Kansas State University

RESEARCH & EXTENSION

Agricultural Experiment Station and Cooperative Extension Service
5 Year Action Plan

Action Plan No. ____________ *(Will be assigned)* Start Date: 01/01/06 *(dd/mm/yyyy)* End Date: 12/31/10 *(dd/mm/yyyy)*

1. **Title:** Utilization of extrusion processing to produce novel value-added food and non-food products.

2. **Action team leader(s):**

Sajid Alavi	(50% time)	Assistant Professor	Grain Science and Industry

3. **Action team:**

Tom Herald	(10% time)	Professor	Animal Sciences and Industry
Scott Bean	(5% time)	Research Chemist	USDA-GMPRC
Keith Behnke	(5% time)	Professor	Grain Science and Industry
Ron Madl	(5% time)	Administrator, BIVAP	Grain Science and Industry
Bhadiraju Subramanyam	(5% time)	Professor	Grain Science and Industry

4. **Collaborators:**

Syed S. H. Rizvi	(5% time)	Professor	Food Science, Cornell University

5. **Collaborating Agencies:**

United States Department of Agriculture (USDA)
Kansas State Agricultural Experiment Station (AES)
Kansas Wheat Commission (KWC)

6. **Graduate Students or Support Scientists:**

Roderick Agbisit	(100% time)	Graduate Student	Grain Science and Industry
Xiaozhi Tang	(100% time)	Graduate Student	Grain Science and Industry
Hyma Gajulah	(100% time)	Graduate Student	Grain Science and Industry
Diptansu Das	(100% time)	Graduate Student	Computing & Information Sciences
Michael Cheng	(100% time)	Post-doctoral Associate	Grain Science and Industry
Shaowei Liu	(100% time)	Post-doctoral Associate	Grain Science and Industry

7. **Core mission themes:**

___ Healthy Communities: Youth, Adults & Families
_x_ Safe Food and Human Nutrition
_x_ Economic Development through Value-added Products
___ Natural Resources and Environmental Management
___ Competitive Agricultural Systems

8. **Long-term intended outcomes addressed by the Action Plan:**

New and enhanced products from agriculture
Safe, secure, high quality food supply
Enhanced nutritional quality of the food supply

9. **Rationale for approval of this Action Plan:**

The proposed action plan stresses on conducting both fundamental and applied research in the area of extrusion processing, and is geared towards benefiting Kansas extrusion equipment manufacturing and allied industries, the food and feed processing industry, and growers. The action plan aims at making the extrusion technology more innovative in order to meet the changing demands of the consumer, and enhancing the value of Kansas grain commodities which are used as raw material in extrusion processed food and feed products.

Biopolymeric foams with both food and non-food applications are increasingly being produced by a variety of techniques ranging from traditional processes like steam-based extrusion to newly developed technologies such as supercritical fluid extrusion. In order to further improve these processes and generate new expanded products with a wide range of raw material formulations and having desired structural, mechanical and physico-chemical attributes, it is extremely important to understand the dynamics of structure formation in foams. The backbone of this action plan is an ongoing research project that addresses these questions. After an extensive literature review on this topic, we have concluded that there is a great need for systematic and accurate mapping of product microstructure characteristics. This is something that has not been done so far because of the inadequacy of current imaging methods, such as light microscopy and scanning electron microscopy, which are not only destructive but also provide us with image-features that are two-dimensional in nature and difficult to detect and measure objectively because of various artifacts from sample preparation and poor contrast. Our preliminary investigations reveal that non-invasive X-ray tomography imaging (XTI) technology can overcome the above mentioned drawbacks in imaging of foam microstructure, and thus will play a pivotal role in the proposed study.

The results of this project will be applied towards the processing of cereal-based human foods, as well as animal and aquatic feed. This study will significantly expand our understanding of the foam dynamics and mechanics, and will be put to practical use in *a priori* design products with unique textures and formulations, for example expanded starch-based foams containing very high levels of whey protein. Another major outcome of this study will be development of a new and non-invasive methodology for measuring the microstructural features of food foams.

An important and applied part of the action plan is a project on developing starch and nano-additive based composite biodegradable packaging films with superior mechanical and barrier properties. Use of petroleum-based plastics has burgeoned over the past many decades. It is estimated that 320 million metric tonnes of plastic materials were produced and consumed in the U.S. alone in 1998. Among the uses of plastics, about 2.5 million tonnes of plastics are made into various types of foamed products annually. Less than 0.3 % of the amount of plastics produced gets recycled, and the rest eventually ends up in land fills. Disposal of used plastics-based material is a big problem as they are not easily degradable, have a negative impact on the environment and take up huge amount of landfill space. Moreover another downside of the use of plastics is the increased dependence on petroleum which is a non-renewable resource. This has spurred the search for sources of renewable and bio-degradable materials as replacements for plastics. The proposed study will utilize ingredients like wheat starch and gluten for producing biodegradable films for packaging applications. Extrusion processing will be used to produce nano-composites of starch/gluten and appropriate nanomaterials for enhancing the barrier and mechanical properties of these films. Wheat starch will provide the structure of the foams while gluten will serve to increase their water-resistance. Both wheat starch and wheat gluten are cheap raw materials produced abundantly by Kansas producers. The overall aim of this study is to produce a packaging film product with cost and physical properties comparable to plastic-based products.

Another important aspect of the action plan is focused towards utilizing extrusion processing for producing pre-cooked whole wheat flours with increased functionality for baked products and pasta, and at the same time have a reduced glycemic index.

Successful completion of these projects will potentially result in enhanced demand for Kansas wheat starch and wheat gluten for production of high-value products, and thus serve the interests of Kansas wheat producers.

10. Literature review:

Microstructure features of foams and their measurement

There have been a number of studies on expansion behavior of biopolymeric extrudates. Most of these studies describe the product expansion only in terms of macro-structural properties like piece density and expansion ratio. Macrostructural features, however, are only an indirect measure of product structure. Products having the same bulk density or expansion ratio can have very different internal structure depending on processing conditions and formulation. It is obvious that any comprehensive attempt to understand the dynamics of foam formation will be grossly inadequate without knowledge of the micro-structure. Moreover, study of foam microstructure is very significant because it is a direct link between process parameters and mechanical properties of any foam (Wilkinson et al., 2000; Niranjan, 1999; Djelveh et al., 1999; Gibson and Ashby, 1988). Important microstructural features of any foam include average cell size, cell size distribution and its uniformity, number density of cells, and presence or absence of an inter-connected network of cells (often measured as open cell fraction).

One of the principle reasons why our understanding of structure formation in bioploymeric foams is incomplete is that few studies have attempted to study microstructure in an objective manner. More often than not studies only report a few cross-sectional images of foams and discuss the microstructure features qualitatively without actually making any measurement of important features (Gropper et al., 2002; Autio and Salmenkallio-Marttilla, 2001; Lee et al., 1999; Lai et al. 1985; Owusu-Ansah, et al., 1984). Microstructure has remained a grey area in our knowledge of biopolymeric foam process dynamics mainly because of the inadequacy of commonly employed imaging techniques like digital video imaging, light microscopy and scanning electron microscopy (SEM). These conventional imaging techniques are 2-dimensional and destructive in nature because sample preparation involves cutting to expose the cross-section to be viewed, which can alter various structural features. Also, the 2-dimensional image of a sample cross-section does not give complete or accurate information on microstructural features like cell size distribution because the diameters measured from the image depend on the depth of cut, as cells are in general sliced off-center (Scanlon and Zghal, 2001; Campbell et al., 1999).

Another problem in SEM or optical imaging is obtaining adequate contrast between air and solid phases, for which the ‘lighting’ and angle of illumination play an important role. Often segmentation techniques like thresholding and edge detection have to be employed to enhance the distinction between the two phases and extract relevant features from any image (Scanlon and Zghal, 2001). These techniques use mathematical treatments like Fourier transfoms and other algorithms which are not only very complex and require a large amount of computational time, but they also might lead to incorrect or varying results depending on the treatment applied (Sapirstein, 1999; Hall and Brachini, 1997).

Sapirstein (1999) employed a video imaging system in conjunction with customized image segmentation software in the C language for analyzing the crumb structure of bread. They computed equivalent cell diameter distributions, mean cell area, cell number density and cell wall thickness. Cilliers and Sadr-kazemi (1999) reported cumulative cell area distributions on the surface of sliced bread produced by dough mixed under different pressures. They employed an image processing algorithm that incorporated high-pass sharpening, thresholding, and edge detection using gradient. Microstructure features like cell area and cell diameter distributions of extruded wheat flour biscuits were analyzed by Smolarz et al. (1989) using a digital camera and computerized image analysis involving extraction of contours by erosion technique and closed loop detection algorithm. Barrett and Ross (1990), Barrett and Peleg (1992a and 1992b), and Barrett et al. (1994) used video image analysis to study the cell structure of various extruded corn meal based foams, and computed the cell area distributions and average cell area using an image analysis software for thresholding. Gao et al. (1999), Tan et al. (1997) and Gao and Tan (1996) extruded corn meal based foams at various moistures and screw speeds and obtained cross-sectional images using SEM and color CCD camera. They used an edge enhancement and segmentation technique based on high-pass filters called Sobel operators and extracted features like cell size using run length analysis and fuzzy edge detection.

Important properties of foams like mechanical strength, bulk infusibility of liquids, and effective diffusivity of gases or liquids are directly impacted by microstructural features such as the degree of inter-connectedness between cells and the open cell fraction (ratio of volume of inter-connected pores to total pore volume). These features are impossible to ascertain using 2-dimensional imaging. Indirect techniques like gas (air, nitrogen or helium) pycnometry have been used to measure the open cell fraction of various bioploymeric foams. Jones et al. (2000) determined open cell fractions in various puffed or flaked commercial breakfast cereal samples using a helium comparison pycnometer. They reported open cell fractions in the range of 68-99%, with majority of the extrusion or gun puffed products having open cell fraction higher than 90%. Bhatnagar and Hanna (1996) used air comparison pycnometry to measure the open cell fraction in corn starch based extruded foams with different levels of talc. They reported open cell fraction ranging from 71 to 96%. Hicsasmaz and Clayton (1992) used a nitrogen stereopycnometer for determination of open cell fraction in white bread (> 97%) and butter cookies (> 84%). These studies confirmed the widespread belief that extruded foams and breads have a high degree of cell inter-connectedness and open cell fraction. A drawback of this technique is that it is indirect and can lead to many inaccuracies in measurement. For example, adjoining cells that are closed and non inter-connnected might be counted as inter-connected if there is a small crack in the cell walls allowing gas to penetrate. Also the pressure applied for penetration of gas into the porous solid might cause further cracks in the walls, especially when cell walls are very thin as in highly expanded extrusion puffed foams. Another indirect technique used for characterizing foam microstructure is mercury infusion porosimetry, in which the pressure required to infuse a certain volume of mercury into a porous solid is correlated with the average size of the pores. This technique has been used to measure the cell size distributions in extruded corn starch foams (Karathanos and Saravacos, 1993), extruded rice flour foams (Clayton and Huang, 1984), and breads and cookies (Hicsasmaz and Clayton, 1992). However, non inter-connected or closed cells and cells larger than 150 microns in size cannot be detected using this technique. Moreover, the structure of the porous material being tested can be altered when high infusion pressures are used (Clayton and Huang, 1984).

It is apparent from the above discussion that conventional 2-dimensional imaging methods are useful for measuring features such as cell size distribution and cell wall thickness, but they require complex and time consuming image analysis techniques, and cannot determine microstructure parameters like degree of cell inter-connectedness and open cell fraction. Moreover, these techniques require cutting of sample to expose its cross-section. This not only alters the cell structure, but also makes it impossible to view cross-sections at more than one depth, thus providing incomplete and inaccurate information on the microstructure. Indirect measures based on gas or mercury penetration are also useful tools for characterizing foam microstructure features like open cell fraction and cell size distribution, but they are not precise and cellular structure can be altered during measurement.

An accurate measurement of various important microstructural features is only possible if the same specimen can be imaged at different incremental depths in a non-invasive fashion and with precise depth of focus. Confocal laser scanning microscopy (CLSM) is a recent development (early 1990s) in this direction. In this technique, in contrast to conventional light microscopy, the light source is replaced by a laser, a scanning unit and pinhole in the back focal plane (Durrenberger et al., 2001). This results in a marked improvement in limiting the depth of focus and removing the blur caused by non-focal information from images of thick objects. CLSM is especially useful in producing optical sections through a 3-D specimen, and can be used to image surface topology of any object and internal structural characteristics of transparent or semi-transparent biological and food materials. However, it is not very useful for imaging of opaque objects such as starch-based foams.

To overcome the drawbacks of previously used imaging methods, other non-invasive imaging technologies need to be explored for characterizing biopolymeric foam microstructure. Low resolution X-ray tomography or computerized axial tomography is widely used in medicine to image body tissues in a non-invasive manner, and is more popularly referred to as CAT scanning. This technology has its origins in the 1970s and conventionally has a resolution of ~ 100 μm, which is not sufficient to explore microstructure of many foams. The only attempt at utilizing this technology for visualization of biopolymeric foams was made by Whitworth and Alava (1999) who used CAT scans to non-invasively image internal structure of bread dough during proofing. They reported their results qualitatively with a series of images but could not make any measurements because of poor image resolution.

In the past few years use of very high energy X-rays, from high intensity synchrotrons or other sources, has allowed resolutions of 1 μm and enabled the use of X-ray tomography in other fields like geology and metallurgy where visualization of internal microstructure of opaque objects like rocks or metallic foams is an important area of study (Coker et al., 1996; Nieh et al., 1998). In order to distinguish it from CAT scanning, this technology will hitherto be referred to as high resolution X-ray tomography imaging or simply XTI. The general methodology involves targeting the specimen with a highly collimated monochromatic X-ray beam. The X-rays not absorbed by the specimen fall on specially designed X-ray scintillators that produce visible light, which is then recorded by a charge-coupled-device (CCD) camera. A tomographic scan is accomplished by rotating the specimen about an axis perpendicular to the X-ray beam while collecting radiographs of the specimen at small angular increments. The radiographs are then reconstructed into a 3-D image using back-projection software. This reconstructed 3-D image can either be presented as a whole or as ‘slices’ of the sample at different depths and in different directions.

Our lab in the Department of Grain Science at Kansas State University, in collaboration with Department of Food Science at Cornell University, has pioneered the use of XTI for non-invasive imaging of 3-dimensional microstructure of biopolymeric foams. We have utilized bench-top XTI equipment to successfully visualize the structure of various foams, and have made preliminary measurements of microstructure features as well. The reconstructed cross-sections of XTI scanned corn starch based extruded foams (corn puffs) showed a distinct difference between the solid phase or cell walls (dark shaded areas) and the gas phase (white color) due to the difference in X-ray absorbency of the two phases. Moreover, the XTI images do not show any features above or below the cross-sectional plane. These images lent themself to easy extraction, via image analysis software, of various parameters such as cell area, average cell wall thickness, solid fraction, etc. In comparison, the SEM image of an exposed cross-section (after cutting with a sharp blade) of the same foam presented much greater complexity in analysis because of presence of ‘extra-planar’ features, alteration of structure due to cutting, and a gradation of grey levels that makes it hard to demarcate cell boundaries.

Also once a sample is scanned with X-rays and a complete set of radiographs collected (this takes about 30 min), manipulation of the data using special software allows reconstructing cross-sections at depth increments as low as 1 μm, and along any desired orientation of the ‘plane of cut’. A series of non-invasive XTI slices of the same sample in any direction can provide lot more information than just one SEM or optical imaging picture. For example, the true volume (V) and equivalent diameter (d) of the cells were obtained by measuring the cell area (A_i) at different depths (z_i) using an image-analysis software. The volume V is given by:

$$V = \tfrac{1}{3}(z_1 - z_0)A_1 + \sum_{i=2}^{n-1}(z_i - z_{i-1})(A_i + A_{i-1})/2 + \tfrac{1}{3}(z_n - z_{n-1})A_n$$

where n is the number of slices.

This method can be applied to each cell encountered in a specified thickness of the specimen in order to obtain the true cell size distribution. The true 3-D shape of the bubble can also be visualized from its 2-D slices. Whether a structure in general comprises of interconnected cells or closed cells can also be ascertained using reconstructed 3-dimesional images from XTI. The 3-dimesional XTI images of starch-based foams produced by both steam-based extrusion and SCFX indicated that both foams have more or less intact walls separating individual cells. Observation of closed cell nature of foams produced by steam-extrusion is especially intriguing as it is contrary to the earlier results obtained by indirect measurements (Jones et al., 2000; Bhatnagar and Hanna, 1996). As part of preliminary investigations, we have used XTI to scan microstructures of a host of other expanded products including oat rings and floating salmon feed produced by steam extrusion, and ordinary dish washing foam. While oat rings are another example of closed cell structure, dish-washing foam is clearly a completely inter-connected open cell structure. Fish feed microstructure is appears to be very porous but without any visible and distinct cellular network.

It is clear from the above discussion that XTI is an important imaging tool that has not yet been employed for imaging of biopolymeric or food foam structures. Its one of the primary goals of this study to use this exciting new technology to develop a better understanding of structure formation in both food and feed products produced by extrusion processing.

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Starch-based nanocomposite biodegradable films using extrusion processing

For biodegradable packaging materials to compete with non-biodegradable synthetics, the critical mechanical and/or barrier properties for the intended application must be matched. This is especially difficult in the case of moisture barrier properties, because no biodegradable polymer approaches the hydrophobic character of synthetic polymers such as LDPE. Because of their inherent hydrophilic nature, biodegradable polymers are usually poor moisture barriers. They are, however, naturally good oxygen barriers at low RH, but oxygen permeabilities increase exponentially as RH increases.

Nanotechnology involves the study and use of material at an extremely small scale - at sizes of millionths of a millimeter – and exploits the fact that some materials have different properties at this ultra small scale from those at a larger scale. Nanostructured materials exhibit unique properties that open windows of opportunity for the creation of new, high performance materials, which will have a critical impact on food manufacturing, packaging, and storage (Moraru et al.,2003)

Biodegradable natural polymer layered silicate nanocomposites have received little attention in the open literature comparing to synthetic polymer nancomposites; however, there has been some research focusing on this area and indicated that clays or modified clays show much promise for starch-based polymer nanocomposites in improvements of the barrier and mechanical properties and stability over the unfilled formulations.

Park et al (2002, 2003) prepared the biodegradable blends of starch, glycerol and clay by a roller mixer and injection molded using a mini-Max molder to get dog-bone shaped specimens for characterization and property measurements. The results indicate that adding only 5 wt.-% of the clay to starch matrix is favorable to improve the tensile strength and the barrier property of the starch composite.

De Carvalho et al (2001), Wilhelm et al (2003), Huang et al (2005), and Chen and. Evans (2005) used the similar method to prepare the starch based biodegradable nanocomposites and characterized their mechanical and barrier properties. Their studies all indicated that it was a promising method to incorporate nanoclay into the starch matrix to reinforce the properties of the films.

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Wheat-based pre-cooked flours using low shear twin-screw extrusion processing

Obesity is a major concern in the U.S., and the problem is reaching epidemic proportions McCarthy, 2003; Polan, 2003). As a result, in the past few years various low carbohydrate dietary regimens like the Atkins diet and the South Beach diet have been adopted by consumers, leading to negative impacts on the market for cereal-based products like breakfast cereal, pasta, breads, and other baked goods (Davis, 2004). However, both cutting-edge scientific research and historic dietary patterns of cultures all over the world support cereal-based carbohydrates as the base for human nutrition. There is growing awareness in consumers of concepts like ‘whole grain products’, ‘dietary fiber’ and ‘low glycemic index’, and the role these play in reduced calorie uptake, at the same time providing health benefits linked to chronic diseases like cardio-vascular impairment, diabetes, colo-rectal and other kinds of cancer, diverticulitis and general problems linked to digestion (McCarthy, 2003; Decker et al., 2002; Haros et al., 2001; Brown et al., 1999). Wheat-based ingredients like wheat flour, whole wheat flour and semolina are major ingredients that provide the above mentioned benefits, but they have certain drawbacks that need to be addressed in order to capitalize on this emerging consumer awareness. Whole wheat ingredients with high fiber content tend to diminish the final product quality and consumer acceptability of baked goods and pasta (Camire, 2004; Manthy and Schorno, 2002). Also, gluten proteins which provide the visco-elastic and binding properties necessary to make products like breads and pasta, are not accepted by a segment of the population suffering from gluten intolerance.

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11. Objectives and procedures:

Five main extrusion-related research projects form the back-bone of this action plan – 1) XTI imaging of microstructure of biopolymeric foams produced by extrusion processing, 2) development of starch-based biodegradable packaging films with enhanced mechanical and barrier properties, 3) production of pre-cooked whole wheat flours using extrusion processing, 4) use of extrusion processing for encapsulation of organic chemicals with starch, and 5) development of aquatic feed with precise control over of characteristics such as sink-rate, floatability and product integrity. The first project is fundamental in nature and strives to answer some basic questions on structure formation during foaming. The other three projects are more application oriented as they involve development of new products, however these studies are closely inter-related. The outcome of the first project will greatly affect the success of the other three application-oriented projects.

Project 1: Non-invasive imaging of extruded foam microstructure
The overall objective of this study is to understand structure formation in biopolymeric foams by utilizing non-invasive imaging technology and identifying material properties critical for engineering desired structures, and to compare the mechanism of expansion in foaming processes such as steam-based extrusion and supercritical CO_2 – based extrusion. The specific objectives are to –

1) Produce biopolymeric foams with different structural and physico-chemical properties by utilizing two extrusion processes employing different blowing agents (supercritical CO2 and steam), and using various combinations of process variables (specific mechanical energy and moisture content) and material formulation.
2) Utilize non-invasive XTI technology to obtain three-dimensional scans of foams generated in Objective 1, and measure the spatial distribution of various fundamental micro-structural attributes like open cell fraction, void fraction, cell size, average cell wall thickness, and cell nucleation density.
3) Develop an understanding of structure formation and collapse during foam formation by utilizing data collected in Objectives 1-2 in conjunction with existing models for bubble dynamics in polymeric foam production. A full factorial experimental design with three replicates will be used to study the inter-relationships between material properties, processing parameters and product micro-structural, mechanical and physico-chemical attributes. Results will be analyzed statistically using analysis of variance (ANOVA) procedures and pair-wise comparison (t-test). Mathematical model will be validated using experimental data and differences in the observed and predicted bubble sizes will be compared using the χ^2 statistic at the $\alpha = 0.05$ level.

Project 2: Starch-based biodegradable films using extrusion processing
This project aims at developing a new generation of biodegradable packaging films with enhanced mechanical and barrier properties by extrusion processing as a means of making starch-nanomaterial composites. The specific objectives of this study are detailed below –

1) The synthesis of nanocomposites using extrusion processing.
2) Characterization of the properties of the nanocomposite films.
3) Clarify the miscibility issues of starch and clay and structure of the nanocomposites.
4) Test the applicability of extrusion processing to produce large volumes of nanocomposites with pilot scale extrusion systems.

Project 3: Production of pre-cooked whole wheat flours using extrusion processing.
The proposed project aims at utilizing extrusion technology for producing pre-cooked whole wheat flours with increased functionality for baked products, and flours based on gluten-free wheat flour or starch – whey protein complexation that will have similar functionality as wheat flour and semolina for making baked goods and pasta,

respectively, at the same time having a reduced glycemic index. The scientists and processing and testing equipment associated with the the departments of Grain Science and Industry and Animal Sciences and Industry will be used to achieve the objectives as detailed below:

1) Produce pre-cooked whole wheat flours utilizing low shear, low temperature extrusion processing.
2) Produce pre-cooked flours based on several combinations of gluten-free wheat flour or starch and whey protein isolates using utilizing low shear, low temperature extrusion processing.
3) Characterize cold and hot water swelling and pasting properties of the pre-cooked wheat flours produced in Objectives 1and 2 and compare them with commercially available wheat flours.
4) Characterize rheological properties of the pre-cooked wheat flours produced in Objectives 1 and 2 and compare them with commercially available wheat flours.
5) Compare quality of bread and pasta products prepared from pre-cooked flours to those based on commercially available wheat flours and semolina.

Project 4: Use of extrusion processing for encapsulation of organic chemicals with starch
The purpose of this research is to use extrusion processing as a means for encapsulation of organic chemicals (like the pesticide Spinosad) with starch. The specific objectives are –

1) To incorporate/encapsulate Spinosad in a corn starch matrix by low shear, low temperature extrusion.
2) To verify the activity of Spinosad/corn starch encapsulates in the laboratory against six stored-product insect pests.
3) To evaluate the effectiveness of Spinosad/corn starch encapsulates as insect bait in food and feed plants.
4) To evaluate stability and residual activity of Spinosad/corn starch encapsulates incorporated into dry expanded dog food.

Project 5: Development of a new generation aquatic feed using extrusion processing
The purpose of this research is to discover new and improved uses for Kansas agricultural products and equipment through the development of extruded aquatic feeds. The specific objectives are –

1) To develop a mechanism for precisely controlling the floatability and sink rate of extruded aquatic feed pellets.
2) To study the affect of various proportions of starch and fat in the formulation on the characteristics of the extruded aquatic feed.
3) Incorporation of a foaming agent like sodium bicarbonate in the pellets either by surface coating of vacuum infusion in order to control their sink rate.

12. <u>Anticipated outcomes and marketing opportunities:</u>

Project 1: Non-invasive imaging of extruded foam microstructure

This study will significantly expand our understanding of the foam dynamics and mechanics, and will be put to practical use in *a priori* design products with unique textures and formulations, for example expanded starch-based foams containing very high levels of whey protein. Another major outcome of this study will be development of a new and non-invasive methodology for measuring the microstructural features of food foams.

Project 2: Starch-based biodegradable films using extrusion processing

The overall aim of this study is to produce a biodegradable film with cost and physical properties comparable to polymer fims. Both wheat starch and wheat gluten are cheap raw materials produced abundantly by Kansas producers. Successful completion of this project will potentially result in enhanced demand for Kansas wheat starch and wheat gluten for production of high-value products, and thus serve the interests of Kansas wheat producers. The study will especially benefit the value of wheat gluten, whose price has fallen below the cost of production in U.S. because of competition from European producers and proteins from other sources such as soybean, egg and dairy.

Project 3: Production of pre-cooked whole wheat flours using extrusion processing.

Successful completion of this project might lead to enhanced demand and value of wheat-based ingredients, and new products like whole wheat based breads and pasta having enhanced quality and nutritional benefits. The results of this study will be made known widely by publication in trade and scientific journals (example, Cereal Foods World, Cereal Chemistry, etc.) and by presenting the work at various regional and national/ international conferences (K-State Annual Research and Extension Conference, American Association of Cereal Chemists Annual Conference, etc.). Due consideration will also be given to any proprietary formulations or processes that arise from this project.

Project 4: Use of extrusion processing for encapsulation of organic chemicals with starch.

The proposed project focuses on novel approach of using Spinosad in a corn starch matrix to develop an insect bait and incorporate Spinosad in dog food for managing insects. This technique can be eventually transferred to other corn-based petfoods. Moreover, Spinosad/corn starch encapsulates have the potential for greater shear, heat and sunlight tolerance, which might lead to wider use in various applications including as a long-term outdoor insecticide and food grade ingredient in pet food formulations for managing stored-product insects, which are ubiquitous in raw and processed corn products.

Project 5: Development of a new generation aquatic feed using extrusion processing.

A thorough understanding of the effects of process and formulation variables on the characteristics of extruded aquatic feed will enable producers to manipulate their products to meet customer demands, leading to increased sales of extruded aquatic feed and processing equipment manufactured in Kansas.

For each of the above projects, the action team will be actively pursuing intellectual property disclosures and patent applications for any novel technology that arises from our investigations.

13. Summary of projects:

Project 1: Non-invasive imaging of extruded foam microstructure

Team: Sajid Alavi, Syed S. H. Rizvi

Description of project:

This study seeks to understand the dynamics of two important foaming technologies for biopolymers like starch and protein – a) steam-based extrusion, which is an established and widely used commercial process, and b) supercritical fluid extrusion, which is a recently developed process that has the potential of engineering a new generation of products. The process of structure formation will be analyzed from a unique perspective involving the following elements –

1) Utilization of X-ray tomography imaging (XTI), which is a unique non-invasive imaging technology, to characterize the microstructural features of expanded foams.
2) Characterization of phase transition behavior of a complex, heterogeneous biopolymer melt consisting of starch, proteins and other ingredients, and measurement of important phase transition properties such as glass transition and melt transition temperatures.
3) Understanding blowing agent (water vapor or CO2) phase transitions critical for imparting microcellular structure to the biopolymeric melt.

A full factorial experimental design with three replicates will be used to study the inter-relationships between ingredients, material properties, cellular structure and mechanical properties of extruded foams. Based on the above investigations, we seek to develop a general mathematical model for predicting bubble growth and mechanical properties of foams, based on existing bubble dynamics models for polymeric foam production (Goel and Beckman, 1995; Schwartzberg et al., 1995). The proposed study will lead to significant advances in the understanding of the role of blowing agents, material formulations and process parameters during structure formation. Results will be analyzed statistically using analysis of variance (ANOVA) procedures and pair-wise comparison (t-test). Mathematical model will be validated using experimental data and differences in the observed and predicted bubble sizes will be compared using the χ^2 statistic at the $\alpha = 0.05$ level. As a result, we expect improvements in predictive capability and process design, and development of new expanded food products.

Evaluation:

Periodic assessment (every 6 months) of the project will be carried out to gage progress. Required yearly progress reports will also be prepared for the USDA as part of the NRI grants procedure. Also required yearly progress report to the Agricultural Experimentation Station will be submitted.

Funding:
The project is funded by the USDA-NRI for a period of three years from September 1, 2003 to August 31, 2006. Additional funding is being provided by the Agricultural Experimentation Station for a period of 5 years from July 1, 2005 to June 30, 2010 in the form of a hatch-grant (Project # KS660).

Project 2: Starch-based biodegradable films using extrusion processing

Team: Sajid Alavi, Tom Herald

Description of project:
This project aims at developing a new generation of biodegradable packaging films with enhanced mechanical and barrier properties by extrusion processing as a means of making starch-nanomaterial composites.
Evaluation:
Periodic assessment (every 6 months) of the project will be carried out to gage progress.
Funding:
Currently this project is funded by the primary investigator's start-up package. Funding opportunities will be explored from the Kansas Wheat Commission, USDA, NSF, and the Agricultural Experimentation Station.

Project 3: Production of pre-cooked whole wheat flours using extrusion processing.

Team: Sajid Alavi, Tom Herald, Ron Madl, Scott Bean

Description of project:
The proposed project aims at utilizing extrusion technology for producing pre-cooked whole wheat flours with increased functionality for baked products, and flours based on gluten-free wheat flour or starch – whey protein complexation that will have similar functionality as wheat flour and semolina for making baked goods and pasta, respectively, at the same time having a reduced glycemic index.
Evaluation:
Periodic assessment (every 3 months) of the project is being carried out to gage progress.
Funding:
Currently this project is funded by the Kansas Wheat for the duration 2005-06.

Project 4: Use of extrusion processing for encapsulation of organic chemicals with starch

Team: Sajid Alavi, Bhadriraju Subramanyam

Description of project:
The purpose of this research is to use extrusion processing as a means for encapsulation of organic chemicals (like the pesticide Spinosad) with starch.
Evaluation:
Periodic assessment (every 6 months) of the project will be carried out to gage progress.
Funding:
Currently this project is funded by the primary investigator's start-up package. A grant proposal was submitted to the Kansas Wheat Commission in 2004 which was not funded. Further funding opportunities will be explored from the Kansas Wheat Commission, USDA, NSF, and the Agricultural Experimentation Station.

Project 5: Development of a new generation aquatic feed using extrusion processing

Team: Sajid Alavi, Keith Behnke

Description of project:

The purpose of this research is to discover new and improved uses for Kansas agricultural products and equipment through the development of extruded aquatic feeds. The study aims to develop a mechanism for producing aquatic feed pellets with desired floatability, sink-rate and product integrity characteristics.

Evaluation:

Periodic assessment (every 6 months) of the project will be carried out to gage progress. A required yearly progress report to the Agricultural Experimentation Station will be submitted.

Funding:

This project was funded by the Agricultural Experimentation Station for a period of 5 years from July 1, 2000 to June 30, 2005 in the form of a hatch-grant (Project # KS572). Additional funding will be sought from Kansas extrusion and feed industries.

Approvals:

Principal Investigator(s)/Action Team Leader(s)	Date
Head(s) of Unit(s)	Date
Consulting Statistician	Date
Associate Director for Research/Extension K-State Research and Extension	Date

Action Team Members:

Team Member Signature	Date	Team Member Signature	Date