded ingredients in the baking industry. Cereals & Grains 19 annual meeting, Denver, CO.

Ovando-Martinez, M., Leon, M.B., & **Simsek, S.** Biodegradable starch biofilms with modified starch for utilization in biomedical industry. Cereals & Grains 19 annual meeting, Denver, CO.

Peterson, K., Green, A.J., & **Simsek, S**. Evaluation of glutopeak as a tool for screening North Dakota hard red spring wheat breeding lines. Cereals & Grains 19 annual meeting, Denver, CO.

Roman, L., & **Martinez, M.M.** Is amylose important during the generation of structurally-driven slowly digestible starch and long term retrogradation? Starch Round Table 2019, Denver, CO.

Roman, L., Yee, J.C., **Hayes, A.M.R.,** Bertoft, E., **Hamaker, B.R., & Martinez, M.M.** Amylose and amylopectin roles in the structurally-driven formation of slowly digestible starch from fully gelatinized starch. Cereals & Grains 19 annual meeting, Denver, CO.

Schmidt, L.C., **Hamaker, B.** 3-Deoxyanthocyanidins increase protein matrix formation, altering starch digestion in cereal porridges. Cereals & Grains 19 annual meeting, Denver, CO.

Simsek, S. Introduction to modified starch: examples, pros and cons. Cereals & Grains 19 annual meeting, Denver, CO.

Simsek, S. 2019. Impact of pre-harvest glyphosate use on wheat protein composition. Cereals & Grains 19 annual meeting, Denver, CO.

Simsek, S. Arabinoxylan: A versatile cereal polysaccharide. Cereals & Grains 19 annual meeting, Denver, CO.

Torres, EV., Valencia, E., Linares, A., Dumas, J., & **Simsek, S.** Analysis of amaranth leaves and seeds grown in Puerto Rico. Cereals & Grains 19 annual meeting, Denver, CO.

Torres, EV., Valencia, E., Linares, A., Dumas, J., & **Simsek, S.** Micro and macromolecule composition of quinoa leaf and grain of three genotypes grown in Puerto Rico. Cereals & Grains 19 annual meeting, Denver, CO.

Whitney, K., & **Simsek, S. 2019.** Evaluation of hard red spring wheat flours by glutopeak at varied speed profiles. Cereals & Grains 19 annual meeting, Denver, CO.

Woodbury, T., & **Mauer, L.J.** Oligosaccharide effects on wheat starch gelatinization. Cereals & Grains 19 annual meeting, Denver, CO.

Yao Y. Applications of phytoglycogen. Starch Round Table 2019. Denver, CO.

Zhang, X., & **Hamaker, B.** A novel soluble crosslinked corn bran arabinoxylan matrix supports a shift to butyrogenic gut bacteria and forms a gel at low pH. Cereals & Grains 19 annual meeting, Denver, CO.

December

Hamaker, B. Fiber-based prebiotic, resistant starch and the gut microbiome. Starch Digestion Consortium meeting, San Antonio, TX.

C. Graduate Degrees Awarded

Spring 2019

1. Riya Thakkar, M.S., *Effect of Bran Particle Size on Gut Microbiota Community Structure and Function*

2. Xiaowei Zhang, Ph.D., *Gut Microbiota Differentially Responds to Corn Bran Arabinoxylans in Different Chemical and Physical Forms*

3. Jinsha Li, Ph.D., *Volume Fraction Dependence of Linear Viscoelasticity of Starch Suspension*

Summer 2019

4. Miguel Alvarez, M.S., *Establishment of High-Throughput Techniques for Studying Starch Functionalities*

5. Yezhi Fu, Ph.D., *Interventions to Reduce Microbial Load of Foodborne Pathogens at the Surface of Fresh Produce*

6. Smith Nkhata, Ph.D., *Post-Harvest Storage of Provitamin A Carotenoid Biofortified Maize in Purdue Improved Crop Storage (PICS) Bags and Effect on Subsequent Flour Rheology and Carotenoid Bioaccessibility*

7. Leigh Robison Schmidt, Ph.D., *Investigating Phenolic-mediated Protein Matrix Development for Potential Control of Cereal Starch Digestion*

8. Maya Frityanti, Ph.D., *Synergistic Effect of Ultrasonication on Antimicrobial Activity of Cecropin P1 Against Escherchia coli*

Fall 2019

9. Nuseybe Bulut, M.S., *Fabrication of Model Plant Cell Wall Materials to Probe Gut Microbiota Use of Dietary Fibers*

10. Dennis Cladis, Ph.D., *Consuming High Doses of Blueberry Polyphenols is Safe but Induces Dose-Dependent Shifts in Metabolism*

11. Rachel Jackson, M.S., *Consequences of Dietary Fibers and their Proportion on the Fermentation of Dietary Protein by Human Gut Microbiota*

12. Jongbin Lim, Ph.D., *Structural Specificity of Flavonoids to Selectively Inhibit Starch Digestive Enzymes for Triggering the Gut-Brain Axis*

13. Moustapha Mousa, Ph.D., *Innovative Millet Foods to Improve Nutrition and Expand Markets in West Africa*

14. Tahrima Rouf, Ph.D., *Design and Mechanistic Understanding of Zein Nanocomposite Films and Their Implementation in an Amperometric Biosensor for the Detection of Gliadin*

D. Recognitions, Awards, and Honors

Jose Bonilla
First Place in the Global Food Science Student Competition at Jiangnan University, Wuxi, China

Osvaldo Campanella
Lifetime Achievement Award 2019, International Association for Engineering and Food (IAEF)

Jingfan Chen
Third Place Winner of the 11th Annual Best Student Research Paper Competition, Cereals & Grains annual meeting, Denver

Enrico Federici
Second Place for Student Poster Competition, Protein Division, Institute of Food Technologists annual meeting, New Orleans

First Place in the Poster Competition, ABE Graduate Industrial Research Symposium, Biotechnology/ Regulations and Food Processing, Purdue University

Mario Ferruzzi
Named David Murdock Distinguished Professor

Gilbert Leveille Award and Lecture from the American Society for Nutrition, Nutrition 2019, Baltimore

Anna Hayes
Purdue Graduate Student Government Travel Grant Recipient (top tier)

Outstanding Service Award, Carbohydrate Division, Institute of Food Technologists annual meeting, Denver

Purdue University Certificate of Practice in College Teaching, 2019

Harrison Helmick
Cereals and Grains Student Association Vice Chair, Cereals & Grains annual meeting, Denver

Mario Martinez
Assistant Professor Research Excellence Award, College of Engineering and Physical Sciences, University of Guelph

Lisa J. Mauer
IFT Research and Development Award 2019, Institute of Food Technologists annual meeting, New Orleans

Cindy Mayorga
Fulbright Scholarship, 2019-2021

Ganesan N. Narsimhan
2019 ABE Outstanding Mentor for Graduate Students, Agricultural and Biological Engineering Graduate Student Association, awarded by the College of Engineering, Purdue University

Tahrima Rouf
Poster Competition Finalist, Food Packaging Division, Institute of Food Technologists annual meeting, New Orleans

Senay Simsek
Eugene R. Dahl Excellence in Research Award, College of Agriculture, Food Systems and Natural Resources, North Dakota State University

Excellence in Teaching Award, American Association of Cereal Chemists International, Cereals & Grains Association annual meeting, Denver

Merve Yildirim
Society of Rheology Student Travel Grant

E. Special Events

Whistler Center Short Course, October 1-3, 2019

As is our tradition, the course was designed to provide one day on carbohydrate fundamentals followed by two days of advanced special topic sessions. Day 1 consisted of a general session. Advanced topical areas were presented on days 2 and 3, so that each participant could attend three advanced topic sessions of their choice.

- Introduction to carbohydrates: Basic concepts – monosaccharides, oligosaccharides, and polysaccharides, Y. Yao
- Starch granule structure and properties, J. BeMiller
- Basic principles in rheology and viscoelasticity, J. Kokini
- Polyols, high-intensity sweeteners, and non-chemical modifications of starch, Y. Yao
- Chemical modification of polysaccharides, J. BeMiller
- Carbohydrate nutrition and labeling, B. Hamaker

Wednesday and Thursday Breakout Sessions
Phase stability of polysaccharide mixtures, O. Jones

Hydrocolloids and functionality (Part I & II), J. Keller

Carbohydrates designed for satiety and weight management, B. Hamaker

Fiber carbohydrate-microbiome interactions, S. Lindemann

Formulating healthy carbohydrate-based foods, M. Martinez

Complex carbohydrate structure analysis (non-starch) (Part I & II), B. Reuhs

Advances in chemical and physical modifications of starch (Part I & II), J. BeMiller

Physical property testing of carbohydrates – solids, L. Mauer

Extrusions technology for the productions of food and non-food materials, O. Campanella

Predictive modeling of multiphase systems (Part I & II), G. Narsimhan

Polysaccharide architecture and functionality, S. Janaswamy

Carbohydrates as functional ingredients in baking, S. Simsek

Modification and fabrication of dietary fibers for gut health, B. Hamaker

An introduction to advanced methods of food material characterization, J. Kokini

Rheological properties of food biopolymers and their role in bioprocessing and product development, O. Campanella

2019 Belfort Lecture

2019 Belfort Lecturer

Dr. Robert G. Gilbert
Centre for Nutrition & Food Sciences
University of Queensland, Brisbane, Australia
Yangzhou University, China

The Belfort Lectures were established and endowed by Dr. Anne D. Belfort in memory of her late husband, Dr. Alan M. Belfort, who was awarded a Ph.D. degree from Purdue University in carbohydrate chemistry in 1960. Support for the Belfort Lectures is generously continued by Alan and Anne's daughter, Anne E. Belfort. Persons honored by being chosen to give a Belfort Lecture are scientists who have made outstanding contributions to glycoscience.

Dr. Robert G. (Bob) Gilbert is Research Professor at both the Centre for Nutrition and Food Science, University of Queensland, and at Yangzhou University, China, under the Chinese Government 1000-Talents Foreign Experts program. He spends 6 months per year in each institution. He received his undergraduate training at Sydney University, graduating in 1966, and his Ph.D. from Australian National University, graduating in 1970. He carried out postdoctoral work at MIT in the US from 1970 to 1972, and then returned to the University of Sydney, where he held a personal chair in polymer chemistry and was Director of the Key Centre for Polymer Colloids. His research is in the area of relations between human health and the structures of complex glucose polymers (starch and glycogen). He is author of about 480 papers, 6 patents, and 2 books (on unimolecular reactions and on emulsion polymerization). He is fluent in English (native speaker), French and German, and speaks basic Mandarin.

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